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Hydrochemical Evaluation of the Tigris River from Kut to Amara sites, Iraq

Hala Mohammed Al-Sekar* , Moutaz Al-Dabbas
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract
The Tigris River is one of the longest rivers in Western Asia and runs through heavily populated areas, especially in Kut and Amara Cities, with nearly 8 million inhabitants. Due to the climatic change and altering the upstream hydrological conditions along the Tigris River, its discharge has severely declined in the last decade, combined with the climate change impact. Hence, studying the impact of climate change on the river and decreasing the annual flow is vital to understand their effect on the river water quality between Kut and Amara sites. The data of this study covers annual flow conditions of the Tigris River, the total dissolved solids (TDS), and the main ions on monthly bases for the period 2005-2010 for the two sites: Kut and Amara. These data were used to establish the relationships between water discharge (m^3/sec) with total dissolved solids (mg/l) and main cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) and anions (Cl^-, SO_4^2, HCO^{3-}). The Climatological data for 1980-2020 show that the annual rainfall values for Kut and Amara sites range between 301-577 mm and 69-200 mm respectively. The annual mean minimum temperature of the Kut ranges between15.7-18.8C^o. For Amara, it ranges between 16.6-20.7 C^o. It is noticed that the rainfall values of both sites decreased over time, and the temperature is constantly increasing due to the climate change effects over the years. The average annual flow of the Tigris River at Kut site ranged from 13 to 367 m^3/sec with an average of 233.2 m^3/sec, and for Amara ranged between 22 and 101 m^3/sec with an average of 50.2 m^3/sec. The mean annual TDS ranged from 466 to 1150 mg/l, with an average mean annual 758.30 mg/l for Kut station. For Amara, it is ranged between 634 and 2075 mg/l with an average of 1168.61 mg/l. The decrease in the Tigris River discharge affects the chemistry. Calcium, magnesium, and sulfate ions in Kut station are dominated. While at Amara, sodium and sulfate ions are dominant. Such variation is related to the decrease in the Tigris River discharge and the effect of the dissolution of ions from the geological outcrops by the action of natural waters. Moreover, the entry of the transported dissolved load, the city's sewage, and the agricultural lands' water that flows into the river increase as the transportation distance increase from Kut to Amara.

Keywords: Climate change, Tigris River, Discharge, salinity, Iraq.

التقييم الهيدروكيميائي لنهر دجلة بين موقعي الكوت والعمارة ، العراق

هالة محمد* ، معتز الدباس
قسم علم الارض، كلية العلوم، جامعة بغداد، بغداد، العراق

*Email: halaalseker@gmail.com

الخلاصه

يعتبرنهر دجلة كاحد أطول الأنهار في غرب آسيا ويمر عبر مناطق مكتظة بالسكان ، خاصة في مدينتي الكوت والعمارة التي يبلغ عدد سكانها حوالي 8 ملايين نسمة. بسبب التغير المناخي وتغيير الظروف الهيدرولوجية في المنبع على طول نهر دجلة ، انخفض تصريفه بشدة في العقد الماضي ، إلى جانب تأثير تغير المناخ. وبالتالي ، من الضروري دراسة تأثير تغير المناخ على النهر وتناقص التدفق السنوي لفهم تأثيرهما على جودة مياه النهر بين موقعي الكوت والعمارة.

تغطي بيانات هذه الدراسة ظروف التصريف السنوي لنهر دجلة ، و المواد الصلبة الذائبة الكلية(TDS) والأيونات الرئيسية على أساس شهري ، للفترة 2005–2010 في الموقعين: الكوت والعمارة. تم استخدام هذه البيانات لتأسيس العلاقات بين تصريف المياه (م 3 / ثانية) مع إجمالي المواد الصلبة الذائبة (ملغم / لتر) والكاتيونات الرئيسية (Na^+ ، Ca^{2+}، Mg^{2+}، و K^+) والأنيونات (Cl^- ، SO_4^{2} ، HCO_3^-). تظهر البيانات المناخية للفترة 1980–2020 أن قيم تساقط الأمطار السنوية لموقعي الكوت والعمارة تراوحت بين 301–577 ملم و 69–200 ملم على التوالي. تراوحت قيم المعدل السنوي لدرجات الحرارة الصغرى للكوت بين 15.7–18.8 درجة مئوية ، بينما كانت للكوت بين 16.6–20.7 درجة مئوية.ويلاحظ أن قيم تساقط الأمطار في كلا الموقعين انخفض بمرور الوقت وأن درجة الحرارة تتزايد باستمرار بسبب تأثيرات تغير المناخ على مر السنين. تراوحت مديات التدفق السنوي لنهر دجلة في موقع الكوت ما بين 135–367 م 3 / ثانية بمعدل 233.2 م 3 / ثانية وبالنسبة للعمارة تراوح بين 22–101 م 3 / ثانية بمعدل 50.2 م 3 / ثانية. تراوحت مديات القيم السنوية للمواد الصلبة الذائبة من 466 إلى 1150 ملغم / لتر بمعدل 758.30 ملغم / لتر لمحطة الكوت. بينما بالنسبة للعمارة تتراوح بين 634–2075 ملغم / لتر بمتوسط سنوي 1168.61 ملغم / لتر. يؤثر انخفاض تصريف نهر دجلة على كيميائية المياة ، بحيث تشير النتائج إلى تغلب أيونات الكالسيوم والمغنيسيوم والكبريتات في محطة الكوت. بينما في العمارة ، تسود أيونات الصوديوم والكبريتات. يرتبط هذا الاختلاف بانخفاض تصريف نهر دجلة وكذلك تأثير اذابة الأيونات من المكاشف الجيولوجية بفعل المياه الطبيعية. علاوة على ذلك ، دخول الحمولة الذائبة المنقولة ومياه الصرف الصحي في المدينة ومياه الأراضي الزراعية التي تصب في النهر ، والتي يزداد تأثيرها مع زيادة مسافة النقل من الكوت إلى العمارة.

