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The Impact of Tharthar - Euphrates Canal Salinity on the Quality of Euphrates River near Fallujah, Iraq

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Abstract

The Tharthar Euphrates Canal adds considerable dissolved material to the Euphrates River near Fallujah. Hence, this study aims to examine the variations of solute concentration within the Tharthar-Euphrates canal and estimate the quantitative production of dissolved matter transported to the Euphrates River near Fallujah city. Ten water samples were taken in 2024 along the canal and the Euphrates River to examine the dissolved material in the Tharthar-Euphrates canal, evaluate the water's physicochemical characteristics, and determine the dissolved load carried through the channel. Historical salinity (TDS) and the chemical constituent ions, Cl^-, $SO4^{2-}$, $HCO3^-$, Na^+, Ca^{2+}, Mg^{2+}, and K^+ of the Tharthar-Euphrates canal, were supplied by the Ministry of Water Resources for the hydrological years 2018 to 2023 for the dissolved load calculation that was carried out through the Tharthar-Euphrates canal. A slight increase in dissolved solid concentration was observed downstream of the canal. None of the water samples were helpful for drinking. The water types have indicated that sulfate ions are the dominant ions in the canal. Meanwhile, the Euphrates River water indicates that sulfate and bicarbonate ions are common in the water. The solute concentrations in the Tharthar-Euphrates canal water were plotted with the canal discharge to the Euphrates River from 2018 to 2024. The rating curve has been plotted, showing a strong positive correlation between the Tharthar-Euphrates Canal discharge and the dissolved loads.

Keywords: Tharthar - Euphrates Canal, Physico-chemical parameters, Discharge, Dissolved load, Sulfate.

تأثير ملوحة قناة الثرثار–الفرات على نوعية مياه نهر الفرات قرب الفلوجة، العراق

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الخلاصة

تضيف قناة الثرثار–الفرات كميات كبيرة من المواد المذابة إلى نهر الفرات بالقرب من الفلوجة . لذا يهدف البحث إلى دراسة التغيرات في تركيز المواد الذائبة في قناة الثرثار–الفرات والتقدير الكمي للمواد الذائبة المحمولة إلى نهر الفرات عند مدينة الفلوجة. تم أخذ عشر عينات من المياه في عام 2024 على طول القناة ونهر الفرات لفحص المواد المذابة في قناة الثرثار–الفرات وتقييم الخصائص الفيزيائية والكيميائية للمياه وتحديد الحمولة المذابة الذي تحملها القناة. قامت وزارة الموارد المائية بتزويدنا ببيانات تاريخية عن الملوحة (TDS)

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مثل الكاتيونات الرئيسية (Na^+, Ca^{2+}, Mg^{2+}, and K^+) والأنيونات (Cl^-, $SO4^{2-}$, and $HCO3^-$) لقناة الثرثار–الفرات للسنة الهيدرولوجية 2018–2023 لحساب الحمولة الذائبة التي تمت عبر قناة الثرثار–الفرات. لوحظ ارتفاع طفيف في تركيز المواد الصلبة الذائبة أسفل القناة. لم تكن أي من عينات المياه مفيدة للشرب. أشارت نوعية المياه إلى أن أيونات الكبريتات هي الأيونات السائدة في القناة. في حين تشير نوعية مياه نهر الفرات إلى أن أيونات الكبريتات والبيكربونات هي أيونات شائعة. تم رسم منحني يوضح تراكيز المواد الذائبة في مياه قناة (الثرثار–الفرات) مع تصريف القناة الداخل إلى نهر الفرات من عام 2018 إلى 2024. كما تم رسم منحنى التصنيف، مشيراً الى وجود ارتباط إيجابي قوي بين تصريف قناة الثرثار–الفرات والحمولة الذائبة.

1. Introduction

The largest water reservoir in Iraq is Tharthar Lake. It is located in the southern portion of a large valley that stretches west of Samarra City after beginning west of Mosul City, northern Iraq. To manage the Tigris River's floods, Tharthar Lake was planned and built. Its purpose was to use the extra water kept for summertime irrigation. The main cross-regulator on the Tigris River, located near Samarra City, is part of the Tharthar Lake system. The primary Tigris-Tharthar head regulator is positioned west of the Samarra Cross Regulator, which is connected to the south of the Tharthar reservoir by a about 70-kilometer-long escape canal [1]. At an elevation of 65 meters above sea level, the lake's volume is around 85 billion cubic meters. At 40 m.a.s.l., its dead storage capacity is approximately 35.8 billion m^3 [2].

