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RESEARCH LETTER

Intense extreme hydro-climatic events take a toll on society

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Abstract
In March 2019, the Iranian meteorological organization warned of the formation of several dense precipitation systems throughout the country. This was followed by a chain of storm events that ended up with three major floods with heavy damages, including at least 78 fatalities. Reportedly, within the first 48 h of the storm, the cumulative rainfall reached about 400 mm. Soon after, 23 provinces of Iran received a severe storm warning and an imminent flood alert as the second wave of rainfall was forming in the region. What was striking about these events was that, according to the historical data, the local rainfall rarely caused such extreme floods, indicating the dominant role of human alteration to natural cycles in these damaging flood events. Extreme hydro-climatic events are unavoidable, yet damages by such events are, to some extent, preventable. With proper, efficient, and timely decision making, the threat of natural hazards can be reduced or avoided. On the other hand, hasty and short-sighted decisions can be costly in the face of a natural catastrophe. This study evaluates the 2019 flood events in Iran and assesses the potential causes that amplified the damages, in search for clues to prevent future flood losses.

Keywords Extreme rainfall · Flood · Water governance · Climate change

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1 Neglecting the nature of floods as a consequence of a changing climate

No single event constitutes a definite proof of climate change, yet the recurrence of abnormal events does provide evidence of the effects of such a phenomenon. Significant increases in the frequency, intensity, duration, and extent of hydro-climatic extremes are arguably some of the worst consequences of climate change. They could, in turn, potentially have significant impacts on the communities, natural resources, and infrastructures that are dependent on them (Zolghadr-Asli et al. 2019a, b).

The 2019 southwestern flood in Khuzestan province, Iran, for instance, is an example of such climatic extremes. The heavy rainfall caused a devastating flood that was unprecedented in the region's climatic record. In fact, in 2019 alone, two other climatic extremes occurred after a prolonged drought spell in Iran. Interestingly, according to the records, these events took place in locations that were approximately 1500 km apart (Mehran et al. 2017; AghaKouchak et al. 2018). Within a few months, floods with a return period of seventy years or longer occurred, simultaneously, in the southwestern and northeastern regions of the country. These extreme events signaled an emerging new level of damaging climatic events, despite the lack of definite precipitation patterns in Iran, where wet and dry spells come and go in a seemingly random manner. The recorded documents indicate that the differences between the rainfall and the eleven-year (2008–2019) average could be considered as a climate change signal in Iran (Fig. 1). The impact of climate change in the regions is a notion that has been entertained for years (Bozorg-Haddad et al. 2020), yet what was striking in this case was that the geographic distribution of the inundated areas did not resemble a typically occurring flooding event. The observed patterns suggest that the 2019 flooding events may be due to climate change, amplified by the construction of hydraulic structures such as dams, urbanization, and over-expansion of cities located near rivers. It is worth noting that a less restricted movement of water could have potentially reduced or, to some extent, mitigated the adverse impacts of such flooding events.

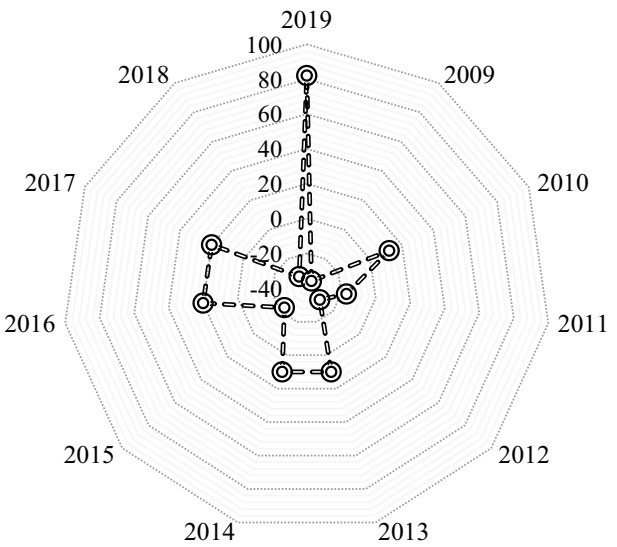

Fig. 1 Differences between annual precipitation and its eleven-year (2008–2019) average (%) in Iran

2 A glance at the damages caused by extreme hydro-climatic events

Apart from the obvious financial losses and the loss of lives, like other extreme natural hazards, the 2019 floods have long-term impacts. Most notably, the flood in Khuzestan province has caused permanent relocation of people to relatively safer places. In turn, the flood event seriously jeopardized the local farmers' livelihood. It was estimated that nearly 750,000 tons of ready-to-harvest wheat were destroyed in Khuzestan province alone, and some 200,000 hectares of agricultural lands were flooded during that period (Yadollahie 2019). Reportedly, 1220 livestock and 25,000 local poultry were killed in the flood (Yadollahie 2019). It was mandated to bury the animal carcasses to prevent any infectious disease outbreaks. Unfortunately, the houses that were built in the vicinity of the Karun River endured the most severe damages. In summary, the overall flood damage in Khuzestan province was estimated to be over US$75 million (2019 value). The majority of these damages, however, could have been prevented with better land-use practices. The houses located at a proper distance from the riverbank, for instance, were only slightly damaged.

