Developing an USACE method to rehabilitate Hour-al-Azim marsh and dust management

Ramin Gorji Shani and Gholam-Abbas Barani

ABSTRACT

Hour-al-Azim marsh is one of the most significant wetlands of the Mesopotamia watershed. In the past few years, severe environmental and hydrological stress have caused the loss of a large part of its area and its bed has become the largest focal point of haze in the southwestern of Iran. Determining delineation is one of the most important and necessary measures to protect a wetland's ecosystem and, in this study, delineation was determined using the USACE-R-G method. This method is a combination of ecological and hydrological criteria with a Remote Sensing and Geographical Information System. The results showed that under the first scenario the marsh is about 3,279 km^2 which about 882 square kilometers constitute free-water surface and its average depth is 2.4 meters. In the second scenario, these numbers were estimated to be 1,619 km^2 with an average depth of 2.7 meters. Moreover, the area of the haze focus is about 1,659 km^2. As well as this, under these conditions the amount of water required to submerge the marsh is 7.9 in the first scenario and 4.4 billion cubic meters in the second one.

Key words | delineation, ecosystem, USACE-R-G, wetlands

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HIGHLIGHTS

- The delineation of Hour-al-Azim marsh was performed based on an USACE-R-G method for prior and current conditions.
- The results confirmed that human activities related to oil harvesting have exerted severe environmental and hydrological stress on the marsh body.
- It was found that the marsh needs a water volume of 7.9 billion cubic meters to satisfy the environmental conditions and the haze problem.

INTRODUCTION

Wetlands in different communities have different meanings and definitions, as more than 50 different definitions have been providing for them. Ramsar Convention, as an international body for the protection of wetlands, provides a comprehensive and broad definition of wetlands: 'wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters' (Conservation of Iranian Wetlands Project *et al.* 2014). Ramsar Convention divides wetlands into two general and partial types. In general classification, wetlands are divided into five categories: Lacustrine, Riverine, Palustrine, Marine and Estuarine; whereas, in partial classification, this method categorizes wetlands into three groups: Marine and Coastal, Inland and Man-made (Ramsar Convention Secretariat 2010). Wetlands as the delta of rivers are one of the most valuable and sensitive natural ecosystems

doi: 10.2166/ws.2021.005

in which organic food production, cultural and tourism services, flood control, biodiversity conservation, sediment control, mineral nitrate stabilization, erosion control of estuaries, climate modification and greenhouse gas reduction are among the most important aspects (Wondie 2018; Wu *et al.* 2018; Asomani-Boateng 2019; Debanshi & Pal 2020). According to Schuyt & Brander (2004), the economic value of wetlands registered at the Ramsar Convention (which amounted to 12.8 million square kilometers at the time of the calculation) was about US$70 billion a year. Today, human activities have had irreversible effects on the shape of these ecosystems while the most important damaging factors in wetlands are wetland pollution, water contamination and reduction in inflow. In general, determining the delineation is one of the most critical issues in protecting a wetland as well as in issuing civil and industrial permits. In other words, it shows how far industries and buildings should be constructed from the ponds to prevent invasion of the ecological and legal privacy of an ecosystem and to guarantee the conservation of life within a wetland. The use of a remote sensing (RS) and geographical information system (GIS) is one of the most common methods for determination among researchers (Zheng *et al.* 2017; McCarthy *et al.* 2018; Simioni *et al.* 2019). Digital elevation models (DEM) and RS have already been employed for watershed delineation, wetland mapping and monitoring (Chu 2017; Kaplan & Avdan 2017; Pal & Saha 2018; Slagter *et al.* 2020). DEM and RS, however, have limitations, leading some researchers to combine these items or use ones with other features. For example, Mwita *et al.* (2013) combined multispatial resolution imagery with GIS and field survey to delineate and map small wetlands in Kenya and Tanzania. Each country has its own set of rules to assess the delineation of wetlands, but the most popular of these methods is the US Army Corps of Engineers (USACE) method, in which hydrological, ecological and geological issues of wetlands are taken into account in identifying their bed size and limitation (Environmental Laboratory 1978). The US Environmental Protection Agency uses this method to calculate the boundary of wetlands in all geographic locations of the country, with any climate, in a way that all natural or man-made wetlands in the country follow this method (Schneider & Sprecher 2000).