The Tharthar Euphrates Canal was built south of the lake to redirect large amounts of water to the Euphrates River south of Fallujah City after the water in the river became limited in 1974 [1]. A head regulator was built in the south section of the lake to regulate the outflow discharges of the lake's stored water to the Tigris and Euphrates Rivers. This regulator is attached to a central canal split into two branches by a division regulator (Figure 1). After 2020, the effects of climate change and dam building in neighbouring countries worsened the water shortage, preventing discharges into the Euphrates River. As a result, even though Tharthar Lake's salinity is more than what is considered normal worldwide, there is a greater need to use it. Tharthar Lake's water quality distribution has not been extensively studied [1, 3, 4, 5, 6, and 7]. The coordinates of the studied sites (Longitude and Latitude) are provided using the Global Position System (GPS) (Table 1).

Table 1: Names and the Sampling sites coordinates of the study area.

Site No.	Sample site name	Coordinates	
		Longitude	Latitude
E1	Tharthar - Euphrates canal	33° 41’ 00’’	43° 27’ 47’’
E2	Tharthar - Euphrates canal	33° 38’ 11’’	43° 29’ 14’’
E3	Tharthar - Euphrates canal	33° 35’ 16’’	43° 32’ 12’’
E4	Tharthar - Euphrates canal	33° 31’ 45’’	43° 36’ 05’’
E5	Tharthar - Euphrates canal	33° 28’ 18’’	43° 36’ 17’’
E6	End of Tharthar - Euphrates canal	33° 23’ 55’’	43° 36’ 18’’
E7	Euphrates river	33° 25’ 30’’	43° 29’ 53’’
E8	Euphrates river	33° 23’ 33’’	43° 34’ 36’’
E9	Euphrates river	33° 20’ 32’’	43° 43’ 14’’
E10	Euphrates river	33° 18’ 54’’	43° 45’ 56’’

