SUPPLEMENTARY MATERIALS FOR:

Salinity Management in the World's Most Saline Dam Reservoir: The Gotvand Reservoir, Iran

Siamak Amiri[1], Mehdi Mazaheri[1,*], Vahid Naderkhanloo[1], Jamal Mohammad Vali Samani[1], Sahand Ghadimi[2], Ali Torabi Haghighi[2], Roohollah Noori[3,4,*]

[1]Department of Water Engineering and Management, Tarbiat Modares University, P.O. Box 14115-336, Tehran, Iran.

[2]Water, Energy, and Environmental Engineering Research Unit, University of Oulu, P.O. Box 4300, FIN-90014 Oulu, Finland.

[3]Graduate Faculty of Environment, University of Tehran, Tehran, 1417853111, Iran.

[4]Faculty of Governance, University of Tehran, Tehran, 1439814151, Iran.

*Corresponding authors: Mehdi Mazaheri (m.mazaheri@modares.ac.ir), ORCID: https://orcid.org/0000-0001-8670-1710 and Roohollah Noori (noor@ut.ac.ir), ORCID: http://orcid.org/0000-0002-7463-8563

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Text S1

The course of developments and social, political, and environmental effects connected to the project of the Gotvand Dam: The Gotvand is the tallest embankment dam in Iran, which is built at a distance of 380 km from the river mouth of Karun (the most important river in Iran). Located 10 km northeast of Gotvand city in Khuzestan, a province in southwest Iran, the Gotvand is the last dam constructed on this river. The Khuzestan Plain and important cities such as Ahwaz, Abadan, Shooshtar, Khorramshahr, and Gotvand are situated downstream of the dam. The Gotvand Dam is Iran's second-largest and largest water reservoir on the Karun River. Furthermore, the highest rate of hydroelectric power generation among the country's hydroelectric power plants belongs to this dam (4250 GWh per year). The primary aims of the construction of the dam include an increase in the country's capacity for electricity generation, growth and promotion of the country's international position in terms of developments in electricity and energy fields, indigenization of related technologies, flood control, water supply for different uses, and job creation (IWPRDC, 2011).

By reviewing the history of the dam development, initial studies suggest that the Gotvand Dam was formerly built 15 km above the current location, which was the suitable leading site designated by foreign researchers. However, the Ministry of Energy ordered the dam site to be relocated. Apparently, the underlying reason for the dam relocation was less reservoir storage capacity, with a storage volume of over 2.2 billion m^3. The final location (the current site) for the dam's construction, nevertheless, has the capacity to store 4.7 billion $m^{3\ of}$ water (IPRC, 2011).

Many economic and social experts in Iran maintain that implementing the Gotvand project (at the current location), despite technical advisories and disagreements, is due to development policies associated with reparation for Iran-Iraq war destructions. Another development policy consisted of developing hydroelectric plants to satisfy increasing domestic demands and, where possible, electricity exports to neighboring countries. Thus, officials of different governments planned and focused on creating high-walled reservoirs and generating maximum electric power using their capacity.

Unfortunately, the greatest mistake in the history of Iranian engineering was made because of the relocation of the dam construction site with the mentioned intentions. The location transfer placed a vast and large salty unit of the Gachsaran evaporite formation (GEF) within the reservoir that would inevitably submerge and salinate the reservoir water after the dam impoundment. Ultimately, the Gotvand Dam was built at the insistence of the relevant officials, and the impoundment was completed.

Many specialists involved in this project noticed the adverse effect of salt masses on the reservoir from the very beginning and communicated it to the proper authorities. Nonetheless, the cautionary observations were dismissed, and a host of documented advisories were ignored at the time, given the state of project development (IPRC, 2011). Later on, as the gravity of warnings increased, and some managerial changes were made, the issue of Gotvand water salinization was raised, and responsible organizations were ordered to investigate it. Regarding the circumstances, a technical panel of pundits and experts in different fields, including the environment, was organized. It was proved that the dam had some problems at the time, and its construction should be discontinued since the complete impoundment of the dam might pose irreversible hazards. However, the body of the dam had approximately achieved physical progress of 70% by that date, and a generous budget had been spent on its development. A similar scenario in the past was repeated; that is, scant regard was paid to warnings concerning the adverse effects of salt masses at the Gotvand Dam, despite the possibility that they could pose an environmental threat to the area of the project's construction. The building of the dam was eventually completed.

