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Abstract

Iraq relies in its water resources on the water of the Tigris and Euphrates Rivers and their tributaries. The long-term average annual flow of the Euphrates River was 30 BCM while it is 21.2 BCM for the River Tigris. The tributaries of the Tigris River contribute about 24.78 BCM and in addition, there are side valleys from the eastern border that contributes at least 7 BCM. The flow of these rivers decreased for since the seventies due to the hydrological projects built in riparian countries and climate change. Now, the discharge of the Tigris River and its tributaries at Baghdad is about 16 BCM while it is about 4.4 BCM in the Euphrates.

Keywords: Tigris, Euphrates, Tributaries, Shat al Arab, Iraq.

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1. Introduction

The Rivers Tigris and Euphrates form the main water resources of Iraq. They join in the southern part of Iraq forming what is referred to as the Shat Alarab, which drains towards the Gulf (Figure 1). Most of the water from these rivers comes from Turkey (71%) followed by Iran (6.9%) and Syria (4%). The remainder, only 8%, is from internal sources (Figure 2).The average annual flow of the Euphrates and Tigris is estimated to be about 30 km^3 (which might fluctuate from 10 to 40 km^3) for the former and 21.2 km^3 for the latter when it enters Iraq. Its tributaries contribute 24.78 km^3 of water and there are about 7 km^3 of water brought by small wadies from Iran, which drains directly towards the marsh area to the south ((Al-Ansari and Knutsson, 2011, Al-Ansari, 2013, 2016, Al-Ansari et.al., 2012). The World Bank (2006) stated that 100% of the Euphrates water comes from outside the borders of Iraq while 67% of the Tigris water also comes from outside sources. They also stated that groundwater resources are about 1.2 billion cubic meters and form about 2% of the total water resources of Iraq.

The total water withdrawal in Iraq was about 42.8 km^3 in 1990, which is used for agricultural (90%), domestic (4%) and industrial (6%) purposes (Al-Ansari, 1998 and 2005, Sadik and Barghouti, 1993, World Bank, 2006). According to the most recent estimates, 85% of the water withdrawal is used for agricultural purposes (Al-Ansari and Knutsson, 2011, Al-Ansari, 2013, 2016, Al-Ansari et.al., 2012). It should be mentioned however, that safe water supplies reach 100% of the urban areas and only 54% of rural areas. The situation had deteriorated after the Gulf war for both water and sanitation sectors. IMMPW (2011) stated that 1/3 of the population of Iraq do not have access to potable water, and the quantity of water production is decreasing to 5469534 m^3/day, which represents 53% of the water demand. The Iraqi government hopes to ensure water supplies reach 91% of the population by 2015 (UN, 2010).

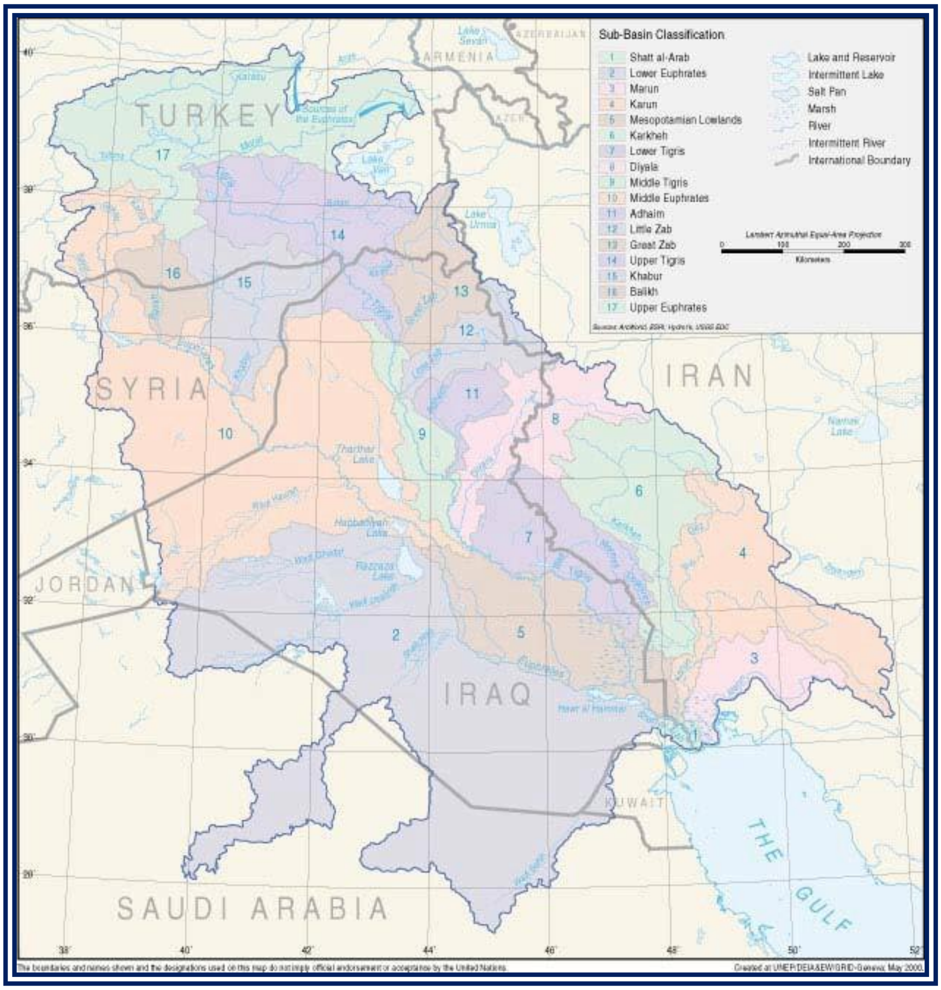

Figure 1: Catchments area of Rivers Tigris and Euphrates.