Introduction

The growing concern over human-induced global warming has brought out serious discussions about the correlation between precipitation intensity and surface temperature [1]. Iraq is currently exposed to climate changes, as these climatic changes have led to a shortage of rainfall in Iraq, affecting the rate of discharge of the Tigris River [2][3] negatively. The Tigris River is a dynamic system with a state of continuous change. It needs successive studies to notice the changes through time due to the construction of dams, climate change impact, the use of irrigation water, and Population growth. Typically, policy discussions and scientific studies today omit the important linkages between water quality and climate change [2]. The Tigris River total length is about 1718 km; it drains an area of 472,606 km^2; about 58% of the basin lies in Iraq rather than Syria and Turkey [4]. Iraq has already experienced drought due to climatic change, which would impact the Tigris River water quality [5][6]. These climatic changes also affected the yearly discharge of the Tigris River; many water infrastructure projects were implemented in the river basin in Turkey. The annual mean Tigris River discharge was 672 m^3/s at the Iraqi –Syrian border from 1960 to 1984, decreased to 596 m^3/s between 1985 and 2008 and became lower to about 413 m^3/s during the recent years [7] [8] [9] [10]. The TDS is a primary factor in the water quality evaluation [11]. Several researchers have inspected the river discharges by applying a variety of methods and approaches [11][12][13][14]. These studies have indicated how some anthropogenic activities have had the main reason for the dissolved sediment transported in the river [14] [15][16] [17] [18]. The effect of the global climatic warming on the chemistry of the Tigris River from the

years 2005 to 2010 is investigated and considered a novelty of the present work. The study area is extending from Kut to Amara sites which is located in southern Iraq within the Latitudes 36°34`89”- 32.911836°:N and Longitudes 43°15`77”- 45.061348°E (Figure 1).
The geological components of the Tigris River are different from one place to another many formations (Muqdadiya, Injana, and Fatha formations) are exposed through its course, with quaternary deposits that appear along the Tigris River beds southward to Amara city [19].

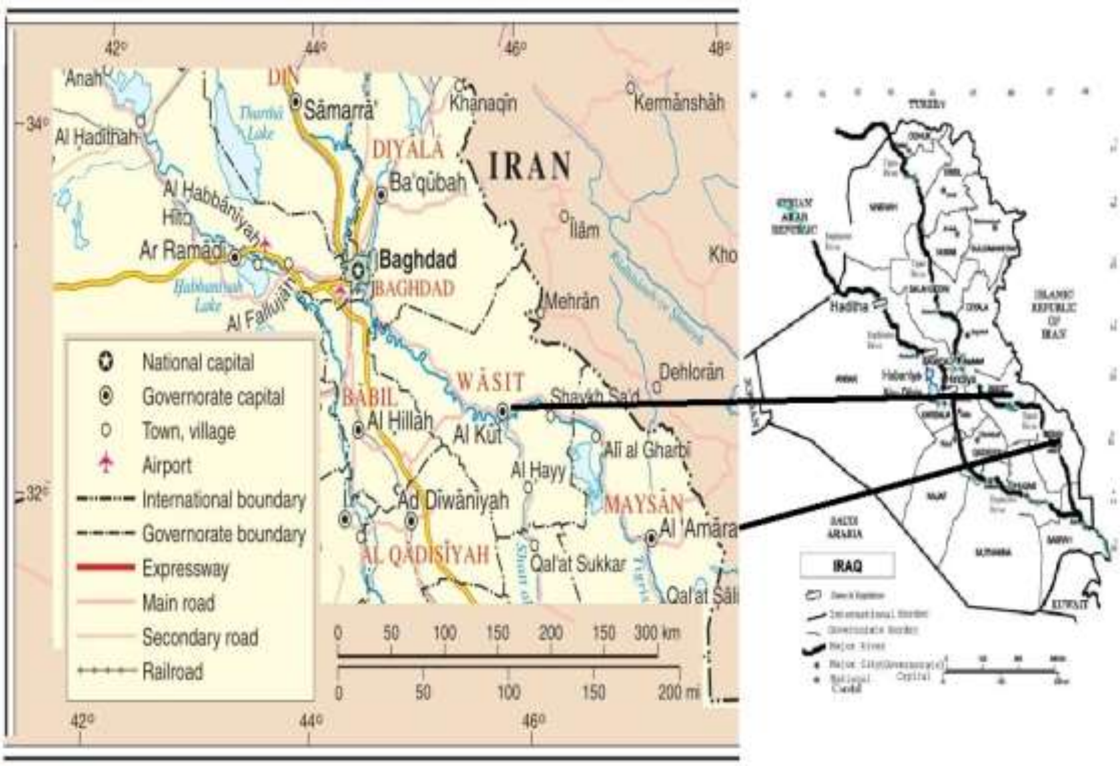

Figure 1: Location map of the study area [9].