After the completion of the construction, it did not take long for the steady unfolding of an environmental crisis in the dam reservoir to upset the expected equations in plain sight. Here, a large salty domain, namely the Gachsaran evaporite formation (GEF), dissolved in the dam reservoir and slowly made it increasingly saline. As the first remedial measure against salt masses at the dam reservoir, experts developed a large clay blanket to prevent salt penetration. With an increase in water surface elevation, however, the clay blanket collapsed at several points and had almost no impact on salinization control. The salinity of the reservoir incrementally increased in the manner that the salinity value was measured three times higher than the salinity of the high seas (Aghasian et al., 2019)

After various vicissitudes during the dam construction process and mounting disapproval by specialized institutions and experts who had warned about the issue, authorities, and organizations issued official statements regarding the project. While most administrators and involved parties supported the practical aspects and objectives of project engineering, alternative strategies were proposed to overcome the ongoing challenge. This could also be interpreted as a response to critical controversies. The authorities, for instance, withstood criticisms by introducing dam functions like water and energy supply and flood control. Most responses to a barrage of criticism by authorities of the water industry and the decision-makers of the Gotvand Dam closely reflected the reality and, in many cases, revealed determination and positive approaches. On the other side, they failed to take responsibility for a likely environmental failure. Many supporters of the dam implementation believed that although the triggered crisis of the dam might be deemed an environmental mistake, engineering mistakes seem virtually unavoidable. Hence, the calculations could differ from the expected results under some conditions. The experts who opposed the resumption and execution of the project, on the other hand, contended that insistence on launching the project under present circumstances would be the outcome of managerial mistakes made during the research phase.

As time went on, due to the importance of the challenge raised for the Gotvand Dam and its practical significance, the challenge gained national stature. Until then, dozens of sectional and cross-sectional institutions had articulated their views on the issue. The sensitivity of the Gotvand situation reached the point where the Iranian Department of Environment and General Inspection Office addressed the issue, and finally, follow-up evaluations and investigations were ordered by the first vice president (IPRC, 2011). It is worth noting that the final cost of the dam design and construction was estimated at over 3.86 billion dollars (IPRC, 2011). Regardless, dam construction advocates and optimistic predictions advocated allocating this colossal budget because it could provide tremendous economic potential. Based on expert evaluations, the benefit-cost of the plan execution was approximately equal to 2.2, which justified the acceleration in its construction by some means (IPRC, 2011). From another point of view, there was a combination of complicating risk factors that experts took into account, namely: the hefty investment fund for the project, the probability of the occurrence of unintended and long-term environmental effects, the likelihood of a decline in drinkable water quality in important cities, downstream farms, and groundwater, and also possible socio-economic consequences of evaporite formation and dissolution, salinization of reservoir water and accumulation of salt inside the reservoir. Against this background, experts were bound to put forward their ideas.

Affected by the existing problem, it seems possible that some of the stated development objectives of the Gotvand project will face administrative and operational ambiguities in the present or the future. Management principles must be observed with absolute discretion when dealing with such a unique and unwanted situation; otherwise, the permanent conveyance of reservoir water to downstream targets may gradually reduce the quality and fertility of farms, followed by major, sometimes irreparable, repercussions.

As a million hectares of agricultural land and thousands of farming operators exist downstream, the dam water quality will significantly impact farmers' activities. Measurements demonstrate that the degree of water salinity (EC) at a distance of 11 km from the Gotvand downstream is nearly 1200 µmhos/cm. Compared to the desirable maximum (1650 µmhos/cm) and allowed maximum (2500 µmhos/cm), outlet water salinity is still at an optimum level. Meanwhile, two salient points should be addressed. First, the degree of EC of pollutant sources in the water path should be considered downstream. Second, there is no guarantee that the quality of the outlet water will not degrade over time.

In this context, the position of farmers seems far more sensitive when compared with that of the other related industries involved in the Gotvand project. If adequate and necessary measures are not considered to control the reservoir water continuously, the water quality of the dam will probably suffer and gradually reduce agricultural productivity and prosperity in the region. It should be stressed that the Khuzestan Plain is one of the most important agricultural hubs in Iran. B. By way of illustration, the Aghili district, with an area of four thousand hectares of agricultural land and thousands of farming operators, is the impoundment location of the Karun River basin and the central region of the Gotvand Dam situated downstream.

