International Journal of Design & Nature and Ecodynamics
Vol. 17, No. 4, August, 2022, pp. 585-593
Journal homepage: http://iieta.org/journals/ijdne

Effects of the Climate Change on the Tigris River Basin in Iraq

Zainab A. Al-Salihi[1*], Ammar Hatem Kamel[2], Isam M. Abdulhameed[3]

[1] Engineer at Dams and Water Resources Engineering Dept., University of Anbar, Anbar, Ramadi 31001, Iraq
[2] Water Resources Engineering, University of Anbar, Anbar, Ramadi 31001, Iraq
[3] Irrigation and Drainage Engineering at Upper Euphrates Basin Developing Center, University of Anbar, Anbar, Ramadi 31001, Iraq

Corresponding Author Email: engzainab97@gmail.com

https://doi.org/10.18280/ijdne.170413

Received: 1 April 2022
Accepted: 6 June 2022

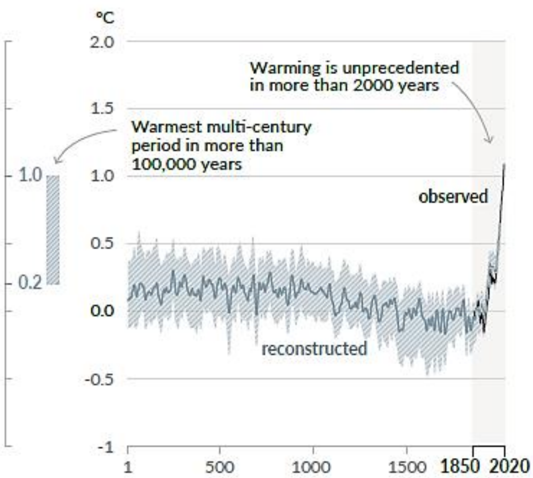
Keywords:
climate change, great Zab, lesser Zab, Tigris River, trend line

ABSTRACT

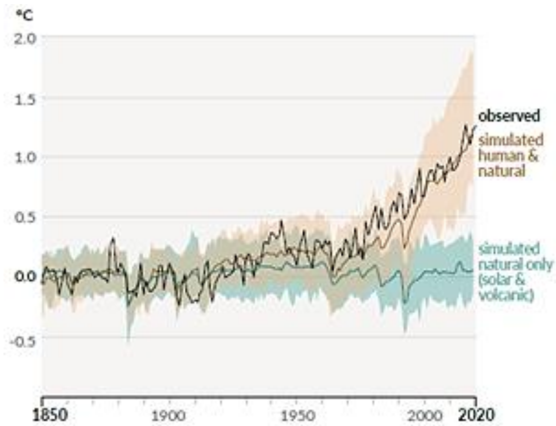
Hydrologists, water managers, and policymakers are all concerned about the potential implications of climate change on water supplies. This paper describes development of water resources management in northern Iraq. The study looks at three hydrological variables that represent various stages of the hydrological cycle. The hydrological variables are discharge, rainfall, and temperature. The result showed that the volume of water for Great Zab River reduced from 264 billion m^3 for the period (1980-1999) to 209 billion m^3 for the period (2000-2020). Due to the absence of dams on the river mainstream, therefore, the Great Zab can be considered as an indicator of the climate change effects. Additionally, the volume of water for Lesser Zab River reduced from 494 billion m^3 for the period (1932-1999) to 0.86 billion m^3 for the period (2000-2020). For Great Zab, the maximum and the minimum annual rainfall was 309.44 mm in 1994 and 104.57 mm in 1999 for the period (1982-1999) respectively, whilst the maximum and minimum annual rainfall was 430.05 mm in 2018 and 152.43 mm in 2017 for the period (2000-2020) respectively. Accordingly, the climate changes have a significant impact on Tigris River in the northern of Iraq.

1. INTRODUCTION

According to scientific data, the globe is now encountering fast climate change [1]. A recent report from the international panel on climate change [2] demonstrates the scientific community's broad agreement on global climate change. Temperature, winds, rainfall, snow, ocean currents, and their interconnections all have a roll in climate change. Due to human involvement, climate change has escalated at a rate not seen in at least the previous 2000 years (see Figure 1).



(a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)



(b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)

Figure 1. History of global temperature change and causes of recent warming [2]

Due to the global temperature rising, this will cause the hydrological cycle to become more intense, as a result, dry seasons are drier and rainy seasons are wetter [3]. Climate change is quickly becoming one of the most important concerns facing the world [4]. With each degree of global warming, changes in regional mean temperature, precipitation, and soil moisture become more evident [5]. Figure 2 indicates that in arid places, large positive percentage increases may equate to tiny absolute changes [2]. Precipitation is also expected to rise in high latitudes, in the equatorial Pacific, and in sections of the monsoon zones, but fall in portions of the subtropics and in a few tropical locations. It may have detrimental consequences for both natural and human systems.

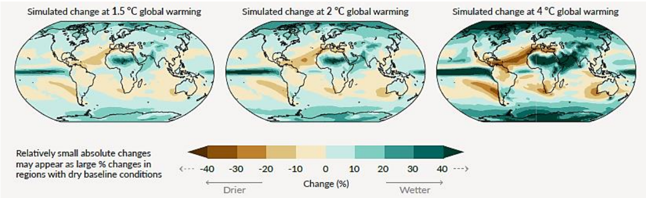


Figure 2. Annual mean precipitation change (%) relative to 1850-1900 [2]

