Hydrol. Earth Syst. Sci. Discuss., 10, 14617–14644, 2013
www.hydrol-earth-syst-sci-discuss.net/10/14617/2013/
doi:10.5194/hessd-10-14617-2013

Hydrology and Earth System Sciences Discussions
Open Access

Trends and future challenges of water resources in the Tigris–Euphrates Rivers basin in Iraq

I. E. Issa[1,2], N. A. Al-Ansari[1], G. Sherwany[3], and S. Knutsson[1]

[1]Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Lulea, Sweden
[2]University of Mosul, Mosul, Iraq
[3]Ministry of Higher Education and Scientific Research – KRG, Erbil, Iraq

Received: 12 November 2013 – Accepted: 13 November 2013 – Published: 3 December 2013

Correspondence to: N. A. Al-Ansari (nadhir.alansari@ltu.se) and I. E. Issa (issa.elias@ltu.se)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Iraq is one of the riparian countries within basins of Tigris–Euphrates Rivers in the Middle East region. The region is currently facing water shortage problems due to the increase of the demand and climate changes. In the present study, average monthly water flow measurements for 15 stream flow gaging stations within basins of these rivers in Iraq with population growth rate data in some of its part were used to evaluate the reality of the current situation and future challenges of water availability and demand in Iraq. The results showed that Iraq receives annually 70.29 km^3 of water 45.4 and 25.52 km^3 from River Tigris and Euphrates respectively. An amount of 1[illegible]4 km^3 is supplied by its tributaries inside Iraq. The whole amount of water in the Euphrates Rivers comes outside the Iraqi borders. Annual decrease of the water inflow is 0.1335 $km^3\,yr^{-1}$ for Tigris and 0.245 $km^3\,yr^{-1}$ for Euphrates. This implies the annual percentage reduction of inflow rates for the two rivers is 0.294 and 0.960 % respectively. Iraq consumes annually 88.89 % (63.05 km^3) of incoming water from the two rivers, where about 60.43 and 39.57 % are from Rivers Tigris and Euphrates respectively. Water demand increases annually by 0.896 km^3; of which 0.5271 and 0.475 km^3 within Tigris and Euphrates basins respectively. The average water demand in 2020 will increase to 42.844 $km^3\,yr^{-1}$ for Tigris basin and for Euphrates 29.225 $km^3\,yr^{-1}$ (total 72.069 $km^3\,yr^{-1}$), while water availability will decrease to 63.46 $km^3\,yr^{-1}$. This means that the overall water shortage will be restricted to 8.61 km^3.

1 Introduction

Scarcity of water resources in the Middle East is one of the most important problems since the last century due to the increase of the demand and climate changes (Naff, 1994; Al-Ansari, 1998; Altinbilek, 2004; Word Bank, 2006; Droogers et al., 2012; Voss et al., 2013). Historically, water had played a vital role at the dawn of the first civilization in the life of human kind. The first development of water resources and land goes back

HESSD
10, 14617–14644, 2013

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 km^2 of land with a total storage capacity of 100 km^3 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 in 1997 and one in 1998). The irrigation projects within the GAP will consume about 22.5 km^3 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 km^3 of water per year. This indicates that the water shortage will be 193 km^3 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 km^3 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 loses 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 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

HESSD
10, 14617–14644, 2013

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 km^2 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 $km^3 yr^{-1}$. During its passage in Iraq the river receives from all of the above tributaries an additional amount of water that reaches 25 to 29 $km^3 yr^{-1}$ (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 km^3 and dropped to 17.7 km^3 (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).

HESSD
10, 14617–14644, 2013
Trends and future challenges of water resources
I. E. Issa et al.

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 4500 m 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 $km^3 yr^{-1}$ (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.

