MODEL DEVELOPMENT FOR LIQUID EFFLUENT DISCHARGE OF SOME PARAMETERS INTO THE RIVER, USING KADUNA REFINERY AND PETROCHEMICAL COMPANY (KRPC) AS CASE STUDY.

BY

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DECLARATION

I, Mustapha, Amina Tani (98/7081EH), declare that this project is my original work and has never been submitted else where before, to the best of my Knowledge.

Signature   Date

CERTIFICATION

This is to certify that this project was supervised, moderated and approved by the following under-listed people, on-behalf of the Chemical Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology, Minna.

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Project Supervisor

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External Supervisor Date

DEDICATION

This is dedicated to the Almighty Allah (S.W.T) who has seen me through out my programme, my dear Parents for their total support and to my beloved Husband and Daughter, for their love, understanding, caring and prayers in all my endeavours.

ACKNOWLEDGEMENT

Praise be to Almighty Allah, my Creator who has given me life and good health to complete my course in this University and for Him seeing me through the successful completion of this project.

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Once again, I am grateful to Almighty Allah (S.W.T), without who nothing is possible and who has spared my life to this time. May His blessings be upon the seal of the Prophets (Amin).

ABSTRACT

This project was an attempt to develop a mathematical model for some parameters contained in Liquid effluent discharged into the river using Kaduna Refinery and Petrochemical Company (KRPC) as case study and Romi river as a specific case study.

Experimental data were collected from KRPC over a period of three months and the analysis of the data carried out to know the factors that affect the pH of the liquid effluent s most. Model equations were developed for the pH based on the analysis of the data results obtained. These parameters include Temperature, Biochemical Oxygen demand (BOD), Turbidity, Total dissolved Solids, Dissolved Oxygen among others. The model was obtained using MathCAD and Excel Programming Softwares.

The results obtained, showed a slight deviation from the experimental pH. A typical model expression for May 2004 is given below.

$$pH\ model := 0.18.T - 0.00393.U + 0.006797.D + 0.008037.O + 0.043.B - 0.025.C + 2.578.D - 0.159.P - 0.033.S$$

Generally it was observed that there is a slight increase in the modeled pH as against the experimental value. This suggests that some experimental parameters were not determined, due to faulty equipments and lamp failure.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

The need for treating Industrial waste water before being discharged into any river body cannot be over emphasized. Many processing Companies utilize large volume (quantity) of water in this Course of production with little or no treatment given to this waste water (by product) thereby posing danger to both plants and animals. Chemical Engineers in their capacities are concerned with the maintenance of the guidelines stipulated as the threshold limit values of these water contaminants.

During processing of petroleum in KRPC, liquid effluent is the major by product with minimal solid wastes and gaseous effluent. Hence for this project to be within a reasonable scope, attention is focused only on the impact of liquid effluent to the receiving water body.

Indiscriminate discharge of wastes; both Domestic and Industrial effluent have adverse effects on the quantity of water resources. Water as an important input of production has to be preserved in quality. Effective implementation of the environmental guidelines and standards for pollution control by FEPA gives a better protection of the water body(river) from pollution.

It is the duty of Individuals, Societies, National and International bodies to protect water/river against an overload by sewage so as to preserve it for various utilization by man.

In order to achieve this, all Manufacturing and Processing Industries are forced to control the amount of disposed water and the concentration of harmful impurities as well as monitoring carefully, the residual influence on the receiving water body (FEPA).

One of the methods of achieving this, is by modeling of analytical data given for the liquid effluent so as to take measures and control of the impurities present in the waste water for subsequent use. Modeling can be described as the determination of a quantitative picture of an important system Characteristic. It could be inform of collected data, analytical studies or Computer simulation of the actual system.

The interest is in formulating Mathematical Models that yield reasonable accurate descriptions or prediction about a given system, while minimizing Computational and Programming time. Modeling and Simulation can be carried out with the aid of some softwares like Excel MathCAD e.t.c (Bryan William Scotney).

1.2 AIMS OF THE PROJECT.

The aim of this Research work is to develop a Mathematical Model for liquid effluent discharge of some parameter into (water) rive in an Industrial area, Case study of KRPC. This can be achieved through the following processes:

i. Collection of data.

ii. Analyzing the data.

iii. Modeling.

1.3 SCOPE.

In order to ensure that adequate Information of the various parameters present in liquid effluent (waste water) from KRPC were obtained for this work, data used were collected at various seasons and stages.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 MATHEMATICAL MODELING.

Mathematical modeling is an explicit technique for representing real world phenomena in terms of Mathematical equations which gives a good understanding of the phenomena and can be used to predict likely occurrences. The model equations and number of variables must be equal i.e. "degree of freedom" of the system must be zero. (William 1990). Model is a simplified representation of a system intended to enhance our ability to understand, explain, change, preserve, predict and possibly control the behaviour of a system (Naelamkavil 1987), James (1973), defined a model as a representation of a system in a form suitable for demonstrating the way the system behaves.

Mathematical Modeling has wide areas of applications in Chemical Engineering, from Research and Development, to plant operations and even in Business and Economic studies. (Luyben, 1995). In developing a Mathematical Model, the necessary parameters need to be identified, in order to obtain a very good representation or approximation of the actual process.

2.2 CLASSIFICATION OF THE MATHEMATICAL MODELS.

Mathematical Model can be grouped into two classes, namely; DYNAMIC and STEADY STATE MODELS.

1.DYNAMIC STATE MODELS are time dependent models.

2. STEADY STATE MODELS shows the interactive behaviours of the system at steady state.

Dynamic models are further classified into continuous time and discrete time models. (Luyben, 1995).

Another classification of the Mathematical Model is the STOCHASTIC(Probabilistic) and DETERMINISTIC models. Stochastic models have at least one random variable in their description Model other than these are called Deterministic. (Luyben, 1995).

2.3 PRINCIPLES OF MODEL FORMATION.

In forming mathematical Models the following Principles ought to be applied.

2.4 BASIC.

The basis is the fundamental, physical and chemical laws like laws of energy, mass conservation and momentum. In studying the dynamics, the time derivatives are also included.

2.5 ASSUMPTIONS.

In making assumptions, care must be taken as these serve as limitation beyond which the Model would not hold. It is necessary to make simple but reasonable assumption while modeling. A simple Model needs many assumptions and yields an approximate result quickly, while a complex model of the same system needs just few assumptions to give an accurate answer by the use of more advanced Mathematical techniques.

2.6 MATHEMATICAL CONSISTENCY OF A MODEL.

The number of variables and equations describing any system or process must not be under-specified or over-specified. The o-called degree of freedom" of the system must be zero, i.e. the number of variables must equal the number of equations in order to obtain a solution. The unit of term used in the equations must also be in consistency.

2.7 SOLUTION OF THE MODEL EQUATION.

When the model has been developed, certain approximations and boundary conditions ought to be taken, outside which the required solution cannot be obtained. The equations should be those which could be solved by the available techniques without much difficulties.

2.8 VERIFICATION.

This is an important aspect of Mathematical Modeling, aimed at proving that the model actually describes the real world situation. One way of achieving this aim, is by comparing the experimental result to the Computer results.

2.9 SIMULATION.

Simulation of a system is designed as the operation of a model, which is a representation of the system, the model being amenable to manipulation which would be impossible, too expensive or impracticable to perform on the system it portrays (Martin Shubik).

A Computer Simulation is used to predict the effect of changing conditions and capacity of mass energy balance and to optimize operation easily and quickly. It provides in-depth Knowledge about complete system behaviour, improve and facilitate cost evaluation and planning of operations.

2.10 SIMULATION PROCEDURE.

The logical steps of Simulation are listed below:

1. Data Collection.
2. Analysis of the problem.
3. Simulation and Model specification.
4. Model Programming.
5. Model Verifications.
6. Simulation Experiments.
7. Evaluation and Interpretation of Simulation results.
8. Report generation.

In Summary, the aims of Modeling and Simulation are itemized below:

1. To estimate the process variable which are not directly measurable.
2. To predict system behaviour in different levels, where any level of predictive ability represents a benefit.
3. To improve understanding of some mechanisms in the studied process.
4. To optimize system behaviour and efficient fault diagnoses.

Modeling and Simulation as a means of control measure becomes necessary in this project as a result of constant monitoring of environment required in KRPC area and its environs, to evaluate the extent of pollution caused by waste water. Modeling could eliminate time and material wastage in carrying out experimental work aimed at finding the impact of waste water on the river body.

2.11 LIQUID EFFLUENT CHARACTERIZATION.

Liquid effluent is obtained as a result of various processing and stages of production of liquid effluent (waste water) becomes contaminated with either solid, liquid or gaseous substances or Compounds which in turn causes some changes in the Physical and Chemical properties in water.

The Physical properties (characteristics) are used in qualifying the Physical appearance of the waste water, examples of these includes; Tastes and Odour, Temperature, Turbidity, Suspended particles, Colour, e.t.c. A brief explanation of some of these properties are given below.

- Taste and Odour which may be due to dissolved impurities, examples like Phenol and Chlorophenols.
- Temperature: Temperature have effects on some other properties like in speeding up the rate of Chemical reaction.
- Turbidity could be due to Clay and Silt particles, discharge of Industrial wastes which gives a cloudy appearance and may be harmful.
- Colour: This is the effect of the Industrial waste particles which may be present in liquid effluent. The colour usually depends on the nature of the materials in it.

The Chemical properties of liquid effluent are of two categories; The Organic and Inorganic matters present in it. The test used to determine the Organic contents are biochemical Oxygen demand (BOD), dissolved Oxygen (DO), Chemical Oxygen demand (COD), Phenols, Oil concentration, e.t.c.

Determination of Inorganic contents of liquid effluent carried out by the following tests; pH, alkalinity, acidity, sulphates, heavy metals (such as Lead, Mercury, Silver, e.t.c). Some important Chemical Characteristics are described below.

pH: It measures the concentration of hydrogen ion present in it. The intensity of acidity or alkalinity of Industrial waste water sample is measured on pH scale.

Dissolved Oxygen(DO): Oxygen is an important element in water quality control, as it is needed by both plants and animals for their well-being, since most of the liquid effluents are discharged into the river, the level of dissolved Oxygen ought to be known as it has impact on the aquatic lives.

2.12 *TABLE. SOME EXAMPLES OF "WHO" GUIDELINES FOR DRINKING WATER QUANTITY.

CHARACTERISTIC	ACTION LEVEL
Arsenic	0.05mg/l
Cadmium	0.005mg/l
Chromium	0.05mg/l
Cyanide	0.1mg/l
Fluoride	1.5mg/l
Lead	0.05mg/l
Mercury	0.001mg/l
Nickel	0.1mg/l
Nitrate and Nitrite	10mg/l
Selenium	0.01mg/l

Chloride Sulphate Hardness as in $CaCo_3$ Total dissolved Solids	250mg/l 400mg/l 500mg/l 1000mg/l
Aluminum Chlorophenols Chloroform Monochlorobenzene 1,4-dichlorobenzene pH	0.2mg/l 0.1μg/l 30μg/l 3.0μg/l 0.1μg/l 6.5 to 8.5μg/l

*Guidelines for drinking Water Quality, WHO, Geneva, 1984

2.13 EFFECTS OF LIQUID EFFLUENT ON MAN AND ENVIRONMENT

Liquid effluent of large quantities (volume) are being discharged from Industrial Companies into the river annually which have effect on both man and environment. Waste water from processing Industries contain a lot of hazardous particles or substances which could be in low or higher concentration, depending on the nature of such industries. For instance, Petroleum Industries like KRPC will have liquid effluent with high concentration of Organic Compounds and certain percentage of non-organic compounds present in it. These compounds adversely affect the health of man, animals and cause damages to plant and materials as well as aquatic life.

The global effects of water pollution on man and his environment due to increased levels of phenols, Chlorophenols, benzene, heavy metals (such as Silver, Mercury, Lead) as well as non-metals (like Arsenic) in poisoning and severe toxicity to both living organisms and non-living organisms (material damages) cannot be over-emphasized. The main concern in water supply is the presence of low levels of contaminants which may produce observable health effects after long exposure, perhaps after many years, some potentially harmful substances appear to have a threshold effect in the sense that, provided the concentration remains below some critical level, no harm is caused. Other contaminants appear not to have a threshold level, so that any intake is potentially harmful and substances which cause Cancer (Carcinogens) often follow this pattern. Contaminants, particularly potential Carcinogens such as polyaromatic hydrocarbons (PAH) trihalomethanes (THM) and organochlorine as well as organophosphorus compounds, it is advisable to ensure that their concentrations in drinking water are kept as low as possible.

Liquid effluent also contains significant amount of Nitrogen in form of nitrate. Its presence in drinking water has not shown any harmful effect on adults and children but it can be dangerous for bottle fed babies up to age of six months. At this stage, babies lack the normal bacterial flora in their intestines which deal with the nitrite produced by the reduction of nitrate in the stomach. The nitrite when absorbed into the blood, prevents Oxygen transport and causes Methaemoglobinemia or "blue-baby disease". (T.H.Y TEBBUTT).

In Summary, pollution causes an economic loss due to the damages and destruction of resources required by man for the normal living standard of life. In other words, a polluted environment posses risks to health of all living things, economic well being of man, as well as development.

CHAPTER THREE

3.0 EXPERIMENTAL DATA
3.1 LIQUID EFFLUENT/WATER ANALYSIS

DATE: NOVEMBER, 2000

	1	2	3	4
Date Sampled	2/11/2000	9/11/2000	6/11/2000	23/11/2000
Installation/Sampling Point	**REFINERY**	**EFFLUENT**		
Area KADUNA				
State KADUNA				
Type of Recipient Environment	**ROMI**	**RIVER**		
All Season Discharge rate (m^3/day)				
Usage	**FARMING**	**AND**	**HABITATION**	
Effluent Quantity Discharge (m^3/day)				
Characteristics				
pH	10.08	7.43	8.91	9.14
Temperature ^0C	26.6	26.1	28.8	28.7
Turbidity NTU	42	19	31	19
Total Dissolved Solids (TDS) mg/l	518	310	402	306
Suspended Solids	88	30	50	158
Alkalinity P	128.00	NIL	12	28
Alkalinity M	128.00	60.00	84	64
Dissolved Oxygen (DO) mg/l	13.65	8.03	9.92	10.7
Biochemical Oxygen Demand mg/l	616.94	102.67	720	537.50
Chemical Oxygen Demand mg/l	204.46	57.86	101.45	37.74
OH + Grease Content mg/l	3.61	15.15	7.01	12.8
Surfactants mg/l	-	-	-	-
Phenolic Compounds mg/l	NIL	0.15	0.68	0.08
Salinity as Chloride (Cl^-) mg/l	38.26	13.87	27.74	22.54
Ammonia (NH_4^+) mg/l	1.15	2.65	2.86	1.41
Anions				
Nitrate (NO_3-) mg/l	2.94	10.22	8.16	6.5
Phosphate (PO_4^{3}-) mg/l	4.42	5.94	9.03	5.33
Sulphate (SO_4-) mg/l	-	-	-	-
Sulphide as H_2S mg/l	0.6	1.37	1.96	NIL
Free CO_2 mg/l	-	-	-	-
Bicarbonate (HCO_3-) mg/l as $CaCO_3$	-	-	-	-
Carbonate (CO_3^{2}-) mg/l as $CaCO_3$	-	-	-	-
Conductivity	840	560	840	900
Cyanide (ppm)	-	-	-	

LIQUID EFFLUENT/WATER ANALYSIS
DATE: NOVEMBER, 2000

	5			
Date Sampled Installation/Sampling Point Area KADUNA State KADUNA Type of Recipient Environment All Season Discharge rate (m^3/day) Usage Effluent Quantity Discharge (m^3/day)	30/11/2000 **REFINERY** **ROMI** **FARMING**	 **EFFLUENT** **RIVER** **AND**	 **HABITATION**	
Characteristics				
pH	7.07			
Temperature ^0C	28.1			
Turbidity NTU	32			
Total Dissolved Solids (TDS) mg/l	240			
Suspended Solids	24			
Alkalinity P	NIL			
Alkalinity M	52			
Dissolved Oxygen (DO) mg/l	11.04			
Biochemical Oxygen Demand mg/l	360			
Chemical Oxygen Demand mg/l	120.32			
OH + Grease Content mg/l	45.7			
Surfactants mg/l	-			
Phenolic Compounds mg/l	0.23			
Salinity as Chloride (Cl^-) mg/l	13.87			
Ammonia (NH_4^+) mg/l	0.48			
Anions				
Nitrate (NO_3-) mg/l	10.00			
Phosphate (PO_4^3-) mg/l	7.20			
Sulphate (SO_4-) mg/l	-			
Sulphide as H_2S mg/l				
Free CO_2 mg/l	NIL			
Bicarbonate (HCO_3-) mg/las $CaCO_3$	-			
Carbonate (CO_3^2-) mg/l as $CaCO_3$	-			
Conductivity	420			
Cyanide (ppm)	-			