Because the recommended ideas are diverse, and appropriate study conditions should be provided for each, there is no immediate and consistently effective action plan that can serve as a complete and obvious solution to the current problem. However, it should be noted that owing to the particular importance of the Gotvand Dam, in-depth studies should be undertaken by experts to identify a comprehensive and reliable method. Considering the acute conditions of the Gotvand challenge, experts in various fields regard it as a historic environmental milestone in Iranian history.

Table S1. Description of other remedial solutions to control the salinity of the Gotvand Dam reservoir.

Classification of the solution	The title of the solution	
Salinity control from the origin	Control of saline branches	
	Control of entering salinity from Gachsaran evaporite formation (GEF)	Use of ion shield
		Covering with materials (submerged)
		Electro osmosis
Desalination and salt confinement	Salt purification	Using nano
		ECR
		Salt eating microorganisms
	Salt trapping	Use of hydrogels
		Using geobags
Reservoir management and Quick wash	Periodic release of very saline water (quick wash)	
	Gradual release of saline water from the reservoir while maintaining the salinity at the acceptable threshold (for the downstream)	
Transfer	Injection to oil wells	
	Delivery to applicant industries	Petrochemical
		Karun Cement, Ramhormoz Sodium Carbonate Industries
	Transfer to evaporation ponds near the dam	
	Evacuation to the Persian Gulf	
Water diversion and closing the dam	Diverting water from before Gachsaran evaporite formation (GEF)	
	Discharge through diversion dams and diversion tunnels at different levels	

Table S2. Average values of discharge and electrical conductivity (EC) of the saline tributaries (i.e., Murghab, Andika, and Lali tributaries), which are joining to the Karun river at the Gotvand reservoir upstream (MGCEC, 2012).

Tributary	Average discharge (m^3/s)	Average EC (µmhos/cm)
Murghab	11.9	3000
Andika	4.2	15700
Lali	4.5	6000

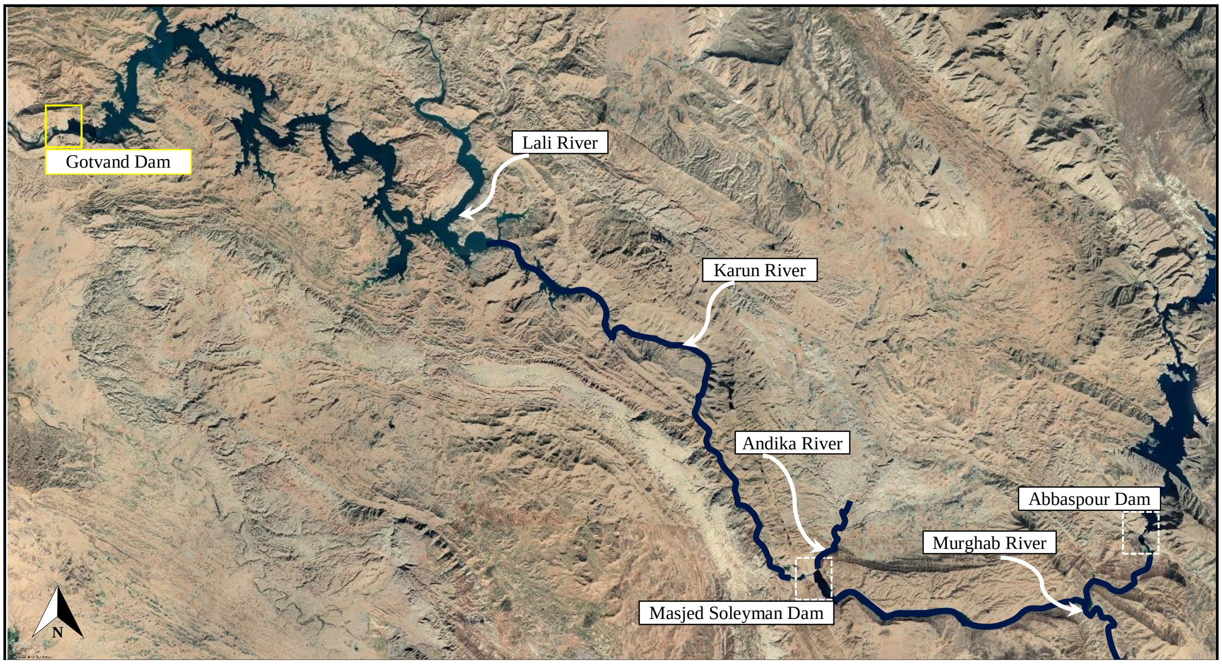

Figure S1. The location of the saline tributaries of Murghab, Andika, and Lali, which are joining to the Karun River at the Gotvand reservoir upstream.

