

Rethinking Oman Coastal Water Transfers Adopting Indigenous Flood Management and Monsoon Wisdom in Baluchestan, Iran

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Abstract

This paper critiques Iran's proposal to transfer water from the Oman Sea inland by presenting a historically grounded, locally adaptive alternative rooted in indigenous floodwater management systems in Baluchestan. The region, influenced by a monsoonal system with a history spanning at least 5000 years, utilizes traditional methods such as Hootak, Dagar, and Qanat to harvest and infiltrate seasonal floodwaters. Our archaeological field investigations in the Bampur Valley (2002 and 2004) and in Dezak-Saravan (2018) offered valuable empirical insights, enabling us to approach this sensitive and pressing issue within the framework of contemporary archaeology. Drawing on archaeological, ethnographic, and environmental data, the study outlines how these systems—rooted in deep ecological knowledge—can recharge aquifers and provide a sustainable alternative to large-scale coastal water transfers. The paper argues that such transfers are economically costly, ecologically disruptive, and culturally misaligned. The research highlights the significant loss of monsoon floodwater annually to the Oman Sea and Pakistan's Mashkid basin. These findings underscore the urgent need to invest in reviving and adapting intangible water heritage as a viable solution to the national water crisis.

1. Introduction

Iran is increasingly affected by water stress, particularly in the southeastern province of Sistan and Baluchestan, one of the driest and most underserved regions in the country (Mortazavi et al. 2015). In response, the government has proposed transferring desalinated water from the Oman Sea to inland areas (Fig. 1). While technically ambitious, this plan has drawn criticism over ecological, financial, and socio-cultural grounds. Critics argue it ignores local hydrology, undervalues indigenous knowledge, and risks long-term sustainability (Fig. 2).

Baluchestan is not devoid of water; it lies within the Indian Ocean monsoonal belt and receives seasonal floods. Historically, these floodwaters were harnessed using traditional systems such as *Hootak*¹, *Dagar*², *Khooshab*³, and *Qanat*⁴. These techniques emerged from generations of ecological adaptation and served both agricultural and domestic needs. Yet, modern water policy in Iran continues to favour large-scale engineering projects over the restoration and upgrading of these culturally rooted methods.

In recent years, prolonged droughts, excessive evaporation, and land fragmentation have deepened the region's water crisis. A prime example is the underutilized Mashkid-e Olya Dam, where water has been left to evaporate for over a decade due to delayed infrastructure rollout (Fig. 3). This case reflects a broader pattern of mismatched planning and resource mismanagement. Over 94% of the province's water goes to agriculture, often through inefficient flood irrigation. Given this context, the paper proposes a shift in strategy: to revive and upgrade traditional floodwater harvesting systems as a sustainable and context-sensitive alternative to coastal water transfers. By drawing on both indigenous practices and modern hydrological science, a hybrid approach could provide long-term water resilience.

This study draws on political ecology, critical infrastructure studies, and insights derived from archaeological fieldwork to frame its argument, critically examining technocratic water solutions that tend to disregard local ecological knowledge. Grounded in the material evidence and long-term perspectives provided by **archaeology**, it explores whether revitalizing indigenous water management systems could offer a more sustainable and context-appropriate alternative to large-scale sea-to-inland water transfer projects in Baluchestan. Additionally, the research investigates the extent to which empirical evidence—including archaeological, ethnographic, and hydrological data—supports the effectiveness of traditional flood-based recharge systems such as *Hootak*, *Khooshab*, *Dagar*, and *Qanat* under current hydrological dynamics and climatic conditions.

By addressing these questions, the paper offers a historically grounded and ecologically informed alternative to the current pipeline-centric paradigm. Rather than relying on large-scale sea-to-inland water transfers, this study advocates for the revitalization and adaptive modernization of indigenous flood-based water management systems that have evolved in Baluchestan over millennia. These systems—such as *Hootak*, *Khooshab/Hooshap* (seasonal flood ponds and natural infiltration zones), *Dagar*, and the well-known *Qanat*—are deeply embedded in the region’s hydrological rhythms and monsoonal cycles. Drawing on insights from *archaeological fieldwork*, combined with ethnographic and environmental data, the paper argues that these systems not only reflect profound local ecological knowledge but also present a viable, sustainable alternative to water importation schemes. This approach reframes floods not as natural disasters to be controlled but as renewable water resources to be captured, managed, and utilized for aquifer recharge and community resilience.

2- Materials and Methods

This study was conducted in the southern Baluchestan region of Sistan and Baluchestan Province, an area characterized by distinct rainfall patterns due to its proximity to the Sea of Oman and the influence of Monsoon Systems. Monthly and annual rainfall data for the meteorological stations of Chabahar, Pishin, Qasr-e-Qand, Bampour Dam, Saravan, Khash, and Ladiz were obtained through reports provided by the Sistan and Baluchestan Regional Water Joint-Stock Company for the water years 2020–2024 (Sistan and Baluchestan Regional Water Joint-Stock Company, 2024). These data included rainfall measurements (in mm) used to analyze seasonal and annual patterns. For instance, the Pishin station recorded a total of 419.8 mm of rainfall in the 2023–2024 water year, marking the highest value in the study period. Additionally, flood volume data (in million cubic meters) were collected from the hydrometric stations of Pishin (Sarbaz River), Qasr-e-Qand (Kajo River), Daman (Karvandar River), and the downstream of Bampour Dam (Bampour River) through reports provided by the Sistan and Baluchestan Regional Water Joint-Stock Company (2025). These data encompassed flood volumes for specific events, such as the March 2024 flood, which recorded 431.471 million cubic meters at the Bahukalat station (representing Chabahar). Due to the unavailability of monthly temperature data, annual average temperatures were estimated based on regional climatic reports from the meteorological bulletin of Sistan and Baluchestan Province (Sistan and Baluchestan Meteorological Organization, 2024).

For example, the annual average temperature for Chabahar was assumed to be 28°C, while that for Bampur Dam was set at 25°C.

The rainfall data were aggregated annually and categorized into two main seasons: the monsoon season (July, August, September) and the winter season (January, February, March). For example, Qasr-e-Qand recorded 162.5 mm of rainfall in the summer of 2023, highlighting the significant role of monsoon systems in rainfall enhancement. Flood analysis focused on extreme events, such as the 138.15 million cubic meter flood in the Pirsourab River on December 31, 2023. To simultaneously visualize temperature, rainfall, and flood data, a combination chart was created (Fig. 4).

In this chart, temperature is represented by solid lines on the left axis (Y-temp), rainfall by bars on a separate left axis (Y-rain), and flood volume by dashed lines on the right axis (Y-flood). This design facilitates a clear distinction between temperature (ranging from 25–28°C) and rainfall (up to 421.6 mm), allowing the exploration of potential relationships between higher temperatures, increased rainfall, and flood occurrences over the 2020–2024 period. Historical and archaeological analysis was also conducted using documented sources and field evidence to investigate traditional water management practices, such as *Khooshab*, *Dagar* and *Hootak*, in Baluchestan (Mortazavi et al. 2018: 1209–1219). These practices were compared with modern water transfer projects, such as the Sea of Oman water transfer line (Pipeline 5), to evaluate their sustainability and environmental impacts.

Data analysis was performed using Microsoft Excel for initial calculations and categorization. To standardize traditional flood management, recurring flood patterns were identified using both contemporary and historical data, enabling the redesign of traditional structures with modern engineering standards. Limitations of this study included the lack of monthly temperature data and incomplete flood data for some years, which constrained the analysis to specific periods.

