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ORIGINAL PAPER

Investigation and classification of water resources management strategies: possible threats and solutions

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Abstract
The scarcity of global water resources has been exacerbated by a variety of factors, including population growth, the impacts of climate change, and mismanagement. Policymakers face a challenge in managing tradeoffs between human water demands and maintaining the world's water resources. This study investigates water resource management strategies using Iran's example, a country in the Middle East with arid and semi-arid climate. A review of water resources management strategies in Iran shows the country's policies leaned more on short-term solutions. Short-term water management addresses immediate shortages and emergencies, implemented during droughts and water scarcity, while long-term strategies reduce water demand by addressing underlying drivers and involve significant investments and planning horizons. Iran has focused on implementing short-term solutions to address the effects of water scarcity on food and water security. This work shows that short-sighted water policies such as the large-scale use of water resources and water transfers may cause adverse impacts, among those land subsidence due to groundwater withdrawal and environmental degradation. It is worth noting that such short sighted water policies do not constitute sustainable solutions to water scarcity. On the other hand, water policies that seek long-term sustainability are frequently ignored by policymakers. The latter water policies are herein evaluated for the purpose of increasing water supply. Strategies such as improving water consumption patterns and setting reasonable water pricing can contribute to remedy the water crises in arid countries like Iran. An overview of case studies is presented and assessed to illustrate the effectiveness of long-term, sustainable, water supply policies.

Keywords Water resources management · Water scarcity · Virtual water · Water pricing · Citizen science · Land use · External cultivation · Consumption management · Waste management

Extended author information available on the last page of the article

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1 Introduction

About 97% of the world's water is saline, mainly found in the oceans. The remaining 3% is freshwater, of which glaciers, groundwater, and surface water account for 69%, 30%, and 1%, respectively (Bozorg-Haddad et al., 2018). Inadequate water resources management, community development, population growth, and uneven temporal and spatial distribution of water resources place growing stress on limited freshwater resources. The increasing stress has created water scarcity in some countries (Bozorg-Haddad 2018).

Water scarcity has risen rapidly during the last century, with studies showing that around 47% of the global population experiences water scarcity at least one month every year (Mekonnen and Hoekstra 2016). It is projected that by 2050 the world population will reach 9.7 billion, and the percentage of people dealing with water scarcity will be more than half (57%) the world population (Boretti & Rosa 2019). However, there is uncertainty involved in the forecasts made. Climatic and societal changes are projected to exacerbate water scarcity in many world regions in the coming decades. It is estimated that between 91 and 96% of people living under water stress conditions will be in Asian countries, while between 4 and 9% will be in Africa (Burek et al. 2016; Loaiciga and Doh 2024).

An ongoing policy debate about water scarcity focuses on identifying practical actions to address the water scarcity challenges in the presence of significant uncertainties. Greve et al. (2018) analyzed uncertainties in global water scarcity projections for the first half of the twenty-first century using a probabilistic approach. They concluded that ranges of uncertainty and levels of median water scarcity are on the rise. However, policymakers are not taking into account challenges related to water scarcity. On the contrary, countries beset by water scarcity that hinders their economic development have increased their surface water and groundwater use.

Iran is one such country, where various studies reported average annual water consumption is about 80% higher than the scarcity threshold level of the country, which is a parameter that defines the absolute maximum amount of water that can be used sustainably in a country (Mesgaran and Azadi 2018). Iran is a country with a dry and semi-arid climate beset by mismanagement of surface water and groundwater resources, declining rainfall (by 58% in recent years compared to the long-term historical average) (Vaghefi et al. 2019), and the resultant reduction in runoff and groundwater recharge, and by population growth and concomitant increased water use.

Ashraf et al. (2019) studied the compounding effects of climate change on the availability of surface water resources in Iran over the twenty-first century. To achieve this, long-term data on surface water withdrawal were combined with climate model projections. Their approach allowed for the quantification of the interplay between water use, climate variability and climate change on a regional scale. They predict that water stress in Iran is likely to persist or even worsen over the next few decades. This is due to the projected variability and change in precipitation patterns, which will likely lead to a further reduction in surface water availability, combined with the anticipated increase in water withdrawals due to the growing population and socio-economic activities.

Another study by Ashraf et al. (2021) investigated similar factors in relation to groundwater resources in Iran. Using publicly available average monthly groundwater level data in 478 sub-basins and 30 basins in Iran, they were able to quantify country-wide groundwater depletion in Iran for the period of 2002–2015, estimating that the total groundwater depletion in Iran to be about 74 km^3 during this period. Meteorological and hydrological droughts exacerbate the rate of depletion in country-wide groundwater storage in Iran.

However, the primary cause of basin-scale groundwater depletion is attributed to excessive human water withdrawals, such as the unsustainable groundwater management practices in Iran that significant threats to the country's water, food, and socio-economic security, potentially leading to irreversible environmental impacts.

It has been suggested that Iran's agriculture is the main reason behind high water consumption, and the government's policy to increase irrigation productivity through modern irrigation systems has been insufficient to accomplish what must be done. In addition, food self-sufficiency from national production has been a primary political goal in Iran, which inevitably leads to higher pressure on water resources and other severe problems such as soil degradation (Ashraf et al. 2019; 2021; Yazdanpanah et al. 2022).

Rising populations have forced policymakers in Iran toward development and management practices that immediately supplied agricultural, industrial, and urban water use demands. Furthermore, technological advancements in deep well drilling and water pumping paved the way for short-term solutions to the water problem (Saatsaz 2020). This has occurred without considering groundwater overdraft, which threatens groundwater resources and poses numerous environmental problems (Zektser et al. 2005; Ashraf et al. 2019). Facing several periods of droughts, a decline in groundwater resources, and a decrease in water reservoirs, policymakers in Iran have pursued water-transfer projects. While water transfer might have social benefits in water-scarce areas of central Iran, there are ecological and environmental concerns, as once again, many aspects of these projects need further study, and the effects of climate change cannot be underestimated in relation to interbasin water transfers (Gohari et al. 2013).

A certain challenge concerning water resources is that water demand will rise with the increasing population, and at the same time, climate change exacerbates water resource conditions (Ashraf et al. 2019). This calls for a change in water-scarce countries' response toward water management, and a possible way to achieve this is through long-term solutions that look to minimize environmental impacts on water resources, help optimize water use, and lighten the pressure on resources. There is a large body of literature on water scarcity and assessment; however, there remains a lack of political and strategic actions toward long-term solutions to achieve the sustainability of water resources use. Short-sighted management practices are temporary answers to an alarming threat: the threats of water scarcity and water insecurity.

