

to the beginning of 5500 BC in the basin of the Tigris and Euphrates Rivers known as the Mesopotamian. The Sumerians and Babylonians used water of Euphrates River to irrigate their fields and cities by systems of canals (Altinbilek, 2004).

Iraq started in 1950 planning for the construction of irrigation and flood control systems by the Board of Development created by the Kingdom of Iraq. Primarily; it was to protect Baghdad, the capital, and other major cities from flooding. The first big dam (Dokan) was constructed in 1959 on the Lesser Zab River. This was followed by the construction of other projects where many dams were constructed for irrigation and power generation purposes. In addition, a system was established on the River Euphrates to control its flood. This system includes Ramadi barrage and the Habbaniye Lake. Other systems on the Tigris River included regulators, canal systems, Lake Tharthar project and the Samarra dam were constructed (UNEP, 2001; Iraqi Ministry of Water Resources, 2013).

In the modern history, Iraq until 1970s was considered rich in its water resources due to the presence of the Tigris and Euphrates rivers. In mid-seventies Syria and Turkey started to build dams on the Euphrates River therefore, its flow decreased due to water impounding of some of the new reservoirs (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). This fact forced the Iraqi Government to speed up building as much as they can from the planned hydrological projects. For this reason, 1970 to 1990 was the best period of the development of Iraq's water systems. The process stopped in 1990 due to the first Gulf War and UN sanctions. Through the last fifty years period, from 1960 to the end of the twentieth century, there was a change in the supply and demand situation. Table 1 summarizes the hydraulic structures on the Tigris–Euphrates Rivers.

In 1977, the Turkish Government started to utilize the water of the Tigris and Euphrates Rivers through the South-eastern Anatolia Project (GAP). The project includes 22 multipurpose dams and 19 hydraulic power plants which are to irrigate 17 103 km² of land with a total storage capacity of 100 km³ which is three times more than the overall capacity of Iraq and Syrian reservoirs (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). Eight of these dams are to be constructed on the River Tigris, only three were built (two

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in 1997 and one in 1998). The irrigation projects within the GAP will consume about 22.5 km³ of water per year after completion (Altinbilek, 2004; Al-Ansari and Knutsson, 2011; Al-Ansari, 2013).

In addition, recent studies indicated that there will be more increase in the water demand in the Middle East and North Africa (MENA region). In 2050, water demand will reach up to 393 km³ of water per year. This indicates that the water shortage will be 193 km³ yr⁻¹ of which 22% due to climate change and 78% to changes in population growth and economic development factors (Droogers et al., 2012). Furthermore, the studies on the Tigris–Euphrates Western Iran region show a total groundwater loss of nearly 144 km³ during 2003 to 2009 (Voss et al., 2013). The reduction of flow in the Tigris and Euphrates Rivers in Iraq is considered to be a national crisis and will have severe negative consequences on health, environmental, industrial and economic development (Altinbilek, 2004; Al-Ansari and Knutsson, 2011; Voss et al., 2013). In view of the above, it became necessary to know the water resources trends in the Tigris–Euphrates rivers basin within Iraq. In the present study the current and future water situation (availability and demand) was evaluated using a new method. The method applied for that purpose was the use of monthly water discharges measurements for 15 stream flow gaging stations on the Tigris–Euphrates Rivers inside Iraq. Population growth data with annual water consumption per capita were used for the southern region of Iraq beyond the gaging stations. The water discharge measurements were used in the calculations due to the fact that it takes into consideration the water consumption due to different uses, infiltration and evaporation losses as well.

2 Study area

2.1 Hydrology of Tigris–Euphrates Rivers basins

The Tigris and the Euphrates Rivers are the two important and greatest rivers of western Asia. The rivers originate from the same region in Turkey about 30 km from each