In Iran, as in other countries, there are sets of rules on how to use surface water resources, and one of these laws is the Land and Coastal Law, which was passed in 1974. According to this law, lands that are created as a result of sea water drop alongside any flow of seas, lakes, islands, or even as a result of lowering and drying up of wetlands are part of national lands and cannot be privately owned and occupied (Ministry of Energy, Planning and Budget Organization 2005; Monem *et al.* 2010). The rest of the laws in the country also apply only to the construction of houses or the location of industries in rivers, lagoons, lakes and seas. Therefore, due to the lack of a legal basis, for the rights of inland wetlands in the country, their delineation is often broken and violated. One of the most prominent inland wetlands in the country that has been subjected to severe stress due to the lack of a well-established law is the Hour-al-Azim marsh that has undergone massive changes over the years due to war and oil harvesting activities; moreover, the lack of sufficient volume of water for marsh life has made its bed the largest focus of dust in the southwest of the country. More than 14 earth and concrete dams have been constructed on the Karkheh and Tigris watersheds for different purposes of water storage, flood control and hydropower generation, among which the Mosul, Samarra (Tharthar) and Karkheh are the most important dams, storing about 91 billion cubic meters water (Abrishamchi *et al.* 2012; Mohammad *et al.* 2016; Abdullah *et al.* 2019). The present study was undertaken to determine the wetland delineation in accordance with the laws governing the country to calculate dust zone area and the amount of water required to submerge it. Therefore, the USACE method in combination with RS and GIS (USACE-R-G method) was used to identify the boundary of the Hour-al-Azim marsh as well as to determine the dust zone area–volume. This method was used to evaluate the legal, ecological and hydrological border of the wetland. This study was conducted using field observations by researchers, RS, GIS, and hydrological, ecological and geological data.

MATERIALS AND METHODS

Study area

Hour-al-Azim marsh, is one of the largest marshes in West Asia, located between Iran and Iraq. The eastern part of it, which is situated in Iran, is known as Hour-al-Azim while the western part is called Hur al-Hoveizeh, but international assemblies refer to it as Hour-al-Azim marsh. Hour-al-Azim marsh is bordered on the north by the Hour al-Sanaf and on the south by the main tributary of the Tigris River and its lowlands. This marsh extends latitude from 31°50′N to 31°0′N and also longitude from 47°58′E to 47°20′E. The length of the marsh from north to south is about 80 kilometers and its width is 30 kilometers. Inflow to the marsh is provided by the Karkheh and the tributaries of the Tigris River, known as Kahla and Mashah, as shown in Figure 1. The inflow to the marsh is also discharged through the Swaib and the Kassara channel.

Model development

In this study, the delineation of the marsh was checked using the USACE-R-G method, in which the delineation unification is based on three general principles of vegetation, soil texture and wetland hydrology. In the USACE-R-G method, two routine and comprehensive (Combination) methods have been proposed for estimating typical wetlands, and the routine method is divided into three levels of office, onsite and combination. In fact, the combination level is a composition of the onsite and the office level. Atypical wetlands are the ones that do not appear to maintain one of the three general principles of wetland designation due to human or non-human activities. In atypical conditions, portions of the marsh that were dried prior to legal determination are not part of the wetland's delineation (Figure 2).

Hydrological, ecological and geological data of the study area are used in this study to verify the delineation of common marsh. Therefore, two scenarios were presented according to the USACE-R-G method to assess the delineation of bedrock marsh and its water storage capacity. These two scenarios are as follows:

(A) Determination of delineation of the bed, under conditions prior to hydrological and environmental stresses (Typical wetland).
(B) Determination of the delineation of the bed under the present conditions (Atypical Wetland). In the second scenario, the wetland was considered special and was excluded from its arid areas, with only the northern portion of the Ramsar International Convention being registered as a conventional wetland using a combination method.

