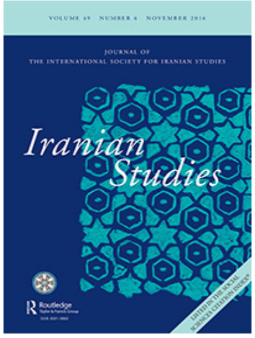

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Iran's Socio-economic Drought: Challenges of a Water-Bankrupt Nation

Iran is currently experiencing serious water problems. Frequent droughts coupled with over-abstraction of surface and groundwater through a large network of hydraulic infrastructure and deep wells have escalated the nation's water situation to a critical level. This is evidenced by drying lakes, rivers and wetlands, declining groundwater levels, land subsidence, water quality degradation, soil erosion, desertification and more frequent dust storms. This paper overviews the major drivers of Iran's water problems. It is argued that while climatic changes and economic sanctions are commonly blamed as the main drivers of water problems, Iran is mainly suffering from a socio-economic drought—i.e. "water bankruptcy," where water demand exceeds the natural water supply. In theory, this problem can be resolved by re-establishing the balance between water supply and demand through developing additional sources of water supply and implementing aggressive water demand reduction plans. Nevertheless, the current structure of the water governance system in Iran and the absence of a comprehensive understanding of the root causes of the problem leave minimal hope of developing sustainable solutions to Iran's unprecedented water problems.

Introduction

Iran enjoys a diverse topography and climate variability. Temperature can vary between −20 and +50 °C while precipitation varies from less than 50 mm to more than 1,000 mm per year. Iran's average annual precipitation is 250 mm (less than one-third of the global average) with most of the country receiving less than 100 mm of rain per year.

Iranians have been successful in coping with this natural limitation, establishing one of the world's oldest civilizations and sustaining life for thousands of years in a mostly arid to semi-arid region with limited water availability. This was done through the invention of ingenious water harvesting techniques, which made farming and food production feasible in a water-scarce region of the world in ancient times. The Persians' contribution to hydraulic engineering was not limited to the invention of

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qanat.[1] Ancient Iranians were successful in withdrawing, controlling and using water through a smart hydraulic infrastructure that included canals (*jouys*), clay pipes, arch dams, large gravity dams, water mills, flood control structures, ice houses and water storage tanks.[2] The technical innovations were combined with the development of some of the world's oldest water regulation, metering, marketing and conflict resolution systems to establish the appropriate socio-economic and regulatory setting for effective management of an essential resource for millennia.

Today's Iran, however, is facing unprecedented water problems. Drying lakes and rivers, declining groundwater levels, land subsidence, deteriorating water quality, desertification, soil erosion and dust storms are the modern problems of a nation which was once one of the world's pioneers in sustainable water management. Madani provided a detailed review of the current status of water resources in Iran and identified three major causes of the problems, namely rapid population growth and inappropriate spatial distribution of population; an inefficient agriculture sector; and mismanagement and thirst for development.[3] This paper complements that study, providing a closer look at the main drivers of Iran's water problems and identifying some of the challenges that the country is facing in solving such problems in a timely manner.

Drivers of Iran's Water Problems

1. Rapid population growth. The socio-economic improvements of Iran in the twentieth century were accompanied by significant population growth. By the time of the Islamic Revolution of 1979, Iran's population had increased from less than 10 million to more than 35 million. The change in the age distribution of the population alongside the ideological, socio-economic and cultural changes after the Revolution caused another serious population boom, which more than doubled the population in just two decades. A simple by-product of a rapid population growth is a commensurate increase in water demand and a drastic decline in per capita water availability. Iran's current per capita water availability is slightly above the average in the Middle East and North Africa (MENA) region (1,300 m^3), but well below the global average (7,000 m^3).

Iran's population, currently estimated at 77 million, has not increased significantly in the twenty-first century. Despite the water management challenges created by population growth the government is interested in increasing the current population growth rate of 1.3 percent due to major concerns about the future national age distribution.[4]

2. Migration and urbanization. The spatial distribution of population in Iran is perhaps a more concerning issue than its population growth. Most parts of the country suffer from a mismatch between water availability and demand.[5] Water delivery and management becomes more challenging in the absence of small and medium-sized cities. The economic inequalities, job opportunities and better living conditions in urban areas have boosted urbanization and encouraged migration from rural areas and small cities to major metropolitan areas, such as Greater Tehran, which hosts 18 percent of the country's population.

Currently, 70 percent of Iran's population is urban. The existing spatial distribution and increasing concentration of population in larger cities that are already struggling to satisfy their current water demand have created major water supply and distribution issues in urban areas. Alerts about the risk of water supply rationing during summer months are common in larger cities. Nevertheless, these cities have managed to supply urban water with no major disruption in recent years.

3. Inadequate water distribution infrastructure. At the national level, 6–7 percent of water in Iran is used in the domestic sector. Ninety-nine percent of the urban population and 75 percent of its rural population have access to clean tap water. Average daily consumption of water is estimated at 250 liters per person (twice the global average) and can reach up to 400 liters in some cities (e.g. Tehran). The increasing knowledge about the current water issues in the country has not led to sufficiently reduced water consumption by the urban population. This is mainly due to the relatively low price of water in Iran which does not provide any water conservation incentives for consumers.

The coverage of Iran's water supply system is generally good, especially in urban areas. Nevertheless, water distribution network leakages can be quite significant ranging from 15 to 50 percent in urban areas[6] because of aging water distribution infrastructure, prohibitive repair and maintenance costs, and the complexity of maintenance operations in populous areas. Given the high costs of water transfer, treatment and distribution, the network losses[7] are economically significant.