HESSD

10, 14617–14644, 2013

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

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 $m^3 yr^{-1}$ 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 (TS_3, TS_6, TS_8 and TS_{11}) and 4 stations on River Euphrates (ES_1, ES_2, ES_3 and ES_4) (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 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 (TS_1, TS_2, TS_4, TS_5, TS_7, TS_9 and TS_{10}) of the River Tigris and its tributaries as well as (ES_1) on the River Euphrates were used (Table 7). The results revealed that Iraq receives annually 45.4 and 25.52 km^3 of water form Tigris and Euphrates respectively. River Tigris receives its water from two sources, 18.04 km^3 from Turkey before entering Iraq and 27.36 km^3 from its tributaries inside Iraq. The annual reduction of water inflow for River Tigris is 0.1335 $km^3\,yr^{-1}$ which is less than Euphrates by 0.245 $km^3\,yr^{-1}$. 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 (RT_1, RT_2, RT_3 and RT_4) and 4 on the Euphrates basin (RE_1, RE_2, RE_3 and RE_4) 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 (RT_1, RT_2, RT_3, RE_1, RE_2 and RE_3). 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 (RT_4 and RE_4 down stations TS_{11} and ES_4 respectively) were estimated using population growth data (Fig. 4) and water withdrawal per capita for Iraq 2616 $m^3\,yr^{-1}$ (Table 8). The calculations results for all zones

HESSD
10, 14617–14644, 2013

showed that the average yearly demand for Iraq is 63.05 $km^3 yr^{-1}$ while Iraq receives annually 70.92 $km^3 yr^{-1}$. The demand is shared by the two river basins where it reaches 38.10 and 24.95 $km^3 yr^{-1}$ for Tigris and Euphrates Rivers respectively. The overall annual increase of the demand is 0.896 $km^3 yr^{-1}$ (0.5271 for and 0.475 $km^3 yr^{-1}$ 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 Kliot (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 $km^3 yr^{-1}$ (42.844 $km^3 yr^{-1}$ for Tigris and Euphrates 29.225 $km^3 yr^{-1}$ respectively). On the contrary, the amount of available water will decrease to 63.46 $km^3 yr^{-1}$ (44.06 and 19.40 $km^3 yr^{-1}$ for Tigris and Euphrates respectively). The total water deficit of Tigris–Euphrates Rivers basin will be 8.61 $km^3 yr^{-1}$. Water shortages will be of 9.83 $km^3 yr^{-1}$ on the Euphrates River basin at 2020. On the contrary the Tigris River will experience a surplus of 1.221 $km^3 yr^{-1}$ (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 $km^3 yr^{-1}$ 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 $km^3 yr^{-1}$ of which are 45.4 and 25.52 $km^3 yr^{-1}$ for Tigris and Euphrates Rivers respectively. Iraq receives annually 18.04 $km^3 yr^{-1}$ from River Tigris this represents 39.73 % of Tigris inflow in Iraq and the remainder 27.36 $km^3 yr^{-1}$ is supplied by tributaries of River Tigris inside Iraq. The rate

HESSD
10, 14617–14644, 2013

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

Acknowledgements. The research presented has been financially supported by Luleå University of Technology, Sweden and by "Swedish Hydropower Centre – SVC" established by the Swedish Energy Agency, Elforsk and Svenska Kraftnät together with Luleå University of Technology, The Royal Institute of Technology, Chalmers University of Technology and Uppsala University. Their support is highly appreciated.

References

Al-Ansari, N. A.: Water Resources in the Arab Countries: Problems and Possible Solutions, UNESCO International conference on Water: a Looming Crisis, Paris, 367–376, 1998.

Al-Ansari, N. A.: Management of water resources in Iraq: perspectives and prognoses, J. Eng., 5, 667–684, doi:10.4236/eng.2013.58080, 2013.

Al-Ansari, N. A. and Knutsson, S.: Toward prudent management of water resources in Iraq, J. Adv. Sci. Eng. Res., 1, 53–67, 2011.

Al-Ansari, N. A., Barazanji, A., Al-Jabari, M., and Gayara, A.: Geological Investigation of Mosul Dam Site, Report submitted to the Ministry of Irrigation, Baghdad, Iraq, 41 pp., 1981.

Al-Ansari, N. A., Sayfy, A., Al-Sinawi, G. T., and Ovanessian, A. A.: Evaluation of the water quality for the lower reaches of River Tigris using multivariate analysis, J. Water Resour., 5, 173–187, 1986.

Al-Ansari, N. A., Assad, N., Walling, D. E., and Hussan, S. A.: The suspended sediment discharges of River Euphrates at Haditha, Iraq, Geogr. Ann. A, 79, 203–213, 1988.

Al-Shahrabaly, K. M.: Rivers water discharges passing in the main gaging-stations on the Tigris–Euphrates Rivers, Ministry of Agriculture and Irrigation, Baghdad, Iraq, 119 pp., 1989.