Since Sumerian times (7500 years ago) the land between the Tigris and Euphrates has been irrigated by the water from these rivers. The suitable land for agriculture is 11.5 million ha, which represent 25% of the total area of Iraq (World Bank, 2006). The irrigation potential is 63%, 35% and 2% for the Tigris, Euphrates and Shat Alarab rivers respectively. The area used for agriculture is 8 million hectares, which forms 70% of the total cultivated area. About 40-50 % of this area is irrigable, and lies in the riverine plains while the remainder is rain fed and is located in the northeastern plains and mountain valleys. The irrigated area is mainly supplied by water from the main rivers, and only 7% is of the area is supplied by ground water (World Bank, 2006). Due to fallow practices and the unstable political situation only 3 to 5 million hectares are now actually cultivated annually. In 1993, it is believed that only 3.73 million hectares were cultivated of which 3.46 and 0.27 million hectares consisted of annual and permanent crops respectively (Al-Ansari and Knutsson, 2011, Al-Ansari, 2013, 2016, Al-Ansari et.al., 2012). Considering the soil resources, about 6 million hectares are classified as excellent, good or moderately suitable for flood irrigation. With the development of water storage facilities, the regulated flow increased and changed the irrigation potential significantly. It is well known that irrigation development depends to a large extent upon the volume of water released by the upstream countries. Existing data estimates that the contribution of the agricultural sector was only 5% of Gross Domestic Product (GDP) which is usually dominated by oil (more than 60%). About 20% of the labour force is engaged in agriculture (Al-Ansari and Knutsson, 2011, Al-Ansari, 2013, 2016, Al-Ansari et.al. 2012).

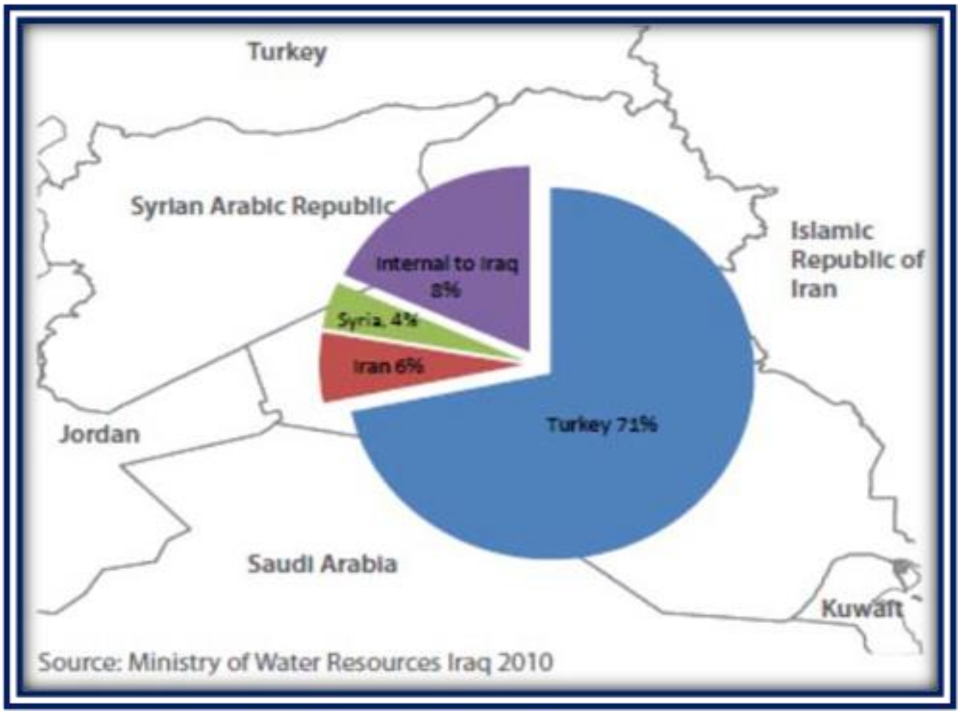

Figure 2: Sources of water for the Tigris and Euphrates Rivers (MWR, 2010).

The Iraqi water strategy is highly influenced by the Euphrates water where 100% of its flow comes from outside the country. While only 50% of the Tigris flow comes from Turkey. According to the negotiations between riparian countries, Iraq is supposed to receive 58% of the Euphrates flow, which crosses the Turkish- Syrian border, while Syria receives 42%. Turkey promised in the past to secure minimum flows of 15.8km^3/year at its border which gives Iraq 9km^3/year. Up to now, there has been no formal agreement between the three countries concerning the Euphrates and Tigris water. Present estimates indicate that Iraq is receiving only about 0.03km^3/year of the Euphrates water (Al-Ansari and Knutsson, 2011, Al-Ansari, 2013, 2016, Al-Ansari et.al., 2012).

In this research, the difficulties facing Iraq will be reviewed and discussed, and recommendations will be given to solve the problems of water resources in Iraq.

2. Surface Water

The rivers Tigris and Euphrates with their tributaries form the main surface resources in Iraq. The catchments area of these rivers is shared by five countries: Iraq, Turkey, Iran, Syria and Saudi Arabia (Table 1 and Figures 1 and 2).
Flow records show that minimum and maximum annual flow of the Tigris was $19x10^9m^3$ in 1930 and $106x10^9$ m^3 in 1969, while for the Euphrates it was $9x10^9$ m^3 in 1974 and $63x10^9m^3$ in 1969, respectively. Tables 2 and 3 summarize the source and uses of water in both rivers.

Table 1: The area of Tigris and Euphrates Basins.

Countries	Tigris River		Euphrates River	
	Catchment area		Catchment area	
	(km^2)	(%)	(km^2)	(%)
Turkey	57,614	12.2	125,000	28.2
Syria	834	0.2	76,000	17.1
Iraq	253,000	58	177,000	39.9
Iran	140,180	29.6	-	-
Saudi Arabia	-	-	66,000	14.9
Total	**473,103**	**100**	**444,000**	**100**

Several ancient civilizations in the Mesopotamia were supported by basin irrigation from the Tigris and Euphrates Rivers since 5,000 B.C during Sumerian time. The ancient irrigation system was so efficient where it support wide spread cultivation of the land for many years without serious decline in land quality. Due to these marvelous water activities the term "hydraulic civilization" was used to describe this society.
Generally, the total annual flow of the Tigris and Euphrates Rivers is of the order $80X10^9m3$. This figure greatly fluctuates from year to year (Figure 3). Furthermore, floods and drought are themselves of variable magnitude. Such variations are due to changing metrological conditions. The period extending from October to February is referred to as variable flood period where discharges in both rivers fluctuate depending on intensity and duration of rainfall at their basins. This period is usually followed by what is known as steady flood period extending from March to April.

