General assessment of Shatt Al-Arab River, Iraq

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Abstract: During the last four decades, the changes in the hydrological system of Shatt Al-Arab River have led to significant shifts in both the quantity and quality parameters in the river water. Therefore, the levels of surface water and the current velocity, water discharge, total dissolved solid and major ions in the river water at four sites have been measured in order to provide the general assessment of water flow in the river. The study indicates that there are spatial and temporal variations of the mixing process between freshwater and seawater within Shatt Al-Arab River. Therefore, the dynamics of the hydrochemical system is often complex and heterogeneous along the river, and the exact measurement of the net water discharge is a very complicated process.

Keywords: current velocity; water discharge; water quality; seawater intrusion; Shatt Al-Arab.

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1 Introduction

Despite the fact that river estuaries are major regions for rapid economic development, the growth of human activities and the increasing water resources utilisation. Therefore, the freshwater flows of many rivers into the sea have been declining (Xu et al., 2019). The city of Basrah depends on the surface water in most of its civil, agricultural and industrial uses. The Shatt Al-Arab River is the main source of surface water in this part of Iraq, which extends from the north of Basrah to the south where it flows into the Gulf. The water source of Shatt Al-Arab River comes from the Tigris and the Euphrates Rivers flow within Iraq and the rivers of Karkheh and Karon flow within Iranian lands. Because of the scarcity of the water, the Euphrates River was cut as a feeder for the Shatt Al-Arab and the water used for feeding Al-Hammar marshes, as well as Iran cut off the waters of Karkheh and Karon Rivers to reach Shatt Al-Arab. So, the Tigris River becomes the only source of fresh water feeding (Al-Asadi, 2017; Alhello et al., 2019).

The hydrological system of Shatt Al-Arab River is affected by the tidal phenomenon of the Arabian Gulf. The seawater flows during the tidal into the river towards the upstream. Therefore, depending on the flow of freshwater from the Tigris River, the extent and distance of the seawater into the river is determined. When the water flows in the river are drastic decreased, the salt front is moving toward the centre of the city of Basrah location (Al-Asadi, 2016; Abdullah, 2016), may be causing high salinity of water to levels where it becomes unsuitable for any use.

The water quality in Shatt Al-Arab River reflects the combined effects of natural and anthropogenic factors (Al-Asadi et al., 2019). Whereas the salinity coming from seawater is one of the most important reasons for the salinity of Shatt Al-Arab waters, as well as the amount of salty water comes to the river from the returned water from sewage and drainage channels. It is also coming from the marshes contribute to raising the salinity of the river water. Shatt Al-Arab water also suffers from another problem, which is the problem of organic pollution due to the discharge of a section of domestic sewage through the river branches especially in the urban area where the main population is grouped in Basrah.

The main objective of the present study is to provide the general assessment of Shatt Al-Arab River water conditions, by describing the main quantity and quality characteristics in the river, such as water level, current velocity and water discharge, as well as distribution of water salinity and major ions.

2 Methods

2.1 Extent of Shatt Al-Arab Basin

Shatt Al-Arab Basin is the largest basin in southwest Asia with a total surface area is around 938,173 km^2 (Table 1). It extends (Figure 1) over 10 degrees of latitude, from 40°N to 30°S, and it is considered a transboundary basin, shared by six countries (Turkey, Iran, Syria, Saudi Arabia and Jordan, in addition to Iraq). The annual total flow of whole basin at about 105.70 km^3/yr. Although the basin is spread over six countries, the regions which actually contribute significant amount to the tributaries flow are largely confined to highlands of Turkey (50.43 km^3/yr) and Iran (34.60 km^3/yr). They contribute to about 80.44% of the total water flow. While Iraq provides 16.53% of the total water volume of the basin via feeding the Tigris and Euphrates Rivers is about 16.77 and 0.7 km^3/yr respectively. Saudi Arabia and Jordan together cover about 1.4% of the total basin area, but there are almost no renewable water resources in these areas.