4. Water quality degradation. Iran's tap water is generally of a high quality and is good for drinking. But there is a growing concern about water quality in urban areas due to discharge of domestic, agricultural and industrial wastewater into urban water sources. Public concerns about high levels of nitrate in drinking water in urban environments such as Tehran are overwhelming, despite its unproven health effects, except for blue-baby syndrome,[8] specific to infants. Use of bottled water is increasing due to the public concerns about the quality of tap water, although appropriate mechanisms are not in place to regulate and monitor bottled water quality —an issue that is not unique to Iran.

Water quality degradation is one of Iran's overlooked water challenges. Gradual discharge of agricultural, municipal and industrial effluent into surface and groundwater can be associated with serious health effects. Despite recent investment in the wastewater sector and major international loans to improve this, on average less than 40 percent of urban populations are served by municipal wastewater collection systems. The capacity of existing treatment plants is insufficient and treatment levels are very limited due to high costs. Illegal dumping of industrial wastewater and the absence of proper wastewater treatment and disposal technologies in the industrial sector, which uses up to 2 percent of the water at the national level, further increase water pollution and the associated health risks.

Farming chemicals, fertilizers and pesticides constitute an additional source of contamination for surface and groundwater in the country. Groundwater drawdown has also resulted in deteriorating groundwater quality that has limited farming capacity in many areas. Using polluted water and untreated wastewater for farming in the vicinity of areas with high population concentrations has health implications due to the risk to the food chain.

5. *Inefficient agriculture*. The agricultural sector uses up to 92 percent of Iran's water.[9] Due to having an oil-based economy, Iran has overlooked the economic efficiency of its agricultural sector in its modern history.[10] The desire for increased agricultural productivity has encouraged an expansion of cultivated areas and infrastructure across the country. However, this sector is not yet industrialized and is suffering from outdated farming technologies and practices leading to very low efficiency in irrigation and production.

The agricultural sector in Iran is economically inefficient and its contribution to gross domestic product has decreased over time.[11] Irrigated agriculture is the dominant practice,[12] while the economic return on water use in this sector is significantly low,[13] and crop patterns across the country are inappropriate and incompatible with water availability conditions in most areas.[14] Recently, concerns about the embodied water content of produced and exported crops[15] have increased, but business still continues as usual as interest in crop choice by farmers is mostly correlated with crop market prices and their traditional crop choices in the area.

The claimed interest in improving the living conditions of farmers is inconsistent with their relative income, which has decreased over time due to increasing water scarcity and decreasing productivity. Forced migration from rural to urban areas has been observed in some parts of the country where farming is no longer possible. However, agriculture continues to play a major role in the country, providing employment to more than 20 percent of the population. This role will remain significant as long as alternative job opportunities are unavailable in other sectors such as services and industry. The recent turmoil in Syria underscores that a loss of jobs in the agricultural sector can cause mass migration, creating national security threats and serious tensions.

6. *The dream of self-sufficiency in food* . Food security has been an enduring challenge of the MENA governments. Limited water availability, high population and political instability make this region vulnerable to food shortages. Therefore, food security has always ranked high on the agendas of the MENA governments and the desire for self-sufficiency in food has been a common theme with dramatic impacts on water resources.[16]

Years of war with Iraq and economic sanctions after the 1979 Islamic Revolution made food security a more pressing challenge for the government. As a result, the interest in self-sufficiency in production of strategic staple crops such as wheat continued to increase after the Revolution, leading to heavy subsidies to expand the agricultural sector, causing excessive stress on the water sector. Not only have the plans for making the country self-sufficient in food production failed, but the aspiration to food security has actually triggered water insecurity. However, food security and self-sufficiency are still controversial topics in the country.[17] While many experts believe that Iran does not have the required capacity for becoming self-sufficient in food, there are serious concerns about making the nation dependent on food imports.

7. Rising water demand. Water demand has continued to increase in light of chronic water scarcity. Rapid urbanization, migration to major urban areas, and land development necessitates a continuous increase in the water supply to keep up with the fast growing water demand in urban areas. The expansion of the agricultural sector and cultivated areas across the country has further increased the burden on the already stressed[18] water resources, which are now believed to be even less than had been previously estimated.[19]

The continuous increase in water demand is quite alarming. While it is hard to accurately estimate Iran's "peak water" use,[20] in the short run its water demand is expected to increase with rapid urbanization, the interest in expansion of its industrial sector, and the major efforts in identifying additional sources of water supply. Nonetheless, the physical scarcity of water is expected to eventually result in reaching the peak water, which will then force an increase in the economic efficiency[21] of water use.[22]

8. Cheap water and energy. Water is extremely cheap in Iran. In urban areas the relatively low price of water does not provide any meaningful incentive for water conservation. Water is nearly free in rural areas and in the agricultural sector. Therefore, water cost is never a limiting factor for agricultural activities and only the physical unavailability of water can limit farming.

Despite the recent increase in energy prices, energy has also been a relatively cheap resource in Iran. Although groundwater extraction requires considerable amounts of energy, the relatively cheap price of electricity or diesel does not make pumping costs prohibitive.

The populist actions of the government to support farmers have resulted in substantial subsidization of water and energy, although the country has not witnessed an improvement in the livelihood of farmers and agricultural productivity. While surface water is becoming scarcer and groundwater[23] is declining[24] across the country,[25] the government continues to pay significant subsidies, eliminating any conservation incentive for domestic, industrial and agricultural water users.