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other. The region is characterized by its cool and humid climate with a rugged land of high mountains and deep gorges. From there, the two rivers flow separately onto a wide, flat, hot, and poorly drained plain. In their middle path, the twin Rivers diverge hundreds of kilometres apart and join together near Qarmat Ali about 160 km above the head of the Gulf, forming the Shatt al-Arab (Fig. 1). The upper basin of the rivers is characterized by the rock and mountain gorges of Anatolia and the high plateaux of Syria and Iraq. The rivers firstly look separate and then parallel, until fall off the final limestone plateau and onto the great plain of Mesopotamia. The climate of the catchment area may be regarded as being similar to a Mediterranean climate except some differences due to the presence of a mountainous region which is located within the Turkish territory. The climate is a hot-dry summer and cold-rainy winter with occasional snowfall taking place in the mountain region. The precipitation in Mesopotamian basin occurs between October and May. The annual precipitation over the Tigris–Euphrates Rivers basin ranges between 100 and 1000 mm annually (Fig. 1) (Al-Ansari and Knutsson, 2011). The heaviest precipitation occurs from December to February. Generally, snow melting begins in February causing higher discharges during spring flows (March to May or early June). Low water discharges are usually during the hotter and drier summer months (July to October). During this period the main source of the rivers runoff is groundwater. The average monthly temperatures range between 6 °C in January to 34 °C in July but the temperatures decrease towards the north (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). The flow discharges vary to 10 times between flood season that occur during winter and spring due to the rain and snow melt and dry period during summer and part of autumn. Table 2 shows the details of contributions for riparian countries in the rivers basins.

2.2 River Tigris

River Tigris is the second-largest river in western Asia. The main source for the Tigris River is Hazar Lake (elevation 1150 m a.s.l.), which is located in the south eastern region of Turkey. The lake is surrounded by the Taurus mountain chain where its height

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reaches 3500 m. The headwaters of the Tigris River begin in the small mountain lake of Jazar Golu in Turkey; 30 km from the upper catchment of the Euphrates. The River flows in the hilly regions located to the south western portion of the mountainous area connecting Turkey, Iran and Iraq. The River Tigris flows directly towards Iraq and the Mesopotamian Plain with only a small part that is parallel alongside the Syrian border. The River crosses the Iraqi border at Faish Khabur village which is located about 400 km from the main sources (Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). Eight major tributaries feed the Tigris River from the left bank three in Turkey before entering Iraq which are Batman, Garzan and Botan and five in Iraq are Khabur, Greater Zab (partly beginning in Turkey), lesser Zab, Uzaym and Diyala rivers (Fig. 1). The tributaries in Iraq flow down from the north east of Iraq (Zagros Mountains) and join to the main river before Baghdad city (Najib, 1980; Al-Ansari et al., 1986; Al-Ansari and Knutsson, 2011). The channel of the Tigris River is shallow and wide in the Diyarbakir area, but after it joins the Batman tributary it becomes a narrow and deep river with high velocity. The width of the river valley (flood plain) north of Mosul city to Faish Khabur before Mosul dam construction ranged from 2 to 10 km. The river drains an area about 375 000 km² which is shared by Turkey, Syria, Iraq and Iran (Table 3). The total length of the river is about 1862 km; only 21 % of the length of the Tigris lies in Turkey and remainder lies in Iraq. According to most of previous studies; the mean annual flow of the Tigris from Turkey before it enters Iraq is ranging from 20 to 23 km³ yr⁻¹. During its passage in Iraq the river receives from all of the above tributaries an additional amount of water that reaches 25 to 29 km³ yr⁻¹ (Biedler, 2004; Al-Ansari and Knutsson, 2011). The most significant features of the River Tigris basin are given in Table 3.

The mean annual flow of the Tigris River at Mosul city prior to 1984 was 22.2 km³ and dropped to 17.7 km³ (Al-Ansari and Knutsson, 2011). The annual hydrograph for Tigris River starts from October to September. The highest mean monthly discharge takes place during April and the driest month is generally September (Fig. 2).

