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The Future of Freshwater in Shatt Al- Arab River (Southern Iraq)

Safaa A. R. Al-Asadi[1]

[1] Department of Geography, Collage of Education, University of Basrah, Basrah- Iraq

Correspondence: Safaa A. R. Al-Asadi, Department of Geography, Collage of Education, University of Basrah, Basrah- Iraq. E-mail: alasadysafaa74@gmail.com

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Abstract

This study uses data from the current rate of population growth, agricultural development and effects of climate change to estimate the future of water demand and the amount of available water in the Shatt Al-Arab River basin. The Shatt Al-Arab River will be facing a freshwater deficit as a result of the decrease of water received from its tributaries. Currently, the river receives freshwater from the Tigris only, as a result to dam construction projects on the tributaries remaining. In 2040, it is expected that the freshwater from the Tigris will not be available to the Shatt Al-Arab; therefore the intrusion of seawater into the river will increase. This may cause a gradual change of water quality in the river from freshwater to seawater. When the Shatt Al-Arab River loses freshwater from all its tributaries the seawater will progress further from Persian Gulf towards the upstream.

Keywords: Water deficit, water demand, water quality, seawater intrusion, Tigris and Euphrates, Shatt Al-Arab

1. Introduction

In full Shatt Al-Arab River (SAR) receives freshwater from four main tributaries, which are; The Tigris, Euphrates, Karkheh and Karun Rivers. Despite the fact that these tributaries originate in the mountains of Turkey and Iran, Syria and Iraq share the waters of this basin. Therefore, the SARB is considered as a transboundary river basin.

The Basin faces accelerated growth of irrigated area, population and dam construction as well as climate warming (Jones et al., 2008; Bozkurt & Sen, 2013; Issa et al., 2014). Moreover, in this region water withdrawal are very high, although the renewal water rate is low because of dominating arid climate (El-Fadel et al., 2012). There is no doubt that the increasing water demand within watersheds has the potential to greatly impact the amount of available water flow in their tributaries. Water shortages are affecting the human welfare, economic activity, and political stability (Jones et al., 2008), so, predict the future situation of water is an urgent goal.

Due to the scarcity of other water resources as a result of the arid and semiarid climates, SAR has been considered as the main water resource in Basrah governorate. The freshwater of the river also plays an important role in the health of the northern the Persian Gulf ecosystem (Al-Yamani, 2008; UN-ESCWA, 2013). Future predictions suggest increasing severe shortages of the water resources within the region (UNWWAP, 2009; Droogers et al., 2012; Al-Ansari, 2013; Abdullah, 2016). Therefore, the expected decline of freshwater discharge in the SAR will severely affect the water quality as a result of the Gulf's seawater intrusion into that river.

The main objectives of this study are (1) to predict the future of freshwater quantity in the Shatt Al- Arab channel based on the amount of water received from the River's tributaries. (2) to study the spatial and temporal variation in concentration of the total dissolved solid (TDS) along the river, as an indicator on the marine waters intrusion from Persian Gulf into the river, and to determine the extent of change in the river's water quality from freshwater to seawater.

2. Method

2.1. General Description of the River and Its Basin

The SAR is created by the confluence of the twin rivers the Tigris and the Euphrates in the city of Qurna in southern Iraq about 160 Km north of Persian Gulf. It extends to the southwest for around 120 km within Iraqi lands and 80 km the river constitutes the Iraqi-Iranian boundaries, before running into the Gulf (Figure 1). The river's total length is about 200 km, its width ranges between 330 m in Qurna to 1250 m in the estuary and its depth varies from 8.5- 24 m (Al-Asdi, 2016).

