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The Parameters Discharge, Salinity and Dissolved loads of Tigris River from Mosul to Baghdad, Iraq

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Abstract:
The Tigris River is the most significant source of water in Iraq. Iraq has been through periods of drought due to climate change and numerous water infrastructure projects that were carried out in the Tigris Basin of Turkey. Four sites have been selected for environmental pollution evaluation, the impact of climate change on the hydrochemistry of the Tigris River, and an estimate of the relationship between dissolved loadings and discharges (m^3/s). Data includes Tigris River discharge and hydrochemical analysis: major ions such as (Ca, Mg, Na, K, Cl, SO_4, and HCO_3), minor ions (NO_3 and PO_4), trace elements, and biological parameters (BOD_5, C.O.D., E-Coli Bacteria, Fecal Coliform Bacteria) as indicators of contamination allowing the identification of sources of pollution. The Tigris River is within the allowable drinking limits, except in the Tharthar-Tigris Canal, and the most ions that have an impact on the Tigris River's water quality are total dissolved solids, E. coli Bacteria, Fecal Coliform Bacteria, BOD_5, and C.O.D. Total ionic salinity (meq/l) was less than 20 in the Mosul and Sammara sites, 20 in the Tharthar-Tigris Canal, and between 20 and 40 in the Baghdad site. By applying for the SPSS program, two factors were identified. The first factor represents 84.03 % indicates (natural factor) represented by the weathering of rocky components of the river. The second factor represented 11.33% (Anthropogenic factor), represented by agricultural wastewater, waste and sewage water thrown directly into the river.

Keywords: Salinity, Tigris River, Dissolved loads, Discharge.

مؤشرات التصريف، الملوحة، والحمولات الذائبة لنهر دجلة بين الموصل وبغداد، العراق

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الخلاصة:
نهر دجلة هو أحد أهم مصادر المياه في العراق. مر العراق بفترات من الجفاف بسبب التغيرات المناخية بالإضافة الى العديد من مشاريع البنية التحتية للمياه التي تم تنفيذها في حوض دجلة في تركيا والدول المجاورة. تم اختيار أربعة مواقع لتقييم التلوث البيئي، وتأثير التغييرات المناخية على الخصائص الهيدروكيميائية لمياه نهر دجلة بين الموصل وبغداد، وتقدير العلاقة بين الحمولات الذائبة وتصاريف مياه نهر دجلة. شملت هذه الدراسة البيانات التالية: تصاريف نهر دجلة للفترة (2005–2020) والتحاليل

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الهيدروكيميائية والتي تتضمن: الأيونات الرئيسية والأيونات الثانوية والعناصر النزرة العناصر البيولوجية والتي تشمل: BOD_5، COD، E. coli، FC MPN/100 ml للفترة (2005–2020) ، تعتبر هذه العناصر كمؤشرات للتلوث حيث تسمح بتحديد مصادر التلوث. تم تطبيق التقنيات الإحصائية متعددة المتغيرات لتقييم الاختلافات المكانية للتحاليل الهيدروكيميائية. يقع نهر دجلة ضمن حدود الشرب المسموح بها، باستثناء ذراع الثرثار– دجلة، وقد تم تحديد العوامل الرئيسية التي تؤثر على جودة المياه في نهر دجلة على أنها إجمالي المواد الصلبة المذابة، وبكتيرياE. coli ، وبكتيرياFecal Coliform ، BOD_5، COD .كان إجمالي الملوحة الأيونية (TIS meq/l) (أقل من 20) لموقعي الموصل وسامراء، (20) لذراع الثرثار– دجلة، وبين (20–40) في موقع بغداد. من خلال تطبيق برنامجSPSS ، تم تحديد عاملين. يمثل العامل الأول 84.03٪ يشير إلى (العامل الطبيعي) الذي يمثله تجوية المكونات الصخرية للنهر. ويمثل العامل الثاني 11.33% (العامل البشري المنشأ) الذي تمثله مياه الصرف الزراعي والنفايات ومياه الصرف الصحي التي تُلقى مباشرة في النهر.

1. Introduction

The Tigris River is one of the most important water sources of the Euphrates River in Iraq. Iraq has experienced periods of drought caused by climate change and numerous water infrastructure projects completed in the Tigris Basin in Turkey [1, 2]. This climate change has had an impact on the annual flow of the Tigris River, an average annual flow of 672 m^3/s when entering Iraq from 1960 to 1984, a reduction to 596 m^3/s from 1985 to 2008 [3], and has dropped to 413 m^3/s over recent years [4]. In addition, during the last few years, Iraq has suffered from pollution, which presents significant risks to the environment and its habitable life forms. The reduction of renewable water resources and there has been a deterioration in the water quality of the Tigris River in Iraq. This is mainly due to the flow of irrigation water through the river. Hazardous materials, including fertilisers and pesticides, are also released into the river [2].

Generally, surface water quality has recently been identified as an important issue due to the expected decrease in fresh water available for future use [6]. A procedure that may serve to hold surface waters in Iraq is to monitor contaminant sources and try to prevent or minimize their effects. The most formalized method used is to evaluate the concentration of the contaminant, identify pollutant sources along the river, analyze the results, identify the reasons for the contamination, and identify methods that can be utilized to reduce their effect, or the worst-case scenario, Identify appropriate investment opportunities for contaminated water elimination or reduction of contaminants to produce high-quality water suitable for consumption, irrigation, and industrial use requirements [7].

The Tigris River's water discharge (m3/sec) decreases over time [4,5,8, and 9]. This decrease is partly due to an increase in the salinity of the water. Thus, this study aims to assess environmental pollution as well as the influence of climate change on the hydrochemistry of the Tigris River, estimate the dissolved discharge (m^3/sec) and determine the relationship among them to analyze and identify sources of water pollution. This study includes the hydrochemistry parameters (main ions, trace ions, and biological ions) from 2005 to 2020, including four stations along the Tigris River at Mosul, Sammara, Tharthar-Tigris Canal, and Baghdad. The site of Baghdad is selected because this is the nation's capital and the largest city with numerous household sewage, industrial manufactory, and medical, draining the non-treated water immediately into the Tigris River.

2. Location and Geology of the study area

The study path is located between Mosul city, which is located in the northern part of Iraq and Baghdad city in the middle part of Iraq, within the following geographical limitations: (36°23'51.96"- 33°31’52” N) and (42°59'53.42"- 44°36’61” E) (Figure 1).

