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ORIGINAL ARTICLE

Impact of the environmental degradation of rivers on the reappraisal of international agreements related to the transboundary watercourse, Shatt Al-Arab River (Southern Iraq): a case study

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Abstract
This paper aims to demonstrate the dramatic environmental degradation of the freshwater flow in the Shatt al-Arab River (SAR) in southern Iraq and to review and evaluate the agreements, particularly the 1975 Algiers Accord, between Iraq and Iran, which share the southern part of the river. The data used were categorized into four parts, the discharges and salinity water data at two main stations located upstream and downstream of the southern of the shared area of the SAR. Data on constructed hydraulic structures, data related to the 1975 Algiers Agreement, and satellite images obtain in 1986, 2002, and 2020 were used in detecting land cover change. Results show that the SAR has been under major threat from the deterioration of freshwater characteristics, green cover degradation, and drought and warming conditions. The Algiers Agreement emphasized the demarcation of the river frontier and the freedom of international navigation without considering the importance of freshwater inflow sustainability. The minimum environmental runoff in the river is approximately 124 m^3/s, which is required to sustain river fresh water. The study proposes a Freshwater Sustainability Principle that can be added as an amendment to the recent accord. This principle allows the contracting parties to collaborate on the security of SAR and sustenance of the minimum environmental inflow of the river.

Keywords Shatt Al-Arab River · Algiers Accord 1975 · Water management projects · Freshwater sustainably · Environmental degradation

Introduction

The Shatt Al Arab River (SAR) is the main water resource of Basrah Province in the southern part of Iraq, which has a population exceeding 3 million people according to the 2019 estimates. Over 82% of the inhabitants rely on the river's water for domestic use (Ministry of Planning 2017). The SAR plays a critical role in Iraq's and Iran's economic plans by supporting navigation, fisheries, agriculture, and various industries. For instance, approximately 105,000 ha of agricultural fields are irrigated by the SAR (Jaradat 2003), including the world's most extensive date palm fields. The SAR has faced significant constraints imposed by freshwater quantity and quality deterioration, which in turn has led to considerable substantial deficiencies in the productivity of the date palm fields.

Historically, Iraq was a part of the Ottoman Empire, and the river course represented the extent of the territorial reach of the Ottoman and Persian Empires; tensions over the SAR existed at that time in the country (Cusimano 1992). In response to these recurring tensions, a series of agreements and treaties were concluded, starting from the Treaty of Erzerum in 1847 to the 1975 Algiers Agreement (Bulloch and Morris 1989). The treaties have provided a quick means to the peaceful resolution of disputes concerning the delimitation of transboundary rivers and are aimed at enhancing cooperation between the riparian states (Wouters 2013; Gupta 2016). In this agreement, the two states adopted the Thalweg lines in the middle and southern parts of the SAR as international water boundaries (UN 1976).

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The Thalweg Principle is an essential concept, commonly adopted to internationally mediated issues between countries sharing transboundary rivers. In non-navigable rivers, the Thalweg line passes through the middle points of the waterway cross section, whereas in navigable rivers, the deepest points of the main navigation channel represent the Thalweg line (Bakhashab 1996).

In the 1975 Algiers Accord, the protocol concerning the delimitation of water boundaries in the SAR included nine articles. It stipulated that the SAR is primarily an international waterway, the demarcation of the borders is according to the Thalweg line (the deepest points along the riverbed), and the two contracting parties enjoy freedom of navigation in the river. It established a joint Iraqi–Iranian committee for periodic surveys, which is conducted once every 10 years, to detect natural changes in the SAR navigational channel and establish a special committee to draw up rules governing the prevention of pollution in the river (UN 1976).

Environmental change has been more rapid in the past 50 years than in any other time in human history, causing the widespread degradation of most Earth's ecosystems (MEA 2005). The fresh water of SAR has been under threat from the deterioration of the quantitative and qualitative characteristics of river waters. This effect is most likely the result of human activities and continuing water management projects implemented to respond to drought seasons and freshwater scarcity in the SAR basin (Jones et al. 2008; Issa et al. 2014; Al-Asadi 2017; Al-Asadi et al. 2019, 2020; Al-Asadi and Alhello 2019). The potential freshwater scarcity and quality deterioration ultimately affect human welfare, economic activity, and political stability (Jones et al. 2008). Unfortunately, awareness of the possible deterioration of the quality and quantity of fresh water in the region is inadequate. The increasing demand for fresh water has presented additional challenges to riparian states avoiding potential tensions (Gupta 2016). Thus, the states should cooperate for the protection and sustainability of the river waters.

Many recent studies (Jones et al. 2008; Abdullah, 2016; Al-Asadi et al. 2019; Adamo et al. 2020; Kadhim et al. 2020; Al-Aesawi et al. 2021; Al-Ansari et al. 2021) have addressed the quantitative and qualitative properties of river water and changes over the past decades. They attempted to understand the causes of the dramatic environmental degradation in the Shatt Al-Arab region, but did not propose practical solutions that can help secure a basic level of fresh water. In those studies, the obligations and responsibilities of the countries sharing the river with regard to their role in mitigating riverine environmental deterioration due to water management projects have not been addressed as parts of the solutions for ensuring sustainable freshwater source in the SAR.

In fact, many international obligations and agreements related to transboundary rivers, such as the Danube River Protection Convention (Wouters 2013), Itaipu Treaty (Gwynn 2019), and Algiers 1975 Agreement between Iraq and Iran (UN 1976; NSI 2004; Schofield 2004, 2018), were concluded to find sustainable reliable solutions among states sharing rivers.

This study addresses the deterioration in the aquatic environment of the SAR during the past 45 years (the period of concluding the Algiers Accord) as a contemporary case to demonstrate the potential weaknesses in international agreements related to transboundary rivers. The hypothesis of the article is that the Algiers Agreement in 1975 needs to be reviewed because it does not ensure the protection of the aquatic environment of the river and the sustainability of freshwater inflow.