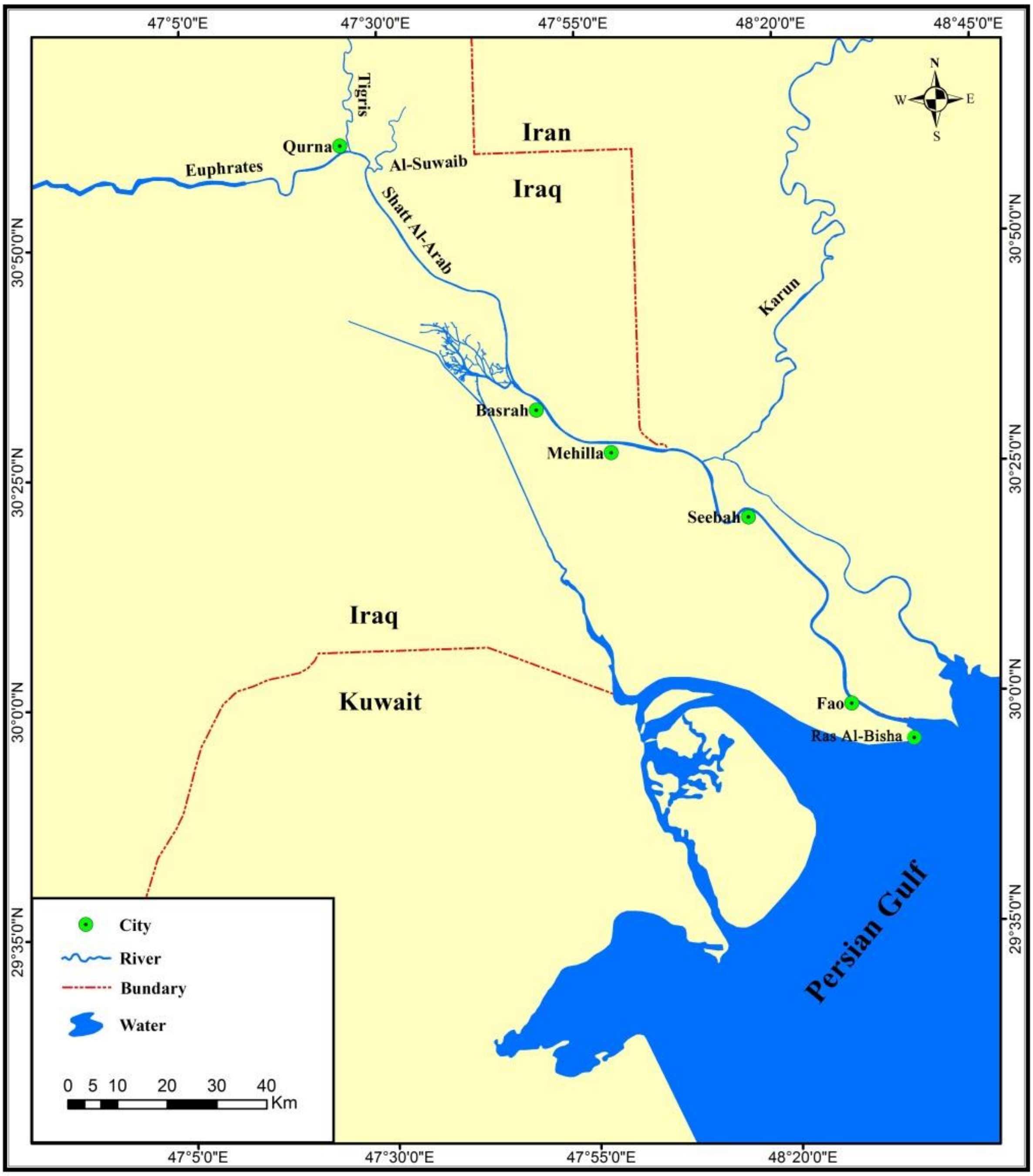

Figure 1. Map of Shatt Al-Arab River (Modified from National Geography Maps in ArcGIS)

In addition to the Tigris and the Euphrates, there are several sub-tributaries disemboguing in the SAR, most importantly the Karkheh and the Karun Rivers. The Karkheh River contributes to feeding Hawizhe marshes, whose water eventually flow into the main river via joining Al-Suwaib River on the eastern bank of the SAR about 5 km south of the Tigris- Euphrates confluence. The Karun River joins the eastern bank of that river about 72 km north of Persian Gulf.

The Shatt Al-Arab River basin (SARB) is considered a transboundary basin, shared by five neighboring countries to Iraq (Turkey, Iran, Syria, Saudi Arabia and Jordan, in addition to Iraq) (Figure 2). It is total surface area is around 938,305 km^2, 53.16% of which lies in Iraq (Table 1). Therefore, the SARB is the largest basin in southwest Asia. The total water potential of that basin is around 106.02 km^3/yr. Iraq provides 15.81% of the total water volume of the basin via feeding the Tigris River in about 16.77 km^3/yr.

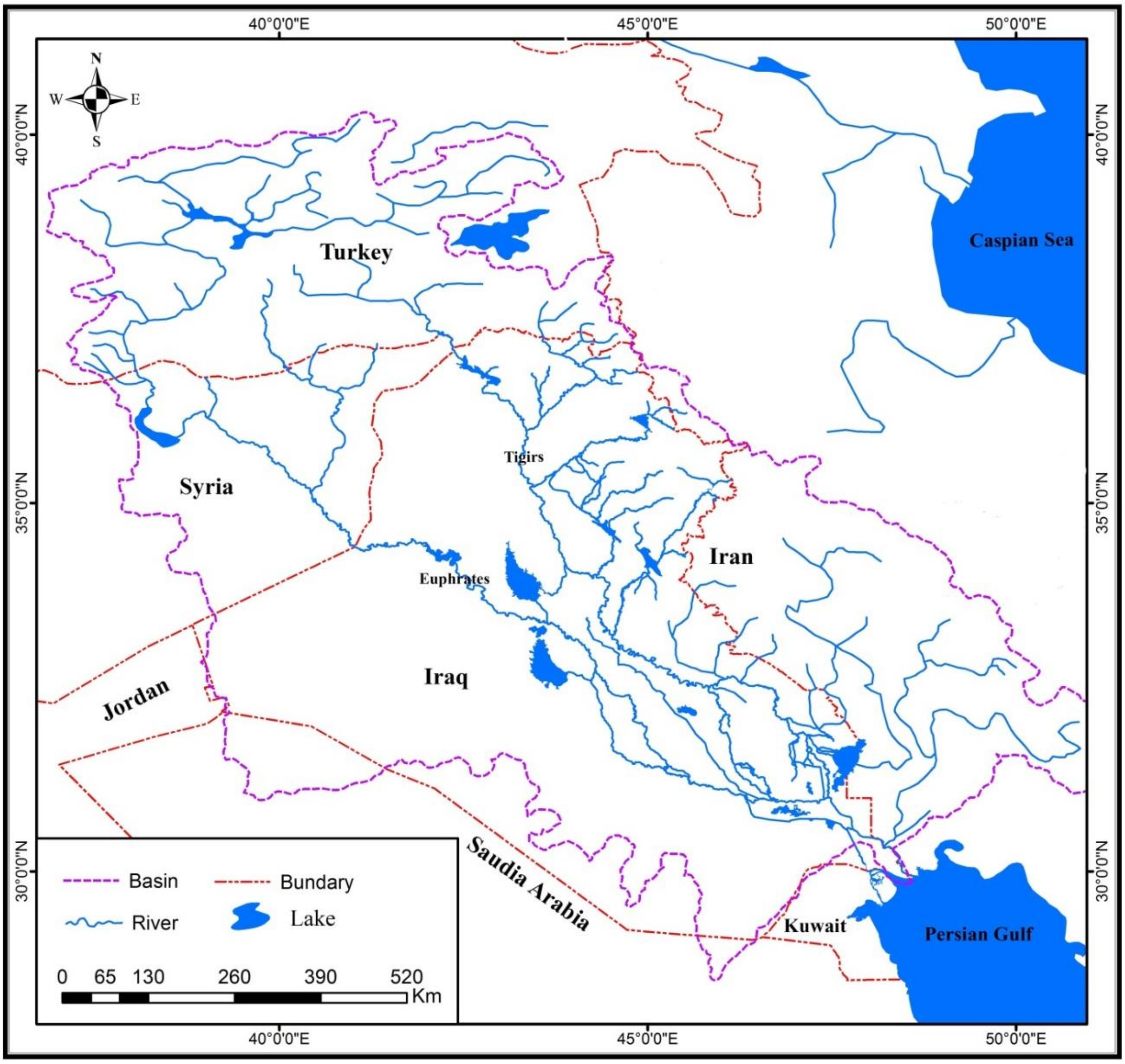

Figure 2. Map of Shatt Al-Arab River Basin (UN-ESCWA, 2013)

The Tigris and the Euphrates are the two important and greatest rivers of the basin. They contribute to about 76.89 % of the total flow, because of the twin rivers produce a mean annual flow of 43.00 km^3/yr and 32.72 km^3/yr, with a total length of 1862 km and 3000 km respectively (Table 1). The Tigris and Euphrates Rivers originate from the same region in eastern highlands of Turkey about 30 km from each other. The Karkheh and the Karun are the sub-rivers of the SARB, their flow reduces to 24.5 km^3/yr and 5.8 km^3/yr respectively. Therefore, these two rivers originate in Iran, which contribute to about 28.58% of the total flow in the SARB.

