Mathematical Models for Predicting the Pollution Load of Al-Razzaza Lake during 2004 - 2007

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Abstract

A mathematical model was developed to predict the pollution load of Al-Razzaza lake, which is applied for an assessment of water pollution of the lake. The following parameters of the water pollution have been investigated: hydrogen ion concentration (pH) turbidity (TUR), total dissolved solids (TDS), and total hardness (TH). Periodical monthly and annual pollution variations have been determined, as well as basic tendencies in the evolution of the water quality for the period from years 2004 to 2007. The analysis focuses on the prediction of total hardness by conducting partial regression analysis to available experimental data, all four parameters were found to exert strong correlation.

These mathematical models were conducted by using Data Fit version 8 software. It was found that the total dissolved solids have positive relation with total hardness for all years, which indicated that the best correlation was for year 2004. The statistical results (correlation matrices, models, regression variables, analysis of variance (ANOVA)) show that the relation between total hardness and total dissolved solids to be significantly related for the years 2004, 2006, and 2007, which were, 0.866, 0.763 , 0.837 respectively, while its 0.682 for the year 2005. The regression model for the year 2004 has the heights coefficient of determination (0.7285), and the lowest (0.497) for the year 2005.

Keywords: Al-Razzaza lake, mathematical models, regression, linear correlation model.

1. Introduction

Water quality monitoring studies have differed widely in purpose and scope, corresponding to the interests and funding of scientific investigators, the information needs of specific agencies and the enthusiasm of volunteers. Such diversity has sometimes been seen as a hindrance to effective, or at least efficient, water quality assessment. Without common goals and sampling protocols, as well as uniform data reporting, it can be difficult to obtain the coherent picture of lake and watershed quality needed for management.

Retrospective analysis, present state survey and pollution prognosis for a long-term period are three interrelated stages in investigating functioning of water ecosystems. The analysis of the information about water pollution gives a chance to define the trends and basic tendencies in the evolution of water quality for the determined period. On the basis of the retrospective analysis, it is necessary to make a prognosis of the pollution dynamic for a long period (from 1 to 3 years). a conclusion may be drawn, that the analysis of the temporary series is suitable for the retrospective assessment of water quality. The integration of determination and statistical models for water quality is necessary means of water ecosystem management. These models use information from environmental monitoring, and their realizations [**Bode et. al., 2002**].

Water quality monitoring is a valuable tool for assessing the level of pollutants, identifying emerging problems, documenting changes resulting from water management, and for building understanding of the aquatic ecosystem. Although some information can be obtained from models and expert opinion, water quality sampling or monitoring programs are the primary sources of data [**Albany, www.dec.ny.gov/chemical/23847.html**].

The water problem in Iraq are due to the country is an estuary, where is located at the bottom of the river basin, and that as the countries in which these rivers flow from the establishment and development projects, dams and reservoirs have led to a lack of water coming to Iraq, as well as the implications of the remnants of the petrochemical and military industries, which led to a lack of water scarcity and poor quality. Noting that this problem requires significant investment and a huge effort in coordination with the relevant states.

The quantity of water available in Iraq up to 77 billion cubic meters of which 48 billion cubic meters of the Tigris river and its tributaries, and the rest to the Euphrates river, but the quantity is actually utilized only 25 billion cubic meters. According to experts, the total amount of water available in Iraq in 2025 reach 2.162 billion cubic meters [**Water Resources Directorate of Kerbela, 2009**].

2. Objectives

The objectives of the study are:

- To characterize the water quality of Al-Razzaza lake to identify status and trends.
- To establish a mathematical model to identify the concentration of pollutants.

3. Study area

Al-Razzaza lake (Fig. 1) is the second largest lake of fresh water to Iraq, located 15 km west of Karbala, south of Baghdad, the capital of Iraq, an area of 1810 km2, located at a height of 40 m from the sea level and can hold about 26 billion cubic meters of water. It is part of the plain includes lakes of Tharthar, Habaniya and the sea of Najaf. The waters come from many sources including, the Euphrates river, Habbaniyah and Rashidiya lakes, springs, groundwater, rainwater, and seasonal flows. The low water level and salinization of Al-Razzaza lake as a result the process of evaporation, and inadequate water contained the lake to compensate for water shortages [**Water Resources Directorate of Kerbela, 2009**].