Table 2: Sources and uses of the Euphrates River (MCM per year).

Natural Flow	Observed at Hit, Iraq Removed in Turkey (pre-GAP) Removed in Syria (pre-Tabqa) Natural flow at Hit	29,800 820 2,100 32,720
Pre-Kaban Dam (before 1974)	Flow in Turkey Removed in Turkey Entering Syria Added in Syria Removed in Syria Entering Iraq Added in Iraq Iraqi Irrigation Iraqi return flow (est.) To Shatt al-Arab	30,670 (820) 29,850 2,050 (2,100) 29,800 0 (17,000) 4,000 16,800
Full Use Scenario (circa 1040)	Flow in Turkey Removed in Turkey Entering Syria Removed in Syria Return flow and Tributaries (Turkey, Syria) Entering Iraq Removed Iraq Return flow in Iraq Deficit to Shatt Al-Arab	30,670 (21,600) 9,070 (11,995) 9,484 6,559 (17,000) 4,000 (6,441)

Table 3: Sources and uses of the Tigris River (MCM per year).

	Pre-Annotation Development Project	Post 2000 AD	Natural Flow
Flow From Turkey	18,500	18,500	18,500
Removed in Turkey	0	6,700	
Entering Iraq	18,500	11,800	
Inflows to Mosul	2,000	2,000	2,000
Greater Zab	12,100	13,100	13,100
Lesser Zab	7,200	7,200	7,200
Other	2,200	2,200	2,200
Sub-Total	**43,000**	**36,300**	**43,000**
Reservoir evaporation	0	(4,000)	
Irrigation (to Fatha)	(4,200)	(4,200)	
Return Flow	1,100	1,100	
Adhaim	800	800	800
Irrigation	(14,000)	(14,000)	
(to Baghdad)	3,600	3,600	
RETURN Flow	(1,200)	(1,900)	
Domestic Use	5,400	5,400	5,400
Diyala River	(5,100)	(5,100)	
Irrigation	1,300	1,600	
Return Flow			
Total Shatt Al-Arab	**30,700**	**19,600**	**49,200**
Reservoir evaporation	0	900	
Irrigation to Tokuf	(8,600)	(8,600)	
Return Flow	2,200	2,200	
		(to outfall drain)	
Total Shatt Al-Arab	**24,300**	**14,100**	**49,200**

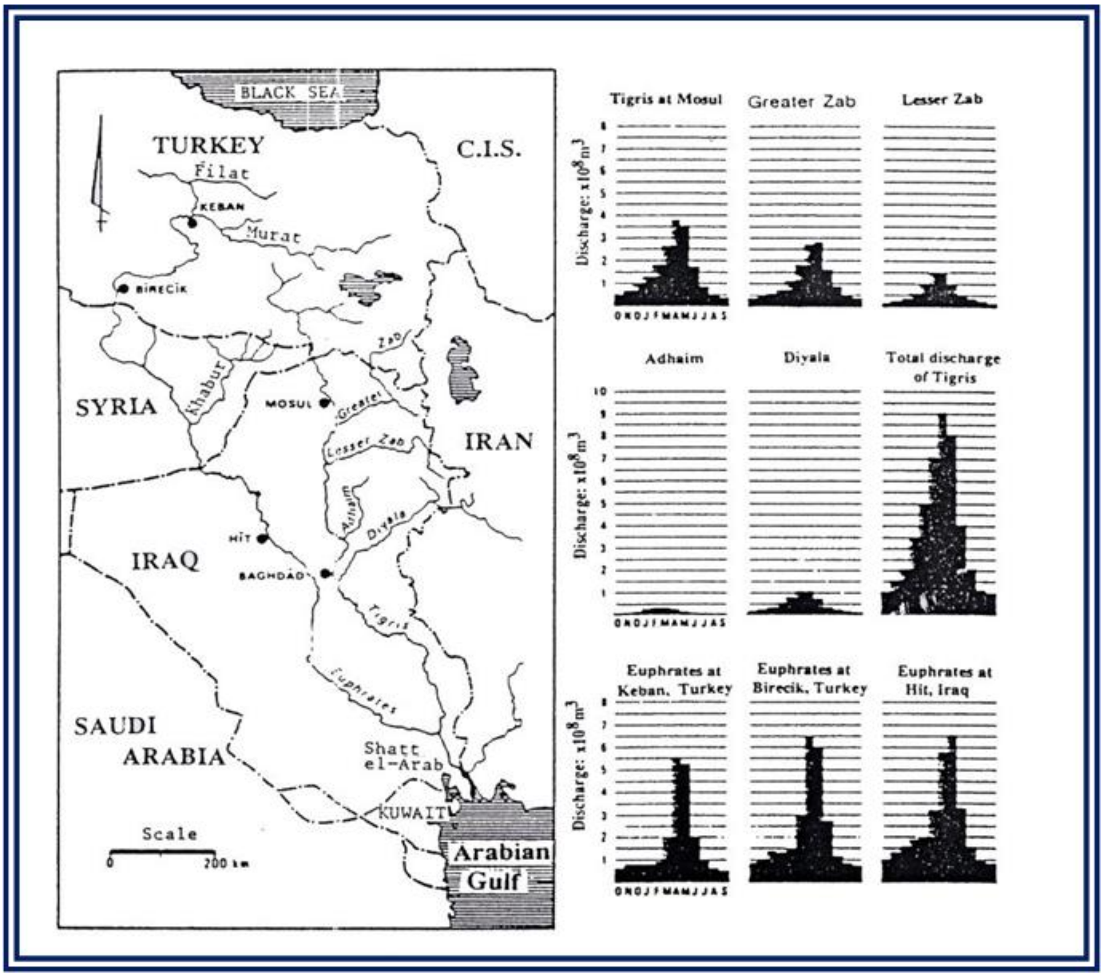

Figure 3: Tigris and Euphrates hydrographs.