2.3 River Euphrates

Euphrates is the longest river in western Asia. The majority of the water resources of the Euphrates are located in the Turkish territories of Anatolia. The river rises near Mount Ararat at heights of around 4500m near Lake Van, the Euphrates is formed from two tributaries, the Murat-Su and the Kara-Sue (or Frat-Sue). They meet near Elazia city; within this region its snow melt from mountain streams is its main water source. The River flows southward to 160 km of the Mediterranean with average slope 2 m per kilometre before it turns left into Syria to continue in a south-east direction, almost straight towards Shatt Al-Arab River (Altinbilek, 2004; Biedler, 2004; Al-Ansari and Knutsson, 2011; Al-Ansari, 2013). After the river enters the Syria's borders at Jarablis, within Syrian territories by two small tributaries join the river. They are Balikh and the Khabur Rivers that contribute with small amount of water to the Euphrates River (Fig. 1). Euphrates enters Iraq at Hasaibah. Its annual flow at the Iraqi border is of the order of 28 to 30 km³ yr⁻¹ (Al-Ansari et al., 1981, 1988). In Iraq, 360 km from the border, the river reaches a giant alluvial delta at Ramadi where the elevation is only 53 m.a.s.l. From that point onward, the river traverses the deserted regions of Iraq, losing part of its waters into a series of desert depressions and distributaries, both natural and man-made. Euphrates has number of small tributaries in the central and southern parts of Iraq for irrigation purposes. No tributary contributes water into the river within Iraqi territories. The river, near Nasiriyah, becomes a tangle of channels, some of which drain into the shallow lake of Hammar as the remainder joins the Tigris at Qurna (Fig. 1). The Euphrates has a very gentle gradient in Iraq. The characteristics of Euphrates basin tabulated in Table 4.

The most significant features of the Euphrates River at Hit city for the period 1932–1997 illustrate in Fig. 3.

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3 Data and methodology used

The water discharges data are very important to study the potential water supply and demand. For these purposes; the averages monthly discharges for 15 stream flow gaging stations within Tigris–Euphrates Rivers basin in Iraq were used to evaluate the reduction in water availability and increasing water demand. These stations are 11 on the River Tigris (TS) and its tributaries and 4 on the River Euphrates (ES) (Fig. 1 and Table 5). The data of these stations were adopted from Al-Shahrabaly (1989) and Saleh (2010). In addition the population growth data for 4 governorates in the southern part (Al-Kut, Al-Amarah, An-Nasiriyah and Al-Basra, Fig. 4) having 2616 m³ yr⁻¹ annual water consumption per capita, were used to estimate the water demand in that area. The population growth data was provided by City Population (2013) and water withdrawal per capita estimated by FAO (2013).

4 Results and discussion

4.1 Water availability

The water discharge data for stream flow gaging stations that mentioned previously were analyzed and used to estimate the average annual reduction in the inflow due to increasing of the demand as well as the consequences of climate change. To compute reduction in the inflow; the average monthly discharge of 4 main stream flow gaging stations have been adopted on River Tigris (TS₃, TS₆, TS₈ and TS₁₁) and 4 stations on River Euphrates (ES₁, ES₂, ES₃ and ES₄) (Fig. 5). The data of these stations were used to develop the Trend lines that were used to estimate the annual flow reduction with time (Table 6). The results showed that the percentage reduction in the inflow rate is increasing with time for Tigris–Euphrates Rivers. The reduction steadily increases downstream the River Tigris while it oscillates downstream the River Euphrates. This

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is due to the fact that some water is diverted from Thrathar depression inside Iraq to the River Euphrates to overcome the water shortage downstream (Al-Ansari, 1998).

To find out the reduction of flow of water entering Iraq from neighbouring countries, the Trend lines of average monthly discharge data for stations (TS₁, TS₂, TS₄, TS₅, TS₇, TS₉ and TS₁₀) of the River Tigris and its tributaries as well as (ES₁) on the River Euphrates were used (Table 7). The results revealed that Iraq receives annually 45.4 and 25.52 km³ of water from Tigris and Euphrates respectively. River Tigris receives its water from two sources, 18.04 km³ from Turkey before entering Iraq and 27.36 km³ from its tributaries inside Iraq. The annual reduction of water inflow for River Tigris is 0.1335 km³ yr⁻¹ which is less than Euphrates by 0.245 km³ yr⁻¹. This implies the annual percentage reduction of inflow rates for Rivers Tigris and Euphrates are 0.294 and 0.960 % respectively.

