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Karun and Shatt Al-Arab River System: Historic and Modern Attempts to Manage Iran's Lifeline

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Abstract

The Islamic Republic of Iran's principal rivers are the Karun and Shatt al-Arab. The Karun River has a 950 km length. The Karun River starting point is the convergence of the Amand, Kuhrang, and Bazoft rivers. From their headwater sources in the mountains of eastern Iran, these rivers descend through valleys and gorges and flow into the plains of Iran. The Shatt al-Arab River drains an area of 879,790 square kilometers which includes land in Iran, Syria, Türkiye, Kuwait, and Iraq. The Karun joins Shatt al-Arab 110 km downriver from the confluence of the Euphrates and Tigris Rivers and flows 85 km into the Persian Gulf. The Karun river flows in a southwestern direction through the central plain and provides about 10 per cent of the water balance of Iran's largest wetland, the Shadegan, which includes permanent marshes, lakes, and riparian habitats. The article summarizes a vast array of publications on the stated topic and this civilizationally important region in order to draw additional attention to its interdependent environmental, economic and political problems the successful resolution of which is only possible with the participation of the entire research community.

Keywords

Shatt Al-Arab River, Iraq, Karun River, Baghdad, Sinjar, Marshes, Soil Tunnels

1. Introduction

The Karun River[1] (**Figure 1**) is the deepest, widest, and largest river and one of

[1]Persian: کارون. *Karoon, Karoun*, and *Kârun* variants of the river's name are also found in English-language sources. The historical Romanian name of the river was *Pasitigris*.

Figure 1. Map of the Karun River and tributaries. Photo Credit: In the public domain.

the most significant natural and water engineering heritages of Iran (**Figure 2**). Karun and its tributaries are the only navigable rivers in Iran. It is a transportation corridor and a tourist attraction. Numerous dams and bridges have been built on the Karun River. The unique ancient hydraulic structures of Shushtar[2] region fed by the Karun River were registered on UNESCO's list of World Heritage sites.

The published length of the Karun River varies between 820 to 950 km depending on what is considered as its starting point: according to some sources, the Karun is formed by the confluence of the Bazoft and Kuhrang rivers. Other authors suggest that the entire Kuhrang River should count as the upper reaches of the Karun. Regardless, the Karun's catchment area approaches 72,000 square kilometers [1] about 75% of which [2] [3] falls on the Zagros mountainous landscapes relatively well moistened by precipitation—this is what ensures relatively high and stable water availability of the Karun, favorable for the biological

[2]Also spelled *Shooshtar* or *Šuštar*.

Figure 2. East Asia including the location of Iran and Iraq. Photo Credit: WorldAtlas.

diversity of the downstream freshwater ecosystems as well as for development of water transport, agriculture, and municipal economy along the river.

The most historically important settlements of the Middle Karun are Gotvand which marks the transition from the mountainous to the lowland part of the basin, Shushtar with its unique hydraulic structures, and Ahvaz, the administrative center of Khuzestan Province. The estimated long-term average annual runoff rate of the Karun drainage area above Gotvand, *i.e.* at the foot of the mountainous part of the basin, is about 400 m^3/s [4]. In the town of Ahvaz, the historic mean river flow exceeds 700 m^3/s [5] thanks to the largest Karun's tributary, the river of Dez, which flows into Karun between Shushtar and Ahvaz.

The Karun divides into branches, in its lower reaches, 200 km below Ahvaz. The historical one of them bears its own name Bahmanshir (or Bahmanšir) and flows directly into the Persian Gulf, while the main channel of the Karun feeds the Shatt al-Arab River which runs parallel to the Bahmanshir and flows into the Persian Gulf 85 km downstream the Karun's current outlet. Two major cities in Iran—Khorramshahr and Abadan—are located near the Karun mouth and at the same time have access to the banks of the Shatt al-Arab which separates the countries of Iran and Iraq.

Iranian, Iraqi, Syrian, and Türkiye dam construction has also contributed to political tension within the basin, particularly during drought. Karun is one of the four major rivers (along with the Tigris, Euphrates, and Shatt al-Arab) draining the large Mesopotamian lowland ecoregion. In the upper watershed, the high mountains receive more rain and snow than the lower watershed, which has an arid and hot subtropical climate. Both seasonal and permanent marshes of the Mesopotamian lowlands are sustained by annual snow melt from the mountains and spring floods. Some of the Tigris tributaries originate in Iran [6]. The flow of these rivers has a significant impact on the seascape of the Persian Gulf the reverse effect of which on freshwater habitats is driven by intrusions of seawater along the course of the Shatt al-Arab and Karun rivers as well as the Bahmanshir branch (**Figure 3**). There is a large floodplain in the lower basin, where the Karun, Euphrates, and Tigris rivers converge to create permanent lakes, marshes, and riparian. These include the Shatt al-Arab River and Hawizeh (or Al Hawizeh) and Shadegan marshes. The hydrology of these marshes affects the ecology of the upper Persian Gulf.

The primary objectives of this study are to restore, manage, and protect the Iranian's Karun and Shatt al-Arab river system ecosystem lifeline and the Hawizeh

Figure 3. The location of the Tigris and Euphrates rivers and tributaries in Iraq. Photo Credit: Published with the approval of the Editor of the Open Journal of Soil Science.

and Shadegan marshes. The marshes are integral to filtering out pollutants and waste before they reach the Gulf and coastal health. In the 1980s, this ecoregion was put in grave danger during the Iran–Iraq War. The marshes' function, of filtering out pollutants and waste, was significantly degraded after their draining. The marshes also serve as nursery and spawning sites for coastal shrimp and fish species.

2. Iran Natural and Cultural Resources Findings

2.1. Ecological Threats

The Karun and Shatt al-Arab river basins suffer from soil salination and desertification partially caused by thousands of years of agricultural activity. Water and plant life are sparse. The loss of the natural habitat poses a threat to the area's wildlife populations. The marshlands were an extensive natural wetlands ecosystem [7], which developed over thousands of years in the Tigris-Euphrates-Karun-Shatt al-Arab basin and once covered 20,000 square kilometers. In the 1980s, this ecoregion was put in grave danger during the Iran–Iraq War. BBC [8] reported that "*the Mesopotamian Marshes, which were inhabited by the Marsh Arabs, were almost completely drained. Although they had started to recover after the fall of Ba'athist Iraq in* 2003*. However, drought, intensive dam construction, and irrigation schemes upstream have caused them to dry up once more*" [8].