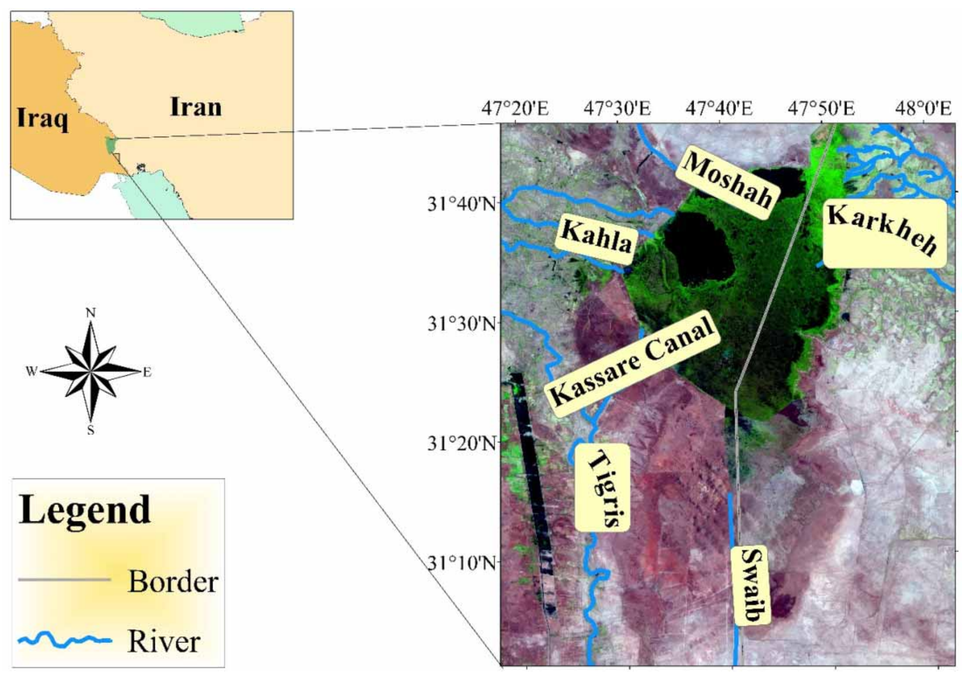

Figure 1 | Hour-al-Azim marsh.

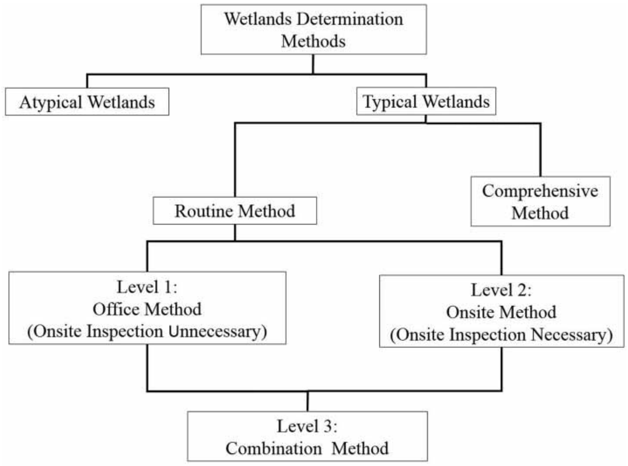

Figure 2 | The flowchart of wetland determination according to USACE-R-G.

The following steps were taken to measure the delineation of Hour-al-Azim marsh under USACE-R-G method:

I. Hydrological study of marsh
II. Field survey of marsh
III. Determination of soil texture and permeability of marsh
IV. Analysis of satellite images
V. Determination of the quantity and quality of vegetation
VI. Using 1: 25,000 maps.

Figure 3 shows a flowchart illustrating the main steps in analysis.

As the marsh has been under stress and disturbance since 1981, hydrological data and satellite images prior to this year were used to determine the delineation in first and second scenarios (North portion).

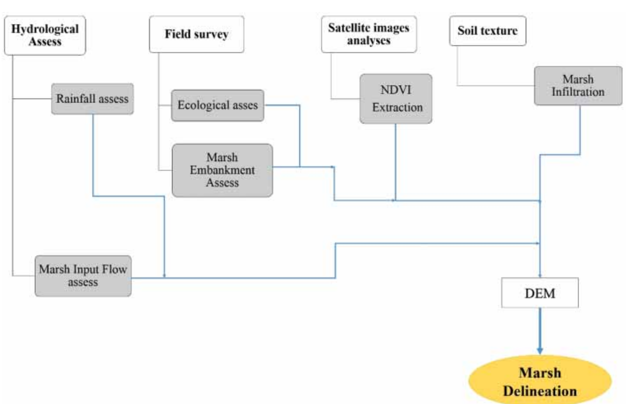

Figure 3 | Flowchart illustrating main steps in analysis.