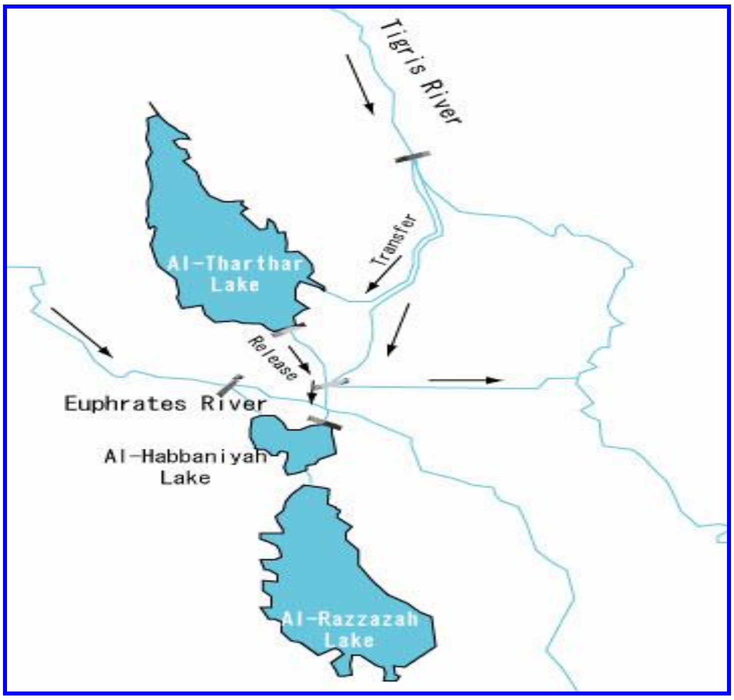

Fig. 1: Map of Al-Razazza Lake Watershed [**Water Resources Directorate of Kerbela, 2009**].

4. Water quality parameters:

4.1 Hydrogen ion concentration (pH)

pH is used to categorize solutions as acidic or basic. Truly pure water in the laboratory isolated from air is neutral and consists of an equal number of hydrogen (H^+) and hydroxide (OH^-) ions. Pure water in nature that is exposed to air will have a pH of approximately 5.7 due to carbon dioxide dissolved in it, since carbon dioxide is a weak acid. Other substances will further change the pH, making it lower or higher. pH is a measure of the number of hydrogen ions in solution [**Somlyody, 1986**].

If water is "acidic" it has a pH below 7.0, and the concentration of hydrogen ions exceeds the concentration of hydroxide ions. If water is "basic" or “alkaline” it has a pH above 7.0, and the concentration of hydrogen ions is less than the concentration of hydroxide ions. A pH increase or decrease of 1 corresponds to a ten-fold difference in the number of hydrogen (and hydroxide) ions. The pH range of 6 to 9 is acceptable for most aquatic organisms in lakes. The pH of streams is quite commonly lower, and stream organisms are therefore adapted to the lower values.

Acid rain is a major problem in many areas, including Al-Razzaza lake. However, the bedrock geology of the watersheds of Al-Razzaza lake is dominated by limestone and other calcareous minerals that tend to keep the pH at acceptably high levels (“buffering”). While acid rain may cause problems with our local environment, lowering the pH is not one of these, and Al-Razzaza lake is very unlikely to ever suffer problems from excess acidity. No units are specified when noting pH.

4.2 Turbidity

Turbidity is caused by suspended materials that cause light to be scattered and absorbed rather than transmitted in straight lines through water. Suspended materials such as clay, silt, algae, and other materials have a major influence on the clarity of the lake. It is particularly important in drinking water supply sources, since turbidity is can be related to substances that either impart tastes or odors to the water or can clog filters and rapidly increase the cost of water treatment. If the source of turbidity is largely organic, it can also create carcinogenic compounds [**Scavia, 1979**].