Despite many recent investigations on the search of sustainable water supply (Akbari-Alashti et al. 2014; Beygi et al. 2014; Bozorg-Haddad and Mariño 2011; Bozorg-Haddad et al. 2007, 2009a, b, 2010a, b, 2013, 2015, 2016, 2017; Fallah-Mehdipour et al. 2011, 2013a, b; Karimi-Hosseini et al. 2011; Orouji et al. 2014; Sabbaghpour et al. 2012; Soltanjalili et al. 2011) this work investigates the effectiveness of long-term strategies in comparison to short-term (i.e., short-sighed) solutions. Water management in Iran is used to illustrate this work's investigative approach. Short-term water management strategies focus on addressing immediate water shortages and emergencies. These strategies are often implemented during periods of drought and water scarcity to meet the water demands from client sectors. Short-term strategies can include temporary water allocation and distribution measures, such as water transfers or increased withdrawal from groundwater. Short-term strategies require rapid and coordinated actopm, and often involve multiple actors from government, civil society, and the private sectors. On the other hand, long-term strategies focus on addressing the underlying drivers of water scarcity and reducing the demand for water. These strategies often involve significant investments and long-term planning horizons. Examples of long-term water management strategies include infrastructure development, such as building new water treatment plants with capacity to recycle used water,

water conservation and demand management, which can include promoting water-efficient technologies, implementing water pricing policies, and increasing public awareness and education. Effective long-term water management strategies require collaboration and coordination across different sectors and stakeholders to ensure sustainable and equitable use of water resources (Agarwal et al. 2000). Given this background, this study's objectives are:

1. Identifying and reviewing the threats water management faces, and classifying water strategies into short and long-term solutions. Furthermore, this work evaluates the challenges that arise when short-term solutions are only response to the water-scarcity problem.
2. Reviewing and assessing long-term water management solutions and their potential for tackling the threat of water scarcity.

Part 2 of this study reviews the threats facing water resources management and their potential consequences, followed by an analysis of long-term solutions to overcome the water scarcity problem in Part 3. Figure 1 shows an overview of this work's components.

2 Threats arising from short-term solutions

Integrated Water Resource Management (IWRM) promotes the coordinated management of water resources through a combination of short and long-term strategies with the objective to maximize the economic benefits while keeping sustainability in mind (Agarwal et al. 2000). However, in Iran water-supply sustainability has been sacrificed to meet high water demands by relying excessively on short-term solutions. This section reviews short term strategies toward water management that have been used, or will be used, in Iran in the near future, and the threats the country will face.

2.1 Geological threats

Water scarcity impacts the societal, environmental, and economic conditions of a society by changing its members' behavior toward water consumption, influencing the labor market, and altering their living conditions. People are forced to emigrate or change

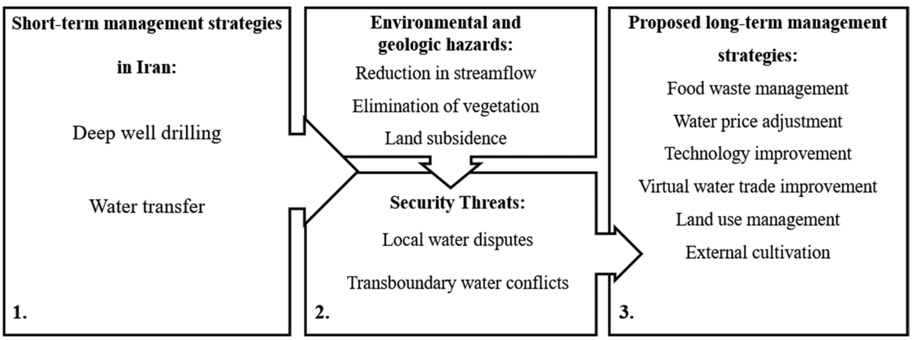


Fig. 1 The study's components and their ordering

their lifestyles and lowering their quality of life when there are barriers to water access for agricultural use and to satisfy basic human needs (Dolan et al. 2021; Rubio-Velazquez et al. 2023). Decision-makers search for new water sources to avoid societal decline and to compensate for the high levels of water demand. Unlike surface water, which is a visible resource where any changes or impacts are readily noticeable, a substantial component of the water resources serving communities are underground resources whose protection against overdraft is often neglected (Katko and Hukka 2015; Loaiciga 2017; Kram et al. 2023; Loaiciga and Doh 2024). Overdraft is a condition created by groundwater withdrawal exceeding groundwater replenishment over long periods of time (twenty years or longer) with associated long-term trends of declining groundwater levels and induced environmental problems. Zektser et al. (2005) summarized a variety of geologic hazards related to groundwater withdrawal, such as reduction of streamflow and lake levels, reduction or elimination of vegetation, seawater intrusion, and land subsidence.

There are examples of land subsidence occurring in the City of Tehran, the capital of Iran, which varied from 0 to 25 cm in ground-level decline (Ravilious 2018; Bagheri-Gavkosh et al. 2021). Bagheri-Gavkosh et al. 2021 studied 290 case studies of land subsidence worldwide. The latter authors reported that nearly 77% of land subsidence cases are human induced, with groundwater depletion being the number one culprit (56% of cases). The same authors reported that in the capital city of Iran, Tehran, the land subsidence cases were induced by dewatering and pumping during construction and to meet domestic water demand. They also reported many cases of land subsidence in central and eastern Iran. The lack of optimal water use and conservation has led to an average annual groundwater withdrawal of 2.7 billion cubic meters (Emadodin et al. 2019). Without groundwater replenishment the overlying land undergoes progressive aridification, resulting in the likely emigration of as many as 13 million people.

Water scarcity is often understood as a local or regional problem but drivers are often global in nature (Dolan et al. 2021). For instance, agricultural commodities are often traded and consumed outside the regions they are produced. Sistan province in Iran, for instance, exports about 500 tons of watermelons every year, which generates annual revenue of about 64 million dollars. The virtual water generated from the watermelon export is equivalent to 250 million cubic meters annually, assuming a unit input (i.e., the "footprint") of 500 L of water per kilogram of watermelon. Watermelon production in Sistan province relies on surface water and shallow groundwater. Meeting other water use in Sistan province with water currently used for watermelon production would reduce watermelon production by about 80%. This would result in an annual revenue loss of about 51.2 million dollars. Iran has taken action to tap new water resources such as deep groundwater. However, the of well installation and the annual maintenance of an approximate 1000 m long deep well in Iran can be as high as three million dollars, as demonstrated by the installation of deep wells in Sistan province for domestic water supply.

The study area lies on an unconfined aquifer that covers an area of 146 km^2 (Khazaei 2004). Studies show that 57 percent of natural recharge to the aquifer is from rainfall infiltration, while urban development in the area has negatively impacted aquifer recharge due to increase in impermeable surfaces (Khazaei 2004). There is a decline in the ground water table over most parts of the aquifer. The magnitude of the fall is about 20 m outside the city limits while within the city area the decline ranges between 5 and 15 m (Khazaei 2004). To prevent the 80% reduction in watermelon export would require 200 million cubic meters of deep groundwater annually, which would involve installing 200 new deep wells in Sistan province (with a yield of one million cubic meters annually per well). Such a level of deep well development would cost 600 million dollars, and funding for well installation must be raised. Moreover, this type of water extraction also requires a significant time investment, and it is not possible to guarantee sufficient groundwater available to sustain deep-well yield (Glotfelty 2019). Thus, pursuing high agricultural production levels puts more pressure on groundwater resources and implies further investments to improve irrigation efficiency to ensure the most beneficial return on investment in deep wells. The stress exerted on the groundwater resources impacts them adversely by overdraft, a situation that is worsened by climate change impacts already underway. Aquifer overdraft compounded by climate change impacts and a rapidly growing population bodes conflict over the remaining water resources in regions and countries poorly endowed with natural freshwater resources, such as Iran.