This paper also aims to demonstrate the dramatic environmental degradation of freshwater flow in the SAR in the southern part of Iraq during the past 45 years (the period of concluding the Algiers Accord) and to assess the 1975 Algiers Agreement between Iraq and Iran, which share the southern part of the river. The current study accomplishes these goals in subsequent sections (1) showing the contributions of Iraq and Iran water management projects within the river basin to decreases in freshwater flow and increasing salinity levels in the river; (2) revealing the environmental degradation of the river region after concluding the 1975 Algiers Agreement; (3) employing the current environmental conditions of the river to demonstrate the weaknesses of the 1975 Algiers Agreement; (4) estimating the minimum environmental flow for the river course; and (5) proposing the concept of freshwater sustainability to ensure joint cooperation between the states to maintain freshwater source in the river.

Materials and methods

Site description

The SAR is formed by the confluence of the Tigris and Euphrates rivers in the Qurna City in southern Iraq about 65 km north of Basrah City (Fig. 1). The SAR flows to the southwest for about 115 km within Iraqi territories, and then about 85 km is shared with Iran, as water boundaries are based on the Thalweg line. The line continues to the end of the river mouth that pours in the Persian/Arabian Gulf. The SAR is about 200 km long in total. Its width ranges between 330 m in Qurna City (north of Basrah) and 1250 m at the river mouth, whereas the water depth varies from 8.5 to 24 m (Al-Asadi 2016).

Further, the Karkheh and Karun rivers also contribute to supplying the SAR with fresh water. The Karkheh River passes through the Hawizhe marshes before flowing into the SAR via the Al-Suwaib River (Fig. 1), which joins the eastern bank of the SAR about 5 km south of

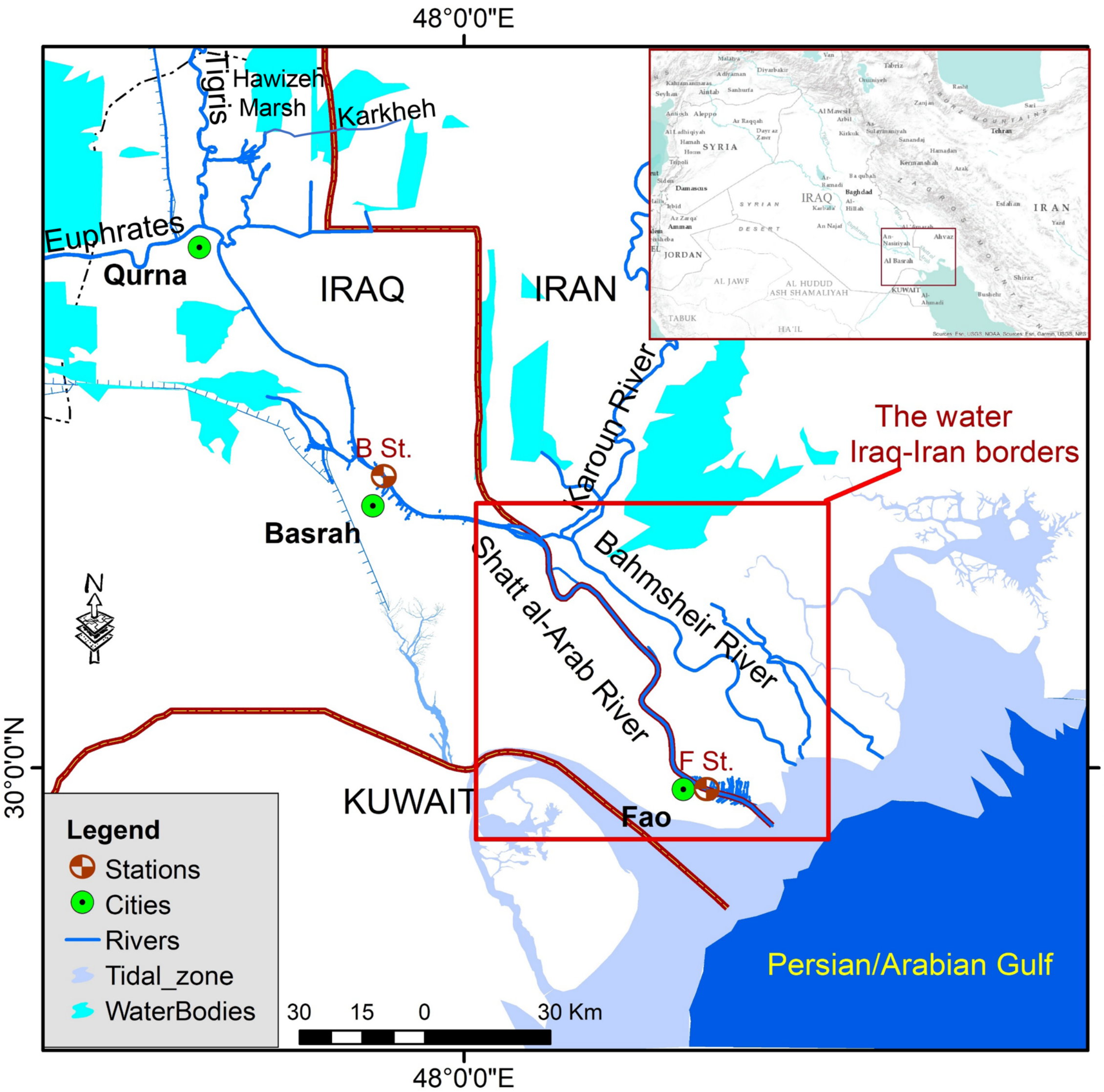

Fig. 1 Location map and the two main stations of surface water set up at SAR

the Tigris–Euphrates confluence. The Karun River merges into the eastern bank of SAR about 72 km north of the mouth.

