

# Lessons Learned from Flood Management in Iran

## *Leçons tirées de la gestion des inondations en Iran*

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**Abstract.** Iran has a longstanding challenge in supplying water during prolonged drought periods. This has drawn considerable attention towards the dam industry over the past four decades, leading to the study, construction and operation of several large dams. These dams played a critical role in controlling the massive floods of 2019 and 2020, among others. Nevertheless, due to the increased intensity and frequency of extreme events because of climate change, the downstream regions of these large storage dams still face significant damages. This is mainly attributed to the insufficient dredging of rivers and tributaries, lack of rule curve and operation guideline for some storage dams, inaccurate prediction of flood volume, violation of land-use and water management action plans, promotion of industries with high water need, and floodplain encroachment. In this study, we aim to evaluate the performance of several large dams in the Karkheh and Karoon river basin, located in southwestern Iran, in managing the floods took place in the aforementioned periods. We also discuss the challenges and the lessons learned, with suggestions for improving the flood management in the country.

**Résumé.** L'Iran est confronté à un défi de longue date concernant l'approvisionnement en eau en cas de sécheresse de longue durée. Une attention considérable s'est donc portée vers l'industrie des barrages au cours des quatre dernières décennies, menant à l'étude, la construction et à l'exploitation de plusieurs grands barrages. Ces derniers ont joué un rôle essentiel dans le contrôle des inondations massives de 2019 et 2020. Néanmoins, en raison de l'intensité et de la fréquence accrues des événements extrêmes, du fait du changement climatique, les régions en aval de ces grands barrages de stockage font toujours face à des dommages importants. En cause : un dragage insuffisant des rivières et des affluents, l'absence de courbe de règle et de guide d'exploitation pour certains barrages

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de stockage, des prévisions inexactes du volume des crues, la violation des plans d'action d'utilisation des terres et de gestion de l'eau, la promotion des industries à fort besoin en eau et l'empiètement des plaines inondables. Dans cette étude, nous visons à évaluer la performance de plusieurs grands barrages dans le bassin fluvial de Karkheh et Karoon, situé dans le sud-ouest de l'Iran, dans la gestion des crues survenues au cours des périodes susmentionnées. Nous évoquons également les défis et leçons apprises, avec des suggestions pour améliorer la gestion des inondations dans le pays.

## 1 Introduction

Global warming is among the current major challenges worldwide, which has reshaped the Earth's climate [1]. This situation has led to prolonged drought periods, wildfires, desertification, river flooding, water erosion, etc. [2–4] influencing food security [5–7], ecosystem biodiversity [8], energy systems [9], and economics [10], among others [11]. In particular, climate change has altered precipitation rate and intermittency, shifted precipitation from snow to rain, and enhanced the occurrence of unprecedented massive flood events in some regions [12–15]. As such, adaptation of traditional reservoir operation to the new norm is unavoidable to avoid the adverse consequences of floods.

Iran is recognized as one of the leading countries in the dam industry. Several dams have been constructed and operated during the past four decades and many others are currently under construction or study. The outcome of the environmental impact assessment of dam construction has been controversial among the community, leading to contrasting opinions [16–18]. Many criticize dams with respect to their impact on water quality, ecosystem biodiversity, urban and agricultural development, and environmental sustainability [19–24]. On the contrary, the increasing trend of water, food, and energy consumption worldwide may justify the operation of reservoirs to meet future water demand [25]. Obviously, neither approaches seem rational if non-structural solutions for a proper management of upstream drainage basins as well as the downstream areas are taken into account. If the technical, economic, social and environmental protocols are met in the design, operation, and planning of reservoirs, their adverse impacts will be inarguably minimum. Nevertheless, these issues are not considered in many instances leading to the construction of reservoirs with improper management. For instance, despite the existence of many large dams across Iran, the country has experienced significant damages due to flood events over the past decade. In particular, the 2019 massive floods across the country led to the loss of lives and remarkable damages to infrastructures, agriculture, and livestock [23].