	1	2	3	4
METALS				
Sodium (Na) mg/l				
Potassium (K) mg/l				
Calcium (Ca) mg/l				
Magnesium (Mg) mg/l				
Lead (Pb) mg/l				
Cadium (Cd) mg/l				
Zinc (Zn) mg/l	**NOT**	**DETERMINED**		
Copper (Cu) mg/l				
Chromium (Total) mg/l				
Chromium (Cr^{6+}) mg/l				
Barium (Ba) mg/l				
Vanadium (V) mg/l				
Nickel (NI) mg/l				
Iron (Fe) mg/l				
Mercury (Hg) mg/l				

ANALYSIS LABORATORY: WATER SECTION (REF. LAB)

ND – NOT DETERMINED

LIQUID EFFLUENT/WATER ANALYSIS
DATE: NOVEMBER, 2000

	1	2
Date Sampled	30/11/2000	30/11/2000
Installation/Sampling Point	**UPSTREAM**	**DOWNSTREAM**
Area KADUNA		
State KADUNA		
Type of Recipient Environment	**ROMI**	**RIVER**
All Season Discharge rate (m^3/day)		
Usage	**FARMING**	**AND HABITATION**
Effluent Quantity Discharge (m^3/day)		
Characteristics		
pH	6.65	6.98
Temperature ^0C	24.6	25.3
Turbidity NTU	23	22
Total Dissolved Solids (TDS) mg/l	74	110
Suspended Solids	20	24
Alkalinity P	NIL	NIL
Alkalinity M	36	46
Dissolved Oxygen (DO) mg/l	11.04	9.95
Biochemical Oxygen Demand mg/l	296.10	275.99
Chemical Oxygen Demand mg/l	184.02	78
OH + Grease Content mg/l	40.9	37.7
Surfactants mg/l	-	-
Phenolic Compounds mg/l	NIL	NIL
Salinity as Chloride (Cl^-) mg/l	NIL	NIL
Ammonia (NH_4^+) mg/l	0.82	0.74
Anions		
Nitrate (NO_3-) mg/l	3.4	2.6
Phosphate (PO_4^3-) mg/l	2.28	1.47
Sulphate (SO_4-) mg/l	-	-
Sulphide as H_2S mg/l	0.39	NIL
Free CO_2 mg/l	-	-
Bicarbonate (HCO_3-) mg/l as $CaCO_3$	-	-
Carbonate (CO_3^2-) mg/l as $CaCO_3$	-	-
Conductivity	92	280
Cyanide (ppm)	-	-

	1	2
METALS		
Sodium (Na) mg/l		
Potassium (K) mg/l		
Calcium (Ca) mg/l		
Magnesium (Mg) mg/l		
Lead (Pb) mg/l		
Cadium (Cd) mg/l		
Zinc (Zn) mg/l	**NOT**	**DETERMINED**
Copper (Cu) mg/l		
Chromium (Total) mg/l		
Chromium (Cr^{6+}) mg/l		
Barium (Ba) mg/l		
Vanadium (V) mg/l		
Nickel (NI) mg/l		
Iron (Fe) mg/l		
Mercury (Hg) mg/l		

ANALYSIS LABORATORY: WATER LAB SECTION (P)

ND – NOT DETERMINED

ANALYSIS REPORT

DATA	RIVER WATER Design spec.			CLARIFIER OUTLET Design spec.			REFINERY EFFLUENT Design spec.	
							Clear, Colorless	
P^H	7.0-7.3		7.66	7.0-7			7.0-8.5	7.07
Electrical conductivity	13-105		90	220(max.370)				420
Total solids ppm	38-3,328		88	200(max.350)				264
Suspended solids	18-3,000		4	20(max.50)			10.0mg\litre	24
Turbidity	20-3,000		26	20(max.50)			50.0units	32
Alkalinity (HCO_3)	20-62		40	62.0				52
Total Iron ppm	0.02-5.5		-	1.0			0.3 mg\litre	-
Total Hardness ppm	12.0 -30.0		28	38.0			500.0 mg\litre	32
Ca Hardness ppm			14					18
Mg Hardness ppm			14					14
Chloride ppm	0.2-24.8		NIL	27.8				13.37
Silica (SiO_2)	0.8-9.3		24.20	1.7				-
Sulphate ppm			-	3.0			200.0 mg\litre	-
Phosphate ppm			2.33					7.20
B.O.D (5 days) ppm			125.19				25 mg\litre	360
C.O.D ppm			88	38.40			60.0 mg\litre	120-32
Settle able Solids	70-326		-				0.3 mg\litre	-
Total Dissolved Solids			84	.350			2.000.0 mg\litre	240
Oil			3.88				0.3 mg\litre	45.7
Hydrocarbons (I.R methods)			-				0.0 mg\litre	-
Phenols			NIL				0.1 mg\litre	0.23
Tar							NIL	

	RIVER WATER			CLARIFIER OUTLET			REFINERY EFFLUENT	
DATA	DESIGN SPEC.			DESIGN SPEC.			DESIGN SPEC.	
Ammonia			0.70				1.0mg/Litre as N	0.48
Sulphide as H_2S			NIL				0.2mg/Litre	NIL
Zinc			-				5.0mg/Litre	-
Lead			-				0.05mg/Litre	-
Arsenic			-				0.05mg/Litre	-
Cyanide			-				0.05mg/Litre	-
Cadmium			-				0.05mg/Litre	-
Boron			-				0.05mg/Litre	-
Vanadium			-				0.05mg/Litre	-
Hexa Chromium			-				0.03mg/Litre	-
Selenium			-				0.01mg/Litre	-
Mercury			-				0.001mg/Litre	-
Temperature			25.4				36^0C	28.1
Taste			-				Unobjectionable	-

0.05mg/Litre is expected value, 0.1mg/Litre is guaranteed value

3.2 LIQUID EFFLUENT/WATER ANALYSIS

DATE: AUGUST, 2003

	1	2	3	
Date Sampled	7/08/2003	14/08/2003	21/08/2003	28/08/200
Installation/Sampling Point	**REFINERY**	**EFFLUENT**		
Area KADUNA				
State KADUNA				
Type of Recipient Environment	**ROMI**	**RIVER**		
All Season Discharge rate (m^3/day)				
Usage	**FARMING**	**AND**	**HABITATION**	
Effluent Quantity Discharge (m^3/day)				
Characteristics				
pH	8.24	6.31	6.77	7.58
Temperature ^{0}C	27.00	26.60	26.60	28.00
Turbidity (NTU)	15.00	14.50	14.00	12.00
Total Dissolved Solids (TDS) mg/l	189.00	234.11	408.25	225.93
Suspended Solids	123.00	160.22	100.42	39.90
Alkalinity P	<0.01	NIL	NIL	NIL
Alkalinity M	52.00	38.20	24.50	23.30
Dissolved Oxygen (DO) mg/l	7.28	6.70	6.67	7.75
Biochemical Oxygen Demand mg/l	110.25	45.57	88.20	99.96
Chemical Oxygen Demand mg/l	600.00	260.00	140.00	220.00
Oil + Grease Content mg/l	ND*	ND*	ND*	ND*
Phenolic Compounds mg/l	0.30	0.49	0.40	0.14
Salinity as Chloride (Cl^-) mg/l	15.40	16.00	14.80	19.30
Ammonia (NH_4^+) mg/l	1.75	1.68	0.36	0.40
Anions				
Nitrate (NO_3-) mg/l	1.20	0.70	0.50	0.50
Phosphate (PO_4^{3-}) mg/l	5.23	1.76	9.29	8.83
Sulphate (SO_{42}^-) mg/l	162.50	215.00	130.00	87.50
Sulphide as H_2S mg/l	0.04	NIL	NIL	0.04
Conductivity (µs)	657.00	318.00	490.00	405.00
Cyanide (ppm)	ND*	ND*	ND*	ND*

ND* - NOT DETERMINED DUE TO FAULTY EQUIPMENT

	1 07/08/2003	2 14/08/2003	3 21/08/2003	4 28/08/2003
METALS				
Sodium (Na) mg/l	30.96	23.94	33.17	39.22
Potassium (K) mg/l	ND	ND	ND	ND
Calcium (Ca) mg/l	ND	ND	ND	ND
Magnesium (Mg) mg/l	2.68	0.95	2.15	2.62
Lead (Pb) mg/l	ND	ND	ND	ND
Cadium (Cd) mg/l	NIL	NIL	NIL	NIL
Zinc (Zn) mg/l	0.25	0.23	0.11	0.80
Copper (Cu) mg/l	NIL	NIL	NIL	NIL
Chromium (Total) mg/l	-	-	-	-
Chromium (Cr^{6+}) mg/l	0.01	NIL	NIL	NIL
Barium (Ba) mg/l	-	-	-	-
Vanadium (V) mg/l	-	-	-	-
Nickel (NI) mg/l	ND	ND	ND	ND
Iron (Fe) mg/l	1.70	1.30	1.28	2.99
Mercury (Hg) mg/l	ND	ND	ND	ND

ANALYSIS LABORATORY: WATER SECTION (Refinery Laboratory)

ND – NOT DETERMINED DUE TO LAMP FAILURE

LIQUID EFFLUENT/WATER ANALYSIS
DATE: AUGUST, 2003

Date Sampled	24/08/2003	28/08/2003
Installation/Sampling Point **ROMI**	**UPSTREAM**	**DOWNSTREAM**
Area KADUNA	**KRPC**	
State KADUNA		
Type of Recipient Environment	**ROMI**	**RIVER**
All Season Discharge rate (m^3/day)		
Usage	**FARMING**	**AND HABITATION**
Effluent Quantity Discharge (m^3/day)		
Characteristics		
pH	6.55	5.83
Temperature ^0C	27.80	28.00
Turbidity (NTU)	160.00	116.00
Total Dissolved Solids (TDS) mg/l	228.79	216.55
Total Hardness mg/l as $CaCO_3$	20.30	27.50
Alkalinity P mg/l	NIL	NIL
Alkalinity M mg/l	13.50	6.70
Dissolved Oxygen (DO) mg/l	7.41	7.76
Biochemical Oxygen Demand mg/l	58.80	70.56
Chemical Oxygen Demand mg/l	380.00	319.20
OH + Grease Content mg/l	ND	ND
Phenolic Compounds mg/l	0.04	1.29
Salinity as Chloride (Cl^-) mg/l	12.00	13.50
Ammonia (NH_4^+) mg/l	1.24	1.66
Anions		
Nitrate (NO_3-) mg/l	0.70	NIL
Phosphate (PO_4^{3-}) mg/l	7.56	6.93
Sulphate (SO_4^{2-}) mg/l	46.00	90.00
Sulphide as H_2S mg/l	0.03	0.03
Electricity Conductivity (μs)	251.30	394.00
Cyanide (ppm)	ND	ND

ND - NOT DETERMINED DUE TO FAULTY EQUIPMENT

	R-UP	R-DOWN
	1 28/08/2003	2 28/08/2003
METALS		
Sodium (Na) mg/l	26.30	32.88
Potassium (K) mg/l	ND*	ND*
Calcium (Ca) mg/l	ND*	ND*
Magnesium (Mg) mg/l	2.00	2.22
Lead (Pb) mg/l	ND*	ND*
Cadium (Cd) mg/l	NIL	NIL
Zinc (Zn) mg/l	0.32	0.41
Copper (Cu) mg/l	NIL	NIL
Chromium (Total) mg/l	-	-
Chromium (Cr^{6+}) mg/l	NIL	NIL
Barium (Ba) mg/l	-	-
Vanadium (V) mg/l	-	-
Nickel (NI) mg/l	ND	ND
Iron (Fe) mg/l	5.10	4.00
Mercury (Hg) mg/l	-	-

ANALYSIS LABORATORY: WATER LABORATORY (REFINERY)

ND – NOT DETERMINED DUE TO FAULTY LAMP

ANALYSIS REPORT <u>AUGUST, 2003</u>

DATA	RIVER WATER Design spec.			CLARIFIER OUTLET Design spec.			REFINERY EFFLUENT Design spec.	
							Clear, Colorless	
P^H	7.0-7.3		6.76	7.0-7			7.0-8.5	7.58
Electrical conductivity (µs)	13-105		45.40	220(max.370)				405.00
Total solids ppm	38-3,328		274.23	200(max.350)				265.83
Suspended solids PPM	18-3,000		41.13	20(max.50)			10.0mg\litre	39.90
Turbidity (NTU)	20-3,000		290.00	20(max.50)			50.0units	12.00
Alkalinity M ppm	20-62		17.40	62.0				23.30
Total Iron ppm	0.02-5.5		13.89	1.0			0.3 mg\litre	2.99
Total Hardness ppm	12.0 -38.0		16.40	38.0			500.0 mg\litre	28.60
Ca Hardness ppm			10.10					18.00
Mg Hardness ppm			6.30					10.60
Chloride ppm	0.2-24.8		7.40	27.8				19.30
Silica (SiO_2)	0.8-9.3		13.05	1.7				-
Sulphate ppm			9.00	3.0			200.0 mg\litre	87.50
Phosphate ppm			22.97					3.83
B.O.D (5 days) ppm			29.40				25 mg\litre	99.96
C.O.D ppm			212.80	38.40			60.0 mg\litre	220.00
Settle able Solids			-				0.3 mg\litre	-
Total Dissolved Solids ppm	70-326		233.10	.350			2.000.0 mg\litre	225.93
Oil			ND*				0.3 mg\litre	ND
Hydrocarbons (I.R methods)			-				0.0 mg\litre	-
Phenols ppm			0.10				0.1 mg\litre	0.14
Dissolved Oxygen			7.07				NIL	7.75

ND – NOT DETERMINED DUE TO FAULTY EQUIPMENT.

	RIVER WATER			CLARIFIER OUTLET			REFINERY EFFLUENT	
DATA (mg/l)	DESIGN SPEC.			DESIGN SPEC.			DESIGN SPEC.	
Ammonia - N			1.48				1.0mg/Litre as N	0.40
Sulphide as H_2S			0.05				0.2mg/Litre	0.04
Zinc			0.30				5.0mg/Litre	0.80
Lead			ND				0.05mg/Litre	ND
Arsenic			-				0.05mg/Litre	-
Cyanide			ND				0.05mg/Litre	NIL
Cadmium			NIL				0.05mg/Litre	
Boron			-				0.05mg/Litre	
Vanadium			-				0.05mg/Litre	
Hexa Chromium			NIL				0.03mg/Litre	NIL
Selenium			-				0.01mg/Litre	-
Mercury			ND				0.001mg/Litre	ND
Temperature (^{0}C)			26.80				36^{0}C	28.00
Taste			-				Unobjectionable	-

0.05mg/Litre is expected value, 0.1mg/Litre is guaranteed value.
ND* - NOT DETERMINED DUE TO FAULTY EQUIPMENT.