The hydrological characteristics of the SAR depend mainly on the freshwater flow from its four tributaries. Because of the presence of a tidal effect, the river is also affected by the progression of seawater from the gulf. The tide regime is a mixed type between diurnal and semi-diurnal, where the latter is the more predominant. The tidal range is about 1 m at the Basrah location to 3 m at Fao station (Al-Asadi and Alhello 2019). The mean annual flow of the SAR was 1191 m^3/s (Al-Asadi 2017; Al-Asadi and Alhello 2019). The Tigris and the Euphrates rivers, forming the SAR, constitute 35% and 24% of their water resources, respectively, while 33 to 8% come from the Karun and Karkheh rivers, respectively (UN-ESCWA 2013).

Data collection

The resources of the obtained data are basically categorized into four main parts: the data extracted from a number of references pertinent to the quantity and quality of water, data of the constructed hydraulic structures, data related to the Algiers Agreement, and data (satellite images) used for detecting land cover change.

For the water quality and quantity flowing into the river, the extracted data are mean annual discharges and salinity measurements, respectively (Al-Asadi 2017; Ministry of Water Resources 2018). The data were taken from two main stations, Basrah and Fao stations, installed on the SAR, as shown in Fig. 1. The stations were set up and are continuously monitored by the Iraqi ministry of water resources. The Basrah station (noted as Basrah St. in the figure) was installed on the river crossing the City of Basrah. The station denotes the measurement of the SAR upstream, whereas the Fao station (Fao St. in the figure) is installed at the river mouth where Fao City is located, and it collects the measurements of the SAR downstream after its confluence with the Karun River. These two main stations measure daily the water discharges and salinity of the SAR. The short- and long-term changes can therefore be qualitatively and quantitatively observed. Since this study only focuses on long-term alterations (per year), the mean annual discharges and salinity at both stations were estimated and shown for every 10 years, on average, throughout the 40–50 years.

The second data group is associated with water management projects that were built on the reaches supplying fresh water to SAR. The data were collected from different resources (Masih et al. 2009; Ruhi and Golabi 2011; Abdullah et al. 2015; Ministry of Water Resources 2018). This data was mainly relevant to the hydraulic structure locations and their freshwater discharges within the Shatt al-Arab basin before and after the completion of these structures. The collected information is used in this paper to show the reduced levels of freshwater inflow into the SAR channel, as elaborated in the next sections.

Moreover, the third part of the data includes reviewing articles of protocols that were discussed and conceded in the 1975 Algiers Agreement between Iraq and Iran, with an emphasis on those concerning the river boundaries adopted from UN 1976; NSI (2004).

The fourth part of the data includes three satellite images (June 1986, June 2002, and June 2020) from the Landsat satellite 1 and 3. These remotely sensed data were used to detect land cover change by determining normalized difference vegetation index (NDVI) within the GIS environment.

Normalized difference vegetation index (NDVI) is a crucial standard relationship used in detecting vegetation density and change. This measure deals with the reflectivity of the electromagnetic spectrum of the near-infrared rays (NIR) and the infrared rays (R). The density of vegetation is then determined according to its reflectivity to the rays (bands). The NDVI equation is:

$$\mathrm{NDVI} = \frac{\mathrm{NIRBand} - \mathrm{RBand}}{\mathrm{NIRBand} + \mathrm{RBand}}. \tag{1}$$

NDVI values range between -1 and $+1$, and values approaching $+1$ indicate vegetation density, while negative values approaching -1 indicate arid lands and arid regions (Pinty and Verstraete 1992). The value 0.1 of NDVI is a reference point that separates vegetation areas (0.1 and below) from the non-vegetation areas (above 0.1) restricted to the areas adjacent to the Shatt al Arab River.

Results and discussion

Algiers Agreement 1975

The Algiers Accord was a bilateral agreement established to discuss and resolve a number of political concerns between Iraq and Iran, such as the Kurd-Iraqi conflict, Iranian revolutionaries in Iraq, re-demarcation of the land borders, reciprocal security responsibilities, and land and river boundaries' problems. Furthermore, several protocols were addressed in the former accords preceding Algiers agreement (NSI 2004). The SAR waterway running between Iraq and Iran is about 85 km long. In accordance with the Algiers Agreement, both countries have sovereignty over half of this waterway part (85 km) adjacent to its territory. The articles of the agreement related to the borders of the SAR elaborated on both states' commitments toward the Thalweg line issue and its international importance for navigational purposes.

Due to its high-quality articles and obligations, the Algiers Accord was the most sophisticated river boundary agreement in international law, where it contains every guarantee required to avoid future disputes (Schofield 2004, 2018). It is observed that the accord's protocols covered and handled several concerns between the two states regarding the water boundary matter of the SAR. It seems, however, the future issues of climate change global warming issue, and consequences of the water management projects were not taken seriously at the time of the accord, 45 years ago.

The accord had inadequately concerned on the issue of joint cooperation in the freshwater quantity and quality of the river fed by tributaries of both sides (Iraq and Iran) as much as it sufficiently concerned on adopting the Thalweg principle from both states.

Developments in international watercourses law

Further rules on transboundary river law were elaborated in the last two decades of the twentieth century. The 1997 UN Watercourses Convention was the most significant development in international law regarding non-navigational uses of international watercourses (Gwynn 2019). This convention which only entered into force in 2014 is a general framework agreement that contains 37 articles, which are divided into seven parts. The convention will ensure the utilization, development, conservation, management, and protection of international watercourses and the promotion of the optimal and sustainable utilization thereof for present and future generations, affirming the importance of international cooperation and good neighborliness in this field, but it is left up to the agreement of the riparian countries (UN 2014). It means that states sharing the transboundary rivers have an affirmative obligation to cooperate in its protection and development and implicitly in its management to achieve the principle of equitable utilization and protection of the freshwater flow in the river course (McCaffrey 2001).

Water management projects

A major revolution has taken place due to water management projects during the second half of the twentieth century. Large dams, barrages, and irrigation canals aiming at storing water, hydroelectricity production, and irrigation projects have significantly influenced the SAR basin hydrology. A significant transformation took place since ancient water control projects in the lowlands of the Mesopotamian basin (southern Iraq) and the modern time when modern projects were implemented, including water storage and hydroelectric projects in the upper lands of Turkey, Syria, Iraq, and Iran on the Tigris, Euphrates rivers, and their tributaries (Beaumont 1998; Partow 2001).