Hydrology of marsh

According to the USACE-R-G method, the maximum rainfall, runoff, and average monthly discharge of inflows to the marsh prior to hydrological stress should be evaluated to obtain the year with the highest rainfall (wet year).

Rainfall

To determine the direct rainfall at the surface of the Hour-al-Azim normal rainfall data from synoptic stations and its adjacent rain gauges were used. The data related to the Basra, Al-Amara, Bostan, Abadan, Ahvaz, Mahshahr, Basra, Aghajari and rain gauge stations of Hamidieh, Abdulkhan and Molassani. After statistical tests, direct precipitation at the surface of Hour-al-Azim marsh were obtained using the IDW (Inverse Distance Weighting) method. In this method, by using IDW at the data stations, precipitation is obtained in the non-data areas. In this case, the value and weight of the station closest to the area is higher than at the other stations.

In general, the missing precipitation calculation P_x equation using the IDW method is as follows (Ward *et al.* 2015):

$$P_x = \frac{\sum P_i W_i}{\sum W} \tag{1}$$

where P_i is the amount of precipitation at the stations studied, W_i is the square of the distance of the stations from the points with unknown precipitation P_x obtained from the following equations:

$$W = \frac{1}{D^2} \tag{2}$$

$$D^2 = D_x^2 + D_y^2 \tag{3}$$

D_x and D_y are distance of stations from unknown points.

Input flow to marsh

As marsh flow is provided from the Karkheh and Tigris watershed, it was necessary to evaluate the normal discharge of these two rivers before environmental and hydrological stress, as well as inlet discharge after the occurrence of stress. For this reason, the data from the Hamidiyeh hydrometric stations and the downstream of Kut barrage were used. Then, after performing statistical tests, and verifying the desired data, the necessary information was obtained.

Soil texture of marsh

To measure the texture of the soil in Hour-al-Azim marsh, studies conducted by Aqrawi (Aqrawi 1993a, 1993b; Aqrawi & Evans 1994) were used to determine the texture of soil in Mesopotamian marshes. Their research was related to the soil texture of Mesopotamian marshes and the sediments in them, which are the outcome of drilling performed in the wetland bed during 1993 and 1994.

Quantitative and qualitative amount of marsh vegetation

Satellite images from 1972 to 1980 was used to calculate the vegetation of the wetlands and after analyzing the satellite images (Landsat MSS) the Normalized Difference Vegetation Index (NDVI) of the marsh was obtained. Using field observations by researchers, reports of Ramsar Convention and the Iran–Iraq Environmental Protection Organization, the plant diversity of the study area was acquired.

In general, the NDVI is used to determine the dispersal, vegetation area, and free-water surface area of a wetland. This index is obtained by analyzing satellite images. The NDVI index was obtained in terms of the two near-infrared bands, the red band of satellite images based on the following equation (Lasaponara & Masini 2012):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4}$$

where NIR: the reflectance from the near-infrared and RED: the reflectance from the red visible band. This index has values from -1 to 1 as presented in Table 1.

After identification of vegetation area and free-water surface using a 1:25,000 map of the study area and elevation points from marsh bed, the delineation of the marsh was obtained under two scenarios.

Table 1 | The NDVI classification (Yengoh *et al.* 2015)

Land cover types	NDVI
Water, snow, ice	$-1 \le NDVI < 0$
Clouds	$0 \le NDVI < 0.002$
Bare ground	$0.002 \le NDVI < 0.05$
Scarce vegetation	$0.05 \le NDVI < 0.1$
Medium vegetation	$0.1 \le NDVI < 0.5$
Dense vegetation	$0.5 \le NDVI \le 1$

RESULTS AND DISCUSSION

Hydrology of marsh

Direct precipitation at the surface of wetlands

The results showed that the maximum amount of direct rainfall in the study area was in January and was about 42 mm and minimum precipitation was in June to September and was less than 0.3 mm. Total direct rainfall in the wetlands was about 204 mm/year which brought about 650 million cubic meters of water directly into the marsh. These values are presented as monthly in Figure 4.