According to the United Nations Environmental Program and the AMAR Charitable Foundation [9], "*between* 84*% and* 90*% of the marshes have been destroyed since the* 1970*s. In* 1994, 60 *percent of the wetlands were destroyed by Hussein's regime—drained to permit military access and greater political control of the native Marsh Arabs* (**Figure 4**)*. Canals, dikes, and dams were built routing the water of the Tigris and Euphrates Rivers around the marshes, instead of allowing water to move slowly through the marshland. After part of the Euphrates was dried up due to re-routing its water to the sea, a dam was built so water could not back up from the Tigris and sustain the former marshland. Some marshlands were burned, and pipes buried underground helped to carry away water for quicker drying. The drying of the marshes led to the disappearance of the salt-tolerant vegetation. The plankton-rich waters no longer fertilized surrounding soils and cannot support* 52 *native fish species, wild boar, buffalo, red fox, and water birds of the marsh habitat*" [9].

Although the Karun River is not directly related to the genesis and conservation of the sensitive Mesopotamian marshlands (the eastern part of the Hawizeh Marshes is fed by another Iranian watercourse, the Karkheh), the influence of its flow and basin's management is mediated indirectly through regulating comingling between freshwater and seawater generally in the Shatt al-Arab valley. In addition, the Karun contributes to the feeding of another large space of wetlands—Shadegan[3]—through water spills and return flows from transitional channels [8] [9]. The share from these water sources comprises about 10% of the total

[3]Shadegan Wetland Management Plan—UNDP/GEF Conservation of Iranian Wetlands. 2011. 15 p.

Figure 4. Drainage of swampland. Photo Credit: Published with the approval of the Editor of the Open Journal of Soil Science.

water budget of this Ramsar wetland fed mainly by the Jarrahi River.

2.2. Geography of Mesopotamian Marshes

Alluvial marshes are a unique ecosystem of Lower Mesopotamia (**Figure 5**) which is part of the larger Fertile Crescent historical region, one of the primary source areas of agriculture, considered for the same reason as the cradle of civilization. Present-day Mesopotamia is now part of Iraq, southeastern Türkiye, southwest Iran, and sections of eastern Syria (**Figure 2**). These marshes lie primarily within southern Iraq and sections of southwestern Iran. Originally the Mesopotamian Marshes covered an area of 20,000 km^2. The Central Marshes lie between the Tigris and the Euphrates, Hawizeh Marshes are to the east of Tigris and the Hammar Marshes lie south of the Euphrates. About 90% of the marshes had been drained before the 2003 Invasion of Iraq.

The marshes lie on a flat alluvial delta. During the last 300 km, Tigris drops 24 m and the Euphrates fall is only 12 m. The Tigris and Euphrates formed distributaries on the alluvial plain. The Euphrates flows often terminated into the Hammar Marshes downstream of the town of Nasiriyah. Near Amarah, the Tigris distributes flows between the Hawizeh and Central marshes (**Figure 6**). Downstream of Amarah, several Tigris tributaries, originating in Iran, permit the flow to increase and become a river again. The three marshes (**Figure 4**) once provided a connected environment, particularly during flooding events [10].

Figure 5. Mesopotamia Marshes. Published with the approval of the Editor of the Open Journal of Soil Science.

Figure 6. Mudhif in Marshes on the Shatt al-Arab River. Mesopotamian Marshes at night, southern Iraq; reed house (Mudhif (reed house) and Mashoof (narrow canoe) in the water. Published with the approval of the Editor of the Open Journal of Soil Science.

2.3. Hawizeh Marshes

The Hawizeh marshes is a transboundary wetland fragmented by a dike along the Iran-Iraq border. The Iranian part of the marshes is fed by the Hawr Al-Azim (Karkheh) River. The Tigris distributaries Al-Kahla and Al-Musharrah supply the Iraqi section with much less water than the Karkheh River. During spring flooding, the Tigris can flow directly into the marshes. The marshes are drained via the Al-Kassarah. This flow through the river prevents the Hawizeh marshes from becoming a closed saline basin.

The marshes are 80 km long (south to north) and 30 km wide and cover a total area of 3000 km^2. The northern and central sections are permanent, and the southern part is seasonal. Moderately dense vegetation in 6 m deep lakes can be found in the permanent areas [11]. During the draining, the Hawizeh Marshes were the least affected of the marshes and later facilitated the reproduction of fauna, flora, and other species in Hammar and Central marshes [12]. Re-flooding efforts in 2003-2008 gave some environmental improvements for this water-dependent area, but periodic droughts along with the adverse effects of the borderline dike prevented restoration of the ecological status of this unique Ramsar wetland. In addition, its eastern part is fragmented and locally withdrawn by hydrocarbon extraction activities.

2.4. Shadegan Marshes

Shadegan Marshes and Mudflats of Khor-al Amaya and Khor Musa is the largest lowland in Iran which occupies about 4000 km^2 in the Province of Khuzestan and includes fresh and brackish sedge marshes, tidal flats, creeks, sandbanks, and a low island. In addition, to the main inflow of Jarrahi River, the wetland is fed by overflow channels of the Karun River, irrigation canals, and local rainfall.

The principal long-term threat to the marshes listed as a Ramsar wetland in 1975 is a diversion of water for irrigation schemes further north due to which some part of the area has been degraded to sterile silt flats. In addition, about 10 percent of the marshlands were severely polluted by bombardments with chemical weapons during the Iran/Iraq war in the 1980s. It is reported that the Shadegan area may also have suffered some damage because of “acid rainfall” during the Gulf War of 1991.[4]

2.5. Marshes Ecology

The marshes (**Figure 7**) are a flooded savannas and grasslands ecoregion, also known as the Euphrates-Tigris alluvial salt marsh [13]. The ecoregion includes both a wetland on the lower Karun River in Iran, the Mesopotamian marshes (Iraq), and the Shadegan marshes (Iran) [14]. The marshes are integral to filtering waste and pollutants before reaching the Gulf and coastal health [15] [16].

Figure 7. Confluence of the Tigris, Euphrates, and Shatt al-Arab rivers. Published with the approval of the Editor of the Open Journal of Soil Science.

[4]Shadegan Marshes and mudflats of Khor-al Amaya and Khor Musa. Information Sheet on Ramsar Wetlands—The Ramsar Sites Information Service (available at https://rsis.ramsar.org/)

This function was significantly degraded after their draining [15]. The marshes also serve as nursery and spawning sites for coastal shrimp and fish species [16].