2.1 River Euphrates

River Euphrates rises in the mountains of southern Turkey. It runs about 1,178km in Turkey before interring the Syrian territory where it runs 604 km to reach the Iraqi border. Inside Iraq the length of river is 1,160 km. the total length of the river from Turkey to its confluence with the River Tigris south of Iraq is 2,940km. The total drainage area of the river catchments is 444000km^2 (Table 3) of which 28%, 17%, 40% and 15% lie in Turkey, Syria, Iraq and Saudi Arabia, respectively.

The Euphrates River raises east the Anatolian plateau between Wan Lake and Black Sea in Turkey with two main tributaries:

a) Furat Su: This forms the northern tributary where it rises from the mountains situated northeast Ardhroom area with altitudes varying from 1,800 to 3,937m above sea level. The total length of the tributary reaches 510km.
b) Murad Su: This forms the southern tributary where it rises north of Wan lake at areas having altitude of 2,350 to 3,519m above sea level with a total length

of 600km.

Both tributaries join together 5km north of Keban city. At Keban area the Keban dam was constructed with a total reservoir capacity of 30.5x$10^9$$m^3$. The average annual flow of the Euphrates River in this area is 672m^3/s. The united river length in Turkey is 455km. The shape of the catchments of the river in Turkey is a fan shaped which collects runoff at rainy periods in a short period of time causing sudden flood peak. The Euphrates River inters the Syrian border near Jorablus and flow to Albkamal at the Syrian-Iraqi border. The catchment's area of the river before entering Iraq reaches 201,000km^2.

In Syria, three tributaries join the Euphrates:

a) Sabor River: total length of the river is 108km, joining the Euphrates, from the right, 30km south of Tripoli city. The average discharge of the river is 3m^3/s.
b) Belaikh River: The length of this river is 105km and joins the Euphrates from the left south of Raka city downstream Tabaka dam. The average discharge of the river is 36m^3/s and its catchment area is 14,400km^2.
c) Khabor River: The length of this river is 446km. Its catchment area is 36,900km^2 and lies in Turkey and Syria. Four small streams, i.e. Jaja, Jabjab, Etehad Aracha Alsaghir and Etehad Aradha Alkabeer, join this river. The khabor join the Euphrates south of Dier Al-Zor city and its mean daily discharge is 55.8m^3/s and could reach 500m^3/s during flood.

There are several dams constructed on the Euphrates River in Syria. One of the main dams is called "Tabaka". The storage capacity of this dam is 11.6x10^9m3 (life storage 7.4x$10^9$$m^3$). The maximum, minimum and mean discharge of the river Euphrates at Tabaka dam is 8500, 450 and 1300m^3/s, respectively. There are three more large dams; Tersanah, Teshreen and Muhardah with storage capacities of 225x$10^6$$m^3$, 210x$10^6$$m^3$ and 50X$10^6$$m^3$, respectively. In addition, 84 other small and medium size dams exist. The largest among these dams is known as Babalhadied with a storage capacity of 25x$10^6$$m^3$, while the storage capacity of the smallest dam is 30,000m^3.

The length of the river Euphrates in Iraq from the Syrian-Iraqi border at Hussaybah to its confluence with the Tigris River is 1,160 km. Once the river enters Iraq it trends toward the east and southeast to reach Anah city 100km south of Hussaybah. The river then runs 220km to reach Hit, with a river channel slope of 1:320m. The channel is characterized by its shallow depth, large width and meanders. Islands are also noticed at the river channel. No tributaries join the Euphrates River inside Iraq apart from dry valleys originating from western desert. These valleys supply the river with flood water at rainy season from the desert. The minimum and maximum recorded discharges at Hit are 55 on 5/9/1973 and 7460m^3/s on 13/5/1969.

The river runs 63km south Hit to reach Ramadi city with a width reaching 250m. At this area, Ramadi barrage was constructed to supply Warrar stream with water. This stream supplies Habariya Lake with excess water from the Euphrates during flood period. The length of this stream is 8.5km which is designed to discharge up to 2,800m^3/s. Water stored in Habaniya Lake can brought back to the river Euphrates when required through Dhiban stream which is located 42km south of

Ramadi city. In case of continuous flood flow, Habaniya lake cannot accommodate huge volumes of water and thus it was connected to Razazah lake and then to Abudibis marsh to release excess water.

South of Ramadi city the river flows 72km to reach Falujah city. A complex of canals system was constructed at this section of the river. A canal was dug from Tharthar large lake to supply the Euphrates River during drought periods; the canal joins the river 35km north of Falujah city. The canal is designed to discharge water up to 1,100m^3/s. It has a diversion which can supply excess water to the Tigris River if required. This diversion canal is 65km long.

The Euphrates River runs south about 110km to reach Hindiyah barrage. The river runs through fluvial deposits in this area. It should be mentioned however, that the Euphrates River channel inside Iraq upstream Hindiyah is higher by 7m than Tigris river channel. This is due to the fact that the Euphrates runs on the edge of the western plateau. This phenomenon was used since ancient times to dug irrigation canals from the Euphrates River running toward the Tigris River.

At Hidiyah, the river is known as Hindiyah River where it flows south to reach Kifil city 18km south of Hindiyah barrage. South of Kifil, the river splits to eastern channel (Shamiyah) which takes 40% of the flow and western channel (Kufa) taking the remaindering 60% of the flow. On shamiyah river there are various regulating schemes established for a number of irrigation projects, i.e. Danaieb Alshanafiyah, Shalal Danaieb Alshanafiyah, Khuman and Naghshiyah regulating schemes. This channel joins the Euphrates River again 8km upstream Shanafiyah city. The distance from Kifil to Shanafiyah is 99km.