Continued greenhouse gas emissions would increase existing threats and complicate things much more for people ecosystems [6]. For any future planning and development inclusive of flood protection, flood control, and sustainable watershed management, water resources have the most important consideration [7]. Climate change and precipitation fragility will necessitate new water storage infrastructure (reservoir) management techniques, including the construction of new dams, the repair of aging dams, and the enhancement of the existing or planned design procedures [4]. Drought has erupted across the middle east, not only in Iraq, because of climate change and global warming, resulting in a considerable reduction in rainfall and snowfall, as well as a noteworthy drop in water revenues [8]. Climate change is without a doubt, one of Iraqi's most pressing issues, with considerable negative consequences for water supplies, the environment, and the economy, particularly in the agricultural sector [9]. The middle east in general, is one of the most impacted regions by climate change, with drought and high record temperatures, which are anticipated to rise and have a substantial impact on populations [10]. In recent years, because of the climate changes, Iraq has been experiencing drought. With these conditions, the loss of water from by evaporation, can cause a serious repercussion [11]. These will result in a significant drop in the quantity of rainfall in Iraq, which was covered in the research that looked at rainfall quantities on Iraqi land, reducing the Tigris and Euphrates discharge. Iraq is classified as arid and semi-arid regions, that characterized by the long dry season with high temperatures and short wet season (December to beginning of March) [12]. Subsequently, this will pose a severe dilemma for the country because Iraqi's water security is predicated on the Tigris and Euphrates rivers, where both of which are in decline [13]. In additional to that, climate change mitigation transnational water management will be challenging to achieve due to national and regional political uncertainties. “The impact of water shortages in Iraq is becoming evident through the lower crop yields for 2021. Urgent action is required to confront climate change, working together to address the root causes,” said FAO Representative in Iraq Dr Salah El Hajj Hassan, WFP Iraq Representative Ally-Raza Qureshi, and IFAD Lead Economist Alessandra Garbero in a joint statement. There are many factors that affect the Tigris River. As a result, the river's flow in the downstream direction has been significantly decreased. Iraq suffers from shortage of water for the Euphrates and Tigris rivers and their tributaries because of the climate changes in addition to the drought and the unequal of sharing the water resources with Turkey, Iran, and Syria [14]. For example, the Tigris River's mean annual flow in Baghdad was 1140 (m^3/s) from 1931 to 1977, but it fell to 701 (m^3/s) from 1978 to 2017 [15]. As a result, it appears that the Tigris water regime was significantly influenced by Iraq's major water control mechanisms, mostly in the mid-1970s. This has had a major role in the Baghdad hydrological station's considerable fall in streamflow and detection of a change-point. Furthermore, the most noticeable dramatic shifts in the late 1990s might be related to extensive human activity. Most of the stations found after the construction exhibited a consistent declining trend in data recordings over the last seven decades [15]. Most of the stations found following the construction major big dams throughout the 1990s exhibited a consistent declining trend in data records over the previous seven decades. Several dams were built in Turkey's upstream catchments throughout the 1990s, including the Goksu, Dicle, Kralkizi, and Batman dams in 1991, 1997, 1997, and 1999, respectively [16]. This has led to the observed large decline in mean annual streamflow and significant decreasing rapid changes in around 65 percent of the hydrometric stations studied, especially in the 1995–1998-time period [15]. Several studies have been carried out in various regions of the world to see if there are any trends in long-term streamflow time series. The majority of these studies indicated that there were clear upward and downward patterns in the flow of the world's main rivers. However, there were often more declines in streamflow than gains. The average monthly [16] water flow measurements have been studied for 15 stream flow gaging stations within basins of these rivers in Iraq were used in this study, along with population growth rate data in some areas, to assess the reality of the current situation and future challenges of water availability and demand in Iraq. They found, along with other findings, that the annual decline in water inflow for the Tigris is 0.1335 km^3 $year^{-1}$, while the Euphrates is 0.245 km^3 $year^{-1}$. This means that the two rivers' yearly percentage reductions in inflow rates are 0.294 percent and 0.960 percent, respectively. Research was carried out on current trends and long-term estimates of northeast Iraq's water resources, as well as climate change adaptation strategies [17]. One of the findings is that under RCP8.5, the region might see precipitation reductions of 12.6 percent and 21% in the near (2049–2069) and far (2080–2099) futures, respectively, according to model estimates. These numbers are 15 percent and 23.4 percent under RCP4.5, and 12.2 percent and 18.4 percent under RCP2.6, respectively. As a result, during the decades 2049–2069 and 2080–2099, the blue water may see declines of roughly 22.6 percent and 40 percent under RCP8.5, 25.8 percent and 46 percent under RCP4.5, and 34.4 percent and 31 percent under RCP2.6, respectively. Also, a study prepared on Flood Forecasting in Upper Zab River Using SWAT hydrological Model [18]. The simulation of the period (1975-2003) which is equal to 390.2 m^3/sec was agreed with the annual flow discharge which. While the outcome of the simulation for the period 2015 to 2075 was 333.70 m^3/s, indicating a 15% drop in mean flow discharge between the two time periods. Furthermore, the annual average basin simulation precipitation quantity decreased from 1057 to 1038 mm, a loss of nearly 2% between the two periods. Also, the influence of climate change was evident in simulation findings, as one of the climatic parameters, evapotranspiration (ET), increased from 378.3 mm to 450.2 mm, implying a 19% rise in ET between two simulation periods owing to temperature increases. Climate change, it is noted, is more damaging than other effects, such as dams in Turkey, Iran, and Syria. Because the scope of these dams' influence is understood, riparian nations may work together to manage these basins and share the advantages and risks. Climate change is impossible to forecast, and its consequences are uncontrollable. The current study aims to determine the extent of climatic changes' impact on Iraq's water imports, as well as whether these climatic changes are more influential than another important factor, dams built in Syria, Turkey, and Iran, or whether resources are the most influential factor, and the extent of these influences on Iraq's water resources management system and its environmental and economic effects. In this study the effect of climate change will be study based on the trend line analyses. The trend lines of hydrologic parameters versus time in years were constructed using the Microsoft Excel application based on the available data. The result of the analysis shows that the effect of climate change on Tigris River is noticeable. Climate change is unquestionably one of Iraq's most important issues, according to the findings, with substantial repercussions for water resources, the environment, and the economy, particularly in the agricultural sector.

2. DATA AND METHODOLOGY

2.1 Study area

Khbour, Greater Zab, Lesser Zab, Al-Adhaim, and Diyala Rivers are the five primary tributaries of the Tigris River (Figure 3). These tributaries are located on the Tigris River's left bank between latitudes 33.2 N and 37.3 N and longitudes 42.9 E and 46.9 E, and they contribute considerably to the Tigris' stream. These tributaries, with the exception of the Al-Adhaim River, are shared by Iraq and Turkey or Iraq and Iran [17]. In this paper the Greater Zab, the Lesser Zab, and the Tigris River downstream of Mosul dam will be taken as a study area.