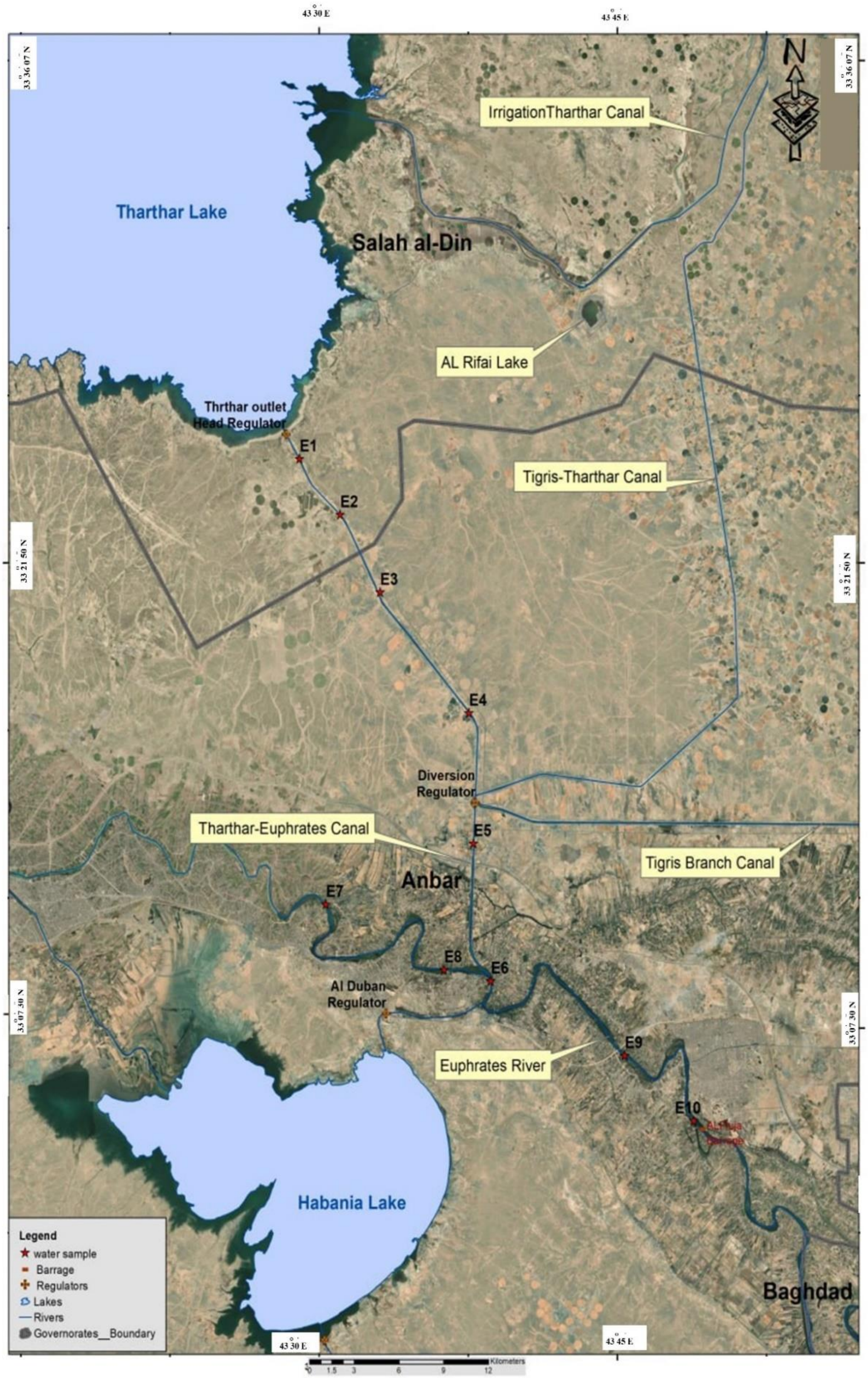

Figure 1: Location and sampling map of the Tharthar Euphrates Canal and its connection with the Euphrates River.

Iraq is an arid nation that is thought to be the most susceptible to climate fluctuation and climate change in the Middle East [1]. Future precipitation may have decreased, and temperatures may have risen [2]. The Tharthar Lake's discharge rate has been adversely affected by the lack of rainfall resulting from Iraq's changing climate [3 and 6]. The growing concern about global warming has sparked serious debates over the relationship between precipitation, evaporation, temperature, and water quality in the southern portion of Tharthar Lake.

Systems for managing water resources must adapt to the unpredictability of climate change, particularly the anticipated shifts in precipitation and temperature. Therefore, emergency or risk management procedures for water supplies are desperately needed. The current methods of managing water resources are likely insufficient to mitigate the adverse effects of climate change. Due to population growth, dam development, and surface water resource issues, further research is required to show the long-term effects of climate change.

Starting from the outlet regulator, the Tharthar-Euphrates Canal is at the lower edge of Tharthar Lake. It is about 37 km in length and has a discharge capacity of 600 m^3/s [7].

The Tharthar-Euphrates Canal has four gates with dimensions of 8 m × 7 m and a discharge capacity of 500 m^3/s. Its confluence with the Euphrates River near Habbaniyah City. Water was first diverted through the canal to the Euphrates River in 1976 [1].

The Tharthar depression area is about 13900 km^2, and the surface area of the lake is estimated to be about 2710 km^2 with a width of 40 km, a length of 120 km, and a capacity of 85 billion m^3 at a water level of 65 m.a.s.l, [1]. Geologically, the selected research region spans the Muqdadiya, Injana, Fatha, and Euphrates Formations of the Miocene, and along the edges of Tharthar Lake, there are Quaternary deposits consisting of carbonates, clay sediments, and evaporates [7, 8, 9 and 10].

Several studies have examined the salinity of Tharthar Lake water, covering various aspects. They are as follows:

CEB, 2011 [11], concluded that the salts in Tharthar Lake originate from three sources: the Tigris River discharge into the lake, Tharthar Wadi runoff, and the Lake Bed and shore. Evaporation from the lake is another factor affecting salt accumulation. The bed and wall of Tharthar Lake lixiviation is no longer the main factor affecting the lake's salinity, as it has flushed out most soluble materials, and evaporation is the dominant factor affecting the lake. The recorded electrical conductivity (EC) values averaged 1570 µs/cm for the three sampling dates.