The decrease in flow is accompanied by deterioration of the water quality due to the increase in salinity and other pollutants.
The main goals of this study are:
1- To investigate the climate change effects on the quality and quantity of the water of the Tigris River from Kut city to Amara sites.
2- To evaluate the dissolved sediment concentrations variation with various discharges.
3- To highlight the deterioration of water quality within the Tigris River from Kut to Amara (Figures 1).

Materials and Methods

A: Historical Climatological data such as Rainfall and Temperature were taken from the Iraqi Meteorological Organization for Kut and Amara Meteorological Stations, for the period (1980-2020), [21]
B: Two gauging stations were chosen on the Tigris River; Kut and Amara (Figure 1).
C: Historical Discharge and Hydrochemical data such as TDS, main cations (Na^+, Ca^{2+}, Mg^{2+} and K^+) and anions (Cl^-, SO_4^{2-}, HCO_3^-) of the Tigris River were collected for the years 2005 to 2010, (NCWRM, 2021).

The collected data was evaluated and tested for independency, stationary and homogeneity. The relationships of these data were constructed among the variables, the water flow (m3/sec) and salinity (as TDS mg/l) and significant ions (mg/l) such as main cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) and anion (Cl^-, SO_4, HCO_3^-) of the examined stretch of river and to indicate the effect of decreasing water flow on the Tigris River water salinity.

Result and Discussion

A. Climate parameters

Mean annual temperature

Mean annual temperature (°C) for Kut and Amara sites during the years 1980 to 2020 were plotted against time for available data (Figures 2: A and B). There is a positive relationship between temperature with time. An increase in temperature demonstrating from the general trend line of this relation. The results show that the mean annual temperature values of the Kut site ranged between 15.7-18.8 °C with an average mean annual of 17.25 (Figure 2A). For Amara, it varied between 16.6 and 20.7 °C with an average of 18.65 (Figure 2B).

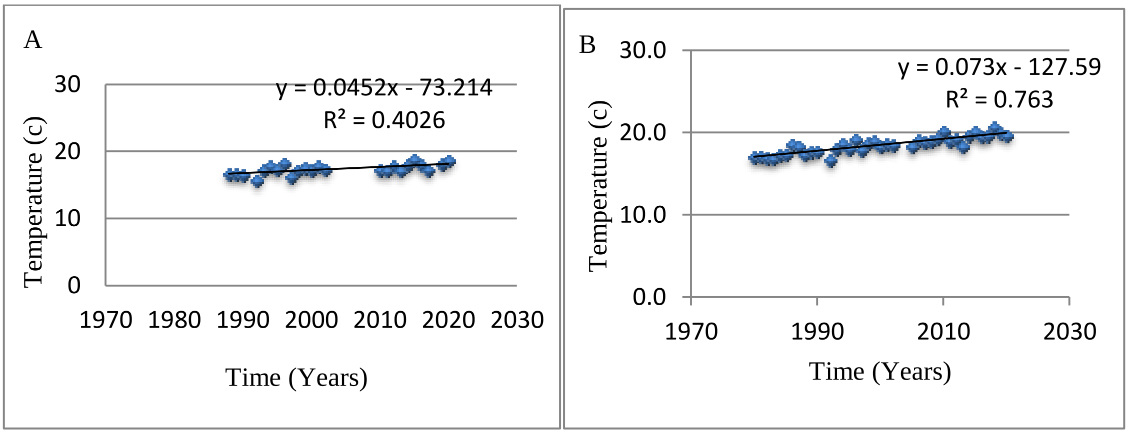

Figure 2: Annual average values of Minimum Temperature (°C) for 1980 to 2020 in A) Kut and B)Amara.

Mean annual Rainfall

The average annual rainfall values (mm) are related to time from 1980 to 2020, reflecting a negative correlation (Figures 3 A and B). The results show that the values of the Kut site range between 9.2 and 220 mm, with an average mean annual of 117.0 (Figure 3A). In the Amara site, the Rainfall values range between (7.8-311.9) mm, with an average mean annual of 133.4 (Figure 3B).

A noticeable decrease in rainfall amounts is demonstrated from the general trend line due to global climatic change.

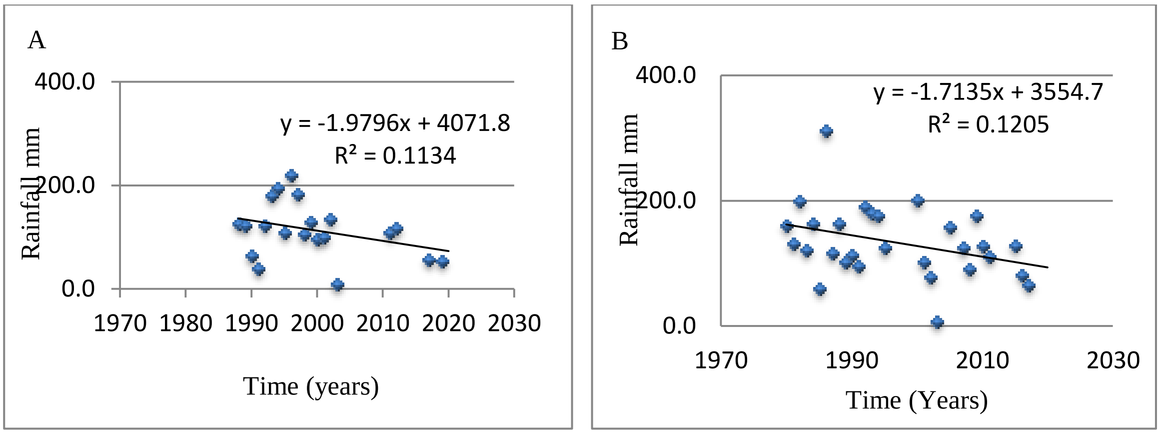

Figure 3: Annual average values of Rainfall for the period (1980-2020) in (A): Kut site, (B): Amara