2.2 Hydrological Characteristics of the SAR

The hydrological regime of the SAR depends mainly on the discharge amount of freshwater from the four tributaries of the river and the progression of seawater by the tides from the Gulf. Declining freshwater flow into that river increases the impact of seawater (Al-Asadi, 2016). The mean annual discharge of the SAR is around 37.5 km^3/yr. The Tigris River contribute to around 14.3 km^3 (38.1%), and 11.4 km^3 (30.4%) from the Euphrates River, while the Karun River 8.5 km^3 (22.7%) and the Karkheh River 3.3 km^3 (8.8%) (Ministry of irrigation, 1979). This freshwater discharge varies seasonally according to its tributaries contribution. As a result to huge discharge of the Shatt Al-Arab, the chemical effects of seawater on the area nearby the river's estuary are limited.

The tidal regime in the river is a mixture of the diurnal and semi-diurnal types with dominant semi-diurnal (Al-Mahdi & Salman, 1997).

Table 1. Riparian countries contribution to the SARB

River	Country	Basin area km^2	%	Discharge km^3	%	Length km	%
Tigris	Turkey	45,000	12.00	21.93	51 [3]	400	21
	Iraq	292,000	77.86	16.77	39 [3]	1418	77
	Iran	37,000	9.87	4.30	10 [3]	0	0.0
	Syria	1,000	0.27	0.00	0	44	2
	Total	375,000 [1]	100	43.00 [2]	100	1862 [1]	100
Euphrates	Turkey	123,200	28.00	29.12	89 [3]	1230	41
	Iraq	206,800	47.00	0.00	0	1060	35
	Syria	96,800	22.00	3.60	11 [3]	710	24
	Saudi	13,068	2.97	0.00	0	0	0
	Jordan	132	0.03	0.00	0	0	0
	Total	440,000 [5]	100	32.72 [2]	100	3000 [3]	100
Karkheh [4]	Iran	51,325	100.0	5.8	100	964	100
Karun [5]	Iran	71,980	100.0	24.5	100	867	100
Shatt Al-Arab	Turkey	168,200	17.93	51.05	48.15	-	-
	Iraq	498,800	53.16	16.77	15.81	120+80	100
	Iran	160,305	17.08	34.60	32.64	80	40
	Syria	97,800	10.42	3.60	3.40	-	-
	Saudi	13,068	1.40	0.00	-	-	-
	Jordan	132	0.01	0.00	-	-	-
	Total	938,305	100	106.02	100	200	-

Sources:

1 (UNEP, 2001, Biedler, 2004)

2 (Kangarani , 2006; Al-Ansari et al, 2014)

3 (FAO, 2009; Biedler, 2004)

4 (Marjanizadeh et al, 2009)

5 (UN-ESCWA, 2013)

2.3 Data Collection

The data used in this study are collected from different resources, such as the population and agriculture of the SARB. These data are used to estimate the water demand. The population size over the basin's countries (Turkey, Iran, Syria and Iraq) in 2010 was adopted from UN-ESCWA (2013), and the rate of population growth during the years 2000 to 2005 was prepared by using tables of the United Nations (2001). A total agriculture area and irrigated area in 2000 within the main tributaries of the basin (the Tigris, Euphrates, Karkheh and Karun Rivers) are extracted from different resources (FAO, 2009; Patrick, 2004; Marjanizadeh et al, 2009; sadeghian et al, 2003; Jaradat, 2002). Agriculture growth rate data during the years 1991- 2000 was provided by Belloumi & Matoussi (2009). Climate change data is important to the potential available water and evaporation losses, these data are extracted from Milly et al. (2005), UNWWAP (2009), Republic of Turkey (2009), Terink et al. (2013) and Bozkurt & Sen (2013). Annual water discharge of the main tributaries was collected from Kangarani (2006), Marjanizadeh et al. (2009), UN-ESCWA (2013) and Al-Ansari et al. (2014). Total dissolved solid (TDS) concentration was used in this study to investigate the changes in river water quality during the years 1977- 1978 as a base year to 2010- 2011 based on data availability. The data concerning TDS were compiled from four important sites along the river from city center (Basrah) to the Fao city (estuary area) (Ministry of Water Resources, 1979; Hussin et al., 1991; Al-Asadi et al., 2015).

The prediction for the future size of the population, irrigated areas, evaporation values and tributaries water discharge are obtained by applying the following formula in Microsoft Excel 2010 software (Mavron & Phillips, 2000):

$$Pt = P0 \ (1 + r) \ t \tag{1}$$

Where:

Pt denotes the size of the variables at time t.

P0 denotes the initial size of the variables.

r denotes the Annual Growth rate of the variable.

It should be noted that there are several economic, cultural and technical factors which contribute to the change of growth rates. However, these rates are assumed to remain constant over the prediction decades. The end of the prediction is defined as the year 2040 to coincide with the completion of the operations of the Southeastern Anatolia Project (GAP) in Turkey is expected to last the year 2030 or even 2040 (USAWC, 2001).

The water balance of the main tributaries for four decades (2000- 2040) is predicted based on data that include the available water and the expected future water demand for agricultural and domestic use that covers about 95% of the total water withdrawal across the basin (Kangarani, 2006), taking into account the decrease of annual water discharge and increase of the evaporation losses from lakes surface due to climate changes. The seepage losses from water bodies and industrial withdrawals are excluded from this study due to the fact that seepage may be insignificant as a result to dominants of silt and clay sediments across the basin (Aqrawi, 1995), and inherent difficulty in determining industrial usage. The result of water balance is used to expect freshwater that could reach the Shatt Al-Arab channel. Water balances are computed with the assumption the growth rate of water utilization is constant for the study horizon. The water balance is computed as (Patrick, 2004):

$$Water\ Balance\ (km3/yr) = Supply - Demand \tag{2}$$

Where:

Supply = annual water discharge (km^3/yr)

Demand = annual water withdrawn (km^3/yr).