In summary, the geological threats of water scarcity in Iran are evident through shifts in behavior, labor market dynamics, and living conditions, with potential consequences including forced migration and a decline in overall quality of life. Decision-makers grapple with the imperative to identify alternative water sources to meet escalating demands and avert societal decline. Overlooked underground water resources face the peril of overdraft, a condition exacerbated by prolonged groundwater withdrawal, leading to declining levels and induced environmental. Notably, Iran's susceptibility to land subsidence, exemplified by cases in Tehran and other regions, highlights the tangible consequences of mismanagement, declining rainfall, and population growth. The country's dry and semi-arid climate further amplifies the challenges, necessitating a comprehensive approach to address the intertwined issues of optimal water use, conservation, and groundwater replenishment. As global drivers contribute to the complexity of water scarcity, it is imperative for Iran and other regions to adopt proactive measures, both locally and internationally, to safeguard water resources, mitigate climate change impacts, and to ensure a sustainable future.

2.2 Security threats

The United Nations (U.N.) has projected that the world's population will reach 9.7 billion people by 2050, more than half of which may lack food and water security (Boretti and Rosa 2019). The convergence of population growth and worsening droughts would likely make it more challenging to achieve water and food security in the coming decades. Over the past 20 years, agricultural water scarcity has caused 1,738 rebellions in Africa (Almer et al. 2017). Agricultural water conflict has occurred in countries with water stress in the Middle East, Asia, and Africa. The lack of alternative water resources and sufficient storage of water resources result in migration, raises food prices, and instills social instability in developing and developed countries.

Water disputes may first erupt at the local scale, but a lack of water security can soon turn them into transboundary water conflicts in places where multiple countries share water resources. Water disputes between Iran and Afghanistan over the Hirmand river, and the Israel and Palestine political tensions followed by the diversion of the Jordan rivers' water by Israel, are some of the examples discussed by Bozorg-Haddad et al. (2019b). Security problems stemming from local short-term solutions that further damage resources or heighten political tensions between countries that share these resources must be dealt with cooperative frameworks for decision making and management.

Generally, the management of natural resources, particularly water resources, is non-trivial. The management systems are often designed by experts relying on the available technical tools and institutional regulations (Pahl-Wostl et al. 2007). Integrated management of water resources requires the participation of all stakeholders. There are many barriers to implementing collaborative approaches to water resources management. They include limited financial resources and organizational skills to achieve successful partnerships and cooperation. A framework for successful participation of stakeholders consists of five steps: (1) understanding the resource management problem and the stakeholders' interests and viewpoints, (2) formulating the management problem-solving process, (3) applying an appropriate management process suitable to specific conditions, (4) developing a collaborative model, and (5) institutionalizing the collaborative model to solve the management problem (Halbe et al. 2018).

For example, the Murray-Darling River basin (Australia) experienced water resources allocation, environmental management, and political-decision making challenges. Four states share the river with various interests in its water (Nogrady 2019). Finding solutions to complex management problems such as those associated with the Murray-Darling River is possible only through the cooperative participation of all stakeholders (e.g., farmers, fishermen, urban water users). In addition, special attention must be paid to environmental health to prevent damage to the ecosystems and ensure the sustainability of the river basins. Stakeholder participation supported by science-driven policies (i.e. by considering hydro-political and socio-economic drivers of water consumption) is imperative to achieve satisfactory resource management resolutions.

Politics and its interaction with water resources management is studied through the field of Hydro-politics, which is uniquely positioned to assist decision-makers and managers in solving river basin management and transboundary water conflicts. Hydro-politics examines the relationship between power, water, society, and technology through major frameworks that consider their interplay with societies, governments, and technological advancements. Interbasin water transfer, transboundary issues, pollution, and water supply are among the subjects investigated by hydro-political frameworks that help decision-makers understand how water relations and government policies can impact societies (Rogers and Cow-Miller 2017).

Nagheeby and Warner (2022) examined the evolution of hydro-political relations between Iran and Afghanistan over the Helmand river basin, identifying the relationship and its changes during the last century. Their study applied the Transboundary Waters Interaction NexuS (TWINS) model to analyze the evolution of hydro-political relations between the two riparian states. The latter authors concluded that water disputes between Afghanistan and Iran have been consistently overshadowed by other priority concerns, such as security, the economy, and military conflict in Afghanistan during the last half century.

Other studies such as Kazemi et al. (2020) considered hydro-political constraints as parameters for finding optimal allocation of water resources in Iran. They used an Artificial Neural Network (ANN) to predict available water resources in Iran by 2024, followed by multi-objective optimization of water resource allocation. They used to objective functions for the NSGA II model. The first objective function was to maximize the revenue from water resources allocation and another objective function was the achievement of equity in water resources allocation in the Sefidrud basin in Iran. The model constraints consisted of available water for allocation to different provinces, and the minimum environmental water requirements of the basin. Through this method they established the existence of injustice in water allocation in this basin. Conflicts between provinces arising from their desire to meet water demands have threatened the Sefidrud basin's riverine environment. Kazemi et al. (2020) suggest self-serving interests on the part of the provinces and lack of integrated water resources management have created complex hydro-politic conditions and inequity of water resources allocation in the study basin.

In summary, the security threats arising from water scarcity in Iran are deeply intertwined with the global challenge of population growth and escalating droughts, potentially jeopardizing water and food security. The repercussions of agricultural water scarcity have been manifested in societal unrest, and as water disputes emerging at the local level, the lack of water security can escalate into transboundary conflicts, exemplified by tensions between Iran and Afghanistan over the Hirmand river and the Israel-Palestine dispute involving the diversion of the Jordan river's water. Amidst these challenges, collaborative frameworks for decision-making and management are imperative, considering the complexity of natural resource management, particularly water resources. The field of Hydropolitics emerges as a crucial tool, examining the intricate interplay between power, water, society, and technology, providing policies and equitable allocation strategies paramount for achieving sustainable resource management resolutions in the face of evolving hydropolitical relations.

3 Long-term water management solutions

Long-term water management may prove effective in avoiding transboundary and national water conflicts. This section reviews methods that have been proposed for overcoming water crises. This work examines how food waste management and water price adjustment may play a positive role in achieving sustainable use of water resources. This is followed by a discussion of the impact of technology and virtual water trading on sustainable agriculture, especially in food-producing countries. Lastly, this work reviews land-use and external cultivation strategies for optimal water use and reducing scarcity.