Table 1 Riparian countries contribution to Shatt Al-Arab River Basin

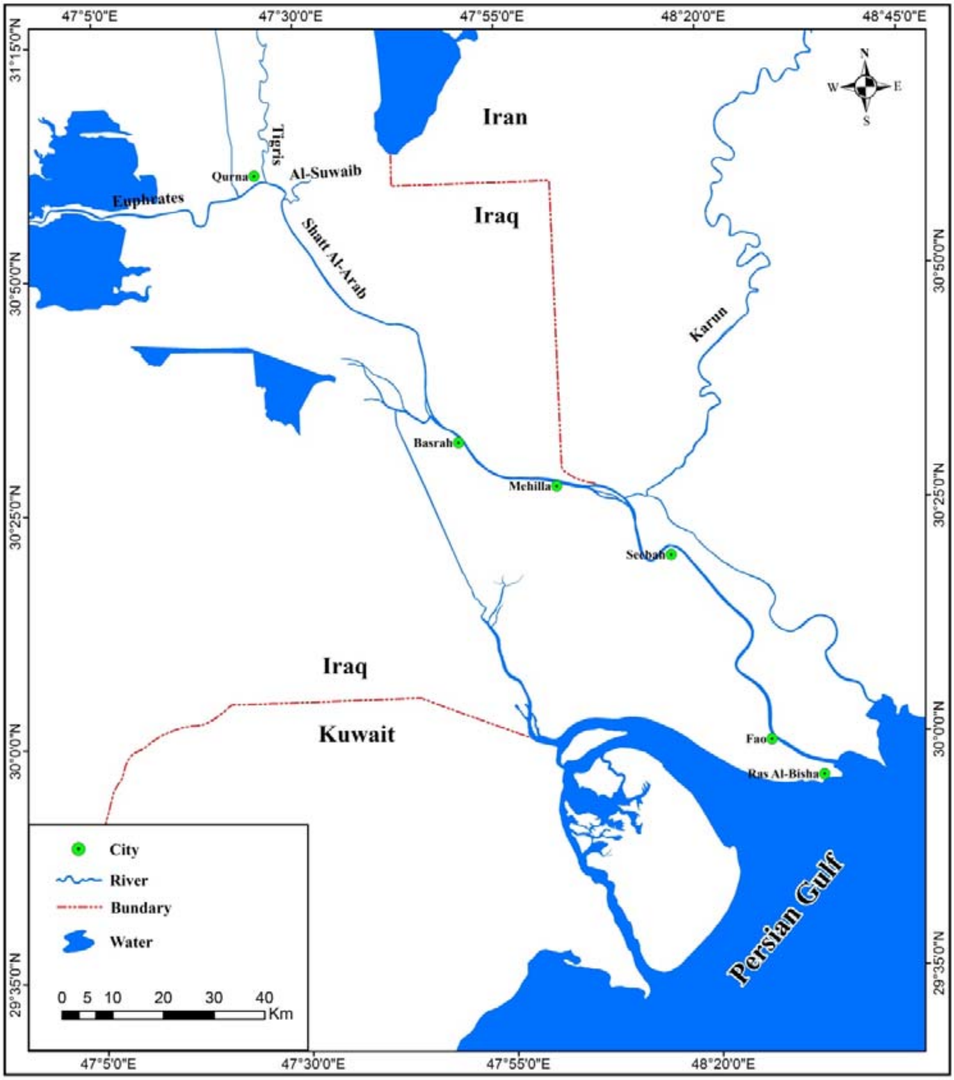
River	*Country*	*Basin area* km^2	*%*	*Discharge* km^3	*%*	*Length km*	*%*
Tigris[1]	Turkey	45,000	12	21.93	51	400	21.6
	Iraq	292,000	54	16.77	39	1,418	76.6
	Iran	37,000	33.8	4.3	10	0	0
	Syria	1,000	0.2	0	0	32	1.8
	Total	375,000	100	43	100	1,850	100
Euphrates[2]	Turkey	123,200	28	28.5	88	1,230	41
	Iraq	206,800	47	0.7	2.0	1,060	35
	Syria	96,800	22	3.2	10	710	24
	Saudi	13,068	2.97	0	0	0	0
	Jordan	132	0.03	0	0	0	0
	Total	440,000	100	32.4	100	3,000	100
Karkheh[3]	Iran	51,325	100	5.8	100	964	100
Karun[4]	Iran	71,980	100	24.5	100	867	100
Shatt Al-Arab	Turkey	168,200	17.93	50.43	47.71	-	-
	Iraq	498,800	53.16	17.47	16.53	115+85	100
	Iran	160,305	17.09	34.60	32.73	85	42.5
	Syria	97,800	10.42	3.20	3.03	-	-
	Saudi	13,068	1.39	0	-	-	-
	Jordan	132	0.01	0	-	-	-
	Total	938,173	100	105.7	100	200	-

Source: [1]UNEP (2001), Biedler (2004), Kangarani (2006), FAO (2009)
[2]UN-ESCWA (2013), Abdullah (2016)
[3]Marjanizadeh et al. (2009)
[4]UN-ESCWA (2013)

2.2 *Hydrological system of Shatt Al-Arab River*

Hydrological characteristics of Shatt Al-Arab River depend mainly on the flow rate of freshwater entering the river from the tributaries and the progression of seawater by the tides from Arabian Gulf. The Tigris, Euphrates, Karkheh and Karun Rivers are the major tributaries of the Shatt Al-Arab River. In the past, the river used to receive freshwater from four main tributaries, with average about 37.5 km^3/yr. The Tigris River contributes around 14.3 km^3 (38.1%), with 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) because of diverting flow of the Karkheh and Karun Rivers inside the Iranian boundaries and cut off the Euphrates River before confluence with Tigris. The present situation of the river hydrological system is completely different. Since 2010, the river depends mainly on the freshwater flow from the Tigris River.