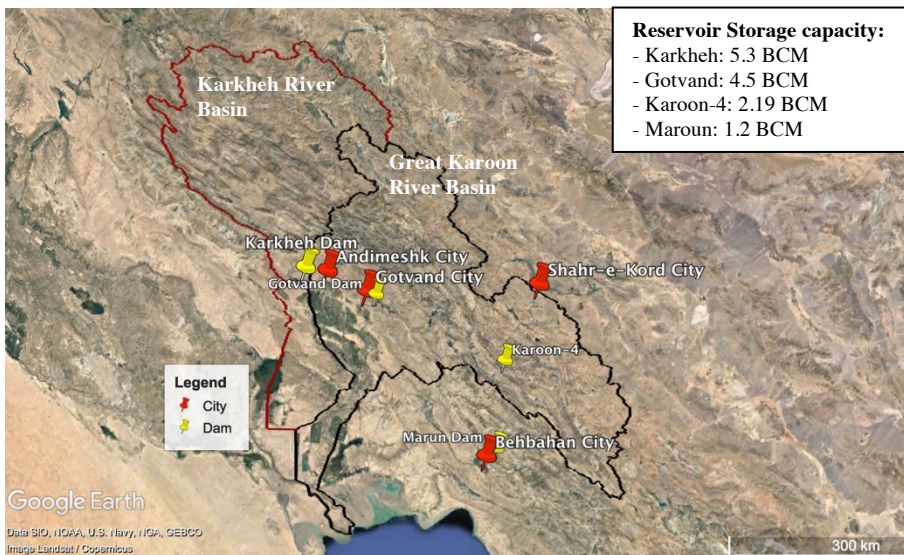
In this article, we aim to assess the functionality of the largest reservoirs in Iran for the flood management using remotely sensed imagery and the most recent recorded in-situ data, i.e., the daily inflow and outflow time series of the so-called reservoirs. We also summarize the lessons learned from the 2019 floods and outline their implications for the future flood risk management plans. Finally, we conclude the article with suggestions to improve reservoir management in unforeseen incidences.

## 2 Study Sites and Data

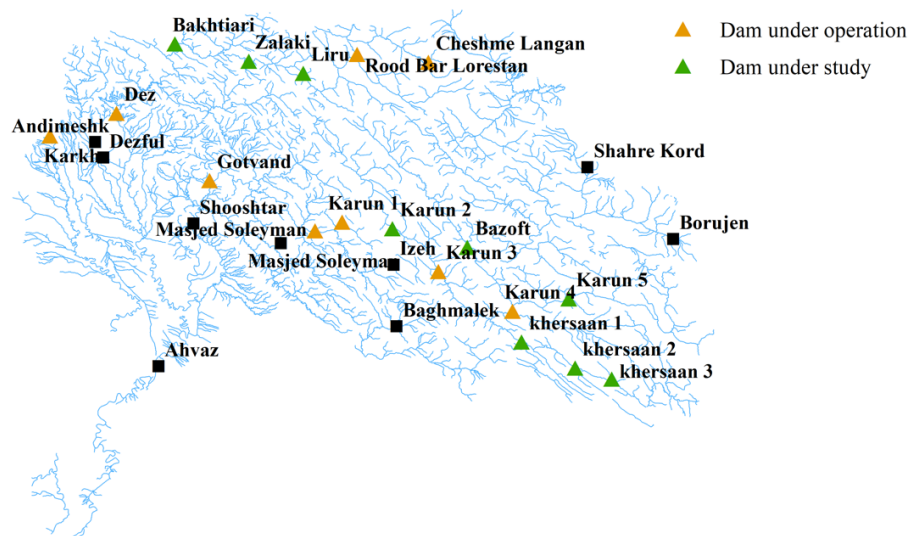
In this study, we evaluate the performance of the Karkheh, Gotvand, Karoon-4, and Maroun reservoirs during the massive flood events taken place in March-April 2019. Fig. 1 shows the geographical location of these reservoirs in the western and southwestern, Iran. The Karkheh