As far as the other channel, the Kufa, it runs to Abuskhhair city and splits into two main channels. The small channel (on the right of the main channel) supplies four small irrigation streams, the main channel south of Abuskhhair

as Mushkhab River where Mushkhab barrage was established. The water flows to the south to reach Qadisiyah city and it again splits and joins again to form one channel. This channel joins Shamiyah channel again at Shanafiya city.

The river continues to run south for 105km where it reaches Simawah city. After that the river Euphrates reaches Nasiriyah city. It should be mentioned however that this section of the river (Simawah – Nasiriyah section) has a number of irrigation projects and small intake stream. South of Nasiriyah city the river runs toward Alshiyokh city and then enters Hammar Lake. Two channels leave Hammar Lake. The first joins the Tigris River at Qurna City while the other, the southern one, joins shat Al-Arab River at Karmat Ali. Table 4 and Figure 4 show the variation of flow along the River Euphrates.

Table 4: Characteristics of the Euphrates Rivers basin.

Euphrates River	Turkey	Iraq	Syria	Total
Discharge km^3/year	32.2	0.0	0.5	32.7
Discharge (%)	98.5	0.0	1.5	100
Drainage Area km^2	125 000	177 000	76 000	444 000
Drainage Area (%)	28.0	40.0	17.0	85
River Length (km)	1 230	1 060	710	3 000
River Length (%)	41.0	35.0	24.0	100

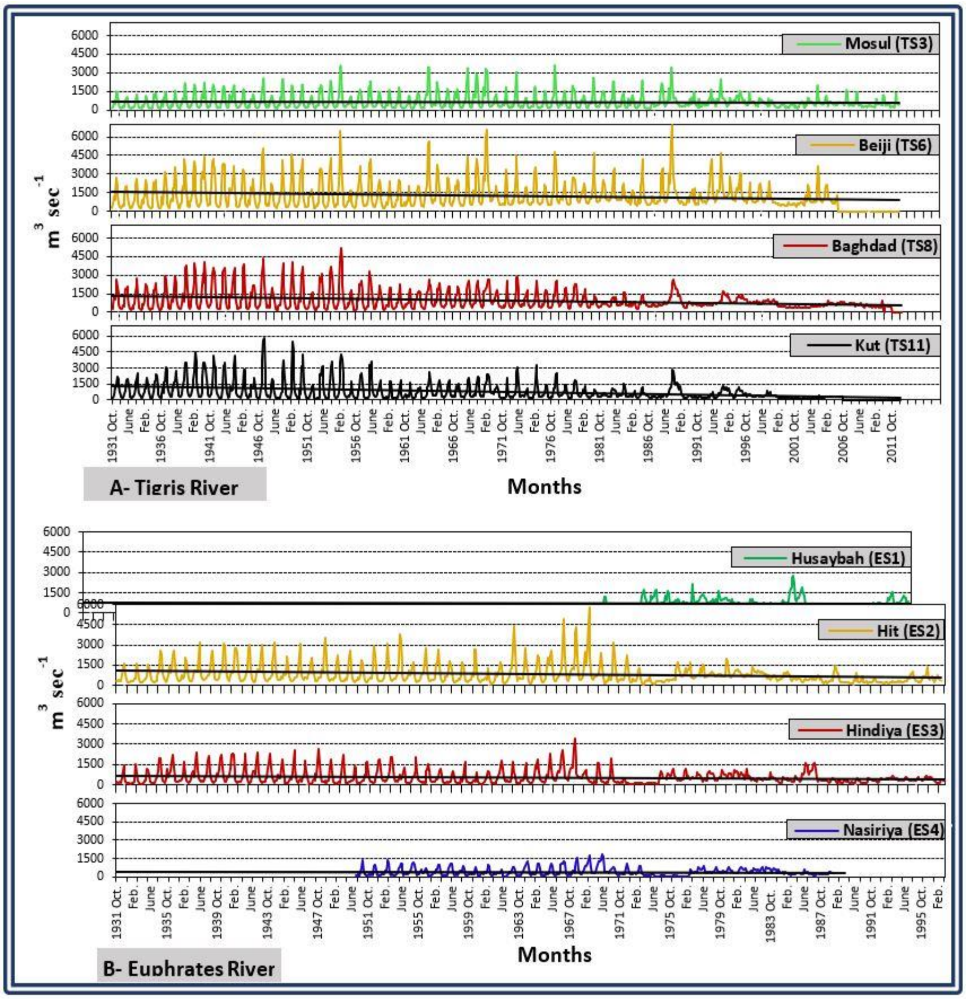

Figure 4: Average monthly inflow of Tigris-Euphrates Rivers for main stream flow gaging- station (source: Issa et.al. 2013).

2.2 River Tigris

The total drainage area of the Tigris River is 235,000km^2 distributed between Turkey (17%), Syria (2%), Iran (29%) and Iraq (52%). The overall length of the river is 1,718km. It rises at the southeastern slope of Taurus Mountains at two sites, the western site is located near Diar city, 1,500m above sea level, with a discharge of 64m^3/s while the eastern site, known as Butman Su, near Sinan city a 2,700m above sea level with a discharge of 96m^3/s. The river runs in a narrow valley bounded by Mardin Mountain range from the right and Raman Surat Hills from the left. Further down, another tributary (Karzan) joins the river near Bishwi village. The river runs south through rough mountainous area till it is joined by another tributary (Hazu) near ZEU village 240km north of the Iraqi border. The discharge of this tributary is 59m^3/s. The river then runs in a plain area and joined by Butan Su River, with a discharge of 20.3m^3/s, to form the united Tigris River. The river enters Iraq 4 km north Fieshkhabur near Zakha city. The Tigris is joined by its first tributary inside Iraq which is known as Khabur River. This tributary is 100km long, it catchment area is 6,268km^2 with an average, maximum and minimum discharge of 68m^3/s, 1,270m^3/s (11/4/1963) and 8m^3/s (6-14/9/1962), respectively. The Tigris River runs south for about 188km in a hilly area to reach Mosul city. At Mosul the average, maximum and minimum discharge of the river is 668m^3/s, 7,740m^3/s (2/5/1972) and 85m^3/s (October 1935). The elevation of the channel bed is 225m above sea level.