Al-Dhamin et al.,2012 [12] studied the effect of the Tharthar-Euphrates Canal. They concluded that some seasons had total hardness, chloride, and calcium concentrations higher than the allowable limits for drinking water [13]. The findings also demonstrated that the Tharthar-Euphrates canal significantly raises the Euphrates River's overall hardness levels. The channel cuts through Pliocene and Quaternary deposits, characterised by alternating gravel and sandstone, interfingered with mudstone, gypcretes, and secondary gypsum [8].

A regulator at the channel's beginning completely controls the discharging rate. Accordingly, different solute and sediment discharges are expected to pass through with the various water discharges. The dissolved load forms a significant part of the sediment budget. Therefore, there is a substantial need to measure solute production and transportation.

The dissolved load is that part of the total solute load carried in solution, i.e., chemical ions, that water removes from a drainage basin. The kind of rocks or soils the water has come into contact with and the duration of that contact are the main factors that determine how much dissolved mineral matter is present in natural water [1].

Many investigators have observed an inverse relationship between stream discharge and total solute concentration [13], and a direct relationship between stream-specific discharge and dissolved transport (solute loads) is normal [14].

This study aims to examine the variations of solute concentration within the Tharthar-Euphrates canal and estimate the quantitative production of dissolved matter transported to the Euphrates River near Fallujah city.

2. Materials and Methods

Water samples were collected in 2024 to examine the dissolved material in the Tharthar-Euphrates canal, to evaluate the water's physicochemical characteristics, and to determine the dissolved load carried through the channel. Ten sites were chosen along the canal and the Euphrates River, which facilitated the sampling procedure to detect the amount of dissolved solids entering the canal.

To relate the concentration to discharge, the water discharges were supplied by the NCWRM (National Center for Water Resources Management) in 2024 [15], at the time of sampling. It should be noted that the fieldwork was done with the assistance of a professional group from the Ministry of Water Resources. Vertical profiles of water samples were taken across the canal using a water sampler at all sampling sites. Brown (1970) [16] discussed the frequency of sampling and the number of samples needed to give a representative description of the dissolved matter in a river. A wide range of discharges and concentrations were examined during the sampling program.

The samples were stored in airtight polythene bottles filled with water, ensuring that no air remained within the bottle to prevent a reaction between entrapped air and the water. Storage of water in polythene does not significantly alter the main constituents of the water during a storage period of up to five months [16].

Water samples were analysed for the major cations (Na, K, Ca, and Mg) and anions (Cl, SO4, and HCO3) according to the international procedures in the National Center for Water Resources laboratories (Table 2) [1, 17, and 18].

The accuracy test was carried out for the average of the three water samples analysed at each site [19] (Table 3). The precision results show that the majority of the parameters are within the accepted limits.

B- Historical salinity (TDS) and the chemical constituent ions, Cl^{-}, $SO4^{2-}$, $HCO3^{-}$, Na^{+}, Ca^{2+}, Mg^{2+}, and K^{+} of the Tharthar-Euphrates canal, were supplied from the National Center for Water Resources Management - Ministry of Water Resources for the hydrological year 2018 to 2023 for the dissolved load calculation that carried through the Tharthar-Euphrates canal [15].

Table 2 : Summary of chemical analysis techniques, (APHA, 1998).

Parameter	Method of analysis
pH	Conductivity meter and PH meter
EC	Conductivity TDS meter, cyber scan10
TDS	Gravimetric method
Ca^{2}+ and Mg^{2+}	EDTA titration method
Na^{+} and K^{+}	Flame photometer
Alkalinity $(HCO3)^{-}$	Titration method using an indicator titrated with HCl
$(SO4)^{-2}$	Turbid metric method & colorimetric method
Cl-	Ion-selective Electrode method

3. Results and Discussion

3.1 The hydrochemistry of the Tharthar-Euphrates Canal and the Euphrates River water

The Tharthar-Euphrates canal water (represented by the sampling sites from 1 to 6) is characterised by a broad range of TDS (from 928 to 1274 ppm) and EC (from 1450 to 1640 µs/cm), as well as pH values between 7.1 and 7.7.