3- Legacy, Land, and Loss: Water Use in Baluchestan across Time

Water, a vital and decisive element in the fate of civilizations, has always played a central role in Iran's history. The flourishing of great civilizations such as Elam—established near reliable water sources like the Karun, Dez, and Karkheh rivers—is clear evidence of this. During the Achaemenid era, with growing urban populations, Iranians developed Qanats to transport water from mountainous regions to the arid central plateau, with public participation in water management playing a crucial role. Baluchestan, too, has followed a similar pattern. From prehistoric times to the present day, major civilizations in the region have been established along river systems such as Ladiz near Mirjaveh, Simish in Saravan, Bampur near Iranshahr, and Sarbaz in southern Baluchestan. Due to population growth and the region's highly permeable geological structure (Fisher 1968), people have historically resorted to methods such as digging Qanats and deep wells to access water. This connection is so embedded in local culture that some places are even named after wells.

Rising temperatures further intensify evaporation, particularly in the hot and arid climate of Saravan. Statistics show the highest average monthly evaporation occurs in July (6.455 mm), and the lowest in

January (7.123 mm). The average annual evaporation is 3,472.5 mm, with extremes ranging from 2,437 mm to 4,191 mm per year. According to the Sistan and Baluchestan Agricultural Organization, over 94% of the province's water is consumed in agriculture. The implementation of the first principle of the White Revolution—land redistribution from large landowners to smallholder farmers—led to fragmentation of land and loss of integrated management of water and soil. This fragmentation, combined with widespread reliance on traditional flood irrigation instead of efficiency-focused methods, has drastically increased water consumption (Nekoei Naini 2016).

Given the high evaporation rates in Saravan, watershed management emerges as a suitable strategy for water resource management. Techniques such as the construction of earth dams, flood spreading, slope seeding, and vegetation restoration can help capture and store rainwater and surface runoff. Leveraging the traditional knowledge of Saravan residents in managing floods and water resources can significantly enhance the effectiveness of watershed management. For generations, local communities have used methods such as Qanat construction and earth barriers to manage water (Mortazavi et al. 2018: 1209–1219). Integrating this indigenous knowledge with scientific and modern watershed techniques can lead to more effective water management outcomes in Saravan. In short, the implementation of appropriate watershed projects—combined with the local community's traditional expertise, particularly in managing Qanat systems (Fig. 5)—can significantly improve water resource management in the region and help prevent water loss and the worsening of water scarcity in this hot, arid region.

4- Historical Context: Monsoon and Indigenous Technologies

The monsoon is a dual-seasonal atmospheric phenomenon affecting southern Iran, particularly Baluchestan. The summer monsoon brings moist winds from the Indian Ocean, resulting in intense but short-lived downpours that cause flash flooding. Historical records and archaeological studies suggest that people in Baluchestan have interacted with this climate pattern for over five millennia (Lückge et al. 2001). Beyond its role in precipitation, the monsoon system significantly aided trade between East African and West Asian communities, especially those in the Persian Gulf within the western Indian Ocean. Due to these periodic winds, merchants were able to efficiently transport goods across the vast expanse of the ocean. The Sassanid era (224–651 AD), evidenced by archaeological finds such as Persian Gulf ceramics discovered in East Africa, indicates the existence of economic links between these regions. However, extensive maritime trade communication in the Persian Gulf is believed to have commenced in the mid-8th century AD. Siraf, an island and inland port in the Persian Gulf, exemplifies this flourishing trade activity. This historical role of Iran as a connective bridge between diverse civilizations underscores the significance of its strategic location (Mortazavi 2024).

Across the Baluchestan region, communities developed water harvesting strategies tailored to the terrain. The Baloch people, through traditional management and the local structures of Dagar (large pools with meter-high walls for accumulating rainwater and floodwater) (Chelvarfoush et al. forthcoming), contributed to the recharge of aquifers and the protection of water resources. Hootaks (shallow, earthen basins dug in flood paths) temporarily collect runoff, slowing the flow and allowing

water to percolate into the ground. Khooshab/Hooshap also functioned similarly (Chelvarforoush et al. 2023: 156), often relying on natural depressions and vegetation to enhance infiltration. These systems, while reducing the impact of flash floods, aided in replenishing groundwater, a process further supported by Qanats—horizontal wells dug to tap and transport water from aquifers to surface settlements and fields (Mortazavi et al. 2018). The remaining ancient remains of Hootak and Khooshab indicate that the history of water and soil management and optimal utilization in Baluchestan dates back thousands of years. In Baluchestan, the collection of floodwater using these structures, in addition to recharging aquifers, helped to make the soil fertile, especially in areas of Saravan where a large percentage of the land is rocky: "The main purpose of constructing Khoshap is to transform sandy and stony lands into suitable land for cultivation through floodwater harvesting and gradual sedimentation" (Kharrad Narooi et al. 2017; Chelvarforoush et al. forthcoming; Mortazavi et al. 2018).

Ethnographic accounts from Saravan, one of Baluchestan's key urban centers, vividly illustrate the pivotal role of the Qanat not merely as a vital water source, but as a foundation for the formation and strengthening of social and cultural structures. As recent research in Saravan County, Baluchestan, reveals, the Qanat has evolved into a national identity, holding profound values in the lives of the region's people, around which extensive social and cultural relationships have developed. Studies indicate a close-knit connection between the Qanat and the local community, with unique rituals and beliefs stemming from this interaction forming a significant part of Saravan's culture. For instance, the mythical beliefs surrounding the construction of Qanats, such as attributing it to jinn due to its technical complexity, highlight the special and revered place of this structure in the people's minds. These beliefs, passed down orally through generations, demonstrate the deep cultural roots of the Qanat in the region. Beyond beliefs, specific rituals in Saravan associated with Qanats have significantly influenced social aspects. The collective undertaking of tasks related to Qanats, such as water distribution and dredging has fostered a strong sense of cooperation and social cohesion among the local population. The traditional water distribution system, employing tools like the Tas and Kapal, served not only as an equitable method for utilizing this precious resource but also functioned as a gathering point and news exchange center. Gorband, the location for water distribution, provided a space for social interactions, important decision-making, and even the resolution of disputes. Furthermore, the financial and symbolic value of Qanats in marriage traditions and social relations is clearly evident. Setting shares of Qanat water as dowry and the social standing of individuals based on their access to water underscore the fundamental importance of this resource in the social fabric of Saravan (Chelvarforoush et al. 2023).

Therefore, the Qanat in Saravan has operated beyond a mere water system, acting as a crucial factor in shaping cultural identity, strengthening social cohesion, and preserving local traditions and rituals. This invaluable heritage, rooted in the long-standing interactions between humans and nature in this region, warrants attention and preservation, especially in the face of recent drought challenges that threaten the survival of these social and cultural structures dependent on the Qanat.

5- Challenges of Water Governance and the Inclination Towards Coastal Water Transfer:

Legislative and institutional challenges in Iran have played a significant role in the erosion of traditional water management systems and the emergence of the current water crisis. The 1968 "Nationalization of Water Law," followed by the 1982 "Fair Distribution of Water Act," by centralizing power in the hands of the government and stripping local communities of ownership, dealt a severe blow to sustainable and indigenous knowledge-based systems. These laws, while aiming to create uniformity and centralized control, often overlooked local realities and the indigenous knowledge of water resource management, leading to the weakening of traditional structures, particularly in marginalized regions such as Baluchestan. The excessive encouragement of deep well drilling and the use of modern pumping technologies, without considering the ecological capacities of the region and the accumulated knowledge of local communities, resulted in a dramatic drop in groundwater levels. This top-down approach not only disregarded the participation of local stakeholders in planning and implementation processes but also, with weak oversight, created the conditions for widespread over-extraction and the abandonment of efficient traditional aquifer recharge systems (Chelvarfoush et al. forthcoming).