About 49km south of Mosul toward Sharkat city, the Tigris joins its biggest tributary, the Greater Zab. The catchment of this tributary lies in Turkey, Iran and Iraq. Its total length is 437km with a mean, maximum and minimum discharges of 450m^3/s, 9,710m^3/s (2/4/1969) and 60m^3/s (22/11 and 4/12/1958) respectively. It supplies 28.7% of the Tigris water.

The Tigris River runs south toward Fatha gorge. About 30km north of Fatha, the Lesser Zab tributary joins the river Tigris. The total catchment area of this tributary is 22,250km^2 of which 5,975km^2 lie in Iran and the remainder in Iraq. The total length of the river is 456km. The mean, maximum and minimum discharges of Lesser Zab are 227m^3/s, 3,420m^3/s on 8/3/1954 and 6m^3/s on 14/5/1964, respectively. The river Tigris mean, maximum and minimum discharges at Fatha gorge are 1,349 m^3/s, 16,380 m^3/s on 3/4/1969 and 200 m^3/s in October 1930, respectively.

Further south, the Tigris River enters the Mesopotamia plain 20km north of Samara city and then Balad city. The Adhaim tributary joins the Tigris 15km south Balad. The tributary drains an area of 13,000km^2 lying within Iraq. Its length is 330km. The mean daily discharge is of the order of 25.5m^3/s; while the maximum recorded on 19/10/1960 reached 3,520m^3/s. this tributary run almost dry during June to November each year. The banks of the river Tigris south its confluence with Adhaim tributary are below the maximum flood peak level by 3m from the left and 1.8m from the right.

Further to the south, the river reaches Baghdad. At Baghdad the mean, maximum and minimum discharges are 1,140m^3/s, 7,640m^3/s on 12/2/1941 and 163m^3/s in October, 1955. The slope of the channel is very low i.e. 6.9cm/km. About 31km south of Baghdad, the last main tributary "Diyala" joins the Tigris. Diyala's drainage basin is 31,896km^2 of which 20% lies in Iran and the rest in Iraq. The mean daily discharge is 182m^3/s while the maximum and minimum discharges are 3,340m^3/s on 25/3/1954 and 12m^3/s on 7/9/1960, respectively.

Downstream the confluence of the Tigris – Diyala River, the Tigris channel is characterized by its large number of meanders. In addition, the river discharge steadily decreases downstream due to losses. These losses include evaporation, infiltration and mainly water withdrawal through irrigation canals. An important irrigation canal includes Gharaf, south Kut city, Great Majar, South Emarah city, Mushrah and Kahlaa, South Emarah city, and Majariah canal, South Qalaat Salih. In addition, this stretch of the river is well known by the abundant occurrence of big marshes on both sides of the Tigris River. There are many small streams running from Iran toward Iraq where they discharge their water in the marshes e.g. Karkha stream discharging its water in Hiwazah marsh.

The Tigris channel reaches its minimum width at Kasarah area south of Emarah city. At Qalaat Salih the mean daily discharge of the river is 80m^3/s. Downstream this city the river joins the Euphrates River at Qurnah city forming Shat Al-Arab River. Table 5 and Figure 4 show the variation of flow along the River Tigris.

Table 5: Characteristics of the Tigris Rivers basin.

Tigris River	Turkey	Iraq	Syria	Iran	Total
Discharge km^3/year	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	1 000	37 000	375 000
Drainage Area (%)	12.0	54.0	0.2	33.80	100
River Length (km)	400	1318	44	—	1862
River Length (%)	21.0	77.0	2.0	—	100

2.3 Shatt AL-Arab River

At Qurnah city the two rivers, Tigris and Euphrates join together forming Shatt Al-Arab River which flow south into the Gulf (Figure 1). The total length of the river is 192km and its drainage area is 80,800km^2. Its annual discharge at Fao city reaches 35.2x10^{9}m^3. Two main tributaries, Suwaid and Karoon, join the main course of the river from Iran. Shat Al-Arab River is characterized by its high sediments which resulted in the formation of large number of islands during its course.

3. Groundwater

Al-Ansari et.al., 1993b and Krasny et.al., 2006 summarized the groundwater resources of Iraq. Kahariez mountain channels and hand dug wells were common practices in the ancient history of Iraq. Some of these wells and Kahariez are still in use now. Large numbers of villages were previously built near springs and later wells were dug to provide water for the inhabitants. The geographic distribution of springs and wells marked the travel routes in ancient Iraq. Development and utilization of groundwater started in 1935 where the first groundwater well was mechanically drilled. This development went through four main stages:

i. Stage one: this stage started in the mid-1930s to the beginning of the 1950s. During this stage wells were drilled without any scientific investigation or studies. Drilling operations were executed to provide water for villages and remote areas. Few basic reports on groundwater resources were written during this stage.
ii. Stage two: this stage started during the 1950s toward the end of the 1960s. This stage is marked by the activities of foreign consultants and contractors. Companies like Parsons and INGRA carried out countrywide surveys for groundwater resources in Iraq. A number of wells were drilled to for the purpose of the study required. This operation resulted in a huge survey report on the groundwater resources of Iraq published in 13 volumes.
iii. Stage three: this stage started at the end of the 1960s. The most important feature of this stage was the availability of Iraqi geologists and drilling engineers to drill the required wells all over Iraq. This stage was relatively poor in its scientific research and studies where field drilling operations were predominant, and hundreds of wells were established.
iv. Stage four: this stage started during the 1970s and marks scientific research for groundwater investigations and utilization. This was executed by national and foreign organizations and companies. The Ministry of Irrigation (now Ministry of Water Resources) was the official body responsible for these operations and practices. During this period, the state company for water wells drilling was established.

Despite the large number of groundwater wells that exists now, ground water utilization in Iraq forms a minor percentage of the water resources of the country despite its extensive use. Using the geological, structural, and physiographic characteristics, groundwater in Iraq can be divided to five main zones.