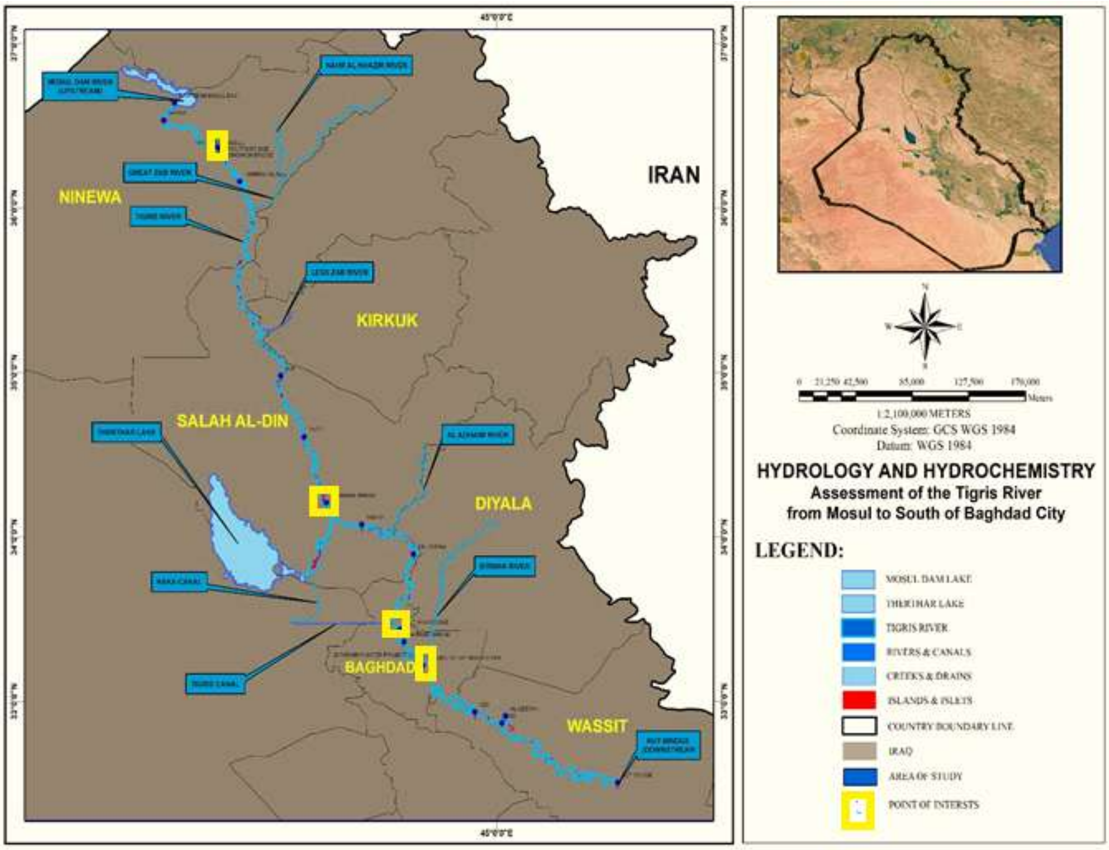

Figure 1: Location map of Tigris River stations.

The main stations consist of Mosul, Sammara, Tharthar-Tigris Canal north of Baghdad and the Baghdad site. Lake Tharthar provides water to the Tiger through the Tharthar-Tigris Channel, which stores water and relieves flooding, which flows through an expanding gypsum soil (Gypcrete) [10]. Tharthar Lake through the Tigris River with saltwater from Tharthar Lake affects the quality of the Tigris River north of Baghdad.

The geological components of the Tigris River vary from one place to another place such as Muqdadiya, Injana, and Fatha Formations, which represent the geological formations at Mosul and continue with quaternary deposits that appear along Tigris River beds to Baghdad city [10], (Figure 2).

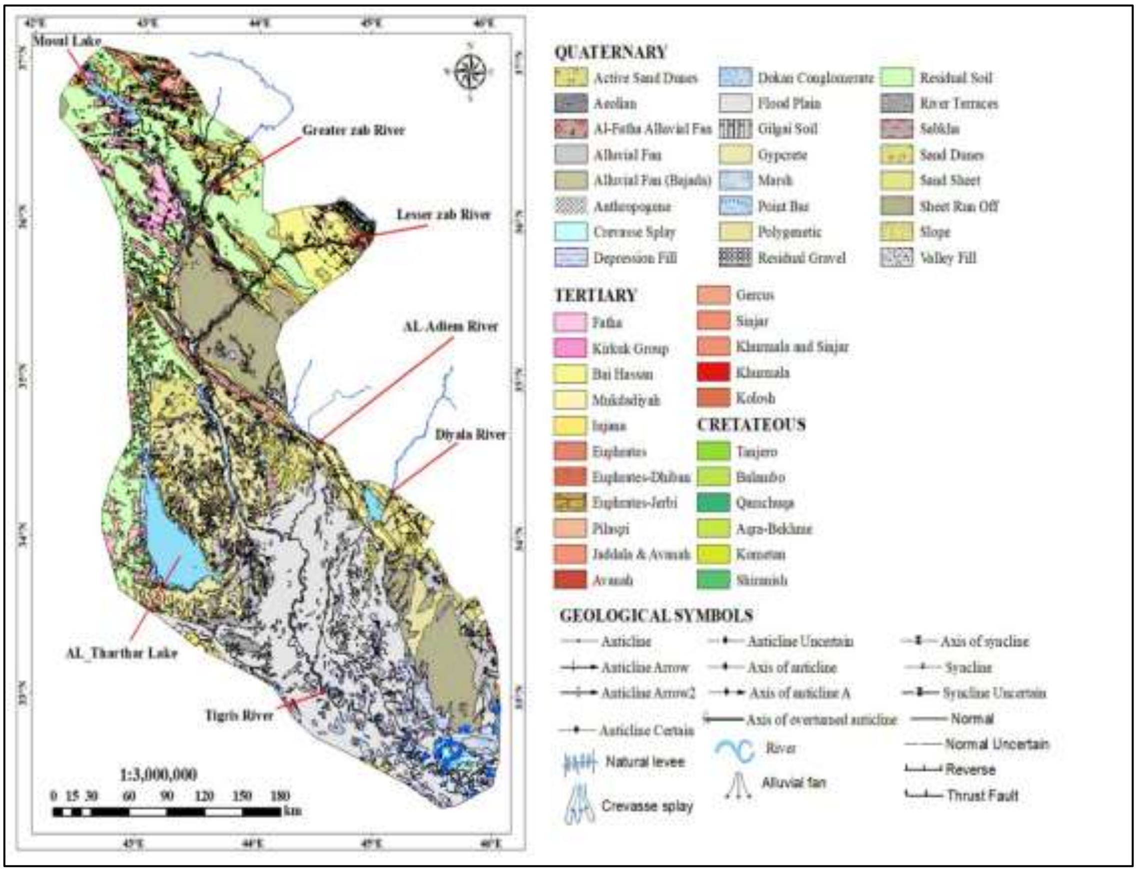

Figure 2: Geological map of the study area.

3. Materials and Methods:

A study is performed on the Tigris River because of its important hydrologic environment, location, and available data. Twenty-two water quality parameters in four sites for 2005 to 2020 were used. They are temperature (T), Hydrogen potential (pH), total dissolved solids (T.D.S.), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), potassium (K^{+}), chlorides (Cl^{-}), sulfate (SO_4^{-2}), bicarbonate (HCO_3^{-}), nitrate (NO_3^{-1}), phosphate (PO_4^{-1}), Copper(Cu), zinc (Zn), cadmium (Cd), lead (Pb), chromium (Cr), iron (Fe), biological oxygen demand (BOD_5), chemical oxygen demand (C.O.D.), E-coli Bacteria, and Fecal Coliform Bacteria, that are regarded virtue indication of surface water pollution, to assess the environmental pollution for Tigris River for the period (2005-2020). In addition to using the water discharge (m^3/sec) data of Tigris River flow and determining dissolved load concentrations [11]. These data were used for the following:

a- To establish the relationships between discharge (m^3/sec) and total dissolved solids (mg/L).

b- Estimate the sediment loads of the examined stretch of the Tigris River.

c- Determine the influence of reduced water flows on the salinity of the Tigris River. Also, multivariate statistics technology (Factor Analysis) has been implemented via SPSS 26.0 to estimate the spatial variation and the interpretation of the water quality along the river. Applying factor analysis (F.A.) assists in interpreting complex data matrices to improve understanding of the water quality and environmental statute of the method studied; and can determine the ability of factors/sources to influence water.

d- The total ionic salinity (T.I.S. meq/l) was calculated as provided by [24].

e- The Aq. Q.A. software was used to plot the Schoeller diagram to view the ions' related concentrations (meq/l) [21].

f- The hydrochemistry method was measured as a mean formula based on a water-type formula, which has been cited in [20].

4. Results

4.1 Discharge variation with time:

The results indicate that the annual discharge of the Tigris River during the period (2005-2020) ranged between (261.83-601 m^3/sec) with an average annual discharge (461.9 m^3/sec) for Mosul station. While Sammara station ranged between (399.5-657.9 m^3/sec) with an average annual discharge (507.7 m^3/sec) and ranged between (15.96-98.02) m^3/sec with an average annual discharge of (46.71 m^3/sec) for the Tharthar-Tigris canal. In the Baghdad site, it ranged between (399.84-711) m^3/sec with an average annual discharge of (525.50 m^3/sec) (Figure 3).