Mean annual Evaporation

The average annual evaporation of Kut and Amara stations plotted against time for the available data for 1980 to 2020 indicated a positive correlation between evaporation and years, with the noticeable increase in evaporation demonstrating this relation general trend line (Figure 4: A, B). The results proved that the Mean evaporation values in the Kut station were ranged between (109.0-4550.2 mm) with an average mean annual of 2757.4 (Figure 4A), While in the Amara station ranged between (1092.2-3772.6) with an average mean annual of 2858.2 (Figure 4B).

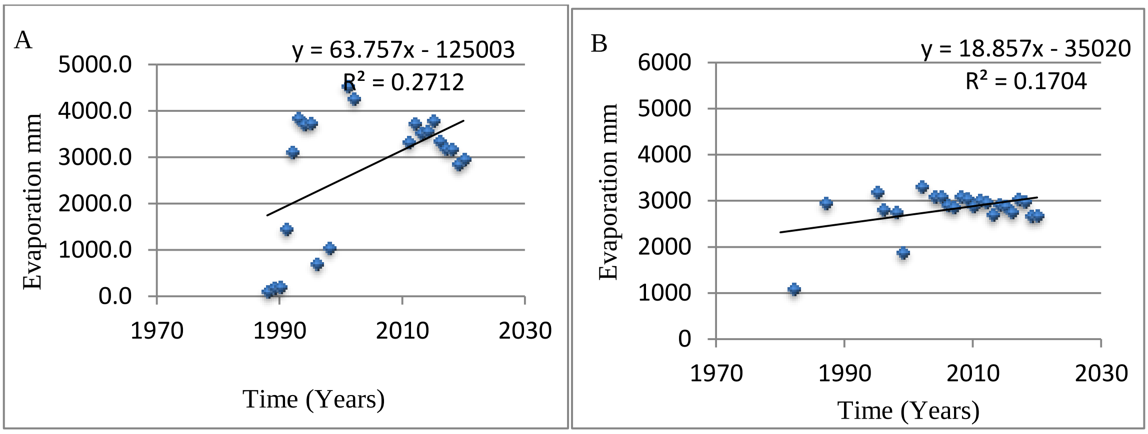

Figure 4: Annual average values of Evaporation for the period 1980-2020 in A: Kut, B: Amara

A. Hydrological and Hydrochemical variations over time of the Tigris River:

It is essential to assess surface water quality by correlating it with the yearly discharge of the Tigris River to determine the effects of global climate warming. Hydrochemical parameters of the Tigris River stations include mean annual values of TDS, Ca, Mg, Na, K, Cl, SO_4, HCO_3, and EC from 2005 to 2010. TDS concentration is correlated inversely with discharge; the high discharge rates act as a dilution agent, therefore; the strength of the solute becomes less when the discharge increase. The correlation between water salinity as TDS concentrations and their variation with discharge rates is beneficial for improving water quality. Also, it is essential to plan water pollution control programs. Contamination of the Tigris River water by transmitting toxic pollutants due to anthropogenic activities such as domestic wastewater, hospitals, and industrial factories that discharge their wastewater directly into the river without any actual treatments pass through Kut and Amara sites and threaten the ecosystem for plants and living organisms. Such untreated wastewater inputs will contaminate the river water with trace element contaminations and by many contaminants indicators and other biological parameters [8] [22][23][24].

1-Discharge and Salinity (as TDS) relationship:

The total dissolved solids of the Tigris River water from 2005 to 2010 ranged from 466 to 1150 mg/l with an average mean annual 758.30 mg/l for Kut station. For the Amara station, it ranges between 634 and 2075) mg/l with an average mean annual of 1168.61 mg/l (Figures 3 and 5). Discharge in the Kut station ranged between (135-367) m^3 /sec with an average value of 223.19m^3/ sec. While it ranged between (22-101) m3/ sec in Amara station with an average value of 50.18. (Figure 5 A and B).

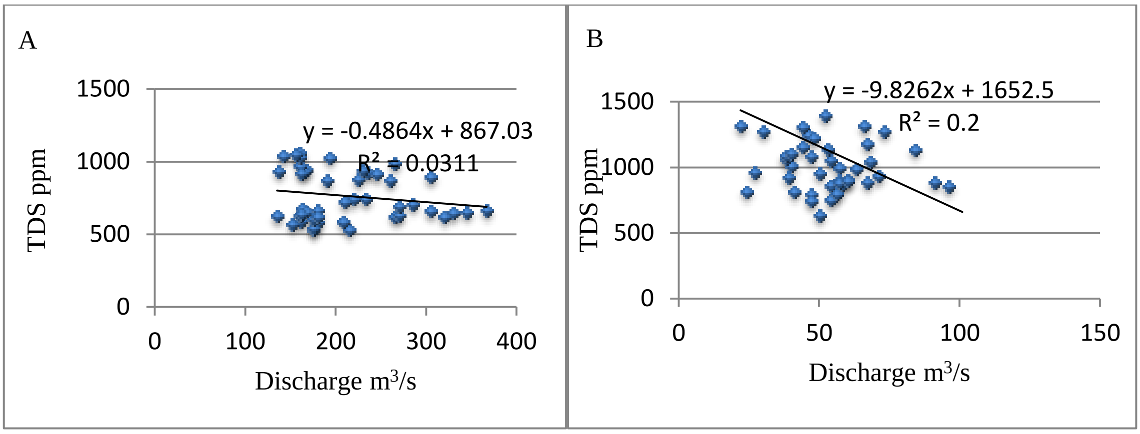

Figure 5: TDS- Discharge relation 2005- 2010/ A: Kut, B: Amara, [19] Generally, there is an inverse correlation between the annual flow of the Tigris River and TDS (Figures 5A and B).