3.1 Mountain Region

This region is confined to a small area, 20,000km^2, in the north and northeastern part of Iraq. It is characterized by the availability of groundwater resources. This region can be divided into three sub regions based on petrology of the aquifers, their age and distribution.

1. Sub region one: this sub region covers limestone, dolomites and other hard rocks. The age of the rocks is cretaceous or older. The rocks of this area are

characterized by their joints and fissures where groundwater is usually found within these features. The quality of groundwater is good and can be used for different purposes. The reserve is considered medium. The groundwater in this region is usually utilized by springs.

2. Sub region two: This sub region is characterized by its weak sedimentary rocks e.g. sandstones, shale and marl, etc. The age of the rocks is cretaceous where fine grained sandstones are the principle aquifers in the area as well as marls and siltstones, where the rocks are usually jointed. The aquifers are usually of the confined type and distributed within the valleys at different depths, there is no detailed exact study regarding the quality of groundwater but it had been estimated to be medium and of good quality. Water is usually utilized through springs, hand and mechanical dug wells.
3. Sub region three: The rocks in this sub region are composed of Pleistocene and Quaternary recent valley deposits. Gravel, conglomerates, sand and sandstones form the main aquifers. Groundwater is found at shallow depths (about 30m) with very good quality (salinity 170-350ppm) and with adequate quantities. Hand dug wells, mechanical wells, springs and kahariez are the methods of groundwater utilization in this area. Kalatdiza, Rania and Shahrzor are the main important groundwater basins within this sub region.

3.2 Plateau and Hill Region

This region border's the mountain region and covers an area of 62,000km^2. The main aquifers are of Pliocene and Pleistocene age (sometimes Miocene). The aquifers of this region are considered to be of the highest quality and have the best quantity. The hills are usually folded strata and are parallel extending from NW-SE. the elevation of these hills is about 200m in the south while it increase's to 500m in the north. These hills are usually narrow with very wide plains between adjacent regions. This region can be sub divided in to two sub regions, according to the rock type of the aquifers their age and distribution:

Sub region one: The main aquifers are Bakhteiari Formation (Pliocene – Pleistocene) and recent alluvial deposits. The aquifers are composed of conglomerates, sandstones, sand and gravel. The thickness of the aquifer varies from place to place and sometimes reaches 400m. Groundwater depth does not exceed 50m below ground level and saturated thickness reaches 400m. The salinity of groundwater varies from 300ppm (Irbil basin) to 2,500ppm (Mandeli and Wend). The main basins are:

<u>Irbil plain:</u> This plain extends between the L-Zab River at south and the G.Zab River at north with a total area of 2,000km^2. The aquifers are composed of conglomerates, sandstone, sand and gravel. The salinity range is 300-500ppm. The yield of the wells is 10-30l/s while the groundwater level is 25-40m above sea level.

<u>Altonkupri plain:</u> This plain is 20km north of KirkEU, bordered by the Klilkhal mountain at the northeast, the L-Zab River from the north-northwest and the Khasa Su river from the south east, the quality of water is good and the yield of the wells

varies from 7 to 30l/s.
Aqra plain: This plain is bordered by the Aqra Mountain from north, the Khabour River from the west, the G. Zab River from east and the Maklob Mountain from the south. The quality of water is very good (salinity range 300-500ppm) and the yield of the wells varies from 10-30l/s.
Wen River basin: This basin extends from Khanaqien city at the northeast toward the confluence of the Wend River with the Diyala River at the southwest. The quality of groundwater is good to medium (salinity 500-2,000ppm) while the yield of wells is 5- 20l/s.
Sub region two: Groundwater in this area is found in Fars Formation beds. The quality and quantity of groundwater is considered medium to poor. The aquifers are mainly sandstones and shales. The most important basins are:
North Sinjar plain: these basin extents from Sinjar Mountain at the south towards the Iraqi-Syrian border at the north covering an area of 1,360km^2. The salinity of water is 300-2,500ppm but it ranges 3,000-13,000ppm in the southern parts of the basin. The yield of the wells is of the order of 7l/s.
Rabia plain: Groundwater aquifers are restricted to sandstone bed of the Upper Fars Formation. The salinity range is 500-1,000ppm, while it ranges 1,000-5,000ppm in the southern and eastern parts of the basin. Wells yield range 7-12l/s.
Tikrit-Sammara basin: This area is bordered by Hemrin and Makhul mountain ranges from the northeast, the Tharthar depression from the west and the Adhaim River from the east. The salinity range 2,000-5,000ppm whiles the yield of the wells range 7-10l/s.

3.3 Mesopotamian plain (Delta) region

This region covers the area bounded by the Rivers Tigris and Euphrates south of Baghdad to the Arabian Gulf. The groundwater in this region is usually found within the recent alluvial deposits. The Tigris and Euphrates are the main source for groundwater in this region. The salinity varies with depth where it is of the order of 3,500ppm at depths less than 20m while it reaches 20,000ppm at greater depths, the groundwater table is very shallow near the ground level. In restricted areas fresh water of very good quality can be found overlying saline groundwater.

3.4 Jezira plain region

This region occupies the northwestern part of Iraq, bordered by Sinjar mountain from the north, the Tharthar depression from the east, the Euphrates river from the south and the Iraqi-Syrian border from the west the area is characterized by its almost horizontal beds, where the Upper and Lower Fars Formations are usually exposed on the surface. These formations usually act as aquifers. The water quality of this region is usually poor due to high salt content from Lower Fars beds. Groundwater quality can be considered medium (salinity 3,000-5,000ppm) within the Upper Fars beds west of the Sinjar area but salinity increases toward the south.

3.5 Western Desert region

This region covers an area of about 226,000km^2. It is bordered from the northwest by the Iraqi-Syrian border, from the west by the Iraqi-Syriaian border, from the southwest by Saudi Arabia, from the southeast by Kuwait and the Euphrates River from its northern border. This region forms a plain area with no marked physiographic features. The slope of the area is directed from the Iraqi-Saudi Arabia border in the south west towards the Euphrates River in the north east; and from the Iraqi-Syriaian border in the west toward the Euphrates River in the east. The maximum altitude reaches 900m above sea level near the Iraq-Syria border while the minimum is less than 50m above sea level near the Hamar marsh.