3. Results

3.1 Factors Affecting Runoff within the SARB

3.1.1 Population Growth in the SARB

Population growth leads to stress on water resources, due to the increase of the demands for freshwater, as well as the contamination events associated with land uses. Moreover, distribution of population within the region also plays a major role in the pressure on water resources available (Abughlelesha & Lateh, 2013). Humans already utilized half of the available runoff, either by consumption and agriculture or indirectly in the form of pollution (Postel, 2000).

Census estimations in the SARB shows that the population was 52.41 million people in 2010 (Table 2), more than half of the basin’s population (28.60 million, 54.57% of the total) live in Iraq. Of these, 64.33% (18.40 million) live in Tigris River and 35.67% (10.20 million) live in Euphrates River. The mean of water consumption for domestic purposes was 250- 350 liters per capita per day.

The annual population growth rate is 1.3% in Turkey, actual population growth is 1.4% in Iran, and with an annual demographic growth estimated at 2.5% in Syria (Table 2). Iraq has the highest rate of population growth among basin's countries; growing at a pace of 2.7% annually in 2000-2005. Population growth is a direct determinant factor of increases in water demand for domestic uses. So the water demand for domestic uses in the SARB is continuously increasing, especially in Syria and Iraq due to the increase of population.

3.1.2 Agricultural Development Sector on the SARB

Turkey is engaged in utilizing both the Tigris and the Euphrates Rivers by the Southeastern Anatolia Project whose contents irrigate around 9,100,000 hectares (ha) along the Euphrates basin and 540,000 ha along the Tigris basin (Table 2). Syria Plans to irrigate around 640,000 ha in the Euphrates River valley, and although it has only one bank of the Tigris River, it Plans to irrigate range from 150,000 to 372,000 ha (Haddad et al, 2013). The Iraqi government decides to irrigate an area of about 3,305,000 ha, 2,200,000 ha are in the Tigris River, 1,000,000 ha in the Euphrates River, in addition to 105,000 ha in the SAR (Jaradat, 2002).

The total planned area to be irrigated is around 600,000 ha in the Karkheh River basin. The Iranian government planned to provide irrigation water for an ultimate development irrigated area of 480,000 ha in the Karun River. With irrigated land development, the water demand is increasing. Irrigation water needs to vary according to human and natural factors in the countries of the river basin. For Turkey, Iran and Syria the annual irrigation water requirement ranges from 10,000 m^3/ha to 12,000 m^3/ha, and rise in Iraq between 13,000 m^3/ha to 15,000 m^3/ha (Table 2).

Table 2. Population and irrigated area water demand within countries of SARB

Country	River basin	P(MP) 2010 [1]	WD (L/P)	PGR [2] 00-2005	TAA (Mha)	IA (ha) 2000	WD [8] (M^3/ha)	AGR [9] 91-2000
Turkey	Tigris	3.47	250	1.3	0.54 [3]	57,000	10,000-	5.7% *
	Euphrates	7.15			0.91 [3]	103,000	12,000	
	Total/mean	10.62			1.45	409,655	11,000	
Iran	Karkheh	4.00	250	1.4	0.60 [5]	93,900	10,000-	2.2 %
	Karun	3.50			0.48 [6]	280,000	12,000	
	Total/mean	7.50			1.08	550,000	11,000	
Syria	Euphrates	5.69	350	2.5	0.64 [4]	240,000	10,000- 12,000	2.6%
Iraq	Tigris	18.40	350	2.7	2.20 [7]	1,166,880	13,000-	0.95%
	Euphrates	10.20			1.00 [7]	549,120	15,000	
	Total/mean	28.60			3.20	1,716,00	14,000	

Note. P(MP): population (Million people); WD (L/P): water demand (liter/ people); PGR: Population growth rate ; TAA (Mha): Total agriculture area (million hectares) ; IA: Irrigated area; AGR: Agriculture growth rate.

* Calculated of present study.

Sources:

1 (UN-ESCWA, 2013)

2 (UN, 2001)

3 (FAO, 2009)

4 (Patrick, 2004)

5 (Marjanizadeh *et al*, 2009)

6 (sadeghian *et al*, 2003)

7 (Jaradat, 2002)

8 (Beaumont, 1998).

9 (Belloumi &Matoussi, 2009)

3.1.3 Hydrological Projects on the SARB

The freshwater in the SAR and hydrological regime have been intensively affected by the development of dam constructions in the countries of the river basin.

Iraq was the first to start utilizing water of the Rivers by constructing irrigation and flood control systems. The first hydraulic projects were Hindiyah barrage in 1918 on the Euphrates River, and Al Kut barrage in 1939 on the Tigris River, the total storage capacity of the reservoirs was around 144.46 km^3 (Table 3). In 1962, Iran completed Dez dam on the Karun River, the overall volume of water in the reservoirs in Iran was around 18.35 km^3. In 1970, Turkey started to utilize the water of the Tigris and Euphrates Rivers by the Southeastern Anatolia Project (Guneydogu Anadolu Projesi) otherwise known as GAP. The project includes 13 sub-projects, seven of which are on the Euphrates River and six on the Tigris. The total capacity storage is around 105 km^3. Syria built three main dams constructed on the Euphrates River with a total storage capacity of 13.69 km^3. Tabaka dam is an important water irrigation project, which was completed in 1975.

3.1.4 Climate Change in the SARB

The flow of tributaries of the Basin depends mainly on winter rains and spring snowmelt in the Turkish and Iranian mountains. The flow is also influenced by the evaporation process in Syria and Iraq. Therefore, the climate conditions are dominant factors which determine the flow amount within the catchment area. Though the SARB lies in a transitional zone between humid Continental in Turkey and Iran, and semi-arid to arid of Syria and Iraq, the headwaters of tributaries has a sub-tropical Mediterranean climate with cold, wet winters and hot dry summers. The average monthly temperature over the river basin ranges between 6 ◦C in January to 34 ◦C in July. It decreases towards the north. The annual precipitation ranges from 100 to 1000 mm annually (Issa et al., 2013).

