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Rural vulnerability to water scarcity in Iran: an integrative methodology for evaluating exposure, sensitivity and adaptive capacity

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Abstract The water crisis is the main stress in arid and semi-arid areas, especially in rural areas where agriculture is the main livelihood. This study assessed vulnerability to water scarcity in six rural regions of Isfahan, Iran. These areas have lost their primary water source of agriculture, the Zayandeh Rud River, since 2006. They have confronted many socio-ecological problems which threatened their existence. A mixed methodology was used to assess vulnerability as a function of exposure, sensitivity, and adaptive capacity. Structured questionnaires and in-depth interviews were conducted with key informants and 266 households. The method of Multidimensional Poverty Index was applied to calculate the sensitivity index, which has not been used for sensitivity assessment yet. The results showed that the leading cause of water scarcity is poor water governance. The three districts that had direct access to the Zayandeh Rud river were more vulnerable to water scarcity (scores of 0.35, 0.39, and 0.44) than those that had never had direct access to the river (scores of 0.19, 0.21, and 0.23) due to the more exposure and less adaption to water shortage. Inappropriate financial resilience (from 0.24 to 0.41) and living standards (from 0.19 to 0.36) have made more contributions to creating sensitivity than socioeconomic factors (from 0.14 to 0.28). Different natural capitals have mainly created differences in adaptive capacity across rural areas. Villages located downstream have lost their natural capital due to water-quality degradation caused by river drying up and groundwater overexploitation.

Keywords Climatic and non-climatic exposure · Sensitivity · Adaptive capacity · Multidimensional poverty index

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Introduction

In these unprecedented times of profound economic crisis, food price peak, and rising inflation, strengthening the resilience to climatic and non-climatic shocks such as water-related extreme events and the COVID 19 pandemic is vital to improving food security and sustaining the economy (World Bank, 2022). Agriculture is the main source of livelihood for the majority of rural people, which depends on water availability. Climate change, in particular, has had significant effects on water resources in arid and semi-arid areas that intensely affect farmers' vulnerability and rural well-being (Field et al., 2014; IFAD, 2016; IPCC, 2021).

Water scarcity is widespread throughout the Middle East and North Africa (MENA) region and is deteriorating (FAO & World Bank, 2018). Twelve of the seventeen countries classified as extremely high water-stressed with the greatest economic losses due to climate-related water shortages are located in the MENA region (World-Bank, 2017a; Hofste et al., 2019). Iran is one such country with a largely arid and semi-arid climate, and the agricultural sector as the most significant water user, which is currently facing new risks to the water resource and increasing rural vulnerability (Maghrebi et al., 2020). In addition, rural vulnerability is also affected by non-climatic factors such as socioeconomic and political-institutional contexts (El Kharraz et al., 2012; IFAD, 2016). These factors have increased unemployment, food insecurity, migration, and poverty in rural areas (Delazeri et al., 2021; IFAD, 2016; Keshavarz et al., 2013; Mavhura, 2019).