Figure 1 Map of Shatt Al-Arab River (see online version for colours)



Source: Modified from National Geography Maps in ArcGIS

The water flow in the Shatt Al-Arab River is very complex because it is affected by the tidal phenomenon of the Arabian Gulf where the river experiences a tidal cycle of approximately 13 hours, which has a mixed-diurnal and semi-diurnal pattern (Abdullah, 2016). The average tidal range varies from about 1 m at Basra to around 3 m at Fao (Al-Ramadhan and Pastour, 1987). By tidal phenomenon the seawater intrudes into river mouth and moves in an upstream direction against the river flow. The seawater diffuses and mixes with the freshwater (UNESCO, 1992; Xinfeng and Jiaquan, 2010), and results in salinisation of river water; it affects the freshwater biota not adapted to saline water (Mikhailova, 2013). Due to freshwater discharge, channel geomorphology and bottom friction, the tidal wave is distorted and damped as it propagates upriver (Matte et al., 2014). However, the length of the seawater intrusion from the Arabian Gulf into the River may reach 92 km (Abdullah, 2016).

2.3 Sample collection and field work

Four locations were selected along Shatt Al-Arab River to collect data and water samples which represent different conditions. Qurna location was considered to be a reference site because it is the input point for the river water which in general has clean water. The area between Basrah and Seebah locations is affected by domestic sewage discharge and agricultural activities which became non-point sources of pollution. In contrast, the impact of seawater is more prevalent in Fao site. Water samples were collected from the middle of the Shatt Al-Arab River channel. The samples were carried out during July to December in 2017 and January to June in 2018. The field measurements for E.C. were done by using Horbia multimeter device. All samples were stored in cool boxes and sent to water quality laboratory at the Department of Marine Environmental Chemistry Marine Science Center, University of Basrah, where they were analysed using standard methods according to APHA (2005).

In general, the history date was collected from the observations and analyses conducted by the researchers for almost twenty years and from some literature sources and scientific studies. A staff gauge was used to collect the water level at the studied locations, the levels were corrected to sea water level. The Acoustic Doppler Current Profile (ADCP) was used to measure the discharge and current velocity. The validation of results was tested according to APHA (2005).

3 Results

3.1 Hydraulic characteristics

3.1.1 Water levels

The field study showed a gradual increase in the tidal range, the range at Qurna site was 22 cm, while the range was 255 cm at the Fao site. the tide range at the Seebah site is 106 cm compared to the Basrah site which recorded 43 cm (Table 2). The flow direction is not uniform for all sites. For example, if there is high tide in Fao then there are low tides in city centre of Basrah (Figure 2). Figure 3 shows the equation of the velocity of the tidal wave as:

$$h = 0.0038 * D + 1.0165$$

where

h water level

D distance reached by the tide wave (km).

According to this equation when the water level is not affected by tide (that means: h = 0) the maximum distance was reached by this wave is 271 km north of Fao site (Figure 3).

Table 2 Levels of surface water (m) at four sites of Shatt Al-Arab River in August 2018