3.3 LIQUID EFFLUENT/WATER ANALYSIS

DATE: MAY, 2004

	1 6/5/2004	2 13/5/2004	3 20/5/2004	4 27/5/2004
Date Sampled Installation/Sampling Point Area KADUNA State KADUNA Type of Recipient Environment All Season Discharge rate (m^3/day) Usage Effluent Quantity Discharge (m^3/day)	**REFINERY** **ROMI** **FARMING**	**EFFLUENT** **RIVER** **AND**	**HABITATION**	
Characteristics				
pH	7.36	2.85	6.09	5.54
Temperature ^{0}C	29.2	29.1	29.4	29.1
Turbidity (NTU)	22	21	16	80
Total Dissolved Solids (TDS) mg/l	437.71	467.57	410.85	321.94
Suspended Solids	38.29	35.43	41.22	54.32
Alkalinity P mg/l	NIL	NIL	NIL	NIL
Alkalinity M mg/l	60.00	84.00	67.00	44
Dissolved Oxygen (DO) mg/l	6.80	6.90	8.16	267.62
Biochemical Oxygen Demand mg/l	179.34	14.70	199.90	72.99
Chemical Oxygen Demand mg/l	360.00	46.16	203.08	120.99
OH + Grease Content mg/l	ND*	ND*	ND*	ND*
Phenolic Compounds mg/l	0.55	0.49	0.36	0.16
Salinity as Chloride (Cl^-) mg/l	27.80	31.60	18.30	20.8
Ammonia (NH_4^+) mg/l	0.92	0.66	0.33	1.25
Anions				
Nitrate (NO_3-) mg/l	1.10	0.40	0.50	0.50
Phosphate (PO_4^{3-}) mg/l	6.87	3.25	0.92	13.50
Sulphate (SO_{42}^-) mg/l	42.00	165.00	200.00	90.00
Sulphide as H_2S mg/l	0.01	0.01	0.07	0.013
Conductivity (μs)	342	1048	832	577
Cyanide (ppm)	ND*	ND*	ND*	ND*

LIQUID EFFLUENT/WATER ANALYSIS – MAY 2004

ND* - NOT DETERMINED DUE TO FAULTY EQUIPMENT

	1 6/5/2004	2 13/5/2004	3 20/5/2004	4 27/5/2004
METALS				
Sodium (Na) mg/l	ND*	ND*	ND*	ND*
Potassium (K) mg/l	ND*	ND*	ND*	ND*
Calcium (Ca) mg/l	ND*	ND*	ND*	ND*
Magnesium (Mg) mg/l	ND*	ND*	ND*	ND*
Lead (Pb) mg/l	ND*	ND*	ND*	ND*
Cadium (Cd) mg/l	ND*	ND*	ND*	ND*
Zinc (Zn) mg/l	ND*	ND*	ND*	ND*
Copper (Cu) mg/l	ND*	ND*	ND*	ND*
Chromium (Total) mg/l	ND*	ND*	ND*	ND*
Chromium (Cr^{6+}) mg/i	ND*	ND*	ND*	ND*
Barium (Ba) mg/l	ND*	ND*	ND*	ND*
Vanadium (V) mg/l	ND*	ND*	ND*	ND*
Nickel (NI) mg/l	ND*	ND*	ND*	ND*
Iron (Fe) mg/l	ND*	ND*	ND*	ND*
Mercury (Hg) mg/l	ND*	ND*	ND*	ND*

ND – NOT DETERMINED DUE TO LAMP FAILURE AND ALSO, FAULTY EQUIPMENT

ANALYSIS LABORATORY: WATER SECTION (Refinery Laboratory)

LIQUID EFFLUENT/WATER ANALYSIS
DATE: AUGUST, 2003

Date Sampled	27/5/2004	27/5/2004
Installation/Sampling Point **ROMI**	**UPSTREAM**	**DOWNSTREAM**
Area KADUNA	**KRPC**	
State KADUNA		
Type of Recipient Environment	**ROMI**	**RIVER**
All Season Discharge rate (m^3/day)		
Usage	**FARMING**	**AND HABITATION**
Effluent Quantity Discharge (m^3/day)		
Characteristics		
pH	66.0	6.47
Temperature ^0C	27.5	28.9
Turbidity (NTU)	450.00	270.00
Total Dissolved Solids (TDS) mg/l	95.49	49.65
Total Hardness mg/l as $CaCO_3$	17.60	31.40
Alkalinity P mg/l	NIL	NIL
Alkalinity M mg/l	29	43
Dissolved Oxygen (DO) mg/l	6.80	7.34
Biochemical Oxygen Demand mg/l	26.16	98.49
Chemical Oxygen Demand mg/l	-	36.50
OH + Grease Content mg/l	ND*	ND*
Surfactants mg/l	<0.01	0.04
Phenolic Compounds mg/l	12.60	19.90
Ammonia (NH_4^+) mg/l	1.44	2.20
Anions		
Nitrate (NO_3-) mg/l	2.60	0.90
Phosphate Sulphate (PO_4^{3-}) mg/l	32.10	18.01
Sulphate (SO_4^{2-}) mg/l	NIL	25.00
Sulphide as H_2S mg/l	0.05	0.03
Electricity Conductivity (μs)	79.60	425
Cyanide (ppm)	ND	ND

ND - NOT DETERMINED DUE TO FAULTY EQUIPMENT

	R-UP	R-DOWN
	1 27/5/2004	2 27/5/2004
METALS		
Sodium (Na) mg/l	ND*	ND*
Potassium (K) mg/l	ND*	ND*
Calcium (Ca) mg/l	ND*	ND*
Magnesium (Mg) mg/l	ND*	ND*
Lead (Pb) mg/l	ND*	ND*
Cadium (Cd) mg/l	ND*	ND*
Zinc (Zn) mg/l	ND*	ND*
Copper (Cu) mg/l	ND*	ND*
Chromium (Total) mg/l	ND*	ND*
Chromium (Cr^{6+}) mg/l	ND*	ND*
Barium (Ba) mg/l	ND*	ND*
Vanadium (V) mg/l	ND*	ND*
Nickel (NI) mg/l	ND*	ND*
Iron (Fe) mg/l	ND*	ND*
Mercury (Hg) mg/l	ND*	ND*

ANALYSIS LABORATORY: WATER SECTION (REFINERY LAB)

ND – NOT DETERMINED DUE TO FAULTY LAMP

ANALYSIS REPORT MAY, 2003

DATA	RIVER WATER		CLARIFIER OUTLET			REFINERY EFFLUENT	
	Design spec.		Design spec.			Design spec.	
						Clear, Colorless	
P^H	7.0-7.3	7.17	7.0-7			7.0-8.5	5.54
Electrical conductivity (μs)	13-105	55.10	220(max.370)				577.00
Total solids ppm	38-3,328	497.59	200(max.350)				321.94
Suspended solids PPM	18-3,000	73.58	20(max.50)			10.0mg\litre	54.32
Turbidity (NTU)	20-3,000	480	20(max.50)			50.0units	80.00
Alkalinity M ppm	20-62	35	62.0				44.00
Total Iron ppm	0.02-5.5	ND*	1.0			0.3 mg\litre	ND*
Total Hardness ppm	12.0 -38.0	16.70	38.0			500.0 mg\litre	48.50
Ca Hardness ppm		11.50					27.20
Mg Hardness ppm		5.20					21.30
Chloride ppm	0.2-24.8	10.60	27.8				20.80
Silica (SiO_2)	0.8-9.3	15.28	1.7				-
Sulphate ppm		NIL	3.0			200.0 mg\litre	90.00
Phosphate ppm		79.58					13.50
B.O.D (5 days) ppm		20.58				25 mg\litre	72.99
C.O.D ppm		-	38.40			60.0 mg\litre	120.54
Settle able Solids		-				0.3 mg\litre	-
Total Dissolved Solids ppm	70-326	424.01	.350			2.000.0 mg\litre	267.62
Oil		ND*				0.3 mg\litre	ND*
Hydrocarbons (I.R methods)		-				0.0 mg\litre	ND
Phenols ppm		<0.01				0.1 mg\litre	0.16
Dissolved Oxygen		6.66				NIL	7.09

ND – NOT DETERMINED DUE TO FAULTY EQUIPMENT.

	RIVER WATER			CLARIFIER OUTLET			REFINERY EFFLUENT	
DATA (mg/l)	DESIGN SPEC.			DESIGN SPEC.			DESIGN SPEC.	
Ammonia - N			3.25				1.0mg/Litre as N	1.25
Sulphide as H_2S			0.11				0.2mg/Litre	0.01
Zinc			ND*				5.0mg/Litre	ND*
Lead			ND*				0.05mg/Litre	ND*
Arsenic			NIL				0.05mg/Litre	ND*
Cyanide			ND*				0.05mg/Litre	ND*
Cadmium			ND*				0.05mg/Litre	ND*
Boron			ND*				0.05mg/Litre	ND*
Vanadium			ND*				0.05mg/Litre	ND*
Hexa Chromium			NIL				0.03mg/Litre	NIL
Selenium			-				0.01mg/Litre	-
Mercury			-				0.001mg/Litre	-
Temperature (^0C)			28.9				36^0C	29.1
Taste			-				Unobjectionable	-

0.05mg/Litre is expected value, 0.1mg/Litre is guaranteed value.
ND* - NOT DETERMINED DUE TO FAULTY EQUIPMENT.

3.4 METHODOLOGY

1. Procedure for the analysis of Total Suspended Dissolved Solids (TSS).

100ml of water sample was filtered through fibre glass filter, the filter was placed in an evaporating dish and dried in the oven at temperature of about 105^{0}C for one hour. The fibre glass intermittently and dried repeatedly till a constant weight was obtained.

Total dissolved solids is given by the equation

$$\frac{(A - B)\times 100}{\text{volume of water sample.}}$$

Where A=weight of filter + residue

B=weight of filter only

2. Procedure for the analysis of Turbidity.

Turbidity was determined using attach turbid meter, the meter was calibrated for operation and the standard supplied with the unit were checked. The appropriate range was selected (100NTU). The cell riser was properly installed in the cell holder. The cell sample was filled with 25ml of sample being tested and covered inside the instrument. The meter readings were recorded.

3. Procedure for analysis of Temperature

Temperatures were determined using a mercury –glass thermometer of range 10^{0}C-50^{0}C. The thermometer was placed at a depth of about 15cm for five minutes before taking reading.

4. Procedure for analysis of pH

pH was determined with Beckam Electric pH meter model H%. The reference electrode was standardized before use. The pH meter was kept on for about 2 hours to warm the equipment. The green bulb was cleaned repeatedly with fresh distilled water and the Temperature of the instrument was adjusted to the room Temperature.

5. Procedure for the analysis of Dissolved oxygen (DO).

Oxygen was determined by Winkler Titrimetric method. The sample was acidified by adding 1ml of concentrated H_2SO_4 and then shaken properly. 100ml of the sample was introduced into a beaker, 5 drops of starch was also added.

Dissolved Oxygen in the sample was titrated using $Na_2SO_4.5H_2O$ until a pale straw or colourless solution was obtained within 2 minutes.

The amount of Dissolved Oxygen in mg/l is given by the equation

$$\frac{\text{Titrants Vol. x 1000}}{\text{Vol. of water sample x Vol. of sample bottle}}$$

6. Biochemical Oxygen Demand's Procedure.

The diluted water was pre-treated followed by pre-treatment of sample. The samples were kept in the water- cooled incubator; at room Temperature before dilution. All samples were well mixed before dilution.

7. Procedure for Analysis of Total Dissolved Solids (TDS).

Total Dissolved Solid was determined by Wrinkle's method. 10ml of the sample was weighed inside a crucible. The sample was dried in a steam bath and dried completely in an oven. The dried crucible was weighed when cold.

TDS mg/l = Initial weight of crucible + sample – Final weight after drying.

CHAPTER FOUR.

4.0 MODEL DEVELOPMENT.

4.1 MODELING FOR LIQUID EFFLUENT USING pH AS DEPENDENT VARIABLE.

Modeling for Liquid effluent using pH as the optimization criteria (dependent variable).

The pH of liquid effluent is dependent upon certain parameters present in the waste water, such as temperature, biochemical oxygen demand (BOD), heavy metal e.t.c. Mathematically, pH is represented as:

pH = f(temperature, BOD, TDS)-----------------------(1)

In this model, the parameters considered include Temperature, Turbidity, TDS, Dissolved Oxygen (DO), BOD, CO, Nitrate, Phosphate, Sulphate, Sulphide.

Let Temperature = T; Turbidity = U; TDS = D; Dissolved Oxygen = O;

Biochemical Oxygen Demand = B; Chemical Oxygen Demand = C;

Nitrate = N; Phosphate = P; and Sulphate = S.

Therefore, the pH can be written as:

$pH = f(aT + bU + cD + dO + eB + fC + gN + hP + iS)$----------------------(2)

where , pH is the dependent variable in the equation, T,U,D,O,B,C,N,P,S are the independent variables, a,b,c,d,e,f,g,h,i are the constants.

Letting I to represent the square of the difference between the values of observed pH and its modeled values (pH model) i.e.

$I = [pH - (aT + bU + cD + dO + eB + fC + gN + hP + iS)]^2$-----------------(3)

For m experimental values,

$$mI = \Sigma[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 \text{-----------} (4)$$

In order to minimize mI with respect to the coefficients, using the first partial derivatives of mI and equating these to zero, the necessary minimum conditions can be obtained. i.e. from equation (4) we have;

$$\frac{\delta(mI)}{\delta a} = -2\,\Sigma T_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{-----} (5)$$

$$\frac{\delta(mI)}{\delta b} = -2\,\Sigma U_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{-----} (6)$$

$$\frac{\delta(mI)}{\delta c} = -2\,\Sigma D_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{-----} (7)$$

$$\frac{\delta(mI)}{\delta d} = -2\,\Sigma O_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{-----} (8)$$

$$\frac{\delta(mI)}{\delta e} = -2\,\Sigma B_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{-----} (9)$$

$$\frac{\delta(mI)}{\delta f} = -2\,\Sigma C_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{----} (10)$$

$$\frac{\delta(mI)}{\delta g} = -2\,\Sigma N_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{----} (11)$$

$$\frac{\delta(mI)}{\delta h} = -2\,\Sigma P_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{----} (12)$$

$$\frac{\delta(mI)}{\delta i} = -2\,\Sigma S_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I]^2 = 0 \text{----} (13)$$

equations (5)-(13) can be arranged to give:

$$\frac{\delta(mI)}{\delta a} = \Sigma T_I\,[pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I] = -2 \times 0$$

which can be written as :

$\Sigma T_I [pH_I - aT_I - bU_I - cD_I - dO_I - eB_I - fC_I - gN_I - hP_I - iS_I] = 0$

Expanding the bracket gives:

$\Sigma T_I pH_I - a \Sigma T^2_I - b \Sigma T_IU_I - c \Sigma T_ID_I - d \Sigma T_IO_I - e \Sigma T_IB_I - f \Sigma T_IC_I - g \Sigma T_IN_I - h \Sigma T_IP_I - i \Sigma T_IS_I] = 0$ -----(14)

from equation (14), making $\Sigma T_I pH_I$ the subject of the formula, we have:

$\Sigma T_I pH_I = a \Sigma T^2_I + b \Sigma T_IU_I + c \Sigma T_ID_I + d \Sigma T_IO_I + e \Sigma T_IB_I + f \Sigma T_IC_I + g \Sigma T_IN_I + h \Sigma T_IP_I + i \Sigma T_IS_I$-----------(15)

applying the technique to the other equations (6)-(13), we obtain:

$\Sigma U_I pH_I = a \Sigma U_II_I + b \Sigma U^2_I + c \Sigma U_ID_I + d \Sigma U_IO_I + e \Sigma U_IB_I + f \Sigma U_IC_I + g \Sigma U_IN_I + h \Sigma U_IP_I + i \Sigma U_IS_I$-----------(16)

$\Sigma D_I pH_I = a \Sigma D_II_I + b \Sigma D_IU_I + c \Sigma D^2_I + d \Sigma D_IO_I + e \Sigma D_IB_I + f \Sigma D_IC_I + g \Sigma D_IN_I + h \Sigma D_IP_I + i \Sigma D_IS_I$-----------(17)

$\Sigma O_I pH_I = a \Sigma O_II_I + b \Sigma O_IU_I + + c \Sigma O_ID_I + d \Sigma O^2_I + e \Sigma O_IB_I + f \Sigma O_IC_I + g \Sigma O_IN_I + h \Sigma O_IP_I + i \Sigma O_IS_I$-----------(18)

$\Sigma B_I pH_I = a \Sigma B_II_I + b \Sigma B_IU_I + + c \Sigma B_ID_I + d \Sigma B_IO_I + e \Sigma B^2_I + f \Sigma B_IC_I + g \Sigma B_IN_I + h \Sigma B_IP_I + i \Sigma B_IS_I$-----------(19)

$\Sigma C_I pH_I = a \Sigma C_II_I + b \Sigma C_IU_I + + c \Sigma C_ID_I + d \Sigma C_IO_I + e \Sigma C_IB_I + f \Sigma C^2_I + g \Sigma C_IN_I + h \Sigma C_IP_I + i \Sigma C_IS_I$-----------(20)

$\Sigma N_I pH_I = a \Sigma N_II_I + b \Sigma N_IU_I + c \Sigma N_ID_I + d \Sigma N_IO_I + e \Sigma N_IB_I + f \Sigma N_IC_I + g \Sigma N^2_I + h \Sigma N_IP_I + i \Sigma N_IS_I$-----------(21)

$\Sigma P_I pH_I = a \Sigma P_II_I + b \Sigma P_IU_I + c \Sigma P_ID_I + d \Sigma P_IO_I + e \Sigma P_IB_I + f \Sigma P_IC_I + g \Sigma P_IN_I + h \Sigma P^2_I\ i \Sigma P_IS_I$-----------(22)

$$\Sigma S_I\, pH_I = a\,\Sigma S_I I_I + b\,\Sigma S_I U_I + c\,\Sigma S_I D_I + d\,\Sigma S_I O_I + e\,\Sigma S_I B_I + f\,\Sigma S_I C_I + g\,\Sigma S_I N_I + h\,\Sigma S_I P_I + i\,\Sigma P^2_I \text{ -----------(23)}$$

Where $\Sigma = \sum_{ii=1}^{n}$ where n = 6. The summation was obtained from the data using MathCAD.

Applying the formula, $t^1 = 1$. Solve (Z, z) s MathCAD programming language used in solving two matrices to a solution.