9. Dams. The asynchrony of the rain and irrigation seasons as well as the spatial mismatch between water-rich areas and regions with high water demand has been the main motivation for Iranians to put a tremendous effort into temporal and spatial flow regulation. Dams have been a popular tool for Iranian water engineers and managers to achieve the desired flow regulation capacity. An unusually wet period coupled with the desire for development after the eight-year war with Iraq encouraged a national interest in dam building. Iran managed to rank as one of the three top dam builders in the world while grappling with economic sanctions and recession. Iran is believed to have built more than 300 large and small dams in addition to having more than 100 dams under construction and another 300 dams under study.[26]

Aggressive dam building has not been free of consequences. Inundation of historic sites, human displacement, land use changes, sedimentation, eutrophication, major ecosystem damage and increased downstream development under the perception of increased water availability are among the well-known consequences of dam building in Iran as in other parts of the world.[27] During recent years, many of the dams have been empty for extended periods of time, calling their justification into question. The government has been blamed by the general public and many experts for the numerous dams built around the country as well as for the lack of comprehensive assessments of the environmental impacts of dam construction. As a result, dam construction projects are currently politically costly to justify, which has caused dam construction to lose momentum.

10. Deep wells. Iran uses a considerable amount of groundwater for irrigation to compensate for surface water deficit. Currently more than 55 percent of the total water demand is satisfied through groundwater pumping. Aggressive groundwater withdrawal has resulted in groundwater table decline[28] and degradation of quality in various regions. Nearly 50 percent of the plains across Iran are in critical condition. Consequently, land subsidence and sinkholes are plaguing the country because of unsustainable groundwater extraction.

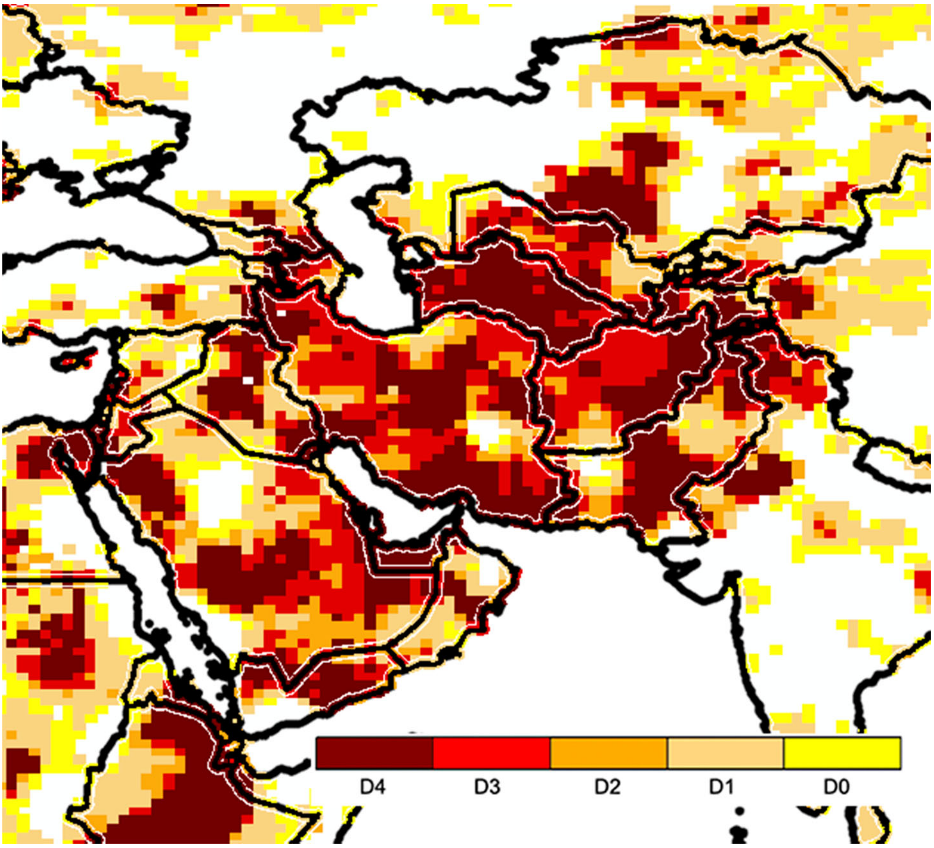
The popularity of deep wells in Iran increased after the introduction of pumping technologies and the land reforms[29] of Mohammad Reza Pahlavi in the 1960s.[30] The increased interest in deep wells and adoption of modern (western) water harvesting technologies made traditional water harvesting techniques less attractive. Many *qanat*s dried up and cooperative management institutions were replaced with fragmented, non-cooperative management systems[31] that promoted competitive pumping, creating a tragedy of the commons.[32]

Groundwater is used as a supplementary source of water when surface water is insufficient. Groundwater pumping increases when surface water becomes scarcer as a result of droughts or allocation of surface water to other uses and users. Hence, the increase in water demand and use over the years has resulted in increased groundwater pumping. Given the low price of energy, the costs of energy for pumping have not been a limiting factor. As wells run dry due to lower groundwater levels, farmers dig deeper wells and buy pumps with higher lifting capacities. The collective effect of such behavior has been drastic.

In theory, wells need to have permits, although in practice, unpermitted wells are ubiquitous. Thus, illegal pumping is another important issue that the decision makers need to deal with. This problem has no easy solution as illegal wells are generally hard to detect and monitor. The government has put serious effort into installing smart energy water meters[33] for better monitoring of groundwater withdrawal and the associated energy use. Nevertheless, this has not yet resulted in a major shift in the behavior of well owners in most parts of the country. The government claims to be vigorously pursuing its national groundwater restoration and balancing plan, which intends to stop and reverse the current trend in groundwater use.