Surface flows

By analyzing hydrometric stations data of Hamidiyeh and downstream of the Kut barrage, it was found that the average inflow to the wetlands from Karkheh River, before the hydrological stress, was about 161 m^3/s, which is about 59 m^3/s after hydrological stress as shown in Figure 5. This means that the inflow to the marsh from the Karkheh River has been reduced to 40% of the initial flow. The average annual

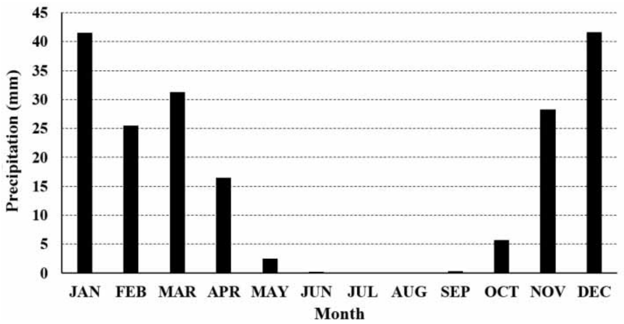

Figure 4 | The monthly average rainfall at the surface of Hour-al-Azim marsh.

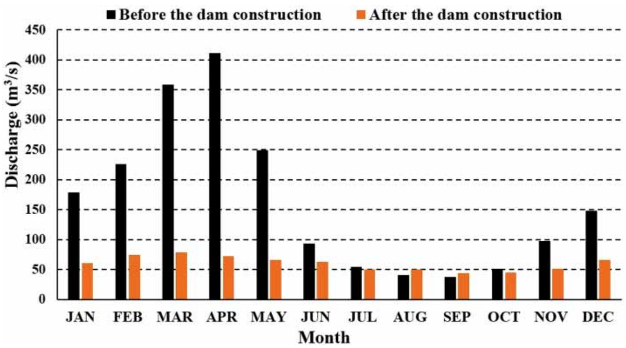

Figure 5 | The average monthly flow rate of the Karkheh River at the Hamidieh Station before and after the construction of the Karkheh Dam.

discharge downstream of the Kut barrage hydrometric station was 819 cubic meters per second, which has reached 391 cubic meters in recent years. In other words, the flow from the Tigris River has also been cut in half. These results are illustrated in Figure 6. Also, the maximum recorded discharge in these stations during the 1970s was in 1972. It can be inferred from the data presented in Figures 7 and 8 that this year is the wet year of the decade.

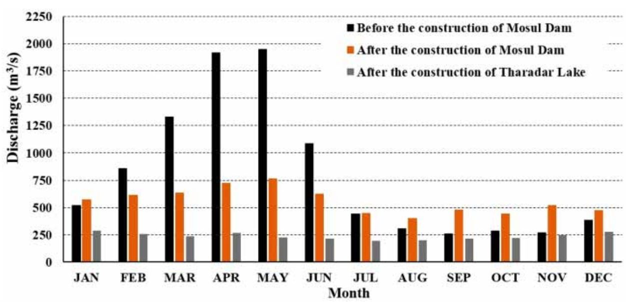

Figure 6 | The monthly changes in the flow rate of the Tigris River at the Kut Barrage downstream station before and after of hydrological stress.

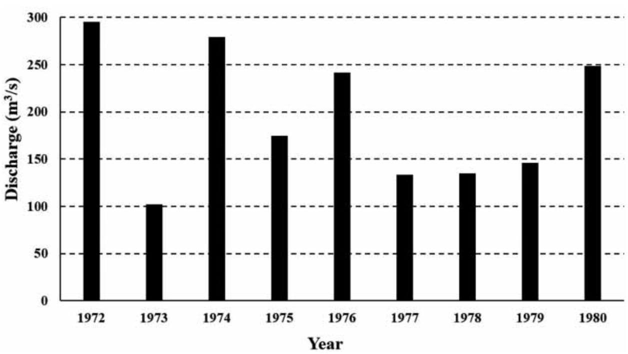

Figure 7 | The annual average flow rate of the Karkheh River at the Hamidieh Station.