Dam is one of the largest earth dams in the world and the largest earth dam in Iran and the Middle East. It is on the Karkheh River and is located at 21 km northeast of the Andimeshk city in the Khuzestan province. The reservoir’s crest is 3 km in length and 127 m in height, with a capacity of 5.3 BCM creating the largest artificial lake in Iran. The release capacity of the reservoir is 18,260 m<sup>3</sup>/sec. This multiple-purpose reservoir is used for the water supply of 350,000 ha agriculture areas, flood control (with the release capacity of 8,650 m<sup>3</sup>/sec), and hydroelectric power generation. The Karoon-4 dam is on the largest river in Iran, i.e., the Karoon River, and is located at 180 km southwest of the Shahr-e-Kord city in the province of Chaharmahal and Bakhtiari. The dam withholds a reservoir with the capacity of 2.19 BCM which is chiefly used for flood control and hydroelectric power generation. Other reservoirs are being studied, constructed and operated on the Karoon River as shown in

Fig. 2. The Gotvand dam with an impoundment capacity of 4.5 BCM is also located on the Karoon River, at 12 km northeast of the Gotvand city in the Khuzestan Province. This reservoir is also used for flood control (with the release capacity of 17,500 m<sup>3</sup>/sec), hydroelectric power generation, and adjusting the water need for the downstream agriculture. Finally, the 1.2 BCM Maroun Dam on the Maroun River is about 15 km north of the Behbahan city in the Khuzestan Province. This reservoir is used for flood control (with the release capacity of 10,800 m<sup>3</sup>/sec), urban water supply of the Behbahan city, water supply of 55,000 ha agriculture plains, and hydroelectric power generation. These four reservoirs collectively provide a total storage capacity of 13.19 BCM.

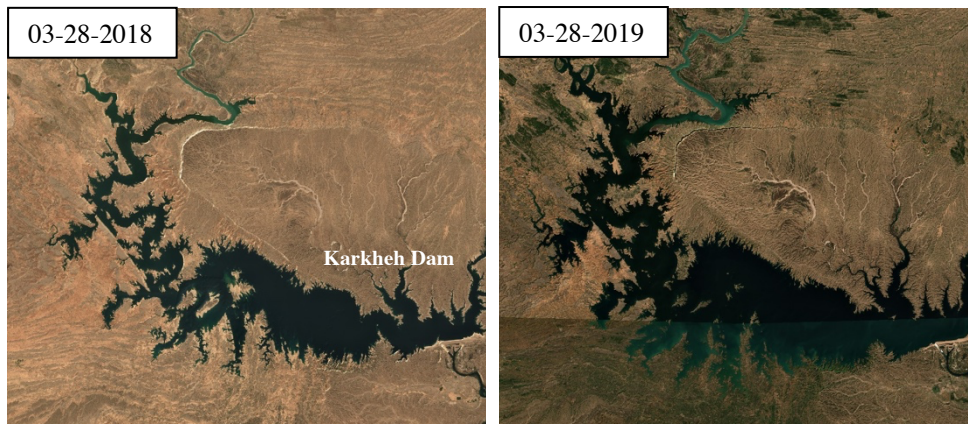


**Fig. 1.** Geographical location of the Karkheh, Gotvand, Karoon-4, and Maroun reservoirs in the western and southwestern, Iran.



**Fig. 2.** The geographical location of the reservoirs (under study, under construction, or under operation) in the Great Karoon River Basin.

We use the daily time series of inflow to and outflow from these reservoirs to assess their performance in the 2019 flood events as well as to compare their effectiveness in controlling the floods and mitigating their adverse impacts. We also leverage satellite imagery to illustrate the flood extent. The studied flood took place in a series of three events during March 17<sup>th</sup>-22<sup>nd</sup>, March 24<sup>th</sup>-27<sup>th</sup>, and March 31<sup>st</sup>-April 2<sup>nd</sup>, 2019. It caused the flooding of 130 rivers, damaging more than 2000 urban and rural areas in 26 out of 31 provinces. The precipitation volume from the latest two events in the Kashkan basin, located in the upstream of the Karkheh dam, was estimated as 1.35 BCM and 1.30 BCM, respectively. The flood in the Kashkan River began on March 25<sup>th</sup>, 2019 and reached 4,600 cms on April 1<sup>st</sup>-2<sup>nd</sup>, which was about four times greater than that in normal condition and destroyed the cities of Poldakhtar and Mamolan. The floods in the Karkheh and Karoon rivers were followed by the opening of the dam gates from March 29<sup>th</sup>, 2019 and continued until the mid-April. The total precipitation in the Karkheh and Great Karoon basins in the March of 2019 was 223 mm and 234 mm, respectively. The return period of precipitation and flood taken place in the upstream of the Karkheh reservoir was estimated as 200 years and 700-1000 years, respectively [26]. The joining of the Karkheh, Karoon and Dez rivers led to an extensive flood plain in the north of Ahvaz city of the Khuzestan province. Fig. 3 shows the Sentinel images on March 28, 2018 (left) and 2019 (right), indicating massive flooding taken place in the upstream of the Karkheh dam during the 2019 flood.