Altinbilek, D.: Water and land resources development in south eastern Turkey, J. Water Resour. Develop., 13, 311–332, 1997.

Altinbilek, D.: Development and management of the Euphrates–Tigris basin, J. Water Resour. Develop., 20, 15–33, 2004.

Beaumont, P.: Restructuring of water usage in the Tigris–Euphrates basin: the impact of modern water management policies, Yale School of Forestry and Environmental Studies, Bulletin Series, 103, 168–186, 1998.

Biedler, M.: Hydropolitics of the Tigris–Euphrates River basin with implications for the European Union, CERIS Centre Européen de Recherche Internationale et Stratégique, Research Papers No. 1, www.ceris.be, CERIS, 1–44, 2004.

City Population: Population Statistics for Countries, Administrative Areas, Cities and Agglomerations – Interactive Maps – Charts, available at: http://www.citypopulation.de/Iraq.html#Stadt_alpha, last access: 14 September 2013.

Droogers, P., Immerzeel, W. W., Terink, W., Hoogeveen, J., Bierkens, M. F. P., van Beek, L. P. H., and Debele, B.: Water resources trends in Middle East and North Africa towards 2050, Hydrol. Earth Syst. Sci., 16, 3101–3114, doi:10.5194/hess-16-3101-2012, 2012.

FAO: Country Fact Sheet, AQUASTAT Survey Iraq, Food and Agriculture Organization of the United Nations, available at: http://www.fao.org/nr/water/aquastat/data/cf/readPdf.html?f=CF_IRQ_en.pdf, last access: 15 July 2013.

Iraqi Ministry of Water Resources: Water Resources, Mosul dam, available at: http://www.mowr.gov.iq/, last access: 25 June 2013.

Kliot, N.: Water Resources and Conflict in the Middle-East, Routledge, London, 1994.

Kolars, J.: Problems of international river management: the case of the Euphrates, in: International Water of Middle East from Euphrates–Tigris to Nile, Water Resources Management Series 2, edited by: Biswas, A. K., Oxford University Press, Oxford, 45–94, 1994.

Naff, T.: Conflict and water use in the Middle East, in: Water in the Arab World: Perspectives and Prognoses, edited by: Rogers, P. and Lydon, P., Harvard University Press, Boston, 253–284, 1994.

Najib, Y. E.: Characteristics of Tigris River at Mosul, M.Sc. thesis, College of Engineering, University of Mosul, 94 pp., 1980.

Saleh, D. K.: Stream Gage Descriptions and Stream flow Statistics for Sites in the Tigris River and Euphrates River Basins, Iraq, Data series 540, US Geological Survey, Reston, Virginia, 154 pp., 2010.

HESSD
10, 14617–14644, 2013

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◂◂ | ▸▸
◂ | ▸
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

UNEP: The Mesopotamian Marshlands: Demise of an Ecosystem, Early Warning and Assessment Technical Report no. 3, UNEP/DEWA/TR.01–3, UNEP, Geneva, 58 pp., 2001.

United Nations, UN: Water Resources Management White Paper, United Nations Assistance Mission for Iraq, available at: http://iq.one.un.org/documents/100/white%20paper-eng_Small.pdf, last access: 25 September 2013, United Nations Country Team in Iraq, 20 pp., 2010.

Voss, K. A., Famiglietti, J. S., Lo, M., Linage, C., Rodell, M., and Swenson, S. C.: Groundwater depletion in the Middle East from GRACE with implications for trans boundary water management in the Tigris–Euphrates Western Iran region, Water Resour. Res., 49, 904–914, doi:10.1002/wrcr.20078, 2013.

World Bank: Iraq: Country Water Resources, Assistance Strategy: Addressing Major Threats to People's Livelihoods, Report No. 36297-IQ, available at: http://documents.worldbank.org/curated/en/2006/06/7269106/iraq-country-water-resource-assistance-strategy-addressing-major-threats-peoples-livelihoods, last access: 25 September 2013, World Bank, Washington, D.C., 97 pp., 2006.

HESSD

10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

Table 1. The constructed dams in the basin of the Tigris–Euphrates Rivers.