Hour	*Site*							
	Qurna		*Basrah*		*Seebah*		*FAO*	
	Status	*Level*	*Status*	*Level*	*Status*	*Level*	*Status*	*Level*
6:00	Flood	1.61	Ebb	1.4	Ebb	0.9	Flood	1.5
6:30	Flood	1.64	Ebb	1.38	Ebb	0.8	Flood	1.7
7:00	Flood	1.66	Ebb	1.35	Ebb	0.72	Flood	1.98
7:30	Flood	1.68	Ebb	1.29	Ebb	0.58	Flood	2.25
8:00	Flood	1.69	Ebb	1.23	Slack	0.56	Flood	2.44
8:30	Flood	1.70	Ebb	1.18	Flood	0.73	Flood	2.65
9:00	Slack	1.70	Ebb	1.15	Flood	0.92	Flood	2.86
9:30	Ebb	1.68	Ebb	1.12	Flood	1.14	Flood	2.95
10:00	Ebb	1.67	Slack	1.13	Flood	1.26	Flood	3.04
10:30	Ebb	1.66	Flood	1.22	Flood	1.4	Flood	3.1
11:00	Ebb	1.63	Flood	1.29	Flood	1.49	Slack	3.1
11:30	Ebb	1.61	Flood	1.36	Flood	1.55	Ebb	3.08
12:00	Ebb	1.59	Flood	1.48	Flood	1.58	Ebb	2.95
12:30	Ebb	1.57	Flood	1.51	Flood	1.58	Ebb	2.72
13:00	Ebb	1.55	Flood	1.52	Slack	1.58	Ebb	2.55
13:30	Ebb	1.53	Flood	1.53	Ebb	1.56	Ebb	2.28
14:00	Ebb	1.52	Flood	1.54	Ebb	1.49	Ebb	1.95
14:30	Ebb	1.51	Flood	1.55	Ebb	1.41	Ebb	1.65
15:00	Ebb	1.50	Slack	1.55	Ebb	1.32	Ebb	1.45
15:30	Ebb	1.49	Ebb	1.52	Ebb	1.22	Ebb	1.15
16:00	Ebb	1.48	Ebb	1.48	Ebb	1.08	Ebb	0.93
16:30	Ebb	1.47	Ebb	1.45	Ebb	0.97	Ebb	0.75
17:00	Slack	1.47	Ebb	1.41	Ebb	0.91	Ebb	0.65
17:30			Ebb	1.38	Ebb	0.82	Ebb	0.6
18:00			Ebb	1.35	Ebb	0.78	Ebb	0.55
Tidal range		22		43		102		255

3.1.2 Current velocity

Current velocity play a key role in the movement of material and growth and species of the aquatic life in rivers (Chambers et al., 1991; Li et al., 2016). The water flow in Shatt Al-Arab River was mainly affected by tide phenomenon from the Arabian Gulf, freshwater discharge from river tributaries, and depth of water. In general, the flow speeds of the river are stronger at springs than at neaps, and the vertical current speed decreases little with depth (Al-Ramadhan and Pastour, 1987). Surface water velocities at two sites of Shatt Al-Arab River are summarised in Table 3. The velocity of flow during flood and ebb tides is asymmetric with changes according time. The measured maximum current velocity reached 0.91 m/sec., which occurred in the flood phase at Fao site, while the minimum value of river velocity was 0.04 m/sec. at Basrah site during slack water time.

Figure 2 Water levels (m) of Shatt Al-Arab River at four sites in August 2018 (see online version for colours)

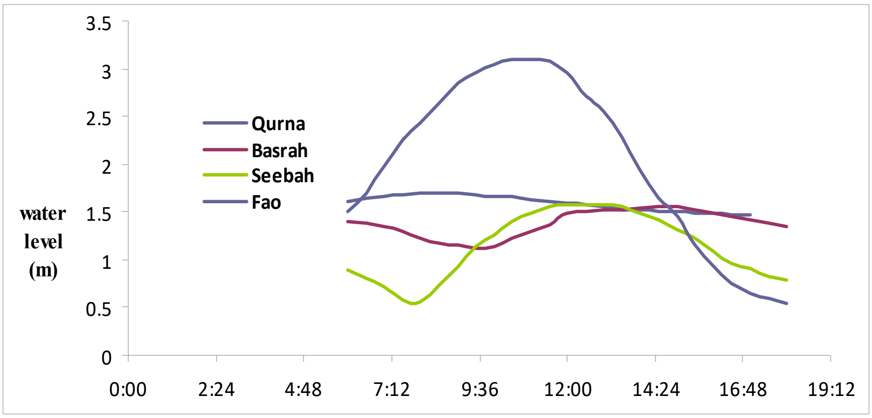
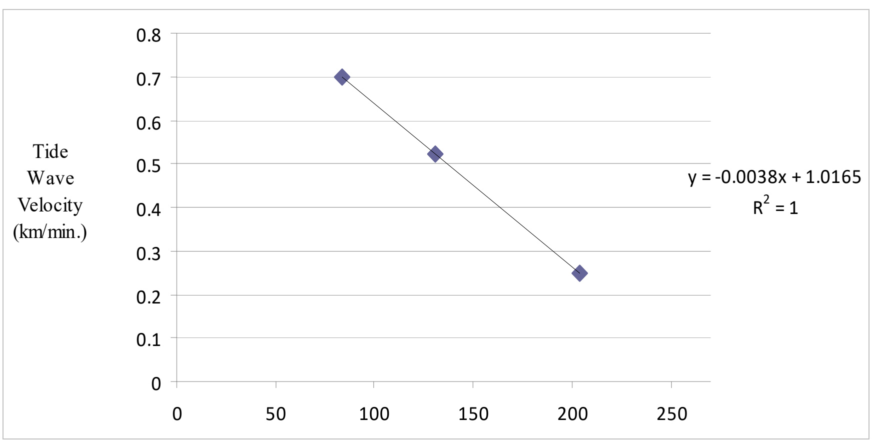