NOV2000

	pH	T	U	D	O	B	C	N	P	H
data :=	0	1	2	3	4	5	6	7	8	9
0	10.08	26.6	42	518	13.65	616.94	204.46	2.94	4.42	0.6
1	7.43	26.1	19	310	8.03	102.67	57.86	10.22	5.94	1.37
2	8.91	28.8	31	402	9.92	720	101.45	8.16	9.03	1.96
3	9.14	28.7	19	306	10.7	537.5	37.74	6.5	5.38	0
4	6.65	24.6	23	74	11.04	296.19	184.02	3.4	2.28	0.39
5	6.98	25.3	22	110	9.95	275.99	78	2.6	1.47	0

$pH := data^{\langle 0 \rangle}$ $T := data^{\langle 1 \rangle}$ $U := data^{\langle 2 \rangle}$ $D := data^{\langle 3 \rangle}$ $O := data^{\langle 4 \rangle}$

$B := data^{\langle 5 \rangle}$ $C := data^{\langle 6 \rangle}$ $N := data^{\langle 7 \rangle}$ $P := data^{\langle 8 \rangle}$ $H := data^{\langle 9 \rangle}$

$\sum \overrightarrow{(T^2)} = 4287.15$ $\sum \overrightarrow{(T \cdot U)} = 4173.6$ $\sum \overrightarrow{(T \cdot D)} = 46833$ $\sum \overrightarrow{(T \cdot O)} = 1688.778$

$\sum \overrightarrow{(T \cdot B)} = 69521.362$ $\sum \overrightarrow{(T \cdot C)} = 17453.972$ $\sum \overrightarrow{(T \cdot N)} = 915.924$ $\sum \overrightarrow{(T \cdot P)} = 780.355$

$\sum \overrightarrow{(T \cdot H)} = 117.759$ $\sum \overrightarrow{(U \cdot T)} = 4173.6$ $\sum \overrightarrow{(U^2)} = 4460$ $\sum \overrightarrow{(U \cdot D)} = 50044$

$\sum \overrightarrow{(U \cdot O)} = 1709.51$ $\sum \overrightarrow{(U \cdot B)} = 73278.86$ $\sum \overrightarrow{(U \cdot C)} = 19497.13$ $\sum \overrightarrow{(U \cdot N)} = 829.52$

$\sum \overrightarrow{(U \cdot P)} = 765.43$ $\sum \overrightarrow{(U \cdot H)} = 120.96$ $\sum \overrightarrow{(D \cdot T)} = 46833$ $\sum \overrightarrow{(D \cdot U)} = 50044$

$\sum \overrightarrow{(D^2)} = 637240$ $\sum \overrightarrow{(D \cdot O)} = 18733.5$ $\sum \overrightarrow{(D \cdot B)} = 857594.58$ $\sum \overrightarrow{(D \cdot C)} = 198375.7$

$\sum \overrightarrow{(D \cdot N)} = 10498.04$ $\sum \overrightarrow{(D \cdot P)} = 9737.72$ $\sum \overrightarrow{(D \cdot H)} = 1552.28$ $\sum \overrightarrow{(O \cdot T)} = 1688.778$

$\sum \overrightarrow{(O \cdot U)} = 1709.51$ $\sum \overrightarrow{(O \cdot D)} = 18733.5$ $\sum \overrightarrow{(O^2)} = 684.584$ $\sum \overrightarrow{(O \cdot B)} = 28155.359$

$\sum \overrightarrow{(O \cdot C)} = 7473.378$ $\sum \overrightarrow{(O \cdot N)} = 336.101$ $\sum \overrightarrow{(O \cdot P)} = 294.972$ $\sum \overrightarrow{(O \cdot H)} = 42.94$

$\sum \overrightarrow{(B \cdot T)} = 69521.362$ $\sum \overrightarrow{(B \cdot U)} = 73278.86$ $\sum \overrightarrow{(B \cdot D)} = 857594.58$ $\sum \overrightarrow{(B \cdot O)} = 28155.359$

$\sum \overrightarrow{(B^2)} = 1362361.339$ $\sum \overrightarrow{(B \cdot C)} = 301441.392$ $\sum \overrightarrow{(B \cdot N)} = 13956.661$ $\sum \overrightarrow{(B \cdot P)} = 13811.103$

$\sum \overrightarrow{(B \cdot H)} = 2037.536$ $\sum \overrightarrow{(C \cdot T)} = 17453.972$ $\sum \overrightarrow{(C \cdot U)} = 19497.13$ $\sum \overrightarrow{(C \cdot D)} = 198375.7$

$\sum\overrightarrow{(C\cdot O)} = 7473.378$ $\sum\overrightarrow{(C\cdot B)} = 301441.392$ $\sum\overrightarrow{(C^2)} = 96815.442$ $\sum\overrightarrow{(C\cdot N)} = 3094.052$

$\sum\overrightarrow{(C\cdot P)} = 2900.762$ $\sum\overrightarrow{(C\cdot H)} = 472.554$ $\sum\overrightarrow{(N\cdot T)} = 915.924$ $\sum\overrightarrow{(N\cdot U)} = 829.52$

$\sum\overrightarrow{(N\cdot D)} = 10498.04$ $\sum\overrightarrow{(N\cdot O)} = 336.101$ $\sum\overrightarrow{(N\cdot B)} = 13956.661$ $\sum\overrightarrow{(N\cdot C)} = 3094.052$

$\sum\overrightarrow{(N^2)} = 240.248$ $\sum\overrightarrow{(N\cdot P)} = 193.93$ $\sum\overrightarrow{(N\cdot H)} = 33.085$ $\sum\overrightarrow{(P\cdot T)} = 780.355$

$\sum\overrightarrow{(P\cdot U)} = 765.43$ $\sum\overrightarrow{(P\cdot D)} = 9737.72$ $\sum\overrightarrow{(P\cdot O)} = 294.972$ $\sum\overrightarrow{(P\cdot B)} = 13811.103$

$\sum\overrightarrow{(P\cdot C)} = 2900.762$ $\sum\overrightarrow{(P\cdot N)} = 193.93$ $\sum\overrightarrow{(P^2)} = 172.665$ $\sum\overrightarrow{(P\cdot H)} = 29.378$

$\sum\overrightarrow{(H\cdot T)} = 117.759$ $\sum\overrightarrow{(H\cdot U)} = 120.96$ $\sum\overrightarrow{(H\cdot D)} = 1552.28$ $\sum\overrightarrow{(H\cdot O)} = 42.94$

$\sum\overrightarrow{(H\cdot B)} = 2037.536$ $\sum\overrightarrow{(H\cdot C)} = 472.554$ $\sum\overrightarrow{(H\cdot N)} = 33.085$ $\sum\overrightarrow{(H\cdot P)} = 29.378$

$\sum\overrightarrow{(H^2)} = 6.231$ $\sum\overrightarrow{(pH\cdot T)} = 1321.161$ $\sum\overrightarrow{(pH\cdot U)} = 1320.91$ $\sum\overrightarrow{(pH\cdot D)} = 15163.3$

$\sum\overrightarrow{(pH\cdot O)} = 526.307$ $\sum\overrightarrow{(pH\cdot B)} = 22205.617$ $\sum\overrightarrow{(pH\cdot C)} = 5507.893$ $\sum\overrightarrow{(pH\cdot N)} = 278.443$

$\sum\overrightarrow{(pH\cdot P)} = 243.741$ $\sum\overrightarrow{(pH\cdot H)} = 36.284$

$$Z := \begin{pmatrix}
\sum\overrightarrow{(T^2)} & \sum\overrightarrow{(T\cdot U)} & \sum\overrightarrow{(T\cdot D)} & \sum\overrightarrow{(T\cdot O)} & \sum\overrightarrow{(T\cdot B)} & \sum\overrightarrow{(T\cdot C)} & \sum\overrightarrow{(T\cdot N)} & \sum\overrightarrow{(T\cdot P)} & \sum\overrightarrow{(T\cdot H)} \\
\sum\overrightarrow{(U\cdot T)} & \sum\overrightarrow{(U^2)} & \sum\overrightarrow{(U\cdot D)} & \sum\overrightarrow{(U\cdot O)} & \sum\overrightarrow{(U\cdot B)} & \sum\overrightarrow{(U\cdot C)} & \sum\overrightarrow{(U\cdot N)} & \sum\overrightarrow{(U\cdot P)} & \sum\overrightarrow{(U\cdot H)} \\
\sum\overrightarrow{(D\cdot T)} & \sum\overrightarrow{(D\cdot U)} & \sum\overrightarrow{(D^2)} & \sum\overrightarrow{(D\cdot O)} & \sum\overrightarrow{(D\cdot B)} & \sum\overrightarrow{(D\cdot C)} & \sum\overrightarrow{(D\cdot N)} & \sum\overrightarrow{(D\cdot P)} & \sum\overrightarrow{(D\cdot H)} \\
\sum\overrightarrow{(O\cdot T)} & \sum\overrightarrow{(O\cdot U)} & \sum\overrightarrow{(O\cdot D)} & \sum\overrightarrow{(O^2)} & \sum\overrightarrow{(O\cdot B)} & \sum\overrightarrow{(O\cdot C)} & \sum\overrightarrow{(O\cdot N)} & \sum\overrightarrow{(O\cdot P)} & \sum\overrightarrow{(O\cdot H)} \\
\sum\overrightarrow{(B\cdot T)} & \sum\overrightarrow{(B\cdot U)} & \sum\overrightarrow{(B\cdot D)} & \sum\overrightarrow{(B\cdot O)} & \sum\overrightarrow{(B^2)} & \sum\overrightarrow{(B\cdot C)} & \sum\overrightarrow{(B\cdot N)} & \sum\overrightarrow{(B\cdot P)} & \sum\overrightarrow{(B\cdot H)} \\
\sum\overrightarrow{(C\cdot T)} & \sum\overrightarrow{(C\cdot U)} & \sum\overrightarrow{(C\cdot D)} & \sum\overrightarrow{(C\cdot O)} & \sum\overrightarrow{(C\cdot B)} & \sum\overrightarrow{(C^2)} & \sum\overrightarrow{(C\cdot N)} & \sum\overrightarrow{(C\cdot P)} & \sum\overrightarrow{(C\cdot H)} \\
\sum\overrightarrow{(N\cdot T)} & \sum\overrightarrow{(N\cdot U)} & \sum\overrightarrow{(N\cdot D)} & \sum\overrightarrow{(N\cdot O)} & \sum\overrightarrow{(N\cdot B)} & \sum\overrightarrow{(N\cdot C)} & \sum\overrightarrow{(N^2)} & \sum\overrightarrow{(N\cdot P)} & \sum\overrightarrow{(N\cdot H)} \\
\sum\overrightarrow{(P\cdot T)} & \sum\overrightarrow{(P\cdot U)} & \sum\overrightarrow{(P\cdot D)} & \sum\overrightarrow{(P\cdot O)} & \sum\overrightarrow{(P\cdot B)} & \sum\overrightarrow{(P\cdot C)} & \sum\overrightarrow{(P\cdot N)} & \sum\overrightarrow{(P^2)} & \sum\overrightarrow{(P\cdot H)} \\
\sum\overrightarrow{(H\cdot T)} & \sum\overrightarrow{(H\cdot U)} & \sum\overrightarrow{(H\cdot D)} & \sum\overrightarrow{(H\cdot O)} & \sum\overrightarrow{(H\cdot B)} & \sum\overrightarrow{(H\cdot C)} & \sum\overrightarrow{(H\cdot N)} & \sum\overrightarrow{(H\cdot P)} & \sum\overrightarrow{(H^2)}
\end{pmatrix}$$

$$
Z = \begin{pmatrix}
4287.15 & 4173.6 & 46833 & 1688.778 & 69521.362 & 17453.972 & 915.924 & 780.355 & 117.759 \\
4173.6 & 4460 & 50044 & 1709.51 & 73278.86 & 19497.13 & 829.52 & 765.43 & 120.96 \\
46833 & 50044 & 637240 & 18733.5 & 857594.58 & 198375.7 & 10498.04 & 9737.72 & 1552.28 \\
1688.778 & 1709.51 & 18733.5 & 684.584 & 28155.359 & 7473.378 & 336.101 & 294.972 & 42.94 \\
69521.362 & 73278.86 & 857594.58 & 28155.359 & 1362361.339 & 301441.392 & 13956.661 & 13811.103 & 2037.536 \\
17453.972 & 19497.13 & 198375.7 & 7473.378 & 301441.392 & 96815.442 & 3094.052 & 2900.762 & 472.554 \\
915.924 & 829.52 & 10498.04 & 336.101 & 13956.661 & 3094.052 & 240.248 & 193.93 & 33.085 \\
780.355 & 765.43 & 9737.72 & 294.972 & 13811.103 & 2900.762 & 193.93 & 172.665 & 29.378 \\
117.759 & 120.96 & 1552.28 & 42.94 & 2037.536 & 472.554 & 33.085 & 29.378 & 6.231
\end{pmatrix}
$$

$\sum \overrightarrow{(pH \cdot T)} = 1321.161$

$\sum \overrightarrow{(pH \cdot U)} = 1320.91$

$\sum \overrightarrow{(pH \cdot D)} = 15163.3$

$\sum \overrightarrow{(pH \cdot O)} = 526.307$

$\sum \overrightarrow{(pH \cdot B)} = 22205.617$

$\sum \overrightarrow{(pH \cdot C)} = 5507.893$

$\sum \overrightarrow{(pH \cdot N)} = 278.443$

$\sum \overrightarrow{(pH \cdot P)} = 243.741$

$\sum \overrightarrow{(pH \cdot H)} = 36.284$

$$
z := \begin{pmatrix}
\sum \overrightarrow{(pH \cdot T)} \\
\sum \overrightarrow{(pH \cdot U)} \\
\sum \overrightarrow{(pH \cdot D)} \\
\sum \overrightarrow{(pH \cdot O)} \\
\sum \overrightarrow{(pH \cdot B)} \\
\sum \overrightarrow{(pH \cdot C)} \\
\sum \overrightarrow{(pH \cdot N)} \\
\sum \overrightarrow{(pH \cdot P)} \\
\sum \overrightarrow{(pH \cdot H)}
\end{pmatrix}
$$

$$z = \begin{pmatrix} 1321.161 \\ 1320.91 \\ 15163.3 \\ 526.307 \\ 22205.617 \\ 5507.893 \\ 278.443 \\ 243.741 \\ 36.284 \end{pmatrix}$$

$$t' := \text{lsolve}(Z, z)$$

$$t' = \begin{pmatrix} 0.329 \\ -0.241 \\ 0.014 \\ 0.423 \\ -0.001 \\ 0.001 \\ -0.592 \\ -0.004 \\ 1.421 \end{pmatrix}$$

$$pH_m := 0.329 \cdot T - 0.241 \cdot U + 0.014 \cdot D + 0.423 \cdot O - 0.00106 \cdot B + 0.001044 \cdot C - 0.592 \cdot N - 0.004394 \cdot P + 1.421 \cdot H$$

SIMULATION

$$pH_m = \begin{pmatrix} 10.308 \\ 7.567 \\ 9.086 \\ 9.271 \\ 6.666 \\ 7.014 \end{pmatrix}$$

$$\text{error} := pH - pH_m$$

$$\text{error} = \begin{pmatrix} -0.228 \\ -0.137 \\ -0.176 \\ -0.131 \\ -0.016 \\ -0.034 \end{pmatrix}$$

$$\%error := \overrightarrow{\left(\frac{error}{pH} \cdot 100\right)}$$

$$\%error = \begin{pmatrix} -2.257 \\ -1.838 \\ -1.973 \\ -1.438 \\ -0.238 \\ -0.484 \end{pmatrix}$$

$$\overrightarrow{(T^2)} = \begin{pmatrix} 707.56 \\ 681.21 \\ 829.44 \\ 823.69 \\ 605.16 \\ 640.09 \end{pmatrix} \quad \overrightarrow{(T \cdot U)} = \begin{pmatrix} 1117.2 \\ 495.9 \\ 892.8 \\ 545.3 \\ 565.8 \\ 556.6 \end{pmatrix} \quad \overrightarrow{(T \cdot D)} = \begin{pmatrix} 13778.8 \\ 8091 \\ 11577.6 \\ 8782.2 \\ 1820.4 \\ 2783 \end{pmatrix} \quad \overrightarrow{(T \cdot O)} = \begin{pmatrix} 363.09 \\ 209.583 \\ 285.696 \\ 307.09 \\ 271.584 \\ 251.735 \end{pmatrix}$$

$$\sum \overrightarrow{(T^2)} = 4287.15 \quad \sum \overrightarrow{(T \cdot U)} = 4173.6 \quad \sum \overrightarrow{(T \cdot D)} = 46833 \quad \sum \overrightarrow{(T \cdot O)} = 1688.778$$

$$\overrightarrow{(T \cdot B)} = \begin{pmatrix} 16410.604 \\ 2679.687 \\ 20736 \\ 15426.25 \\ 7286.274 \\ 6982.547 \end{pmatrix} \quad \overrightarrow{(T \cdot C)} = \begin{pmatrix} 5438.636 \\ 1510.146 \\ 2921.76 \\ 1083.138 \\ 4526.892 \\ 1973.4 \end{pmatrix} \quad \overrightarrow{(T \cdot N)} = \begin{pmatrix} 78.204 \\ 266.742 \\ 235.008 \\ 186.55 \\ 83.64 \\ 65.78 \end{pmatrix} \quad \overrightarrow{(T \cdot P)} = \begin{pmatrix} 117.572 \\ 155.034 \\ 260.064 \\ 154.406 \\ 56.088 \\ 37.191 \end{pmatrix}$$

$$\sum \overrightarrow{(T \cdot B)} = 69521.362 \quad \sum \overrightarrow{(T \cdot C)} = 17453.972 \quad \sum \overrightarrow{(T \cdot N)} = 915.924 \quad \sum \overrightarrow{(T \cdot P)} = 780.355$$