3.1 Food waste management

A country's vulnerability to food shortage depends on its overall imports, the network characteristics of its source nodes (e.g., its export propensity), and its internal agricultural production (Tamea et al. 2016). On the other hand, consumption management is as crucial as imports and internal agricultural production to avoid food crises. About 28% of the world's agricultural production eventually becomes waste (Bellù 2016) and about one-third of food produced globally is wasted (FAO 2011). The amount of water contained in the wasted food is lost in the form of virtual water. Virtual water refers to the water used in the production and trade of agricultural and industrial products. It is an important concept for understanding the water footprint of a product and its environmental impact. The term was first used by Allan (1996), and in later works the meaning was expanded to also consider the water used in production of commodities (Yang and Zehnder 2007). The virtual water of these wastes could support half of the world's water demand according to the current global per capita consumption of water (Segrè et al. 2015). It could also spare billions of people annually from hunger regarding lost caloric content (Chen et al. 2020).

Iran is exposed to a medium to high vulnerability to food shortages due to high imports and low internal production. One-third of Iran's total agricultural production is converted to waste every year. From the consumption management perspective, the annual amount of the virtual water from these wastes could fully support Iran's domestic water demand based on the current Iranian water use, which exceeds the global per capita consumption of drinking water (Ladi et al. 2021).

Scientists have studied the relations between water, energy, and food seeking to promote water and energy consumption frameworks through management strategies. A reduction in food waste would also reduce agricultural production, which means a decrease in water and energy reliance. FAO (2013) reported that 162 m^3 of water loss per capita (annually) is caused by food waste. On the demand side, a large proportion of food loss occurs by individual choice (FAO 2011), which means a higher emphasis on education is needed for food management. Other methods such as small-scale farming, or food composting have been suggested for food waste reduction on the individual level. Moreover, local food production, using urban agricultural methods such as green roofs, allows food transport to be reduced, limiting the food waste generated (Walters and Stoelzle Midden 2018). Moreover, urban agriculture increases the awareness of sustainable food consumption, with a consequent waste reduction (Cristiano et al. 2021). However, a considerable amount of food is wasted on the farm-to-retail level, which must be minimized through management practices (Kibler et al. 2018).

On the supply side, food production and management must be optimized through mechanisms that consider the demand to forecast production needs, trace products to their destination, and reroute them to markets with a higher demand to avoid disposal. This mechanism can be applied to food that will spoil soon, and this time-sensitive food can be available to other consumers in need, or be considered for animal use (Giuseppe et al. 2014). In addition, traced food whose edibility ceases must be managed on its route to disposal. Food waste management's energy and water consumption justify the need for adopting economically beneficial, environmentally friendly practices that benefit the water and energy sectors.

Rupani et al. (2019) evaluated solid waste in 7 metropolises in Iran and reported that nearly 15,814 tons of municipal waste are disposed of daily (Table 1). The largest percentage is organic waste comprising between 61.1% and 73.4% of total waste generated in these cities. Other studies have reported the amount of stale bread in food waste in Tehran and Mashhad, the two largest cities of Iran, at around 42.6% and 14.59%, respectively, with an average value of 22% for the whole country (Mohammadi 2006; Rupani et al. 2019; Fami et al. 2019) (Table 1).

This work's authors have calculated the amount of annual virtual water wasted through 4 categories of solid waste disposal, namely Bread, Glass, Plastic, and Paper in major cities of Iran, which exceeds 2 billion m^3 per year (Table 2). The calculation was based on data from Rupani et al. (2019), Huang et al. (2016), and Matohlang Mohlotsane et al. (2018). In

Table 1 The total amount of solid waste produced in major cities of Iran (obtained from Rupani et al. 2019)

Cities	Population (×1000)	Total solid waste (ton/day)	Total solid waste (ton/year)
Tehran	8693	7476	2,728,740
Mashhad	3001	2233	815,045
Isfahan	1961	1559	569,035
Karaj	1592	1297	473,405
Shiraz	1565	1177	429,605
Tabriz	1558	1220	445,300
Ahvaz	1184	852	310,980
Total	19,554	15,814	5,772,110

Table 2 The total amount of virtual water wasted by 4 categories of solid waste

Waste (ton/year)*									VW** content	
Product	Tehran	Mashhad	Isfahan	Karaj	Shiraz	Tabriz	Ahvaz	Total	Average VW content (m^3/ton) ***	Total VW (m^3/year)
Bread	1,146,071	122,257	170,711	142,022	128,882	133,590	93,294	1,936,825	0.53	1,026,517
Glass	43,660	9,781	13,657	6,628	4,296	5,344	11,195	94,560	0.3	28,368
Plastic	160,996	43,197	53,489	22,723	42,101	26,273	16,482	365,262	19.5	7,122,603
Paper	261,959	70,094	37,556	23,197	64,870	21,374	25,500	504,551	5,064	2,554,996,720
Total	1,612,685	245,329	275,413	194,569	240,149	186,581	146,472	2,901,198	5,084	2,563,174,209

*(Rupani et al. 2019)

***VW* Virtual water

***(Huang et al. 2016; Matohlang Mohlotsane et al. 2018) comparison, the total amount of water that could be saved annually within Iran by modernizing irrigation systems is estimated at 7 billion m^3 (Mesgaran & Azadi 2018). Water loss through waste disposal could be avoided if the aforementioned procedures were in place. Keep in mind that this is only a portion of the total value of water loss, and the magnitude of virtual water wasted in other components of municipal solid waste and other cities of Iran is unknown. Further research is needed in this area.

Six out of seven cities studied by Rupani et al. (2019) use landfills for waste disposal. Tehran, the capital of Iran, is the only city where alternative waste disposal methods, namely, composting and conversion methods to energy, are used. Collection and transportation of waste to landfills and leachate treatment based on regulatory standards consume a lot of energy and water resources since large volumes of water are diluted to meet contaminant concentration standards (Kibler et al. 2018). Alternatives methods to landfilling are promoted to reduce carbon footprints and provide other environmental benefits (Herva and Roca 2013). Composting involves the aerobic degradation of organic wastes, and water consumption is considerable due to the addition of moisture during processing; however, compost induces carbon sequestration and moisture retention in soils, decreasing the amount of irrigation needed (Hansen et al. 2016; Doan et al. 2015). Thermal conversion produces heat that is converted to energy, and the resulting ash can be used for agricultural production and to reduce the water used in manufacturing.

The decomposition of urban solid waste landfills has been recognized as one of the largest sources of global methane emissions. The amount of methane production by waste must be reduced because of the risks associated with its storage (explosion, fire) (Powell et al. 2016). The reduction of methane emissions in developing countries would be beneficial because these countries do not possess the advanced technology to make profitable use of methane. In contrast, many developed countries have advanced relevant technology to harness the emitted methane at the source points. Methane generated from the solid wastes is a source of energy usable for several purposes, including:

A. The heat from methane burning may be injected to accelerate the decomposition of garbage to compost, which has many uses in sustainable agriculture.
B. Accelerating the decomposition of solid wastes lengthens the storage sites' service life.
C. Methane burning and the released heat can be used to evaporate clean water from the leachate, which contains contaminants at high concentrations of contaminants and cannot be used for direct injection of water.