The complicated mountainous region of Iran has required to establish more hydraulic structures on the Karkheh and Karun rivers to secure the inexorably increasing water demands of the population and irrigation. Census estimations in 2010 show that the populations in the Karkheh and Karun basins have reached about 4.00 and 3.50 million people, respectively (UN-ESCWA 2013). The annual rate of population growth in Iran is 1.4% (UN 2001), and the total irrigated planned area is about 600,000 and 480,000 ha in the basins of the two rivers, respectively (Al-Asadi 2017).

Regarding Iraq, the population increases, according to 2010 estimates, in the Tigris and Euphrates basins to about 18.40 and 10.20 million people, respectively (UN-ESCWA 2013). The annual rate of population growth rises to about 2.7% (UN 2001). On both sides of the rivers, toward the southern region of the country, agricultural areas dedicated to the cultivation of crops demanding large amounts of water, such as rice, are distributed. Further, the southern marshes, which extend over large areas in north of the SAR region, are fed by the Tigris and Euphrates rivers and their tributaries. In addition, Iraqi water resources still need improvement of water management methods, which unfortunately still rely on traditional irrigation methods, since it may ultimately affect the volume of water feeding to the Shatt al-Arab River.

Figure 2 shows the major water management projects that were built on both the Iranian and Iraqi sides (Partow 2001).

Iranian water management projects

Iran completed its large water management system, having five reservoir dams called the Dez dam, on the Karun River in 1962, which was mostly running into the SAR. The main purposes of these dams are the irrigation of about 250,000 km^2, hydropower generation, and flood control (Heydari et al. 2016). In particular, the storage capacity of the reservoir Karun #4 dam was around 2.19 km^3 by 2009 (Ruhi and Golabi 2011) (Fig. 2). The Karun fresh water

Fig. 2 Most water management projects on the Tigris, Euphrates, Karun, and Karkheh rivers. Modified map after (UNEP 2001)

was significantly important to the SAR, since its freshwater inflow constituted a natural dam against seawater intrusion that substantially impedes the tidal effects of the saline tidal currents. However, due to irrigation needs and the establishment of several hydraulic projects on the Karun River in Iran, the vital role of the Karun River for SAR was no longer effective after 2009 when the trajectory of the Karun River was diverted inside the Iranian boundaries by the Bahmashir canal.

Regarding the Karkheh River, the construction of a large dam was launched in 2001, with a designed storage capacity of about 7.5 km^3. Its main purposes were to irrigate about 350,000 ha in the Khuzestan plains, generate hydropower, and control floods (Masih et al. 2009). The import of freshwater inflow of Karkheh River feeds the Hawizhe marshes located at the borders between the two countries, as shown in Fig. 2. After the Karkheh dam's construction, the freshwater inflow from Iran to the Hawizhe marshes was greatly altered. As a result, in 2005, the discharge levels significantly declined and technically appeared to be negligible compared to the measures in 1979 (Partow 2001; Abdullah et al. 2015). The river had contributed about 6.3 km^3 to the marshes (Grego et al. 2004).

Iraqi water management projects

Iraqi development plans included a series of water management projects with similar purposes, i.e., fulfilling the Iraqi needs for water. On the Tigris River, several reservoir dams were built, mainly for the irrigation, hydropower generation, and flow diversion purposes. The most important of these dams are the Hamrin, Mosul, and Al-Adheem built in 1981, 1986, and 1999, with the capacity storages around 3.56, 12.5, and 1.5 km^3, respectively (UNEP 2001), as well as building many barrages such as the Al-Amarah barrage which was constructed in 2005 in the south of the Maysan Province (Fig. 2). It mostly aims at controlling potential floods and regulating freshwater inflow into the SAR by Qal'at Saleh regulator.

Across the Euphrates River, Haditha dam (or called Al-Qadisiyah) was built in 1984 with a storage capacity of 8.2 km^3 (UNEP 2001), as well as the establishment of many dams on the river to regulate the flow of water. Moreover, in 2009, because of the high water salinity of the Euphrates, the main river course was dammed with a barrage that was built at the south of Nasiriya Province (northwest of Basrah). The water was then transferred from the main course, through the Hammar marshes, before reaching the SAR (Fig. 2).

The development of water management projects, in addition to long drought seasons, has thus increased the salinity of marshes water/soils. Saltwater intrusion directly affects the SAR fresh water of the upstream and downstream sides, respectively. The saline water movement into the river and groundwater aquifers is a serious issue that causes the deterioration of the water quality. Therefore, since 2011, a number of projects and scenarios were suggested to build a barrage or barriers on the lower reaches of the SAR. They were aimed at impeding saltwater intrusion moving from the Persian Gulf and preventing the deterioration of freshwater quality flowing from the upstream (IEI 2018).

Land cover change

Figure 3 demonstrates the change over time (35 years) in the distribution and intensity of those vegetated areas around SAR. These areas predominantly include palm trees, farms, and marshland. The figure illustrates three NDVI maps representing three periods 1986, 2002, and 2020 that reflect three stages of noticeable change in the hydrological system of the SAR region.