Table 3. The constructed dams and barrage within the SARB

Country	Name of dam	River	Capacity Storage km^3	Water surface area km^2	Date of operation	Use *
Turkey	Devegecidi	Tigris	0.2	32.1	1972	I
	Goksu	Tigris	0.06	3.9	1991	I
	Dicle	Tigris	0.60	24	1997	HP,I
	Kralkizi	Tigris	1.92	57.5	1997	HP
	Batman	Tigris	1.18	49.2	1998	HP, I
	Ilisu	Tigris	10.41	299.5	UC	HP
	Keban	Euphrates	31	675	1975	HP
	Karakaya	Euphrates	9.58	268	1987	HP
	Ataturk	Euphrates	48.7	817	1992	HP, I
	Karkamis	Euphrates	0.16	28.4	1999	HP, FC
	Birecik	Euphrates	1.22	56.3	2000	HP, I
Syria	Tabaqa	Euphrates	11.7	610	1975	HP, I
	Baath	Euphrates	0.09	27.2	1988	HP, I, FC
	Tishrine	Euphrates	1.9	166	1999	HP
Iran	Dez	Karun	3.46	-	1962	HP, I
	Karun	Karun	3.14	54.8	1977	HP, I
	Marun	Karkheh	1.2	25	1998	HP, I
	Karkheh	Karkheh	7.8		2001	HP, I, FC
	Karun-2	Karun	2.75		2001	HP
	Karun-3	Karun	2. 97		2004	I, H
Iraq	Al-Kut *	Tigris			1939	FD
	Samarra	Tigris	72.8	2170	1956	FD, I, HP
	Dokan	Tigris	6.8	270	1959	HP,I
	Derbendikhan	Tigris	3	114	1961	I
	Hamrin	Tigris	3.56	450	1981	I,FC
	Mosul	Tigris	11.1	280	1986	HP,I,FC
	Al-Adheem	Tigris	1.5	-	1999	HP,I
	Al-Amarah *	Tigris	-	-	2001	FD
	Al Hindiyah	Euphrates	-	-	1918	FD
	Raazza	Euphrates	26	1810	1951	FC
	Habbaniyah	Euphrates	3.3	426	1956	FC
	Haditha	Euphrates	8.2	500	1984	HP, I
	Fallujah *	Euphrates	-		1985	I

Note. HP: hydropower; I: irrigation; FC: flood control; FD: flow diversion; UC: under construction.

* Barrage.

Sources:

1(UNEP, 2001)

2(FAO, 2009)

The mean temperature in the headwaters for the 1941-2007 climatic periods is about 13 ℃, and annual mean precipitation for the same climatic periods is about 643 mm. Approximately, 70% of the total precipitation fall during the period between October and April (Republic of Turkey, 2009).

The Middle East is one of the most affected regions by the global climate change. It will suffer from warm and dry conditions at the end of the 21st century (Bozkurt & Sen, 2013). Climate change in this region results in greater water scarcity, as rainfall decreases to 25% (regionally) and up to 40% (locally) (UNWWAP, 2009). The temperature has an increasing trend of 0.64 ℃/100 years (Republic of Turkey, 2009). The Evaporation also increases but the increase is small, its maximum rate is about 9% (Terink et al., 2013; Bozkurt & Sen, 2013) the average increase is around 0.23% per year. Consequently, there will be a reduction of 10- 30% in the annual surface runoff from the headwaters regions by the year 2050 (Milly et al., 2005), with an average that decreases is about 0.5% per year.

3.2 Water Availability within the SARB

The total potential flow of the Tigris River reduction and water demand increase with time. Annual mean of water flow amount is 43.00 km^3/yr, whereas the total water withdraw at the basin is 24.56 km^3/yr, so there are water surpluses of 18.44 km^3/yr (Table 4), it can reach the SAR. A water of the river will decrease to 35.19 km^3/yr by 2040, in contrast water demand could climb up to 41.69 km^3/yr, and the water balance will be in deficits of 6.50 km^3.

In 2030, the water balance of the Euphrates River will be negative, with a mean deficit of 4.58 km^3/yr (Table 5). Due to decline in the discharge water to 28.14 km^3/yr and increase of the water consumption to about 32.72 km^3/yr. Furthermore, the water deficit in that river could increase to 14.30 km^3/yr in 2040. The reduction rate of water flow in the Euphrates River is 0.5665 km^3/yr.

Due to decreased water flow in the Tigris and Euphrates Rivers, the water salinity of the two rivers is increasing in place and time (Abdullah, 2016).

Water demand within the Karkheh and Karun Rivers basins is increasing to 4.19 km^3/yr and 7.08 km^3/yr respectively by 2040; in contrast the water discharge in both rivers is decreasing to 4.75 km^3/yr and 20.05 km^3/yr. However, the water balances in two rivers are surplus of 0.24 km^3/yr and 12.57 km^3/yr respectively (Table 6).

Table 4. Potential water use in the Tigris River basin (km^3/ yr)

Year	Country	AW	P (m)	PWD	IA (ha)	IWD	Eva.	TC	Balance
2000	Turkey	21.93	3.05	0.28	57,000	0.63	0.63 [1]	1.54	+20.39
	Iran	4.30	0	0	0	0	0	0	+4.30
	Iraq	16.77	14.10	1.80	1,166,880	16.34	4.88 [2]	23.02	+18.44
	Total	43.00	17.15	2.08	1,223,880	16.97	5.51	24.56	+18.44
2010	Turkey	20.86	3.47	0.32	99,226	1.09	0.65	2.06	+18.80
	Iran	4.09	0	0	0	0	0	0	+4.09
	Iraq	15.95	18.4	2.36	1,282,595	17.96	4.99	27.37	+11.47
	Total	40.90	21.87	2.68	1,381,821	19.05	5.64	29.43	+11.47
2020	Turkey	19.84	3.95	0.36	172,733	1.90	0.67	2.93	+16.91
	Iran	3.89	0	0	0	0	0	0	+3.89
	Iraq	15.17	24.02	3.07	1,409,785	19.74	5.11	28.13	+7.84
	Total	38.90	27.97	3.43	1,582,518	21.64	5.78	31.06	+7.84
2030	Turkey	18.87	4.49	0.41	300,694	3.31	0.69	4.41	+14.46
	Iran	3.70	0	0	0	0	0	0	+3.70
	Iraq	14.43	31.35	4.01	1,549,588	21.69	5.23	30.93	+1.66
	Total	37.00	35.84	4.42	1,850,282	25.00	5.92	35.34	+1.66
2040	Turkey	17.95	5.11	0.47	540,000	5.94	0.71	7.12	+10.83
	Iran	3.52	0	0	0	0	0	0	+3.52
	Iraq	13.72	41.92	5.37	1,703,253	23.85	5.35	34.57	-6.50
	Total	35.19	47.03	5.84	2,243,253	29.79	6.06	41.69	-6.50

Note. AW: Available water; TC: Total consumption.