3.2 Water pricing

More than half of the world population will be affected by global water crises by 2050, and some countries such as Indonesia, Iran, and South Africa will be among the countries suffering from high or extreme water stress (Boretti & Rosa 2019). The underpricing of water is one of the primary reasons for this calamity (Catley-Carlson 2019). Underpricing water is the practice of selling it to customers at a price below the average cost of producing and delivering it in usable form to customers (Loaiciga and Renehan 1997). This means that the total revenue accruing from water sales does not recover the total cost of water production. Other sources of revenue must be found to pay for water provision. If those sources are not sufficient in economies plagued by funding scarcity this translates into poorly built and operated water-supply systems that do not meet water demands. Water is underpriced in Iran by resorting to price subsidies. The government gives significant subsidies in water to the agricultural sector to control the price of products, support farmers' incomes, and reach food self-sufficiency (Saatsaz 2020). The government's low water prices and unsuccessful efforts to ban illegal installation of wells and uncontrolled water exploitation have exacerbated the pressure on groundwater resources (Moghimi Benhangi et al. 2018). The subsidy on water results in high water consumption by individuals and the agricultural sector, with no incentives for practicing efficient water use. Water leakage in urban water supply networks is about 32%, while the overall irrigation efficiency is between 15 and 36%. Improper maintenance of water distribution and irrigation systems, improper design, and pricing water below its production cost are among the reasons behind the high rates of water being wasted in Iran (Keshavarz et al. 2005).

Attempts have been made to study water prices in Iran's agricultural and urban sectors and evaluate their effect on socio-economic factors. Radmehr and Shayanmehr (2018) simulated the behavior of farmers toward water pricing. Through Positive Mathematical Programming (PMP) they were able to produce changes in different crop production patterns in various socio-economic scenarios and rank the results using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Their results confirmed that environmental factors (such as nitrogen and phosphorus balance, soil management) are important determinants in irrigation water prices in Iran, where the rise in environmental concerns calls for governmental action in raising the price of irrigation water. Another study by Momeni et al. (2019) compared the price of agricultural water in two provinces of Iran with the state of California in the USA. The crops analyzed in this study were wheat, sugar beets, onion, tomato, barley, potato, corn, alfalfa hay, and watermelon. They computed water prices using the Purchasing Power Parity (PPP) Index, and their results showed the price of water for the cited crops are 60 to 80% of that in California. For example, based on their method, the prices of one cubic meter of water for wheat and barley production, the two main agricultural products of Iran are 0.06 and 0.01 USD, respectively. In comparison, the price of water for the wheat and barley in California is 0.07 and 0.07 USD, respectively.

In East and West Azarbaijan, two Iranian provinces, there are 165,948 and 42,263 hectares cultivated annually with wheat barley, respectively (Momeni et al. 2019). The average water use of these crops per hectare is 5000 and 6400 cubic meters, respectively, based on data from the Ministry of Jihad-Agriculture of Iran and Sadeghi et al. (2010). Based on prices reported by Momeni et al. (2019) a simple comparison with the water price in California shows that Iran's government pays 25 million dollars annually in water subsidies in East and West Azarbaijan solely for the water supply of wheat and barley. At the same time Renewable Energy Assisted Desalination (RED) water production costs are estimated between 2.4 and 15 USD per cubic meter (Mollahosseini et al. 2019). With 25 million dollars Iran could produce up to 10 million cubic meters of desalinated water through sustainable desalination methods such as wind or geothermally assisted methods.

Groundwater is an essential source of water supply for the domestic, industrial, and agricultural sectors. Its extraction or development costs generally exceed those of surface water. Nevertheless, villages in Iran use more groundwater because agriculture in rural areas is practiced to a larger extent than in urban areas, and most of the water used for irrigation is groundwater (Saatsaz 2020). Soltani and Saboohi (2008) determined the explicit and external costs of groundwater overdraft in Iran, considering factors such as well relocation and deepening costs, effects on water quality, and groundwater pumping costs. They estimated a total cost of \$1.13 per cubic meter, considering the exchange rates of the Iranian Rial to USD. The price per cubic meter of groundwater paid by villagers is on average 30% of the unit price of water paid in cities. The unit water prices in Iran are \$0.12 and \$0.035 in cities and villages, while it is only one cent in villages distant from cities.

The differences between the development cost of water and the sale price of water in Iran represent the subsidies provided for water by the government. If water were priced at its actual cost its use would become economically efficient. Water consumption patterns would once water is sold at its true price, ultimately leading to sustainable water use. There would also be potential for the government, industries, and agricultural users to invest in more water-efficient production systems, reducing water use and unsustainable water consumption.

Another approach to modify water pricing is to reduce subsidies based on environmental, economic and social limitations. Guedes Pinto and Voivodic (2021) studied the interplay of climate change, water supply and demand for the city of Sao Paulo, Brazil. The latter study discusses the importance of setting tariffs for water supply systems that consider changing environmental and economic factors. This helps to control negative financial and environmental outcomes that may result from extreme events, such as droughts. Proper planning and implementation of required investments are necessary to achieve sustainable adaptation measures. The impact of water-supply initiatives can be significant, but this necessitates stakeholder engagement and adequate water pricing. However, as reported by numerous studies such as Momeni et al. (2019), Attari and Dijk (2016), and Saatsaz (2020), modification of water prices alone does not lead to optimal water consumption, which also requires technological improvements in water production and funding support for agricultural to achieve sustainable practices for food production.

3.3 Technology improvement

3.3.1 The agricultural sector

The primary water consumers in Iran are the agricultural, domestic, and industrial sectors, representing 92%, 5%, and 3% of the national water use, respectively. Agriculture is the predominant user, while the other two water-use sectors use much less water but have inordinate institutional influence.

It is estimated by the Iranian Ministry of Agriculture (2013) that 104 million tons of agricultural goods are produced annually. This production level has ensured food security for Iran's population of 80 million. However, food safety and self-reliance have been achieved at the expense of water resources depletion. Iran's irrigation efficiency ranges between 15 and 36%, and the annual water consumption is estimated at 96 billion cubic meters (Mesgaran and Azadi 2018).

Agriculture accounts for 92% of the water consumed in Iran, and this amounts to 88 billion cubic meters of annual agriculture water use. A water-use efficiency of 36% means that there are 31.7 billion cubic meters of annual water loss. Part of agricultural water loss contributes to water resources through percolation (Perry et al. 2017). Yet, Iran has a semi-arid climate, and high volumes of water losses occur due to evapotranspiration. Moreover, the quality of agricultural water declines due to high fertilizer levels. High water losses in agriculture can be avoided by adopting high-tech irrigation systems such as drip irrigation that increase the irrigation efficiency by up to 80%.

Mesgaran and Azadi (2018) reported that by upgrading of 100,000 hectares of farmlands annually with modernized irrigation systems Iran could conserve 4.2 billion cubic meters of water by 2040. The authors further investigated Iran's Ministry of Agriculture's plans for modernizing agriculture. They concluded that improving water distribution networks and drainage systems and expanding agricultural production in greenhouses could save 6.9 billion cubic meters annually in Iran by 2040.