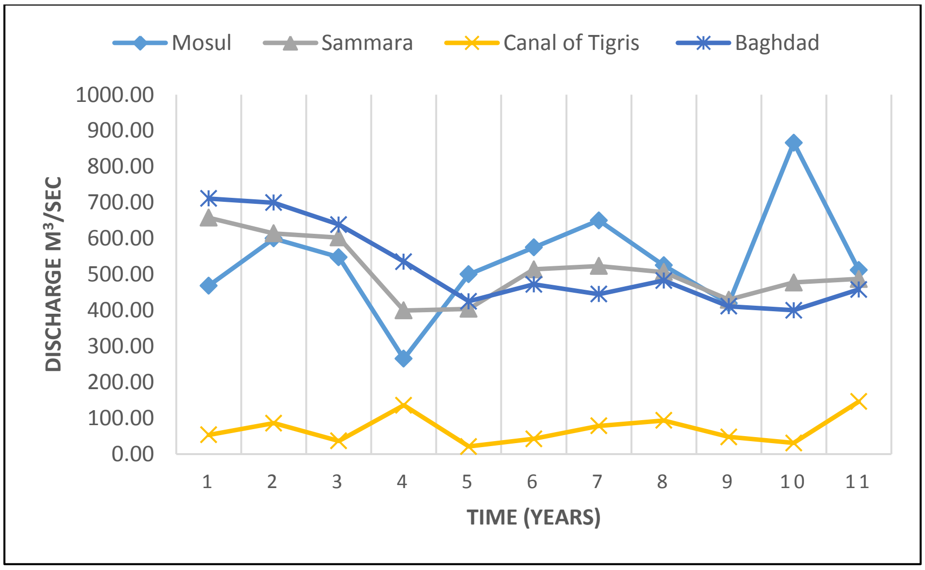

Figure 3: Hydrograph shows the annual mean values of the flow of the Tigris River from Mosul to the Baghdad site from 2005 to 2020 [10].

As noted, the average annual discharge (m^3/sec) values of the Tigris River are increased at Sammara and Baghdad stations due to the contributions of the tributaries. The Greater and Lesser Zab tributaries join the Tigris River in the northern part of Sammara city. The Greater Zab tributary with an average annual discharge of (418 m^3/sec). To the south, Lesser Zab tributary joins Tigris at Fatha with an average annual discharge of (227 m^3/sec). South of Sammara station. The Adhaim tributary joins the Tigris River with an average annual discharge of (25.5 m^3/sec) [12]. In addition, it diverted water from Tharthar-Tigris Canal to the Tigris River in the northern part of Baghdad with an average annual discharge of about (78 m^3/sec).

4.2 The Hydrochemistry of Tigris River:

Total dissolved solids along the path of the Tigris River for the period 2005 to 2020 ranged from 185 to 290 mg/L with a mean of (162.7 mg/L) of Mosul station. At the same time, Sammara station ranges from (191 to 424 mg/L) with mean of (267.7 mg/L) and varies between (847-1601.8) mg/L with a mean of (1089.4 mg/L) at Tharthar Canal in the north of Baghdad site, while at Baghdad site ranged from (640 to 815 mg/L) with a mean of (621 mg/L), (Table 1). T.D.S. values were greater in the Tharthar Canel, which can be caused to the increased salinity of Lake Tharthar. This is caused by high evaporation and passage of this cannel through the Gypsum soil and the drainage from farmland. The pH of the Tigris River ranged between (7-8.7) and (7.0-8.4) with a mean (7.5) and (7.7) at Mosul and Sammara stations. As for the Tharthar-Tigris canal and Baghdad stations, pH values ranged between (6.5-8.5) and (7-8.7) with a mean (7.8) and (7.8). The Temperate (C^o) of the Tigris River ranged between (10.8-18) and (19.6-23) with a mean (17.6) and (20.6) C^o at Mosul and Sammara stations. While for Tharthar-Tigris Canal and Baghdad stations ranged between (21-25) and (17-28) with a mean (23) and (21.5) C^o.

4.2.1 Main Ions:

The results of the major ions for the period 2005 to 2020 of Tigris River sites were tabulated in Table (1). Calcium (Ca^{2+}) concentration of Tigris River ranges between (20-92) ppm at Mosul station, while, at Sammara, it ranges between (12-280) ppm. As at Tharthar-Tigris Canal, it ranged between (72.9-232) ppm. For Baghdad, it varied from 34 to 128) ppm. Ca^{2+} concentrations were higher at Tharthar-Tigris Canal and Baghdad than at others. This may be attributable to increased evaporation and reduced water supply through the years and can indicate the geology of the Tharthar-Tigris Canal beds. Magnesium (Mg^{2+}) ranges between (15-97) ppm at Mosul station, while at Sammara ranges between (4.8-336) ppm. At Tharthar-Tigris Canal varies between (14-391) ppm. As for Baghdad varies between (13.2-150) ppm. Sodium (Na^+) concentration ranges between (7.3-37) ppm at Mosul station, while at Sammara ranges between (7.8-375) ppm. At the Tharthar-Tigris Canal site varies between (81-524) ppm, and at Baghdad, was ranged between (12-140) ppm. (K^+) concentration ranged between (1.2-23.6) ppm at Mosul station, while, at Sammara ranged between (1-9) ppm. At Tharthar Canal, it ranged between 2.5 and 8 ppm. At Baghdad, it ranged between (1.2-5.5) ppm.

Chloride (Cl^-) concentration of Tigris River ranges between (4-53) ppm at Mosul station, while, at Sammara ranges between (11-227) ppm and varies between (107-192) ppm at Tharthar-Tigris Canal. The Cl concentration at Baghdad ranged between 17 and 121 ppm. Sulfate (SO_4^2) concentration ranges between (15.5-178) ppm at Mosul station, while, at Sammara ranges between (33.1-266) ppm, while at the Tharthar-Tigris Canal, the SO_4^2 value varies between (67-610.7) ppm. In Baghdad, it ranges between 106 and 509 ppm. Bicarbonate (HCO_3^-) concentration ranges between (14-283) ppm at Mosul station. In Sammara, it ranges between (104-232) ppm and varies between (55-207) ppm at Tharthar-Tigris Canal. In the Baghdad site, HCO_3^- concentration ranges between (36-153.5) ppm (Figure 5). The high level of Na^+, K^+, and SO_4^{2-} is probably due to human activities (including wastewater), and natural sources such as the lithology of the basin. HCO_3^- (ppm) depends on the annual rainfall and controlling discharges from Mosul-Dam reservoirs.

Table 1: The Physical–chemical parameters of Tigris River sites (2005-2020) [11]

Stations	Ions (ppm)	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-	TDS	pH	T C^o	NO_3	PO_4
Mosul	Max.	92	97	37	23.6	53	178	238	290	8.7	18	10	9.1
	Min.	20	15	7.3	1.2	4	15.5	14	185	7.0	10	0.09	0.1
	Average	48.2	30.5	21.2	3.8	23.9	107.8	154.4	162.7	7.5	17.6	2.1	1.1
Sammara	Max.	280	336	375	9	227	266	232	424	8.4	23	9.3	0.7
	Min.	12	4.8	7.8	1	11	33.1	104	191	7	19.6	0	0.01
	Average	54.8	26.4	34	3.15	32	102.6	152.3	267.7	7.7	20.6	3.8	0.2
Tharthar -Tigris canal	Max.	232	391	524	8	192	610.7	207	1601.8	8.5	25	18.8	6.1
	Min.	72.9	14	81	2.5	107	67	55	847	6.5	21	0.4	0.1
	Average	138.1	102.5	135.2	13.1	166.7	527.3	114.8	1089.4	7.8	23	2.8	2.3