Name of dam	Country	Use	Data of operation	Height (m)	Storage capacity (km^3)	Water surface area (km^2)	Hydropower (MW)
			Major dams in the River Tigris basin				
Batman	Turkey	HP,I	1998	71	1.18	49.2	198
Devegecidi	Turkey	I	1972	33	0.2	32.1	–
Cag-cag	Turkey	HP,FD	1968				14
Dicle	Turkey	HP,I	1997	75	0.60	24	110
Goksu	Turkey	I	1991	46	0.06	3.9	–
Kralkizi	Turkey	HP	1997	113	1.92	57.5	90
Al-Adheem	Iraq	HP,I	1999	–	1.5	–	–
Derbendikhan (Diyala)	Iraq	I	1961	128	3	114	–
Dibbis (L. Zab)	Iraq	I	1965	22	0.05	32	–
Diyala	Iraq	I	1969	12	–	–	–
Dokan (L. Zab)	Iraq	HP,I	1959	116.5	6.8	270	400
Hamrin (Diyala)	Iraq	I, FC	1981	40	3.56	450	50
Mosul	Iraq	HP,I,FC	1986	113	11.1	380	750
Samarra-Tharthar	Iraq	FD, I, HP	1956	–	72.8	2170	87
Dez	Iran	HP,I	1962	203	3.46	–	520
Karkheh	Iran	HP,I,FC	2001	128	7.8	–	400
Karun	Iran	HP,I	1977	200	3.14	54.8	1000
Marun	Iran	HP,I	1998	165	1.2	25	145
			Major dams in the River Euphrates basin				
Ataturk	Turkey	HP, I	1992	166	48.7	817	2400
Birecik	Turkey	HP, I	2000	53	1.22	56.3	672
Karakaya	Turkey	HP	1987	158	9.58	268	1800
Karkamis	Turkey	HP, FC	1999	21	0.16	28.4	189
Keban	Turkey	HP	1975	163	31	675	1330
Baath	Syria	HP, I, FC	1988	–	0.09	27.2	75
Tabaqa	Syria	HP, I	1975	60	11.7	610	800
Tishrine	Syria	HP	1999	40	1.9	166	630
Upper Khabur	Syria	I	1992	–	0.99	1.4	–
Al Hindiyah	Iraq	FD	1913(1989)	–	–	–	–
Haditha	Iraq	HP,I	1988	57	8.2	503	660
Fallujah	Iraq	I	1985	–	–	–	–
Ramadi-Habbaniyah	Iraq	FC	1956	–	3.3	426	–
Ramadi Raazza	Iraq	FC	1951	–	26	1810	–

HP: hydropower; I: irrigation; FC: flood control; FD: flow division. Source: UNEP (2001); Iraqi Ministry of Water Resources (2013).

HESSD
10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

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).

HESSD
10, 14617–14644, 2013

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).

HESSD
10, 14617–14644, 2013

Table 4. Characteristics of the Euphrates Rivers basin.

Euphrates River	Turkey	Iraq	Syria	Total
Discharge ($km^3 yr^{-1}$)	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)	1230	1060	710	3000
River Length (%)	41.0	35.0	24.0	100

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

HESSD
10, 14617–14644, 2013

Table 5. Details of stream flow-gaging stations.

Station	Location		Catchment area up station (km^2)	Period of record		Discharge ($m^3 s^{-1}$)			Average yearly inflow (km^3)
	Northing	Easting		From	To	Ave. yearly	Max.	Min.	
Tusan (TS_1)	37°04′00″	42°23′00″	46 700	Jan 1958	Sep 1975	666.42	3040	54.40	21.016
Zakho (TS_2)	37°08′00″	42°41′00″	3500	Nov 1958	Sep 1989	63.84	413.20	4.37	2.013
Mosul (TS_3)	36°37′57″	42°49′03″	54 900	Oct 1931	Sep 2011	569.75	3514	87.70	17.96
Eski-kelic (TS_4)	36°16′00″	43°39′00″	20 500	Jan 1932	Sep 2004	401	1781	33.80	12.646
Altun-Kupri (TS_5)	35°45′41″	44°08′52″	15 600	Nov 1931	Sep 2004	221.53	1270	19.8	6.986
Beiji (TS_6)	34°55′45″	43°29′35″	107 600	Apr 1931	Mar 2005	1295.94	6988	200	40.87
Injana (TS_7)	34°30′00″	44°31′00″	9840	Oct 1945	Sep 1997	25.48	423.90	0.00	0.803
Baghdad (TS_8)	33°24′34″	44°20′32″	134 000	Mar 1930	Sep 2009	979.26	5233	170.7	30.882
Diyala (TS_9)	35°06′01″	45°42′02″	29 700	Jan 1930	Sep 1991	180.12	1497	29.50	5.68
Gharraf (TS_{10})	32°31′55″	45°47′25″	–	Dec 1940	Mar 2005	219.89	495.30	0.00	6.934
Kut (TS_{11})	32°29′00″	45°50′00″	166 200	Oct 1931	Sep 2005	815.50	5792	65.30	25.72
Husaybah (ES_1)	34°25′20″	41°00′38″	205 000	Oct 1973	Sep 1997	708.30	2760	85.00	22.34
Hit (ES_2)	33°36′23″	42°50′14″	264 100	Oct 1932	May 1997	802	5797	71.5	25.292
Hindiya (ES_3)	32°43′01″	44°16′01″	274 100	Oct 1932	Sep 1999	551.62	3382	38.3	17.4
Nasiriya (ES_4)	31°03′01″	46°14′01″	325 000	Oct 1950	Sep 1988	430	1810	29	13.5