$$\overrightarrow{(T \cdot H)} = \begin{pmatrix} 15.96 \\ 35.757 \\ 56.448 \\ 0 \\ 9.594 \\ 0 \end{pmatrix} \quad \overrightarrow{(U \cdot T)} = \begin{pmatrix} 1117.2 \\ 495.9 \\ 892.8 \\ 545.3 \\ 565.8 \\ 556.6 \end{pmatrix} \quad \overrightarrow{(U^2)} = \begin{pmatrix} 1764 \\ 361 \\ 961 \\ 361 \\ 529 \\ 484 \end{pmatrix} \quad \overrightarrow{(U \cdot D)} = \begin{pmatrix} 21756 \\ 5890 \\ 12462 \\ 5814 \\ 1702 \\ 2420 \end{pmatrix}$$

$$\sum \overrightarrow{(T \cdot H)} = 117.759 \quad \sum \overrightarrow{(U \cdot T)} = 4173.6 \quad \sum \overrightarrow{(U^2)} = 4460 \quad \sum \overrightarrow{(U \cdot D)} = 50044$$

$$\overrightarrow{(U \cdot O)} = \begin{pmatrix} 573.3 \\ 152.57 \\ 307.52 \\ 203.3 \\ 253.92 \\ 218.9 \end{pmatrix} \quad \overrightarrow{(U \cdot B)} = \begin{pmatrix} 25911.48 \\ 1950.73 \\ 22320 \\ 10212.5 \\ 6812.37 \\ 6071.78 \end{pmatrix} \quad \overrightarrow{(U \cdot C)} = \begin{pmatrix} 8587.32 \\ 1099.34 \\ 3144.95 \\ 717.06 \\ 4232.46 \\ 1716 \end{pmatrix} \quad \overrightarrow{(U \cdot N)} = \begin{pmatrix} 123.48 \\ 194.18 \\ 252.96 \\ 123.5 \\ 78.2 \\ 57.2 \end{pmatrix}$$

$$\sum \overrightarrow{(U \cdot O)} = 1709.51 \quad \sum \overrightarrow{(U \cdot B)} = 73278.86 \quad \sum \overrightarrow{(U \cdot C)} = 19497.13 \quad \sum \overrightarrow{(U \cdot N)} = 829.52$$

$$\overrightarrow{(U \cdot P)} = \begin{pmatrix} 185.64 \\ 112.86 \\ 279.93 \\ 102.22 \\ 52.44 \\ 32.34 \end{pmatrix} \quad \overrightarrow{(U \cdot H)} = \begin{pmatrix} 25.2 \\ 26.03 \\ 60.76 \\ 0 \\ 8.97 \\ 0 \end{pmatrix} \quad \overrightarrow{(D \cdot T)} = \begin{pmatrix} 13778.8 \\ 8091 \\ 11577.6 \\ 8782.2 \\ 1820.4 \\ 2783 \end{pmatrix} \quad \overrightarrow{(D \cdot U)} = \begin{pmatrix} 21756 \\ 5890 \\ 12462 \\ 5814 \\ 1702 \\ 2420 \end{pmatrix}$$

$$\sum \overrightarrow{(U \cdot P)} = 765.43 \quad \sum \overrightarrow{(U \cdot H)} = 120.96 \quad \sum \overrightarrow{(D \cdot T)} = 46833 \quad \sum \overrightarrow{(D \cdot U)} = 50044$$

$$\overrightarrow{(D^2)} = \begin{pmatrix} 268324 \\ 96100 \\ 161604 \\ 93636 \\ 5476 \\ 12100 \end{pmatrix} \quad \overrightarrow{(D \cdot O)} = \begin{pmatrix} 7070.7 \\ 2489.3 \\ 3987.84 \\ 3274.2 \\ 816.96 \\ 1094.5 \end{pmatrix} \quad \overrightarrow{(D \cdot B)} = \begin{pmatrix} 319574.92 \\ 31827.7 \\ 289440 \\ 164475 \\ 21918.06 \\ 30358.9 \end{pmatrix} \quad \overrightarrow{(D \cdot C)} = \begin{pmatrix} 105910.28 \\ 17936.6 \\ 40782.9 \\ 11548.44 \\ 13617.48 \\ 8580 \end{pmatrix}$$

$$\sum \overrightarrow{(D^2)} = 637240 \quad \sum \overrightarrow{(D \cdot O)} = 18733.5 \quad \sum \overrightarrow{(D \cdot B)} = 857594.58 \quad \sum \overrightarrow{(D \cdot C)} = 198375.7$$

$$\overrightarrow{(D \cdot N)} = \begin{pmatrix} 1522.92 \\ 3168.2 \\ 3280.32 \\ 1989 \\ 251.6 \\ 286 \end{pmatrix} \quad \overrightarrow{(D \cdot P)} = \begin{pmatrix} 2289.56 \\ 1841.4 \\ 3630.06 \\ 1646.28 \\ 168.72 \\ 161.7 \end{pmatrix} \quad \overrightarrow{(D \cdot H)} = \begin{pmatrix} 310.8 \\ 424.7 \\ 787.92 \\ 0 \\ 28.86 \\ 0 \end{pmatrix} \quad \overrightarrow{(O \cdot T)} = \begin{pmatrix} 363.09 \\ 209.583 \\ 285.696 \\ 307.09 \\ 271.584 \\ 251.735 \end{pmatrix}$$

$$\sum \overrightarrow{(D \cdot N)} = 10498.04 \quad \sum \overrightarrow{(D \cdot P)} = 9737.72 \quad \sum \overrightarrow{(D \cdot H)} = 1552.28 \quad \sum \overrightarrow{(O \cdot T)} = 1688.778$$

$$\overrightarrow{(O \cdot U)} = \begin{pmatrix} 573.3 \\ 152.57 \\ 307.52 \\ 203.3 \\ 253.92 \\ 218.9 \end{pmatrix} \quad \overrightarrow{(O \cdot D)} = \begin{pmatrix} 7070.7 \\ 2489.3 \\ 3987.84 \\ 3274.2 \\ 816.96 \\ 1094.5 \end{pmatrix} \quad \overrightarrow{(O^2)} = \begin{pmatrix} 186.323 \\ 64.481 \\ 98.406 \\ 114.49 \\ 121.882 \\ 99.002 \end{pmatrix} \quad \overrightarrow{(O \cdot B)} = \begin{pmatrix} 8421.231 \\ 824.44 \\ 7142.4 \\ 5751.25 \\ 3269.938 \\ 2746.101 \end{pmatrix}$$

$$\sum \overrightarrow{(O \cdot U)} = 1709.51 \quad \sum \overrightarrow{(O \cdot D)} = 18733.5 \quad \sum \overrightarrow{(O^2)} = 684.584 \quad \sum \overrightarrow{(O \cdot B)} = 28155.359$$

$$\overrightarrow{(O \cdot C)} = \begin{pmatrix} 2790.879 \\ 464.616 \\ 1006.384 \\ 403.818 \\ 2031.581 \\ 776.1 \end{pmatrix} \quad \overrightarrow{(O \cdot N)} = \begin{pmatrix} 40.131 \\ 82.067 \\ 80.947 \\ 69.55 \\ 37.536 \\ 25.87 \end{pmatrix} \quad \overrightarrow{(O \cdot P)} = \begin{pmatrix} 60.333 \\ 47.698 \\ 89.578 \\ 57.566 \\ 25.171 \\ 14.626 \end{pmatrix} \quad \overrightarrow{(O \cdot H)} = \begin{pmatrix} 8.19 \\ 11.001 \\ 19.443 \\ 0 \\ 4.306 \\ 0 \end{pmatrix}$$

$$\sum \overrightarrow{(O \cdot C)} = 7473.378 \quad \sum \overrightarrow{(O \cdot N)} = 336.101 \quad \sum \overrightarrow{(O \cdot P)} = 294.972 \quad \sum \overrightarrow{(O \cdot H)} = 42.94$$

$$\overrightarrow{(B \cdot T)} = \begin{pmatrix} 16410.604 \\ 2679.687 \\ 20736 \\ 15426.25 \\ 7286.274 \\ 6982.547 \end{pmatrix} \quad \overrightarrow{(B \cdot U)} = \begin{pmatrix} 25911.48 \\ 1950.73 \\ 22320 \\ 10212.5 \\ 6812.37 \\ 6071.78 \end{pmatrix} \quad \overrightarrow{(B \cdot D)} = \begin{pmatrix} 319574.92 \\ 31827.7 \\ 289440 \\ 164475 \\ 21918.06 \\ 30358.9 \end{pmatrix} \quad \overrightarrow{(B \cdot O)} = \begin{pmatrix} 8421.231 \\ 824.44 \\ 7142.4 \\ 5751.25 \\ 3269.938 \\ 2746.101 \end{pmatrix}$$

$$\sum\overrightarrow{(B\cdot T)} = 69521.362 \qquad \sum\overrightarrow{(B\cdot U)} = 73278.86 \qquad \sum\overrightarrow{(B\cdot D)} = 857594.58 \qquad \sum\overrightarrow{(B\cdot O)} = 28155.359$$

$$\overrightarrow{(B\cdot B)} = \begin{pmatrix} 380614.964 \\ 10541.129 \\ 518400 \\ 288906.25 \\ 87728.516 \\ 76170.48 \end{pmatrix} \quad \overrightarrow{(B\cdot C)} = \begin{pmatrix} 126139.552 \\ 5940.486 \\ 73044 \\ 20285.25 \\ 54504.884 \\ 21527.22 \end{pmatrix} \quad \overrightarrow{(B\cdot N)} = \begin{pmatrix} 1813.804 \\ 1049.287 \\ 5875.2 \\ 3493.75 \\ 1007.046 \\ 717.574 \end{pmatrix} \quad \overrightarrow{(B\cdot P)} = \begin{pmatrix} 2726.875 \\ 609.86 \\ 6501.6 \\ 2891.75 \\ 675.313 \\ 405.705 \end{pmatrix}$$

$$\sum\overrightarrow{(B\cdot B)} = 1362361.339 \qquad \sum\overrightarrow{(B\cdot C)} = 301441.392 \qquad \sum\overrightarrow{(B\cdot N)} = 13956.661 \qquad \sum\overrightarrow{(B\cdot P)} = 13811.103$$

$$\overrightarrow{(B\cdot H)} = \begin{pmatrix} 370.164 \\ 140.658 \\ 1411.2 \\ 0 \\ 115.514 \\ 0 \end{pmatrix} \quad \overrightarrow{(C\cdot T)} = \begin{pmatrix} 5438.636 \\ 1510.146 \\ 2921.76 \\ 1083.138 \\ 4526.892 \\ 1973.4 \end{pmatrix} \quad \overrightarrow{(C\cdot U)} = \begin{pmatrix} 8587.32 \\ 1099.34 \\ 3144.95 \\ 717.06 \\ 4232.46 \\ 1716 \end{pmatrix} \quad \overrightarrow{(C\cdot D)} = \begin{pmatrix} 105910.28 \\ 17936.6 \\ 40782.9 \\ 11548.44 \\ 13617.48 \\ 8580 \end{pmatrix}$$

$$\sum\overrightarrow{(B\cdot H)} = 2037.536 \qquad \sum\overrightarrow{(C\cdot T)} = 17453.972 \qquad \sum\overrightarrow{(C\cdot U)} = 19497.13 \qquad \sum\overrightarrow{(C\cdot D)} = 198375.7$$

$$\overrightarrow{(C\cdot O)} = \begin{pmatrix} 2790.879 \\ 464.616 \\ 1006.384 \\ 403.818 \\ 2031.581 \\ 776.1 \end{pmatrix} \quad \overrightarrow{(C\cdot B)} = \begin{pmatrix} 126139.552 \\ 5940.486 \\ 73044 \\ 20285.25 \\ 54504.884 \\ 21527.22 \end{pmatrix} \quad \overrightarrow{(C^2)} = \begin{pmatrix} 41803.892 \\ 3347.78 \\ 10292.103 \\ 1424.308 \\ 33863.36 \\ 6084 \end{pmatrix} \quad \overrightarrow{(C\cdot N)} = \begin{pmatrix} 601.112 \\ 591.329 \\ 827.832 \\ 245.31 \\ 625.668 \\ 202.8 \end{pmatrix}$$

$$\sum\overrightarrow{(C\cdot O)} = 7473.378 \qquad \sum\overrightarrow{(C\cdot B)} = 301441.392 \qquad \sum\overrightarrow{(C^2)} = 96815.442 \qquad \sum\overrightarrow{(C\cdot N)} = 3094.052$$

$$\overrightarrow{(C\cdot P)} = \begin{pmatrix} 903.713 \\ 343.688 \\ 916.093 \\ 203.041 \\ 419.566 \\ 114.66 \end{pmatrix} \quad \overrightarrow{(C\cdot H)} = \begin{pmatrix} 122.676 \\ 79.268 \\ 198.842 \\ 0 \\ 71.768 \\ 0 \end{pmatrix} \quad \overrightarrow{(N\cdot T)} = \begin{pmatrix} 78.204 \\ 266.742 \\ 235.008 \\ 186.55 \\ 83.64 \\ 65.78 \end{pmatrix} \quad \overrightarrow{(N\cdot U)} = \begin{pmatrix} 123.48 \\ 194.18 \\ 252.96 \\ 123.5 \\ 78.2 \\ 57.2 \end{pmatrix}$$

$$\sum\overrightarrow{(C\cdot P)} = 2900.762 \qquad \sum\overrightarrow{(C\cdot H)} = 472.554 \qquad \sum\overrightarrow{(N\cdot T)} = 915.924 \qquad \sum\overrightarrow{(N\cdot U)} = 829.52$$

$$\overrightarrow{(N\cdot D)} = \begin{pmatrix} 1522.92 \\ 3168.2 \\ 3280.32 \\ 1989 \\ 251.6 \\ 286 \end{pmatrix} \quad \overrightarrow{(N\cdot O)} = \begin{pmatrix} 40.131 \\ 82.067 \\ 80.947 \\ 69.55 \\ 37.536 \\ 25.87 \end{pmatrix} \quad \overrightarrow{(N\cdot B)} = \begin{pmatrix} 1813.804 \\ 1049.287 \\ 5875.2 \\ 3493.75 \\ 1007.046 \\ 717.574 \end{pmatrix} \quad \overrightarrow{(N\cdot C)} = \begin{pmatrix} 601.112 \\ 591.329 \\ 827.832 \\ 245.31 \\ 625.668 \\ 202.8 \end{pmatrix}$$

$$\sum\overrightarrow{(N\cdot D)} = 10498.04 \qquad \sum\overrightarrow{(N\cdot O)} = 336.101 \qquad \sum\overrightarrow{(N\cdot B)} = 13956.661 \qquad \sum\overrightarrow{(N\cdot C)} = 3094.052$$

$$\overrightarrow{(N^2)} = \begin{pmatrix} 8.644 \\ 104.448 \\ 66.586 \\ 42.25 \\ 11.56 \\ 6.76 \end{pmatrix} \qquad \overrightarrow{(N \cdot P)} = \begin{pmatrix} 12.995 \\ 60.707 \\ 73.685 \\ 34.97 \\ 7.752 \\ 3.822 \end{pmatrix} \qquad \overrightarrow{(N \cdot H)} = \begin{pmatrix} 1.764 \\ 14.001 \\ 15.994 \\ 0 \\ 1.326 \\ 0 \end{pmatrix} \qquad \overrightarrow{(P \cdot T)} = \begin{pmatrix} 117.572 \\ 155.034 \\ 260.064 \\ 154.406 \\ 56.088 \\ 37.191 \end{pmatrix}$$

$$\sum \overrightarrow{(N^2)} = 240.248 \qquad \sum \overrightarrow{(N \cdot P)} = 193.93 \qquad \sum \overrightarrow{(N \cdot H)} = 33.085 \qquad \sum \overrightarrow{(P \cdot T)} = 780.355$$

$$\overrightarrow{(P \cdot U)} = \begin{pmatrix} 185.64 \\ 112.86 \\ 279.93 \\ 102.22 \\ 52.44 \\ 32.34 \end{pmatrix} \qquad \overrightarrow{(P \cdot D)} = \begin{pmatrix} 2289.56 \\ 1841.4 \\ 3630.06 \\ 1646.28 \\ 168.72 \\ 161.7 \end{pmatrix} \qquad \overrightarrow{(P \cdot O)} = \begin{pmatrix} 60.333 \\ 47.698 \\ 89.578 \\ 57.566 \\ 25.171 \\ 14.626 \end{pmatrix} \qquad \overrightarrow{(P \cdot B)} = \begin{pmatrix} 2726.875 \\ 609.86 \\ 6501.6 \\ 2891.75 \\ 675.313 \\ 405.705 \end{pmatrix}$$

$$\sum \overrightarrow{(P \cdot O)} = 294.972 \qquad \sum \overrightarrow{(P \cdot D)} = 9737.72 \qquad \sum \overrightarrow{(P \cdot O)} = 294.972 \qquad \sum \overrightarrow{(P \cdot B)} = 13811.103$$

$$\overrightarrow{(P \cdot C)} = \begin{pmatrix} 903.713 \\ 343.688 \\ 916.093 \\ 203.041 \\ 419.566 \\ 114.66 \end{pmatrix} \qquad \overrightarrow{(P \cdot N)} = \begin{pmatrix} 12.995 \\ 60.707 \\ 73.685 \\ 34.97 \\ 7.752 \\ 3.822 \end{pmatrix} \qquad \overrightarrow{(P^2)} = \begin{pmatrix} 19.536 \\ 35.284 \\ 81.541 \\ 28.944 \\ 5.198 \\ 2.161 \end{pmatrix} \qquad \overrightarrow{(P \cdot H)} = \begin{pmatrix} 2.652 \\ 8.138 \\ 17.699 \\ 0 \\ 0.889 \\ 0 \end{pmatrix}$$

$$\sum \overrightarrow{(P \cdot C)} = 2900.762 \qquad \sum \overrightarrow{(P \cdot N)} = 193.93 \qquad \sum \overrightarrow{(P^2)} = 172.665 \qquad \sum \overrightarrow{(P \cdot H)} = 29.378$$

$$\overrightarrow{(H \cdot T)} = \begin{pmatrix} 15.96 \\ 35.757 \\ 56.448 \\ 0 \\ 9.594 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot U)} = \begin{pmatrix} 25.2 \\ 26.03 \\ 60.76 \\ 0 \\ 8.97 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot D)} = \begin{pmatrix} 310.8 \\ 424.7 \\ 787.92 \\ 0 \\ 28.86 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot O)} = \begin{pmatrix} 8.19 \\ 11.001 \\ 19.443 \\ 0 \\ 4.306 \\ 0 \end{pmatrix}$$