4.3 Total hardness

The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts. The total content of these salts is known as general hardness, which can be further divided into carbonate hardness (determined by concentrations of calcium and magnesium hydrocarbonates), and non-carbonate hardness (determined by calcium and magnesium salts of strong acids). Hydrocarbonates are transformed during the boiling of water into carbonates, which usually precipitate. Therefore, carbonate hardness is also known as temporary or removed, whereas the hardness remaining in the water after boiling is called constant.

Hardness may vary over a wide range. Calcium hardness is usually prevalent (up to 70 per cent), although in some cases magnesium hardness can reach 50– 60 per cent. Seasonal variations of river water hardness often occur, reaching the highest values during low flow conditions and the lowest values during floods. Groundwater hardness is, however, less variable. Where there are specific requirements for water hardness in relation to water use it is usually with respect to the properties of the cations forming the hardness. Hard water occurs when excess minerals in the water create certain nuisance problems. While these water problems can be frustrating, water hardness is not a safety issue. Hard water is safe for drinking, cooking, and other household uses [**S.E.Jorgensen, 1983**].

Hard water can cause several problems for consumers including decreased life of household plumbing and water-using appliances, increased difficulty in cleaning and laundering tasks, decreased efficiency of water heaters, and white/chalky deposits on items such as plumbing, tubs, sinks, and pots and pans [**Somlyody, 1986**].

4.4 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) usually refers to the mineral content of water, although it can also include dissolved organic material. In essence, TDS is the total amount of material remaining after evaporation of the water. TDS include common salts such as sodium, chloride, calcium, magnesium, potassium, sulphates and bicarbonates. The most common source of dissolved solids in water is from the weathering of sedimentary rocks and the erosion of the earth's surface. Since many minerals are water soluble, high concentrations can accumulate over time through the constantly reoccurring process of precipitation and evaporation [**Xie, 1993**]. Groundwater usually has higher levels of TDS than surface water, since it has a longer contact time with the underlying rocks and sediments. In addition to the main inorganic components of total dissolved solids, TDS can come from organic sources such as decaying organisms (plants and animals), urban and agricultural runoff and municipal and industrial effluent discharges [**S.E.Jorgensen, 1983**].

The minerals (salts, such as sodium and calcium bonded to chloride and carbonate) and small amounts of soluble minerals are deposited by the weathering of sedimentary rocks and erosion of the earth's surface. They are water soluble, and may accumulate to high concentrations over time through precipitation and evaporation. Some laboratories will report "Conductivity" or the sum of ions as an indirect measure of TDS. Conductivity meters are often used in the field to provide an approximate TDS value. The conductivity of the water is a measure of its ability to carry an electrical charge. This is related directly to the concentration of ions in the water, and thereby provides an estimate of the TDS [**Cayuga Lake Watershed Intermunicipal Organization, 2000**].

5. Data analysis and discussion

Continuous and periodic monitoring have allowed the identification of trends in hydrogen ion concentration (**pH, X1**), turbidity **(TUR, X2)**, total dissolved solids (**TDS, X3**), and total hardness (**TH, Y**). Varying chemical concentrations during high flows have a substantial effect on calculated chemical loads, and concentration data from manual samples often are not available for these conditions. Therefore, continuous monitoring of total hardness for the estimation of TDS, turbidity, and hydrogen ion concentration in lake may increase the accuracy of load estimates. With the development of surrogate relations between continuous turbidity measurements and periodic collection of samples for analysis, a more accurate representation of actual daily loads is probable. This information can be used by resource managers. Monthly variation of these parameters during study period 2004-2007, [**Water Resources Directorate of Kerbela, 2009**], are represented by Figs. 2 to 5.