It can be concluded that the type of Tharthar-Euphrates canal water indicates mineralised water, which is classified as brackish water according to the TDS, and which is not good for drinking [20, 21, 22, and 23].

The dominant cation is Ca^{2+}, while the dominant anion is $SO4^{2-}$ (Table 3). The dissolution of gypsum of the Fatha Formation, gypsiferous soil, and the partial mixing of water from multiple aquifers through the horizontal and vertical groundwater flow within the local fault system are thought to be the sources of sulfate. The sulfate group contains two major families: sulfate-calcium and sulfate-magnesium [24].

Chloride (Cl-) is also of significance. The sources of chlorine ions include evaporates, such as halite [18]. Agriculture, sewage, industrial wastes, and the dissolution of salt-rich rocks are other sources of Cl- ions [25 and 26].

TDS (ranging from 403 to 943 ppm) and EC (ranging from 630 to 1460 µs/cm) vary in the Euphrates River water (indicated by the sampling sites from 7 to 10), while the pH values range from 7.1 to 7.6. The Euphrates River water indicates that sulfate and bicarbonate ions are common ions in the water. The sulfate group has two families: sulfate-sodium and sulfate-calcium. The bicarbonate group also contains two families: bicarbonate-calcium and bicarbonate-magnesium (Table 3) [24]. The primary sources of HCO_3^- in Euphrates River water are carbon dioxide (CO2) in the atmosphere, carbon dioxide in the soil, and carbonic acid, which dissolves carbonate rocks such as calcite and dolomite and weathers silicate rocks into feldspar [27].

Moreover, Mg^{+2} is noticed along the Euphrates River course, ranging from 17.4% to 37.9%. The primary source of Mg^{+2} in the study area's surface water is the erosion of Euphrates Formation rocks, including dolomite and magnesite rocks, in addition to the anthropogenic source, which includes industrial waste and sewage products thrown in the river directly [1]. Na^+ and K^+ ions vary from 17.9% to 39.1%. The primary source of sodium in the surface water is from the ionic exchange of clay minerals, erosion of alkalinity feldspar, and the dissolution of evaporated rocks within the river basin [28]. K^+ ions increase in surface water near agricultural lands because of the application of fertilizers [29]. The most abundant dissolved materials in Euphrates River water (above the Tharthar -Euphrates canal outlet) are calcium or magnesium compounds in Alkalinity (Table 2). The high concentration of alkaline ions is believed to have originated from the rainfall in the catchment area of the Euphrates River. The most abundant dissolved materials in Euphrates River water (below the Tharthar-Euphrates canal outlet) are calcium or sodium compounds in the form of sulfate. Therefore, the canal adds noticeable amounts of dissolved material to the water of the Euphrates River, affecting its water quality.

Table 3: Physico-chemical parameters (Average values) of the water samples for the Tharthar-Euphrates Canal and the Euphrates River.