Richarson *et al*. [17] [18] found "*the seasonal and permanent marshlands are dominated by aquatic plants, including reeds* (*Phragmites australis*), *cattail rushes* (*Typha domingensis*), *and papyrus sedge* (*Cyperus papyrus*). *Riparian forests of poplar* (*mainly Populus euphratica*), *tamarisk* (*Tamarix pentandra and Tamarix meyeri*), *and willow* (*mainly Salix acmophylla*) *occur on islands and river banks*" [17] [18].

Olson reported [19] "*The marshes demarcate a range limit for several bird species and are home to* 40 *species of bird. Flamingos, herons, and pelicans inhabit the marshes. The marshes were once home to a large number of birds and the stopover for many other migratory birds as they traveled from Africa to Siberia. At risk are* 90*% of the world's population of Basra reed-warbler and* 40*% to* 60*% of the world's marbled teal population that live in the marshes*" [19] [20]. Also at risk are the African darter and sacred ibis [21]. A subspecies of the hooded crow known as the Mesopotamian crow is found in this section of southern Iraq [22]. The Bunn's short-tailed bandicoot rat, the Indian crested porcupine, and the marsh gray wolf are extinct [23]. The draining of the marshes resulted in a significant bio-productivity decline. Following the overthrow of the Saddam Hussein regime, by the Multi-National Force the ecosystem has begun to recover after water flow to the marshes was restored [24]. Recent surveys have confirmed that the Eurasian otter and the endemic *maxwelli* subspecies of the smooth-coated otter both still survive [25].

2.6. Inhabitants of the Marshes

Rojas-Burke [26] found *that "Maʿdān live in secluded villages of elaborate reed houses throughout the marshes, often only reached by boat. Fish, rice cultivation, water buffalo, and other resources are also used in their daily lives. In the* 1950*s, there were an estimated* 500,000 *Marsh Arabs. This population shrank to about* 20,000 *following the draining and Saddam's violent reprisals, and between* 80,000 *and* 120,000 *fled to neighboring Iran*" [26]. Following the 2003 Iraq invasion, Marsh Arabs returned to the marshes (**Figure 5**) [27]. Many Marsh Arabs destroyed the dikes and dams that Saddam had built [28]. The Iraqi government has provided support via the Iraq Cultural Health Fund, which funds Marsh Arabs' efforts to protect traditional cultural practices [29]. Marsh Arabs struggle to obtain healthcare, clean drinking water, and adequate nutrition and remain one of Iraq's most underserved populations [16] [30]-[32].

Many Marsh Arabs were forced again to relocate as the marshes became increasingly polluted and saline [32]. For those who stayed, their traditional lifestyle was threatened [31]. The marshes supplied 60 percent of Iraq's fish; however, that number has dwindled to less than 10%. This is driving some Marsh Arabs to marsh perimeters, where they grain farm, due to a lack of portable water for raising water buffalo [17].

2.7. Marsh Draining and Subsequent Restoration Efforts

Olson [21] determined "*In the* 1950*s, the draining of Mesopotamian Marshes began with the Central Marshes* (**Figure 4**). *The drainage was gradually accelerated as it affected the two other main marshes until the* 2003 *invasion of Iraq. The draining of the marshes was intended at first to reclaim land for agriculture and later for oil exploration. Intensified agriculture later served as a punishment for Shia Arabs in response to the* 1991 *uprisings in Iraq. The draining of the marshes was exacerbated by upstream dam construction in Syria and Türkiye and due to dams, dykes, and other diversion structures constructed within Iraq*" [19] [23].

Lewis *et al.* [30] noted "*The British engineers worked with the Iraqi government; Frank Haigh developed the Haigh Report in* 1951. *His report recommended a complex of canals, sluices, and dykes on the lower portions of both the Tigris and Euphrates. These water control structures could be used to drain marshes to create profitable farmland. In* 1953, *construction began on the Third River or Main Outfall Drain and later the Saddam River which would drain water from the Central Marsh under the Euphrates and through a canal* (**Figure 8**) and (**Figure 9**) *eventually into the Persian Gulf. Work on the Third River and other draining projects, particularly for the Hawizeh Marsh, quickly progressed in the* 1980*s during the Iran–Iraq War to afford Iraqis a tactical advantage in the marshes*" [30]. Part of the Hammar Marshes was also drained in 1985 to clear an area for oil exploration [33] [34].

Olson [15] reported "*Shia Muslims in southern Iraq rebelled, after the* 1991 *Gulf War, against Saddam Hussein who in turn crushed the rebellion and further accelerated the draining of the Hammar and Central marshes to evict Shias that had taken refuge in the marshes* [10] [30]. *Except for the Nasiriyah Drainage Pump Station* (**Figure 9**), *the* 565 *km Third River was completed in* 1992.

Figure 8. Prosperity River drainage above Central marshes. Picture of the canal under Euphrates. Special Inspector General for Iraq Reconstruction. Published with the approval of the Editor of the Open Journal of Soil Science.

Figure 9. Nasiriyah Drainage Pump Station. Photo Credit: Special Inspector General for Iraq Reconstruction.

Two other canals were constructed parallel to the Third River to the south. The Mother of Battles canal was constructed to divert the flow of the Euphrates south of and below the Hammar Marsh. Second, the 240 *km Basrah Sweetwater Canal* (*Loyalty to Leader Canal*)*, originated in the lower Euphrates region and collected water from the terminus of the Gharraf River. The water was diverted away from the Central Marshes and below the Hammar Marshes passing under the Euphrates and flowing towards Basrah* [10] [35]*. In addition, the Glory River was constructed to divert water from the Tigris's southern-flowing distributaries. The water was diverted parallel and east to the Tigris until the flow reached the Euphrates at its confluence with the Tigris near Qurna*" [10].

Olson [20] reported *"The marshes had lost* 90 *% of their size from the previous decades before the* 2003 *invasion of Iraq* [27]*. Only* 35 *% of the Hawizeh and Shadegan Marshes* (*Iraq and Iran*) *remained and the Hammar and Central Marshes* (*Iraq*) *were nearly drained. After the invasion, returning locals and locals destroyed dikes. The combined efforts of the Iraqi government, U.S. agencies, the United Nations, and record precipitation in Türkiye helped begin the restoration of the marshes* [36] [37]*. Approximately* 58 *% of the original marshes had been re-inundated by* 2006 [38]. *The Nasiriyah Drainage Pump Station* (**Figure 9**) *was completed in* 2009*, allowing the Third River to be used for agricultural drainage* [39]*. The marshes were reduced to* 30 *% of their original size, because of continued upstream dam construction and operation in Türkiye, Syria, and Iran and recent drought* [36]*. Türkiye has built at least* 34 *dams on the Euphrates and Tigris rivers, threatening marsh recovery*" [40]-[42] and the river flow into Shatt al-Arab.