Figure 3. The basins of the five tributaries in northeast Iraq [17]

2.1.1 Greater Zab

The Greater Zab is a tributary of the Tigris River in northern Iraq (Figure 4), between 36° N and 38° N latitudes and 43°18' E and 44°18' E longitudes [19]. The river starts in a hilly area of Turkey at a height of roughly 4,168 m a.m.s.l (ESCWA), with Turkey accounting for 34.8 percent of the watershed [17-23]. The Greater Zab and its tributaries have a catchment area of 26,473 (km^2). The river basin receives the majority of its precipitation in the winter and spring, with annual rainfall ranging from 350 to 1000 mm. The following is a typical distribution of precipitation in the watershed throughout a year: 48.9% in winter as snowfall, 37.5% in spring, 12.9% in autumn, and 0.57% in summer [24]. Before they meet around 49 kilometers south of Mosul, in Sharkat city, this river's discharge is about 70% that of the Tigris [19]. In terms of water supply, the Greater Zab River is the greatest Tigris tributary. The Greater Zab is one of the few unregulated rivers in the region since no dams have been built. As a result, the Great Zab plays a critical role in assessing the impact of climate change on Iraq's rivers when it comes to examining climate change in Iraq.

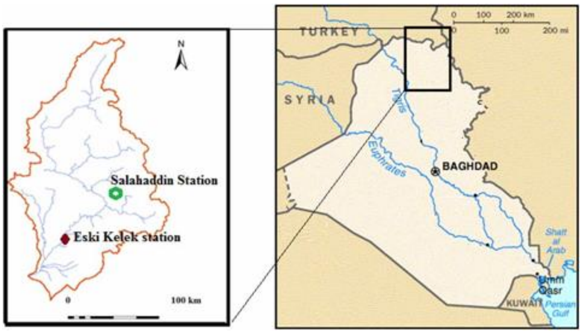


Figure 4. Location of Greater Zab [19]

2.1.2 Tigris River in Mosul city

Mosul, where the Tigris River flows through, has a hot semi-arid climate that borders on Mediterranean, with extremely hot, long, dry summers, brief and mild autumn and spring seasons, and moderately rainy, reasonably temperate winters. The Tigris River in Mosul has been analyzed in this study based on the outflow from the Mosul Dam for the period (1986-1999) and (2000-2020).

2.1.3 Lesser Zab

Lesser Zab (also known as Little or Lower Zab) is an Iranian mountain range in the northeastern Zagros Mountains (see Figure 3). The river travels through steep valleys linked by various tiny streams in the basin's upstream section before flowing across flat territory until entering the Tigris River near Fatah [25]. The climate of the basin is arid to semi-arid, with wet winters and dry summers. The average yearly temperature ranges from 10 degrees Celsius in the north to 22 degrees Celsius in the south. The average annual rainfall in the hilly north varies from 1500 mm to 350 mm in the lowlands of the south. Together, the Greater and Lesser Zab produce around 50–60% of Tigris flow. On the Iraqi side of the river, the Dukan and Dibis dams have been built for agricultural use, electricity, and flow management. Grasslands represent approximately 70% of the watershed, with agriculture covering the remaining 30% [26].

2.2 Methodology

In a changing climate, trend analysis for hydrological parameters is critical for recommending future water resource management methods. The Data was collected from the required stations for the chosen rivers (Figure 5). According to the available data, the trend lines between years and hydrologic parameters, such as rain, and discharges, as well as temperature, were drawn using the Microsoft Excel program. The trend line between discharge and years has been drawn for two periods (1932-1999) and (2000-2020) for the rivers (because the Turkish government has finished constructing the majority of the dams in 2000, and after 2000 the effects of climate change are beginning to manifest, these two periods has been chosen). The trend lines were then examined to determine if there are any implications for climate change.

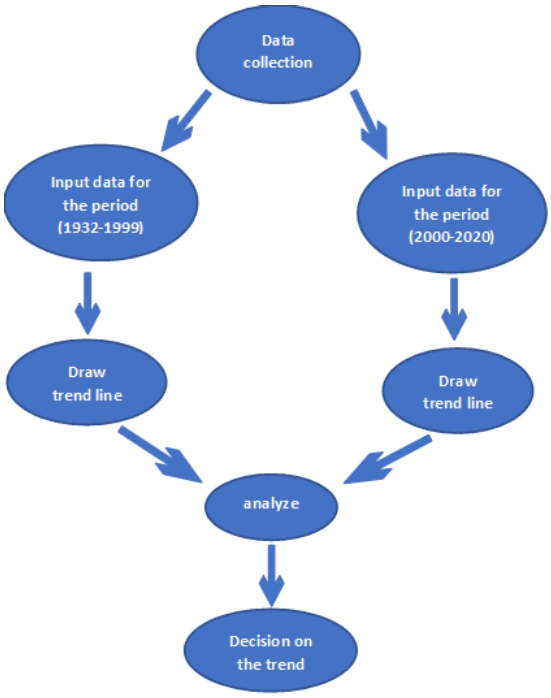


Figure 5. Flow chart of methodology

3. RESULT AND DISCUSSION

In this section, the trend analysis results will be presented for each variable at the annual scales and some of the result at the monthly scales. For the period before 2000, the discharge from the Mosul Dam was used for estimation of incoming water and river discharge for the Tigris River analysis, where the highest monthly discharge was 3380 m^3/sec in April 1988 and the lowest discharge was 88 m^3/sec in December 1986 during the period 1932-1999. The trend line (see Figure 6) of Tigris River in Mosul city for the period (1986-1999) shows a depression.

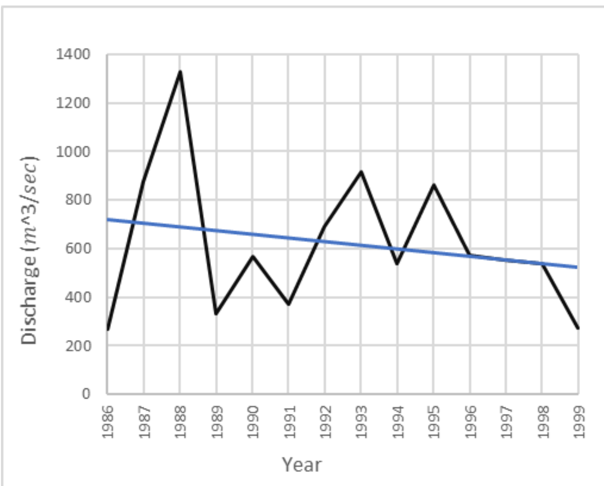


Figure 6. Trend line of annual average discharge for Tigris River for the period (1986-1999)

As shown in Figure 7, the rain trend line for Tigris River is stable, where the maximum annual rainfall was 391.18 mm in 1996 and the minimum annual rainfall was 155.7 mm in 1999 for the period (1982-1999). As shown in Figure 8 the trend line for temperature shows a rise. Where the maximum average monthly temperature was 34.3 © in July and the minimum average monthly temperature was 5.5 in © in January for the period (1981-1999).