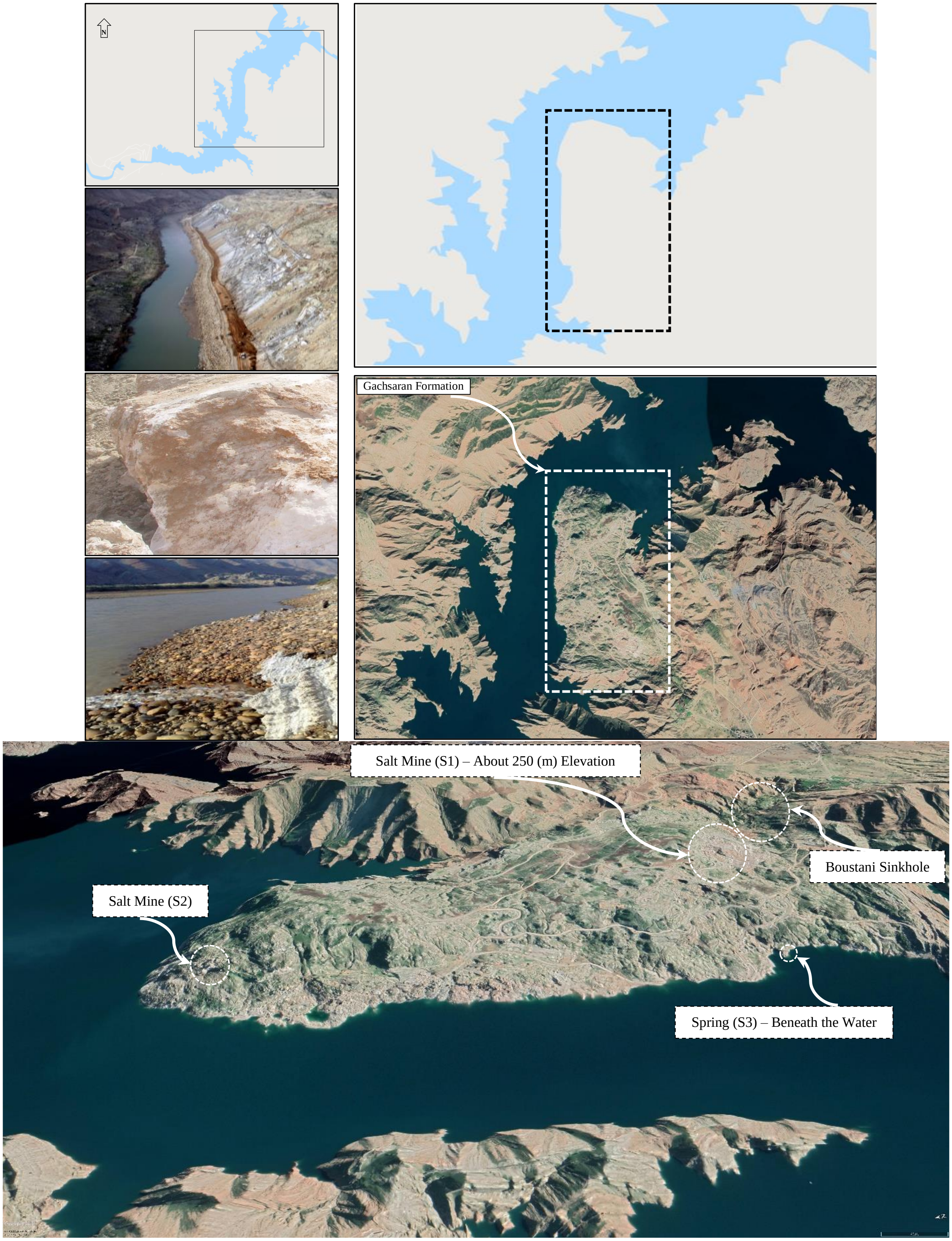

Figure S2. The location of Gachsaran evaporite formation (GEF) in the Gotvand Dam reservoir.