In 2008 approximately 75% of the marshes were restored. By spring of 2015, the marshes had receded to 58% of their average pre-drained level. As the water level fell, salinity increased to 15,000 parts per million in some areas, up from 300 to 500 ppm in the 1980s. Bruneau and Al-sudani [32] noted "*When the river water levels were high, the low-saline Tigris washed over the marshes, cleansed them, and pushed the salty residue into the saltier Euphrates, which flows along the western edge. But now the Tigris is so low that the Euphrates provides most of the water in the marshes*" [32]. The government prioritizes providing water to cities, such as Baghdad (**Figure 10**), along the Tigris and Shatt al-Arab, resulting in a reduction of flow into the marshes [43] and into Shatt al-Arab.

Figure 10. Baghdad Green Zone. Photo Credit: En-academic.com.

2.8. Threats from Climate Change and Pollution

Region temperatures have risen over 0.5 degrees Celsius per decade, causing drought in Iran, Iraq, and neighboring countries whose waters flow into the Euphrates and Tigris [44]. Combined with upriver dams, this reduction in water, because of upstream dams has caused the three primary marshes to fragment into 10 smaller marshes [31]. Massive amounts of untreated sewage and other pollutants are dumped into the Karun, Tigris, and Euphrates, moving downstream into the marshes and further degrading the water quality [26] [39] [40].

3. Results

3.1. Shatt al-Arab River

Olson [19] found "*The Shatt al-Arab* [45] *is a river formed at the confluence of the Euphrates and Tigris rivers near the town of al-Qurnah in southern Iraq. The southern end of the* 200 *km Shatt al-Arab River* (**Figure 11**) *constitutes the Iraq-Iran border down to its mouth, where it flows into the Persian Gulf. The Shatt al-Arab* (**Figure 12**) *varies in width from about* 800 *m at its mouth to* 232 *m at Basra. The Tigris and Euphrates originally emptied into the Persian Gulf via a channel further to the west. Kuwait's Bubiyan Island is part of the Shatt*

Figure 11. Shatt al-Arab at Basra. Photo Credit: Blogspot.com.

Figure 12. Ships on Shatt al-Arab. Photo Credit: Juergen Braker. Fleet Mon.

al-Arab delta [46]*. The Karun, a tributary, joins the river from the Iranian side and deposits large amounts of silt into the river. The silts necessitated continuous dredging to keep the river navigable*" [19] [47] [48]. Derelict vessels (**Figure 13**) remain on the sides of the rivers.

In the mid-1970s, Mesopotamia region had 17 - 18 million date palms, or an estimated one-fifth of the world's 90 million palm trees. By 2002, more than 14 million of the palms had been killed by the combination of salt, pests, and war. This count includes around 5 million in Iran and 9 million palms in Iraq. As many as 3 - 4 million remaining trees are in poor health [49].

Under Shah Mohammad Reza Pahlavi in the late 1960s, Iran developed a strong military and took a more assertive stance in the Near East [50]. Iran abrogated the 1937 treaty in April 1969 and Iranian ships stopped paying Shatt

Figure 13. Karun III Dam in Iran. Photo Credit: Blogspot.com.

al-Arab tolls to Iraq [51]. The British journalist Patrick Brogan [52] stated "*The Shah argued that because most of the ships that used the Shatt al-Arab* (**Figure 12**) (**Figure 13**) *were Iranian the* 1937 *treaty was unfair to Iran. Almost all river borders around the world ran along the thalweg. Iraq threatened war over the Iranian move. On* 24 *April* 1969*, an Iranian tanker escorted by Iranian warships* (*Joint Operation Arvand*) *sailed down the Shatt al-Arab. Iraq, being the militarily weaker state, did not challenge* [7]*. The Iranian abrogation of the* 1937 *treaty by Iran marked the beginning of a period of acute Iranian-Iraqi tension that was to last until the Algiers Accords of* 1975" [8] [52].

Olson [19] reported "*Attempts by the United Nations to intervene and mediate the Iraqi-Iranian dispute were rebuffed. Baathist Iraq claimed the frontier, agreed to in* 1937*, was still the legitimate frontier. In the early* 1970*s, Iran became the main patron of Iraqi Kurdish groups fighting for independence from Iraq. In* 1974 *with the open support and encouragement of Iran, the Iraqi Kurdish peshmerga rebelled against Iraq. The Peshmerga fought a conventional war, instead of waging a guerrilla war, against Iraq which led to very intense fighting* [52]*. Iraq and Iran almost went to war, in the winter of* 1974–75*, over Iran's support of the Kurds in Iraq* [52]*. The Iraqis decided against war, given Iran's greater population and military strength. To end the Kurdish rebellion, Iraq chose to make concessions to Tehran* [52]*. In March* 1975*, the Shah of Iran and Vice President Saddam Hussein of Iraq signed the Algiers Accord. Iraq recognized a series of lines closely approximating the thalweg of the waterway, as the official border. In exchange for this Iran agreed to end its support of the Iraqi Kurds* [52]*. The Algiers Accord caused much bitterness in Iraq over what was seen as Iranian bullying* [8] [52]*. However, the Algiers Accord saw Iran cease* *supporting the peshmerga as the Iranians closed the frontier, causing the Kurdish rebellion to promptly collapse"* [19]. Brogan [52] wrote that *"the Iraqis celebrated their victory in the usual manner, by executing as many of the rebels as they could lay their hands on*".

President Saddam Hussein of Iraq abrogated the 1975 treaty, in 1980, before Iraq invaded Iran. The main thrust of the military movement occurred across the Shatt al-Arab River and adjacent floodplains, which was the stage for most military battles between the two armies. The Shatt al-Arab River was Iraq's only outlet to the Persian Gulf, and thus, its shipping lanes were greatly affected by Iranian attacks.