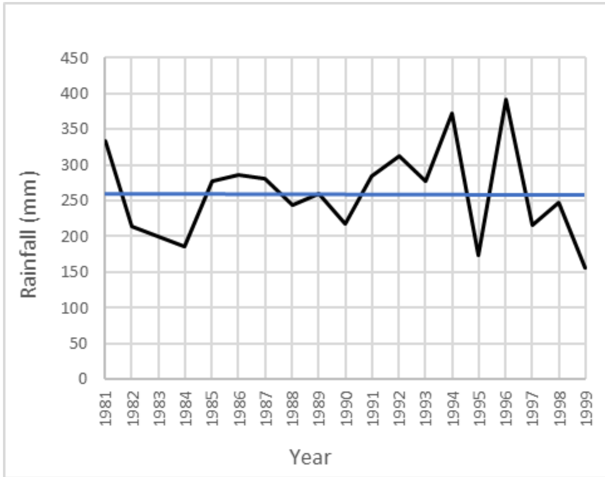


Figure 7. Trend line of annual rainfall for Tigris River for the period (1981-1999)

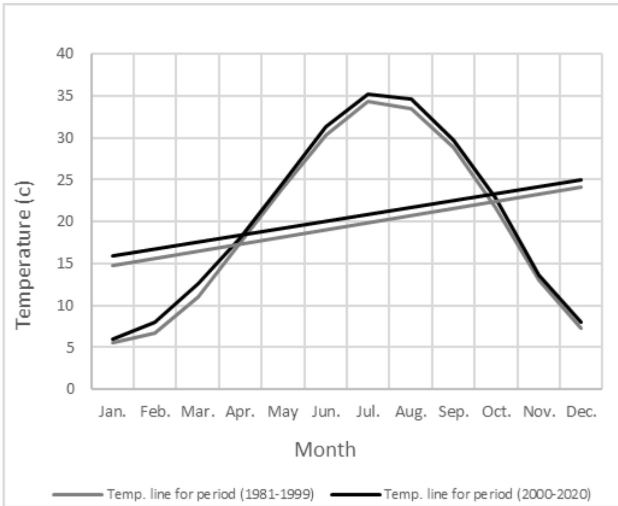


Figure 8. Trend line of temperature of Tigris River for the periods (1981-1999) & (2000-2020)

For the Lesser Zab analysis, Altun Kupri station was used for estimation of incoming water and river discharge, where the highest monthly discharge was 1433 m^3/sec in March 1988 and the lowest discharge was 19.8 m^3/sec in September 1951 during the period 1932-1999. As shown in Figure 9 the trend line for Lesser Zab shows a rise for the period (1932-1999). The trend line of precipitation shows a depression for the period (1982-1999), where the maximum annual rainfall was 467.45 mm (see Figure 10) in 1993 and the minimum annual rainfall was 56.05 mm in 1999 for the period.

As shown in Figure 11 it's worth noting that the trend line temperature for Lesser Zab shows a rise. Where, the maximum average monthly temperature was 35.34 © in July, and the minimum average monthly temperature was 7.53 mm in January for the period (1981-1999).

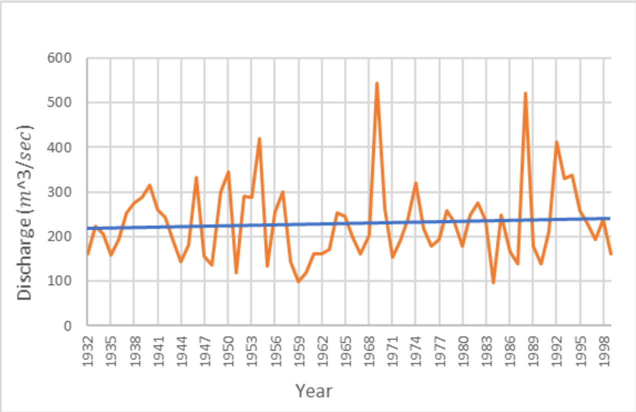


Figure 9. Trend line of annual average discharge for Lesser Zab for the period (1932-1999)

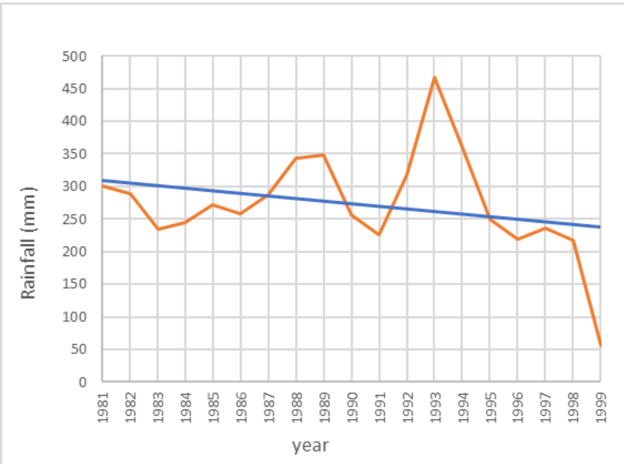


Figure 10. Trend line of annual rainfall for Lesser Zab for the period (1981-1999)

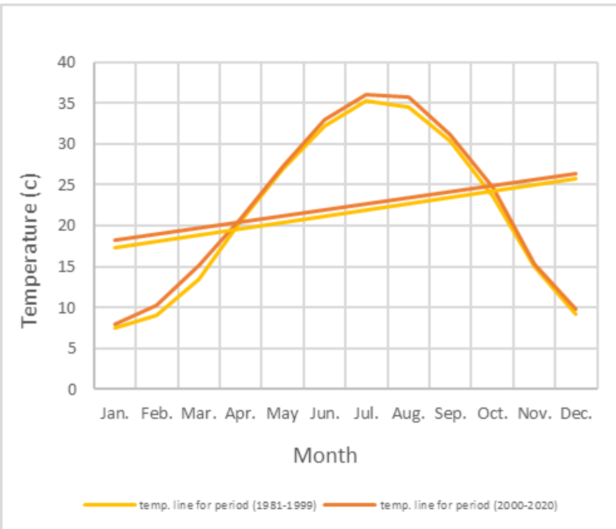


Figure 11. Trend line of temperature of Lesser Zab for the periods (1981-1999) & (2000-2020)

For the Great Zab River analysis, Asky Kalak station was used for estimation of incoming water and river discharge, where the highest monthly discharge was 1780 m^3/sec in April 1969 and the lowest discharge was 34 m^3/sec in 1989 during the period 1932-1999. The trend line for Great Zab is stable over the years (1932-1999) as shown in Figure 12.