Sources:

1(Beaumout, 1998)

2(Ohara *et al*., 2011)

Table 5. Potential water use in the Euphrates River basin (km^3/ yr)

Year	Country	AW	P (m)	PWD	IA (ha)	IWD	Eva.	TC	balance
2000	Turkey	29.12	6.28	0.57	103,000	1.13	1.10 [1]	2.8	+26.32
	Syria	3.60	4.45	0.57	240,000	2.64	1.45 [2]	4.66	+25.26
	Iraq	0	7.81	1.00	549,120	7.67	3.62 [2]	12.29	+12.97
	Total	32.72	18.54	2.14	892,120	11.44	6.17	19.75	+12.97
2010	Turkey	27.70	7.15	0.65	179,303	1.97	1.12	3.74	+23.96
	Syria	3.42	5.69	0.73	310,080	3.4	1.48	5.61	+21.77
	Iraq	0	10.2	1.31	603,574	8.45	3.70	13.46	+8.31

	Total	31.12	23.04	2.69	1,092,957	13.82	6.30	22.81	+8.31
2020	Turkey	26.35	8.14	0.74	312,131	3.43	1.15	5.32	+21.03
	Syria	3.25	7.28	0.93	400,623	4.41	1.52	6.86	+17.42
	Iraq	0	13.31	1.70	663,428	9.29	3.78	14.77	+2.65
	Total	29.60	28.73	3.37	1,376,182	17.13	6.45	26.95	+2.65
2030	Turkey	25.05	9.26	0.84	543,359	5.98	1.17	7.99	+17.06
	Syria	3.09	9.32	1.19	517,605	5.69	1.55	8.43	+11.72
	Iraq	0	17.37	2.22	729,217	10.21	3.87	16.3	-4.58
	Total	28.14	35.95	4.25	1,790,181	21.88	6.59	32.72	-4.58
2040	Turkey	23.83	10.54	0.96	910,000	10.70	1.20	12.86	+10.97
	Syria	2.95	11.93	1.53	640,000	7.04	1.58	10.15	+3.77
	Iraq	0	22.67	2.90	801,531	11.22	3.95	18.07	-14.30
	Total	26.78	45.14	5.39	2,351,531	28.96	6.73	41.08	-14.30

Sources:

1(Beaumout, 1998)

2(Ohara *et al*., 2011)

Table 6. Potential water use in the Karkheh and the karun Rivers basins (km^3/ yr)

Year	River	WA	P (m)	PWD	IA (ha)	IWD	Eva.	TC	Balance
2000	Kharkeh	5.80	3.48	0.32	93,900	1.03	1.07 [1]	2.42	+3.38
	Karun	24.50	3.05	0.28	280,000	3.08	1.2 [1]	4.56	+19.94
	Total	30.30	6.53	0.6	373,900	4.11	2.27	6.98	+19.94
2010	Kharkeh	5.51	4.00	0.37	116,718	1.28	1.09	2.74	+2.77
	Karun	23.30	3.50	0.32	348,040	3.83	1.23	5.38	+17.92
	Total	28.81	7.5	0.69	464,758	5.11	2.32	8.12	+20.69
2020	Kharkeh	5.25	4.60	0.42	145,080	1.60	1.12	3.14	+2.11
	Karun	22.16	4.02	0.37	432,614	4.76	1.26	6.39	+15.77
	Total	27.41	8.62	0.79	577,694	6.36	2.38	9.53	+15.88
2030	Kharkeh	4.99	5.29	0.48	180,335	1.98	1.14	3.60	+1.39
	Karun	21.08	4.62	0.42	480,000	5.28	1.29	6.99	+14.09
	Total	26.07	9.91	0.9	660,335	7.26	2.43	10.59	+15.48
2040	Kharkeh	4.75	6.07	0.55	224,156	2.47	1.17	4.19	+0.56
	Karun	20.05	5.31	0.48	480,000	5.28	1.32	7.08	+12.97
	Total	24.80	11.38	1.03	704,156	7.75	2.49	11.87	+13.53

Source:

1(Ohara *et al*., 2011)

3.3 Water Demand of the SARB

Most of water in the SARB is used for agricultural irrigation, domestic purposes and limited industrial activity. Although water demands among the basin's countries vary, the Agriculture field is the largest water consuming for each country. The average of irrigation water needs represented about 87.62%, while domestic use about 7.35% (Table 7). Therefore, the agricultural and domestic demands have around 95% of the total water withdrawal in that basin. Irrigation water requirements of Syria are 94.4% of water use in comparison with domestic and industrial uses form 3.7% and 1.9% respectively. In Turkey Irrigation water demands represent 72.5% of total water use, while domestic and industrial forms 16.4% and 11.1% respectively.

In 2000, the overall estimation of the total water demand in the SARB is 51.29 km^3/yr, the average annual water inflow was 106.02 km^3/yr. Hence, the water balance was +54.73 km^3/yr (Table 8). The water demand will be expected to increase to 94.64 km^3/yr during 2040 due to agricultural development and population growth, whereas water flow will decrease to 86.77 km^3/yr because of climate warming. This case will lead to deficit of the water balance of about 7.87 km^3/yr.