Brogan [52] found "*In* 1986*, Iraq's shipping activities came to a halt after Iran captured the Al-Faw peninsula. Iraq shipping had to be diverted to other Arab ports such as Kuwait and Aqaba, Jordan. The Iraqi offensive was started on* 17 *April* 1988 *and resulted in Al-Faw peninsula recaptured after three days of fighting. The Iraqis began a sustained drive to clear the Iranians out of all of southern Iraq once Al-Faw was retaken. In May* 1988*, the Iraqis expelled the Iranians from Salamcheh and took Majnun Island. The Iranians showed all the signs of collapsing morale during the spring of* 1988 *fighting* [53]*. Brogan reports from the front, outside Basra and Faw, indicated that the Iranian resistance was surprisingly weak. The Iranian Army that had shown such courage and élan early in the war now broke in a rout and fled before the Arabs. The Iranians seemed tired and worn out by the nearly eight years of the war. They "put up very little resistance" to the Iraqi offensives during the* 1988 *battles. At the end of the Iran-Iraq War, both sides agreed again to treat the Algiers Accord as binding*" [52].

3.2. Pollution and Human-Induced Transformation of the Karun River in Iran

Olson [18] found "*The* 950 *km long Karun is the only navigable river in Iran. The Karun forks into two branches, the Haffar and Bahmanshir, before flowing into Arvand Rud* (*Shatt al-Arab*)*. As a result of Iran's construction of new dams on the Karun and tributaries. These dams* (**Figure 14**) and (**Figure 15**) *increased the salinity levels in the Shatt al-Arab as a cumulative effect of both the increase in river water salinity and the increase in the recurrence and extent of seawater intrusions due to the decrease in river discharge. Salinity destroyed farm areas and threatened livestock in the Basra area of Iraq. Civilians were forced to* evacuate*. The dams are often delayed because of fear of submerging archaeological sites. Construction was preceded by exploratory archaeological surveys where evidence of archaeological sites was found and emergency excavations. The Karun and tributary dams had significant effects on the ecology of the river and sediment transport*" [18].

The Karun River is a unique water body in Iran due to its length, catchment area, and navigability but also in terms of the level and duration of human-induced transformation of its flow. Beginning in ancient times with the

Figure 14. Abandoned ships plus bridge over Shatt al-Arab. Photo Credit: In the public domain.

Shushtar[5] Historical Hydraulic System which includes numerous dams, canals, water mills, and bridges, the use of water resources of the Upper Karun has continued with their partial transfer to the neighboring drainless Zayandeh[6] basin. In particular, the system of dams and tunnels which originated in the Sassanid dynasty (3rd-7th centuries CE), intensively developed during the reign of Shah Abbas I (late 16th - early 17th centuries) and reached its present level in the 20th century, transports part of the Kuhrang (Upper Karun) flow to the Zayandeh Valley, including for water supply to Isfahan[7], the third largest city in Iran.

[5]According to the World Heritage Centre's official description [Shushtar Hydraulic System (Iran)—UNESCO World Heritage Centre. No 1315] with additional details from [Cultural Heritage of Water/The Cultural Heritages of Water in the Middle East and the Maghreb. Thematic Study. First edition—ICOMOS 2015], "*the first confirmed water irrigation systems from canals in the region date back to the Elamite civilization* (*Chogha Zanbil region*), *notably in the* 13*th century BCE. They were probably influenced by the large-scale irrigation work undertaken in Mesopotamia by the Sumerians from the* 4*th millennium BCE. The Shushtar Historical Hydraulic System dates from the* 3*rd century CE* (*with the construction of the large Shâdorvân weir dammed and provided a passage across the river Kârun*), *probably on older bases from the* 5*th century BCE. With the later addition of the monumental Mizân water intake upstream from Shâdorvân and the Gargar canal, the hydraulic ensemble as then reworked and extended was designed to supply water to the new city of Tustar, later called Chouster or Shushtar, and to irrigate the vast semidesert plain to the south, along the last of the mountain foothills, for the systematic development of agriculture, notably the planting of orchards, over an area of* 40,000 *ha. known as Mianâb* (*Paradise*). *During the Islamic period, the various Iranian dynasties carefully maintained the Shushtar Hydraulic System as an essential component in the country's development. They carried out significant maintenance work, and sometimes additional work, such as during the Safavid* (1500-1700) *and then the Qadjar* (1779-1925) *dynasties for the Gargar bridge dam and the Shâdorvân Grand Weir. The mill, bridge-dam, and tunnel region were developed from the origins of the system through to at least the* 15*th century, and then again in the* 19*th and* 20*th centuries*".

[6]Also spelled *Zāyandarud or Zayandeh Rood*.

[7]Also spelled *Esfahan*.

Figure 15. Karun IV Photo Credit: Orange Smile.

Many of the large dams on the Karun River were built to generate hydroelectric power and provide flood control. These include Masjed Soleyman Dam, Gotvand Dam, Karun I, Karun III, and Karun IV. Karun II would be located on the Sussan Plain between Shahid Abbaspour and Karun III. Construction has been delayed because of the potential of submerging archaeological sites. Karun V has been proposed upstream of Karun IV dam. The dams on the Karun have required the relocation of thousands of residents and had a significant effect on the ecology of the river and on sediment transport [18]. There are many dams on the Karun River tributaries including Dez Dam, Bakhtiari Dam, and Khersan III Dam (*under construction*). The rest of proposed are Khersan I, Khersan II, Zalaki, Rooudbar, Liro, Bazoft, and others [52] [53].

3.3. Irrigation Dams on the Karun River

Before the construction of the dams (**Figure 16**) and (**Figure 17**), the Karun was utilized for irrigation by means of water lifts on the banks which were worked by animals. Modern irrigation projects have benefitted from the regulated flow of the Karun, which is estimated at more than 160,000 hectares from Shushtar in the north to the Bahmanshir in the south [53].