Water as the key to climate change adaptation

There is a pressing need for increased convergence between water and climate change strategies in light of rising climatic uncertainty (Srivastava et al., 2022). Water security plays a vital role in adapting to and mitigating climate change for at least four reasons (Caretta et al., 2022). First, global water insecurity is still widespread: about half of the world's population faces severe water scarcity for at least one month of the year, and more than 2 billion people continue to lack access to safe drinking water (WHO, 2021). Secondly, the vulnerability to water-related effects of climate change and extreme weather is expected to worsen in the future, notably in agriculture, which accounts for 60–70% of all freshwater withdrawals globally (Müller Schmied et al., 2021). In addition, the 10% most water-stressed basins encompass 35% of the total irrigated calorie production and account for 31% of total water consumption (Qin et al., 2019). Between 2010 and 2050, global water withdrawal is expected to rise by 12 to 29% (Bijl et al., 2018). Third, many mitigation measures can either increase or decrease water consumption or water withdrawals. Some actions, such as bioenergy with carbon capture and storage, reforestation, and afforestation, can leave a significant water footprint if implemented improperly (Canadell et al., 2021). Therefore, limiting potential water-related hazards will necessitate a system-wide approach that considers both the direct effects of mitigation measures on water resources and their indirect effects through lowering climate change. This requires a profound understanding and articulation of the significance of water in agriculture, as well as water governance and socioeconomic circumstances (Caretta et al., 2022). Finally, approximately 60% of adaptation responses are geared toward coping with water-related risks such as droughts and floods, with agriculture accounting for a sizable proportion of water-related adaptations (Caretta et al., 2022). Water, however, has a complex and nonlinear function in climate change adaptation since it may both facilitate adaptation and, if ignored, be a major source of disruption (Srivastava et al., 2022). It remains unclear about the effectiveness and benefits of water adaptation measures and whether or not those benefits also reduce climate risk (Singh et al., 2021). Maladaptation often results from ineffective planning and implementation, as well as a failure to address the root causes of vulnerability (Eriksen et al., 2021). Failure to identify the underlying causes of vulnerability may result in adaptation efforts that aggravate rather than alleviate present vulnerabilities (Srivastava et al., 2022).

The importance of evaluating vulnerability to water scarcity

The vulnerability of ecosystems and communities to climate change varies substantially across and within regions, and developing an adaptation pathway for rural livelihoods requires a comprehensive vulnerability assessment (IPCC, 2022). There is generally limited knowledge on how socioeconomic, political, and biophysical factors heighten or weaken households' vulnerability to water scarcity and their ability to cope with and adapt to it (Inkani, 2015; Zarafshani et al., 2020). The assessment of vulnerability to water scarcity is complex when considering both natural and human-induced factors. The majority of scholars assessed vulnerability to climate variability and climate change (Gbetibouo et al., 2010; Vo & Tran, 2022; Yiridomoh et al., 2021); however, there have been few studies on vulnerability assessment toward non-climate factors (McCubbin et al., 2015; Teng et al., 2022).

This work aims to assess vulnerability to water scarcity in dry rural areas. The study was conducted in six rural districts of Isfahan province, Iran. This region is one of the most water-stressed catchments in Iran, with about 600 m^3 per capita water availability (Ziaei, 2020). Agriculture as the primary occupation of the rural areas is entirely dependent on the Zayandeh Rud River -the principal and the largest river of the central plateau in Iran. The river had significant flow all year long; however, it has been dry for almost 90% of the year in recent 15 years due to climate change, climate variability and the steady growth of water demand, and intensifying rivalry between regions and economic sectors (Mohajeri & Horlemann, 2017). This has led to groundwater overexploitation and a drastic decrease in farmers' livelihoods, especially in the downstream (east) of the basin (Loghmani Khouzani et al., 2022; Raber et al., 2017). Water problems in this region have sparked security and socio-political challenges, as reflected in the increasing number of farmers' protests in recent years (Yousefi et al., 2022). The protest of thousands of farmers in this region against severe water shortages in November 2021 was the biggest demonstration over the water crisis in Iran (Anonymous, 2021).

The contribution of this paper is threefold: First, the vulnerability to water scarcity in dry rural areas was assessed by an integrated approach for mapping exposure in terms of climatic and non-climatic shocks, sensitivity, and adaptive capacity. Second, limited studies have been conducted at the household level or local level (Inkani, 2015; McDowell et al., 2016); this research evaluated sensitivity at the household level using the Multidimensional Poverty Index methodology. Third, different aggregation rules were compared for constructing a composite vulnerability index. This study highlights such questions as: Who and why are some households more vulnerable to water scarcity? To what extent has vulnerability been amplified by the degree of sensitivity to stresses and the capacity of districts to cope/adapt? How can more resilient and adaptive communities be built?