It is always instructive in the study of floods to evaluate the various dimensions of human and environmental impacts of such events. After the typhoon of 2009, for instance, the outbreak of infectious diseases such as leptospirosis was reported in the Philippines (Al-shere et al. 2012). A similar situation was observed in Sudan, where the outbreak of several vector-borne diseases, including Malaria, has been reported after the 2020 flooding event (Ahmed et al. 2020). As for the case of the 2019 flooding in Iran, the affected residents were facing the risk of various infectious diseases, such as rabies and El Tor (Yavarian et al. 2019). It should be noted that in addition to the life-threatening diseases, the community often experiences the imminent threat of mental trauma in the aftermath of such events. A variety of mental disorders were reported among the affected residents following the 2019 flash floods in Iran. Private and public parties' timely and proper responses had a head-start to mitigate the impacts of the floods and control the outbreak of any health hazards. In the case of Iran, the Red Crescent Society assisted and rescued over 257,000 people affected by these flood events (IFRC 2019). Numerous volunteer groups, non-governmental organizations, government agencies, and private parties also offered their assistance during the flooding event.

3 Next steps: lessons learned from the 2019 Iran floods

The 2019 floods revealed some concerning issues and gaps in Iran's general practices and flood control strategies. The affected region is an arid/semiarid region that suffered from a prolonged drought prior to the 2019 flash flooding (Bozorg-Haddad et al. 2020). This encouraged the decision-makers to opt for a conservative practice when it came to water resources planning and management. While such a practice was safe and reliable during dry spells, they might not be effective for wet spells, especially in the face of extreme events such as the 2019 floods. During the years prior to the 2019 flooding, the dams and reservoirs in the region were operated to store as much water as possible, which led to insufficient storage for flood control. This modus operandi is called the "hot hand-fallacy" in water resources management (Zolghadr-Asli et al. 2019a, b). That is, it is easy to become complacent with the assumption that the current status would remain unchanged, and, as such, one tends to underestimate the likelihood of

experiencing a change. In the case of Iran, flood control policies should have accounted for the wet condition and provided sufficient flood control storage in reservoirs prior to the events. Thus, the current conservative plans and practices are in desperate need for major revisions to mitigate similar extreme events in the future.

Another management fault during the 2019 Iran floods was partially rooted in the errors in the predictions of two consecutive extreme floods. Although the stochastic nature of hydro-climatic events introduced some uncertainty and inaccuracy in the predictions, the quality of the data used for these predictions had an undeniable impact on the accuracy of such projections (*e.g.*, the source and resolution of maps) (Moon et al. 2019; Yuan et al. 2019). In the 2019 Iran floods, the 5-day short-term predictions turned out to be relatively accurate, but this was not the case for the medium- and long-term forecasts, which were far less accurate. Unfortunately, the inaccuracies of the latter cases damaged the credibility of all the available predictions in the eyes of the decision-makers during the storm events that led to the floods. Although the 5-day short-term forecasts could not have prevented the flood events per se, one may argue that such information could have mitigated the damages caused by the floods.

Another setback associated with the 2019 Iran floods was the overlapping jurisdictions and the bureaucratic inefficiency, which are common during emergency-management situations. The bureaucratic hierarchy jeopardized the efficiency and pace of decision making, especially for flood management, where timely and precise decisions are crucial. Unfortunately, in Iran, the decision-makers are often overwhelmed with multiple sources of data, which has proven to obstruct and delay effective decision making during a crisis. Such data may follow different protocols, have different scales, or come from different models. Particularly, they sometimes can even contradict one another, which raises another issue: which data source should be trusted when no additional information is available? Thus, reducing the information sources, to some extent, could potentially have a positive impact on the decision-making process. An efficient government hierarchy can make coordination and cooperation among decision-makers much more manageable, which might be the edge needed at the time of crisis. One could argue that the lack of a centralized flood management committee might have amplified the damages caused by the 2019 floods in Iran. This flooding case clearly demonstrated how establishing multiple operating agencies and committees could hinder critical decision making when timely actions are needed to have things under control.