Site No.	EC (µs/cm)	pH	TDS (ppm)	UNIT	Ca^{+2}	Mg^{+2}	Na^{+}	K+	$SO4^{=}$	Cl^{-}	$HCO3^{-}$	Water type
1	1530	7.2	1274	ppm	212	41	97	8.16	634	114	61	Ca:SO4
				epm	10.6	3.42	4.21	0.21	13.24	3.25	1.00	
				epm %	57.47	18.52	22.86	1.13	75.62	18.64	5.70	
2	1590	7.7	1018	ppm	92	48	100	5.16	422	107	37	Ca:SO4
				epm	5	4	4.34	0.13	8.79	3.06	0.61	
				epm %	35.17	30.58	33.24	1.01	70.58	24.54	4.80	
3	1640	7.3	1050	ppm	236	38	69	10.89	643	99	61	Ca:SO4
				epm	11.8	3.17	3.00	0.27	13.39	2.80	1.00	
				epm %	64.67	17.35	16.40	1.51	77.77	16.42	5.70	
4	1620	7.1	1037	ppm	224	50	107	8.16	730	128	85	Ca:SO4
				epm	11.2	4.16	4.65	0.20	15.20	3.65	1.39	
				epm %	60.55	19.63	21.91	0.98	75.00	18.05	8.57	
5	1610	7.5	1030	ppm	200	41	94	9.16	605	128	49	Ca:SO4
				epm	10	3.42	4.08	0.23	12.60	3.65	0.80	
				epm %	56.37	19.26	23.04	1.32	73.86	21.45	4.49	
6	1450	7.2	928	ppm	104	72	107	6.16	547	107	61	Mg:SO4
				epm	5	6	3	0.16	11.39	3.05	1.00	
				epm %	32.48	37.47	19.78	0.98	73.70	19.78	5.70	
7	630	7.6	403	ppm	54	30	31	2.2	132	28	179	Ca:HCO3
				epm	2.7	2.50	1.30	0.06	2.80	0.80	2.90	
				epm %	40.90	37.90	20.40	0.83	42.40	12.30	45.30	
8	850	7.5	544	ppm	80	59	100	8.2	218	92	279	Mg:HCO3
				epm	4	4.90	4.4	0.2	4.5	2.6	4.61	
				epm %	29.70	36.50	32.30	1.6	38.7	22.4	39.00	
9	1460	7.1	943	ppm	144	60	107	6.2	595	107	73	Ca:SO4
				epm	7.2	5	4.6	0.2	12.4	3.1	1.2	
				epm %	42.68	29.4	27.3	0.9	74.5	18.40	7.2	
10	1400	7.5	896	ppm	108	50	132	15	384	170	98	Na:SO4
				epm	5.4	4.2	5.7	0.4	8	4.9	1.6	
				epm %	34.4	26.6	36.6	2.5	55.3	33.6	11.1	

3.2 Solute Concentration and Water Discharge

The relationship between TDS concentration (ppm) and river discharge (m^3/s) has been widely used as evidence of the hydrochemical processes that control surface water chemistry. The concentrations of dissolved solids exhibit an almost inverse relationship with water discharge [1]. The solute concentrations in the Tharthar-Euphrates canal water were plotted with the canal discharge to the Euphrates River from 2018 to 2024 (Figure 2). The annual solute concentrations in the Tharthar-Euphrates canal water varied from 898 to 1350 ppm. The homogeneity of the Tharthar-Euphrates canal water throughout the cross-section reflects the completeness of mixing due to the turbulence in the flow of the channel. [1] have pointed out similar relationships. The relationship between solute concentration and discharge is linear, indicating a slight decrease in concentration as discharge increases. At the end of the canal, there was a minor rise in the dissolved material, which was indicative of the kind of soil the water had come into contact with and the duration of that contact. Additionally, there is increased input from agricultural activity along the canal floodplain.