3.3.2 The domestic sector

Innovative and cost-effective technologies are paving the way for water resource assessment through the engagement of water users and policymakers. One such area is the availability and collection of data. Limitations in data collection and the low quality of collected data in many parts of the world hinder the implementation of data-driven models and algorithms and restrict effective water resource management. Accurate data are necessary to identify potential issues such as overuse of groundwater resources and allow for proactive management strategies to be developed or regulations to be designed. Without access to accurate data, water resource management can only function on a reactive level where failures are addressed after they have appeared and inflicted high levels of damage to the water resources and infrastructure (Cherqui et al. 2019). Water-related data in Iran are collected through governmental agencies under the supervision of Iran's Ministry of Energy and Ministry of Agriculture. However, the collected data often lacks the accuracy needed for analysis and decision-making. Accurate data and well-organized information are necessary to achieve water and food security. Government agencies must take the lead in creating comprehensive databases. In addition, ordinary people can contribute to data collection. This concept is known as "citizen science", which is an approach to scientific research that involves the participation of members of the public in data collection, analysis, and interpretation (Buytaert et al. 2016). Recent technology advancements, particularly the availability of low-cost and reliable environmental sensors, are opening up new avenues for the application of citizen science and participatory methodologies in the context of water resources (Bozorg-Haddad et al. 2019b). The advance of citizen science and the popularity of the data collected by citizens has mitigated the limitations posed by data deficiency. Social media can be used for data gathering to expedite the development of citizen science (Weyhenmeyer et al. 2017). Parameters such as precipitation rates or surface water quality could be collected from volunteers (Zheng et al. 2017), flood levels could reported through social media (Chaudhary et al. 2019). Farms may install weather stations for precision agriculture or nongovernmental organizations (NGOs) install monitoring to quantify ecosystem services (Celleri et al. 2010; Buytaert et al. 2016). Such data could complement data collected by established monitoring networks such as national hydrometeorological stations and allow for more robust analysis of climate trends.

The urban sector can benefit from its users' involvement by monitoring their drinking, bathing, and other essential water uses. Collected data could be transferred through smartphones and computers, and engaged users could participate in adjusting their water use based on their data while facilitating data collection for improved analysis and understanding of the public water consumption patterns (Bozorg-Haddad et al. 2019b). One of the requirements for encouraging more users to participate in this effort is to provide access to the results of the data analysis and maintain privacy. Sometimes the results from data applications are used for sensitive tasks that may affect people's lives. Citizen science implements data analysis but does not verify the data. It is therefore vulnerable to data errors. Sabotage and national security threats often lead to misinformation, reduced analysis accuracy, increased complexity in the data analysis, and uncertainty. It is imperative to create support services and develop accurate algorithms to prevent oversight or errors and ensure the data's accuracy. There are legal and ethical issues that bear on citizen science, including copyright, information sharing agreements, confidentiality, privacy, and the safety and welfare of contributors. These issues must be carefully managed to realize a participatory and effective citizenry contributing to data gathering and analysis (Kelleher and Tierney 2018).

3.3.3 The industrial sector

Water demand among the agricultural, municipal, and industrial sectors differs in terms of quantity and quality, and given the higher profits of industrial applications, water-supply priority in Iran has been given to drinking and industrial use (Zehtabian et al. 2023). Water is used in energy production, manufacturing, mining, and waste processing. Water supplied to industry is used for cooling, washing, diluting, transporting or processing products. Industrial water use needs to be determined to reach sustainable consumption rates through increased water efficiency. The assessment of water consumption can reveal the leading causes of water loss in the industrial sector (Willet et al. 2019).

For illustrative purposes, consider that 128 million cubic meters of water annually are used for cooling devices in the industrial sector in Iran. Using water-cooling systems instead of an air-cooling system to cool industrial devices means an additional cost of 371.2 million dollars annually. Using the water that would be saved from switching from water-cooling technology to air-cooling technology to grow tomatoes and applying 185.7 L of water to produce one kilogram of tomatoes would produce 689.283 thousand tons of tomatoes annually, with an equivalent value of 425.87 million dollars. The benefit/cost ratio of switching from water-cooling to air-cooling technologies with reallocation of the saved water to tomato production would be $BC = \frac{425.87}{371.2} = 1.15$. The saved 54.67 $(425.87 - 371.2)$ million dollars annually could be used to plant 60 thousand hectares with irrigated crops, create more jobs, and invest in irrigation technology.

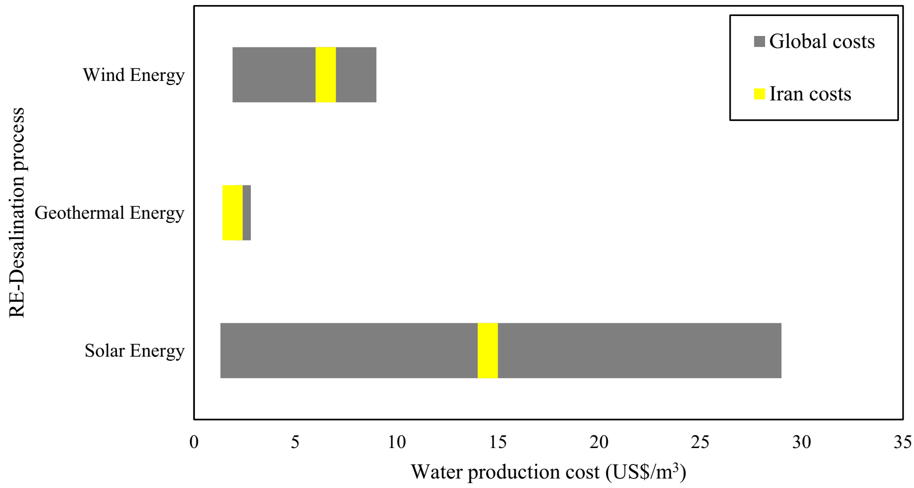
3.3.4 Alternative water sources

Another domain with technological improvements is seawater desalination, a technology of freshwater production that has undergone rapid innovations (Manju and Sagar 2017). Due to its high cost and energy consumption seawater desalination is not a viable solution for agricultural water supply currently, but it provides millions of people with potable water worldwide. Iran has been surrounded by three main water bodies of the "Caspian Sea" in the north and "Persian Gulf" and "Sea of Oman" at the south of its borders. More than 10 million Iranian people live in the coastal provinces of the country (Gorjian and Ghobadian 2015). Iran is not among the group of countries with the highest installed desalination capacities. The fossil-fuel powered desalination systems used in Iran are no longer sustainable to overcome the water crisis in the country due to both depletion risks of available energy resources and increase of greenhouse gas emissions (Gorjian and Ghobadian 2015). However, seawater desalination powered by solar, geothermal, and wind energy is rising in arid regions of the Middle East (Israel, Saudi Arabia, for example), Spain, and Australia to cite a few countries. Iran produces 121,000 cubic meters of desalinated water annually, most of it through Reverse Osmosis (R.O.) plants. However, the country has massive potential for renewable energy desalination, primarily through wind and solar energy sources. Mollahosseini et al. (2019) have studied Iran's potential for renewable energy desalination. The latter authors argued that Iran could produce up to 813,055 cubic meters of desalinated water daily with the existing capacities, potentially reaching an estimated production of 28,000,000,000 cubic meters daily. Figure 2 reviews the total desalination costs through different energy sources with Iran's capacities for water desalination.