4.2 Water demand

The demand increases due population growth, economic development and environmental considerations. In this study the water demand for Iraq was computed using difference in the inflows for successive stream flow gaging stations on the Tigris–Euphrates Rivers. In some parts it was computed depending on the population growth rates with annual water withdrawal per capita due to the lack of discharge records. To complete the calculations the basin was divided into 8 zones, 4 on the Tigris basin (RT₁, RT₂, RT₃ and RT₄) and 4 on the Euphrates basin (RE₁, RE₂, RE₃ and RE₄) depending on the location of stream flow-gaging stations (Table 8). Figure 6 shows the annual difference rates in the water inflow of the successive stations that represents the annual water demand (water consumed) for zones (RT₁, RT₂, RT₃, RE₁, RE₂ and RE₃). The Trend lines of the above relations showed the demand increased with time and the annual increasing rates of demand for these zones are tabulated in Table 8. The demand details for the remainder zones (RT₄ and RE₄ down stations TS₁₁ and ES₄ respectively) were estimated using population growth data (Fig. 4) and water withdrawal per capita for Iraq 2616 m³ yr⁻¹ (Table 8). The calculations results for all zones

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showed that the average yearly demand for Iraq is 63.05 km³ yr⁻¹ while Iraq receives annually 70.92 km³ yr⁻¹. The demand is shared by the two river basins where it reaches 38.10 and 24.95 km³ yr⁻¹ for Tigris and Euphrates Rivers respectively. The overall annual increase of the demand is 0.896 km³ yr⁻¹ (0.5271 for and 0.475 km³ yr⁻¹ for Tigris and Euphrates basins respectively). This implies that the consumption is 88.89 % of total incoming water (60.43 and 39.57 % for Rivers Tigris and Euphrates respectively).

The potential water demand was compared with previous studies of Klot (1994), Kolars (1994), Altinbilek (1997), Beaumont (1998) and UN (2010) (Table 9). The results showed that the average water demand in Iraq in 2020 will increase to 72.069 km³ yr⁻¹ (42.844 km³ yr⁻¹ for Tigris and Euphrates 29.225 km³ yr⁻¹ respectively). On the contrary, the amount of available water will decrease to 63.46 km³ yr⁻¹ (44.06 and 19.40 km³ yr⁻¹ for Tigris and Euphrates respectively). The total water deficit of Tigris–Euphrates Rivers basin will be 8.61 km³ yr⁻¹. Water shortages will be of 9.83 km³ yr⁻¹ on the Euphrates River basin at 2020. On the contrary the Tigris River will experience a surplus of 1.221 km³ yr⁻¹ (Table 9). These figures are calculated assuming that there will be no dams constructed on both rivers in future. In case these are considered then the water availability after 2015 will be 9.16 and 8.45 km³ yr⁻¹ for Tigris and Euphrates respectively (UN, 2010). In addition, restoring the marshes was not considered.

5 Summary and conclusion

The averages monthly inflow for 15 stream flow gaging stations on the Rivers Tigris and Euphrates inside Iraq were used to estimate water availability and its rate of reduction. Furthermore, these data with population growth data and water consumption per capita were used to compute the demand and its increase. The results showed that the total water availability in Iraq from these rivers is 70.92 km³ yr⁻¹ of which are 45.4 and 25.52 km³ yr⁻¹ for Tigris and Euphrates Rivers respectively. Iraq receives annually 18.04 km³ yr⁻¹ from River Tigris this represents 39.73 % of Tigris inflow in Iraq and the remainder 27.36 km³ yr⁻¹ is supplied by tributaries of River Tigris inside Iraq. The rate

of reduction of inflow for River Tigris is $0.1335 \text{ km}^3 \text{ yr}^{-1}$ (0.294 %) which is less than Euphrates $0.245 \text{ km}^3 \text{ yr}^{-1}$ (0.961 %) The average water demand in Iraq is $63.05 \text{ km}^3 \text{ yr}^{-1}$. About $38.1 \text{ km}^3 \text{ yr}^{-1}$ is for the River Tigris basin and $24.95 \text{ km}^3 \text{ yr}^{-1}$ is for the Euphrates basin. The rate of demand in Iraq is increasing annually by $0.896 \text{ km}^3 \text{ yr}^{-1}$ (0.5271 $\text{km}^3 \text{ yr}^{-1}$ for Tigris River basin and $0.475 \text{ km}^3 \text{ yr}^{-1}$ for Euphrates basin). In addition, the water inflow at 2020 will decrease to $63.46 \text{ km}^3 \text{ yr}^{-1}$ and the demand will increase to $72.069 \text{ km}^3 \text{ yr}^{-1}$.