	Max.	128	150	140	5.5	121	509	153.5	815	8.7	28	16.5	0.8
Baghdad	Min.	34	13.2	12	1.2	17	106	36	640	7	17	0	0.09
	Average	56.3	44.8	66.9	9.0	69.4	233.8	153.1	621	7.8	21.5	3.5	0.4
WHO,2018		**200**	**150**	**100**	**12**	**250**	**250**	**-**	**1000**	**9.5**		**<50**	**0.4**
IQS,2009		**200**	**150**	**100**	**12**	**350**	**400**	**-**	**1500**		**<35**		

NO_3 concentration ranged between (0.09-10), (0-9.3), and (0.4-18.8) with an average of (2.1), (3.8), and (2.8) mg/L at Mosul, Sammara, and Tharthar -Tigris Canal sites respectively. For Baghdad site ranges between (0-16.5) with an average of (3.5) mg/L. PO_4 ranges between (0.1-9.1) and (0.01-0.7) mg\L with an average value of (0.2) and (1.1) mg/L for the sites in the Mosul and Sammara, respectively, and varies between (0.1-6.1) and (0.09-0.8) with an average value (2.3) and (0.4) mg/L for sites in the Tharthar-Tigris Canal and Baghdad sites respectively. A high concentration of PO_4 may be due to agricultural activity.

4.2.2 Trace Elements:

Trace elements in naturally occurring water are defined as elements with a concentration of less than 1%. This means that trace elements are not considered in calculating the total amount of salts dissolved in natural waters because their amounts are insignificant compared with the major ions as a whole [38]. The trace elements Cu, Cd, Zn, Fe, Cr, and Pb were assessed. The concentrations of these trace elements from zero to high are shown in Table (2).

Their maximum values are relatively increased in the Baghdad site. [34] concluded that due to the high quantities of suspended loads in the Tigris River, the movement of trace ions along the river is often associated with the transport of suspended matter. This is, in turn, caused by the discharge of the river. It is believed that these trace elements are within the same range indicated by [15 and 16], as well as they reflect the considerable influence on the background rate by various components, including the source of the rocks, soil-generating processes that control soil development, and maturity, including climate, vegetation, and drain [17].

Table 2: Trace ions concentration (ppm) of Tigris River water from 2005 to 2020 and compared with [13 and 14].

Stations	Ions	Cu	Cd	Zn	Pb	Fe	Cr
	Max.	0.1	0	0	0.02	0.01	0.2
Mosul	Min.	0	0	0	0	0	0
	Average	0.007	0	0	0.004	0.001	0.03
	Max.	0.1	0.09	0.87	0.12	0.2	0.2
Sammara	Min.	0	0	0	0	0	0
	Average	0.07	0.001	0.04	0.006	0.001	0.009
	Max.	0	0	0	0	0.02	0.05
Tharthar- Tigris canal	Min.	0	0	0	0	0	0
	Average	0	0	0	0	0.01	0.001
	Max.	0.16	0.02	0.62	0.008	0.05	0.2
Baghdad	Min.	0	0	0	0.005	0.005	0.006
	Average	0.025	0.002	0.17	0.006	0.015	0.04
Al-Bassam and Yousif,2014	ppm	16		56	5	30000	190

WHO,2018	**ppm**	**1.5**	**0.005**	**3**	**0.01**	**0.3**	**0.05**
IQS,2009	**ppm**	**1**	**0.003**	**1**	**0.01**	**0.3**	**0.05**

4.2.3 Biological ions:

The biological ions consist of BOD_5, C.O.D., Fecal Coliform Bacteria, and E. coli Bacteria (Table 3). BOD_5 indicates poor water quality, and it measures the amount of oxygen consumed by bacteria that decompose the organic matter for both wastewater and surface water. The results of BOD_5 ranged between (0.14-6.4) and (0.6-1.1) ppm with a mean value of (1.61) and (0.68) ppm. Mosul and Sammara sites ranged between (0.09-9.3) and (0.1-10.5) with a mean value· (1.16) and (1.73) ppm at the Tharthar-Tigris Canal and Baghdad sites, respectively. COD· is an indication of poor water quality and a measure of the number of chemicals that consume dissolved oxygen· The results of C.O.D. of the Tigris River ranged between (0.1-4.1) and (0.1-11.02) mg\L with an average value of (0.93) and (0.58) mg/L for sites in the Mosul and Sammara sites respectively, and ranging between (0.3-2.3) and (0.1-3.6) mg\L with an average value of (1.0) and (0.9) mg/L for sites in the Tharthar-Tigris Canal and Baghdad sites respectively.

Table 3: Biological ions concentrations of Tigris River sites from (2005 to 2020) [11].

Stations	Ions	C.O.D. (mg/L)	BOD_5 (mg/L)	FC Bacteria	E.coli Bacteria
Mosul	Maximum	4.1	6.4	16,000	2,4196
	Minimum	0.1	0.14	100	100
	Average	0.93	1.61	2,516.03	1,499.35
Sammara	Maximum	3.6	1.1	28,146.45	16,000
	Minimum	0.1	0.6	110	78
	Average	0.58	0.68	4,454.25	3,112.45
Tharthar- Tigris Canal	Maximum	2.3	9.3	198,630	24,961
	Minimum	0.3	0.09	480	100
	Average	1.0	1.16	25,483	9,162
Baghdad	Maximum	11.02	10.5	155,310	120,330
	Minimum	0.1	0.1	100	100
	Average	0.9	1.73	13,408	6,617
[39]		**< 100.0**	**< 40.0**	**5 cells /100 ml***	**5cells /100 ml***

The mean values of Fecal Coliform Bacteria of the Tigris River were (2,516.03) and (4,454.25) mg/L at Mosul and Sammara sites and (25,483) and (6,617) mg/L at Tharthar-Tigris Canal and Baghdad sites, respectively. The mean values of E. coli Bacteria were (1499.35) and (3,112.35) mg/L at Mosul and Sammara sites, and (9,162) and (13,408) mg/L at1Tharthar-Tigris canal and Baghdad sites respectively. The Tigris River quality deteriorates as indicated by C.O.D., BOD_5, and other biological elements, which may be more polluted due to the anthropogenic impacts, including the river's municipal sewage and irrigation drainage.

The biological pollution in the Tigris River, especially in Baghdad city, caused by the effect of Medical City’s liquid waste on the Tigris River manifests itself in different ways:
1) the appearance of bacteria in the wastewater, which can resist antibiotics; 2) The count of bacteria in the wastewater of the hospitals was higher than those in the city’s wastewater; and 3) The effluent of Medical city contains viral water contaminator such as intestinal viruses, as

well as other viruses such as blood viruses (Cirrhosis and H.I.V.), inflow directly from the infected bodies of patients.

4.3 Relationship Between Discharge (m^3/sec) and TDS

The correlation between T.D.S. concentrations and their variation in discharge rates is very helpful in developing a quantitative study, such as improved or degraded water quality over time, and is critical
to plan water pollution programs. T.D.S. concentration is correlated inversely with discharge; the high rates of discharge act as a dilution agent. Therefore, the strength of the solute becomes less when the discharge increase [6]. Generally, an inverse correlation between the annual flow of the Tigris River and T.D.S. concentration, (Figure 4 A, B, C and D).