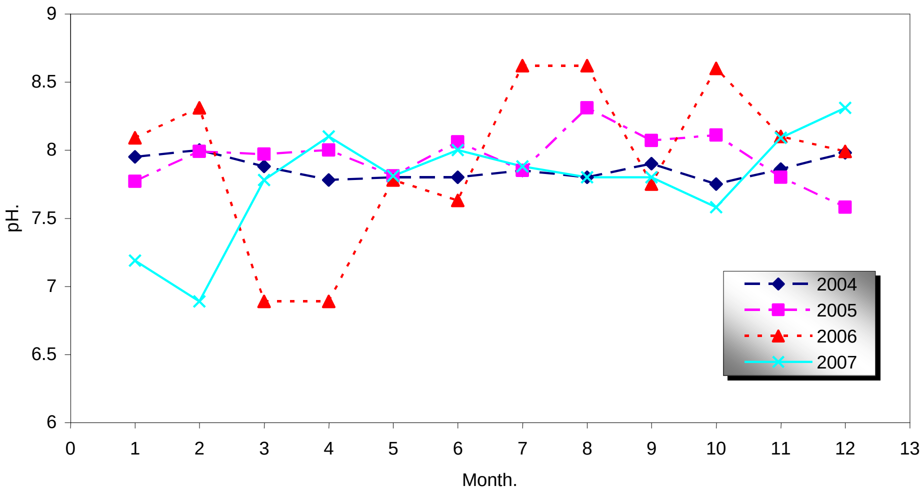

Fig. 2: pH variation during study period.

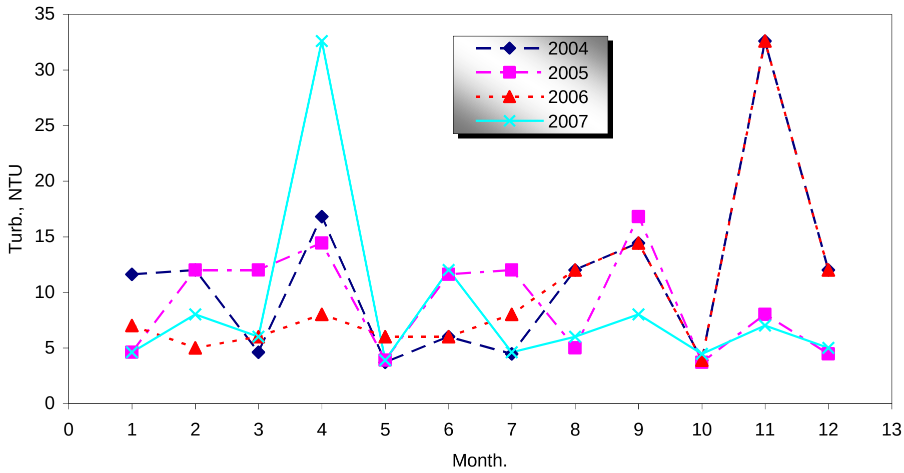

Fig.3: Turbidity variation during study period.

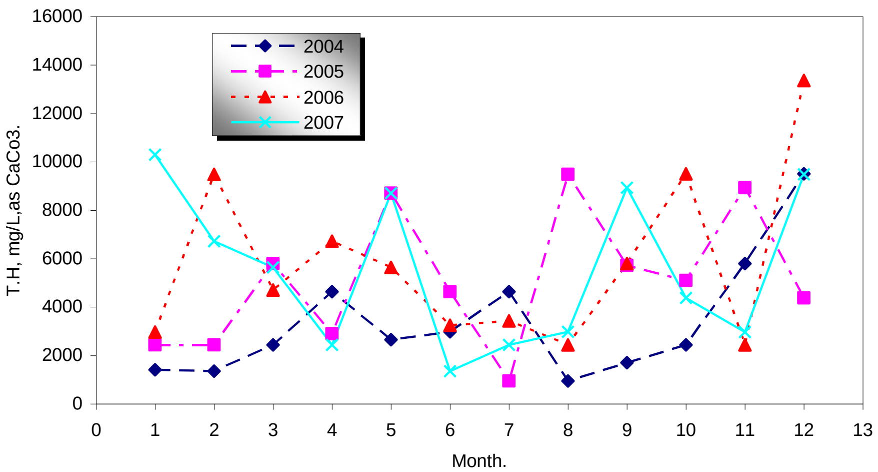

Fig.4: Total hardness variation during study period.