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Table 2. The contributions in the Tigris–Euphrates Rivers basin for riparian countries.

Tigris–Euphrates Rivers	Turkey	Iraq	Syria	Iran	Total
Discharge (km ³ yr ⁻¹)	65.7	6.8	0.5	11.2	84.2
Discharge (%)	78.1	8.1	0.5	13.3	100
Drainage Area (km ²)	170 000	469 000	77 000	37 000	819 000
Drainage Area (%)	20.5	46.0	9.0	19.0	94.5
Rivers Length (km)	1630	2478	754	–	4862
Rivers Length (%)	33.5	51.0	15.5	–	100
Irrigable lands (km ²)	24 270	40 000	9500	–	73 700
Irrigable lands (%)	33	54.2	12.8	–	100

Source: UNEP (2001); Biedler (2004).

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Table 3. Characteristics of the Tigris Rivers basin.

Tigris River	Turkey	Iraq	Syria	Iran	Total
Discharge (km ³ yr ⁻¹)	33.5	6.8	0.0	11.2	51.5
Discharge (%)	65.0	13.2	0.0	21.8	100
Drainage Area (km ²)	45 000	292 000	1000	37 000	375 000
Drainage Area (%)	12.0	54.0	0.2	33.8	100
River Length (km)	400	1318	44	–	1862
River Length (%)	21.0	77.0	2.0	–	100

Source: UNEP (2001); Biedler (2004).

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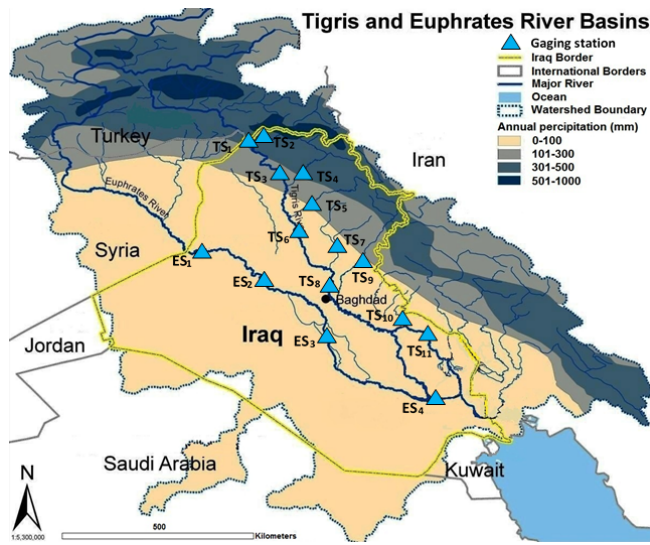


Fig. 1. General layout of the Tigris–Euphrates Rivers and locations of streamflow-gaging stations.

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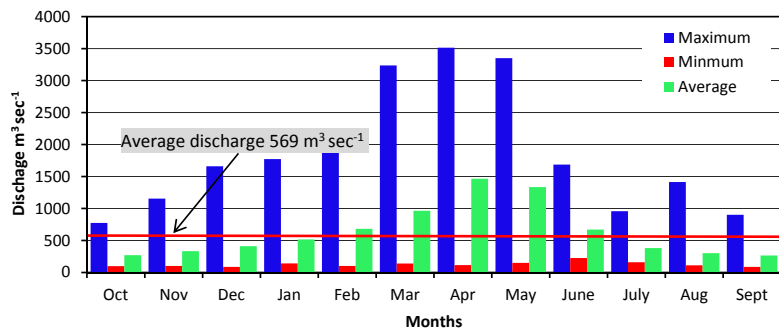


Fig. 2. Monthly (mean, minimum and maximum) discharge of Tigris River at Mosul dam site (1931–2011).