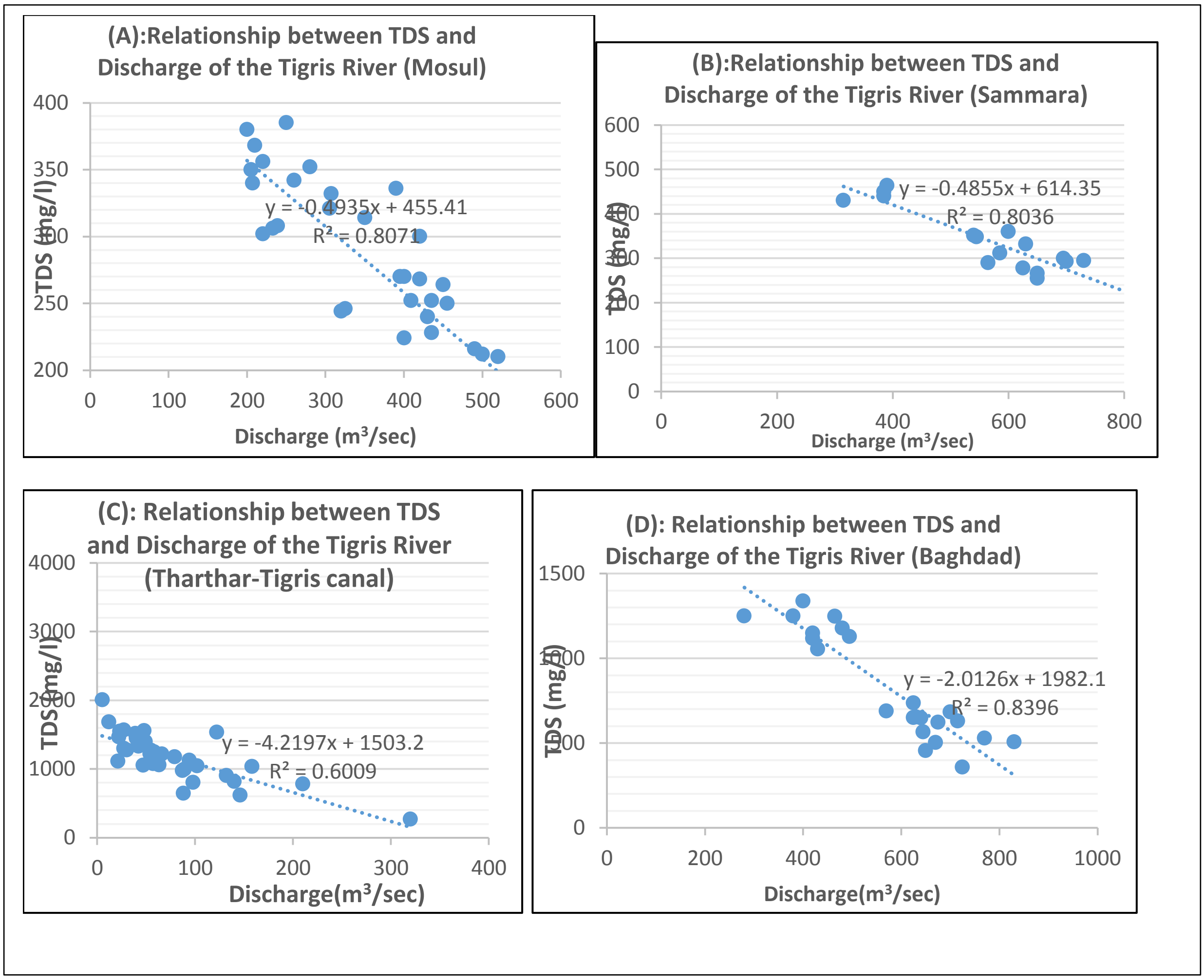

Figure 4: The relationship between total dissolved solids concentrations (mg/L) and discharge (m^3/sec) along Tigris River (2005-2020), (A): Mosul station, (B): Sammara station, (C): Tharthar-Tigris canal, and (D): Baghdad station.

It is noted that the salinity at Baghdad station was increased more than other stations, which is believed to be because of the influence of the Tharthar-Tigris Canal higher salt content in the water. In addition to the evaporation process and the release of untreated wastewater from different anthropogenic sources directly into the river. By comparing with previous studies, the results showed that the current mean value of T.D.S. concentration at studied stations is relatively higher than the previous studies [8]. Such results are according to the present research idea that the water quality changes over time because of climate change and inadequate releases of the water level of the Tigris River.

4.4 Sediments loads:

The rating curve was used to determine the correlation between monthly flow (m^3/sec) and monthly sediment loads transferred at some sites surveyed. A precise form of rating curve is used to regress stream discharge on the dissolved sediment load through the following equation:

$$Qs = \frac{Q*Cs}{1000}$$

Where:
Qs = Sediment load in tons.
Q = Stream Discharge in m^3/s.
Cs = Sediment concentration in mg/L.
The basic equation of suspended-sediment discharge is

$Q_s = C_o Q$ (with appropriate units)

The sediment load was estimated using the formula above for 2005-2020 as mean values (tons/month) along Tigris River sites, as presented in Table (4). The accumulative values of the sediment load of the Tigris River during 2005-2020 at the Mosul site was (4,433,759.71) tons/month. At the Sammara site, the sediments loads were (3,593,282.91) tons/month, whereas; at Tharthar-Tigris Canal was (1,098,261.06) tons/month; and at the Baghdad site was (7,322,579.45) tons/months.

Using the discharge (m^3/sec) of Tigris River for the period (2005-2020) and related with sediment loads to create the rating curves, as presented in Figure (5) for the Mosul, Tikrit, Sammara, Tharthar-Tigris Canal, and Baghdad sites.

Table 4: Mean monthly values with the accumulative of the sediments loads (tons/months) of Tigris River for during (2005-2020).

Years	Mosul	Sammara	Thathar canal	Baghdad
2005/2006	307,140.70	304,352.25	13,443.20	804,281.50
2006/2007	477,163.33	502,856.51	14,443.90	864,803.93
2007/2008	467,319.45	486,205.45	103,054.82	922,389.78
2008/2009	197,793.70	315,096.10	144,614.40	1,013,210.01
2009/2010	815,011.25	292,734.57	147,483.73	527,052.10
2011/2012	416,859.84	323,640.10	190,346.93	590,629.18
2016/2017	487,890.41	445,751.38	108,169.43	658,414.37
2017/2018	341,630.10	222,141.34	284,050.42	749,099.57
2018/2019	305,307.29	332,256.60	60,499.75	624,255.57
2019/2020	617,643.64	368,248.61	121,216.62	568,443.44
ACCUMULATIVE	4,433,759.71	3,593,282.91	1,187,323.20	7,322,579.45