The traditional hydrology of the Karun has been radically impacted by the construction of dams since the mid-20th century. The first of these dams was the Kuhrang dam-and-tunnel system at the headwaters of the Karun [53]. This dam-and-tunnel (so-called qanats or kārīzes) system diverted the water that would have eventually joined the ocean into the Zayandeh drainless basin. Water seepage into the Kuhrang tunnels may cause technical problems as well as a spring flow rate decrease which may lead to environmental, social, and technical problems [54]. This tunnel with a length of 23.3 km aims to provide part of the

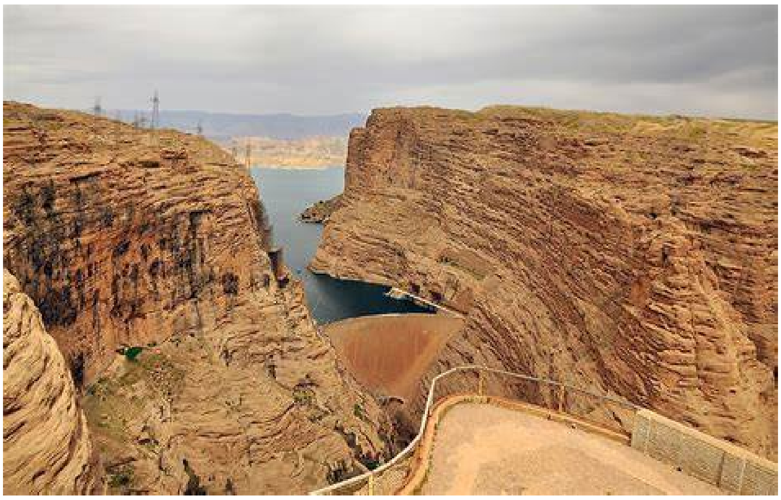

Figure 16. Dez Dam on the Dez River in the Khuzestan province of Iran. Photo Credit: Iran Water & Power Resources.

Figure 17. Perlite Construction Company's Masjed Soleyman Dam. Photo Credit: Uni Royal—Own work. CC BY-SA4.0.

water shortage in the central region of Iran for drinking, industry, and agriculture purposes (-120 million cubic meters per year, MCM/year). Before tunnel sealing, the amount of water seeping into the tunnel was estimated at 11.6 MCM/year, with the highest seepage occurring in karstic formations. However, after sealing the tunnel, the total water seeping into the tunnel is about 5.1 MCM/year. Kuhrang III tunnel, which transfers surface water from the Karun catchment to the Zayandehrud catchment through extremely complex geologic settings, has caused a decrease in the flow of some springs [54]. To determine the source of water seeping into the tunnel and to investigate the effect of tunnel excavation on the flow rate of springs, two sampling campaigns were conducted during wet and dry seasons, 2018-2019. Samples were taken from the seeps within the tunnel, groundwater, and precipitation and analyzed for isotopic and hydrochemical evaluations. The results show that groundwater enters the tunnel from the catchment area of several karstic springs in the study area [54]. The water now flows into the inner Iranian plateau and supports the water resources of the Isfahan Province. In 1948-1953 the first 2.7 km long Kuhrang diverting tunnel was constructed. Later, two more tunnels were dug.

The upper course of the Karun and its tributaries have also been exploited by the construction of large dams and associated reservoirs. These facilities control floods, generate hydroelectric power, and store water for irrigation and other purposes (**Table 1**). The first dam on the Karun, completed in 1976-1978, is commonly referred to as the Karun I dam. The concrete-arch dam was built at the entrance of a gorge, behind which a large lake has been created (**Figure 16**). Three more dams have been completed to date, and all are reinforced concrete arched dams. A Karun V dam, upstream from Karun IV (**Figure 16**), has been proposed. Dams, including the Dez (**Figure 17**), were also built on the Karun's tributaries. Dez dam (**Figure 17**) located on Dez River in Khuzestan province is the third tallest in Iran at 203 meters. It was primarily constructed for hydroelectricity. It was completed in 1962-1963 and has an installed capacity of 520 megawatts [55]. These projects, ambitious as they are, trouble those who are concerned about the ecology of the region, sediment transport, and the relocation of settlements.

The Masjed Soleyman Dam (**Figure 17**) is on the Karun River. It is 177 meters

Table 1. Main Dams of the Karun Basin (based on UN-ESCWA and BGR, with additions).

Name	River	Flow Distance to the Karun River Mouth/Persian Gulf, km	Completion Year	Reservoir Surface Area, sq. km	Total Capacity of Reservoir (Dam Volume), MCM, km^3	Main Purposes	Hydropower capacity, MW
Dez	Dez	520/610	1962	65	3340	IR HP WS	520
Karun 4 (Karun IV)	Karun	730/820	2010	29	2190	HP	1020
Karun 3 (Karun III)		660/750	2004	48	2970	IR HP FC	2280
Karun 1 (Karun I, Shahid Abbaspour)		540/630	1976	55	3139	IR HP	2000
Karun 2 (Karun II, Masjed Soleyman)		510/600	2001	8	261	IR HP	2000
Upper Gotvand (or Gotvand, Gotvand-e-Olya)		420/510	2015	97	4500	HP IR	2000
Lower Gotvand (Nader Shah)		410/500	1977	1,4	1620	IR	None

Note: The main dams' purposes are irrigation (IR), hydropower (HP), water supply (WS) flood control (FC).

high, has an installed capacity of 2000 MW, and its reservoir holds 261 million cubic meters of water. The dam was built by Iran Water and Power Resources Development Company [52] and was completed in 2001-2002. The power station was built in two 1000 MW stages and completed in 2003 and 2007 [52].

The Upper Gotvand Dam (**Figure 18**) is an embankment dam northeast of Gotvand in Khuzestan Province, Iran. It is on the Karun River [53]. The dam is the tallest earth-fill dam in Iran and has two 1000 MW generators. The Lower Gotvand Dam is 22 m high and serves to divert the Karun River into two canals for the irrigation of 42,000 ha of farmland [52] [53]. Before the water extraction of this dam, one of the important debates and disagreements surrounding the construction of this dam was that in the downstream part of this dam, the ground has salt veins, and this can cause the saltiness of the water used by the cities and villages downstream [56].

Figure 18. The reservoir behind the Upper Gotvand Dam in Iran. Photo Credit: Rehman Abubakr.

Engineer Meshkat, a geologist, and a member of the team that prepared the geological map of the dam, said that the design team was aware of the problem of the dam lake being located on salt masses. In addition, Isa Kalantari, the former head of the Environmental Protection Organization, [56] said: "*Before the revolution, the Americans examined the Gotvand dam from an environmental point of view and decided to build the dam* 15 *kilometers higher*". He believes that the executors of the Gotvand Dam project should be tried for the error in the implementation of this project. He told Tehran University Geography faculty, students, and environmental activists" [56] that "*The salinity of the water below the dam is* 5.5 *times the salinity of the water in the Persian Gulf, and nothing can be done to solve this problem*".