For the year 1986 (Fig. 3a), the resulting NDVI values ranged from the lowest value – 0.58, which represents

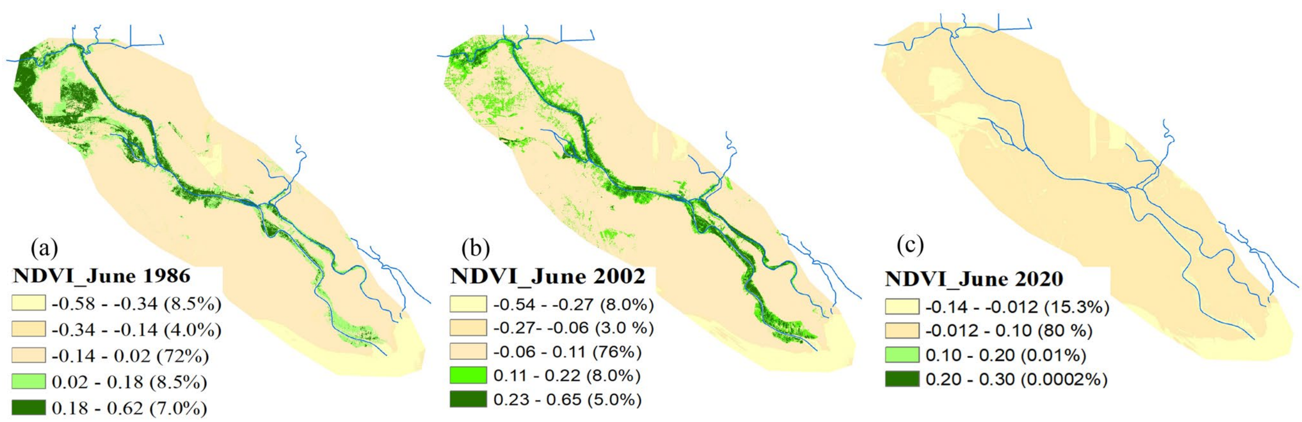

Fig. 3 The NDVI change over time (35 years) at three dated stages: **a** June 1986, **b** June 2002, and **c** June 2020 in the Shatt al Arab River (SAR) basin

drylands in the selected SAR basin, whereas the highest value for the same year was 0.62 which represents the dense vegetation that grows in some parts of the SAR basin. For the NDVI value of the year 2002, it was 0.65, which indicates dense vegetation cover, while the low value −0.15 pertains to non-vegetation areas, which spreads in the southern and some eastern parts of the SAR basin. For the period 2020, it was observed that the highest NDVI value was 0.30, while the lowest NDVI value reaches 0.013, which in general indicates the lack of vegetation cover, representing the southern regions of the SAR basin and some eastern and northwestern parts.

As shown in the figure, percentages of the vegetated areas, having NDVI value greater than 0.1, quantitively revealed substantial change over 35 years represented by the three periods 1986, 2002, and 2020. These percentages were 15.5%, 13%, and 0.01% of the total selected area (86,000 km^2), respectively. The reduction of vegetation cover during the first two periods, 1986 and 2002, is around 2.5%. This insignificant reduction (2.5%) is most likely related to the minor change of the salinity levels of the soil and water over the two periods (1986 and 2002) despite the high decline of the water discharges in the SAR basin. This allowed the natural plant and agricultural activities to be slightly affected with less deterioration. For the last period (2002–2020), the salinity of the water significantly increased, and the soil had deteriorated, which in turn led to a remarkable decline in natural vegetation and agricultural activities (UNDP 2018; Al-Asadi et al. 2019). Besides, the urban expansion toward agricultural lands from 2003 until now has caused large areas of the vegetation cover to be replaced.

Climate change in the SAR basin

The SAR basin is located in a transitional zone between humid continental and semi-arid to the arid zone, while the headwaters of its tributaries have a sub-tropical Mediterranean climate with cold wet winters and hot dry summers.

The mean monthly temperature over the basin ranges from 6 to 34 °C, while the annual mean precipitation varies between 100 and 1000 mm (Issa et al. 2013). The mean temperature in the headwater areas for the period 1941–2007 is about 13 °C. The temperature has an increasing trend of 0.64 °C/100 years (Republic of Turkey 2009). The annual mean precipitation in the headwaters for the same period (1941–2007) is about 643 mm. Approximately, 70% of the total precipitation fall during the period between October and April (Republic of Turkey 2009). The rainfall decreases range from 25 to 40% (UNWWAP 2009). Concerning the evaporation rate, it increases about 9% (Terink et al. 2013; Bozkurt and Sen 2013). 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).

The climate data for the period 1975–2019 provide clear evidence of trends of climate change in the SAR course region over the past 45 years. Figure 4 illustrates the trend and variation of the temperature and the rainfall in the river region. The mean temperature for the 1975–2019 climatic period ranges between 22.9 and 27.7 °C. Regarding the precipitation, the annual mean ranges between 48.3 and 296.6 mm, approximately, and 90% of the total precipitation falls between November and April (Muslih 2014). As a result, the study area is characterized by warm dry summers, and it is very evident that there is a declining tendency of the rainfall and increase in temperature in the SAR region which clearly contributes to the deterioration of the river ecosystems.

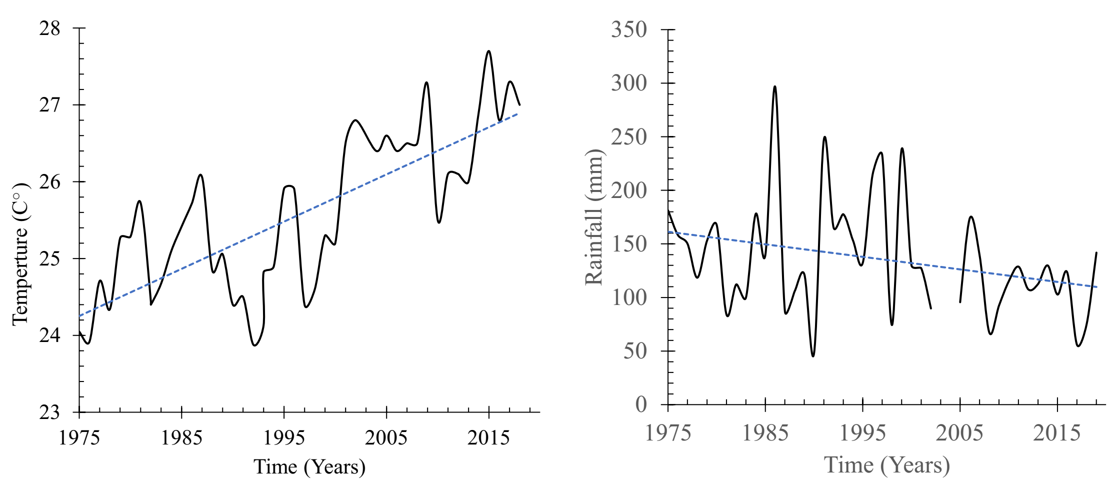

Fig. 4 Mean change of the temperature and rainfall in the SAR region during 1975–2019

Water deterioration in the river course

The constructed projects in Iran and Iraq cut off most of the tributaries recharging the SAR and, consequently, altered the hydrological system of the SAR environment. In the past, the river was provided with fresh water from four main tributaries, with an average of about 1191 m^3/s. Between 2010 and 2018, the river most often received fresh water from the Tigris River only (Al-Asadi 2017; Al-Asadi and Alhello 2019). In addition, freshwater discharge into the SAR course dropped from 1191 m^3/s in 1977–1978 to around 50 m^3/s after 2010 (Fig. 5a).