TS – stream flow gaging stations on River Tigris; ES – stream flow gaging stations on River Euphrates.

HESSD
10, 14617–14644, 2013

Table 6. Annual reductions in water inflow of main gaging stations.

Station	Average annually inflow		Average annual water reduction		Annual percentage reduction
	$m^3 s^{-1}$	km^3	$m^3 s^{-1}$	km^3	%
Mosul (TS_3)	569.75	17.96	1.35	0.0426	0.2372
Beiji (TS_6)	1295.94	40.87	8.64	0.272	0.666
Baghdad (TS_8)	979.26	30.882	9.73	0.307	0.994
Kut (TS_{11})	815.50	25.72	14.73	0.464	1.804
Husaybah (ES_1)	708.30	22.33	1.57	0.0495	0.222
Hit (ES_2)	802	25.292	7.72	0.243	0.961
Hindiya (ES_3)	551.62	17.40	4.02	0.127	0.730
Nasiriya (ES_4)	430	13.5	1.452	0.0458	0.339

HESSD
10, 14617–14644, 2013

Table 7. Water availability and inflow reductions for Tigris–Euphrates Rivers.

River		Average annually inflow		Average annual water reduction		Annual percentage reduction
		$m^3 s^{-1}$	km^3	$m^3 s^{-1}$	km^3	%
Tigris	Turkey	572	18.04	1.448	0.04566	0.253
	Tributaries from Iraq and Iran	867.46	27.36	2.787	0.0879	0.3213
	Total	1439.82	45.4	4.235	0.1335	0.294
Euphrates		802	25.52	7.777	0.245	0.960
Total		2241.81	70.92	12.012	0.3785	1.254

HESSD
10, 14617–14644, 2013

Table 8. Water demand for Tigris–Euphrates basin in Iraq.

Region name	Region boundary (between)	Average yearly demand		Increasing yearly demand		% demand from total demand	% annual increasing in demand
		$m^3 s^{-1}$	km^3	$m^3 s^{-1}$	km^3		
RT_1	TS_6–TS_1	100.4	3.166	0.7	0.0221	5.02	0.698
RT_2	TS_8–TS_6	258.4	8.15	4.89	0.154	12.92	1.89
RT_3	TS_{11}–TS_8	612.5	19.32	4.013	0.1265	30.64	0.655
RT_4	Down TS_{11}	236.65	7.463	7.12	0.2245	11.84	3.01
RE_1	ES_2–ES_1	141	4.447	3.414	0.1077	7.05	2.422
RE_2	ES_3–ES_2	331.6	10.46	4.042	0.127	16.6	1.214
RE_3	ES_4–ES_3	224	7.06	4.66	0.147	11.2	2.081
RE_4	Down ES_4	94.65	2.985	2.96	0.0933	4.73	3.125
Total	Iraq	1999.3	63.05	28.42	0.896	100	1.42

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

HESSD

10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

Table 9. Potential water demand on the Tigris–Euphrates basin in Iraq for the period after 2020. (Note: Beaumont (1998) used two annual water tariffs 13 300 and 15 000 $m^3 ha^{-1}$.)