Figure 3 Water level (m) relation across the river course (km) (see online version for colours)



3.1.3 River discharge

Due to tidal phenomenon, the flow conditions of Shatt Al-Arab River are varying rapidly. The time variation of water level and discharge has shown that during ebb currents the sign of discharge will be positive, with a negative sign during flood flows. Ebb discharge shows that the direction of flow is toward downstream and flood discharge refers to the opposite direction. Net water discharge in the river is the difference between ebb and flood discharges. The water discharge rates in the Shatt Al-Arab River at Fao site were highest, with the range varying from 1,318 to –2,366 m^3/sec. in ebb and flood respectively. The lowest discharge rate was found at Basrah site, ranging from –730 to 934 m^3/sec. during flood and ebb respectively (Table 4).

Table 3 Surface water velocities (m/sec.) at two sites of Shatt Al-Arab River during spring tidal cycle in May 2011

Hour	*Site*			
	Basrah		*Fao*	
	Status	*Velocity*	*Status*	*Velocity*
8	Ebb	0.30	Ebb	0.65
9	Ebb	0.33	Ebb	0.63
10	Ebb	0.34	Ebb	0.59
11	Ebb	0.35	Slack	0.16
12	Ebb	0.35	Flood	0.37
1	Ebb	0.21	Flood	0.91
2	Slack	0.04	Flood	0.91
3	Flood	0.13	Flood	0.61
4	Flood	0.32	Slack	0.09
5	Flood	0.22	Ebb	0.34
6	Flood	0.29	Ebb	0.41
7	Flood	0.22	-	-
8	Slack	0.03	-	-
Average ebb		0.31		0.52
Average flood		0.24		0.70

Table 4 Water discharge (m^3/sec.) at two sites of Shatt Al-Arab River during spring tidal cycle in May 2011

Hour	*Site*			
	Basrah		*Fao*	
	Status	*Velocity*	*Status*	*Velocity*
8	Ebb	919	Ebb	1,648
9	Ebb	988	Ebb	1,615
10	Ebb	1,008	Ebb	1,414
11	Ebb	1,044	Slack	–898
12	Ebb	1,027	Flood	–1,292
1	Ebb	617	Flood	–3,093
2	Slack	–292	Flood	–3,189
3	Flood	–474	Flood	–1,890
4	Flood	–969	Slack	45
5	Flood	–651	Ebb	829
6	Flood	–897	Ebb	1,083
7	Flood	–657	-	-
8	Slack	–62	-	-
Average ebb		934		1,318
Average flood		–730		–2,366

3.1.4 Freshwater discharge

The average annual freshwater discharge of Shatt Al-Arab River at Basrah site was 919 m^3/sec. during 1977–1978. Water flow of Karun River increases freshwater discharge in Fao site to 1189 m^3/sec. (Table 5). In 1994–1995 the mean annual discharge decreased to 724 and 815 m^3/sec. at the two sites respectively. The rate of annual freshwater flow was 246 m^3/sec. at Basra and Fao sites during 2007–2008. The rates of monthly freshwater discharge gradually rise from January to July. The greatest freshwater flow occurred in June and May, with an average of 1,506 m^3/sec. and 2,465 m^3/sec. at two sites respectively. In 1994–1995 the maximum freshwater discharge occurred in April at Basrah and in February at Fao. The rates were 900 and 1,064 m^3/sec. respectively. In 2010, Shatt Al-Arab River discharge was completely dependent on the freshwater flow from the Tigris River only. Therefore, the mean annual discharge of the river dropped to 58 m^3/sec., with a monthly variation limited from 42 to 90 m^3/sec. during October and May respectively.

3.2 Water quality

3.2.1 Salinity distribution

The mean TDS concentration at Qurna site for the 1977–1978 year was 0.8 g/l, increasing to 1.25 g/l at Fao site (Table 6). In 1997–1998 year, the average of TDS values increased to 0.95 g/l at Qurna 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 2017–2018 combined with increases of the seawater intrusion from Arabian Gulf, thus the mean TDS values increased to 1.5 g/l at Qurnan site, 8.4 g/l at Basrah, 12.2 g/l at Seebah and the maximum TDS value of 26.3 g/l at Fao.

3.2.2 Major ions

The concentrations of the major ions in river's water are summarised in Table 7 and Figure 4, ionic concentrations trend in Table 8, and changing ratio for ionic concentration in Table 9. The concentrations of major ions (Na, Ca, Mg, K, HCO_3, Cl and SO_4) were recorded at high levels, ranging from 14 to 16,810 mg/L. There are a geographical differences among the locations of Shatt Al-Arab River. Pattern of the anion and cation concentrations were clearly seen as increasing from north toward south along the river. Hence, the highest concentrations of ions are found at Fao site, while Qurna has lowest levels of concentration in river water. The Cl ion in water is the predominant one at each of the studied sites, ranging from 321 to 16,810 mg/l compared to other ions. The K ion has the lowest concentration of 14 to 323 mg/l. The major ions distribution pattern is in the order of Cl > Na > Mg > Ca > SO_4 HCO_3 at the different sites.