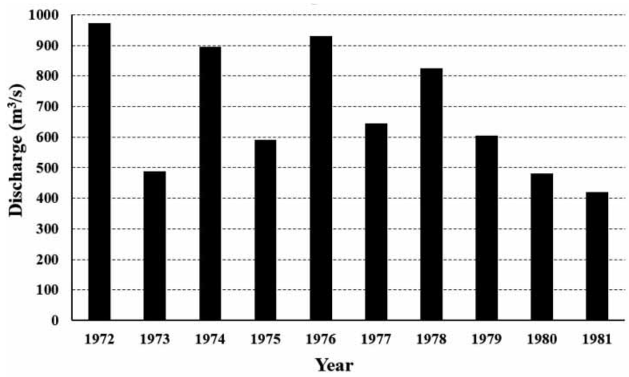

Figure 8 | The average annual flow rate of the Tigris River in the Kut Barrage downstream station.

Soil texture

Based on Aqrawi's or Aqrawi and Evan's studies (1993a, 1993b, 1994), it was found that the soil texture of the marsh consists of three layers. The first layer, which is about 7 cm thick, contains plant residues, and its color is black and in some places olive-gray. The second layer is silty clay soil texture with a thickness of about 30 cm and after this 30 cm layer, the clay content increases sharply and the soil texture becomes clayey silty. Because of the soil texture triangle, these soils contain at least 40% clay, soils considered to be impermeable, so that water permeability was neglected in the marsh.

Marsh vegetation

By analyzing Landsat satellite images between 1972 and 1980, the NDVI index of the wetlands was obtained. The index showed that, on average, 64 percent of the marsh area had vegetation, which decreased from north to south. In the northern part, the highest density is present in the marsh, and Figure 9 shows the changes in vegetation and free-water area over the years. As well as this, according to field observations by researchers and reports from the Ramsar Convention, and Iran–Iraq Environmental Protection Organizations, the vegetation of Hour-al-Azim marsh is divided into three sections: submerged, emergent and floating aquatic plants in Hour. These plants are included in Table 2. The swamp reed (Common Reed) is the dominant species in the region and accounts for 90% of the

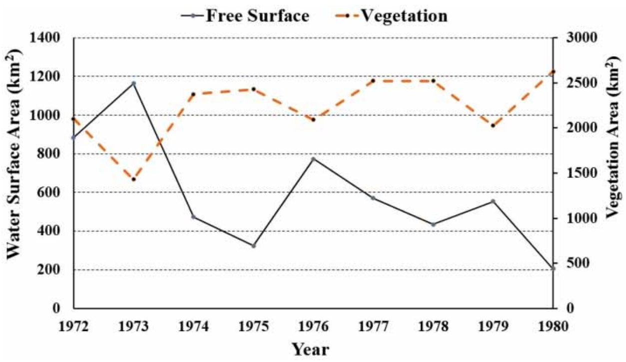

Figure 9 | Vegetation and water level variations in Hawizeh Marshes.

Table 2 | Plant species of the Hour-al-Azim marsh

Species name	Common name
Cyperus papyrus	Umbrella sedge
Phragmites australis	Common reed
Typha domingensis	Reed mace
Schoenoplectus litoralis	Bulrush
Salicornia sp.	Glasswort
Tamarix sp.	Salt cedar
Arundo donax	Giant reed
Salvinia natans	Water fern
Lemna gibba	Duckweed
Nymphaea alba	White water lily
Bacopa monnieri	Brahmin

marsh vegetation alone. Field surveys have shown that not only are they habitat for living creatures in wetlands, but are also used as a food source for water buffalo.

Delineation of the marsh in the first scenario

After quantitative and qualitative determination of the three main parameters of marsh and satellite images at the scale of 1:25,000 maps of the study area and elevation points of the marsh, their delineation was determined. Investigation of the hydrometric data and satellite images showed that the maximum and minimum inflows to the marshes belonged to the years 1972 and 1973, respectively. By investigating the satellite images of 10 years and field observations, it was found out that due to the presence of a high and steep embankment around the marsh, the area of Hour-al-Azim did not exceed a certain level; so that, in case of an increase in the inflow, the excessive flood would be drained from the Marsh and discharged into the Tigris River through the Swaib and Kassare Canal. Accordingly, the area of the Hour-al-Azim before the ecological and hydrological stress and before any changes were 3,279 square kilometers, of which about 882 square kilometers constituted a free-water surface. The NDVI index included in Figure 10.