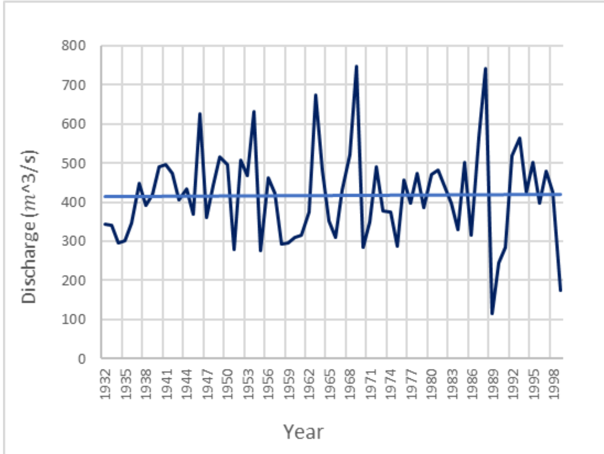


Figure 12. Annual average discharge for Great Zab for the period (1932-1999)

In terms of rain, the trend line for period (1982-1999) shows a small depression (see Figure 13). The temperature trend line for Great Zab (see Figure 14) also shows a rise, where the maximum average monthly temperature was 34.53 © in July and the minimum average monthly temperature was 6.21 © in January for the period (1981-1999). For the period after 2000, the trend line of discharge for Tigris River downstream Mosul dam is stable as shown in Figure 15.

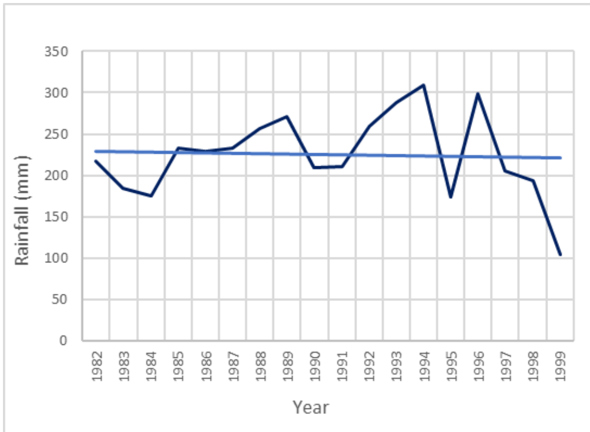


Figure 13. Trend line of annual rainfall for Great Zab for the period (1981-1999)

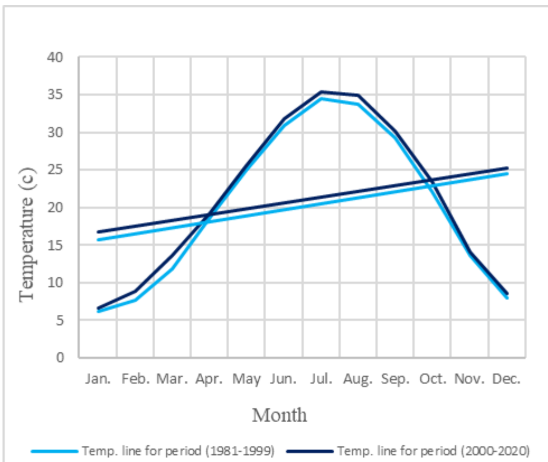


Figure 14. Trend line of temperature of Great Zab for the periods (1981-1999) & (2000-2020)

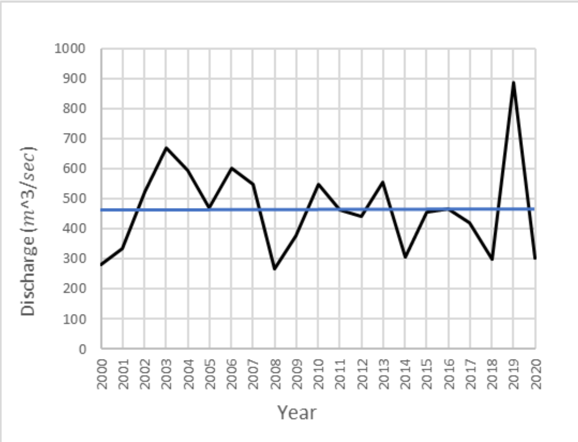


Figure 15. Annual average discharge for Tigris River for the period (2000-2020)

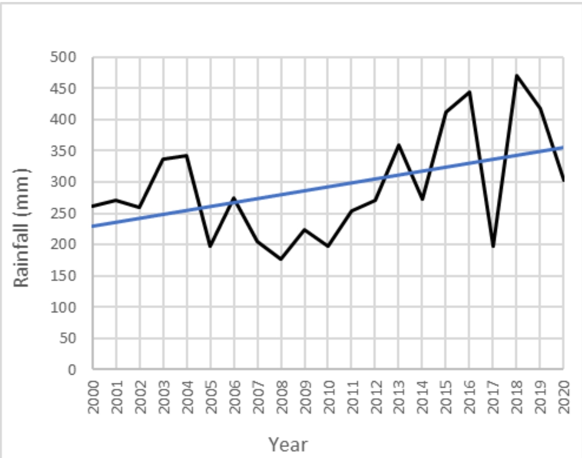


Figure 16. Trend line of annual rainfall for Tigris River for the period (2000-2020)