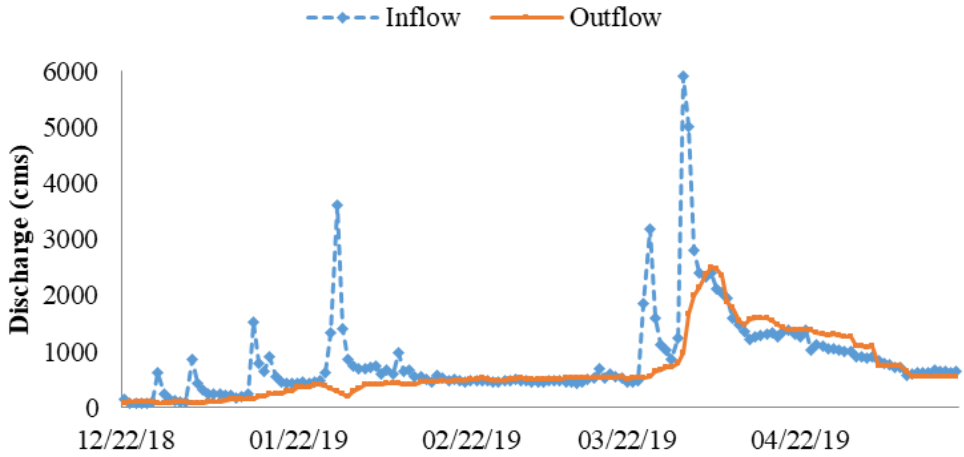


**Fig. 3.** Sentinel images on March 28, 2018 (left) and 2019 (right), indicating massive flooding taken place in the upstream of the Karkheh reservoir.

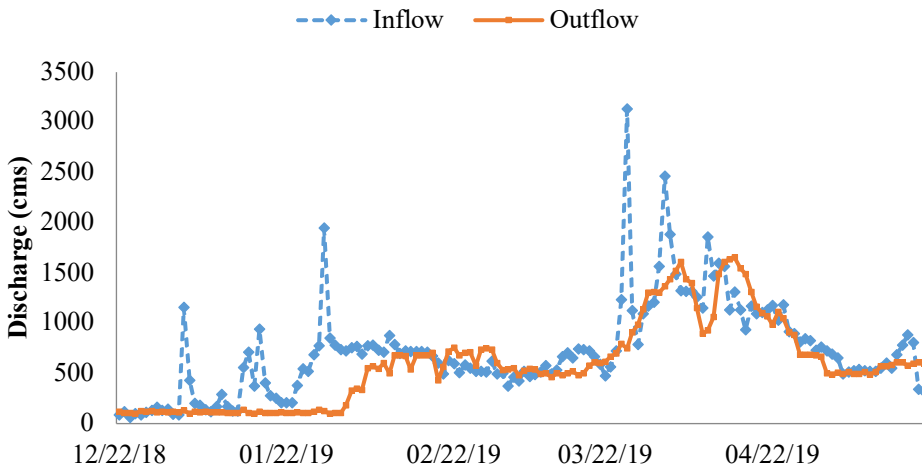
### 3 Results and Discussion

Figures 4 and 5 show the hydrographs of the inflow and outflow of the Karkheh and Gotvand reservoirs, respectively, during the massive flood events in March-April 2019. We observe that the flood peaks were dampened largely by the Karkheh reservoir, i.e., >8000 cms instantaneous flood peaks in the Karkheh reservoir were reduced to less than 2300 cms. Similar observation is found in the Gotvand reservoir, which reduced the instantaneous flood peak from 7200 cms to 2800 cms. Figures 6 and 7 also show the performance of the Karoon-4 reservoir and the Maroun reservoir at the same flood events, respectively. We observe a similar remarkable dampening effect on reducing the flood peaks downstream.