From a qualitative point of view, the levels of water salinity in the river increased from 0.81 to 1.25 g/l at Basrah and Fao stations in 1977–1978 to 8.46–21.10 g/l at both the stations in 2017–2018 (Fig. 5, b).

This remarkable change of the river's hydrological system evidently influenced the overall human activities in the region and aquatic ecosystems in the river. For instance, the salinity and contamination of tap water used for daily purposes were one of the main reasons for the infection and toxicity of roughly 118,000 people who suffered from rashes, abdominal pain, vomiting, and diarrhea during the summer of 2018 (HRW 2019). This situation led to large-scale protests in Basrah, against the government's action as a response to the people's demand for healthy water. The number of palms has also dropped from 18 million in 1970 to only 4 million date palms by 2002 (Brandimarte et al. 2015; Kadhim et al. 2020).

The SAR course has been relatively an outlet draining water out into the gulf, and both states were mostly concerned only with keeping the SAR useful as a navigable river, as the Algeria's accord conceded. It was not much concerning sustaining freshwater inflow and addressing salinity problems of the river waters. This inadequacy of the accord led to a negligence of potential negative effects taking place nowadays on the quantitative and qualitative characteristics of the water flowing into the river. In this regard, the Iraqi side took several steps to resolve issues related to the reduction of freshwater discharges and increasing salinity levels. Firstly, freshwater released from the Tigris River via a Qal'at Salih regulator to the SAR was increased from 50 to 100 m^3/s. Secondly, the planned irrigated areas were rationed (Ministry of Water Resources 2018). Thirdly, there were official attempts to convince the Iranian side to recharge the SAR from the Karun River (Chulov 2009).

It is worthy to note that the maintenance of the river course for navigation was a very remarkable issue that requested hard efforts from both sides. The high sediment loads deposited into the river course, in addition to shipwrecks from the wars, discouraged navigation in the SAR channel. Thus, in 1990, Iran and Iraq made considerable progress toward clearing the SAR navigational channel from shipwrecks and other fragments (Schofield 2004). Yet, the removal issue of sediment loads deposited in the channel was not activated well and almost neglected by one side. The sunk wrecks are considered as evident pollution sources increasing pollutant levels in the river. By the time of the decline of the freshwater discharges of the SAR, the level of these pollutants have been significantly highlighted, and it has been difficult to be removed or even mitigated from the river.

Salinity and freshwater discharge relationship

Figure 6 shows the behavior of the discharge (m^3/s) in relation to salinity and TDS (mg/l) at the two studied sites: the Basrah and Fao locations. Figure 6a reveals the logarithmic behavior of water discharges over time, according to which the Fao site (the downstream station) has higher values than

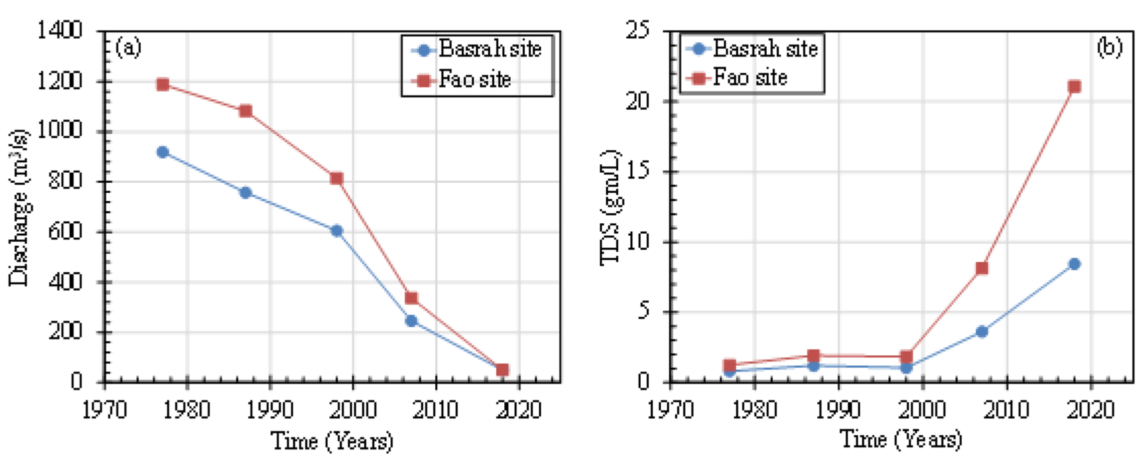

Fig. 5 **a** The annual mean of freshwater discharge (m^3/s) in the SAR at Basrah and Fao sites, and **b** the annual mean of TDS (g/l) in the SAR at the same sites