The area is characterized by its large number of seasonal streams and lakes. The Khir valley divides the region into what is known as the north Badia and the south Badia. Groundwater forms the main source of water in this area and it can be found in different geologic formations. Generally groundwater movement is toward the northeastern part of the desert where in some places it runs to the surface in the form of springs.

Using the type of aquifers and its age the area can be divided into three main sub regions:

- Sub region one (Dibdibah):

This area is confined to the extreme south eastern part of the region. The main aquifer is the Dibdibah Formation (Pliocene–Miocene) which is mainly composed of sand, gravel and gypsum. The thickness of this formation varies from place to place and it can reach 140m. Groundwater salinity is relatively high (2,500-8,000ppm). Generally shallow groundwater (top 10 m of the saturated thickness) is of a better quality relative to deeper water. Yield of the wells ranges from 5 to 10l/s. Utilization of groundwater is extensive in this area for agricultural purposes especially near the Zubair-Safwan area. Despite the high salinity of the water, agricultural activities are very successful which might be due to the light and higher porosity of the soil.

- Sub region two (Calcareous rock area):

This area covers most of the western desert region and is characterized by its calcareous rock of different geologic ages (Miocene to Tertiary). The most important formations are: Dammam, Umerdhumah, Tagarat, Masad and Euphrates. The rocks of the area are jointed and fractured with thicknesses reaching 400m. Groundwater occurs at a depth of 300m and the aquifers are usually unconfined except the eastern parts where they are of a confined type. The salinity range is 2,000- 5,000ppm. The yield of the wells is usually 4-25l/s. the most promising basins for groundwater utilization are:

Salman basin: this basin covers 35,000km^2 in the southern desert. Three main aquifers are found in this basin (Dammam, Umerdhumah and Tayarat). Groundwater depth is usually 50-130m while the salinity is 2,000-8,000ppm. The yield of the wells is 3-10l/s.

Hawar-Muainah basin: This basin is located within the southern desert. The aquifers are composed of limestone and dolomite. Groundwater depth is 75-110m with salinity range 2,800-3,500ppm. The average yield of well reaches 15l/s.
Arar Valley basin: The area of this basin is 2800km^2. Umerdhumah and Tayarat Limestone beds form the main aquifers of this basin. The salinity is 700-3,000ppm and the yield of wells is 25-30l/s.
Wadi Khir basin: The area of this basin is 3,000km^2. The main aquifers are Dammam and Umerdhumah Limestone beds. The salinity is 1,700-3,000ppm and wells yield is 30l/s.
Wadi Hamer basin: This basin covers 3,400km^2 in the northern desert. The main aquifer is Tayarat Limestone Formation. The salinity is 500-3,000ppm and well yield varies from 20 to 25l/s.
Kasra area basin: This basin is located in the northern desert about 125km west of Ramadi city. It extends between the Ghadof valley at the north and the Abyiadh valley at the south. The basin is 75km in length and 50km in width. Tayarat Limestone Formation is the main aquifer. The quality of water is excellent to very good, salinity 160-1000ppm and the average yield of wells is 25l/s.

- Sub region three (Sandstone area):

This sub region is characterized by cretaceous and older rocks and covers a wide area within the northern desert. Groundwater is found in sandstone and limestone beds at depths of 50-300m. The yield of wells varies from less than 1l/s to 20l/s in confined and unconfined aquifers. The main aquifers are: Mehawir, Ubaid, Mulusa, Qaara and Sufi.
Qaara Formation (Upper Permian – middle and lower Triassic) is the most important aquifer with a varying thickness from 180 to 720m. This formation contains two aquifers. The first is 150-450m deep. The yield of this aquifer is 2-10l/s with salinity ranging 550-3,000ppm. The second aquifer is 700m deep with high groundwater yield, up to 20l/s. The salinity is of the order of 3000ppm. It should be mentioned however that the most promising areas for water utilization is the Qaara depression and Turaibiel.
Despite the presence of the great Tigris and Euphrates Rivers, groundwater is considered the only source of water in the western desert and 70% of water consumed by villages in north Iraq. Thousands of wells, Table 2-5, were drilled in different parts of Iraq for various purposes, especially in the 1980s where a large number of wells were drilled for agricultural purposes.
The total number of wells drilled up to 1990 reached 8,752 of which 1,200 are used for agricultural purposes. These wells were drilled by the government. The number of wells drilled by the private sector reached 400. After the Iraq-Kuwait war no records are available about the number of wells drilled. It is believed that a large number of wells drilled during the 1990s where the government encouraged the private sector to increase agricultural productivity due to UN sanctions.

Table 6: Number of groundwater wells drilled in each governorate in Iraq.

Governorate	Number of Wells
Duhuk	410
Naynawa	1299
Erbil	1286
Sulaymaniah	423
Tameem	1093
Diyala	647
Salahaldin	1118
Baghdad	308
Anbar	608
Muthana	201
Qadisiya	6
Karbala	148
Najaf	286
Wasit	116
Mesan	80
Dhiqar	17
Basra	576
Babil	30
Total	**8752**

It is believed that groundwater utilization will be tremendously important in Iraq in the near future due to:

About 90% of the irrigation practice in Iraq depends largely on Tigris and Euphrates Rivers. These activities are confined to areas within the vicinity of these rivers and the Mesopotamian plain. This leaves about 60% of the total area of Iraq where surface water is not available. This fact will inevitably increase the importance of groundwater utilization to secure food for the continuous increasing population in the country.

The increasing water projects in Turkey, e.g. GAP, and Syria's intention of reducing the flow of the Tigris and Euphrates to Iraq in the near future. One of the solutions to overcome this crisis is to increase groundwater utilization.

There are increasing problems with regard to the allocation of water from surface irrigation projects between the farmers and the time water is released to the different farms. These problems led some farmers to drill their private wells to maintain the required water at the required time.

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