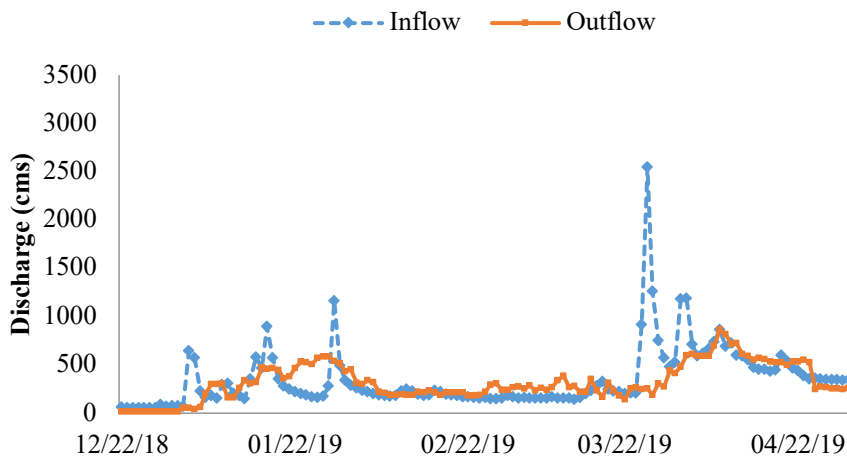
The volume of water entering the reservoirs of the Khuzestan province from the beginning of the water year until the flood occurred was more than 33 BCM, which is about six times greater than that in the previous water year. In addition, the precipitation height in the Karkheh River Basin in the second and third 2019 flood events was about 37 and 6 times greater than that in the same period in 2018 and as compared to the long-term 50-years, respectively. Similarly, in the Great Karoon River Basin, the precipitation height was about 52 and 3 times greater than that in the same period in 2018 and in the long-term 50-years window, respectively. This amount of precipitation caused the runoff generation of about 14 BCM, which was more than the total active volume of all the so-called reservoirs in the Khuzestan province. This points out that even if the reservoirs were hypothetically out of water storage, it would still not be possible to fully control the generated runoff. Also, regarding the experience of the most recent drought in Iran lasting for nearly two decades, there is a limit to which such reservoirs can be released due to the multi-purpose functioning of the Khuzestan reservoirs. While some insensitively flooded areas were among the regions experienced long-term drought in former years, the 2019 flood led to the 72% filling of total reservoirs across the country.



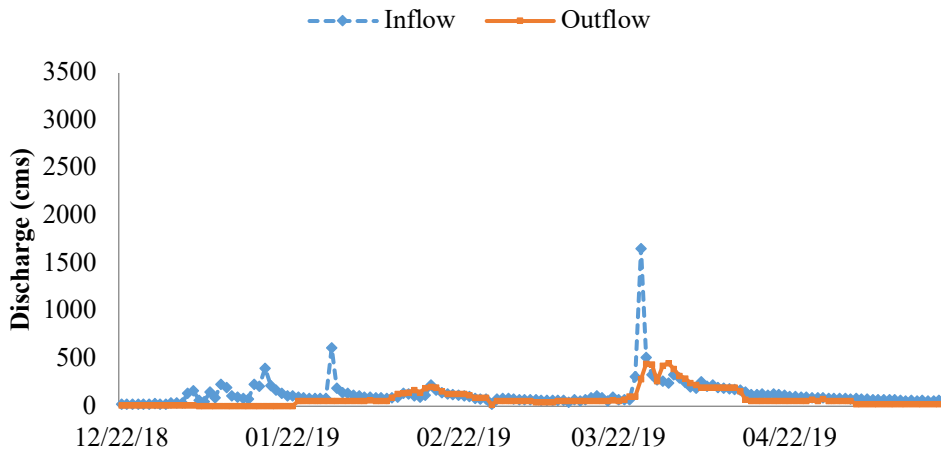
**Fig. 4.** Daily time series of inflow to and outflow from the Karkheh reservoir during the massive flood events in March-April 2019.