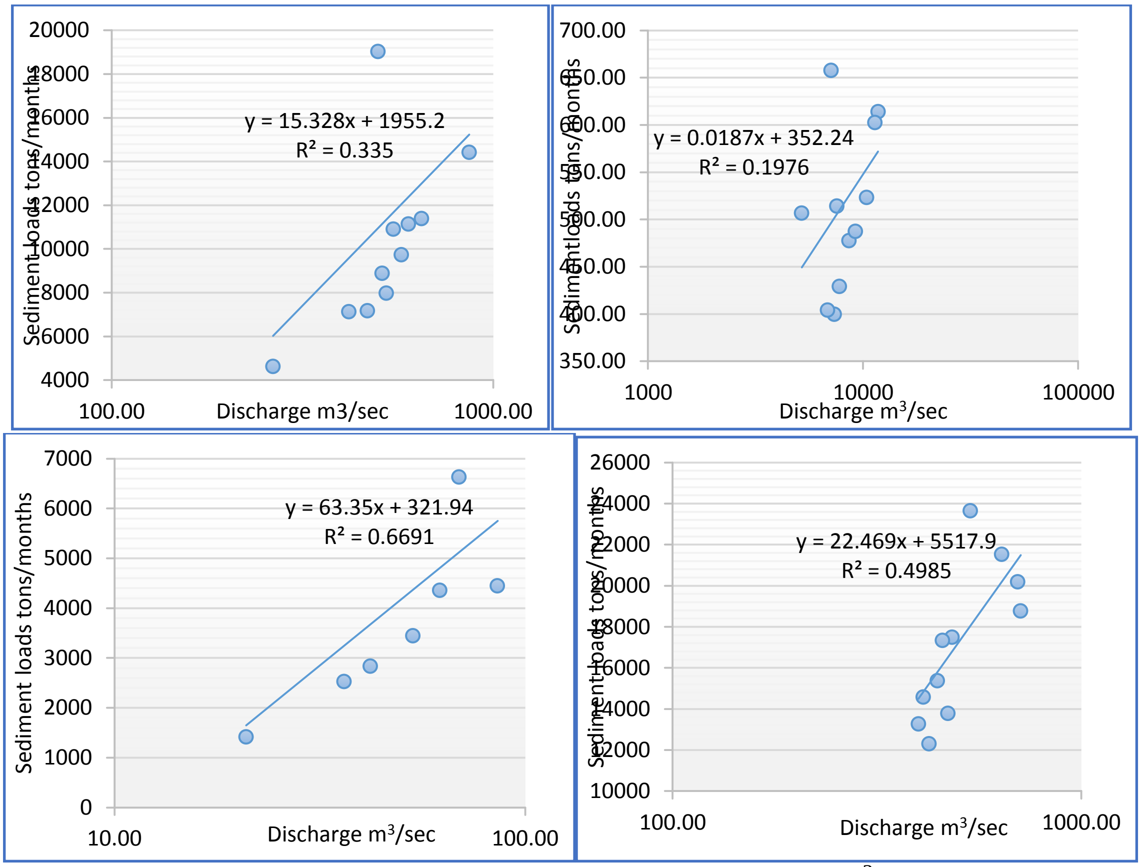

Figure 5: Rating curves between the Discharge of Tigris River (m^3/sec) and the dissolved load (ton/year) for the period (2005-2020) (A): Mosul station, (B): Sammara station, and (C): Tharthar-Tigris canal, and (D): Baghdad station.

4.5 Hydrochemical Formula:

The variation in water types points to the interaction between elements such as lithology, recharge, well locations, well depths, aquifer geochemistry, and local contamination [19]. [20] Suggested a hydrochemical formula depending on the ratio of major ions per epm, where the availability is higher than 15%, cations as a basis for the equation, and anions above that are arranged in descending order. T.D.S. value should be put in (mg/L) unit also, the value of pH should be mentioned too, as in the following formula:

$$TDS\ (g/l)\ \frac{(SO_4^{=}\ .Cl^{-}\ .HCO_3)epm\%}{(Na^{+}\ .Ca^{++}\ .Mg^{++}\ .k)\ epm\%}\ pH$$

The variety of water types is due to the dynamic water system and still in movement, climate conditions, and consequently other anthropogenic factors such as irrigation water and other waste thrown into a river and dissolution of rocks in contact with water. The hydrochemical formula and water type for Tigris River stations were (Ca-HCO_3) for Mosul and Sammara stations and (Na-SO_4) for Tharthar-Tigris Canal and Baghdad stations. The type of water is variable from time to time during the study period, and depending on the application [20] on the hydrochemical parameters for each year from 2005 to 2020, the water type classified between $CaHCO_3$ (90%) and $CaSO_4$ (10%) at Mosul station, and at Sammara station varies between $CaHCO_3$ (90%) and $MgHCO_3$(10%). The water Type was $NaSO_4$ (80%) and $CaSO_4$ (20%) at the Tharthar-Tigris Canal. While at Baghdad is classified between $MgSO_4$ (5%), $NaSO_4$ (45%), and $CaSO_4$ (40%). Schoeller diagrams are also used to show relative anion and cation concentrations generally expressed as milli equivalents per liter [21]. Based on the average values of hydrochemical parameters for the period (2005-2020) along the Tigris River, the major ions in descending order of abundance at the Mosul site are Ca^{2+} >Mg^{2+}> Na^{+}>K^{+}; HCO_3^->SO_4^{2-} >Cl^- and, at Sammara site, Mg^{2+}> Ca^{2+}>Na^{+}> K^{+}; HCO_3^- >SO_4^{2-}> Cl^-. At Tharthar-Tigris Canal site, Mg^{2+}> Ca^{2+} > Na^{+}> K^{+} ; SO_4^{2-}> Cl^- > HCO_3^- and, at Baghdad site,Ca^{2+}>Mg^{2+} > Na^{+}> K^{+} ; SO_4^{2-} >HCO_3^->Cl^- (Figure 6).

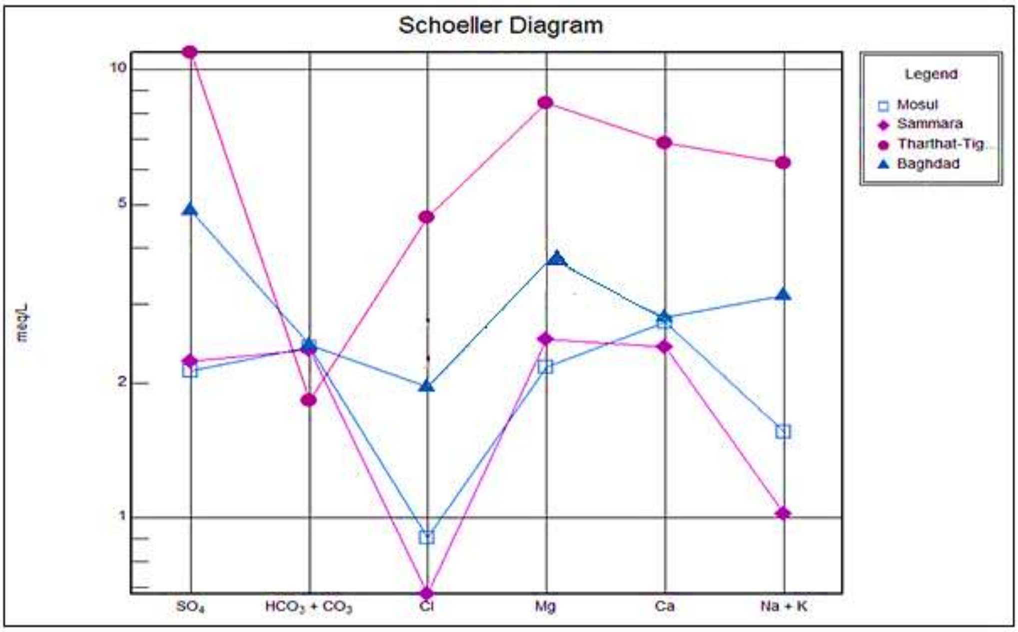

Figure 6: Schoeller diagram of the Tigris River sites from 2005 to 2020.

4.6 Water-Rock Interaction Processes:

Hydrochemical functioning can indicate the characterization of the river by concluding the rock-water relationship [22]. A few of these varieties are used in this study to distinguish the effects of various weathering procedures from the sites studied. The results indicated that the ratio of rCa^{2+}/rMg^{2+} with a mean value of 1.65 is between the effects of saline groundwater 0.14 and rainwater 7.14 [23]. While the ratio rNa^{+}/rCl^{-} shows the Na^{+} concentration is comparatively high in comparison to the Cl^- value (1.1). This indicates that there is an alternative source of Na^{+} instead of halite that provides dissolving dissolution of land-based minerals during partial leachings, such as clayey minerals.

The dissolving of the gypsum and anhydrite in surface water are pointed out rSO_4^{2-}/rCl^{-} ratio (Collins, 1975). The result of $rSO_4^{2-}/r\ Cl^{-}$ (epm) ratio is (2.89) at Mosul site, (1.05) at the Sammara site, (2.3) at the Tharthar-Tigris Canal, and (2.5) in the Baghdad site, (Figure 7).

The graphic relation of Ca^{2+}+ Mg^{2+} versus SO_4^{2-} + HCO_3^- is to be near line 1:1 like we usually do whether calcite dissolutions, the dolomite, and gypsum, the predominant responses in the water. The points will be moved towards the left because of the significant excess of Ca^{2+}+ Mg^{2+} relative to SO_4^{2-} + HCO_3^-. The opposite is true when ion exchange tends to shift points to the right for reasons of an excess of SO_4^{2-} +HCO_3^-. Tigris River sites are moved relative to the left because of excess (Ca^{2+}+ Mg^{2+}) in comparison to (SO_4^{2-} + HCO_3^-).