3.4 Virtual water trade improvement

Humans use water daily for drinking, bathing, washing, and other purposes, which constitutes a direct water use. Such direct water use can be controlled in various ways (e.g., conservation, technological improvements, water pricing). The indirect water use can be tens of times larger than the direct water use. For example, the watering of gardens, the production of fruits, vegetables, and other horticultural and agricultural products requires large volumes of water, which is an indirect use of water by humans. Therefore, significant water savings can be achieved by controlling these indirect uses by resorting to the concept of virtual water and its management.

Virtual water is moved by trading goods and products, whose production involves large volumes of water (Allan 1998). Such transport of water is referred to as virtual water trading. Managing this trade can help alleviate water shortages. A country can effectively reduce water stress by reducing the cultivation and production of crops that consume much water and importing them from other countries. Many countries manage domestic water demands by importing water-intensive commodities and exporting crops with lower water needs. It has been estimated that Japan saved 94 billion cubic meters of its water resources through imports between 1997 and 2001 (Mohammadi-Kanigolzar et al. 2014).



	Capacity (m³ / day)	
RE-Desalination process	**Existing**	**Potential**
Solar Energy	130,000	8,000,000,000
Geothermal Energy	3,055	111,111
Wind Energy	680,000	20,000,000,000

Fig. 2 Comparison of desalination costs of 1 cubic meter of water through various Renewable Energy (RE) resources and Iran's existing and potential capacities for desalination (Obtained from Mollahosseini et al. 2019)

Iran is a case in point, where wheat has the largest share in the virtual water trade in the agricultural production group. Mohammadi-Kanigolzar et al. (2014) studied the flow of virtual water in Iran between 2001 and 2008 and reported that Iran imported 2.581 billion cubic meters of virtual water during the studied period. Maize and rice are other imported products with the highest virtual water value. Despite this, Mohammadi-Kanigolzar et al. (2014) demonstrated that Iran faces water import dependency since water-intensive products such as dried fruits (e.g., pistachios) are being exported while goods with low amounts of virtual water are being imported. About 40 billion cubic meters of water could potentially be saved annually by importing all of the country's wheat needs (Delpasand et al. 2020). However, the Iranian decision-makers encourage the production and export of wheat, which exerts severe pressure on Iran's water resources.

The industrial sector is another focus area in virtual water trading. Studies have supported the need for a joint analysis of virtual water flow in agricultural and industrial trade (Đokić and Jović, 2017). Delpasand et al. (2020) studied the integrated management of the virtual water trade of strategic agricultural and industrial products of Iran in 2018, using multi-objective optimization and the Nash Bargaining method. They applied a self-sufficiency constraint to meet 50% of the demand for strategic commodities through domestic production. Their analysis of the self-sufficiency scenario suggested that agricultural products such as wheat, rice, barley, and date should not be exported (export values of 0 were achieved), while potato and tomato should not be imported. On the other hand, industrial products should not be imported, namely steel, aluminum, iron ore, copper, and cement. Their results confirmed the importance of the virtual water trade and its consideration in decision-making.

Hoekstra (2003) introduced the concept of "water footprint" (see also Hoekstra et al. 2011; Kenway et al. 2022). The water footprint is an indicator that measures both direct and indirect water usage and is a comprehensive measure of freshwater resource appropriation which also considers virtual uses of water. It measures the volume of freshwater used in a product and includes water consumption volumes by source and polluted volumes by type of pollution. The blue water footprint refers to the consumption of resources surface and groundwater resources, while the green water footprint refers to the consumption of rainwater before it is considered as run-off. The grey water footprint refers to pollution and is the volume of freshwater required to assimilate pollutants given existing ambient water quality standards (Hoekstra et al. 2011).

To better understand the development of water consumption in relation to food production, consumption and trade, a comprehensive water footprint assessment was conducted for Iran between 1980 and 2010 by Karandish and Hoekstra (2017). Iran has placed an emphasis on increasing water volumes for irrigation, resulting in little attention to water use efficiency and no consideration of consumption and trade. The study estimated the green and blue water footprint related to production and consumption of 26 crops for 30 provinces of Iran. The results showed an increase in crop production by 175%, total water footprint of crop production by 122%, and blue water footprint by 20%. In 2010, 26% of the total water consumption in the semi-arid region served the production of crops for export to other regions within Iran or abroad. Qasemipour and Abbasi (2019) also quantified the 10-year average of virtual water trade and the water footprint within South Khorasan, the third largest province in Iran. The results of their study highlights the need to align cropping patterns to spatial differences in water availability and productivity while reducing the water footprints of crop production to benchmark levels per crop and climatic region. By doing so, Iran would achieve sustainable use of water supplies and food security.

3.5 Land use management

Each country exhibits specific conditions in terms of geographical setting, climate, topography, water resources, soil types, and Land Use/Land Covers (LULC). Land-use strategies determine the crops produced in a region based on its priorities, capabilities, and feasibility. Land use affects food security, and the achievement of food security is a pressing current and future concern in many parts of the world. Modern society must rely on comprehensive long-term land use planning to ensure present and future wellbeing.

As an interaction that links natural environmental processes to human activities, land use/land cover changes impact water resources through changes in vegetation, surface infiltration, surface runoff, and soil moisture status, among other things. Large-scale changes in land systems influence the hydrologic cycle and climate system in various ways because hydrologic components are linked. For example, vegetation loss can increase river discharge and surface runoff on the one hand, and change soil characteristics on the other hand (Sahin and Hall; 1996; Costa et al. 2003). Changes in soil characteristics affect evaporation and transpiration. Moreover, when the physical characteristics of the land surface change, the reflection or absorption of solar radiation and some other atmospheric processes are also affected (Fig. 3). Moreover, the cycling of chemical elements (especially the carbon cycle) is also affected by changes made in the land system (Houghton et al. 2001).

Besides hydrology and water resources, LULC changes alter water demand/requirements patterns. A high population growth rate triggers growing demand for natural resources and municipal services: freshwater, food, energy, shelter, transportation, and sanitation. Growing demand for food has led to a nearly 12% increase in the whole cropland area of the world with enlarging use of chemical fertilizers, the development of high yielding technology, and the emergence of modern irrigation methods (Matson et al. 1997; Wood et al. 2000). One negative side effect of an increased rate of food production is the deterioration of water quality in many parts of the world, which stems from the excessive use of fertilizers (Matson et al. 1997; Pimm and Raven 2000). Another important