**Fig. 5.** Daily time series of inflow to and outflow from the Gotvand reservoir during the massive flood events in March-April 2019.



**Fig. 6.** Daily time series of inflow to and outflow from the Karoon-4 reservoir during the massive flood events in March-April 2019.



**Fig. 7.** Daily time series of inflow to and outflow from the Maroun reservoir during the massive flood events in March-April 2019.

We note that the Tang-e-Mashoureh reservoir, located in the upstream of the Karkheh reservoir, has not been constructed yet due to the limited financial resources. This caused the downstream cities suffer significant damages because of the flood. The flooding extent in the Mamolan and PolDokhtar cities, downstream of the Tang-e-Mashoureh reservoir is shown in Figures 8 and 9, respectively. According to the economic assessments after the floods, the caused damages are much larger than the budget required for the construction of this reservoir. The results of numerical analysis demonstrated that if the Tang-e-Mashoureh reservoir was in place, the peak flood rate in 2019 could be reduced from about 2300 cms to about 1400 cms, diminishing the downstream damages extensively. Figure 10 shows the degree of flood reduction by the Tang-e-Mashoureh reservoir if it were under operation during the 2019 flood.

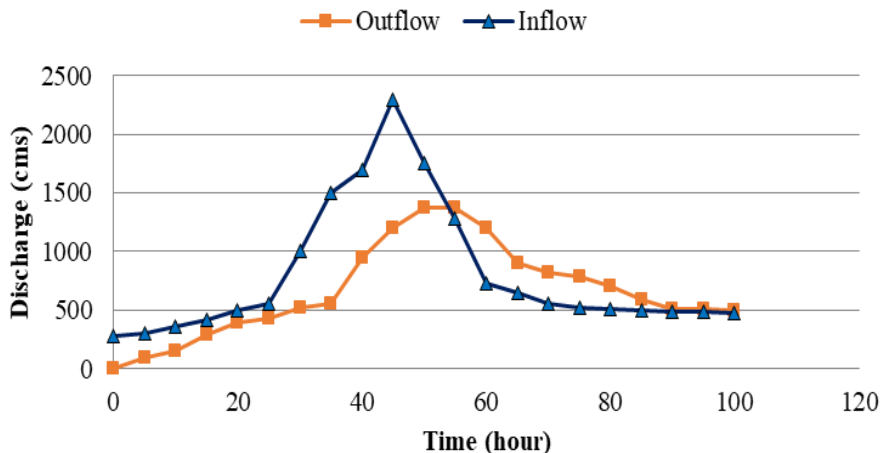


**Fig. 8.** Satellite image of the flooding extent in the Mamulan city located in the downstream of the unconstructed Tang-e-Mashoureh reservoir.



**Fig. 9.** Satellite image of the flooding extent in the PolDokhtar city located in the downstream of the unconstructed Tang-e-Mashoureh reservoir.





**Fig. 10.** The degree of flood reduction by the Tang-e-Mashoureh reservoir if it were under operation during the 2019 flood.

A few points are noteworthy here. Since the occurrence of the mentioned floods was predicted long enough before the flood occurrence, a larger release of stored water in the studied reservoirs earlier than the flood occurrence was plausible and thus the damages could be reduced significantly. Also, since the storage volume required for flood control is sometimes disregarded in operation to save a larger volume of water for the dry seasons, this extra storage would increase the risk of maladjustment to the flooding condition in a relatively short period.

Exploring the river capacity for flood in the downstream of the reservoirs before and after their construction further witnesses that as soon as large reservoirs are constructed, floodplain encroachment in the downstream regions remarkably reduce the flood flow. Currently, there exist no guidelines or protocols for the downstream flood flow management after the construction of large reservoirs in Iran. Accordingly, the typical misunderstanding of increased safety within the rivers’ buffer zone against flood has led to floodplain encroachment and consequently, the downstream regions have suffered severe damages when the reservoirs are released with high rates to provide enough capacity to absorb the flood inflow. In other words, the diminished capacity of flood flow in these areas cannot compensate for the emergency releases from the reservoirs. For instance, when the outflow from the Karkheh dam reached 400 cms during the March 24<sup>th</sup>-27<sup>th</sup>, 2019 flood event, downstream damages increased remarkably while the release from the dam even increased to 2450 cms in following flood event. Therefore, the development of residential areas in the river floodplains has considerably contributed to the damages caused by the floods.