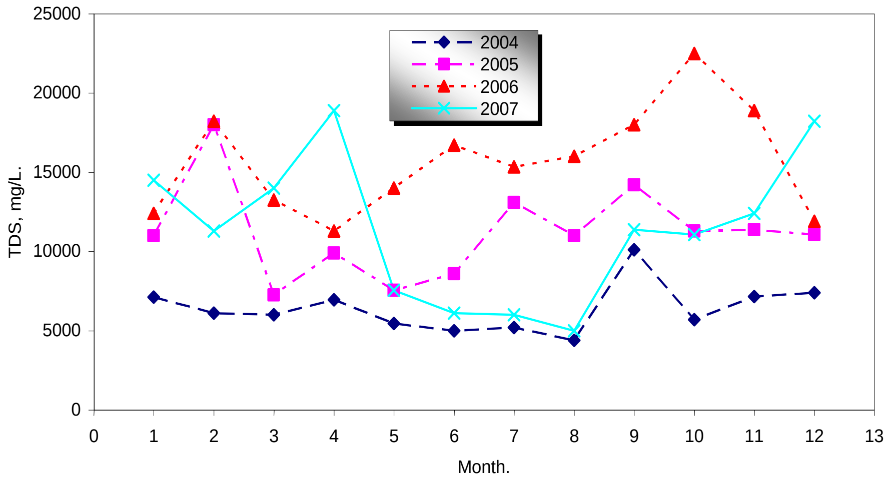

Fig.5: Total dissolved solids variation during study period.

6. Model formation

In the present study, linear regression model in single form was used for design requirements which gives the best fitting of data. These models were calculated by using Data Fit version 8 software. The results of the regression analysis are shown in tables 1 to 4. It was found that the total dissolved solids have positive relation with total hardness for all years, which indicated that the best correlation was for year 2007. The statistical results (correlation matrices, models, regression variables, analysis of variance (ANOVA)) for each year are listed in that tables. a relation between total hardness and total dissolved solids were found to be significantly related for the years 2004, 2006, and 2007, which were, 0.866, 0.763, 0.837 respectively, while its 0.682 for the year 2005. The regression model for the year 2004 has the heights coefficient of determination (0.7285).

Table 1: Statistics results for data of year 2004

Statistics				
Variable	**X1**	**X2**	**X3**	**Y**
Number of Points	12	12	12	12
Maximum Value	8.14	32.6	7400	4200
Minimum Value	7.75	3.7	4400	945
Range	0.39	28.9	3000	3255
Average	7.90	10.6	6073.33	2857.16
Standard Deviation	0.13	8.1	961.08	976.79

Correlation Matrix				
	X1	**X2**	**X3**	**Y**
X1	1			
X2	0.511441388	1		
X3	0.612941309	0.545631872	1	
Y	0.764309329	0.464255672	0.866357511	1

Model	StdError	Residual Sum	RSS	R^2
a*x1+b*x2+c*x3	562.6899076	-50.67497516	2849579.389	0.7284917559

Regression Variable Results					
Variable	**Value**	**Standard Error**	**t-ratio**	**Prob(t)**	
a	-308.3929065	155.9497524	-1.977514564	0.07938	
b	1.57019678	24.73854165	0.063471679	0.95078	
c	0.869573268	0.219892308	3.954541544	0.00333	
95% Confidence Intervals					
Variable	**Value**	**95% (+/-)**	**Lower Limit**	**Upper Limit**	
a	-308.3929065	352.7895298	-661.1824363	44.3966233	
b	1.57019678	55.96352891	-54.39333213	57.53372569	
c	0.869573268	0.49744038	0.372132888	1.367013647	
Variance Analysis					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob(F)**
Regression	2	7645790.277	3822895.139	12.07408236	0.00283
Error	9	2849579.389	316619.9322		
Total	11	10495369.67			