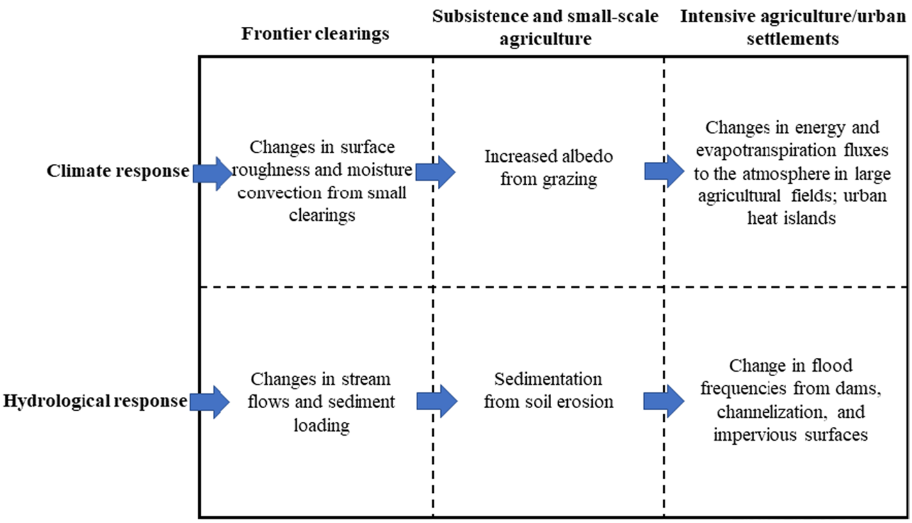


Fig. 3 Climate and hydrological response of ecosystems to different stages of land-use transition (Adopted from DeFries et al. 2004)

consequence of the growing population is the growing demand for freshwater. An increase in irrigated croplands directly affects and increases freshwater withdrawals. Nearly 85% of global water consumption is attributed to the agricultural sector in Iran. In addition, the global over-extraction of groundwater resources has resulted in the decline of groundwater levels in many areas of the world, contributing to global concerns about water supply.

Sustainable land use policy actions must be followed in view of the current trends of diminishing the capacity of the environmental ecosystems for meeting human needs. In this regard, some authors have suggested using new methods to increase crop production per unit of water, fertilizer, and land area used (Mann 1999; Rosegrant et al. 2002; Frink et al. 1999; Cassman et al. 2002). Other authors recommend maintaining soil organic matter in agricultural lands to preserve soil water holding capacity, nutrient source, and organic carbon storage (Tilman 1998; Lal 2001). Worldwide, there are land-use practices yield environmental, social, and economic benefits. As an example, the discharge of the river in the Yangtze watershed is highly moderated by forests, which y enhances the river flow in dry seasons and decreases wet-season discharge. Indeed, the hydro station of Gezhouba generates an additional 40 million kWh yearly which equals 40% of the income from forested areas (Guo et al. 2000).

3.6 External cultivation

Food security means access to healthy and adequate food for all people. Its fulfillment is a crucial goal in many countries. Some countries have increased their agricultural productivity and have made infrastructure investments; others have turned to external crop cultivation while improving internal agricultural productivity. External cultivation means importing crops planted in other countries to realize food security in a specific country. The U.S., the U.K., and China are leading practitioners of this practice as they meet their agricultural production demands through purchasing or renting other countries' lands. This practice is worthy of consideration for better management of natural resources, especially water resources, in future planning.

The FAO has estimated that an average of US $209 billion annual investment is needed in developing countries to meet agricultural demand, and less developed countries need foreign investment to achieve food security and reach their development goals (Kaarhus 2018). Developing and developed countries must rely on international markets to provide water and agricultural resources since they cannot rely only on domestic markets with their growing populations. External cultivation as a form of Foreign Direct Investment (FDI) could be a win–win practice for the investing and hosting countries. Investing countries can rely on the host country's resources to support themselves. Furthermore, agricultural investment has the potential to solve capital shortages, transfer novel agricultural and irrigation technologies, improve agriculture efficiency, and create job opportunities in the host country (Amanor 2013).

Aust et al. (2020) analyzed 44 African countries to assess the role of FDI on the achievement of Sustainable Development Goals (SDGs) in host countries. The U.N. set targets for 17 SDGs in 2015, with one of its aims being the protection of the natural environment. Aust et al. (2020) concluded that FDI positively influences less developed countries in their way of achieving SDGs. The partnership through FDI is an opportunity for less developed countries to use the financial resources and job opportunities to move forward with their plans for sustainable development. On the other hand, the investing countries also have the chance to preserve biodiversity and save their resources, such as clean water and defeat hunger and poverty. External agriculture has been an effective tool for China to rely on the resources of developing countries to support itself.

Food security pressure has inclined China toward raising its agricultural FDI in less developed countries and a few developed ones. China's agricultural FDI is in the form of land leasing in countries such as Singapore, Thailand, Russia, Tanzania, and Mauritania (Jiang et al. 2018). China's FDI consists of private and state-owned enterprises, and in the period between 2006 and 2016, China has increased its FDI from 190 million to 3.29 billion dollars. Jiang et al. (2018) concluded that China's agricultural FDI is a possible successful solution for itself and for developing countries. Their analysis of more than 8000 articles and media reports showed that China had achieved its goal of national food security while keeping the pressure off of its water and agriculture resources. At the same time, China has brought agricultural technology, management experience, and employment opportunities to the host countries.

China's experience in external cultivation could serve as a learning lesson for water-scarce countries such as Iran. For decades, Iranian leaders have focused on the domestic self-sufficiency of agricultural production. Self-sufficiency could cause irreparable harm to Iran's water resources given its current water resource conditions. Food security would not be achieved at expense of losing water security. Investments in short-term solutions to the water deficiency problem, such as water transfer projects, must be redirected to more sustainable long-term plans that remove the pressure from domestic natural resources. External cultivation could serve as one of these solutions, with social, political, and environmental benefits to Iran and its population.

4 Concluding remarks

The dramatic water security challenges faced by Iran are rooted in decades of disintegrated planning and managerial myopia. Iran has suffered from a symptom-based management paradigm, which mainly focuses on curing the problem symptoms rather than addressing the main causes. Short-term solutions (e.g., tapping new water resources, dam building, water transferring) have been Iran's main strategies in facing the problem of water scarcity. Although addressing and mitigating emergency risks of water scarcity necessitates actions to avoid its various impacts on health and well-being, such as heightened risks of water-borne diseases and poor sanitation, such short-term strategies can exacerbate the conditions in the long-term. In this regard, the adverse consequences of taking such measures were discussed (e.g. land subsidence or adverse ecological impacts), with a review case studies from Iran and other countries facing such matters. Furthermore, long-term solutions (e.g., correcting consumption patterns, land use management), were described (as the forgotten solutions) can effectively reduce the water-scarcity crisis in Iran and similar countries in the Middle Eastern region. A review of studies on application of short-term and long-term strategies confirms that supplying water demand for agricultural, urban, and industrial purposes might bring food and social security in the short run. However, in the long run, water scarcity and climate change impacts will threaten the illusional security created through short-term solutions. Water security hinges on the implementation of an integrated water management plans. This study suggests multiple long-term strategies such as the development of new water sources (desalination, water recycling, waste management), water conservation (land use management and water price adjustment), water trading (through virtual water or external cultivation), and increased water use efficiency (using technological advancements), to tackle the issue of water scarcity in Iran.

Further studies are needed to evaluate various dimensions (social, political, economic, and environmental) of adapting such long-term plans, and the combinational effects of comprehensive approaches that considers both short-term and long-term policy choices, on the water resources in Iran.

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Consent to publish All authors consent to publish.

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