11. Droughts. Iran's agriculture industry is highly sensitive to droughts and even short-term dry spells due to natural climatic conditions. Every 1 mm of rainfall below the historical climatic norm is estimated to cause around $90 million in losses.[34] The most extreme drought in the past decades occurred in 1998–2001 (Figure 1) when almost the entire country was affected, including 8 million hectares of agricultural lands.[35]

Figure 1. Spatial patterns of drought in mid-2000 based on the Multivariate Standardized Drought Index (MSDI)*

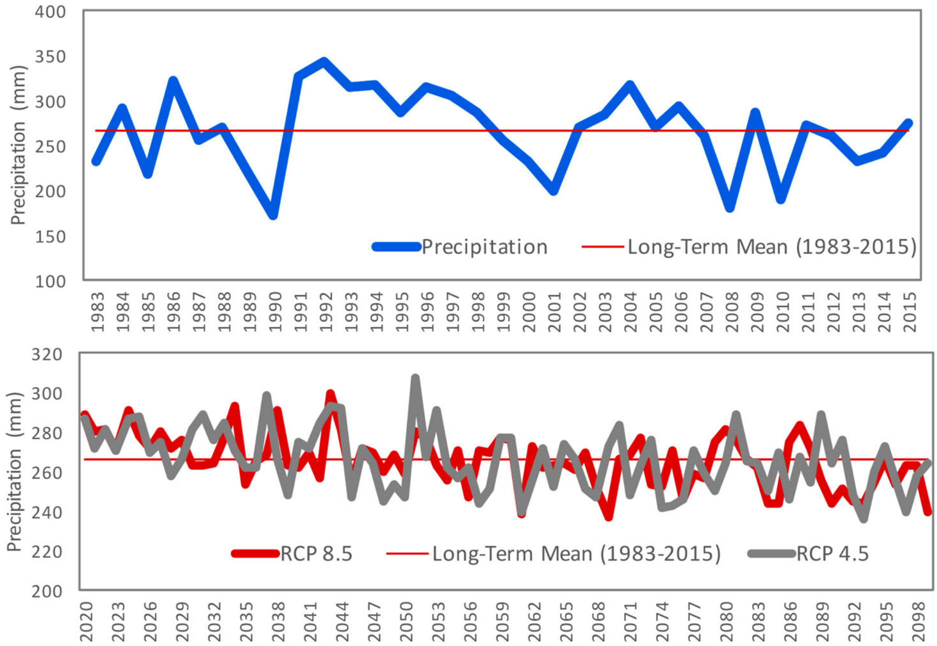


Notes: Most of Iran was in extreme and exceptional drought (D0: abnormally dry; D1: moderate drought; D2: severe drought; D3: extreme drought; D4: exceptional drought).
*Hao and AghaKouchak, "A Nonparametric Multivariate Multi-index."

Contradictory reports exist on droughts in Iran.[36] Satellite observations of precipitation over Iran do not indicate any significant change in droughts over most regions:[37] data for the entire country does not show a statistically significant trend.[38] However, some researchers have shown that while no statistically significant trend has been observed in the average precipitation of Iran over the past three decades, a significant drying trend has been observed in northern and northwestern Iran.[39] Likewise, there are reports[40] of increasing drought severity over parts of Iran.[41] Figure 2 (top) shows precipitation variability over the past three decades.

In recent years, however, Iran has experienced a multi-year drought (i.e. precipitation below the long-term mean as shown in Figure 2 (top), creating serious chal-

Figure 2. Satellite-based observed annual precipitation 1983–2015 (top); Precipitation projections based on ensemble means of multiple climate model simulations under two Representative Concentration Pathways 4.5 and 8.5 (bottom)



Source: http://rainsphere.eng.uci.edu/

lenges for water managers[42] and having major impacts on agricultural productivity and the groundwater extraction rate.

12: Floods. Drought is not the only water-related extreme climatic event that Iran is dealing with. The country is highly vulnerable to flooding, especially flash floods that occur over a very short period of time. On average, floods have killed more than 130 people every year while about 11 million people were affected by flooding incidents in the last two decades of the twentieth century. Floods can become more destructive with increased land development and reduced infiltration capacity of parched soils during rain events.

The Iranian provinces that are most affected by floods include Golestan, Mazandaran, Gilan, Khuzestan, East Azerbaijan and West Azerbaijan. Studies on extreme precipitation indicate a statistically significant positive trend in precipitation over parts of northeastern Iran.[43] In 2001, in just one single event, around 300 people perished in a flash flood in Golestan Province.[44] In the same region, sixty-four major floods occurred during 1990–2005, leading to significant damage and human casualties.[45] Diagnostic studies blame many of the recent flooding events on land use/cover changes and deforestation that have occurred as a result of growth and development.

13. Climate change. The extent of climate change impacts on Iran over the last decades is hard to estimate[46] but most studies project a warmer and drier climate for Iran[47] and the entire Middle East in the future.[48] The expected climate warming could intensify droughts and dry spells,[49] with major implications for agricultural production,[50] hydroelectricity generation,[51] reliability of water supply[52] and reservoir operations.[53]

Even though the extent of climate change impacts on Iran's water resources in the past is unknown (with a reasonable certainty level), climate change is a common element of the water dialogues of many politicians and experts in the country. Climate change is continuously blamed for the current water scarcity. When it comes to future projections, a drier and hotter Iran is a common narrative, which is consistent with the scientific projections (Figure 2, bottom).[54] Nevertheless, the severity of climate change impacts and the level of uncertainty in future projections are not well understood by the general public as well as by many decision makers and professionals.[55]

14. Thirst for development and incomplete hydraulic mission. Iran's push for rapid modernization has had major benefits for the country, including significant progress in infrastructure development, before and after the 1979 Revolution. The Iranians' "thirst for development" increased after the Revolution as Iran was trying to prove its independence to the world during an eight-year war with Iraq and under numerous international economic sanctions.[56] In the rush for infrastructure and technological development, less attention was paid to long-term environmental impacts.