River	Kolars (1994) ($km^3 yr^{-1}$)	Kliot (1994) ($km^3 yr^{-1}$)	Altinbilek (1997) ($km^3 yr^{-1}$)	Beaumont (1998) ($km^3 yr^{-1}$)	UN (2010) ($km^3 yr^{-1}$)	Current study ($km^3 yr^{-1}$)
Tigris	29.20	40.00	31.90	38.2 to 61.0	–	42.844
Euphrates	17.00	16.00	15.50	25 to 28.1	–	29.225
Total	46.20	46.00	47.4	58.2 to 89.1	77	72.069

HESSD
10, 14617–14644, 2013

HESSD
10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

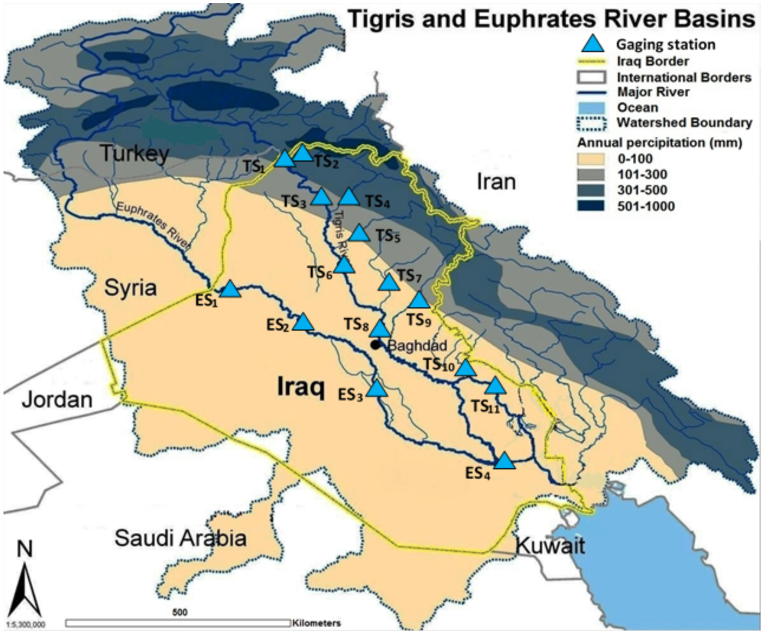

Fig. 1. General layout of the Tigris–Euphrates Rivers and locations of streamflow-gaging stations.

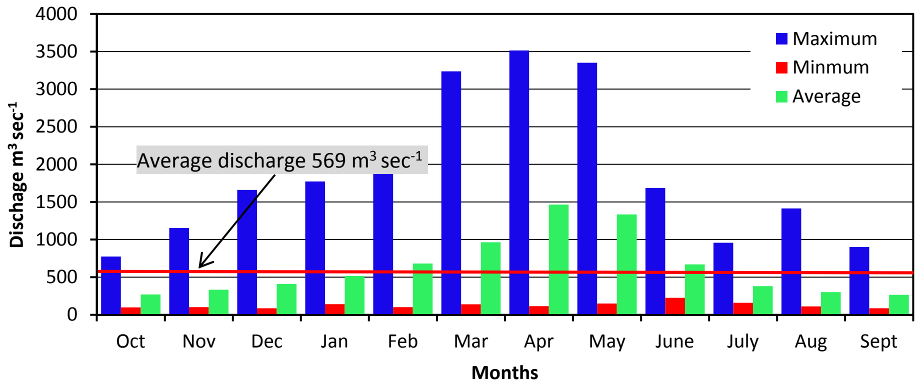

Fig. 2. Monthly (mean, minimum and maximum) discharge of Tigris River at Mosul dam site (1931–2011).

HESSD
10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◄ ►
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