The depth of the marsh also decreases from north to south, with different parts of the marsh having different depths, so that about 60% of the marsh has depths of -1 to 3 meters as presented in Table 3 and Figure 11. In general, the average depth of marsh was 2.4 m. It was also found that the slope of the marsh in the northern part was steeper than the southern parts; beside this, the slope was from northeast to southwest, indicating that the inflow into the marsh, either from Karkheh or the Kahla and Mushhash rivers,

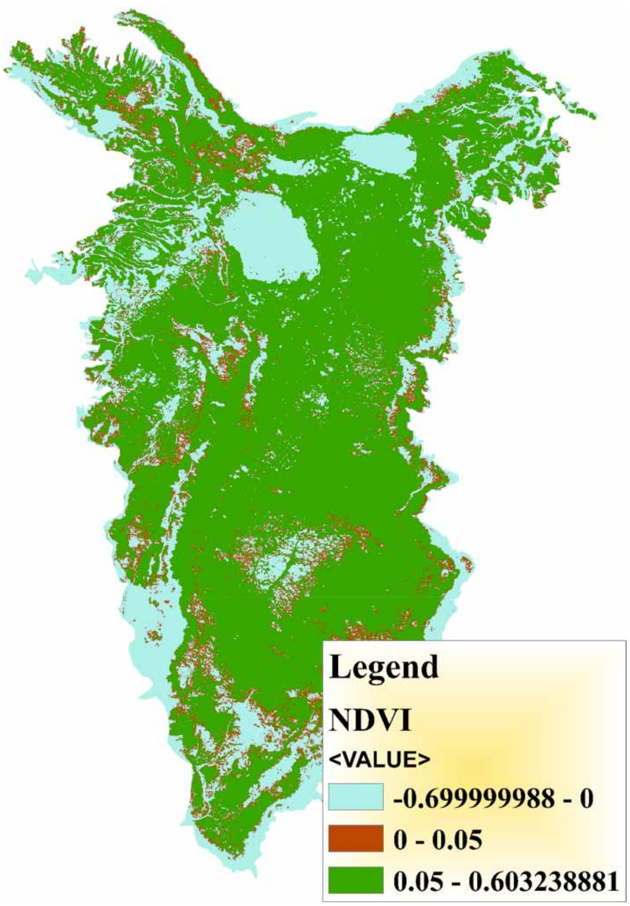

Figure 10 | The NDVI index of Hour-al-Azim marsh under the first scenario conditions.

Table 3 | Classification of water depths in Hour-al-Azim marsh under the first scenario

Area from marsh	Depth range
62	−1–3
11	3–4
27	4–14

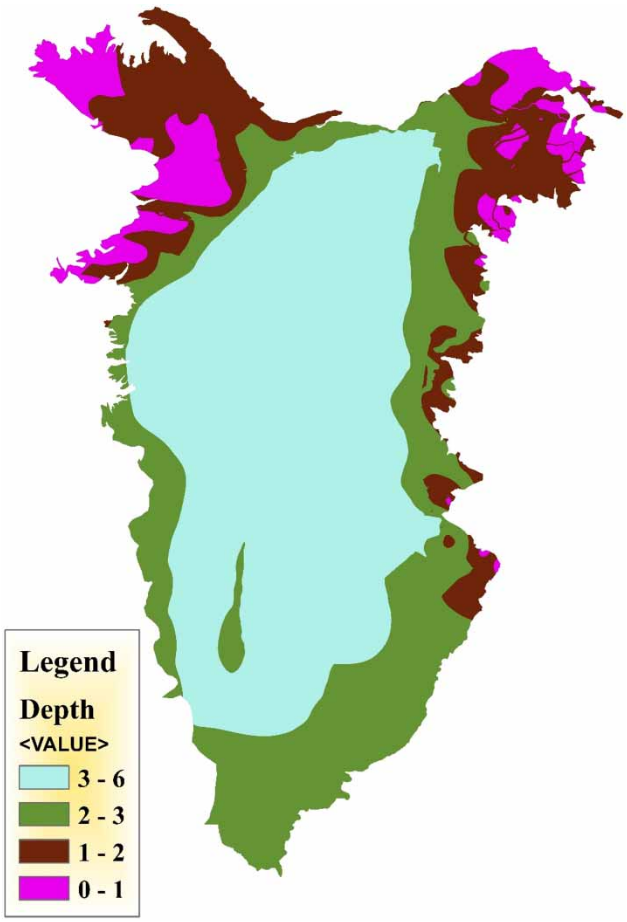

Figure 11 | The bathymetric map of Hour-al-Azim Marsh under the first scenario conditions.