Table 5 Monthly average of water discharge (m^3/sec.) in the Shatt Al-Arab River at Basrah and FAO sites

Year		*Months*												
	Site	*October*	*November*	*December*	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*Av.*
1977–1978[1]	Basrah	230	317	495	797	916	1,082	1,191	1,313	1,506	1,463	963	563	919
1948–1960[2]	FAO	392	449	565	753	1,021	1,515	2,111	2,465	2,270	1,456	785	486	1,189
1994–1995[3]	Basrah	632	616	600	831	891	895	900	729	686	678	612	615	724
	FAO	834	879	-	1,039	1,064	-	725	547	-	601	826	-	815
2008–2008[3]	Basrah	188	197	217	256	264	295	306	301	281	263	216	164	246
	FAO	188	197	217	256	264	295	306	301	281	263	216	164	246
2017–2018[4]	Basrah	42	44	44	46	49	60	75	90	76	65	59	49	58
	FAO	42	44	44	46	49	60	75	90	76	65	59	49	58

Source: [1]Ministry of Irrigation (1979)
[2]Al-Mahdi and Salman (1997)
[3]Al-Asadi et al. (2015)
[4]Ministry of Water Resources (2018)

Table 6 Average monthly of TDS (g/l) in the Shatt Al-Arab River at four sites

Year	*Site*	*Months*												
		October	*November*	*December*	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*Av.*
1977–1978[1]	Qurna	1.2	1.1	1.0	0.8	0.7	0.7	0.6	0.5	0.5	0.5	1.0	1.1	0.8
	Basrah	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
	Seebah	0.63	0.65	0.89	0.94	0.80	0.83	0.78	0.88	-	-	-	0.85	0.81
	FAO	0.98	1.62	1.70	-	0.89	1.12	-	1.16	0.78	0.94	2.20	1.15	1.25
1997–1998[2]	Qurna	1.3	1.2	1.2	1.0	1.0	0.8	0.9	0.8	0.7	0.6	0.9	1.1	0.95
	Basrah	1.44	1.35	1.17	1.00	1.01	1.06	1.08	0.73	0.87	0.89	-	0.29	0.96
	Seebah	1.44	1.36	-	0.99	1.07	1.08	1.05	0.71	0.88	1.01	1.02	-	1.06
	FAO	1.27	0.83	-	0.96	0.94	-	1.08	0.97	-	2.68	5.99	-	1.84
2017–2018	Qurna	1.0	1.2	1.4	1.3	3.9	2.2	1.3	1.2	1.1	1.1	1.2	1.2	1.5
	Basrah	2.2	3.8	3.4	3.2	3.0	3.4	2.9	2.5	4.9	17.4	22.8	31.2	8.4
	Seebah	6.1	2.4	5.7	5.2	4.1	4.9	4.1	3.6	9.8	28.6	35.9	36.2	12.2
	FAO	14.3	13.4	16.2	17.9	20.1	20.3	22.3	24.5	32.7	39.4	47.4	47.5	26.3

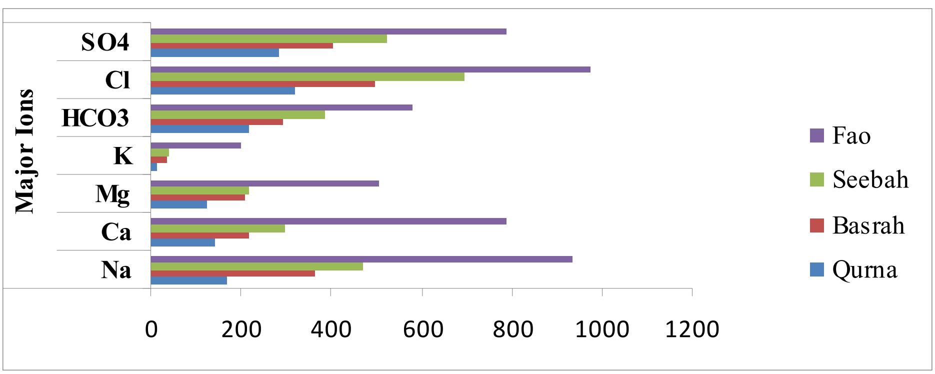
Source: [1]Ministry of Irrigation (1979)
[2]Al-Asadi et al. (2015)