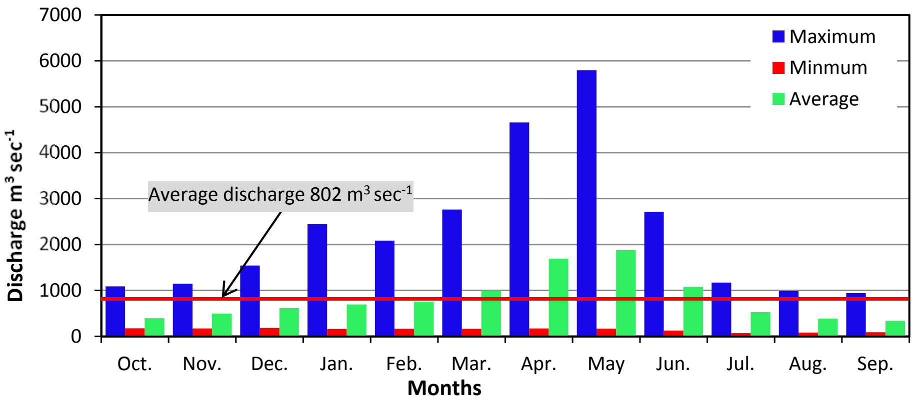

Fig. 3. Monthly (mean, maximum and minimum) discharge of Euphrates River at Hit site (1932–1997).

HESSD
10, 14617–14644, 2013

Trends and future challenges of water resources

I. E. Issa et al.

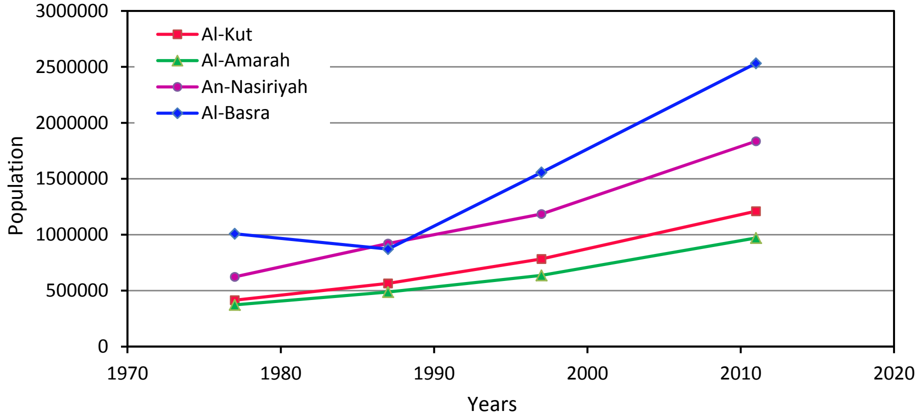

Fig. 4. Population growth distribution for Al-Kut, Al-Amarah, An-Nasiriyah and Al-Basra.