2-Major ions and Total Dissolved Solids relationship:

TDS-Ca^{+2} Correlations

Limestone is the main source of Ca^{2+} dissolved in water [16]. The Annual average of Ca in the Tigris River ranges between 34 and 144 ppm, with an average value of 82.56 for the Kut station, respectively (Figure 6A). In comparison, it increases in the Amara station up to 36-180 ppm with an average value of 94.46 (Figure 6B).

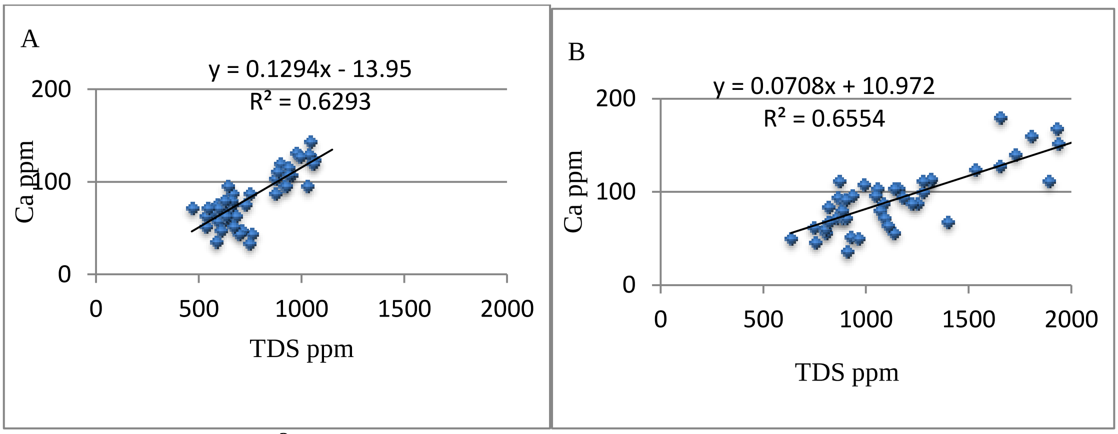

Figure 6: TDS- Ca^{2+} relation for the years from 2005 to 2010, A: Kut, B: Amara

-TDS-Mg^{2+} correlation

Limestone and dolomite are the main sources of Mg^{2+}. High magnesium may be a result of soil erosion [16]. Magnesium annual average values in the Tigris River range between 21.6

and 82 ppm for the kut station with an average value of 48.006 (Figure 7.7A), while it increases in the Amara station (101-33) ppm with an average value of 58.1 ppm (Figure 7.7B).

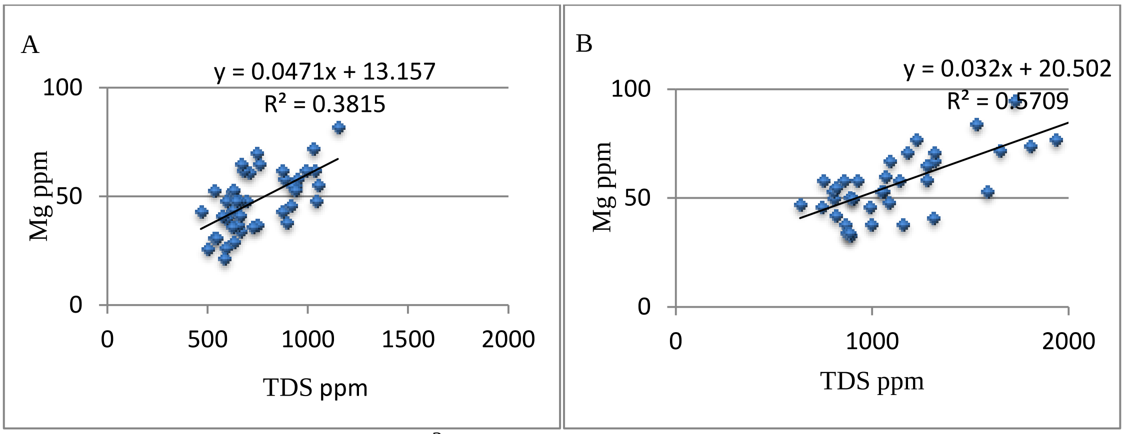

Figure 7: TDS- Mg^{2+} relation 2005- 2010 A: Kut, B: Amara

-TDS-Na^+ correlation

Results had shown significantly high sodium during the study period, which is responsible for general water quality deterioration. The increase in sodium salts in the feeding areas through agricultural areas, in the rocks, evaporation process, and man-made activities.

A positive correlation resulted from plotting Na+ ppm with TDS ppm in Kut and Amara stations for 2005- 2010. Na^+ ranged between 41 and 136) ppm with an average of 89.7 in Kut, and it ranged between 90 and 340 ppm with an average of 201.4 in Amara (Figures 8 A and B).