As a consequence of this weakness in planning and the lack of attention to indigenous capacities, many Qanats, which have been the lifeblood of arid and semi-arid regions of Iran for centuries, have been put at risk of destruction due to lack of maintenance funding, land use changes, and legal ambiguities regarding ownership. The current water crisis, largely stemming from this neglect of indigenous knowledge and sustainable resource management, has driven the government towards costly solutions with uncertain environmental consequences, such as water transfer from the Oman Sea. This is while the revival and modernization of traditional water management systems, relying on indigenous knowledge and the participation of local communities, could offer a more sustainable and adaptable solution to the ecological and social conditions of various regions in Iran.

6- Seawater Transfer Drawbacks: Oman Sea Warning

Transferring seawater to inland regions—especially through large-scale desalination and long-distance pipelines—poses significant environmental challenges. One of the most serious concerns is the threat to the biodiversity of marine and coastal ecosystems. The desalination process produces large quantities of brine, which, if not properly managed, can destroy marine habitats and lead to the mass death of aquatic species (Lattemann & Höpner, 2008). Moreover, the high-energy consumption of desalination facilities contributes to a substantial carbon footprint, contradicting the principles of sustainable development (Elimelech & Phillip, 2011). In addition to environmental concerns, such projects often lead to severe socio-economic consequences. The initial investment, as well as the long-term costs of maintenance for desalination units and extensive pipeline networks, are extremely high. This can burden national budgets and divert limited financial resources away from more pressing priorities (Cooley & Herberger, 2013). Moreover, these projects can result in the displacement of local communities and

destruction of agricultural lands along pipeline routes, which may trigger social unrest and instability (WWF, 2007).

Desalination at an industrial scale also requires massive amounts of energy, mostly derived from fossil fuels. This not only exacerbates greenhouse gas emissions and accelerates climate change, but also transforms such projects into significant sources of air pollution (Elimelech & Phillip, 2011). Additionally, the discharge of brine containing high concentrations of salt, heavy metals, and chemical additives into the sea can drastically alter marine ecosystems—disrupting food chains, causing mass die-offs of marine organisms, and threatening biodiversity (Lattemann & Höpner, 2008). It is important to note that marine ecosystems are not only a natural heritage of our generation, but a legacy we must protect for the future. Environmental damage to these systems represents a violation of intergenerational ecological rights (WWF, 2007).

Moreover, researchers have highlighted that in the Persian Gulf region, poorly managed desalination discharges have led to increased salinity levels and heavy metal accumulation along the coasts, affecting marine biodiversity and fisheries. These examples should serve as cautionary lessons for Iran. Without inclusive environmental impact assessments and genuine participation of affected communities, the Oman Sea project may become another instance of environmentally unjust and ecologically hazardous infrastructure.

7. Indigenous Practices vs. Desalination and Water Transfers

While the fervor to find solutions for the water scarcity crisis has presented seawater desalination and national-scale water transfer projects as technological marvels and appealing, readily available options, and numerous studies (Karagiannis & Soldatos, 2008; Reddy & Ghaffour, 2007; Bernat et al., 2010; Fritzmann et al., 2007) justify them by focusing solely on economic calculations, a clear oversight is evident: the neglect or downplaying of the heavy environmental toll of these seemingly life-saving technologies in comparison to the sustainability and adaptability of indigenous methods. This is despite the fact that several studies (Lattemann & Höpner, 2008; Nisan & Benzarti, 2008) have pointed to the environmental costs of the desalination process, but these references are often insufficient and not comprehensive.

Large-scale desalination and water transfer schemes, particularly those on a national scale, are often framed as technological marvels capable of solving the water scarcity problem. However, these projects come with enormous ecological, financial, and political costs. For example, the Oman Sea desalination and transfer project involves energy-intensive processes, long-distance pipelines, and the disruption of marine ecosystems. Furthermore, it diverts investment away from smaller, localized solutions that may be more effective and sustainable. In contrast, indigenous methods like Hootak and Qanat are low-cost, low-energy systems that capitalize on natural hydrological cycles. They require minimal infrastructure and, when maintained, offer remarkable durability and efficiency. According to a report by the Islamic Republic News Agency (IRNA), approximately 1.3 billion cubic meters of runoff water are lost annually

from the southern regions of Sistan and Baluchestan province due to the lack of soil absorption capacity. Of this amount, around 365 million cubic meters are discharged from the Mashkid Basin in Pakistan, and about 860 million cubic meters are lost through the Oman Basin (Aghbatbekhair, 2014). As stated by the former CEO of the Sistan and Baluchestan Regional Water Joint-Stock Company, the primary cause of this phenomenon is the low permeability of the soil in the southern parts of the province, which prevents proper absorption of rainfall and runoff. Consequently, the majority of dams in this region have been constructed with the aim of capturing surface water and preventing its loss beyond national borders. Furthermore, the water consumption pattern in Sistan and Baluchestan indicates that approximately 94% of the province's water resources are allocated to the agriculture sector, which is higher than the national average of 91%. The share of drinking water is around 5% (compared to the national average of 7%), and the industrial sector **uses** less than **1%** (while the national average is **2%**) (Aghbatbekhair, 2014).

Most of these studies, in the best-case scenario, offer a fleeting mention of environmental costs, as if the destruction of marine ecosystems from desalination, the greenhouse gas emissions from immense energy consumption in both desalination and transfer processes, and the disruption of natural water cycles due to large-scale transfers are merely negligible side effects of an engineering solution. However, the long-term consequences of these interventions could be far more severe than the initial water scarcity problem. Indeed, as previous research indicates, a sole focus on the economic costs of investment and operation (Karagiannis & Soldatos, 2008; Reddy & Ghaffour, 2007; Bernat et al., 2010; Fritzmann et al., 2007) without considering the real and widespread benefits for society and stakeholder groups, especially in comparison to the total costs including desalination, water transfer, and ecological damage, constitutes a superficial and one-dimensional analysis.

This lost resource represents a critical planning failure. Rather than diverting water from the coast to the interior at great expense, why not prevent inland water from leaving in the first place? Redirecting and storing even a portion of this floodwater could alleviate local scarcity, recharge aquifers, and reduce the need for external interventions. The construction of massive desalination plants on coastlines is in itself a blatant encroachment on sensitive coastal habitats. The destruction of wetlands, mangrove forests, and other vital ecosystems that play a crucial role in maintaining biodiversity and environmental sustainability is often disregarded as incalculable costs in economic equations. Furthermore, the process of desalination and water transfer over long distances demands the consumption of staggering amounts of energy, primarily sourced from fossil fuels. This, in turn, leads to the emission of greenhouse gases and the exacerbation of climate change – a phenomenon that itself can lead to the intensification of water scarcity crises in other regions. However, perhaps the most significant environmental challenge stemming from seawater desalination is the disposal of concentrated and toxic brine produced by the process. This brine, containing high levels of salt, chemicals used in the desalination process, and heavy metals, can lead to the devastation of marine ecosystems, the reduction of biodiversity, and the contamination of the food chain if disposed of improperly into the sea. Similarly, large-scale water transfer projects can lead to the alteration of natural river flows, the drying up of wetlands and lakes at the source, and damage to ecosystems along the transfer routes.