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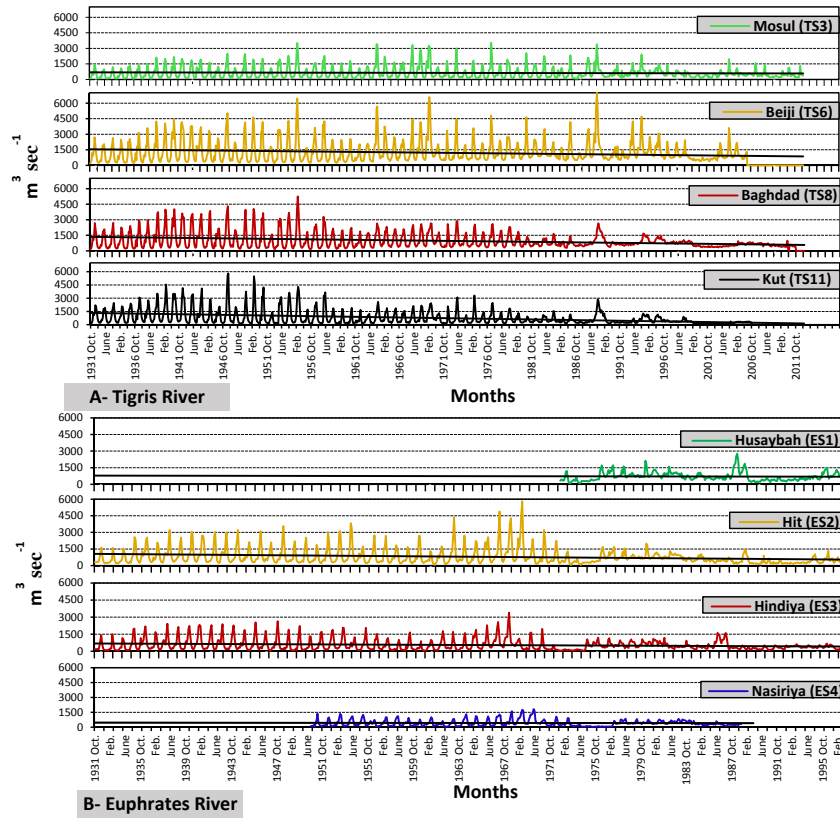


Fig. 5. Average monthly inflow of Tigris–Euphrates Rivers for main stream flow gaging-station.

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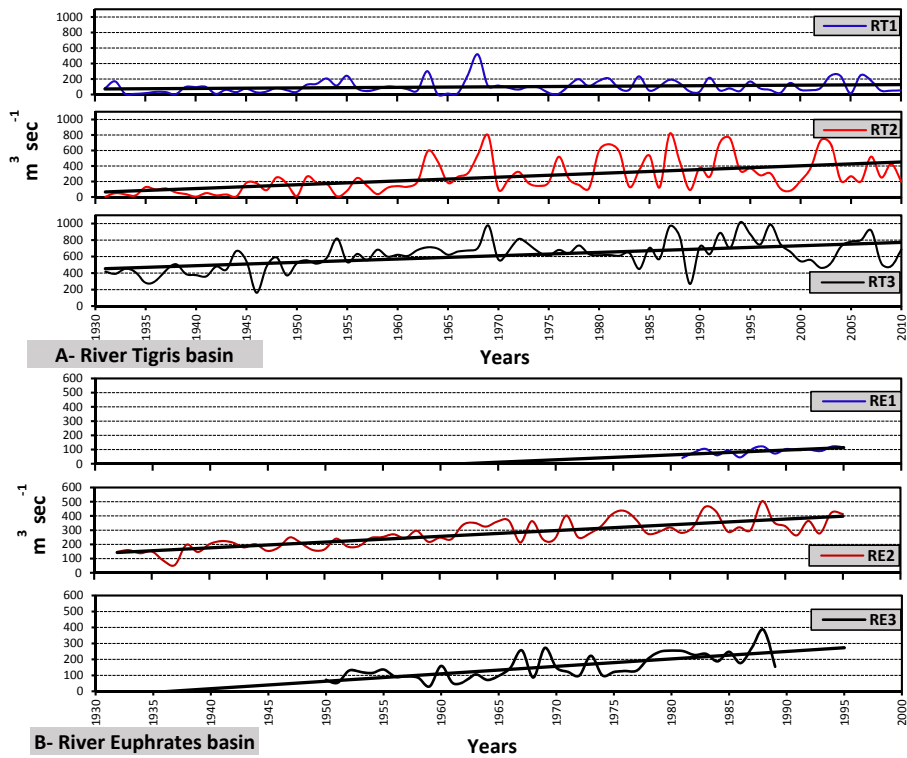


Fig. 6. Average annual demand of Tigris–Euphrates Rivers basin in Iraq.

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