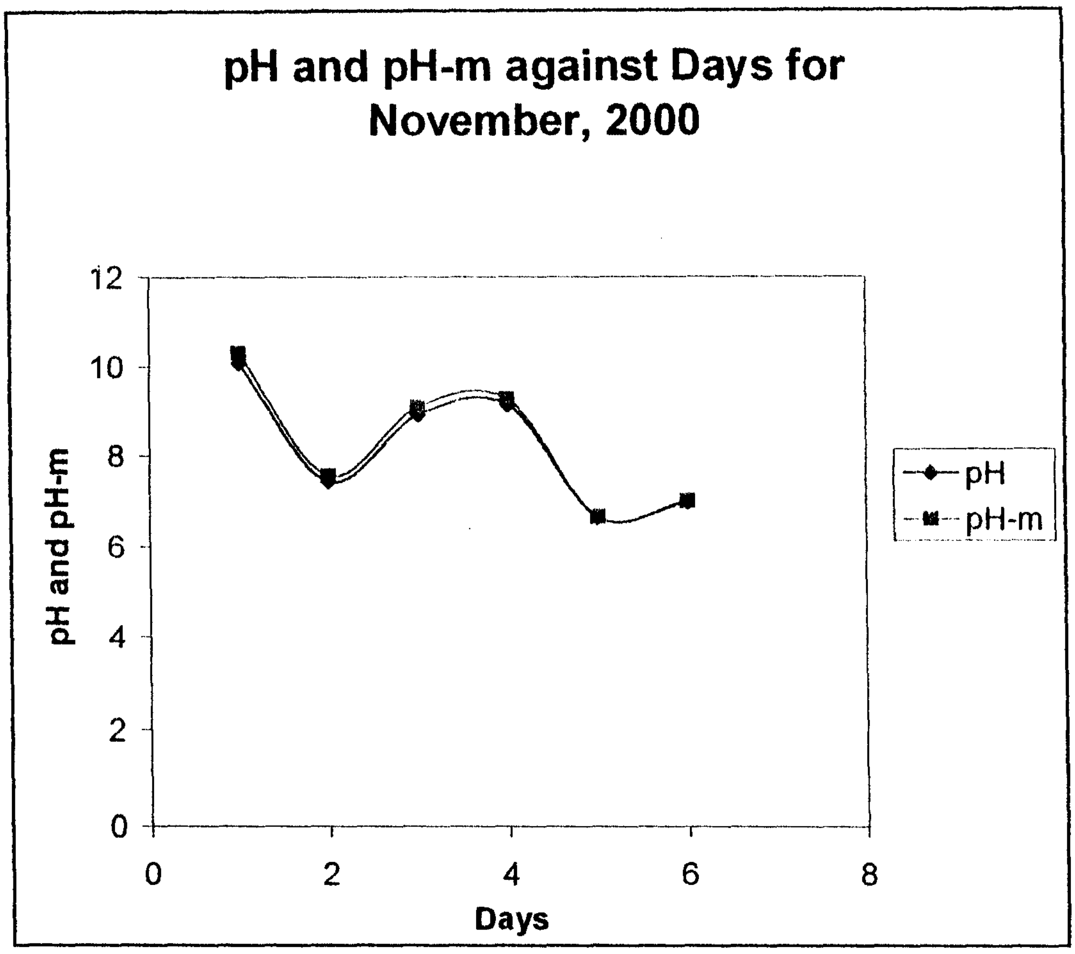
$$\sum \overrightarrow{(H \cdot T)} = 117.759 \qquad \sum \overrightarrow{(H \cdot U)} = 120.96 \qquad \sum \overrightarrow{(H \cdot D)} = 1552.28 \qquad \sum \overrightarrow{(H \cdot O)} = 42.94$$

$$\overrightarrow{(H \cdot B)} = \begin{pmatrix} 370.164 \\ 140.658 \\ 1411.2 \\ 0 \\ 115.514 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot C)} = \begin{pmatrix} 122.676 \\ 79.268 \\ 198.842 \\ 0 \\ 71.768 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot N)} = \begin{pmatrix} 1.764 \\ 14.001 \\ 15.994 \\ 0 \\ 1.326 \\ 0 \end{pmatrix} \qquad \overrightarrow{(H \cdot P)} = \begin{pmatrix} 2.652 \\ 8.138 \\ 17.699 \\ 0 \\ 0.889 \\ 0 \end{pmatrix}$$

$$\sum \overrightarrow{(H \cdot B)} = 2037.536 \qquad \sum \overrightarrow{(H \cdot C)} = 472.554 \qquad \sum \overrightarrow{(H \cdot N)} = 33.085 \qquad \sum \overrightarrow{(H \cdot P)} = 29.378$$

$$\overrightarrow{(H^2)} = \begin{pmatrix} 0.36 \\ 1.877 \\ 3.842 \\ 0 \\ 0.152 \\ 0 \end{pmatrix} \qquad \sum \overrightarrow{(H^2)} = 6.231$$

Days	pH	pH-m
1	10.08	10.308
2	7.43	7.567
3	8.91	9.086
4	9.14	9.271
5	6.65	6.666
6	6.98	7.014



AUGUST 2003

MODELLING

pH	T	Tu	TDS	DO	BOD	COD	NO	PO	SO

data :=

	1	2	3	4	5	6	7	8	9	10	11
1	1	8.24	27	15	189	7.28	110.25	600	1.2	5.23	162.5
2	2	6.31	26.6	14.5	234.11	6.7	45.57	260	0.7	1.76	215
3	3	6.77	26.6	14	408.25	6.67	88.2	140	0.5	9.29	130
4	4	7.58	28	12	225.93	7.75	99.96	220	0.5	8.83	87.5
5	5	6.55	27.8	160	228.79	7.41	58.8	380	0.7	7.56	46
6	6	5.83	28	116	216.55	7.76	70.56	319.2	0	6.93	90

$pH := data^{\langle 2\rangle}$ $T := data^{\langle 3\rangle}$ $U := data^{\langle 4\rangle}$ $D := data^{\langle 5\rangle}$ $O := data^{\langle 6\rangle}$

$B := data^{\langle 7\rangle}$ $C := data^{\langle 8\rangle}$ $N := data^{\langle 9\rangle}$ $P := data^{\langle 10\rangle}$ $S := data^{\langle 11\rangle}$

$\sum \overrightarrow{(T)^2} = 4.485 \times 10^3$ $\sum \overrightarrow{(T \cdot U)} = 9.195 \times 10^3$ $\sum \overrightarrow{(T \cdot D)} = 4.094 \times 10^4$ $\sum \overrightarrow{(T \cdot O)} = 1.192 \times 10^3$

$\sum \overrightarrow{(T \cdot B)} = 1.294 \times 10^4$ $\sum \overrightarrow{(T \cdot C)} = 5.25 \times 10^4$ $\sum \overrightarrow{(T \cdot N)} = 97.78$ $\sum \overrightarrow{(T \cdot P)} = 1.087 \times 10^3$

$\sum \overrightarrow{(T \cdot S)} = 1.981 \times 10^4$

$\sum \overrightarrow{(U \cdot T)} = 9.195 \times 10^3$ $\sum \overrightarrow{\left(U^2\right)} = 3.983 \times 10^4$ $\sum \overrightarrow{(U \cdot D)} = 7.638 \times 10^4$ $\sum \overrightarrow{(U \cdot O)} = 2.478 \times 10^3$

$\sum \overrightarrow{(U \cdot B)} = 2.234 \times 10^4$ $\sum \overrightarrow{(U \cdot C)} = 1.152 \times 10^5$ $\sum \overrightarrow{(U \cdot N)} = 153.15$ $\sum \overrightarrow{(U \cdot P)} = 2.353 \times 10^3$

$\sum \overrightarrow{(U \cdot S)} = 2.623 \times 10^4$

$\sum \overrightarrow{(D \cdot T)} = 4.094 \times 10^4$ $\sum \overrightarrow{(D \cdot U)} = 7.638 \times 10^4$ $\sum \overrightarrow{\left(D^2\right)} = 4.075 \times 10^5$ $\sum \overrightarrow{(D \cdot O)} = 1.079 \times 10^4$

$\sum \overrightarrow{(D \cdot B)} = 1.188 \times 10^5$ $\sum \overrightarrow{(D \cdot C)} = 4.372 \times 10^5$ $\sum \overrightarrow{(D \cdot N)} = 867.92$ $\sum \overrightarrow{(D \cdot P)} = 1.042 \times 10^4$

$\sum \overrightarrow{(D \cdot S)} = 1.839 \times 10^5$

$\sum \overrightarrow{(O \cdot T)} = 1.192 \times 10^3$ $\sum \overrightarrow{(O \cdot U)} = 2.478 \times 10^3$ $\sum \overrightarrow{(O \cdot D)} = 1.079 \times 10^4$ $\sum \overrightarrow{\left(O^2\right)} = 317.565$

$\sum \overrightarrow{(O \cdot B)} = 3.454 \times 10^3$ $\sum \overrightarrow{(O \cdot C)} = 1.404 \times 10^4$ $\sum \overrightarrow{(O \cdot N)} = 25.823$ $\sum \overrightarrow{(O \cdot P)} = 290.06$

$\sum \overrightarrow{(O \cdot S)} = 5.208 \times 10^3$

$\sum\overrightarrow{(O \cdot B)} = 3.454 \times 10^3$ $\sum\overrightarrow{(O \cdot C)} = 1.404 \times 10^4$ $\sum\overrightarrow{(O \cdot N)} = 25.823$ $\sum\overrightarrow{(O \cdot P)} = 290.06$

$\sum\overrightarrow{(O \cdot S)} = 5.208 \times 10^3$

$\sum\overrightarrow{(B \cdot T)} = 1.294 \times 10^4$ $\sum\overrightarrow{(B \cdot U)} = 2.234 \times 10^4$ $\sum\overrightarrow{(B \cdot D)} = 1.188 \times 10^5$ $\sum\overrightarrow{(B \cdot O)} = 3.454 \times 10^3$

$\sum\overrightarrow{(B^2)} = 4.044 \times 10^4$ $\sum\overrightarrow{(B \cdot C)} = 1.572 \times 10^5$ $\sum\overrightarrow{(B \cdot N)} = 299.439$ $\sum\overrightarrow{(B \cdot P)} = 3.292 \times 10^3$

$\sum\overrightarrow{(B \cdot S)} = 5.698 \times 10^4$

$\sum\overrightarrow{(C \cdot T)} = 5.25 \times 10^4$ $\sum\overrightarrow{(C \cdot U)} = 1.152 \times 10^5$ $\sum\overrightarrow{(C \cdot D)} = 4.372 \times 10^5$ $\sum\overrightarrow{(C \cdot O)} = 1.404 \times 10^4$

$\sum\overrightarrow{(C \cdot B)} = 1.572 \times 10^5$ $\sum\overrightarrow{(C^2)} = 7.419 \times 10^5$ $\sum\overrightarrow{(C \cdot N)} = 1.348 \times 10^3$ $\sum\overrightarrow{(C \cdot P)} = 1.192 \times 10^4$

$\sum\overrightarrow{(C \cdot S)} = 2.371 \times 10^5$

$\sum\overrightarrow{(N \cdot T)} = 97.78$ $\sum\overrightarrow{(N \cdot U)} = 153.15$ $\sum\overrightarrow{(N \cdot D)} = 867.92$ $\sum\overrightarrow{(N \cdot O)} = 25.823$

$\sum\overrightarrow{(N \cdot B)} = 299.439$ $\sum\overrightarrow{(N \cdot C)} = 1.348 \times 10^3$ $\sum\overrightarrow{(N^2)} = 2.92$ $\sum\overrightarrow{(N \cdot P)} = 21.86$

$\sum\overrightarrow{(N \cdot S)} = 486.45$

$\sum\overrightarrow{(P \cdot T)} = 1.087 \times 10^3$ $\sum\overrightarrow{(P \cdot U)} = 2.353 \times 10^3$ $\sum\overrightarrow{(P \cdot D)} = 1.042 \times 10^4$ $\sum\overrightarrow{(P \cdot O)} = 290.06$

$\sum\overrightarrow{(P \cdot B)} = 3.292 \times 10^3$ $\sum\overrightarrow{(P \cdot C)} = 1.192 \times 10^4$ $\sum\overrightarrow{(P \cdot N)} = 21.86$ $\sum\overrightarrow{(P^2)} = 299.902$

$\sum\overrightarrow{(P \cdot S)} = 4.18 \times 10^3$

$\sum\overrightarrow{(S \cdot T)} = 1.981 \times 10^4$ $\sum\overrightarrow{(S \cdot U)} = 2.623 \times 10^4$ $\sum\overrightarrow{(S \cdot D)} = 1.839 \times 10^5$ $\sum\overrightarrow{(S \cdot O)} = 5.208 \times 10^3$

$\sum\overrightarrow{(S \cdot B)} = 5.698 \times 10^4$ $\sum\overrightarrow{(S \cdot C)} = 2.371 \times 10^5$ $\sum\overrightarrow{(S \cdot N)} = 486.45$ $\sum\overrightarrow{(S \cdot P)} = 4.18 \times 10^3$