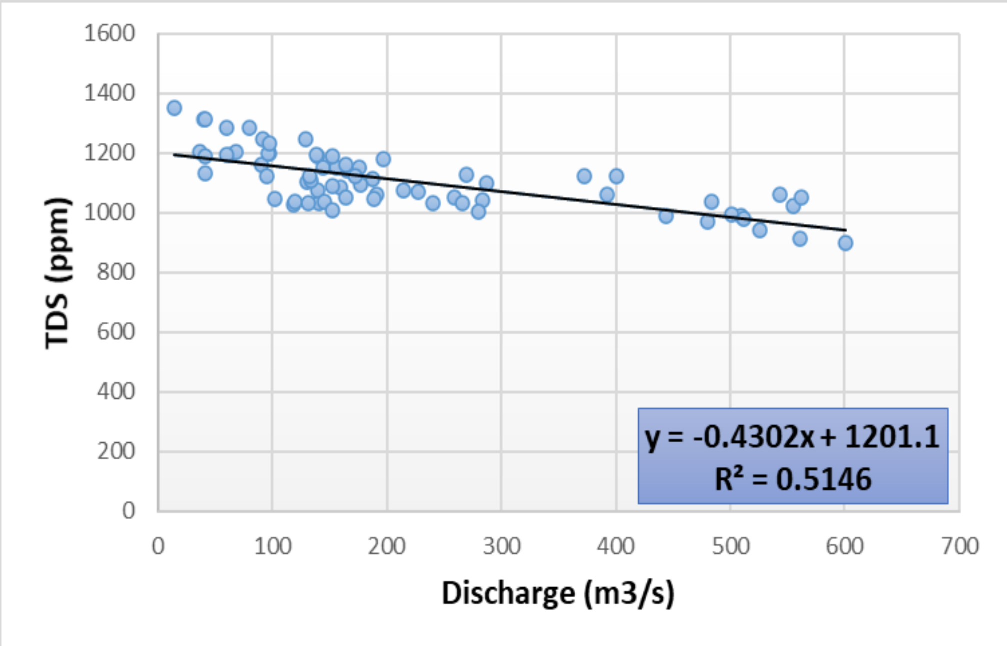

Figure 2: The relationship between the solute concentration of the Tharthar Euphrates Canal and the canal discharge from 2018 to 2024.

3.3 Dissolved loads transportation and rating Curve

The primary requirements for computing the dissolved loads are the concentration of TDS and the canal discharge rates to provide a longer-term load determination. Calculating dissolved loads is a method for developing an understanding of the movement of material in solutes and expanding the knowledge of controlling conditions for dissolved load outflow of the Tharthar Euphrates Canal to the Euphrates River. High rates of a dissolved load exceeding 200 mg/L are observed in the Sabka and arid areas [14]. The interactions between water and the basin rocks affect the chemical composition of the water and, consequently, the dissolved loads. The primary goal of studying the dissolved load's transportation to the Euphrates River is to explain the negative effect on its water quality. The rating curve is the relationship between the canal discharge and the loads transported within the canal course. Canal loads differ temporally and spatially, depending on the discharge rates and water salinity concentrations, which require frequent concentration measurements at specific gauging stations where discharge is regularly measured [30, 31 and 3]. So, in canals such as the Tharthar-Euphrates Canal, the bed material represents the primary source of sediment load. The dissolved loads transported from the Tharthar-Euphrates Canal Site No. 6 to the

Euphrates River are computed using the rating curve technique, which benefits from the parametrisation of the relationship between the relevant variable (load) and the auxiliary variable (discharge). The Ministry of Water Resources supplied the available records for water discharges to estimate the total dissolved loads. The correlation between load and discharge is calculated (Figure 3).

There is a direct relationship between river discharge and the transport of dissolved sediment load. The discharge is likely to increase water velocity, leading to a rise in the capacity of water currents to carry and transport sediment.

An equation is derived from the relationship between discharge and total dissolved solid concentration as shown (Eq. 1). This equation can be used for predicting purposes for computing the monthly dissolved load as in Eq. 1:

$$Y = -0.8885X^2 + 3029.9X + 2372.1 \qquad \text{............ (1)}$$

Where:

Y: Discharge of dissolved loads (tons/ month).

X: Discharge in the Tharthar-Euphrates Canal (m^3/s).