Table 7 Average of major ions (mg/l) in the Shatt Al-Arab River at four sites during 2008 and 2018

Year	*Site*	*Major Ions*						
		Na	*Ca*	*Mg*	*K*	*HCO_3*	*Cl*	*SO_4*
2008[1]	Qurna	168	142	126	14	218	321	285
	Basrah	364	215	207	34	292	415	405
	Seebah	469	295	218	39	384	696	523
	FAO	936	789	506	198	581	974	790
2018	Qurna	183	92	87	28	162	502	181
	Basrah	2,788	2,230	1,972	92	842	8,180	742
	Seebah	3,109	3,450	6,070	187	802	12,520	880
	FAO	4,989	5,732	8,276	323	662	16,810	1,110

Source: [1]Al-Saad et al. (2015)

Figure 4 Ions trend at studied locations on Shatt Al-Arab River for the years of 2008 and 2018 (see online version for colours)



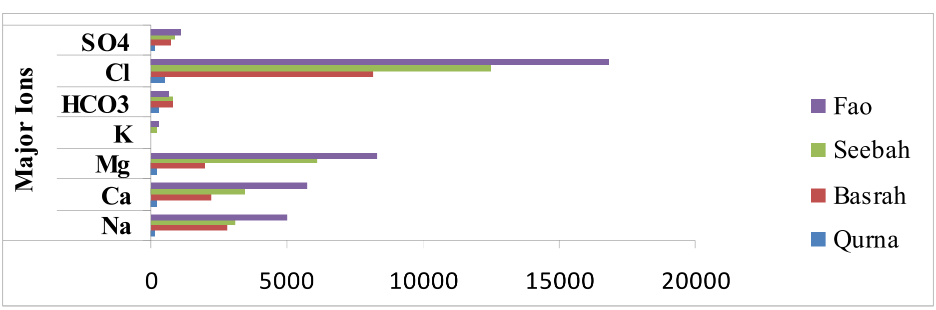


Table 8 Ions trend at studied locations on Shatt Al-Arab River for the years of 2008 and 2018

Site	*2008*	*2018*
Qurna	Cl > SO_4 > HCO_3 > Na >Ca > Mg > K	Cl > Na > SO_4 > HCO_3 >Ca> Mg > K
Basrah	Cl > SO_4 > Na > HCO_3 >Ca > Mg > K	Cl > Na >Ca > Mg > HCO_3 > SO_4 > K
Seebah	Cl > SO_4 > Na > HCO_3 >Ca > Mg > K	Cl > Mg >Ca > Na > SO_4 > HCO_3 > K
FAO	Cl > Na > SO_4 > Ca> HCO_3 > Mg > K	Cl > Mg >Ca > Na > SO_4 > HCO_3 > K

Table 9 Changing ratio (%) for ions concentration between 2008 and 2018

Site	*Na*	*Ca*	*Mg*	*K*	*HCO_3*	*Cl*	*SO_4*
Qurna	8	26	33	50	17	36	–57
Basrah	87	90	90	63	65	94	45
Seebah	85	91	96	79	52	94	41
FAO	81	86	94	39	12	94	29

4 Discussion and conclusions

The Shatt Al-Arab River basin is a transboundary basin with a total area of 938,173 km^2. The main basin tributaries include the Euphrates and Tigris rivers that originate in Turkey, in addition to the Karkheh and Karun rivers that are located in Iran. Although the basin is shared by six countries, the regions which contribute most to the water flow are confined to Turkey and Iran. They contribute about 80.44% of the total water flow. The total freshwater potential of the basin is about 105.70 km^3/yr, while the average annual freshwater discharge of Shatt Al-Arab River was 37.45 km^3/yr in 1977–1978. Therefore, freshwater amount of the river represents around 35.43% of water potential of whole basin. Freshwater sources of the Shatt al-Arab River were 38.1% from the Tigris and 30.4% from the Euphrates, also 30.4% via the Karun and 8.8% from the Karkheh.

The gradual increase in the tidal range in Shatt Al- Arab River as shown in Table 2 is due to the slope of the river from north towards south downstream at Fao site. The source of the tide wave is the Arabian Gulf, The reasons of variation in the tidal range was despite the compatibility in the measurement time in the four sites to the amount of approach to the Gulf, the geomorphology of the river, the presence of islands and meanders, which increase the friction of the current with the cross section, which works to weaken the movement of water and thus contributes to reduce the intrusion of sea water heading north towards Qurna site.