$\sum\overrightarrow{(S^2)} = 1.074 \times 10^5$

$$H := \begin{pmatrix}
\sum \overrightarrow{(T)}^2 & \sum \overrightarrow{(T \cdot U)} & \sum \overrightarrow{(T \cdot D)} & \sum \overrightarrow{(T \cdot O)} & \sum \overrightarrow{(T \cdot B)} & \sum \overrightarrow{(T \cdot C)} & \sum \overrightarrow{(T \cdot N)} & \sum \overrightarrow{(T \cdot P)} & \sum \overrightarrow{(T \cdot S)} \\
\sum \overrightarrow{(U \cdot T)} & \sum \overrightarrow{(U)}^2 & \sum \overrightarrow{(U \cdot D)} & \sum \overrightarrow{(U \cdot O)} & \sum \overrightarrow{(U \cdot B)} & \sum \overrightarrow{(U \cdot C)} & \sum \overrightarrow{(U \cdot N)} & \sum \overrightarrow{(U \cdot P)} & \sum \overrightarrow{(U \cdot S)} \\
\sum \overrightarrow{(D \cdot T)} & \sum \overrightarrow{(D \cdot U)} & \sum \overrightarrow{(D)}^2 & \sum \overrightarrow{(D \cdot O)} & \sum \overrightarrow{(D \cdot B)} & \sum \overrightarrow{(D \cdot C)} & \sum \overrightarrow{(D \cdot N)} & \sum \overrightarrow{(D \cdot P)} & \sum \overrightarrow{(D \cdot S)} \\
\sum \overrightarrow{(O \cdot T)} & \sum \overrightarrow{(O \cdot U)} & \sum \overrightarrow{(O \cdot D)} & \sum \overrightarrow{(O)}^2 & \sum \overrightarrow{(O \cdot B)} & \sum \overrightarrow{(O \cdot C)} & \sum \overrightarrow{(O \cdot N)} & \sum \overrightarrow{(O \cdot P)} & \sum \overrightarrow{(O \cdot S)} \\
\sum \overrightarrow{(B \cdot T)} & \sum \overrightarrow{(B \cdot U)} & \sum \overrightarrow{(B \cdot D)} & \sum \overrightarrow{(B \cdot O)} & \sum \overrightarrow{(B)}^2 & \sum \overrightarrow{(B \cdot C)} & \sum \overrightarrow{(B \cdot N)} & \sum \overrightarrow{(B \cdot P)} & \sum \overrightarrow{(B \cdot S)} \\
\sum \overrightarrow{(C \cdot T)} & \sum \overrightarrow{(C \cdot U)} & \sum \overrightarrow{(C \cdot D)} & \sum \overrightarrow{(C \cdot O)} & \sum \overrightarrow{(C \cdot B)} & \sum \overrightarrow{(C)}^2 & \sum \overrightarrow{(C \cdot N)} & \sum \overrightarrow{(C \cdot P)} & \sum \overrightarrow{(C \cdot S)} \\
\sum \overrightarrow{(N \cdot T)} & \sum \overrightarrow{(N \cdot U)} & \sum \overrightarrow{(N \cdot D)} & \sum \overrightarrow{(N \cdot O)} & \sum \overrightarrow{(N \cdot B)} & \sum \overrightarrow{(N \cdot C)} & \sum \overrightarrow{(N)}^2 & \sum \overrightarrow{(N \cdot P)} & \sum \overrightarrow{(N \cdot S)} \\
\sum \overrightarrow{(P \cdot T)} & \sum \overrightarrow{(P \cdot U)} & \sum \overrightarrow{(P \cdot D)} & \sum \overrightarrow{(P \cdot O)} & \sum \overrightarrow{(P \cdot B)} & \sum \overrightarrow{(P \cdot C)} & \sum \overrightarrow{(P \cdot N)} & \sum \overrightarrow{(P)}^2 & \sum \overrightarrow{(P \cdot S)} \\
\sum \overrightarrow{(S \cdot T)} & \sum \overrightarrow{(S \cdot U)} & \sum \overrightarrow{(S \cdot D)} & \sum \overrightarrow{(S \cdot O)} & \sum \overrightarrow{(S \cdot B)} & \sum \overrightarrow{(S \cdot C)} & \sum \overrightarrow{(S \cdot N)} & \sum \overrightarrow{(S \cdot P)} & \sum \overrightarrow{(S)}^2
\end{pmatrix}$$

$$H = \begin{pmatrix}
4.485\times 10^3 & 9.195\times 10^3 & 4.094\times 10^4 & 1.192\times 10^3 & 1.294\times 10^4 & 5.25\times 10^4 & 97.78 & 1.087\times 10^3 & 1.981\times 10^4 \\
9.195\times 10^3 & 3.983\times 10^4 & 7.638\times 10^4 & 2.478\times 10^3 & 2.234\times 10^4 & 1.152\times 10^5 & 153.15 & 2.353\times 10^3 & 2.623\times 10^4 \\
4.094\times 10^4 & 7.638\times 10^4 & 4.075\times 10^5 & 1.079\times 10^4 & 1.188\times 10^5 & 4.372\times 10^5 & 867.92 & 1.042\times 10^4 & 1.839\times 10^5 \\
1.192\times 10^3 & 2.478\times 10^3 & 1.079\times 10^4 & 317.565 & 3.454\times 10^3 & 1.404\times 10^4 & 25.823 & 290.06 & 5.208\times 10^3 \\
1.294\times 10^4 & 2.234\times 10^4 & 1.188\times 10^5 & 3.454\times 10^3 & 4.044\times 10^4 & 1.572\times 10^5 & 299.439 & 3.292\times 10^3 & 5.698\times 10^4 \\
5.25\times 10^4 & 1.152\times 10^5 & 4.372\times 10^5 & 1.404\times 10^4 & 1.572\times 10^5 & 7.419\times 10^5 & 1.348\times 10^3 & 1.192\times 10^4 & 2.371\times 10^5 \\
97.78 & 153.15 & 867.92 & 25.823 & 299.439 & 1.348\times 10^3 & 2.92 & 21.86 & 486.45 \\
1.087\times 10^3 & 2.353\times 10^3 & 1.042\times 10^4 & 290.06 & 3.292\times 10^3 & 1.192\times 10^4 & 21.86 & 299.902 & 4.18\times 10^3 \\
1.981\times 10^4 & 2.623\times 10^4 & 1.839\times 10^5 & 5.208\times 10^3 & 5.698\times 10^4 & 2.371\times 10^5 & 486.45 & 4.18\times 10^3 & 1.074\times 10^5
\end{pmatrix}$$

$$constants := \begin{pmatrix} \sum\overrightarrow{(T \cdot pH)} \\ \sum\overrightarrow{(U \cdot pH)} \\ \sum\overrightarrow{(D \cdot pH)} \\ \sum\overrightarrow{(O \cdot pH)} \\ \sum\overrightarrow{(B \cdot pH)} \\ \sum\overrightarrow{(C \cdot pH)} \\ \sum\overrightarrow{(N \cdot pH)} \\ \sum\overrightarrow{(P \cdot pH)} \\ \sum\overrightarrow{(S \cdot pH)} \end{pmatrix}$$

$$constants = \begin{pmatrix} 1.128 \times 10^3 \\ 2.125 \times 10^3 \\ 1.027 \times 10^4 \\ 299.941 \\ 3.347 \times 10^3 \\ 1.355 \times 10^4 \\ 26.065 \\ 273.945 \\ 5.065 \times 10^3 \end{pmatrix}$$

$c' := \text{lsolve}(H, constants)$

$$c' = \begin{pmatrix} 0.465 \\ -0.057 \\ 0.093 \\ 2.915 \\ 0.187 \\ 1.754 \times 10^{-3} \\ -0.737 \\ -5.5 \\ -0.21 \end{pmatrix}$$

$$pH_{model} := 0.465 \cdot T - 0.057 \cdot U + 0.093 \cdot D + 2.915 \cdot O + 0.187 \cdot B + 0.001754 \cdot C - 0.737 \cdot N - 5.5 \cdot P - 0.21 \cdot S$$

SIMULATION OF MODEL

$$pH_{model} = \begin{pmatrix} 8.393 \\ 6.477 \\ 6.957 \\ 7.709 \\ 6.591 \\ 5.907 \end{pmatrix}$$

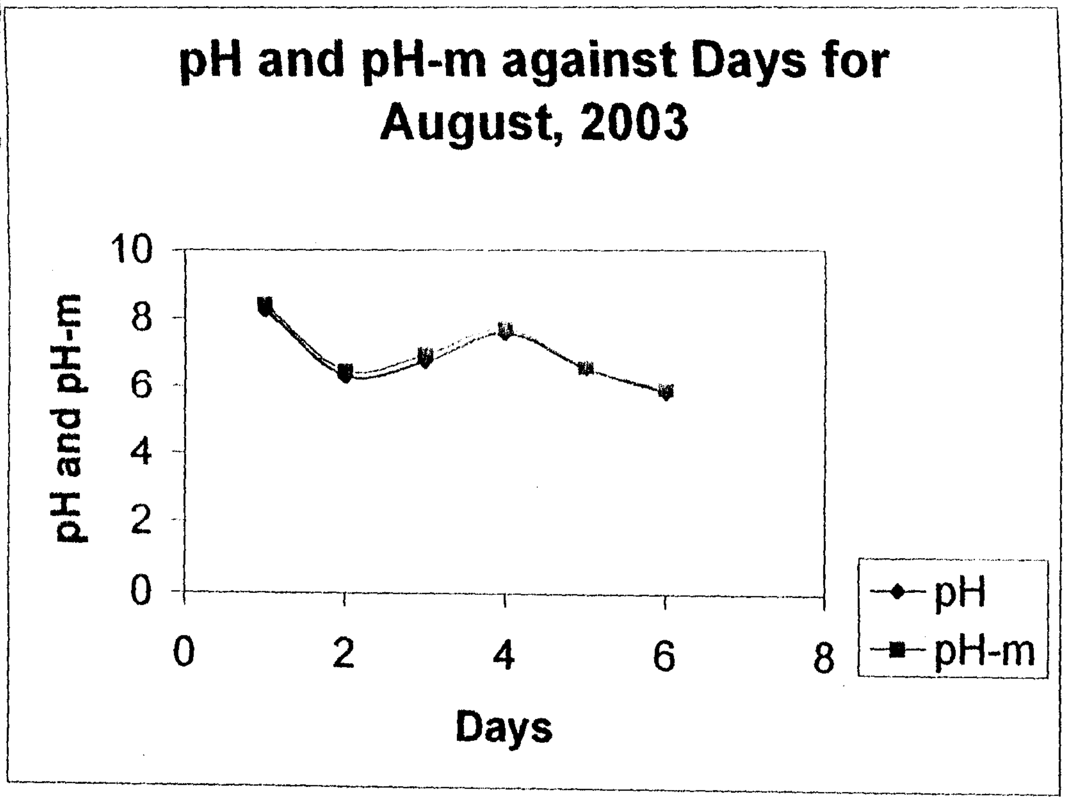
$$error := pH - pH_{model}$$

$$error = \begin{pmatrix} -0.153 \\ -0.167 \\ -0.187 \\ -0.129 \\ -0.041 \\ -0.077 \end{pmatrix}$$

$$\%error := \overrightarrow{\left(\frac{error}{pH} \cdot 100\right)}$$

$$\%error = \begin{pmatrix} -1.856 \\ -2.646 \\ -2.759 \\ -1.697 \\ -0.624 \\ -1.323 \end{pmatrix}$$

ays	pH	pH-m
1	8.24	8.393
2	6.31	6.477
3	6.77	6.957
4	7.58	7.709
5	6.55	6.591
6	5.83	5.907



MAY2004

pH	T	Tu	TDS	DO	BOD	COD	NO	PO	SO

data :=

	0	1	2	3	4	5	6	7	8	9	10	11
0	7.36	29.2	22	437.71	6.8	179.34	360	1.1	6.87	42		
1	2.85	29.1	21	464.57	6.9	14.7	46.16	0.4	3.25	165		
2	6.09	29.4	16	410.85	8.16	199.9	203.08	0.5	0.92	200		
3	5.54	29.1	80	321.94	267.62	72.99	120.9	0.5	13.5	90		
4	6.6	27.5	450	95.49	6.8	26.16	0	2.6	32.1	0		
5	6.47	28.9	270	49.65	7.34	98.49	36.5	0.9	18.01	25		

$pH := data^{\langle 0 \rangle}$ $T := data^{\langle 1 \rangle}$ $U := data^{\langle 2 \rangle}$ $D := data^{\langle 3 \rangle}$ $O := data^{\langle 4 \rangle}$ $B := data^{\langle 5 \rangle}$

$C := data^{\langle 6 \rangle}$ $N := data^{\langle 7 \rangle}$ $P := data^{\langle 8 \rangle}$ $S := data^{\langle 9 \rangle}$

$$M := \begin{pmatrix}
\sum\overrightarrow{(T^2)} & \sum\overrightarrow{(T\cdot U)} & \sum\overrightarrow{(T\cdot D)} & \sum\overrightarrow{(T\cdot O)} & \sum\overrightarrow{(T\cdot B)} & \sum\overrightarrow{(T\cdot C)} & \sum\overrightarrow{(T\cdot N)} & \sum\overrightarrow{(T\cdot P)} & \sum\overrightarrow{(T\cdot S)} \\
\sum\overrightarrow{(U\cdot T)} & \sum\overrightarrow{(U^2)} & \sum\overrightarrow{(U\cdot D)} & \sum\overrightarrow{(U\cdot O)} & \sum\overrightarrow{(U\cdot B)} & \sum\overrightarrow{(U\cdot C)} & \sum\overrightarrow{(U\cdot N)} & \sum\overrightarrow{(U\cdot P)} & \sum\overrightarrow{(U\cdot S)} \\
\sum\overrightarrow{(D\cdot T)} & \sum\overrightarrow{(D\cdot U)} & \sum\overrightarrow{(D^2)} & \sum\overrightarrow{(D\cdot O)} & \sum\overrightarrow{(D\cdot B)} & \sum\overrightarrow{(D\cdot C)} & \sum\overrightarrow{(D\cdot N)} & \sum\overrightarrow{(D\cdot P)} & \sum\overrightarrow{(D\cdot S)} \\
\sum\overrightarrow{(O\cdot T)} & \sum\overrightarrow{(O\cdot U)} & \sum\overrightarrow{(O\cdot D)} & \sum\overrightarrow{(O^2)} & \sum\overrightarrow{(O\cdot B)} & \sum\overrightarrow{(O\cdot C)} & \sum\overrightarrow{(O\cdot N)} & \sum\overrightarrow{(O\cdot P)} & \sum\overrightarrow{(O\cdot S)} \\
\sum\overrightarrow{(B\cdot T)} & \sum\overrightarrow{(B\cdot U)} & \sum\overrightarrow{(B\cdot D)} & \sum\overrightarrow{(B\cdot O)} & \sum\overrightarrow{(B^2)} & \sum\overrightarrow{(B\cdot C)} & \sum\overrightarrow{(B\cdot N)} & \sum\overrightarrow{(B\cdot P)} & \sum\overrightarrow{(B\cdot S)} \\
\sum\overrightarrow{(C\cdot T)} & \sum\overrightarrow{(C\cdot U)} & \sum\overrightarrow{(C\cdot D)} & \sum\overrightarrow{(C\cdot O)} & \sum\overrightarrow{(C\cdot B)} & \sum\overrightarrow{(C^2)} & \sum\overrightarrow{(C\cdot N)} & \sum\overrightarrow{(C\cdot P)} & \sum\overrightarrow{(C\cdot S)} \\
\sum\overrightarrow{(N\cdot T)} & \sum\overrightarrow{(N\cdot U)} & \sum\overrightarrow{(N\cdot D)} & \sum\overrightarrow{(N\cdot O)} & \sum\overrightarrow{(N\cdot B)} & \sum\overrightarrow{(N\cdot C)} & \sum\overrightarrow{(N^2)} & \sum\overrightarrow{(N\cdot P)} & \sum\overrightarrow{(N\cdot S)} \\
\sum\overrightarrow{(P\cdot T)} & \sum\overrightarrow{(P\cdot U)} & \sum\overrightarrow{(P\cdot D)} & \sum\overrightarrow{(P\cdot O)} & \sum\overrightarrow{(P\cdot B)} & \sum\overrightarrow{(P\cdot C)} & \sum\overrightarrow{(P\cdot N)} & \sum\overrightarrow{(P^2)} & \sum\overrightarrow{(P\cdot S)} \\
\sum\overrightarrow{(S\cdot T)} & \sum\overrightarrow{(S\cdot U)} & \sum\overrightarrow{(S\cdot D)} & \sum\overrightarrow{(S\cdot O)} & \sum\overrightarrow{(S\cdot B)} & \sum\overrightarrow{(S\cdot C)} & \sum\overrightarrow{(S\cdot N)} & \sum\overrightarrow{(S\cdot P)} & \sum\overrightarrow{(S^2)}
\end{pmatrix}$$

$$M = \begin{pmatrix} 5 \times 10^{3} & 2.42 \times 10^{4} & 5.18 \times 10^{4} & 8.83 \times 10^{3} & 1.72 \times 10^{4} & 2.24 \times 10^{4} & 1.71 \times 10^{2} & 2.12 \times 10^{3} & 1.52 \times 10^{4} \\ 2.42 \times 10^{4} & 2.83 \times 10^{5} & 1.08 \times 10^{5} & 2.69 \times 10^{4} & 5.17 \times 10^{4} & 3.17 \times 10^{4} & 1.49 \times 10^{3} & 2.06 \times 10^{4} & 2.15 \times 10^{4} \\ 5.18 \times 10^{4} & 1.08 \times 10^{5} & 6.91 \times 10^{5} & 9.67 \times 10^{4} & 1.98 \times 10^{5} & 3.03 \times 10^{5} & 1.33 \times 10^{3} & 1.32 \times 10^{4} & 2.07 \times 10^{5} \\ 8.83 \times 10^{3} & 2.69 \times 10^{4} & 9.67 \times 10^{4} & 7.19 \times 10^{4} & 2.34 \times 10^{4} & 3.7 \times 10^{4} & 1.72 \times 10^{2} & 4.04 \times 10^{3} & 2.73 \times 10^{4} \\ 1.72 \times 10^{4} & 5.17 \times 10^{4} & 1.98 \times 10^{5} & 2.34 \times 10^{4} & 8.81 \times 10^{4} & 1.18 \times 10^{5} & 4.96 \times 10^{2} & 5.06 \times 10^{3} & 5.9 \times 10^{4} \\ 2.24 \times 10^{4} & 3.17 \times 10^{4} & 3.03 \times 10^{5} & 3.7 \times 10^{4} & 1.18 \times 10^{5} & 1.89 \times 10^{5} & 6.09 \times 10^{2} & 5.1 \times 10^{3} & 7.51 \times 10^{4} \\ 1.71 \times 10^{2} & 1.49 \times 10^{3} & 1.33 \times 10^{3} & 1.72 \times 10^{2} & 4.96 \times 10^{2} & 6.09 \times 10^{2} & 9.44 & 1.16 \times 10^{2} & 2.8 \times 10^{2} \\ 2.12 \times 10^{3} & 2.06 \times 10^{4} & 1.32 \times 10^{4} & 4.04 \times 10^{3} & 5.06 \times 10^{3} & 5.1 \times 10^{3} & 1.16 \times 10^{2} & 1.6 \times 10^{3} & 2.67 \times 10^{3} \\ 1.52 \times 10^{4} & 2.15 \times 10^{4} & 2.07 \times 10^{5} & 2.73 \times 10^{4} & 5.9 \times 10^{4} & 7.51 \times 10^{4} & 2.8 \times 10^{2} & 2.67 \times 10^{3} & 7.77 \times 10^{4} \end{pmatrix}$$

$$m := \begin{pmatrix} \sum \overrightarrow{(pH \cdot T)} \\ \sum \overrightarrow{(pH \cdot U)} \\ \sum \overrightarrow{(pH \cdot D)} \\ \sum \overrightarrow{(pH \cdot O)} \\ \sum \overrightarrow{(pH \cdot B)} \\ \sum \overrightarrow{(pH \cdot C)} \\ \sum \overrightarrow{(pH \cdot N)} \\ \sum \overrightarrow{(pH \cdot P)} \\ \sum \overrightarrow{(pH \cdot S)} \end{pmatrix}$$

$$m = \begin{pmatrix} 1.007 \times 10^{3} \\ 5.479 \times 10^{3} \\ 9.783 \times 10^{3} \\ 1.694 \times 10^{3} \\ 3.793 \times 10^{3} \\ 4.924 \times 10^{3} \\ 38.034 \\ 468.603 \\ 2.658 \times 10^{3} \end{pmatrix}$$