Following the 2019 flood, 90% of the flood control levees have been repaired in the Karkheh basin. However, there is a potential for their failure in the future flood events because, for instance, farmers have piped through them to supply water to their farmlands. The repaired levees are thus at the danger of re-breakage if the Karkheh River discharge increases remarkably. In addition, the Karkheh River at the downstream of the Karkheh reservoir, i.e., from Hamidiyeh to Hoor-Al-Azim, has not been dredged for about 25 years, which has diminished the river carrying capacity. Any integrated flood management plan should thus consider these issues in the Karkheh and other flood-prone rivers across the country.

The uncontrolled exploitation of forests over the past 50 years has also resulted in flood intensification. The forest cover in Iran declined from 18 million hectares in 1960's to 3.1 million hectares in 2019, indicating that 60,000 hectares of forests are destroyed annually. For instance, land-cover monitoring show that out of 1.2 million hectares of oak forests in the Kashkan basin, 600 hectares are in danger of destruction. Such a deforestation is mainly attributed to the anthropogenic activities and is recognized as one of the key causes of soil erosion and intensification of flooding in 2019.

Furthermore, due to the lack of best management practices and guidelines to control flow and sediment in the upstream tributaries, the increased frequency of large floods has typically led to intense erosion, discharging a significant unforeseen volume of sediment to the reservoirs. This situation was observed in upstream of the Tang-e-Mashoureh reservoir because of the 2019 flood, when a large volume of flow and sediment entered the cities of PolDakhtar and Mamolan. This situation poses a quest to consider sediment transport in any flood risk management plants to mitigate the adverse impact on the morphological changes of rivers as well as the deterioration of agricultural lands.

We also note that the massive volumes of water from the recent floods were flowing into some wetlands such as Hoor-Al-Azim and Shadegan. Although a comprehensive study has not been conducted yet to estimate the economic value of these wetlands, the findings of other studies on wetlands of international interest indicate that the annual damages due to flooding increases by \$33,000 per the deterioration of hectare of a wetland [27], which points out the valuable role of wetlands in flood control and prevention. However, many of these wetlands were facing a continuous drying trend over at least the past two decades. According to the latest report by the Iran's Department of the Environment in 2019, 55% of the surface area of 45% of wetlands in Iran has been dried and are currently recognized as the potential sources of aerosol generation. Therefore, the partial restoration of such wetlands should not slow or stop the implementation of restoration plans necessary to guarantee the long-term sustainability of these ecosystems.

Finally, the flood insurance industry has not been fully and comprehensively developed in Iran so far. In case of organizing a principled development of flood insurance in the country, it is expected that damages will be reimbursed quickly after the flood occurrence. Developing such an efficient system will require precise information on flood-prone areas, access to flood warnings, executive management instructions before, during and after floods, rivers' dredging condition, and stream restoration plans in high-risk areas.

## **4 Conclusion**

In the dam industry, it is necessary to design and implement integrated development plans for land and water management to guarantee the best system performance with least environmental degradation. Basin management in the upstream tributaries as well as protection of riverbed and buffers from encroachments in the downstream areas of reservoirs should be taken into account through mandatory guidelines. As such, we suggest to (1) develop protocols and guidelines for the management of flow and sediment from flood in the upstream of large reservoirs, (2) develop and mandate the implementation of the protocols in order to protect the floodplain from encroachment in the downstream of reservoirs before starting their operating, (3) develop a comprehensive flood insurance plan in the flood-prone regions across the country, (4) study and identify those wetlands that can be leveraged for flood control and prevention, (5) implement watershed management practices to control

erosion and reduce sediment load, and (6) execute appropriate land use and soil protection policies to increase the soil infiltration capacity and reduce the risk of floods.

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