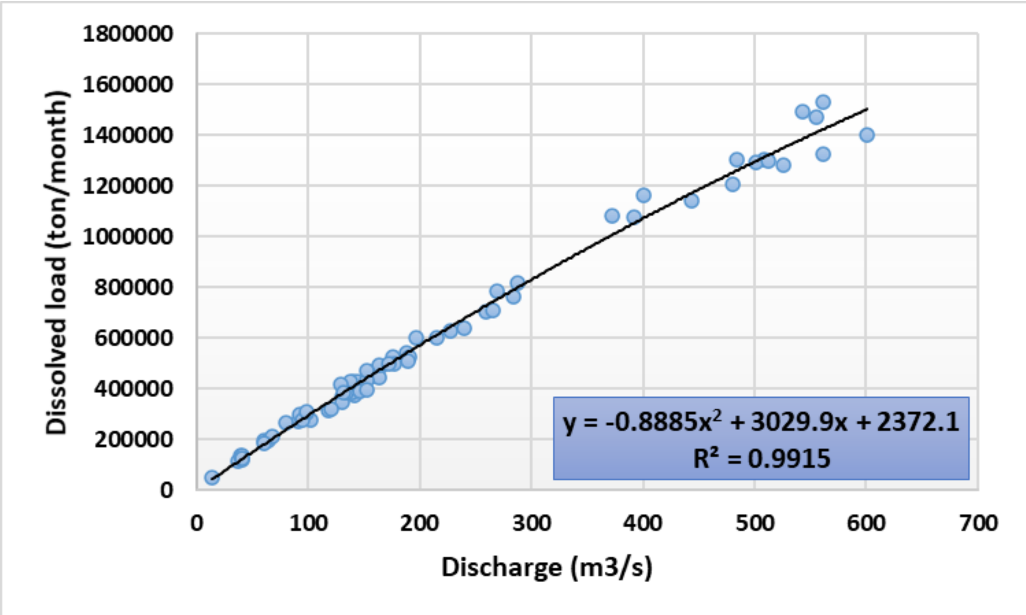

Figure 3: Rating curve of the mean monthly dissolved loads (tons/month) at the Tharthar-Euphrates Canal outlet to the Euphrates River for 2018 -2024.

Obtaining the results of dissolved loads represents one of the most critical aspects of the sustainable development of the Tharthar- Euphrates Canal, so it is used for preparing a quantitative study on water quality and the ability of the canal to transmit the loads over the years, also to propose plans and proposals for managing water resources and the ways of protecting the Euphrates River from further deterioration. The rating curve revealed a strong positive correlation between the discharge of the Tharthar-Euphrates Canal (X) and the discharge of dissolved loads (Y). The spatial variation in dissolved loads emitted from the Tharthar-Euphrates Canal has been calculated using Eq. 1, and the rating curves have been plotted (Figure 3).

It was observed that high solute loads are strongly correlated to high-flow discharge. The maximum dissolved load was recorded in September 2020 (153,000 tons/month), while the minimum was recorded in January 2020 (42000 tons/month) (Table 4).

Table 4: Mean monthly dissolved loads (Tons x10^3/Month) that discharge to the Euphrates River near Fallujah from 2018 to 2024.

Year/Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
2018-2019	116	51	75	541	388	817	450	630	1306	1399	1473	1284
2019-2020	432	729	126	42	44	45	47	385	1323	1407	1298	1530
2020-2021	1140	705	1155	266	120	1080	276	445	1433	1427	1412	1479
2021-2022	1302	116	784	488	525	764	427	399	501	398	323	297
2022-2023	201	109	46	132	103	133	127	111	139	198	207	212
2023-2024	136	417	139	199	266	297	116	404	312	299	276	50

The dissolved loads change periodically over time, depending on the difference in discharge rates and the concentration of dissolved solids, which in turn depend on climate parameters such as temperature and rainfall, as well as geological factors.
Therefore, the canal adds considerable dissolved material to the Euphrates River near Fallujah, which may influence water quality. Further detailed investigations should be recommended in the future.

4. Conclusions

1-The Tharthar-Euphrates Canal's hydrochemistry is distinguished by its broad range of TDS (from 928 to 1274 ppm) and EC (from 1450 to 1640 µs/cm), as well as pH values between 7.1 and 7.7. The dominant cation is Ca^{2+}, while the dominant anion is $SO4^{2-}$. The dominant water type is CaSO4 (about 84%), but MgSO4 is significant downstream of the canal (about 16%). According to international EC and TDS criteria, it is categorised as mineralisation and brackish water. None of the water samples were suitable for human consumption.

2- The pH of the water of the Euphrates River ranges from 7.1 to 7.6, while its TDS and EC levels vary from 943 to 403 ppm and 630 to 1460 µs/cm, respectively. Before mixing with the water from the Tharthar-Euphrates Canal, the predominant anion is $HCO_3^{\ -}$, while following mixing, the dominant anion is $SO4^{2-}$. The type of soil the water has come into contact with and the duration of that contact are thought to be the causes of this difference, in addition to the increased input of irrigation water from agricultural activities.

3- The solute concentrations in the Tharthar-Euphrates canal water were plotted against the canal discharge from 2018 to 2024. The rating curve shows a strong positive correlation between the Tharthar-Euphrates Canal discharge and the dissolved loads. The maximum dissolved load was recorded in September 2020 (153,000 tons per month), while the minimum was recorded in January 2020 (42000 tons per month).

4-The total dissolved load transported through the channel revealed that the most abundant dissolved materials in the canal water are calcium and sulfate compounds.

5- Further detailed investigations that take into consideration the Tharthar-Euphrates Canal dissolved loads as well as the Euphrates River discharge should be recommended in the future.

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