Table 7. Percentage of water Consumption by main sectors within countries of SRB

		Water withdrawal	
Country	agricultural purposes %	domestic supplies %	industrial use %
Turey	72.5	16.4	11.1
Syria	94.4	3.7	1.9
Iraq	92	3	5
Iran	91.6	6.3	2.1
Mean	87.62	7.35	5.03

Source:

(Kangarani, 2006)

Table 8. Water balance (km^3/yr) of whole river basin

Year	Total water available	Total conception	Water balance
2000	106.02	51.29	+54.73
2010	100.83	60.36	+40.47
2020	95.91	67.54	+28.37
2030	91.21	78.65	+12.56
2040	86.77	94.64	-7.87

3.4 Freshwater discharge in the SAR

The mean annual flow of the SAR at Basrah and Mehilla sites during 1977-1978 year was 919 m^3/s (28.95 km^3/yr). This increased to 1189 m^3/s (37.45 km^3/yr) at Seebah and Fao sites due to the water received from the Karun River (Table 9). In 1994- 1995 year the average annual discharge decreased to 724 m^3/s (22.81 km^3/yr) and 815 m^3/s (25.67 km^3/yr) upstream and downstream Karun River respectively. The mean monthly discharge gradually increases from January to July. The greatest flow occurred in June and May for the 1978-1979, with an average of 1506 m^3/s and 2465 m^3/s upstream and downstream respectively. In 1994-1995 the maximum flow occurred in April and February. The average values at Basrah and Fao were 900 m^3/s and 2465 m^3/s respectively.

Table 9. Monthly average of water discharge (m^3/s) in the SAR at four sites

		Months												
Year	Site	Oct.	Nov	Des	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug	Sep.	Av.
77-1978 [1]	A	230	317	495	797	916	1082	1191	1313	1506	1463	963	563	919
	B	230	317	495	797	916	1082	1191	1313	1506	1463	963	563	919
48-1960 [2]	C	392	449	565	753	1021	1515	2111	2465	2270	1456	785	486	1189
	D	392	449	565	753	1021	1515	2111	2465	2270	1456	785	486	1189
94-1995 [3]	A	632	616	600	831	891	895	900	729	686	678	612	615	724
	B	632	616	600	831	891	895	900	729	686	678	612	615	724
	C	834	879	-	1039	1064	-	725	547	-	601	826	-	815
	D	834	879	-	1039	1064	-	725	547	-	601	826	-	815
10-2011 [3]	A	39	36	35	39	51	45	38	50	43	42	45	62	44
	B	39	36	35	39	51	45	38	50	43	42	45	62	44
	C	39	36	35	39	51	45	38	50	43	42	45	62	44
	D	39	36	35	39	51	45	38	50	43	42	45	62	44

Note. A: Basrah; B: Mehilla; C: Seebah; D: Fao.

Sources:

1 (Ministry of Irrigation, 1979)

2 (Al- Mahdi & Salman, 1997)

3 (Al-Asadi *et al*., 2015)

In 2010 the hydrological regime of the SAR discharge was almost completely dependent on the freshwater influx from the Tigris River as a result of diverting flow of the Karkhah and Karun Rivers inside the Iranian boundaries and cutoff the Euphrates River. Therefore, the mean annual discharge of the SAR dropped to 44 m^3/s (1.39 km^3/yr), with a monthly variation limited, it's from 35 m^3/s and 62 m^3/s.

3.5 Water quality of the SAR

Water quality of the SAR is influenced by the chemical ions inflow from the main tributaries of the River and the marine salt from Persian Gulf (Moyel & Hussain, 2015; Abdullah, 2016). The mean TDS concentration at Basrah site for the 1977-1978 year was 0.71 g/l, increasing to 1.25 g/l at Fao site (Table 10). In 1997-1998 year the average of TDS values increased to 0.96 g/l at Basrah and 1.84 g/l at Fao in 1994-1995. Due to the loss of most tributaries the freshwater flow in the river was reduced during 2010-2011 year combined with increases of the seawater intrusion from Persian Gulf, thus the mean TDS values high increase to 1.77 g/l at Basrah, 2.30 g/l at Mehilla site, 2.27 g/l at Seebah site and the maximum TDS value of 12.21 g/l at the Fao.

Table 10. Average monthly of TDS (g/l) in the SAR at four sites

		Months												
Year	Site	Oct.	Nov	Des	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug	Sep.	Av.
77-1978 [1]	A	1.1	1.0	0.8	0.6	0.5	0.6	0.5	0.7	0.4	0.4	0.7	1.2	0.71
	B	0.63	0.65	0.89	0.94	0.80	0.83	0.78	0.88	-	-	-	0.85	0.81
	C	0.48	1.14	1.15	0.92	0.58	0.42	0.31	0.71	0.35	0.55	1.94	0.26	0.73
	D [2]	0.98	1.62	1.70	-	0.89	1.12	-	1.16	0.78	0.94	2.20	1.15	1.25
97-1998 [3]	A	1.44	1.35	1.17	1.00	1.01	1.06	1.08	0.73	0.87	0.89	-	0.29	0.96
	B	1.44	1.36	-	0.99	1.07	1.08	1.05	0.71	0.88	1.01	1.02	-	1.06
94-1995 [3]	C	1.36	0.94	-	0.90	0.83	-	0.95	0.96	-	1.10	1.47	-	1.07
	D	1.27	0.83	-	0.96	0.94	-	1.08	0.97	-	2.68	5.99	-	1.84
10-2011 [3]	A	1.59	1.94	1.82	1.58	1.70	1.89	2.01	1.89	1.55	1.80	-	1.65	1.77
	B	-	1.70	2.00	2.07	2.43	2.29	2.45	2.39	-	-	2.93	2.46	2.30
	C	2.42	1.81	1.93	1.77	2.75	-	1.51	1.19	1.83	1.40	3.05	5.27	2.27
	D	9.74	13.39	12.85	17.12	-	9.40	8.36	16.75	8.65	11.45	26.61	33.17	12.21

Note. A: Basrah; B: Mehilla; C: Seebah; D: Fao.

Sources

1 (Hussin *et al*., 1991)

2 (Ministry of Water Resources, 1979)

3 (Al-Asadi *et al*., 2015)

4. Discussion and Conclusions

The SARB is a transboundary basin, as is comprised of two main tributaries, namely the Tigris and the Euphrates Rivers that originate in Turkey, in addition to the Karkheh and the Karun Rivers which originate in Iran. The potential of the total water flow in the whole basin is 106.02 km^3/yr, whereas the mean annual freshwater of the SAR during 1977-1978 water year was 37.45 km^3/yr. This represents about 35.37% of the total available water of the basin. The Tigris and the Euphrates contribute to about 68.5% of the total freshwater of the SAR, 38.1% from the Tigris and 30.4% from the Euphrates. The Karkheh and the Karun Rivers contribute to 31.5% of the mean discharge, with 8.8% from the Karkheh and 30.4% from the Karun. Hydrological regime of the SAR depends on freshwater from these four tributaries plus the progression of seawater by the tides from Persian Gulf.