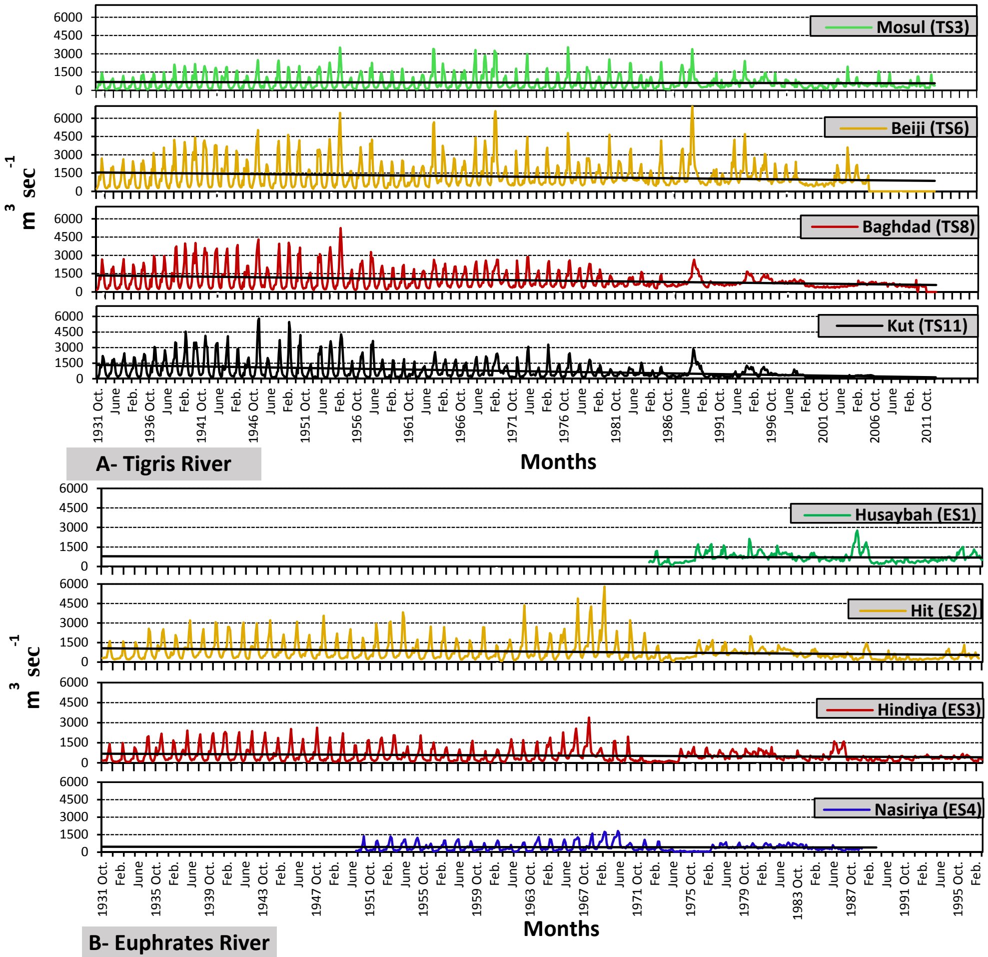

Fig. 5. Average monthly inflow of Tigris–Euphrates Rivers for main stream flow gaging-station.

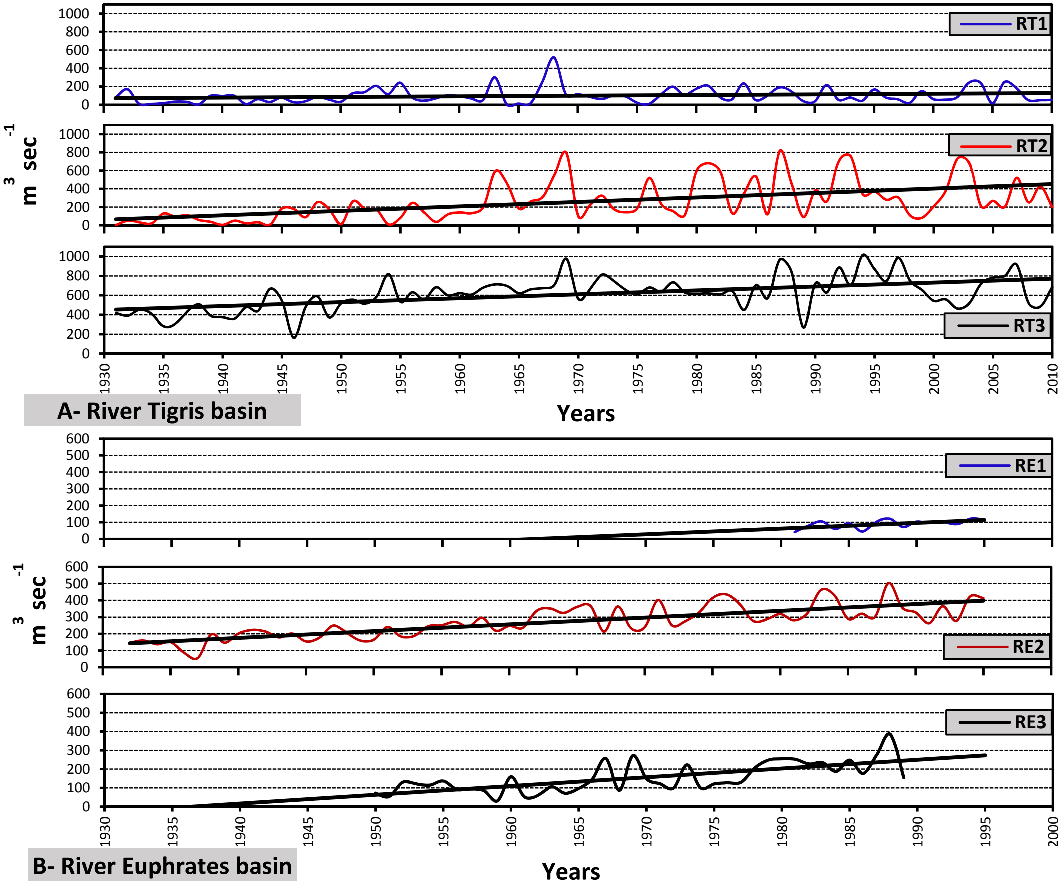

Fig. 6. Average annual demand of Tigris–Euphrates Rivers basin in Iraq.

HESSD
10, 14617–14644, 2013