With the obvious influence of climate change, the highest average monthly discharge was 2837 m^3/sec in April 2019 and the lowest average monthly discharge was 115 m^3/sec in April 2001. In terms of rain, the trend line for the period (2000-2020) shows a rise (see Figure 16). The maximum annual rainfall was 391.18 mm in 1996 and the minimum annual rainfall was 155.7 mm in 1999. For temperatures, it can be noticed that they have risen recently, where the maximum average monthly temperature was 35.21 in July, and the minimum average monthly temperature was 5.99 © in January (see Figure 8). For Lesser Zab River discharges, the trend line after the period 2000 shows a little rise (see Figure 17), where the highest monthly discharge was 1433 m^3/sec in March 1988 and the lowest discharge was 19.8 m^3/sec in September 1951. As shown in Figure 18, the trend line for precipitation shows a rise, where the maximum annual rainfall was 555.06 mm in 2018 and the minimum annual rainfall was 167.6 mm in 2000. It's worth noting that the temperature trend line in Lesser Zab River has lately climbed (see Figure 11), where the maximum average monthly temperature was 36 © in July, and the minimum average monthly temperature was 7.92 © in January. The Great Zab River discharge with the obvious influence of climate change, the highest average monthly discharge was 1600 m^3/sec in May 2003 and the lowest average monthly discharge was 50 m^3/sec in September 2017, and the monthly general rate decreased from 990 m^3/sec in April during the first period to 730 m^3/sec in April in the second period. It should be noted that the highest rate of discharges was in the months of April and May, which clearly indicates that they were greatly affected by the melting of snow and their quantities.

In Figure 19, it is quite clear that the trend line of Great Zab shows a depression. The trend line for rain after the period 2000 shows a rise, where the maximum annual rainfall was 430.05 mm in 2018 and the minimum annual rainfall was 152.43 mm in 2017 for the period (see Figure 20). it can be noticed that temperatures have risen recently, as shown in Figure 15, which is an indication of climate change's consequences. Where the maximum average monthly temperature was 35.41 © in July, and the minimum average monthly temperature was 6.69 © in January.

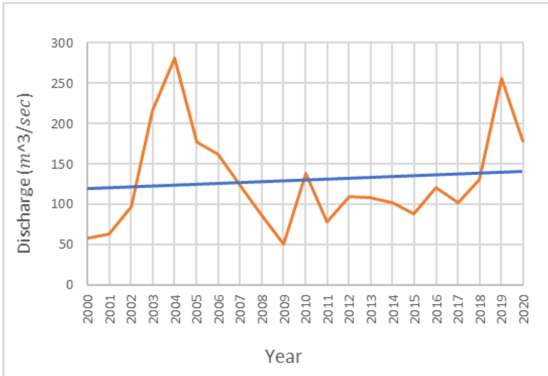


Figure 17. Annual average discharge for Lesser Zab for the period (2000-2020)

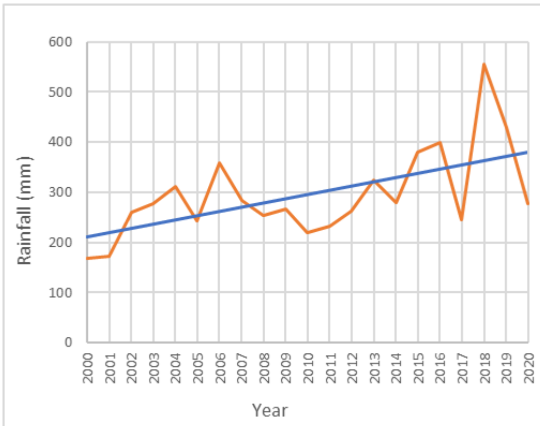


Figure 18. Trend line of annual rainfall for Lesser Zab for the period (2000-2020)

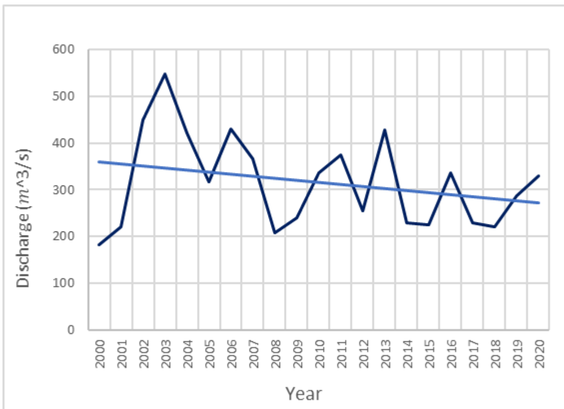


Figure 19. Annual average discharge for Great Zab for the period (2000-2020)

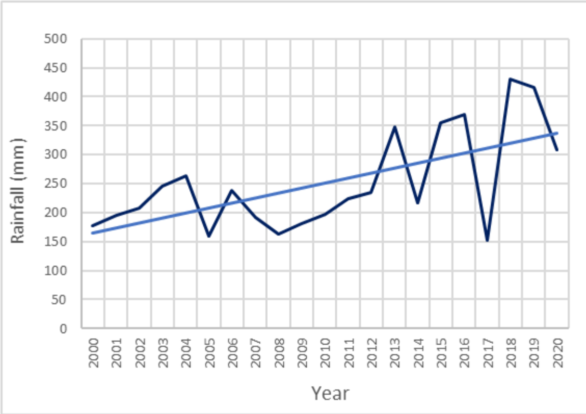


Figure 20. Trend line of annual rainfall for Great Zab for the period (2000-2020)

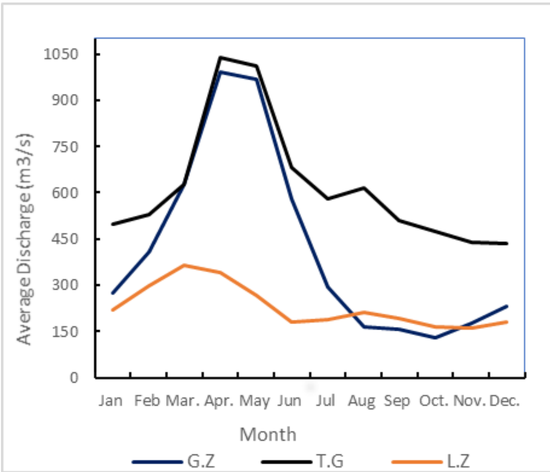


Figure 21. Average monthly discharge before 2000 for Tigris River, Lesser Zab, and Great Zab 38%

Figures 21 and 22 shows the monthly average discharge for Great Zab, Lesser Zab, and Tigris River downstream of Mosul Dam for the two periods. It is clear that the Great Zab discharge in March is almost equal to the Tigris River discharge and yet there is no dam control the river. Table 1 shows the percentage of Lesser Zab and Great Zab from Tigris River (downstream of Mosul Dam) for the period (1932-1999) and Table 2 for the period (2000-2020).