The Karun I Dam (Shahid Abbaspour Dam) (**Figure 19**) is a hydroelectric dam on the Karun River. The large arch dam (with a height of 200 m and a crest width of 6 m) is located 50 km northeast of Masjed Soleiman, in the Khuzestan province of Iran [53]. It was completed in 1976. It contains two power stations with each having four water turbines connected to electric generators. The combined capacity is 2000 MW.

Figure 19. Karun I (Shahid Abbaspour) Dam. Photo Credit: Hydroelectric Energy.

The Karun III hydroelectric dam on the Karun River is in the province of Khuzestan, Iran. It was built to provide seasonal flood control and help meet Iran's energy demands. This dam has a concrete arch-type design (**Figure 19**). The arch dam design is good for this location which has a narrow, rocky gorge behind the water reservoir. Moreover, because of its arch shape, the force of the reservoir water presses downward against the dam which strengthens the dam foundation [53]. The dam is 205 m high and 185 m above the riverbed [56].

Karun IV is an arch dam (**Figure 14**) on the Karun River in the provinces of Chaharmahal and Bakhtiari, Iran. The dam is a concrete double curvature arch-type and 230 meters high from the foundation [53]. The arch dam design is an ideal one for a dam built in a narrow, rocky gorge to hold back water in a reservoir. The dam is curved. Because of the arch shape, the force of the backed-up water presses downward against the dam and has the effect of strengthening the dam foundation. The dam withholds a reservoir with a surface area of 29 square kilometers and a capacity of 2.19 cubic kilometers. Concrete pouring began in 2006 and the power plant began producing electricity in November 2010 *[52]*. On December 11, 2010, the second generator for the dam became operational and was connected to the grid. The dam will eventually have an installed capacity of 1020 MW. The dam was inaugurated on 6 July 2011 by Iranian President Mahmood Ahmadinejad.

Hydraulic engineering construction combined with various forms of water use have significantly transformed not only the water regime of the Karun River and tributaries but also the chemistry of water and bottom sediments. In particular, the influence of such a natural factor forming the macro-ionic composition of water as dissolution of sediment components by groundwater discharged into the river and evaporites, such as halite and gypsum, directly eroded by the river [57] is enhanced by the impact of the cascade of dams. Due to the vertical stratification of the water column, which is pronounced in mountain reservoirs, water with higher salinity enters the lower reach [58]. Downstream, this effect is further multiplied by discharges of drainage water from irrigation systems, as well as wastewater from settlements and industrial facilities [59]-[62].

Water withdrawal for agricultural, municipal, and industrial needs reduces the river flow, concurrently increasing the concentration of dissolved and suspended contaminants. At the same time, long-term observations of the hydrological regime of the Karun in its middle and lower reaches since the 1950s demonstrate that the downward trend of the river's water content in recent decades is caused not so much by water use as by changes in the hydrometeorological conditions of the catchment area [63].

One of the significant unfavorable effects of water salinization is an increase in its corrosivity which is monitored and considered in the design of structures in contact with river water [64]. The no less important consequence of contamination of the Karun River water is the deterioration of the quality of associated freshwater habitats. While the water areas of relatively young mountain reservoirs remain predominantly oligotrophic [65], in the middle and lower reaches of the Karun River the waters and bottom sediments are intensively enriched with nutrients and organic matter brought by drainage effluents from irrigation systems and municipal wastewater from urban and rural settlements.

In the Karun basin, monitoring of aquatic organisms that act as intermediate recipients of the above impacts and at the same time are indicators of their intensity and manifestation of so-called cumulative effects has been organized [66]. Many hydrobionts, including 13 freshwater fish species, are endemic to the Karun basin [67]. Their communities are affected by invasions by non-native (alien) species. Several immediate public awareness and other relevant measures to manage more effectively the fishery and aquaculture sectors of the region are proposed to prevent invasions and improve habitat quality [68].

The main part of the measures implemented for water contamination control envisages a reduction of water consumption, as well as increasing the share of treated wastewater and the efficiency of its treatment. When developing and implementing the Integrated plan for pollution reduction in Karun River [69], it was considered that the largest contribution to water consumption (88.5%) as well as discharge of contaminants with wastewater (48%) is made by agriculture, followed by industrial sector (7.8% and 23%, respectively), and the third by municipal services (3.7% and 26%).

The actions taken by Iran to maintain water availability and improve the water quality of the Karun River are also of international importance, as part of the contaminants are discharged into the Shatt al-Arab borderline stream and further into the Persian Gulf. In addition, the flow of the Karun significantly affects the balance between fresh and marine water within the vast estuarine area drained by the Shatt al-Arab River and Bahmanshir Branch, restraining the unfavorable intrusions of brackish water [70].

3.4. Main Bridges across the Karun River and Tributaries

The Karun valley [71] is widely known and unique not only for its hydraulic structures and ancient centers of agriculture but also for bridges. Before the introduction of modern technology, bridges existed only in the mountainous course of the Karun, as European travelers reported in the 19th and early 20th centuries. These included timber bridges of impermanent nature, and stone and mortar constructions in the rest of the upper course of the Karun. These bridges were too few and widely dispersed to facilitate communication across the Karun on any significant scale. The Bakhtiari tribesmen, in their annual migrations, often had to cross this winding river more than once each way.

The Karun IV Arch Bridge (**Figure 20**) is an arch deck bridge in Lordegan, Chaharmahal and Bakhtiari province, Iran. The bridge flies over Karun-4 Reservoir (**Figure 21**) in Chaharmahal and Bakhtiari, Iran. The deck is located 245 meters above the reservoir's bed and 70 meters above the normal water level. Access to the bridge is possible by driving through a couple of tunnels with 550

Figure 20. Karun III Dam. Photo Credit: Ahura 21.

meters and 450 meters in length at two sides of the bridge. It has the longest arch bridge span in the Middle East and is the 49th longest arch bridge in the world. Karun River bridge has a 378-meter arch span. This arch deck bridge has an orthotropic deck system with 11.8 meters total width which incorporates a two-way carriageway and a walkway at each side. It weighs 3875 tons and is constructed of 1212 pieces. The bridge construction finished in 2013 and opened to traffic in 2015.

The Karun River Bridge (**Figure 22**) near Karun III dam is one of two large steel truss arches that were necessary to carry a former road across the deep reservoir. Upon its completion in 2005, the West span became the highest bridge

Figure 21. Bridges over a reservoir on the Karun River in Iran. Photo Credit: In the public domain.