In this context, studies that focus solely on economic aspects and the comparison of technologies (Abdolmajidi et al., 2011; Sadeghi et al., 2016; Zou and Liu, 2016) avoid addressing these hidden environmental costs and comparing them with the potential benefits of indigenous methods. For instance, calculating the cost per cubic meter of desalinated water (Abdolmajidi et al., 2011) without considering the price of environmental destruction and the costs of transfer to the end consumer is a misleading metric for overall project evaluation. The economic comparison of renewable and fossil energies (Sadeghi et al., 2016), while important, constitutes only a small part of the complex equation of water resource sustainability and overlooks the direct consequences of toxic brine disposal and the ecological effects of water transfer. Even large-scale economic analyses, such as the study in China (Zou and Liu, 2016), may fail to account for the irreparable damage to local ecosystems and disregard the potential of environmentally friendly solutions. Indeed, as the previous text points out, there is a research gap in quantifying the benefits of desalination for society and comparing them with the total costs (desalination and transfer) and environmental costs in comparison to the sustainability of indigenous methods.

Therefore, a fundamental paradigm shift is necessary in evaluating seawater desalination and water transfer projects. We need a holistic approach that accurately quantifies and incorporates not only direct financial costs but also all long-term and indirect environmental costs and the sustainability and adaptability benefits of indigenous methods into decision-making equations. Instead of solely relying on large-scale technological solutions, serious attention must also be paid to the potential of local and environmentally friendly solutions such as local floodwater management and the revival of traditional water harvesting methods. Otherwise, in our attempt to solve one problem with exorbitant costs, we may bequeath far greater and more complex issues to future generations, paying a heavy price for every seemingly modern drop of water, while indigenous wisdom could have offered a more sustainable and cost-effective path.

8- Case Study: The Qanats of Saravan and Seasonal Floods - Re-examining a Historical Interaction for Sustainable Water Management with an Emphasis on Cultural Dimensions and Policy Recommendations

The Saravan region, situated in the Mashkid watershed with its seasonal rivers and floodplains, has relied on Qanats as vital arteries for supplying drinking and agricultural water for centuries. Historical and archaeological surveys (Mortazavi et al., 2018) indicate that the inhabitants of Baluchestan have long adapted to the region's monsoon climate pattern for over five millennia (Mortazavi et al., 2020). This deep interaction with nature has led to the development of ingenious indigenous strategies for managing water resources.

As evidenced by the Saravan case study, many of the region's Qanats were strategically constructed in close proximity to the beds of seasonal rivers. This deliberate choice was not accidental but rather the result of a profound understanding of the region's hydrological dynamics. This historical awareness is

even reflected in travelogues from later periods; for instance, Farmanfarma explicitly mentions the possibility of constructing Qanats in the waterways and rivers of this area in his travelogue of Baluchestan and Kerman (Farmanfarma, 2001:71). Local elders also recall in interviews (Mortazavi 2018: 67) how the powerful flows of summer monsoon rains, although short-lived and torrential, were directed through managed channels into these underground systems. This infiltrated water was gradually stored in the ground and flowed as reliable freshwater sources from the Qanats weeks and months later. This approach, which relied on precise timing and indigenous knowledge of the region's topography and soil permeability, is a prime example of adaptation to environmental conditions.

In addition to Qanats, other indigenous technologies of Baluchestan, such as *Dagar* (large ponds with high walls for collecting rainwater and floodwater), *Hootak* (shallow earthen ponds in the path of floods), and *Khooshab/Hooshap* (relying on natural depressions and vegetation cover to increase water infiltration), also played a significant role in managing runoff and recharging groundwater (Kharrad Narooi, 2017; Chelvarforoush et al., forthcoming;). The ancient remains of these structures testify to the millennia-old history of water and soil management in Baluchestan. In the Saravan region, collecting floodwater using these methods, in addition to recharging aquifers, also contributed to the fertility of stony soils (Mortazavi et al., 2018).

8-1- Cultural Dimensions of Water Management:

In Baluchestan, water is not merely a resource; it is deeply rooted in social memory, oral traditions, and spiritual life. The seasonal arrival of monsoon rains was traditionally associated with collective activities: cleaning Qanats, repairing *Hootaks*, and redistributing water rights through customary gatherings. Local elders and water experts (*Moghannies*) served as respected authorities, passing on their knowledge through generations.

Unfortunately, these intangible cultural elements are often overlooked in modern hydrological planning, which tends to focus more on efficiency, quantification, and scale. However, neglecting these dimensions leads to reduced community participation and long-term sustainability. Reviving traditional systems without revitalizing the cultural fabric that sustained them is likely to fail. Furthermore, many local terms and practices are not translatable into technocratic language. For example, the difference between a "*Hootak*" and a general flood basin lies not only in form but also in function, ritual, and collective memory. Incorporating these elements into policy discourse can open new avenues for inclusive water governance.

Regrettably, field surveys in Saravan indicate that most of these ingenious systems are currently inactive. Satellite imagery and aerial (drone) mapping reveal that floodwaters bypass former infiltration points, leading to increased surface runoff and damage to infrastructure. The 2019 flood is a stark example of this situation, where the destruction of agricultural land and homes could have been significantly reduced by reviving *Hootak* ponds and associated Qanats. Hydrological modelling also confirms this

potential, showing that with minor restoration, these systems could store up to 30 percent of the flood volume that is currently wasted.

This case study in Saravan not only highlights the importance of Qanats as a vital water source but also their role in shaping and strengthening the region's social and cultural structures. The deep connection between Qanats and the local community, with the unique rituals and beliefs arising from this interaction, forms an important part of Saravan's culture. This valuable heritage, rooted in the long-standing interactions between humans and nature in this region, and its revival, considering the cultural dimensions, can offer a sustainable and environmentally friendly solution to address the challenges of drought in Baluchestan (Chelvarforoosh et al., 2023).

8-2- Policy Recommendations:

The "Policy Recommendations" section, developed based on the findings of this study, encompasses key directions for improving water resource management with consideration for the cultural dimensions and indigenous experiences of the Saravan region. Chelvarforoush et al. (forthcoming) suggest five policy recommendations as follow:

The first recommendation is the Legal Recognition of Traditional Systems. In this regard, it is proposed that existing water laws be reformed to legally recognize community-managed water systems, such as Qanats and Hootaks. This recognition should be accompanied by clear frameworks for co-governance and the active participation of local communities to protect the rights and responsibilities of stakeholders.

The second policy priority is Floodwater Harvesting Programs. In this area, it is suggested that the revival of traditional water infiltration systems be considered an integral part of national strategies for mitigating flood impacts and recharging groundwater. This can help reduce the damage caused by seasonal floods and improve the sustainability of groundwater resources.

The third recommendation emphasizes Decentralized Planning. It is proposed that regional water authorities and local communities be empowered to jointly develop solutions tailored to the geographical characteristics and cultural practices of each region. This participatory approach can lead to more effective and sustainable solutions that are better aligned with local needs and conditions.

The fourth policy direction is Capacity Building and Education. Training a new generation of water managers who integrate scientific hydrological knowledge with ethnographic and historical understanding appears essential. This interdisciplinary approach can provide a deeper understanding of traditional systems and how to integrate them with modern approaches.