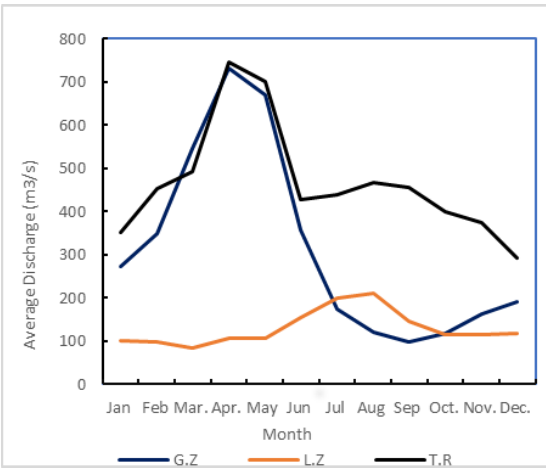


Figure 22. Average monthly discharge after 2000 for Tigris River, Lesser Zab, and Great Zab 38%

Table 1. The percentage of discharges of Great Zab (G.Z) and Lesser Zab (L.Z) from Tigris River for the period before 2000 (all discharge in m^3/sec)

Months	T. R	G. Z	L.Z	% G. Z	% L. Z
Jan.	498	276	218.27	55	44
Feb.	529	410	297.92	78	56
Mar.	626	627	365.88	100	58
Apr.	1040	990	339.64	95	33
May	1010	969	266.17	96	26
Jun.	684	582	179.47	85	26
Jul.	579	295	189.13	51	33
Aug.	615	166	211.43	27	34
Sep.	511	157	191.89	31	38
Oct.	474	131	164.31	28	35
Nov.	440	177	159.78	40	36
Dec.	437	233	180.54	53	41
Aver.	620.25	417.75	230.37	62	38

Table 2. The percentage of discharges of Great Zab and Lesser Zab from Tigris River for the period after 2000 (all discharge in m^3/sec)

Months	T. R	G. Z	L.Z	% G. Z	% L. Z
Jan.	351	273.48	100.76	78	29
Feb.	453	348.86	97.52	77	22
Mar.	492	546	85.76	100	17
Apr.	746	731	106	98	14
May	702	668.71	105.67	95	15
Jun.	429	357.43	154.57	83	36
Jul.	439	174.62	200.29	40	46
Aug.	468	122.38	211.67	26	45
Sep.	455	98	146.81	22	32
Oct.	400	118.4	115.38	30	29
Nov.	374.7	162.24	116.05	43	31
Dec.	292	191.14	118.91	65	41
Aver.	466.81	316.02	129.949	64	30

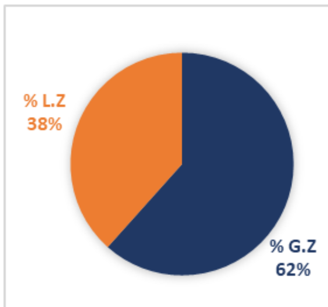


Figure 23. Pie chart for the percentage of Great Zab and Lesser Zab from Tigris River for the period before 2000

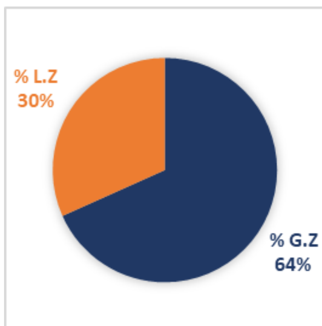


Figure 24. Pie chart for the percentage of Great Zab and Lesser Zab from Tigris River for the period after 2000

Figure 23 and 24 shows the percentage of Lesser Zab and Great Zab from Tigris River for the period before 2000, and after 2000. Before 2000, Lesser Zab River is representing a percent of 38 from the Tigris River, whilst the Great Zab River represents a percent of 62 from the Tigris River. For the period after 2000, Lesser Zab River is representing a percent of 30 from the Tigris River, whilst the Great Zab River represents a percent of 64 from the Tigris River.

4. CONCLUSIONS

A larger number of significant trends have been found in several hydrological variables in the Great Zab, Lesser Zab, and Tigris River Basins than would be expected by chance.

Noteworthy results were a steady trend in the annual flow for Great Zab River for the period (1932-1999), a decreasing trend in the annual flow for the period (2000-2020). Consequently, it is an indication of climate change's influence on the Great Zab River, even though there is no dam on it to control the flow.

It is worth mentioning that the choice of these two periods (1932-1999 and 2000-2020) was based on two factors, the first is that the Turkish government has finished constructing the majority of the dams at the end of 2000, and the other is the effects of climate change after 2000, that were beginning to manifest. Therefore, by comparing these two periods, the effects of the climate change on the rivers that were chose to analyze in this study can be known.

From Figures 21 and 22 it can be seen that in March, the great Zab flow is equal to the Tigris flow. The percentage of Great Zab before 2000 was 62% from the Tigris River and percentage of Lesser Zab from Tigris River was 38%, while the percentages after 2000 was 64% and 30% for great Zab and Lesser Zab from Tigris River successively.

According to the results that showed that the volume of water for Great Zab River reduced from 264 billion m^3 for the period (1980-1999) to 209 billion m^3 for the period (2000-2020), climate change is undeniably one of Iraq's most significant challenges, having serious implications for water resources, the environment, and the economy, notably in the agricultural sector.

The lesser Zab result revealed that dams in Syria and Turkey had a greater impact than climate change, as average rainfall rose from 272.77 mm before 2000AD to 295.14 mm after 2000AD, but flow reduced from 229.56 (m^3/sec) before 2000AD to 129.95 (m^3/sec) after 2000AD.

The effect of the dams in Syria and Turkey on the Tigris River is also greater than that of climate change, since average rainfall increased from 259.24 mm before 2000AD to 292.72 mm after 2000AD, but discharge declined from 620.21 (m^3/sec) before 2000AD to 466.67 (m3/sec) after 2000AD.