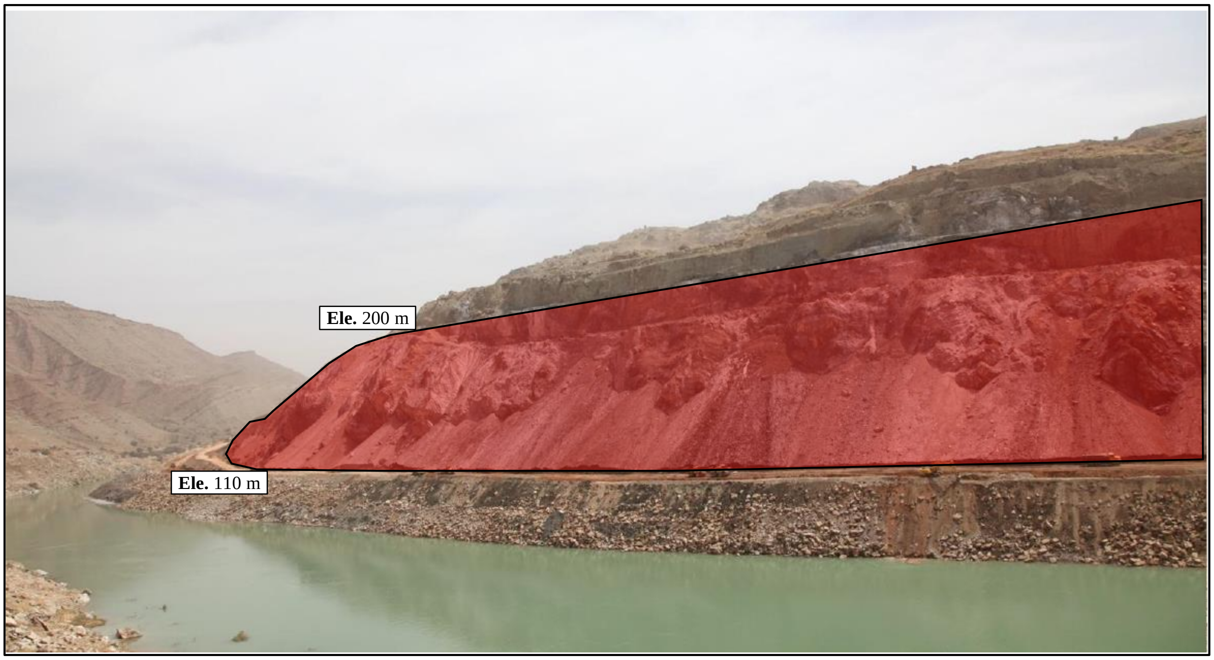

Figure S3. The location of salinity sources of evaporite formations in the 3D model.

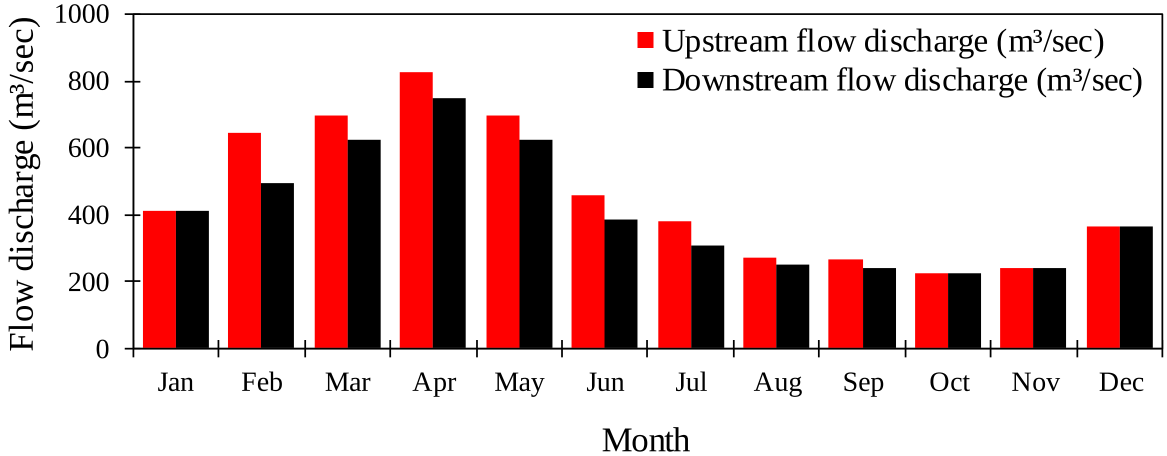

Figure S4. The average inlet/outlet discharge values of the Gotvand dam reservoir in different months of the year.

References

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