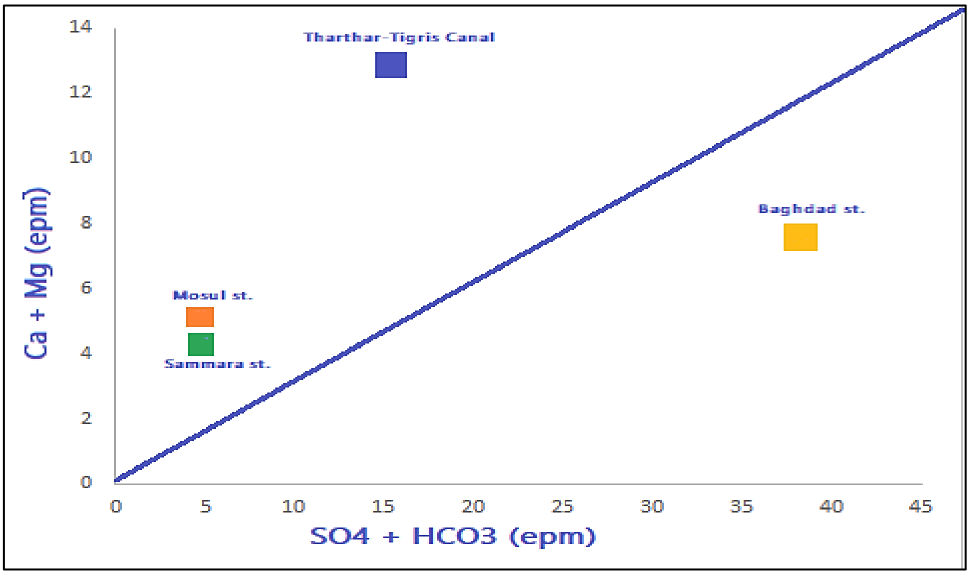

Figure 7: Relationship of (Ca^{2+}+Mg^{2+}) versus (SO_4^{2-}+HCO_3^-) per epm in Tigris-River water sites.

4.7 Total Ionic Salinity (T.I.S.):

The investigation of geochemical properties aims at making it easier to understand and interpret changing trends, mainly in the surface water mechanism, when understanding maps of hydrochemical divisions and their apportionment. Regarding surface waters, most have T.I.S. values of 10 to 30 meq/l [24]. At the Mosul and Sammara sites of the Tigris River, the T.I.S. was less than 20 meq/l, while at the Tharthar-Tigris Canal T.I.S. was 20 meq/l, and at the Baghdad site, T.I.S. ranged between (20 and 40 epm), as shown in Figure 8.

4.8 SPSS Software Application:

To identify the most significant factors affecting water quality, it was found that performing a factor analysis of the samples is indicative of two principal factors influencing the concentrations of the principal variables. Factor analysis was utilized for 16 hydrochemical parameters for the four mean sites along the Tigris River from 2005 to 2020 from Mosul to Baghdad stretching using the SPSS software16.0 [25]. The selected parameters for the estimation of surface water quality include T.D.S., mean ions such as (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, $SO_4^{2}$and HCO_3^-) and biological parameters such as (BOD_5, C.O.D., Fecal Coliform Bacteria, and E. coli Bacteria).

Correlation matrix of the water quality variables was obtained from principal component analysis (P.C.A.) and rotation approach (Varimax with Kaiser Standardization). The Pearson correlation coefficient matrix determines the correlation among the variables. These correlation factors are examined to determine whether factor analysis can be applied to the parameters. Therefore, the factor analysis method was determined to be applicable. Furthermore, an eigenvalue gives a measure of the meaning of the factor. The highest eigenvalue is considered to be the highest. Eigenvalues greater than or equal to 1.0 are regarded as significant [26]. Therefore, according to the results of the impact investigation, the first two eigenvalues were above 1, and the second eigenvalue was slightly below (1).

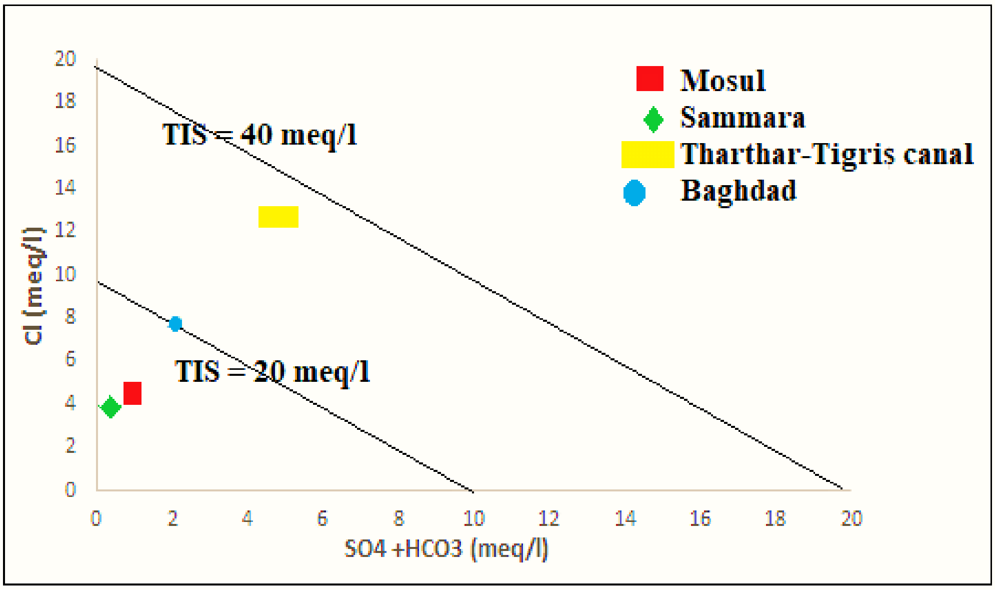

Figure 8: Total Ionic Salinity diagram.

The results were found by performing a factorial analysis of two principal factors that influence the concentrations of the principal variables. Depending on (Figure 8) and a subsequent interpretation of the load factors, the first two components were extracted, and the remaining components were eliminated. This means that the first two factors explain, to a large extent, the total variance of the original data. Then, factor rotation (Varimax) was used to obtain easily interpretable factor loads [27 and 39]. The first factor accounts for 84.03% of the difference with an own value of approximately 11.54, while the second factor accounts for 11.30% with an own weight of roughly 3.6 (Table 5).

4.8.1 First Factor:

The first factor (F1) shows 84.03%, with the total variance being strongly positive (T.D.S., Ca^{+2}, Mg^{+2}, HCO_3^-, SO_4^{-2}, T C°, PO_4, and C.O.D.), moderate positive loading (pH, and K^+), and a weak loading (NO_3, E. coli, F.C. bacteria, and BOD_5. The first factor (F1) has a part of sources that may be associated with pollution at the source of the weather processes and agricultural activities. This factor also invariably indicated that the Ca^{+2} and Mg^{+2} mostly contributed to the TDS in the river. This factor explains the chemical alteration of the rocky elements and is common in the basin of the Tigris River. Precipitation causes the transfer of weathering products from various rock types and from all parts of the basin to the Tigris River. During the transfer of the dissolved loads into different rock layers, the sedimentary rocks are mainly represented by carbonated rocks, gypsum, marl, and quaternary sediments. This suggests a natural factor represented by the alteration of the rocks in the river basin.

Table 5: Results of the loading and (Variance), (Eigenvalues) and (Communalities) for the first and second factors of the samples.