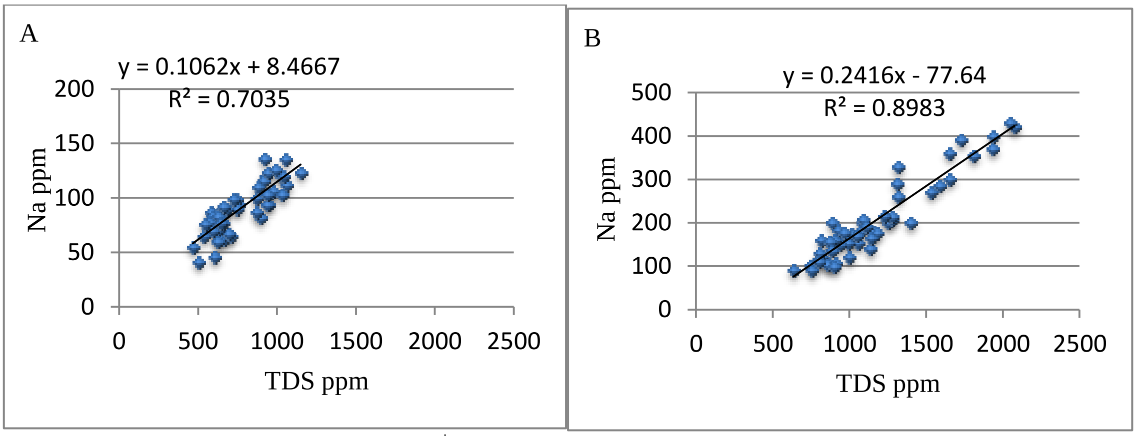

Figure 8: TDS- Na^+ relation 2005- 2010 A: Kut, B: Amara

-TDS-K^+ Correlation

The K Annual averages in the Tigris River in the Kut station ranged between 2.4 and 6 ppm with an average of 3.84, and in the Amara station, it ranged between 2.7 and 7.5 with an average value of 4.43 (Figure 9A and B).

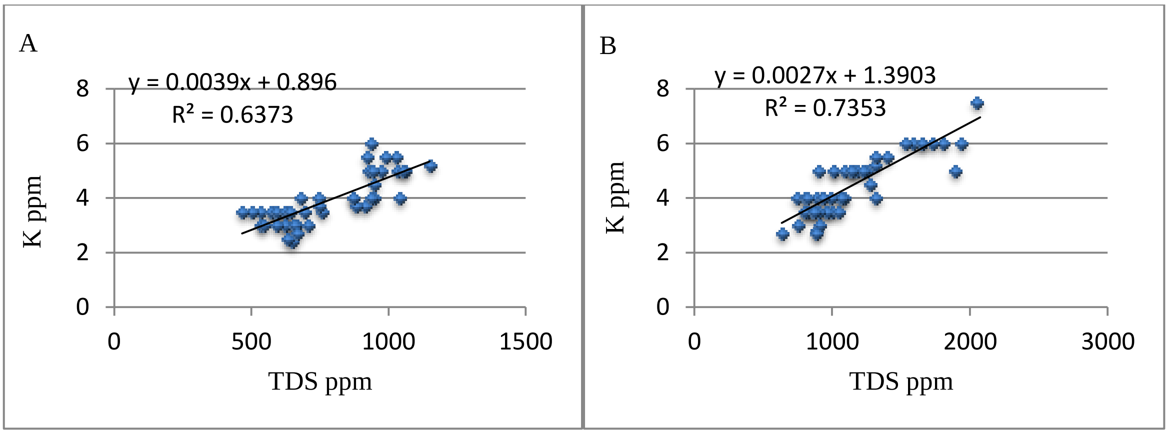

Figure 9: TDS- K^+ relation 2005- 2010 A: Kut and B: Amara

-TDS- SO4 $^{2-}$ correlation

Gypsum and anhydrite and pollutants dumped into the river are the main sources of sulfates dissolved in water [16]. The SO_4 Annual average values of the Tigris River in the Kut station range between 182 and 466 ppm with an average of 324.7, while it increases in the Amara station to be ranged between 211 and 768 ppm with an average of 401.79 (Figure 10 A and B)