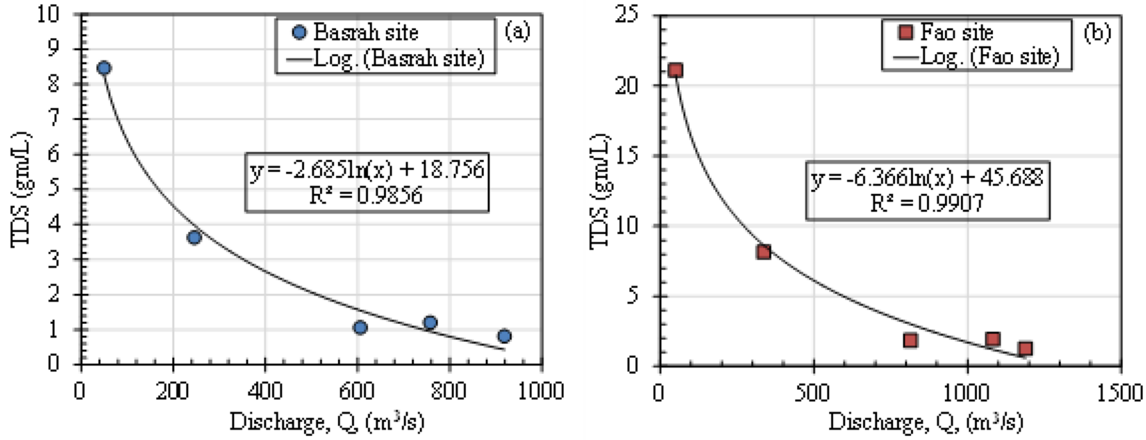

Fig. 6 The discharges–salinity relationship at the two stations: **a** Basrah and **b** Fao

the Basrah site (the upstream location). As shown in the figure, the variation between both stations is about 1200 m^3/s by 1980, yet it was gradually reduced over time and recently ended up to be inconsiderable, with a discharge value of less than 100 m^3/s at both stations. This evidently shows the critical influence of water management projects, which significantly affected the river and are therefore very critical for it.

On the contrary, the salinity levels in Fig. 6b shows, over time, lower values, with no variation between both stations. It ranges from 1 to 2 mg/l. After 1995, there was a significant increase of salinity levels which were 7–8 mg/l and 21–22 mg/l, respectively, at both upstream and downstream stations, with a high variation, reaching 14 mg/l.

It is so obvious that these variations in discharge and salinity along with the construction of water management projects in the SAR basin continue to influence the natural hydrological environmental parameters of the river. In this study, the variations of the salinity and the discharge parameters over time were addressed, and plausible correlations were found.

Figure 6 shows the discharge/salinity relationship between both stations (Basrah and Fao stations). The relation reveals that the salinity is a strong negative function of the discharge at both stations. Equations 2 and 3 show natural logarithmic relations with correlation coefficients, R2, which is about 0.99 in the two sites. The gradient line (the slope) of Eq. 2 is about 2.6851, with an intercept of 18.76 mg/l at the Basrah location. On the other hand, in Eq. 3, the slope is about 6.3661, with an intercept of 45.688 mg/l at the Fao location.

$$\mathrm{TDS} = 18.756 - 2.6851\ln(Q) \quad \text{at Basrah station,} \tag{2}$$

$$\mathrm{TDS} = 45.688 - 6.3661\ln(Q) \quad \text{at Fao station,} \tag{3}$$

where TDS is the salinity parameter in mg/l, and Q is the water discharge of the SAR in m^3/S. These associations (Eqs. 2 and 3) could be a very useful approach to predict the qualitative and quantitative behavior of the river over time and the impact of discharge and salinity on the river.

It was noticed that decreasing freshwater discharge into the river downstream allows tidal impacts to increase remarkably (Al-Asadi 2016) to a distance of 92 km toward the river upstream (Abdullah et al. 2015). On the contrary, in the past, fresh water flowing into the river reached a distance of about 5 km inside the gulf (Saad 1978). In the summer of 2018, salinity concentrations of the river increased to 20–45 g/l at Basrah and Fao sites, and encountered a decrease in freshwater flow to 18 m^3/s. Meanwhile, the reduction of the water stored in Iraqi reservoir dams, in addition to drought conditions (Ministry of Water Resources 2018), entailed an increase of seawater intrusions. The water quality, therefore, became inappropriate for drinking and agricultural irrigation.

Freshwater sustainability principle

The deterioration of the freshwater characteristics of the river, green cover degradation, and climate change may provide a typical opportunity to undertake a re-appraisal of the treaty's articles concerning the SAR. In particular, most of the bilateral watercourse treaties that were signed in the 1970s are lack of the alignment needed to maintain long-lasting sustainable practices (Gwen 2019). No consideration was given, in the Algiers Agreement to, the "Sustainability Principle", and in particular, freshwater discharges protection.

The authors believe that the agreement should ensure the sustainability of the vital and positive role of a shared river (SAR) for the preservation of freshwater supply to surrounding populations. Therefore, it is suggested to add the

"Freshwater Sustainability Principle" in the Algiers Accord. The situation is similar to the Danube River Protection Convention (DRPC), which entered into force in 1998 after having been signed by nine of the riparian states (Wouters 2013). If added, the Freshwater Sustainability Principle could also be seen as a commitment to the international law of the transboundary river agreements even if this measure would be conflicting with the interests and desires of the riparian states.

This newly proposed concept could force both riparian states to make serious bilateral contributions, positively maintain freshwater inflow and achieve the ultimate goals relevant to the principle of stability. The inclusion of the principle of sustaining freshwater flow in a critical provision of the agreement would not constitute an infringement of the spirit of Algiers Agreement. Furthermore, it would very well match with the principle of a comprehensive settlement and pollution prevention rules specified in the agreement as well as support the continuity of positive relationships among riparian states. It is also consistent with current developments in the law of transboundary rivers, regarding the protection of the environmental and freshwater flow in the river course. Moreover, the presence of such a proposed concept (Freshwater Sustainability Principle) might generally constrain the upstream countries in its actions and motivate it to be more cooperative with, and committed to, downstream states (Lowi 1995). It is very obvious that adopting the new concept of freshwater sustainability could impose more obligations on both Iran and Iraq and allow positive reciprocal relationships between two states sharing around 12,000 km of borders, in addition to history and civilizations (Kemp 2005).