Finally, the fifth recommendation is to conduct Cost-Benefit Audits of Mega-Projects. It is proposed that transparent and long-term assessments of water transfer and desalination projects be carried out, and their results be compared with local alternatives in terms of cost, resilience, and social equity. This

comprehensive evaluation can lead to more informed decision-making and the selection of more sustainable solutions for water supply.

8-3-Connection to the Discussion of the Study Area (Dezak):

This study focuses specifically on the Baluchestan region, particularly the village of Dezak in Saravan County. Due to its permeable soil, this area has long relied on Qanats for the exploitation of groundwater resources, and its inhabitants have accumulated valuable indigenous knowledge in water resource management, especially in utilizing seasonal floods. Archaeological investigations in Dezak testify to the ingenious efforts of past inhabitants in consciously directing floodwaters into Qanats for the purpose of recharging and managing these precious resources. This knowledge, shaped over centuries of interaction with the environment and supported by historical evidence, along with the deep cultural dimensions of water management in this region, provides a rich foundation for inspiring modern and sustainable approaches to flood and water resource management.

The present research aims to investigate the efficiency of an algorithmic skin at the mouth of Qanats in the Baluchestan region for controlling and directing floodwater flow into them. These skins are the result of our previous studies and research, the findings of which have been published in a separate scientific article. This point underscores the originality and innovation of this proposed solution, indicating that this idea is based on documented research and engineering analyses. Inspired by the ancient motifs of pottery from the Bampur region, a hexagonal skin with a rhombus and triangular structure was designed, capable of intelligently adjusting the floodwater inflow into the Qanat by altering the dimensions of its pores using algorithms based on Rhinoceros software and the Grasshopper plug-in (Fig. 6) (Ebrahimi et al., Forthcoming).

The technical performance of these skins relies on the intelligent control of the opening and closing of their pores. The structure, inspired by indigenous motifs and combined with adjustable algorithms, enables the active management of floodwater flow. Water flow simulation analyses using ANSYS software demonstrated that this skin, with its fractured structure, has the ability to divert a significant portion of the floodwater flow and, with the gradual opening of its pores, allows for a controlled and vortex-like entry of flow into the Qanat. This not only prevents damage to the Qanat structure but also enables the optimal utilization of seasonal floods for aquifer recharge (Fig. 7).

A key advantage of these algorithmic skins, the study and design of which have been previously published by us in another article, lies in their ability to integrate with traditional structures such as Qanats and Hootaks and enhance their performance using modern technologies. While preserving cultural values and building upon centuries of accumulated indigenous knowledge, this offers a modern solution for the sustainable utilization of local water resources. In this way, by effectively managing seasonal floods and recharging aquifers locally, the need for costly and destructive inter-basin water transfer projects can be reduced, thereby preventing the associated environmental, economic, and social damages. Water transfer from the Oman Sea, although proposed as a solution to water scarcity in inland areas, can have significant negative environmental, economic, and social consequences. Some of these

damages include ecological changes at the source and destination, habitat destruction along the transfer route, high energy consumption, impact on local water resources at the destination, and high implementation and maintenance costs.

In contrast, the approach of using algorithmic skins for flood management and groundwater recharge appears to be a local, less costly, and more environmentally friendly solution. By relying on existing water resources in the region (seasonal floods) and leveraging indigenous knowledge and modern technologies, this method can enhance water resilience and reduce dependence on risky and expensive water transfer schemes. In fact, this research suggests that instead of large-scale investments in water transfer projects with extensive adverse consequences, the focus should be on developing and implementing innovative solutions based on algorithmic knowledge and inspired by traditional local water management methods. These intelligent skins, with their ability to adjust and adapt to varying flood conditions and regional water needs, can play a pivotal role in ensuring sustainable and resilient water security in Baluchestan and provide a model for other regions with similar conditions. In this way, by intelligently reviving and modernizing traditional methods, a fundamental step can be taken towards local water self-sufficiency and the protection of the natural resources of these regions. The present study demonstrates that these algorithmic skins, the design and performance results of which have been previously published by us in another article, can serve as a modern and efficient alternative to traditional flood management and groundwater recharge methods in the Baluchestan region, particularly in Dezak and similar areas, significantly reducing the need for water transfer with all its associated harms.

To complement the proposed strategies in this study, it is important to consider broader perspectives on water management. The study by Shumilova et al. (2018) demonstrates that although large-scale water transfer megaprojects may initially appear to be a solution to water scarcity, they are often inefficient, costly, and environmentally and socially harmful in the long term. The authors emphasize the integration of gray infrastructure with nature-based solutions, recommending alternatives such as water reuse, improvements in distribution systems, utilization of wetlands and aquifers as natural storage systems, and increasing irrigation efficiency in agriculture (Shumilova et al., 2018). As illustrated in Fig. 8 (Shumilova et al., 2018), these projects are distributed across major river basins worldwide, many crossing international borders and impacting hydrological balances at regional and continental scales. In addition to the solutions proposed by Shumilova et al., the watershed management and flood control practices based on local and indigenous knowledge, such as those applied in Iran's Baluchistan region, can effectively complement these strategies, offering context-specific and sustainable alternatives to costly interbasin water transfer projects.

Conclusion

Iran's water policy faces a crucial decision point, where the appeal of costly, high-tech solutions often eclipses the deep-rooted wisdom gained from centuries of living alongside monsoons and enduring water scarcity. Our focused study on the Baluchestan region, particularly the village of Dezak in Saravan

County, underscores that indigenous water management systems are not outdated relics but dynamic and relevant examples of sustainable, community-driven practices. The historical integration of Qanats with seasonal floodwaters in Dezak, alongside traditional technologies like *Dagar*, *Hootak*, and *Khooshab* across Baluchestan, demonstrates a profound understanding of the region's hydrology and a remarkable capacity for environmental adaptation.

Furthermore, our research introduces and validates the potential of algorithmic skins, a modern innovation inspired by the cultural heritage of Baluchestan and grounded in engineering analysis. These skins, designed to intelligently control and direct floodwaters into Qanats, offer a technologically advanced yet locally attuned approach to water management. By reframing seasonal floods not as disasters but as potential resources to be harnessed through both traditional wisdom and modern algorithmic solutions, Iran can forge a more resilient and equitable water future.

This path necessitates recognizing and revitalizing the indigenous knowledge within communities like Dezak, empowering local expertise, and fostering a collective responsibility for water resources. Instead of prioritizing large-scale, energy-intensive inter-basin water transfers, particularly from sources like the Oman Sea with their significant environmental and socio-economic drawbacks, the emphasis should shift towards investing in and scaling up these time-tested, nature-based solutions, enhanced by innovative technologies like our algorithmic skins. This "transfer of wisdom from past to present," augmented by cutting-edge design and engineering, not only promises more sustainable water management but also strengthens social cohesion and respects the deep cultural connections to water that are integral to Iran's identity. Embracing this paradigm shift, which integrates traditional ecological knowledge with modern algorithmic tools, can pave the way for a future where water is not just conserved as a precious resource, but also celebrated as a vital element of Iran's rich natural and cultural heritage, ensuring water security for communities like Dezak and the wider Baluchestan region.

Declarations

Funding Declaration

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Ethics and Consent to Participate declaration

Ethics and Consent to Participate declarations: not applicable

Author Contribution

Author Contributions StatementM. M is the sole author of this manuscript. He conceived the research idea, conducted all analyses, prepared the figures, and wrote the entire manuscript.