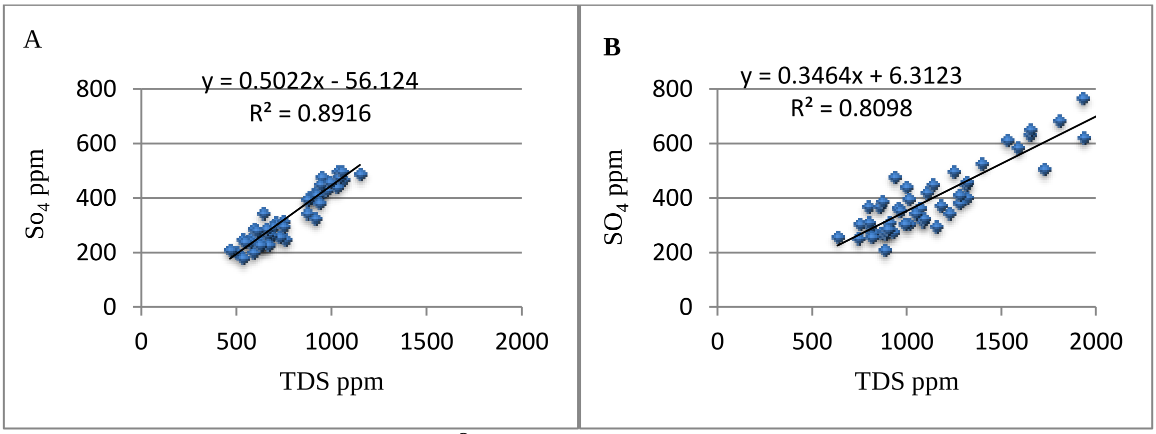

Figure 10: TDS- So_4^{2-} relation 2005- 2010 A: Kut, B: Amara

-TDS –Cl^- correlation

A positive relation of Cl^- with TDS was indicated. The Cl annual average values of the Tigris River in the Kut station range between 57 and 156 ppm with an average of 104.2, while the Cl increase in Amara to be ranged from 75 to 561 ppm with an average of 263.87 (Figure 11 A, and B).

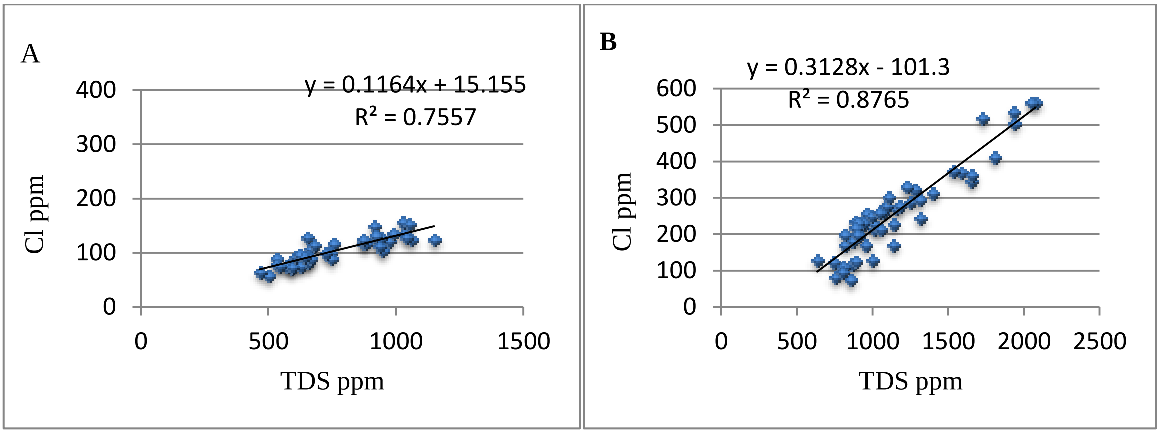

Figure 11 : TDS- Cl^- relation 2005- 2010 A: Kut, B: Amara

-TDS-HCO_3^- correlation

The HCO_3 Annual average values of the Tigris River in the Kut station range between (122-214) ppm with an average of 163.6 and (128-189) ppm with an average of 160.1 in the Amara station (Figure 12A and B).

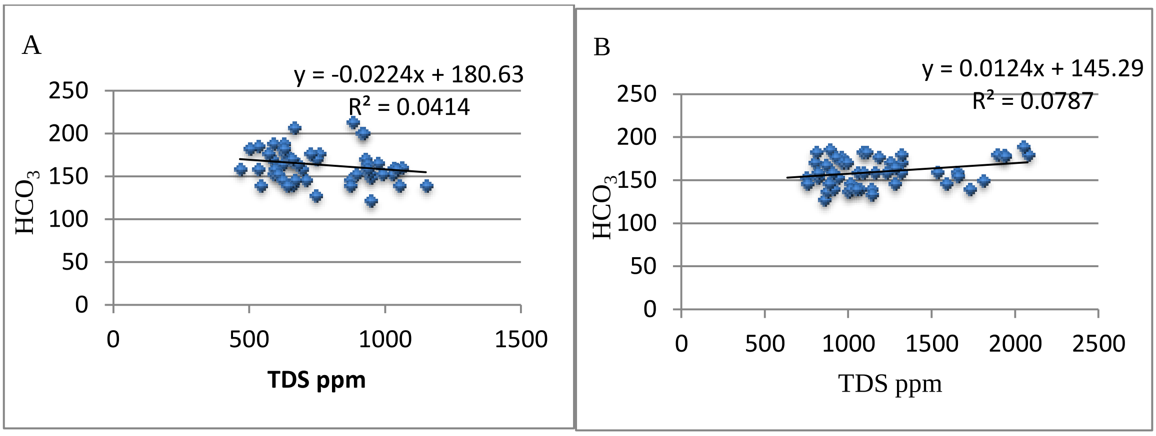

Figure 11: TDS- HCO_3^- relation 2005- 2010 A: Kut, B: Amara

-TDS- Electrical conductivity

The Annual average EC ds/m of the Tigris River in the Kut station varied between 0.78 and 1.7 ds/m with an average of 1.13, and in Amara, it ranges between 1.1 and 3 ds/m with an average value of 1.8 (Figure 12 A and B).