In the past (until 2000), the SAR used to receive freshwater from four main tributaries, with average about 37.5 km^3/yr. This quantity of freshwater could prevent the progress of seawater in the river and may reach a distance of about 5 km inside Persian Gulf (Massoud, 1978). Therefore, the annual mean of TDS concentration in the river water ranges from 0.71 g/l at Basrah site to 1.25 g/l at Fao site for the 1977-1978 water year.

The Present data indicate a shift toward water stress at the tributaries of the SAR in the future. Due to the increasing water demand as a result to growth of population and development of irrigated area, as well as the constructed dams within river basin. In addition to the contribution of climate warming in reduce water discharge, by reducing runoff and increasing water evaporation losses. This expected result will affect the amount of freshwater flowing in the Shatt Al-Arab channel.

The mean annual water discharge of the Tigris River will reduce to 35.19 km^3/yr by 2040, whereas the water withdraw increases to 41.69 km^3/yr, so the water balance will be in deficits of 6.50 km^3. After entering Iraq, the reduction rate of water flow in the Tigris River is 0.26 km^3/yr, while this rate increases to 0.62 km^3/yr at the confluence point (Qurna). This indicates that Iraq is the largest consuming country of water from this river.

In 2030, the water consumption of the Euphrates River will be about 32.72 km^3/yr, whereas the expected decline in the discharge water to 28.14 km^3/yr. Hence, the water balance deficit of 4.58 km^3/yr. The early deficit in the Euphrates River because of extensive water consumption in agricultural irrigated land and domestic uses, compared with the limited amount of water discharge, in addition great water loss by evaporation from reservoirs. The reduction rate of water flow in the Euphrates River is 0.5665 km^3/yr. SAR is losing freshwater from the Euphrates; as a result of the dike construction by Iraqi government in 2010 on the river at Basra boundaries about 32 km west the confluence point. Hence, the SAR lost 30.4% of the total freshwater discharge.

It should be noted that in future the surface water shortage within Iraq, eventually lead to decrease irrigated area. Hence, it cannot be expected that the Tigris and Euphrates flow dries, but the quantity and quality water properties will be unavailable for usage to extreme water flow scarcity.

Though, Turkish developing their water supply projects within the Tigris and the Euphrates Rivers basins, the overall estimation of water demand is about 7.12 km^3/yr and 10.97 km^3/yr in 2040 at the two rivers respectively. These represent 20.23% and 40.96% of the available water (35.19 km^3/yr and 26.78 km^3/yr) of the basins. While water withdrawals are increasing for Iraq into 34.57 km^3/yr and 18.07 km^3/yr in 2040 at the two rivers respectively, it represents 98.24% and 67.48% of the total water flow. Due to development of agricultural land and lack of regulatory framework for efficient use of water supply (FAO, 2012). Therefore, Iraq will witness severe shortages in water resources, as a result of the location in the lower part of basin.

The future water balances in the Karkheh and the Karun Rivers are expected to be positive, with a mean surplus of 0.24 km^3/yr and 12.57 km^3/yr respectively. The SAR is not receiving flow from two rivers since 2001 and 2009, as result of the diversion of these rivers by Iran. Hence, the SAR lost 31.5% of the total amount.

Currently, the sources of freshwater in the SAR were limited to the Tigris River, with an annual discharge of 1.39 km^3/ yr by Al-Amarah barrage, for that then the river became part of the Tigris and its basin. The freshwater discharge of the SAR dropped about 96.29% of the total discharge in the water year 1977-1978, this quantity of freshwater flow can't prevent of seawater progress to the north of Fao city. Thus, the mean TDS values in the river water were highly increased to 1.86 g/l at Basrah, and the maximum TDS values occurred at the Fao site with average 12.21 g/l. This high values due to the freshwater flow in the river was reduced during 2010-2011 year, combined with increases of the seawater intrusion from Persian Gulf, especially at the Fao site. Besides, there was a loss of most river's tributaries, in particular the Karun River which was as a natural dam that blocks or delays the progression of marine waters.

When TDS value for categorizing waters method is used (Hiscock, 2005), the river water within upstream from Basrah to Fao is considered to be of brackish water, while the downstream section from Fao to Persian Gulf is considered to be of saline water (seawater). This water is almost similar to the marine water environment at the north part of Persian Gulf, with ranges of TDS from 21.5-37.6 g/l (Al-Mahdi et al., 2007), and it's unsuitable for different uses. This could be an indicator fact that the estuary area of the SAR is regression distance of about 30 km in the river from Ras Albisha to the northern Fao city.

In 2040, the freshwater from the Tigris River will not be available to the SAR, as a result to extensive upstream water developments. Accordingly, it is expected that the TDS concentration in the Shatt Al-Arab water will record the highest levels, and progress increase of the marine waters towards the north in the river channel to reach Basrah city. As it occurred in August 2009, the saline marine water intrusion reaches to Basrah city and increased TDS values to more than 15 g/l as a result of decline freshwater discharge from the Tigris River to around 18 m^3/s. (Ministry of water resources, 2009).

According to the current changes expected, the Shatt Al-Arab channel will be just a waterway for marine waters flowing by tide phenomenon, or as drainage channel for the wastewater flowing from different uses in the watershed, especially in the part extended from the city of Basrah to Persian Gulf, with a length is about 110 km. Therefore, some researchers called for the construction the barrage in the southern part of the Shatt Al-Arab channel to prevent the intrusion of marine waters in to the river.

5. Recommendations

The study gives forward the following recommendations:

1- Reconsidering the areas irrigated by surface water, irrigation systems and crop plants within Iraq especially in Basrah province.

2- Search for new solution to avoid freshwater scarcity in the SAR by using desalination plants.

3- Dispense with an idea of a construction barrage on southern SAR, due to the fact that in the future marine waters may be the main source of water supply to the peoples.

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