Iran's thirst for development caused serious managerial myopia in the country,[57] whereby the main focus of the decision makers was on rapid development with the serious expectation of immediate economic benefits. Thus, the important linkage between "development" and "environment"[58] was largely overlooked, resulting in implementation of infrastructure and engineering projects that have seriously impacted or will negatively affect the wellbeing of both humans and natural systems in the long run.

Iran's "hydraulic mission"[59] is still ongoing. Despite the environmental and economic effects, the thirst for rapid technical and technological development (as opposed to sustainable development) is still the main driver of the country's development decisions. While dam construction is falling out of favor, Iran's interest in alternative technological solutions such as interbasin water transfer and desalination has been increasing. Recently, President Rouhani made announcements about massive water transfer projects from the Persian Gulf and Caspian Sea to central Iran.[60]

15. Sanctions and economic instability. Iran has been subjected to a series of economic sanctions following the Islamic Revolution of 1979. These sanctions were expanded following the adoption of Resolution 1696 by the UN Security Council in 2006[61] in relation to Iran's nuclear program.[62] While these sanctions have not directly impacted Iran's environment,[63] they have indirectly catalyzed some environmental impacts that will last through generations.[64]

Although most of Iran's water problems are non-technological, the lack of access to state-of-the-art water technologies and scientific exchanges at the international level limited Iran's technical capacity[65] to solve some of the problems in its water sector. In addition, the economic and political instabilities caused by international sanctions increased the decision makers' interest in populist development actions[66] that could produce immediate and noticeable economic impacts.[67]

The agreement over Iran's nuclear program, also known as the Joint Comprehensive Plan of Action (JCPOA) or Iran Deal, and the gradual lifting of sanctions are believed to be helpful in rebuilding Iran's deteriorating environment[68] by giving the country better access to international technology, scientific exchanges and foreign investments.

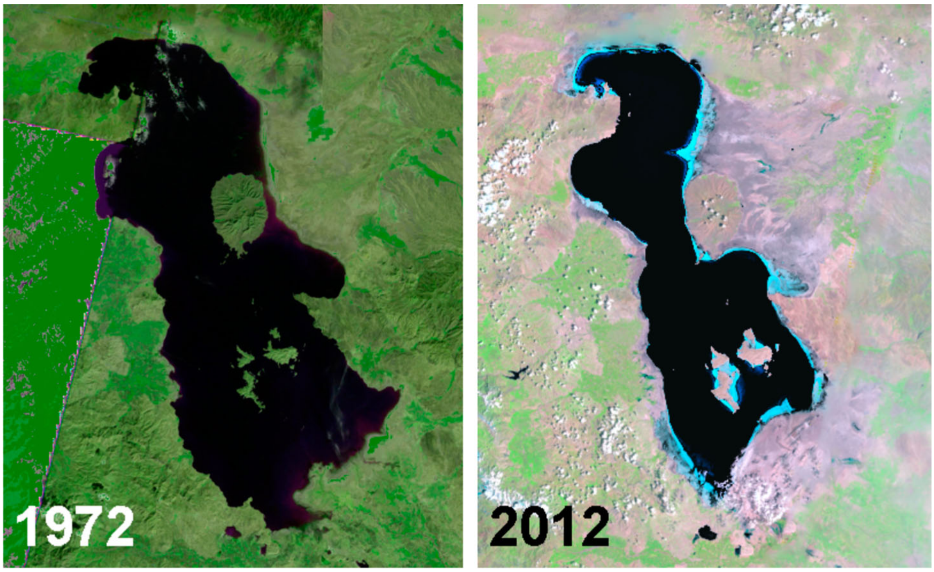
16. Improper water governance structure. Iran's water resources suffer seriously from an improper water governance structure. Within the water sector, multiplicity of stakeholders and regulators is naturally associated with conflicts and competition. The Department of Environment, responsible for safeguarding the country's environment, has limited political power and lacks the required regulatory capacity to prevent environmental damage. The institutional water management reforms by President Ahmadinejad that resulted in a change of water management jurisdictions from watershed-based boundaries to political (provincial) boundaries have further complicated water management in Iran. These reforms have led to additional competition among riparian provinces and conflicts over water allocation in trans-provincial river systems.[69]

The hierarchical structure of the water management system in Iran creates opportunities for corruption and causes serious inefficiencies in turning decisions into action. Lack of coordination among parties is not limited to the water sector only. The water sector suffers from major problems that are rooted in other sectors (e.g. rapid urbanization). Lack of coordination amongst the parties and focus on projects with short-term visible benefits have resulted in disintegrated and unsustainable water management. The long-term effects of decisions and the possible unintended consequences are generally neglected. Problem prevention is not the main focus and challenges remain unaddressed as long as they do not receive a "crisis" label and the situation is not critical. Given that serious environmental damage can be irreversible, the "crisis management" paradigm results in damage that cannot be mitigated or that is very costly to repair.

17. Environmental unawareness. Environmental awareness in Iran is generally low but has increased significantly in recent years. This seems to be mainly due to multiple massive environmental problems across the country such as the shrinkage of Lake Urmia as well as the frequent occurrence of different tangible environmental challenges such as droughts, air quality issues in major cities, dust storms and the extinction of some endangered species. The Lake Urmia tragedy (Figure 3) can be considered a turning point in Iran's environmental history. The scale of the problem was so significant that it drew the attention of the government and public to the possible tragic environmental impacts of unsustainable development.