would initially drown the Hur al-Hoveizeh or then lead to a massive submergence in Hour-al-Azim.

Delineation in the second scenario

In this case, the marsh fell into the category of special wetlands such that, according to the UCACE method, dry areas of marsh are not recognized as a limitation. Thus, the Hour-al-Azim area was approximately 1,619 square kilometers; Figure 12 shows the current delineation of the wetlands. Also, about 37% of the marsh had a maximum depth of 2 meters as presented in Table 4. In general, the average depth of the marsh was about 2.7 meters. In this case, 4.4 billion cubic meters of water are needed to submerge the northern part of the marsh and, given that up to

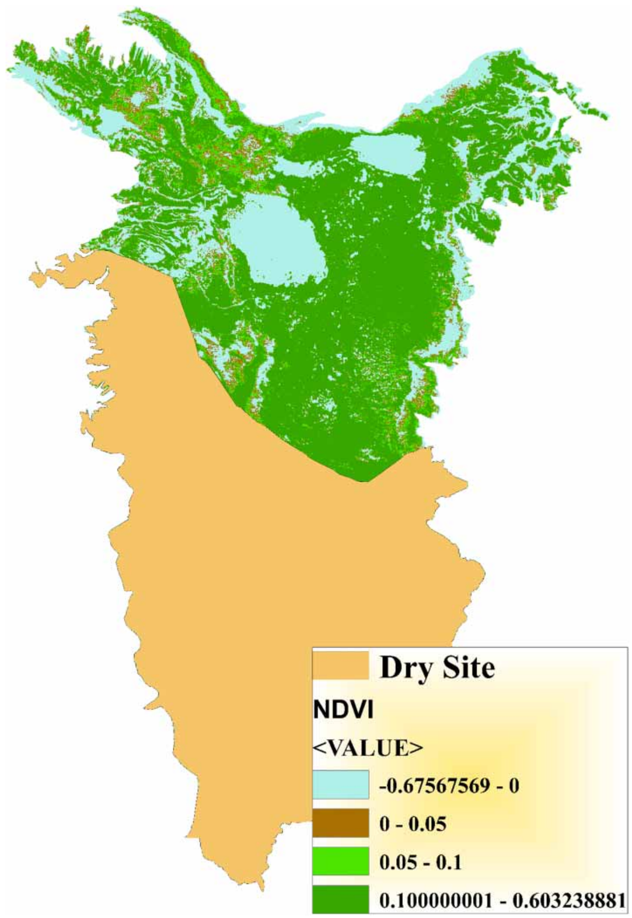

Figure 12 | The NDVI index of Hour-al-Azim Marsh under the second scenario conditions.

Table 4 | Classification of water depths in Hour-al-Azim marsh under the second scenario

Area from marsh	Depth range
37	−1–2
17	2–4
17	4–6
22	6–8
7	8–14

1,659 square kilometers have been dried up, droughts have not been ideal in the environment and have become the focus of the hazes.

CONCLUSION

In this research, we tried to delineate the Hour-al-Azim marsh using the USACE-R-G method as well as determine dust zone area. For this purpose, two scenarios were considered. The results revealed that the USACE-R-G method was better than the other methods. It has potential benefits for wetlands monitoring because not only can it consider RS and GIS features in studies but it can also analyze the hydrological and ecological factors affecting ecosystems delineation. In addition, the results showed dams that had been constructed in the Karkheh and the Tigris watersheds have key roles in reducing input flow to the marsh and create the largest focal point of haze in about 1,660 km^2 of the marsh.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 19 June 2020; accepted in revised form 25 December 2020. Available online 6 January 2021