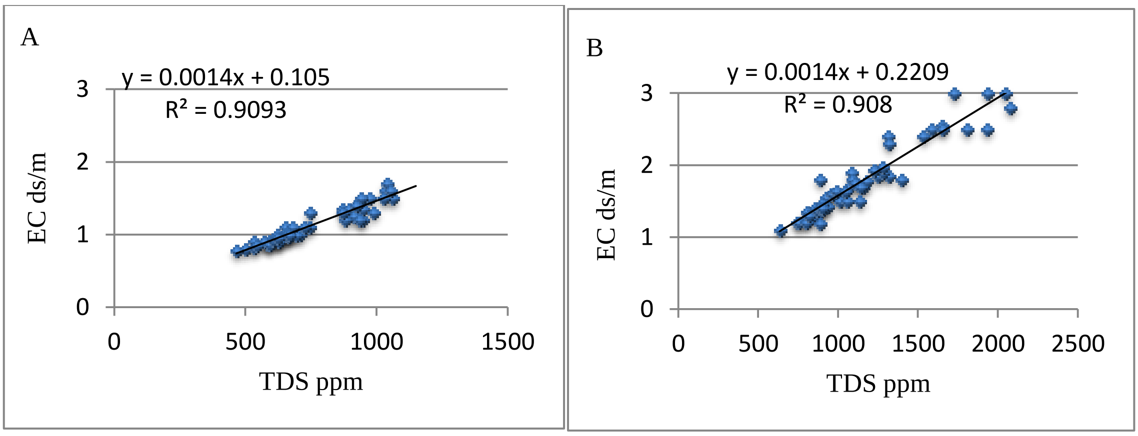

Figure 12: TDS- EC relation 2005- 2010 A: Kut, B: Amara

Hydrochemical Formula of the Tigris River:

The type of water varies from time to time during the study period. The formula of water classification depends on the ratio of the main ions expressed by epm % units which has more than 15% availability [22]. The cations are at the base of the equation, while anions are above pH and TDS values, as shown in eq (1).

$$TDS\ (g/l)\ \frac{(SO_4^{=}\ .Cl^{-}\ .HCO_3)epm\%}{(Na^{+}\ .Ca^{++}\ .Mg^{++}.k)\ epm\%}\ pH \qquad \textbf{.... (1)}$$

By applying the water type formula to the hydrochemical parameters for each year, the water type is classified between $NaSO_4$ (20%), and $CaSO_4$ (80%) at Kut, while at Amara is classified between $MgSO_4$ (5%), $NaSO_4$ (45%), and $CaSO_4$ (40%).

Generally, the water type of the Tigris River for the period (2005-2010) is Ca-Na-Mg-SO_4-Cl at Kut and classified as: $CaSO_4$ water type, while it is of Na-Ca-Mg-SO_4-HCO_3 at the Amara station and classified as $NaSO_4$-water type.

This finding may reflect the Tigris water's deterioration with time due to climate change effects, low river discharge, and relatively high contamination within the past decades. The salinity varies within the studied sites depending on nature, geographic location, and the affected factors within each site, such as soil variation, agriculture and population density …etc.

Accordingly, it was noticed that the salinity within the Amara site is higher than that of the Kut site, and the main ions behave the same as the salinity.

Moreover, the high salinity values indicate the high pollution loads related to the input of untreated wastewater directly into the river and pouring the contaminated surface drainage from irrigation, industrial and domestic activities.

Discussion

The temperature increased from 1980 to 2020 in the studied meteorological stations, decreasing the rainfall. Climate change has a direct effect on the discharge rates. Accordingly, the Tigris River discharge rates were reduced as the discharge is positively correlated with precipitation. Consequently, such a situation affects to increase the water salinity and deteriorates the water quality of the Tigris River. The high TDS and EC values indicate the high pollution loads related to the high evaporation rates and limited water discharge, throwing the wastewater into the river and pouring the contaminated surface and subsurface drainage from irrigation, industrial and domestic activities. When comparing the hydrochemistry between Kut and Amara stations, a relative increase in TDS and water quality was changed to Ca-SO_4 and Mg-SO_4, indicating the high solubility of evaporated rocks. Moreover, the high percentages of SO_4 ionic load in both sites may reflect the dissolution and leaching of such ions from the geological outcrops by the water action that increases as the transportation distance increases from Kut to Amara.

Conclusion

1-The averages mean yearly discharge of the Tigris River from 2005 to 2010 is 223.2 m^3/sec and 50.2 m^3/sec for Kut, and Amara sites, respectively.

2-The averages annual mean total dissolved solids of the Tigris River (2005-2010) are 758.3 mg/l and 1168.6 mg/l for Kut, and Amara sites, respectively. Such results reflect the nature of the exposed rocks within the Tigris River course and the entry of the sewage water and the drainage water of the agricultural lands that flow into the river.

3-The averages mean annual ionic concentrations of Ca, Mg, Na, K, Cl, SO_4, and HCO_3 for the Kut and Amara sites reflect that they are in the order SO_4 > HCO_3 >Cl for Kut, while they are in the order SO4>Cl> HCO3 for Amara station. Such ion concentration trend may reflect the high percentages of SO_4 at Kut, indicating that the Tigris River water was of good quality

and deteriorated near Amara station due to relative pollution of sewage water and the irrigation water of the agricultural lands. The process is becoming more intense with increasing temperatures and decreasing precipitation due to climate change.
4-The Tigris River water type in Kut is calcium – sulfates, but sodium–sulfates in Amara.
5-There has been a strong effect of global climate warming on the Tigris River discharge and its water quality.

Recommendations: This work recommends that strict measures be taken to control the levels of pollutants discharged into the Tigris River. Tigris River water needs further treatment, especially south of Kut. The local governments could take effective policies, such as establishing a periodic monitoring system and reducing the industrial discharge, agricultural fertilizer and wastewater discharge.

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Conflicts of Interest: The authors1declare that there are no 1conflicts}of interest regarding1 the publication of this1 manuscript.

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