Study area

This study was conducted in six rural districts of Isfahan County, located in the center of Iran. According to the Köppen Climate Classification System, the study area has a cold desert climate (i.e., BWk) with an average annual temperature of 17 °C (Shojaei et al., 2017). The region is an arid region with a mean annual precipitation of less than 100 mm/year. The agricultural water requirement of the study area is supplied by the Zayandeh Rud River, directly from the surface water and indirectly from the groundwater pumping. The Zayandeh Rud dam regulates the river flow upstream. The river has been dry for almost 90% of the year in recent 15 years due to drought and excessive water extraction before reaching the city of Isfahan.

Figure 1 shows six rural districts of study, namely Markazi, Jolgeh, Bon-Rood, Kouhpayeh, Jarghouyeh Olya (J. Olya), and Jarghouyeh Sofla (J. Sofla), which are located downstream of the Zayandeh Rud river, near the Gavkhoni wetland. The rural population and the number of rural households have been 130,184 and 40,930, respectively (SCI, 2016). The most populated district was Markazi, with a population of 77,008. The primary source of livelihood was agricultural production, with 24,548 agricultural holders, including annual crops (49%), horticulture (17%), and animal husbandry (34%) (SCI, 65).

Methodology

In general, vulnerability can be defined as a degree of susceptibility to natural and socioeconomic hazards (Smit et al., 2000) and as a way of being liable for the consequences of environmental changes (Inkani, 2015). There are different models and frameworks to assess vulnerability (Turner et al., 2003; Füssel, 2007; Bruno Soares et al., 2012; Dilshad et al., 2018; Panthi et al., 2016; Unks et al., 2019). Vulnerability is conceptualized as being constituted by exposure, sensitivity, and adaptive capacity to stressors (Adger, 2006; Eze & Onokala, 2021; Fellmann, 2012; Field et al., 2014; Nazari et al., 2015; Räsänen et al., 2016). Although a system might be significantly exposed and/or sensitive to stress and shock, it cannot be considered to be definitely vulnerable (Fellmann, 2012). The reason for this is that the ability of a system to