It seems that the surface current velocity in the river course has been excessively influenced by the flood and ebb tides status and the moon phases. There has been no obvious effect of the freshwater discharge variation on the river flow velocity. Where the results of field measurements showed that there are geographical differences among the water velocity values, because of the sequence of the tide as the river approaches the Gulf. The highest average speeds were found at Fao site, varied between 0.52 and 0.70 m/sec. during ebb and flood respectively. The minimum current velocity was found at Basrah site, with average 0.24–0.31 m/sec. during flood and ebb respectively. This variation is due to the locations of sites from the tide source and difference in water discharge. In comparison to Basrah site, in most of 13-hour tidal cycle at Fao site, the maximum and average velocities during the flood tides were larger than those during the ebb tides. In the southern part of Shatt Al-Arab River, the current velocity in the flood tide was larger than in the ebb tides. This indicates that the seawater intrusion was the dominant flow in the river, whereas freshwater was the dominant factor affecting the flow in the northern parts of the river. This may be due to the increasing of freshwater mass during ebb tides.

The water discharge at Fao site was high, due to Fao location near the river mouth. The lowest water discharge was found at Basrah site due to the decreasing and dispersing the strength of the tidal wave towards upstream, as a result of the current friction with the wetted cross section and the effect of river slop. Therefore, the seawater of Arabian Gulf is often responsible for the spatial and temporal variations of water discharge rates found in the river. The average ebb discharge at the Fao site was 44.3% lower than the rate flow during flood current. This result gives an indication of the marine water mass contribution to the amount of water flowing along the course of the river. The rate of ebb discharge of Basrah was 27.9% more than the water flow during flood. This may be due to the pushing back of freshwater by the tide wave and rising water level upstream. The critical decreasing of the freshwater flow from the upstream with average 58 m^3/sec. as compared to impulsion of seawater intrusion in the river course with an average of 730 to 2399 m^3/sec. during the flood tides, and 934 to 1,318 m^3/sec. during the ebb current. This result shows that the dominant flow is the seawater flow in the river. Thus, the marine water represents about 43.87 and 64.54% of the total water flow in the river at Basrah and Fao sites respectively. Because of the huge amount of the marine water flow in the river the exact measurement of the net water discharge was a very complicated process.

Shatt Al-Arab River receives freshwater from four tributaries, with average 37.45 km^3/yr. Currently, the river discharge is completely dependent on the freshwater flow from the Tigris River only, as the river became part of the Tigris and its basin. The mean annual freshwater discharge of the river dropped to 44 m^3/sec, about 96.29% of the total discharge in the water year 1977–1978. Due to the temporal variation of freshwater flowing in the river, the extent of interaction between the freshwater flow and the tidal currents is different. Decreasing freshwater discharge in Shatt Al-Arab River increases the impact of seawater (Al-Asadi, 2016). In past, the diluted runoff from the Shatt Al-Arab River can reach about 5 km upstream from the Arabian Gulf (Massoud, 1978). This case greatly impacts on the ecology of northern part of the Gulf (Al-Yamani, 2008; UN-ESCWA, 2013). Currently (in 2009 and 2018), the seawater intrusion into the river exceeded the city of Basra. In the future, the mean freshwater discharge of the river will drasticly decrease following the completion of the hydraulic control structures in the river basin, which are expected to last the year 2030 or even 2040 (Al-Asadi, 2017). This expected result of freshwater discharge will lead to an increase of seawater intrusion further upriver. Current amount of freshwater flow can't prevent seawater intrusion to the city of Basrah.

The pattern of TDS values clearly increased from north to south along the Shatt Al-Arab River, due to the increased seawater incursion from Arabian Gulf. However, the freshwater discharge of Karmat Ali River (north of Basrah city) and Karun River (nearby of Seebah) resulted in a slightly reduced TDS values due to the dilution the concentration of salinity. In 2017–2018, the mean TDS values in the river water increased from 8.4 to 26.3g/l at Basrah and Fao, respectively. These are as a result of decrease in the freshwater discharge and increasing seawater progress into the river. Besides, there was a loss of most of the river's tributaries, in particular the Karun River which acted as a natural dam that blocked or delayed the progression of marine waters. According to TDS values during 2017, the river water from Basra to the Gulf is considered to be of saline water (seawater), and it's unsuitable for different uses. This could be an indicator that the estuary area of Shatt Al-Arab River is regression distance of about 110 km in the river from RasAlbisha to city of Basrah.

The concentrations of major anions and cations in river water were high and increased toward the estuary. The main source of these variations is due to the effect of the tidal current, as well as the random uncontrolled activity of construction in the catchment area of the river. Differences in the major ionic concentrations in Shatt Al-Arab River showed a significant change in over the last 10 years, as shown in Figure 4. This clearly shows that the chloride concentration increased by around 94% for all sites except Qurna site (36 %) which indicated the effect of marine water on water quality of Shatt Al-Arab River. This conclusion was confirmed by the increasing sodium ion concentrations by more than 80%.

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