The government is now pursuing the incorporation of the topic of the environment into study curricula at both university and K-12 levels. Environmental NGOs have also been active in raising environmental awareness and attention to environmental matters. Social media have had a major role in educating the public and sharing infor-

Figure 3. Substantial reduction in the area of Lake Urmia over the past decades due to growth-oriented development plans, inefficient agricultural practices, and aggressive upstream water storage and diversion in addition to some climatic variabilities



Source: modified after AghaKouchak et al., "Aral Sea Syndrome Desiccates Lake Urmia."

mation on environmental and water issues.[70] Iran's public media now cover more environment-related stories and frequently interview experts and decision makers on environmental issues, especially on problems related to the water sector. Iranian decision makers now recognize water scarcity as a national security problem. The Iranian leaders and political figures have reacted to the country's environmental problems[71] and environmental issues have found a more serious place in the election campaigns of politicians.[72]

However, the level of environmental awareness in Iran is not yet high enough to result in a major shift in the environmental behavior of the public.[73]

Natural or Anthropogenic?

Natural climate variabilities, climate change, droughts and economic sanctions have had undeniable impacts on Iran's water resources. Yet Iran's water problems are mostly man-made and the product of decades of poor management caused by lack of foresight, uncoordinated planning and the wrong perception of development. Iran is, indeed, suffering from a socio-economic drought[74] caused by aggressive development which has resulted in water demand being far greater than the available water supply of the country, i.e. a state of water bankruptcy.

Instead of rigorous water conservation efforts, Iran is still focused on structural solutions that can increase water supply. Despite the failure experienced in solving water shortage problems through water transfer in the case of Zayandeh-Rud,[75] water transfer projects are becoming more popular. Similarly, massive desalination projects are gaining popularity even though they are associated with high environmental and economic costs while reduced water consumption and increased efficiency in water use can be achieved at a significantly lower cost.

Iran requires a shift from the "nature control" paradigm to the "nature management" paradigm[76] and reduced reliance on structural and technological solutions. This is only achievable if the decision makers realize that they have limited ability to control nature in order to maximize economic benefits.[77] Without recognizing the inadequacy of technological water supply-oriented solutions and the major role that humans have played in causing and exacerbating Iran's water scarcity, i.e. the "anthropogenic drought,"[78] the country's efforts at solving its water problems are bound to fail.

Conclusions

Iran's current water problems have been formed over decades and cannot be solved immediately. Much of the damage to the country's water and ecosystem are irreversible within a short period of time. Thus, in addition to damage prevention and restoration efforts, serious investment is needed to prevent similar problems across the country. This requires proactive management of water resources rather than the existing "crisis management" style that tends to tackle problems only when they have become too overwhelming to solve.

Complex problems require complex solutions. No single solution will "fix" Iran's water problems. Iran has many interrelated water challenges with complicated root causes. To solve these issues, it is necessary to adopt a portfolio approach that involves implementing multiple concurrent strategies (Figure 4). Since some of the root causes of Iran's water management problems are outside its water sector, coordination among multiple sectors[79] and stakeholder engagement are essential to developing sustainable solutions.

The most effective solutions to Iran's water problems (Figure 4) are long term and they are economically and politically costly to implement. This makes these solutions less attractive to the decision makers who need a proven record of positive and noticeable impacts for the extension of their service term.[80] Similar to environmental damage, most environmental benefits take a long time to become apparent. Therefore, unless there is a change in public opinion regarding pro-environment actions and policies, Iran's water management will continue its inertia and will not pursue radical changes in its solutions and regulations. Extreme events leading to increased pressure and public awareness can reduce the political cost of radical regulatory changes.[81] Thus, while extreme events and crises are destructive and costly in the short term, they can have long-term benefits if the system under management does not collapse before reforms are applied.

Figure 4. Iran's water solutions package

- Revisiting the new population growth policy, paying careful attention to the spatial distribution of population and limiting urbanization growth rate
- Modernizing agriculture and empowering farmers and rural communities
- Revising the crop pattern across the country with respect to national food security priorities as well as regional resource availability and economic efficiency conditions
- Increasing the water and energy prices together with technological improvements to prevent socio-economic pressure on rural and farmer communities
- Promoting and developing regional farming cooperatives and water management institutions
- Implementing water markets and setting up environmental water accounts
- Shifting from reactive to proactive management of the water sector
- Optimizing the distribution of water management efforts to solve the existing water problems and to prevent emerging ones
- Reorganizing the current water governance structure and empowering the Department of Environment
- Raising environmental awareness and educating the public

Source: After Madani, "Water Management in Iran."

The political cost of change in the current water governance system and regulations is high but the long-term costs of business as usual are much higher for the country. So Iran must pay for sustainable water management today or it must expect to pay significantly more for its unsustainable management in the near future. Iranian decision makers need to realize that Iran is water-bankrupt and is suffering from a socio-economic drought. Thus, unless major efforts are directed at reduction of the country's water demand, further deterioration of water resources should be expected.

Notes

1. A *qanat* system comprises a series of well-like vertical access shafts connected through a gently sloping hand-dug underground channel that is used to extract and transport groundwater in arid areas.
2. Ice-house (*yakh-chawl*) and water storage tank (*ab-anbaar*) systems were used not only for ice/water storing but also for cooling buildings. Gholikandi et al., "Water Resource Management."
3. Madani, "Water Management in Iran."
4. Madani, "Iran's Looming Water Crisis."
5. Madani Larijani, "Iran's Water Crisis."
6. Rahimpour, "Optimization of Leakage."
7. Also known as unaccounted water in Iran.