Rotated Component Matrix[a]		
Parameters	**F1**	**F2**
TDS	.989	.146
Ca^{+2}	.934	.357
Mg^{+2}	.898	.440
Na^+	.724	.690
K^+	.920	.392

HCO_3^-	.906	.423
SO_4^{-2}	-.994	-.113
CL^-	.857	.515
pH	.383	.524
T C^o	.653	.757
NO_3	-.418	-.997
PO_4	.980	.198
C.O.D.	.471	.836
BOD_5	-.497	.772
Fecal coliform	.480	.877
E.coli	.430	.903
Eigen values	11.54	3.601
Variance (%	84.031	11.30
Cumulative (%)	84.031	95.331

Extraction Method: P.C.A.
Rotation Method: Varimax & Kaiser Normalization.

4.8.2 Second Factor:

This factor represents 11.30% of the total variance and is considered limited in effect compared to the first factor. F2 has strong loading with BOD_5, COD, F.C. bacteria and E. coli bacteria, which represent microorganisms. It is an unnatural source (human activity) formed from that which is discharged into the river, such as wastewater from agricultural lands, garbage, and other sources [39] (Figure 9).

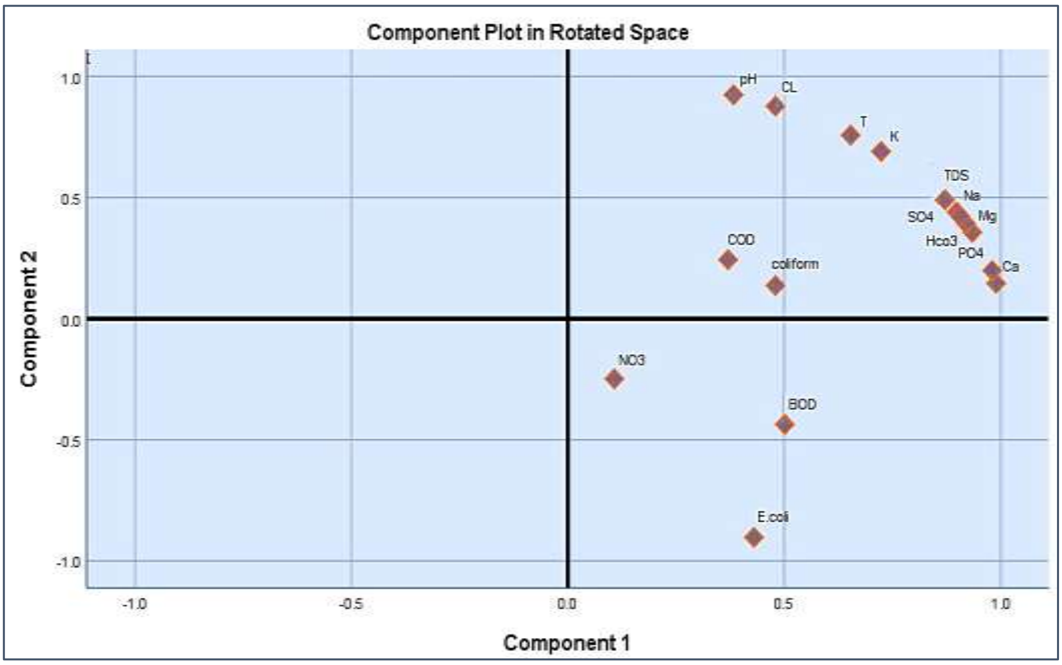

Figure 9: The relationship between the first and second factors.

5. Discussion:

High levels of TDS indicate high pollution loads associated with the direct inflow of untreated sewage into the river and surface drainage contaminated by industrial and domestic irrigation operations (Tables 1, 2, and 3). Salinity varies within the sites studied as a function of the nature, geographic location, and factors impacted within each site, such as (soil) variation, agriculture, population density, etc.). As a result, it was observed that salinity at the site of the Tharthar-Tigris Canal is higher than in the Baghdad site because of its geology consisting of gypsum-bearing soil (Gypcrete) extending from (Lake of Tharthar) to Tigris River, the saline water of this lake generally affects the quality of Tigris in the city of the Baghdad. Also, Tigris River waters degraded in the Baghdad site because the wastewater was thrown directly into the river without being treated by different sources such as industrial activities, hospitals, etc.

The dissolved load is in a state of continuous increase along the Tigris River as a result of dissolution process, in addition to agricultural activity and to the nature of the rocks exhibited within the path of the river. There is a temporal variation in TDS concentration and dissolved load. This result agrees with [28], which concluded that there is a seasonal variation in the concentrations, corresponding to the high suspended and dissolved loads during dry seasons. Most load (50-70%) is usually transported during March-June. It is noticed that the dissolved transport rate at Baghdad station and the dissolved load discharge are higher due to the annual flow of the Tharthar-Tigris Canal of salinity ranging from 1000 ppm to 3000 ppm [12]. Furthermore, before to 2005, the rate of dissolved load differential was substantially lower due to climatic change [29]. The results of this study are in concordance with the previous studies for the same gaging stations [30 and 32].

The results of this research are compared to drinking water quality standards. It was found that the concentrations of T.D.S., Na^+, K^+, and SO_4^{2-} in all sites are within the standards of [13 and 14] except for the Tharthar-Tigris Canal, which exceeded the standards (Table 1). The results of water temperature, pH, as well as Ca^{2+}, Mg^{2+}, Cl, and NO_3 concentrations are within acceptable limits [13 and 14] in all studied sites. SO_4^{2-} values were above the accepted limits of [14]. The PO_4 concentration of Sammara, Tharthar-Tigris Canal, and Baghdad sites were exceeded the acceptable limits of [13]. The results of the Trace Elements (Cu, Cd, Zn, Fe, Cr and Pb) and the results of the BOD and COD values reflect that their concentrations are below permission limits of [13 and 14]. The results display the high variability in Tigris River's levels and count of bacteria indicators, possibly resulting from changes in environmental conditions, turbidities, temperature, salinization, dissolved oxygen, and organic matter [33]. All sites' Fecal Coliform Bacteria and E. coli Bactria exceeded the limits [34]. According to [14], coliform bacteria should be removed from water treatment to make potable water acceptable. Also, comparisons between the results of this study and previous studies demonstrate that most parameters are relatively higher than those from previous studies, such as [35, 12, 36, 37, and [38]. This conclusion may reflect the deteriorating water of the Tigris River over time due to the effects of climate change, decreasing in the annual flow m^3/sec and almost high infection over the past two decades [40].

6. Conclusion:

Concentrations of main and trace elements, generally, vary in waters along Tigris River sites. The Tiger's annual flow has declined with time due to climate change and the building of dams at the border between Iraq and Turkey. In addition, water use increases because of high population growth rates. By comparing this to local and international drinking water quality standards, high TDS levels have been found in the Tigris River at the Tharthar-Tigris Canal site is high and has exceeded the limit allowed. These factors can be attributed to increased salinity at Tharthar Lake. This is due to high evaporation and passage of this duct through the gypsum soil, drainage water from farmland, and the effects of the untreated water flowing directly into the river. Trace elements along the Tigris River are below allowable levels. Bacterial concentrations along Tigris exceeded internationally permitted. It should be noted that the river's water quality is evolving towards an increasing salinity towards the Baghdad site. The sediment load of the Tigris River increased due to the erosion process, apart from agricultural activity, and the nature of the rocks exposed inside the river path. Additionally, there is a temporal variation in TDS concentration and sediment loads. The study's findings highlight the importance of surface water. Strong action should be taken to control pollution limits in the Tigris River and reduce the spread of bacteria to protect human health. Water from the Tigris River needs additional treatment, particularly in the city of Baghdad, for this recommendation, which should implement a periodic monitoring system for monitoring pollution levels via seasonal investigations.

7. Author Contributions: A.S.O.: data processing and validation, software, formal analysis, data preservation, writing—writing an original draft—review and revision. M.A.-D.: supervision, project administration, conceptualization, investigation, visualization, all authors have read and agreed to the published version of the manuscript.

8. Conflict of Interest: The authors state that there is no conflict of interest relating to the publication of this manuscript.

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