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Footnotes

1. The *Hootak* is a structure constructed with the aim of collecting floodwaters for livestock drinking and agricultural purposes. In some cases, hootaks represent the only available water sources in the Dashtyari region of Chabahar (Behbahani, 1987: 25).
2. The *Dagar* is an earthen pond with very short walls (less than 1.5 meters in height) and a large surface area (1 to 25 hectares), built for the purpose of flood control and flood-based cultivation on very flat and fine-grained lands of the coastal plains of Chabahar, particularly in the Dashtyari district. It is constructed on silty and clayey soils with minimal slope.
3. The term *Khooshab* refers to land saturated with water—a flat area that is uniformly and efficiently inundated and remains submerged for a period. Water enters through a narrow canal and spreads over the land in a cluster-like pattern (literally meaning "water cluster"). The term *khooshab* and its equivalents are commonly used in the counties of Saravan, Iranshahr, Sarbaz, and Nikshahr, and it appears that the origin of the term is older in the regions of Saravan and Sarbaz (Bakhtiarinasab, 1997 :3).
4. The Qanat is one of the oldest and most remarkable water management systems in the world, and Iran is widely considered its place of origin. A Qanat is an underground tunnel system that taps into subterranean water sources in highland areas and conveys it to the surface at lower elevations, using gravity alone. This ingenious system has allowed communities in arid and semi-arid regions to access reliable water for agriculture and domestic use for thousands of years. According to Henri Goblot, a prominent French scholar on Qanats, the system likely originated in northwestern Iran around 800 BCE and gradually spread to the rest of the Persian Empire and beyond. By the time of the Achaemenid Empire, Qanats were already widely used, with royal edicts encouraging their construction and maintenance. The technology spread westward to Egypt and North Africa, and eastward to Central Asia, China, and eventually to Spain and the Americas via Islamic and colonial influence (Goblot, 1979). Qanats played a crucial role in the rise of urban and agricultural civilizations across Iran's central plateau, enabling the development of settlements far from rivers. Many Iranian cities—such as Yazd, Kerman, and Nishapur—flourished due to extensive Qanat networks. Remarkably, some of these systems are still functioning today. Even in the study area of Saravan, numerous ancient and modern active Qanats can be observed, reflecting the enduring relevance of this traditional water management technology.

Figures

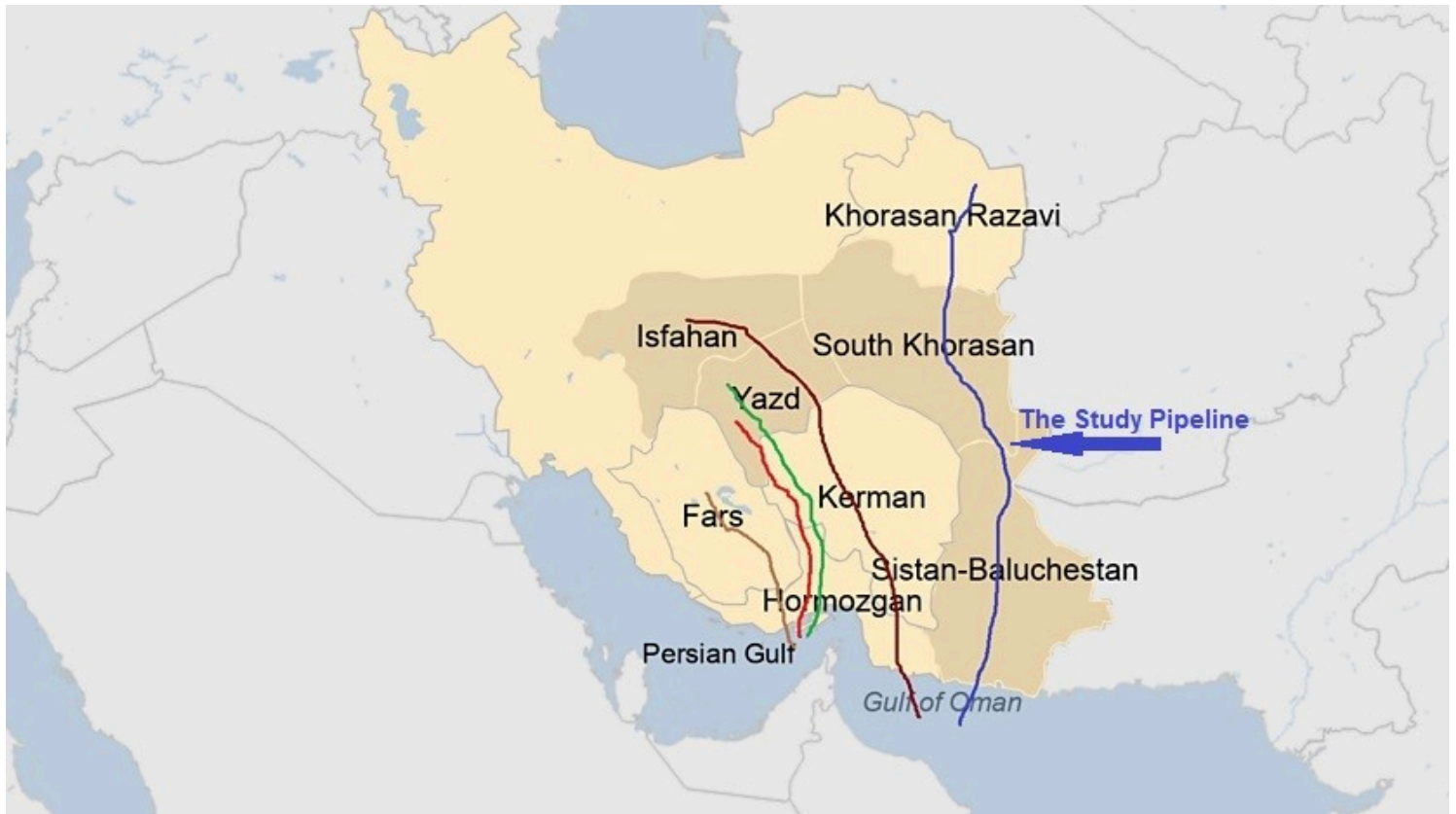


Figure 1

Government's Sea Water Transfer Project Pipelines. **Pipeline 1:** This line is aimed at supplying water to the southern Fars Province; **Pipeline 2:** This line is aimed to transfer water from Hormozgan to Kerman and Yazd; **Pipeline 3:** This Project is complete and pipeline of 826 km transfers water from the west of Bandar Abbas in Hormozgan Province to Kerman and Yazd Provinces; **Pipeline 4:** This line is planned to transfer desalinated water from the Oman Sea to industries and households in Central Isfahan Province; **Pipeline 5:**)Case Study) This line is known as the east Corridor and planned to transfer water from Oman sea to Sistan and Baluchestan and South Khorasan and Khorasan Razavi (totally 1790 km) mostly for household usage (BBC Monitoring 2022a).



Figure 2

Potential Environmental Impacts of Sea Water Desalination and Transfer Projects in Iran (BBC Monitoring, 2022b).