8. Blue-baby syndrome or methemoglobinemia is the main known effect of exposure to high levels of nitrate in drinking water. High levels of nitrate in blood can decrease its oxygen carrying capacity, leading to death in infants.
9. Allocation of a high proportion of water to the agricultural sector is common in arid and semi-arid areas if irrigated agriculture is a desirable practice. For example, the state of California in the US uses 80 percent of its water in the agricultural sector.
10. Katoutzian, "Oil versus Agriculture"; Madani, "Iran's Looming Water Crisis."
11. The current contribution of the agricultural sector to GDP is estimated to be around 10 percent.
12. It is argued that Iran has not fully utilized its potential for rain-fed agriculture and dryland farming, which can help reduce the water use for agriculture.
13. In theory, the economic efficiency of water use in Iran can be increased by transferring from agriculture to industry, once the industrial sector is expanded.
14. Rice is a good example of a crop which is unsuited for central Iran with limited water availability, but it continues to be grown.
15. Virtual water, embedded water or embodied water of food refers to the amount of water used during production of food. The embedded water of some crops like watermelon, which was recently a popular exported crop, has been a subject of controversy in the country. Due to the high water use of watermelon and its relatively low price, many believe watermelon exports should be stopped, as it results in high volumes of water being virtually exported. See Allan, "Virtual Water."
16. Saudi Arabia's determination to become self-sufficient in wheat production is a classic example of a short-sighted food security plan that resulted in a rapid depletion of groundwater in the country.
17. Food security is currently being promoted by some experts and government officials as a replacement for food self-sufficiency, implying that through appropriate policies the country can become food secure without a need to be self-sufficient in food production.
18. Iran is using more than 70 percent of its renewable freshwater supplies. This rate is far above the safe rate of using renewable freshwater supplies, which is recommended by some scholars to be set below 40 percent for sustainable water use. See Brown and Matlock, "Review of Water Scarcity Indices."
19. Iran's total renewable freshwater supply had been previously estimated to be 130 billion cubic meters per year. Recently, Iran's Ministry of Energy (in charge of water supply operations and allocation) has announced that the annual renewable freshwater supply of the country is less than 100 billion cubic meters.
20. The maximum amount of water Iran has ever used or will ever use throughout history.
21. Considering the opportunity costs, increased economic efficiency can be gained through transfer of water from the agricultural sector with lower economic return to urban, industrial and service sectors with higher economic return (or shortage costs), as well as transferring water from low value crops to high value crops within the agricultural sector.
22. In addition to increased water use efficiency resulting from urbanization and industrial growth, rising environmental awareness in Iran can facilitate reductions in water consumption and increased allocation of water to the environment.
23. A recent study in California shows that increased groundwater pumping due to unavailability of surface water resources can increase energy use and greenhouse gas emissions. See Hardin et al., "California Drought."
24. The groundwater table declines when the amount of groundwater withdrawal from the aquifer is more than its natural recharge.
25. A decline in groundwater level increases the energy need for pumping exponentially, which leads to a substantial increase in the cost of energy subsidies for the government. See Madani and Dinar, "Exogenous Regulatory Institutions."
26. The exact number of dams (built and under construction) in Iran is not clear as various figures have been reported by different authorities and experts.
27. Madani, "Water Management in Iran."

28. Decline in groundwater level has also affected surface water availability in many regions due to the natural connection of surface and groundwater. This effect has been mostly overlooked and less studied.
29. Land reforms were implemented as part of Mohammad Reza Pahlavi's White Revolution in 1963 which intended to abolish feudalism. Land ownership was transferred from influential feudal landlords to peasants, representing 40 percent of Iran's population at the time.
30. Madani, "Reasons behind Failure of Qanats."
31. Madani and Dinar, "Non-cooperative Institutions"; Hardin, "Tragedy of the Commons."
32. The tragedy of the commons refers to a situation within a shared resource system where individual users acting independently based on self-interest (individual rationality) behave contrary to the common good of all users (group rationality) by depleting that resource through their collective action. In case of groundwater, tragedy of the commons happens when users extract water from their wells independently, leading to depletion of the aquifer, with a high cost for all users. See Hardin, "Tragedy of the Commons."
33. Smart energy water meters measure groundwater withdrawal by monitoring the energy use of electric pumps. See Moazedi et al., "Energy-Water Meter."
34. Ghaffari, "Drought Impacts on Rainfed Field Crops."
35. In this unique extreme event, most of the country was in extreme and exceptional drought based on the combined soil moisture and precipitation conditions. See Darvishi et al., "Risk and Disaster Management"; Golian et al., "Trends in Meteorological and Agricultural Droughts."
36. The contradiction is partly due to using different sources of data (e.g. gauge vs. satellite data), quality of observed/measured data, and in some cases statistical manipulation of data.
37. Damberg and AghaKouchak, "Global Trends and Patterns of Drought."
38. This has been tested at the 95 percent significance level using the commonly used Mann-Kendall trend test.
39. This is based on reanalysis data. See Golian et al., "Trends in Meteorological and Agricultural Droughts ."
40. This study bases its judgments on the Palmer Drought Severity Index (PDSI).
41. Zoljoodi and Didevarasl, "Evaluation of Spatial-Temporal Variability."
42. Some decision makers mainly attribute the country's water problems to droughts during last decades However, this is not scientifically founded.
43. Tabari and Talaee, "Temporal Variability of Precipitation over Iran."
44. Tabari et al., "A Perturbation Approach"; Panahi et al., "The Effect of the Land Use."
45. Sharifi et al., "Causes and Consequences of Recent Floods."
46. This is mainly due to the inability to accurately disaggregate the regional anthropogenic effects (resulting from human activities and development in the region) from the global climate change impacts.
47. The level of uncertainty in climate projections is very high. Different general circulation models (GCMs) provide different predictions about the different parts of Iran and the difference in their projections increase toward the end of the century. At this point in time, it is hard to tell which parts of Iran will experience decreased or even increased precipitation. But all models agree that in the future Iran will be warmer. As our knowledge improves, our projections of future climate are expected to become less uncertain.
48. Dai, "Increasing Drought under Global Warming"; IPCC SREX, "Managing the Risks of Extreme Events"; IPCC, "Climate Change 2007."
49. AghaKouchak et al., "Global warming."
50. Gohari et al., "Climate Change Impacts."
51. Jamali et al., "Climate Change and Hydropower Planning."
52. Davtalab et al., "Evaluating the Effects of Climate Change."; Gohari et al., "Adaptation of Surface Water".
53. Gohari et al., "System-Dynamics Approach."