A critical factor in the path of achieving a sustainable and effective strategy for extreme hydro-climatic events is understanding and, in turn, addressing the multifaceted nature of water resources management (Zolghadr-Asli et al. 2017). This notion indicates that due to the central role of water in the water–food–energy nexus, any plan or strategy regarding water resources must also account for the socioeconomic aspects of this natural resource (Zolghadr-Asli et al. 2021). Thus, these critical points must be reflected in any practical flood management plan, which could ultimately help establish a trusting bond between the governing body and the community since cooperation is of utmost importance in the face of a crisis.

The achievement of socioeconomic equality in a given community can ultimately reduce the vulnerability of the society against the potential impacts of extreme hydro-climatic events such as flooding. From a financial standpoint, some members of the society are more vulnerable when natural hazards such as floods ravage a community. It is an ethical duty for any decision-maker involved in the process of devising the flood management strategies to account for such realities. The bottom line is that a community's

vulnerability could be reduced substantially by improving health care and education of its inhabitants while eradicating socioeconomic inequity and discrimination.

Another pillar of effective flood management strategy is to account for the dynamic nature of hydro-climatic events. As stated earlier, climate change has been affecting and, in turn, altering the *status quo*. It has been established that these changes could have significant impacts on water resources and water resource systems (Zolghadr-Asli et al. 2019a, b). Thus, any comprehensive flood management guideline and water resources planning and management "blueprint" must be *flexible* and *robust* enough to account for these plausible changes. The procedures, standards, and protocols enacted to manage floods failed to perform as they were intended for flood control during the 2019 Iran flooding. Installing a pre-flood warning system is, for instance, something that could have made a considerable difference. A comprehensive guideline to address public relations can help utilize the potential of social media and cyber-infrastructure to warn, inform, and keep in touch with the public. This was another missing element in the related flood management protocols at the time (de Bruijn et al. 2018; Jongman 2018).

A good rule of thumb for flood management is that any effective attempt to achieve sustainability must be pursued under the umbrella of *watershed governance*. The idea behind watershed governance, which is a much broader term than *water governance*, is to integrate the roles of humans, technologies, and ecosystems within the bounds of a basin. Through watershed governance, it is possible to address water allocation across all sectors in a *flexible* and *robust* manner. Previous studies in the field of forensic hydrology have shown the role of human alteration of flood plains in the rise of flood losses (Loáiciga 2001; Delpasand et al. 2021). A watershed governance-oriented plan could mitigate the risk of hydrological extremes such as floods. One could argue that for the 2019 Iran flooding a different path could have been taken if watershed governance had been used to form the protocols and guidelines for flood management at that time. The lack of such long-term integrated visions had allowed improper land development, which unfortunately became a costly catastrophe during the 2019 floods in Iran. At that time, the decision-makers' ability to control the floods via the in-place flood-control reservoirs was hindered, given that storing the upstream inflows of the reservoirs would flood the populated areas in the region. Implementing such plans also required pre-planning and purchasing the lands prior to the floods, compensating the residents, and relocating them to more suitable places. Nonetheless, the prolonged drought spell in the region had driven people to relocate to the river riparian areas, increasing the risks of such floods to life and property. Alternatively, artificial channel networks can be used for conveying flood water, a practice that has proven helpful in the case of the Sacramento River floodplain in California for over 100 years. Large water volumes can be discharged through the constructed channel networks at times of need by bypassing adjacent villages, farming lands, and residential areas. It is worth noting that such a solution is effective even when the inflow of a reservoir is greater than its available storage for flood control.

4 Conclusion

The 2019 flooding in Iran signaled a troubling trend in water resources planning and management fueled by improper and short-sighted decision making and amplified by climatic change and inappropriate land use, which made the communities vulnerable to extreme hydro-climatic events such as floods. It has been clearly indicated that the current protocols

and guidelines for flood control are in desperate need of a major revision to reflect a more comprehensive, integrated policy (i.e., watershed governance) that can account for the multifaceted nature of water resources management. Such a policy is critical to cope with intensified climatic extremes and growing populations, which are imposing new threats to sustainable development and management of water resources. As a general rule of thumb, it can be inferred from the catastrophic floods reviewed and assessed herein that "controlling" extreme hydro-climatic events may not be the way to deal with them; instead, decision-makers should strive for "managing" and "adapting" to such events.

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Declarations

Conflict of interest None.

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