Figure 3

Water accumulated behind the Mashkid-e Olya Dam

(After: Chelvarforoush et al. forthcoming)

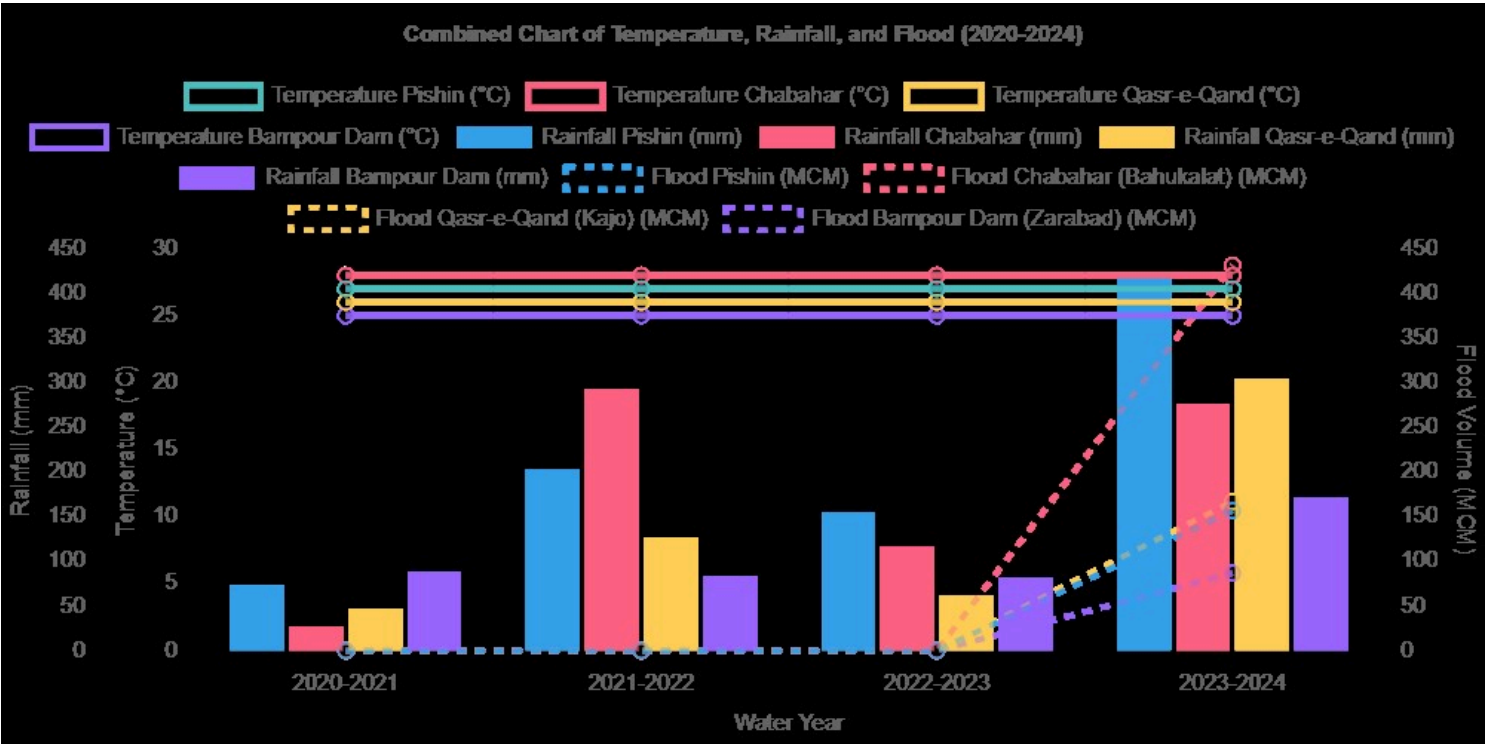


Figure 4

Combined Chart of Temperature, Rainfall, and Flood in Baluchestan Stations (2020-2024), with raw data obtained from the Sistan and Baluchestan Regional Water Joint-Stock Company (2024) for rainfall and flooding, and the Sistan and Baluchestan Meteorological Organization (2024) for temperature.

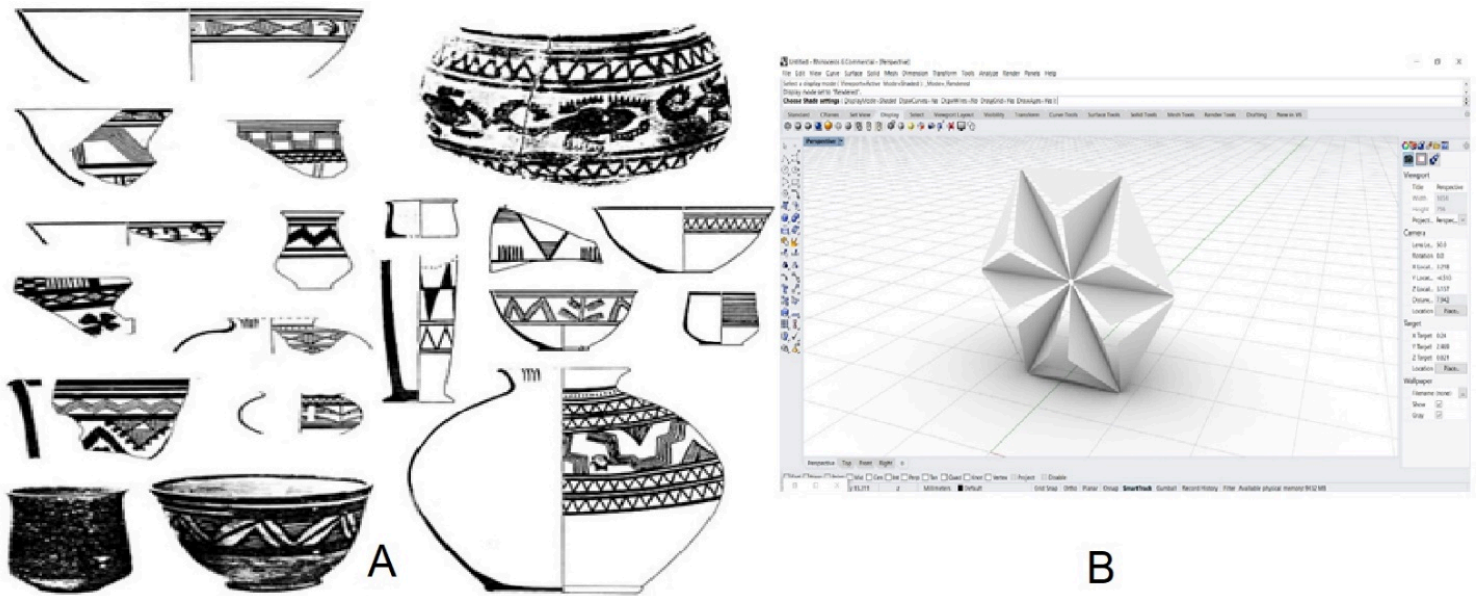


Figure 6

A. Design concept of the hexagonal skin inspired by ancient pottery motifs from the Bampur region, featuring a combination of rhombus and triangular geometries. **B.** Algorithmically generated adaptive surface developed using Rhinoceros and Grasshopper, showing variable pore dimensions for intelligent floodwater regulation in the Qanat system (After: Ebrahimi et al., Forthcoming).