Figure 22. Karun River Suspension Bridge near Dam III bridge in Khuzestan Province. Photo Credit: HighestBridges.com.

in the Middle East, surpassing the record previously held by Iran's 35-year-old Ghotour bridge. The larger West crossing over the main channel of the Karun River has a hinge-to-hinge span of 252 meters with an overall length of 336 meters. The smaller East span crosses a smaller side canyon with a span of approximately 175 meters and a height of approximately 130 meters. The West span has a much greater span-to-rise ratio than the East bridge since both are of equal height above the river.

The 501-meter White bridge (**Figure 23**) is nearly 10 meters wide and soars 13 meters at its highest point. This suspension bridge, located on the Karun River at Ahvaz (**Figure 24**), was built by a German engineer and his wife in the early 1900s. The German engineer died after raising one of the two arches of the bridge and his wife completed the project in 1937. The bridge was renovated in 2011 and light fixtures were added to it. The bridge was registered as a National Heritage site in 2000.

Figure 23. White Bridge: Arch Bridge in Iran's Ahvaz. Photo Credit: Milad Hamidi: Tasnim News Agency.

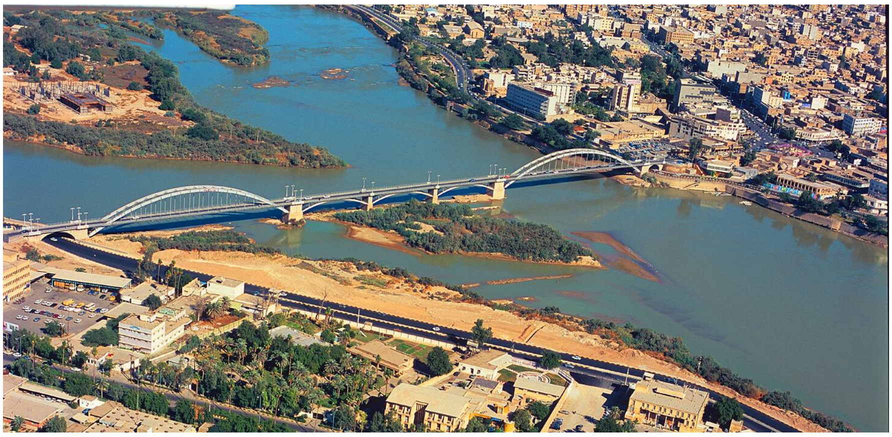

Figure 24. Bridge in Ahvaz over Karun River with island. Photo Credit: Visitiran.1r.

3.5. Climate Change in Iran

Climate change is thought to be affecting Iran's economic, environmental, political, and security challenges worse even among the other countries of the Middle East [72]. Rising temperatures, declining precipitation, intense droughts, desertification, salinization, and the increasing prevalence of dust storms have undermined Iran's agricultural sector. Additionally, Iran's water security is based on the declining Karun-Shatt al-Arab water system. Both national and regional political uncertainty will make mitigating the effects of climate change and addressing transnational water management very difficult. Any climatic changes such as increasing temperatures, reduced precipitation, and increasing water scarcity will likely have serious implications for the states of Iran and Iraq for years to come [73]. In 2018, after Iran's years of drought land under cultivation was reduced by half. The cultivation of irrigated crops such as corn, cereals, and rice was suspended by the government. Production losses were estimated at 39 million dollars [74]. In 2019, an unusually wet winter "*restored freshwater marshes of southern Iran*" and caused widespread flooding on the Karun River [75].

3.6. Navigation and Territorial Claims

The Iraqi cities and major ports of Al-Faw and Basra are situated along this river as are the Iranian cities and major ports of Khorramshahr and Abadan. Between 1980 and 1988, conflicting disputes over navigation rights and territorial claims between Iran and Iraq were among the main causes of the Iran–Iraq War. After 1988, the pre-1980 status quo was restored.

4. Conclusions

Both the ecological and historical significance of the Fertile Crescent region serving a unique habitat and the cradle of modern civilization has developed thanks to the availability of water resources resulting from the combination of climatic and precipitation-fed river basin conditions. For the same reason, the ecological and socio-economic conditions of these territories are so vulnerable to climate change and require international efforts for effective adaptation of economies and conservation of terrestrial, freshwater, and associated marine habitats.

The eastern part of this area, on which the article is focused, is the most sensitive and has not yet fully recovered from a series of devastating military conflicts of the 1980s and 1990s, which significantly disrupted both historically modified ecosystems and nature-based land use practices. The functions of the rivers in this unique area are diverse: along with traditional river-based ecosystem services (like water supply, navigation, fisheries, etc.), some of them serve as state boundary lines (Shatt Al-Arab), the basins of others (Euphrates, Tigris) are transboundary and have been seriously transformed along their entire length for irrigation, flood control, and hydropower generation.

The example of non-transboundary Karun River which has also been seriously transformed throughout its entire length has shown that its flow also affects the availability and quality of water resources in neighboring countries, so it should be considered when developing and implementing international water management and biodiversity conservation programs.

An objective of this research was to document the settlement history in Iran on the Karun and Shatt al-Arab rivers which became the pathway for invasions, wars, settlement, conflicts, navigation, and trade in the Karun basin has put the river system at risk for more than 2500 years. The Karun and Shatt al-Arab rivers have had a huge environmental, economic, and social impact on all four West Asia countries. However, with five countries sharing the Tigris-Euphrates-Karun-Shatt al-Arab river system it has been difficult to mitigate and manage the threats and risks to the rivers and their water quality. Environmental risks include pollution, military activities, gas, and oil production, industrial and urban wastewater, over-fishing, desertification, population growth, climate change, threats to the food supply, urban development, watershed dams in neighboring countries, shoreline erosion, saltwater intrusion, and flooding.

Using the example of Iran's largest river, the Karun, it can be seen that rivers remain systems evolving under the influence of natural factors many of which are hard to predict and beyond the control of society, even though the changes in these factors, including climate, may themselves be a response to regionally or globally significant and long-term human activities. Iran's Government policies can affect challenges from climate change and recovery from war damage to irrigation infrastructure. Outside assistance by governments with interests in regional stability should be considered.

A regional approach that addresses the best use of the resources from all countries' interests, and the environment using local funds, sciences, and national policies will improve the chance of success by allowing Iran to solve their problem. How outside nations can shape such a solution will require a long-term investment of intellectual resources over funds or military influence. There is a need for governmental policies and integrated management of the environment, to secure self-sufficiency, environmental security, and food security for The Islamic Republic of Iran. A balanced approach to water management is needed and must include efficient measures and aggressive conservation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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