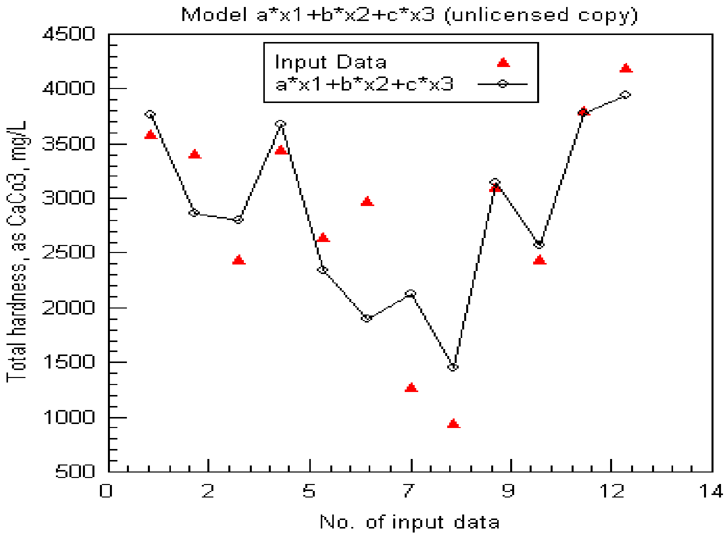

Fig. 2: Plot model of Al-Razzaza lake during 2004.

Table 2: Statistics results for data of year 2005

Statistics				
Variable	**X1**	**X2**	**X3**	**Y**
Number of Points	12	12	12	12
Missing Points	0	0	0	0
Maximum Value	8.18	16.8	11914	3950
Minimum Value	7.77	3.7	6500	2440
Range	0.41	13.1	5414	1510
Average	8	9.3825	8156.166667	3419.583333
Standard Deviation	0.111028252	4.225533049	1433.848593	494.912565

Correlation Matrix				
	X1	**X2**	**X3**	**Y**
X1	1			
X2	-0.1989614139	1		
X3	0.7978222539	-0.203508667	1	
Y	0.8851214709	-0.1928180736	0.6825918936	1

Model	**StdError**	**Residual Sum**	**RSS**	**R^2**
a*x1+b*x2+c*x3	414.664667	-33.27845796	1547521.07	0.497423134

Regression Variable Results					
Variable	**Value**	**Standard Error**	**t-ratio**	**Prob(t)**	
a	185.5148233	125.7546514	1.475212417	0.17426	
b	-9.027608342	29.20769037	-0.309083266	0.76429	
c	0.253450971	0.112802088	2.246864171	0.05127	
95% Confidence Intervals					
Variable	**Value**	**95% (+/-)**	**Lower Limit**	**Upper Limit**	
a	185.5148233	284.4821725	-98.96734917	469.9969958	
b	-9.027608342	66.07363716	-75.1012455	57.04602881	
c	0.253450971	0.255180884	-0.001729914	0.508631855	
Variance Analysis					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob(F)**
Regression	2	1531651.843	765825.9216	4.45385424	0.04523
Error	9	1547521.073	171946.7859		
Total	11	3079172.917			

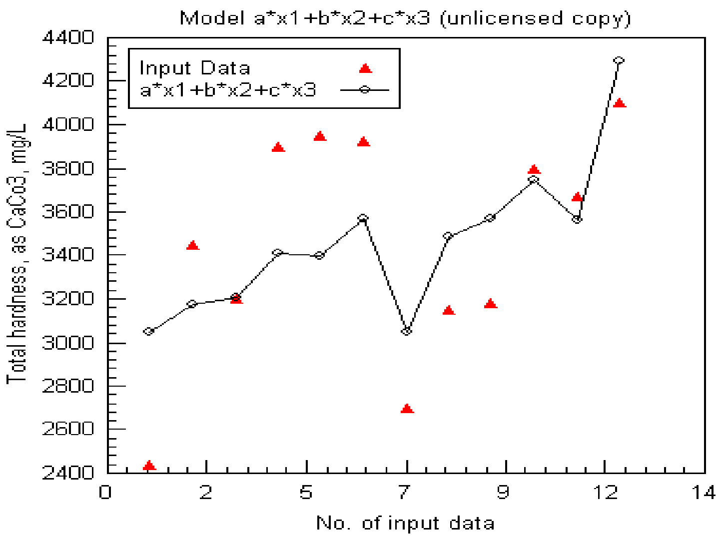

Fig. 6: Plot model of Al-Razzaza lake during 2005.