54. Figure 2 (bottom) displays Iran's precipitation projections (2020-99) based on the ensemble means of multiple climate model simulations under two commonly used future emission scenarios known as Representative Concentration Pathways (RCP) 4.5 and 8.5. Both scenarios exhibit statistically significant downward trends (tested at 95 percent significance level using the Mann-Kendall trend test).
55. The described effects of climate change in the future are sometimes exaggerated or have no scientific basis. For example, media, experts and even government officials have reported that the US National Aeronautics and Space Administration (NASA) has projected a thirty-year drought for Iran, although this cannot be scientifically verified.
56. Madani, "Water Management in Iran."
57. Madani, "Water Crisis in Iran."
58. This linkage is known to be very important in coupled human-natural systems. Understanding this linkage is, indeed, essential to sustainable water resources management. See Hjorth and Madani, "Frames and mental models for sustainable water management;" Hjorth and Madani, "Systems Analysis."
59. The hydraulic mission is the era of engineers, when technological water supply-oriented strategies are most popular. Many developed countries (e.g. the US) have already gone through this era when the dominant thinking is that water scarcity could be solved through structural (hardware) solutions.
60. Mirchi and Madani, "Grand but Faulty Vision."
61. Resolution 1696 was passed by the United Nations Security Council on 31 July 2006 and imposed sanctions on Iran after it refused to halt its uranium enrichment program to address the expressed concerns about its intentions.
62. Farhidi and Madani, "Game Theoretic Analysis."
63. Decision makers continuously blame sanctions as one of the main causes of Iran's environmental degradation. Nevertheless, the short-term and direct impacts of sanctions on Iran's environment have been exaggerated.
64. It is also argued that the indirect environmental damage from sanctions might even impact its neighboring counties. See Soroush and Madani, "Every Breath You Take"; Madani and Hakim, "Iran: Reversing Environmental Damages."
65. It is noteworthy that despite this limitation, Iran was more successful than most nations in maintaining its independence and relying on national expertise under serious economic sanctions. See Foltz, "Iran's Water Crisis"; Madani, "Water Management in Iran."
66. Madani, "Water Management in Iran."
67. In addition to the effects on the management side, economic instabilities and high inflation can justify short-term benefit maximization and more aggressive use of water resources by farmers. See Madani and Dinar, "Cooperative Institutions for Sustainable."
68. Lewis and Madani, "End of Sanctions."
69. Madani et al., "A New Framework."
70. It must be noted that part of the social media information on environmental issues has no solid basis and this can be considered as a negative aspect of information exchange on social media. But this aspect is minor in comparison to the positive impact of information sharing on environmental education and awareness.
71. Mirchi and Madani, "Iran's Leaders React."
72. Mirchi and Madani, "How Iran's Elections."
73. Even in urban areas with higher education levels and better access to media, one can find many instances of waste or improper use of water such as washing cars, watering lawns during the day and hot hours, washing streets and sidewalks.
74. Socio-economic drought refers to a situation in which the available water supply is not sufficient to meet the total demand. See Mehran et al., "Hybrid Framework for Assessing."
75. Studies of water transfer to Zayandeh-Rud river basin in Iran prove the inadequacy of water transfer as a fix to water shortage problems. See Madani and Mariño, "System Dynamics Analysis"; Gohari et al., "Water Transfer as a Solution." In addition to creation of some environmental and socio-economic issues in the donor basin, water transfer can result in a perception of increased water availability

in the recipient water basin, See Madani Larijani, "Watershed Management and Sustainability"; Mirchi et al., "Synthesis of System Dynamics Tools." The latter motivates further increase in development and migration to the recipient basin leading to subsequent water shortages. See Mirchi et al., "Modeling for Watershed Planning." If selected as a solution, water transfer must be accompanied by water demand reduction and conservation strategies that can limit water use in the recipient basin. See Madani, "Towards Sustainable Watershed Management."

76. Madani, "Water Management in Iran."
77. Madani et al., "The Next Step."
78. AghaKouchak et al., "Water and Climate."
79. For example, alternative job opportunities can be created for the farmers through industrial growth in the country. Those in charge of water are not in charge of the major decisions in relation to industrialization. Similarly, the water sector can benefit from strategies related to controlling urbanization growth and land use planning which are both out of the control of water managers of the country.
80. Bruce and Madani, "Successful Collaborative Negotiation."
81. The recent governor orders in California during its major drought (e.g. stricter monitoring of groundwater use and mandatory cutback of water use in urban areas) prove that some regulatory changes can be made during extreme events while the political cost of such changes make them profitable at other times.

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