The Great Zab result revealed that climate change has a greater impact because there are no dams on the river, and the discharge has fallen from 417.74 (m^3/sec) before 2000AD to 315.57 (m^3/sec) after 2000AD.

In terms of temperature, the data show that it rose after 2000AD compared to the previous period, which may be interpreted as a climate change influence on the rivers.

REFERENCES

[1] Bergkamp, G.J.J., Orlando, B., Burton, I. (2003). Change: Adaptation of water resources management to climate change. IUCN. http://www.iucn.orghttp://www.waterandnature.org.

[2] The Physical science basis summary for policymakers working group i contribution to the sixth assessment report of the intergovernmental panel on climate change. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf.

[3] Ehsani, N., Vörösmarty, C., Fekete, B., Stakhiv, E. (2017). Reservoir operations under climate change: Storage capacity options to mitigate risk. Journal of Hydrology, 55: 435-446. http://dx.doi.org/10.1016/j.jhydrol.2017.09.008

[4] Atkins. (2013). FD2628 Impact of Climate Change on Dams & Reservoirs Final Guidance Report.

[5] Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. Scientific Reports, 10(1): 13768. http://dx.doi.org/10.1038/s41598-020-70816-2

[6] Garbrecht, J.D., Piechota, T.C. (2005). Climate variations, climate change, and water resources engineering. American Society of Civil Engineers. http://dx.doi.org/10.1061/9780784408247

[7] ISAB. (2007). Independent scientific advisory board climate change impacts on Columbia river basin fish and wildlife. https://www.nwcouncil.org/reports/climate-change-impacts-on-columbia-river-basin-fish-and-wildlife/.

[8] Wodon, Q., Liverani, A., Joseph, G., Bougnoux, N. (2014). Climate change and migration: evidence from the Middle East and North Africa. World Bank Publications.

[9] Price, R. (2018). Environmental risks in Iraq. K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.

[10] Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M.A., Tanarhte, M., Tyrlis, E., Xoplaki, E. (2012). Climate change and impacts in the Eastern Mediterranean and the Middle East. Climatic Change, 114(3): 667-687. http://dx.doi.org/10.1007/s10584-012-0418-4

[11] Kamel, A.H., Afan, H.A., Sherif, M., Ahmed, A. N., El-Shafie, A. (2021). RBFNN versus GRNN modeling approach for sub-surface evaporation rate prediction in arid region. Sustainable Computing: Informatics and Systems, 30: 100514. http://dx.doi.org/10.1016/j.suscom.2021.100514

[12] Sulaiman, S.O., Najm, A.B.A., Kamel, A.H., Al-Ansari, N. (2021). Evaluate the optimal future demand of water consumption in al-Anbar province in the west of Iraq. International Journal of Sustainable Development and Planning, 16(3): 457-462. http://dx.doi.org/10.18280/IJSDP.160306

[13] Adamo, N., Al-Ansari, N., Sissakian, V.K., Knutsson, S., Laue, J. (2018). Climate change: consequences on Iraq's environment. Journal of Earth Sciences and Geotechnical Engineering, 8(3): 43-58.

[14] Sulaiman, S.O., Kamel, A.H., Sayl, K.N., Alfadhel, M.Y. (2019). Water resources management and sustainability over the Western desert of Iraq. Environmental Earth Sciences, 78(16): 495. http://dx.doi.org/10.1007/s12665-019-8510-y

[15] Al-Hasani, A.A. (2021). Trend analysis and abrupt change detection of streamflow variations in the lower

Tigris River Basin, Iraq. International Journal of River Basin Management, 19(4): 523-534. http://dx.doi.org/10.1080/15715124.2020.1723603
[16] Issa, I.E., Al-Ansari, N., Sherwany, G., Knutsson, S. (2014). Expected future of water resources within Tigris–Euphrates rivers basin, Iraq. Journal of Water Resource and Protection, 6(5): 421-432. http://dx.doi.org/10.4236/jwarp.2014.65042
[17] Abbas, N., Wasimi, S.A., Al-Ansari, N., Nasrin Baby, S. (2018). Recent trends and long-range forecasts of water resources of northeast Iraq and climate change adaptation measures. Water, 10(11): 1562. http://dx.doi.org/10.3390/w10111562
[18] Tamween Ajeel AL-Heetimi, O., Abidalla, W.A., Abbas Jaber, J. (2015). Flood forecasting in upper Zab River using SWAT hydrological model. Journal of Kerbala University, 11(4): 133-144.
[19] Osman, Y., Al-Ansari, N., Abdellatif, M. (2019). Climate change model as a decision support tool for water resources management in northern Iraq: A case study of Greater Zab River. Journal of Water and Climate Change, 10(1): 197-209. http://dx.doi.org/10.2166/wcc.2017.083
[20] Mohammed, R.J. (1989). Development of A Mathematical Model for Wadi Horan Catchment. M. Sc. Thesis.
[21] Al-Ansari, N., Knutsson, S. (2011). Water and climate change in the MENA-region adaptation, mitigation, and best practices. International Conference Possibilities of Restoring the Iraqi Marshes Known as The Garden of Eden.
[22] Al-Ansari, N. (2013). Management of water resources in Iraq: Perspectives and prognoses. Engineering, 5(6): 667-684. http://dx.doi.org/10.4236/eng.2013.58080
[23] United Nations. Economic and Social Commission for Western Asia. and Bundesanstalt für Geowissenschaften und Rohstoffe., Inventory of shared water resources in western Asia.
[24] Abdulla, F., Al-Badranih, L. (2000). Application of a rainfall-runoff model to three catchments in Iraq. Hydrological Sciences Journal, 45(1): 13-25. http://dx.doi.org/10.1080/02626660009492303
[25] Sissakian, V.K., Al-Ansari, N., Adamo, N., Knutsson, S., Laue, J. (2018). Geology of the Tigris River with emphasize on the Iraqi Part. Journal of Earth Sciences and Geotechnical Engineering, 8(3): 145-166.
[26] Al-Faraj, F., Shami, A., Abdulqadir, H., Kareem, K. (2015). The preparation of the world bank's country water resources assistance strategy for Iraq. http://dx.doi.org/10.13140/RG.2.1.2702.8323