Table 3: Statistics results for data of year 2006

Statistics				
Variable	**X1**	**X2**	**X3**	**Y**
Number of Points	12	12	12	12
Maximum Value	8.62	32.6	15900	4100
Minimum Value	6.89	3.89	6700	2780
Range	1.73	28.71	9200	1320
Average	7.9075	10.07666667	10116.5	3529.083333
Standard Deviation	0.568076899	7.779030476	2572.554885	432.9067627

Correlation Matrix				
	X1	**X2**	**X3**	**Y**
X1	1			
X2	0.050032953	1		
X3	0.748801327	0.060239453	1	
Y	0.823742848	-0.000986857	0.763342144	1

Model	StdError	Residual Sum	RSS	R^2
a*x1+b*x2+c*x3	250.639787	-18.01501501	565382.726	0.72574086

Regression Variable Results					
Variable	**Value**	**Standard Error**	**t-ratio**	**Prob(t)**	
a	365.8436844	49.1903764	7.437301991	0.00004	
b	-2.979158016	9.717942746	-0.306562623	0.76615	
c	0.066000656	0.036277626	1.819321235	0.10221	
95% Confidence Intervals					
Variable	**Value**	**95% (+/-)**	**Lower Limit**	**Upper Limit**	
a	365.8436844	111.2784695	254.5652149	477.1221538	
b	-2.979158016	21.98393008	-24.9630881	19.00477206	
c	0.066000656	0.082067246	-0.01606659	0.148067902	
Variance Analysis					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob(F)**
Regression	2	1496108.19	748054.0952	11.90783967	0.00296
Error	9	565382.7262	62820.30291		
Total	11	2061490.917			

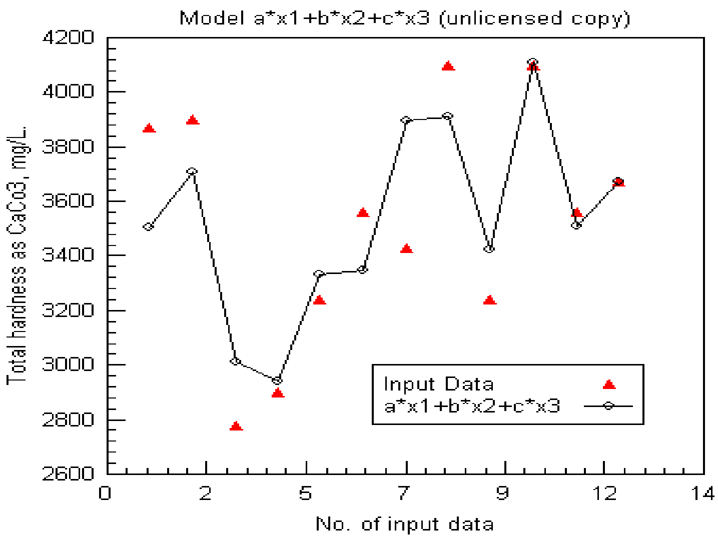

Fig. 7: Plot model of Al-Razzaza lake during 2006.