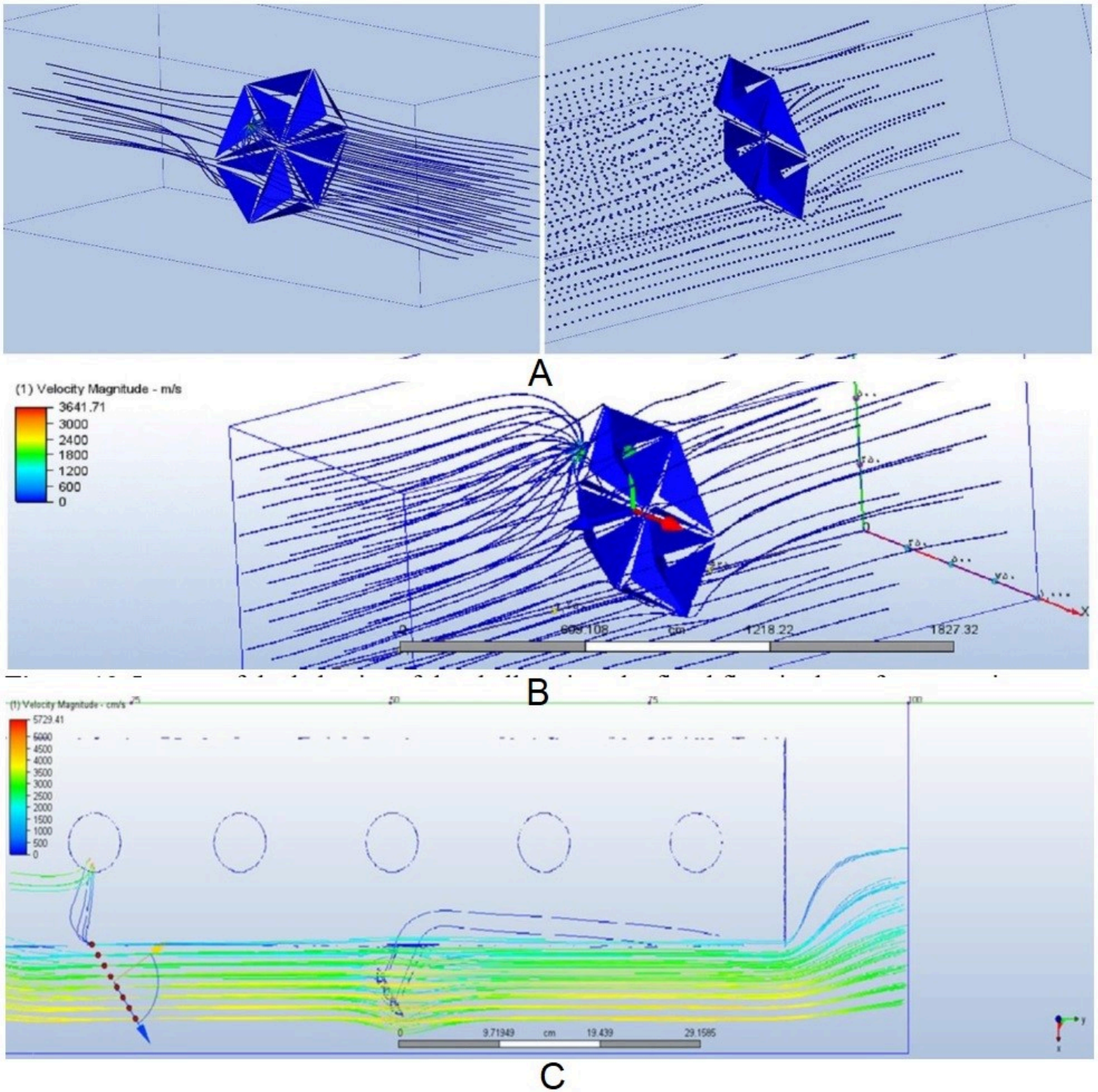


Figure 7

A & B. Visualization of the shell's performance under simulated flood flow conditions in the digital modeling environment; **C.** Performance of the shell structure under flood flow conditions (After: Ebrahimi et al., Forthcoming).

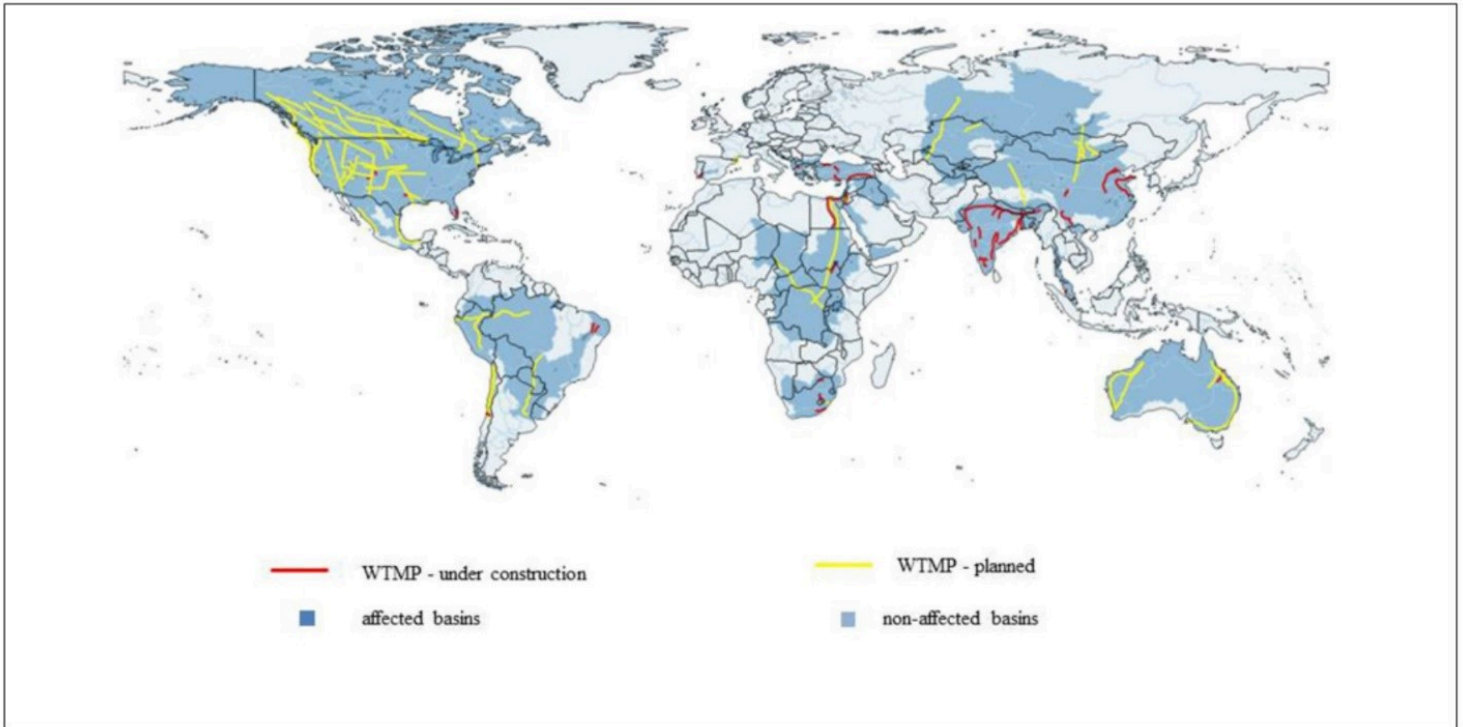


Figure 8

Geographic distribution of future Water Transfer Megaprojects (WTMP) under construction (red lines) and planned (yellow lines) across major global river basins. Dark blue shading indicates basins significantly affected by water transfers, while light blue denotes basins not affected. Black lines represent international borders, emphasizing the transboundary scale and potential geopolitical implications of these projects (After: Shumilova et al., 2018: 5).