Cooperation for freshwater sustainability

The increasing scarcity of freshwater mostly stimulates cooperation among both states sharing the river. On the other hand, a relationship was established between the level of cooperation among riparian states and the scarcity of fresh water (Dinar 2009; Dinar et al. 2011). Most international agreements have codified some type of collaboration between states sharing rivers to address freshwater scarcity issues and protect the river's environmental systems.

However, the 1975 Algiers Agreement between Iraq and Iran which share 85 km of SAR lacks this type of cooperation despite the recent deteriorating quality of the SAR water. Additionally, it was observed that freshwater quality and quantity deterioration have an asymmetric impact. Basrah's population is more affected by freshwater scarcity and deterioration as compared to the population on the Iranian side, as mentioned in previous sections. However, Iraq and Iran should realize that addressing and solving the issues of water quality deterioration cannot happen without the collaboration of both states. The proposed new Freshwater Sustainability Principle, if added in the shape of an amendment to the agreement, would impose a commitment to cooperation on behalf of both states. It would consequently lead to sustaining acceptable levels of freshwater inflows into the SAR.

Two different approaches are employed to determine the minimum freshwater quantity (called environmental flow) for the SAR. The environmental flow is identified as 10% of the mean annual freshwater discharge in the natural year (Rahi and Halihan 2018), which was represented by the water year 1977–1978 when the rate of the annual flow was about 1189 m^3/s. Another method designates that the flow equaled 85% of the flow of the driest month ever recorded for the river (Kienitz 1971) During the period 1977–2009, October 1989 recorded the minimum monthly mean discharge in the SAR, where the freshwater flow decreased to150 m^3/s, as highlighted in Table 1 in bold, underlined font (150 m^3/s). Table 1 shows the monthly mean data of freshwater flow (m^3/s) in the SAR, collected from several references (Al-Asadi 2017; Al-Asadi and Alhello 2019; Ministry of water resources 2019; Al-Mahmood 2020).

According to these approaches, the minimum flow for the SAR varying between about 119 and 127.5 m^3/s (124 m^3/s) is required to sustain a plausible freshwater quality for the entire length of the river course.

The increasing number of water management projects under noticeable drought conditions makes it difficult for one state to keep the same amount of fresh water flowing into the SAR without impacting the other state. Hence, both states need to redirect the fresh water into the river. Therefore, three rational cooperation ways are given as hypothesis in this study. They should be followed by the parties if they want to address the issue of freshwater scarcity:

1. Both countries supply 50% of the fresh water needed to sustain plausible water quality to the SAR's environment (about 62 m^3/s for each state).
2. Previous freshwater percentages feeding the SAR should be considered before the construction of new water management projects. These percentages were as follows: 41% (about 51 m^3/s) and 59% (about 73 m^3/s) from the Iranian and Iraqi sides, respectively.
3. According to the length ratio of the SAR, it extends 115 km (57.5%) within the Iraq territory and 85 km (42.5%) as a water border between both states. In this case, Iran and Iraq may have the obligation to supply about 53 m^3/s and 71 m^3/s of freshwater, respectively.

The current study provides only an illustrative evaluation aiming at demonstrating the importance of cooperation between both states. It suggests the three above ways to be considered seriously. Future research might be necessary to

Table 1 Monthly mean of freshwater flow (m^3/s) in the SAR, collected from Al-Asadi (2017), Al-Asadi and Alhello (2019), Ministry of water resources (2019) and Al-Mahmood 2020

Year	Months													
	Station	Oct	Nov	Des	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Av
77–1978	Basrah	230	317	495	797	916	1082	1191	1313	1506	1463	963	563	919
	Fao	392	449	565	753	1021	1515	2111	2465	2270	1456	785	486	1189
85–1986	Basrah	189	255	296	643	844	913	1010	1129	1256	1275	727	566	759
89–1990	Basrah	150	203	245	281	352	600	534	478	399	306	247	218	334
94–1995	Basrah	632	616	600	831	891	895	900	729	686	678	612	615	724
	Fao	834	879	–	1039	1064	–	725	547	–	601	826	–	815
97–1998	Basrah	304	568	664	692	725	741	949	875	760	428	296	274	606
04–2005	Basrah	216	261	292	315	324	336	405	383	360	292	211	203	300
05–2006	Basrah	322	349	345	357	497	555	566	610	449	404	356	312	427
06–2007	Basrah	267	269	274	325	335	360	373	357	323	313	307	246	313
07–2008	Basrah	188	197	217	256	264	295	306	301	281	263	216	164	246
10–2018	Basrah	45	36	43	46	51	53	56	64	51	48	47	50	49
	Fao	45	36	43	46	51	53	56	64	51	48	47	50	49

address these cooperation options in detail. Further analysis may be needed as to the levels of cooperation required to maintain plausible freshwater inflow into the SAR.

Conclusions

This paper demonstrates that over the past 45 years, the SAR environment has been facing a major threat imposed by the dramatic deterioration of freshwater characteristics, degradation of green cover, and prevalence of drought and warming conditions, which seriously impact economic activities. Despite this observation, the importance of freshwater inflow sustainability has not been considered by Iraq and Iran. Moreover, although both states have actively used the river as a navigational channel, according to the 1975 Algiers Accord, the Thalweg Principle has been based on the demarcation of water borders in the SAR. The paper addressed the significant impacts of the water management projects of Iran and Iraq over the past 45 years on the hydrological system of the SAR. These projects were implemented to address the climate change impacts and freshwater scarcity. The development of international law and its emphasis on environmental protection and climate change will affect the articles of transboundary rivers' accords. Hence, renegotiating the treaty in a manner that both states practices are consistent with the current international commitments regarding environmental protection and climate change and foster sustainable development is necessary. Therefore, the paper proposes the inclusion of the Principle of Freshwater Sustainability, in the shape of an amendment to the agreement, alongside the Thalweg Principle. This item can be added to the agreement's provisions related to the demarcation of the water borders of the SAR between Iraq and Iran to maintain the integrity of the SAR and establish a long-term stable relationship. The current study suggested three practical ways in the form of recommendations with a non-binding nature to sustain fresh water in the river that the states can utilize fresh water for their different purposes.

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