$d' := \text{lsolve}(M, m)$

$$d' = \begin{pmatrix} 0.18 \\ -3.93 \times 10^{-3} \\ 6.797 \times 10^{-3} \\ 8.037 \times 10^{-3} \\ 0.043 \\ -0.025 \\ 2.578 \\ -0.159 \\ -0.033 \end{pmatrix}$$

$pH_{model} := 0.18 \cdot T - 0.00393 \cdot U + 0.006797 \cdot D + 0.008037 \cdot O + 0.043 \cdot B - 0.025 \cdot C + 2.578 \cdot N - 0.159 \cdot P - 0.03$

$$pH_{model} = \begin{pmatrix} 7.268 \\ 2.916 \\ 6.149 \\ 5.551 \\ 6.609 \\ 6.492 \end{pmatrix}$$

$error := pH - pH_{model}$

$$error = \begin{pmatrix} 0.092 \\ -0.066 \\ -0.059 \\ -0.011 \\ -8.977 \times 10^{-3} \\ -0.022 \end{pmatrix}$$

$$\%error := \overrightarrow{\left(\frac{error}{pH} \cdot 100\right)}$$

$$\%error = \begin{pmatrix} 1.245 \\ -2.321 \\ -0.963 \\ -0.203 \\ -0.136 \\ -0.333 \end{pmatrix}$$

$\sum\left(\overrightarrow{T^2}\right) = 5.002 \times 10^3$ $\sum\overrightarrow{(T \cdot U)} = 2.423 \times 10^4$ $\sum\overrightarrow{(T \cdot D)} = 5.181 \times 10^4$ $\sum\overrightarrow{(T \cdot O)} = 8.826 \times 10^3$

$\sum\overrightarrow{(T \cdot B)} = 1.723 \times 10^4$ $\sum\overrightarrow{(T \cdot C)} = 2.24 \times 10^4$ $\sum\overrightarrow{(T \cdot N)} = 170.52$ $\sum\overrightarrow{(T \cdot P)} = 2.118 \times 10^3$

$\sum\overrightarrow{(T \cdot S)} = 1.525 \times 10^4$ $\sum\overrightarrow{(U \cdot T)} = 2.423 \times 10^4$ $\sum\left(U^2\right) = 2.83 \times 10^5$ $\sum\overrightarrow{(U \cdot D)} = 1.081 \times 10^5$

$\sum\overrightarrow{(U \cdot O)} = 2.688 \times 10^4$ $\sum\overrightarrow{(U \cdot B)} = 5.166 \times 10^4$ $\sum\overrightarrow{(U \cdot C)} = 3.167 \times 10^4$ $\sum\overrightarrow{(U \cdot N)} = 1.494 \times 10^3$

$\sum\overrightarrow{(U \cdot P)} = 2.062 \times 10^4$ $\sum\overrightarrow{(U \cdot S)} = 2.154 \times 10^4$ $\sum\overrightarrow{(D \cdot T)} = 5.181 \times 10^4$ $\sum\overrightarrow{(D \cdot U)} = 1.081 \times 10^5$

$\sum\left(\overrightarrow{D^2}\right) = 6.914 \times 10^5$ $\sum\overrightarrow{(D \cdot O)} = 9.671 \times 10^4$ $\sum\overrightarrow{(D \cdot B)} = 1.983 \times 10^5$ $\sum\overrightarrow{(D \cdot C)} = 3.032 \times 10^5$

$\sum(D \cdot N) = 1.327 \times 10^3$ $\sum\overrightarrow{(D \cdot P)} = 1.32 \times 10^4$ $\sum\overrightarrow{(D \cdot S)} = 2.074 \times 10^5$ $\sum(O \cdot T) = 8.826 \times 10^3$

$\sum\overrightarrow{(O \cdot U)} = 2.688 \times 10^4$ $\sum\overrightarrow{(O \cdot D)} = 9.671 \times 10^4$ $\sum\left(O^2\right) = 7.188 \times 10^4$ $\sum\overrightarrow{(O \cdot B)} = 2.339 \times 10^4$

$\sum\overrightarrow{(O \cdot C)} = 3.705 \times 10^4$ $\sum\overrightarrow{(O \cdot N)} = 172.416$ $\sum\overrightarrow{(O \cdot P)} = 4.04 \times 10^3$ $\sum\overrightarrow{(O \cdot S)} = 2.733 \times 10^4$

$\sum\overrightarrow{(B \cdot T)} = 1.723 \times 10^4$ $\sum\overrightarrow{(B \cdot U)} = 5.166 \times 10^4$ $\sum\overrightarrow{(B \cdot D)} = 1.983 \times 10^5$ $\sum\overrightarrow{(B \cdot O)} = 2.339 \times 10^4$

$\sum\left(B^2\right) = 8.805 \times 10^4$ $\sum\overrightarrow{(B \cdot C)} = 1.183 \times 10^5$ $\sum\overrightarrow{(B \cdot N)} = 496.256$ $\sum\overrightarrow{(B \cdot P)} = 5.063 \times 10^3$

$\sum\overrightarrow{(B \cdot S)} = 5.897 \times 10^4$ $\sum\overrightarrow{(C \cdot T)} = 2.24 \times 10^4$ $\sum(C \cdot U) = 3.167 \times 10^4$ $\sum(C \cdot D) = 3.032 \times 10^5$

$\sum\overrightarrow{(C \cdot O)} = 3.705 \times 10^4$ $\sum(C \cdot B) = 1.183 \times 10^5$ $\sum\left(C^2\right) = 1.889 \times 10^5$ $\sum\overrightarrow{(C \cdot N)} = 609.304$

$\sum(C \cdot P) = 5.1 \times 10^3$ $\sum(C \cdot S) = 7.515 \times 10^4$ $\sum(N \cdot T) = 170.52$ $\sum(N \cdot U) = 1.494 \times 10^3$

$\sum(N \cdot D) = 1.327 \times 10^3$ $\sum\overrightarrow{(N \cdot O)} = 172.416$ $\sum\overrightarrow{(N \cdot B)} = 496.256$ $\sum\overrightarrow{(N \cdot C)} = 609.304$

$\sum\left(N^2\right) = 9.44$ $\sum\overrightarrow{(N \cdot P)} = 115.736$ $\sum\overrightarrow{(N \cdot S)} = 279.7$ $\sum\overrightarrow{(P \cdot T)} = 2.118 \times 10^3$

$\sum(P \cdot U) = 2.062 \times 10^4$ $\sum(P \cdot D) = 1.32 \times 10^4$ $\sum(P \cdot O) = 4.04 \times 10^3$ $\sum\overrightarrow{(P \cdot B)} = 5.063 \times 10^3$

$\sum\overrightarrow{(P \cdot C)} = 5.1 \times 10^3$ $\sum\overrightarrow{(P \cdot N)} = 115.736$ $\sum\left(\overrightarrow{P^2}\right) = 1.596 \times 10^3$ $\sum(P \cdot S) = 2.674 \times 10^5$

$\sum(S \cdot T) = 1.525 \times 10^4$ $\sum(S \cdot U) = 2.154 \times 10^4$ $\sum(S \cdot D) = 2.074 \times 10^5$ $\sum\overrightarrow{(S \cdot O)} = 2.733 \times 10^4$

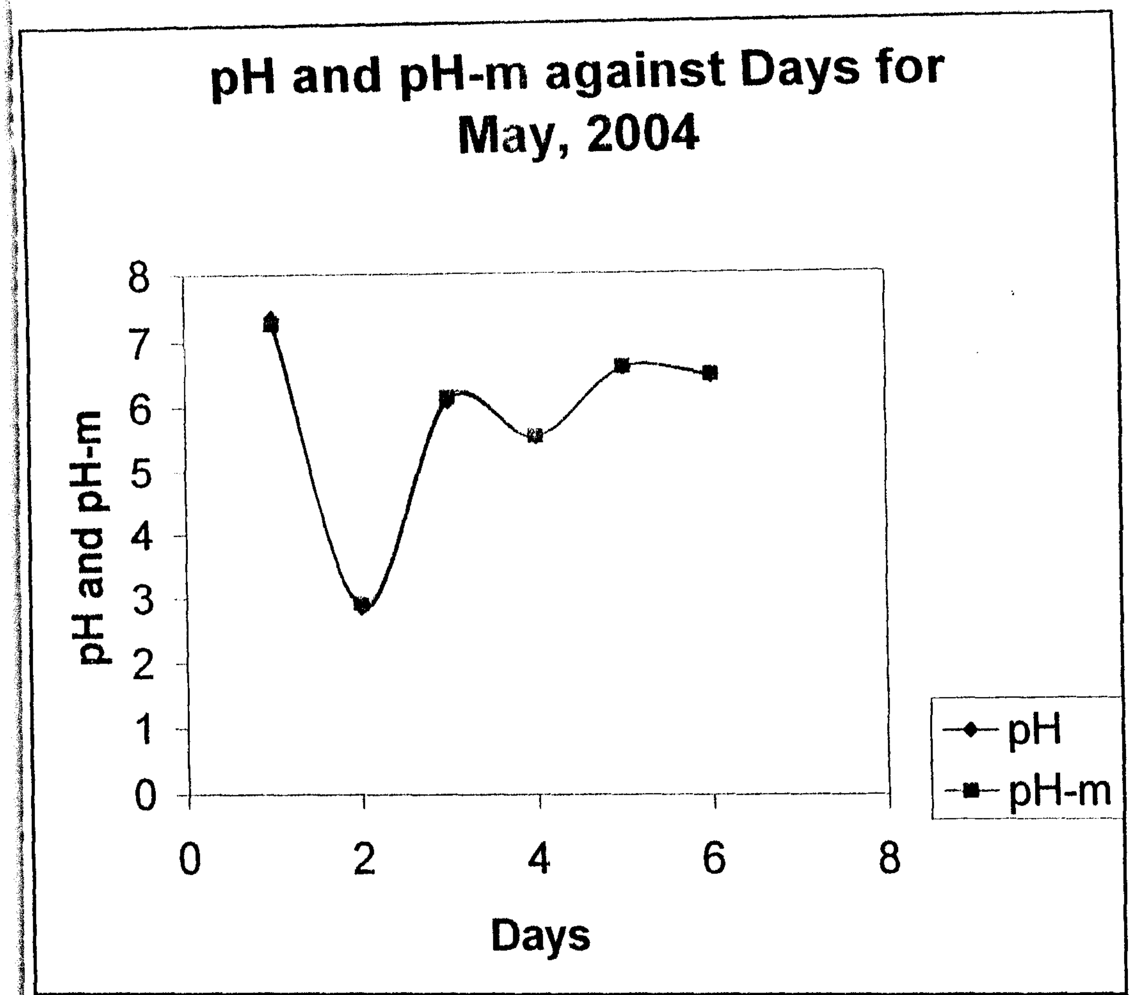
$\sum\overrightarrow{(S \cdot B)} = 5.897 \times 10^4$ $\sum(S \cdot C) = 7.515 \times 10^4$ $\sum(S \cdot N) = 279.7$ $\sum(S \cdot P) = 2.674 \times 10^5$

$\sum\left(S^2\right) = 7.771 \times 10^4$ $\sum\overrightarrow{(pH \cdot T)} = 1.007 \times 10^3$ $\sum\overrightarrow{(pH \cdot U)} = 5.479 \times 10^3$ $\sum\overrightarrow{(pH \cdot D)} = 9.783 \times 10^3$

$\sum\overrightarrow{(pH \cdot O)} = 1.694 \times 10^3$ $\sum\overrightarrow{(pH \cdot B)} = 3.793 \times 10^3$ $\sum\overrightarrow{(pH \cdot C)} = 4.924 \times 10^3$ $\sum\overrightarrow{(pH \cdot N)} = 38.034$

$\sum\overrightarrow{(pH \cdot P)} = 468.603$ $\sum\overrightarrow{(pH \cdot S)} = 2.658 \times 10^3$

Days	pH	pH-m
1	7.36	7.268
2	2.85	2.916
3	6.09	6.149
4	5.54	5.551
5	6.6	6.609
6	6.47	6.492



4.5 DISCUSSION OF RESULTS

The results obtained for the modeled pH of the three months showed that the values were very close to the experimental values. The percentage error for November 2000 ranged from -2.25% to -0.238%, for August 2003 the percentage error ranged from -2.759% to -0.624% also May 2004 have percentage error range of -2.321% to 1.2455.

pH which is the dependent variable depends on certain parameters such as temperature, total dissolved solids, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, turbidity, Nitrate, Sulphate and Phosphate compounds. These parameters affect the pH of the liquid effluent either directly or indirectly.

Considering the graphs of the three months, it was observed that the curves for the experimental pH and modeled pH overlapped due to the closeness of their values. Take for instance the experimental pH values obtained for November 2000 were 10.08, 7.43, 8.91, 9.14, 6.65, 6.98 with the corresponding modeled pH as 10.308, 7.567, 9.086, 9.271, 6.666, 7.014 respectively. For August 2003, the pH values obtained were 8.24, 6.31, 6.77, 7.58, 6.55 and 5.83 with the corresponding modeled pH as 8.393, 6.477, 6.957, 7.709, 6.591 and 5.907 respectively. The experimental pH values obtained for May 2004 were 7.36, 2.85, 6.09, 5.54, 6.60 and 6.47 with the corresponding modeled pH as 7.268, 2.916, 6.149, 5.551, 6.609 and 6.492 respectively.

The two graphs for November 2000 and August 2003 showed the same pattern of curve which was as a result of similar variation in their pH values. The liquid effluents discharged were either in acidic or basic medium. In case of May 2004, the liquid effluent was mainly in acidic medium because the values were below 7.0 on the pH scale.

It can be said that pollutants presents in water seriously affect its pH. Water being an effective solvent can easily be ionized by another compound thereby replacing its ions with other ions causing an increase or decrease in the concentration of hydrogen ions present. Example of such pollutants include Sulphide Phosphate, Nitrate compounds among others.

CHAPTER FIVE

5.0 CONCLUSION

pH, which is a term indicating the hydrogen ion concentration of a solution either in acidic or basic medium. It depends upon certain parameters such as temperature, dissolved oxygen, biochemical oxygen demand, pollutants (like Nitrate, Phosphate, Sulphide). These parameters either increase or decrease the pH level of the liquid effluent

The modeled pH equations for the three months were given below

i. November 2000

pHm: = 0.329 . T - 0.241 . U+ 0.014 . D + 0.423 . O-0.0011 . B + 0.001.4 . C - 0.592 . N - 0.00439 . P + 1.421 . H

ii. August 2003

pHm: = 0.465 . T - 0.057 . U + 0.09 3 . D +2.915 . O + 0.187 . B + 0.001754 .C - 0.737.N - 5.5 . P - 0.21. S

iii. May 2004

pHm: = 0.18 . T - 0.00393 .U+ 0.006797 . D + 0.008037 . O + 0.043 . B-0.025 .C + 2.578 . N - 0.159 . P - 0.033 . S

Comparing the coefficients of the three equations it was observed that the temperature (T), total dissolved solids (D),dissolved oxygen (O) all had positive values, Phosphate (P) has negative value while those of turbidity (U), biochemical oxygen demand (B), chemical oxygen demand (C) and Nitrate (N) changed.

5.1 RECOMMENDATION

Facilities for determination of metallic pollutants in the liquid effluent should be provided.

pH of the liquid effluent should be checked before being discharged into the river. The standard pH (5.6) value for the Industrial liquid effluent should not be neglected (F.E.P.A).

More treatment procedures should be carried out because most of the pH values were either above or below the standard value stipulated as a result of certain parameters not determined due to faulty equipment and lamp failure.

Government should provide proper funding for the environmental protection agencies to ensure effective implementation of the pre-sent sewage policy.

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