Table 4: Statistics results for data of year 2007

Statistics				
Variable	**X1**	**X2**	**X3**	**Y**
Number of Points	12	12	12	12
Maximum Value	8.31	32.6	13670	4100
Minimum Value	7.56	3.89	6100	890
Range	0.75	28.71	7570	3210
Average	7.864166667	8.5125	9482.833333	2726.666667
Standard Deviation	0.19970243	7.911739408	2147.867011	876.4632786

Correlation Matrix				
	X1	**X2**	**X3**	**Y**
pH, X1	1			
TUR, X2	-0.39426656	1		
TDS, X3	0.882415009	-0.346116309	1	
TH, Y	0.733615414	-0.254170806	0.837400394	1

Model	**StdError**	**Residual Sum**	**RSS**	**R^2**
a*x1+b*x2+c*x3	528.356231	-0.641667295	2512442.77	0.702671841

Regression Variable Results					
Variable	**Value**	**Standard Error**	**t-ratio**	**Prob(t)**	
a	-84.6896934	118.0468661	-0.717424327	0.49131	
b	4.251379768	21.29252356	0.199665378	0.84618	
c	0.353960047	0.087871788	4.028142085	0.00298	
95% Confidence Intervals					
Variable	**Value**	**95% (+/-)**	**Lower Limit**	**Upper Limit**	
a	-84.6896934	267.0456204	-351.7353139	182.355927	
b	4.251379768	48.1679468	-43.91656703	52.41932656	
c	0.353960047	0.198783559	0.155176488	0.552743606	
Variance Analysis					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob(F)**
Regression	2	5937623.901	2968811.95	10.63479253	0.00426
Error	9	2512442.766	279160.3073		
Total	11	8450066.667			

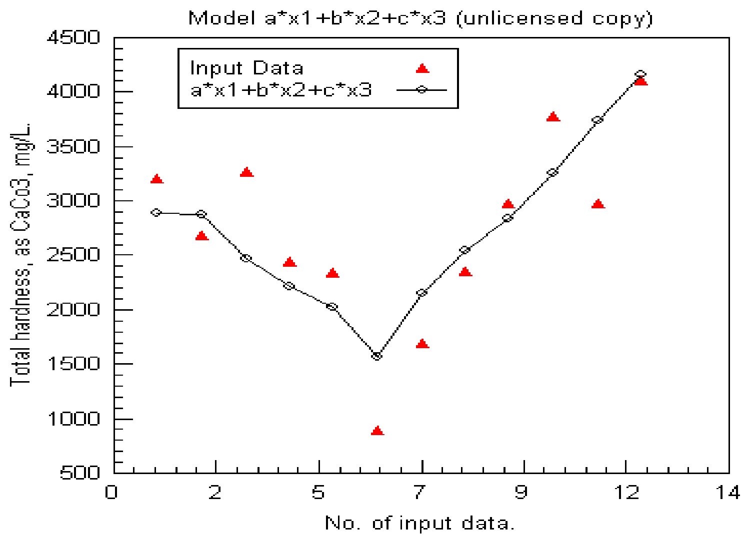

Fig. 8: Plot model of Al-Razzaza lake during 2007.

7. Conclusions

The main reasons for higher salinity in the lake are increasing the evaporation due to climate changes and rising atmospheric temperature, in addition to inadequate water because of low water levels in the Tigris and Euphrates rivers, the most important sources of water to that lake. The program successfully could be used for modeling and prognosis of the water pollution of the lake ecosystems…..

The results of the regression analysis were found that the total dissolved solids have positive relation with total hardness for all years, which indicated that the best correlation was for year 2004. The statistical results (correlation matrices, models, regression variables, analysis of variance (ANOVA)) show that the relation between total hardness and total dissolved solids to be significantly related for the years 2004, 2006, and 2007, which were, 0.866, 0.763 , 0.837 respectively, while its 0.682 for the year 2005. The regression model for the year 2004 has the heights coefficient of determination (0.7285), and the lowest (0.497) for the year 2005.

8. Recommendations

The following recommendations are put forward for further research:

- Using more measuring or sampling water quality parameters in the future studies to draw complete picture of lake pollution.
- Using control devices to reduce the dischargers of pollutants into lake.
- Increasing awareness of water quality issues by in-depth investigations, for example by surveys investigating the occurrence of substances that are potentially harmful. Surveys provide insight into many information needs for operational water management.

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