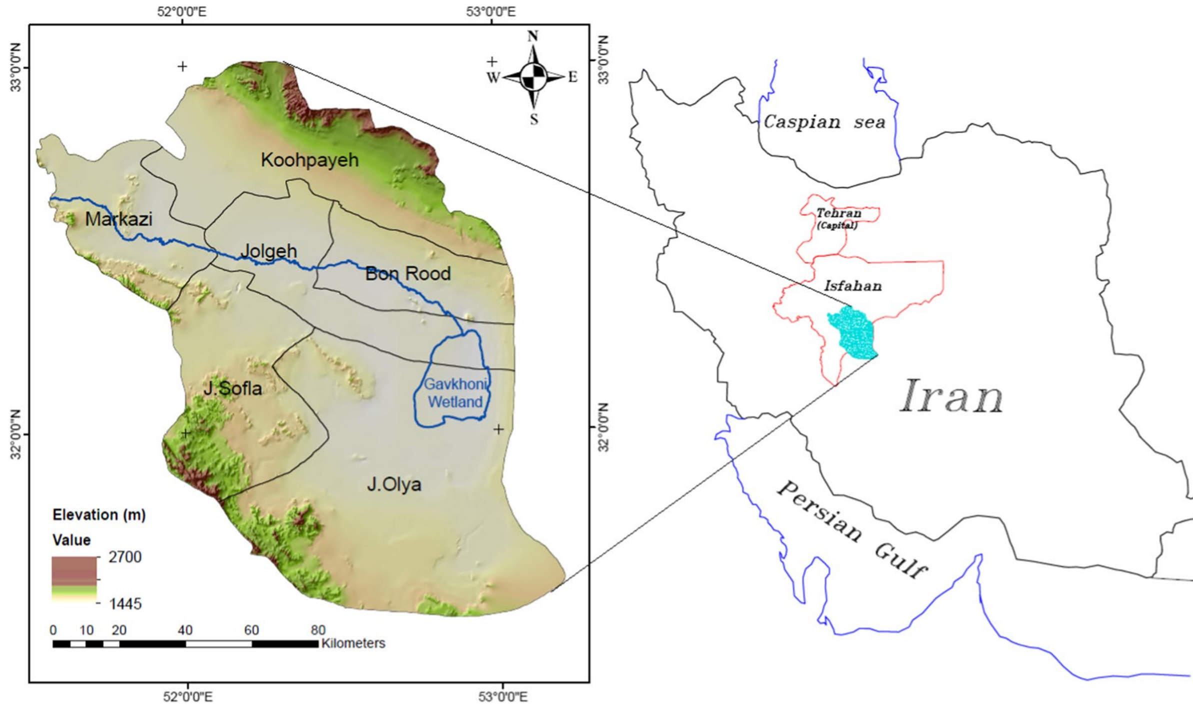

Fig. 1 Location of study region and districts. Source: GSI, 2019

adapt to stresses cannot be characterized only by exposure and sensitivity (Nazari et al., 2015). The following sections describe the assessment of vulnerability to water scarcity and its components, including exposure in terms of climatic and non-climatic shocks, sensitivity, and adaptive capacity.

Exposure

In this study, the exposure (E) is to what extent a system/people is/are exposed to significant water shortage. We used the results of related literature (desk research) for climatic shocks, including Eslamian et al., 2017; Rahmani Fazli & Salehian, 2017; Nasri & Modarres, 2019. The changes in annual average temperatures and precipitation over one decade prior to the research year (2017), as well as the effects of climate change on temperature and precipitation, were analyzed as climate factors (Table 1).

We assessed the non-climatic exposure to water scarcity from people's perspectives. People's perceptions can be used in cases where access to systematic and reliable data is impossible (Devkota et al., 2017). Although the knowledge of local people and farmer perceptions cannot detect climate variability trends as models do (Dakurah, 2021; Rao et al., 2011), some studies have shown that farmers' perceptions match historical climate data (Maddison, 2007; Vedwan & Rhoades, 2001). It is common to employ implied equivalency between local perceptions of climate change, local decadal trends, extreme events, and global change (Castro et al., 2012; Ensor & Berger, 2009; Stojanov et al., 2017). In fact, farmers' perceptions can be used in the context of social-scientific analysis of the vulnerability, adaptive capacity, and their determinants (Dasgupta et al., 2014). We assessed the non-climatic stresses of water scarcity by a qualitative method (Mubaya et al., 2012; Qaisrani et al., 2018). As the first step to better understanding stresses, we prioritized the vulnerable areas based on the frequency and intensity of lack of access to water by conducting in-depth interviews with key informant actors and local leaders (Qaisrani et al., 2018; Wise et al., 2014). Snowball sampling was continued until theoretical saturation (Priest & Blaikie, 2019). To prioritize and allocate weights to the questions, we designed and filled semi-structured questionnaires with more key actors and the local community by

Table 1 Description of components

Component	Sub-component	Indicator	Description of indicator	Data Source
Exposure	Climatic	Climate change	Effect of climate change on precipitation and temperature (+)	IWRM[a]
		Climate variability	Change in annual average temperature during the last 10 years[b] (+)	IWRM[a]
			Change in annual average precipitation during the last 10 years[b] (+)	
	Non-climatic	Miss-governance	Human-made physical access to water (+)	Interview
Sensitivity	Living standard	Housing	Adequate housing materials in floor, roof, or walls (-)	Survey
		Home appliance	Own essential appliance like TV, refrigerator, oven, heater, etc. (-)	Survey
		Assets	Own these assets: bicycle, motorbike, car, or truck. (-)	Survey
	Financial resilience	Basic needs	Ability to pay costs (-)	Survey
		Traveling	Ability to pay costs (-)	Survey
		Health and treatment	Ability to pay costs (-)	Survey
		Loan	On-time repayment (-)	Survey
	Socio-economic status	Job	Types of job (-)	Survey
		Literacy	Literacy of head of household (-)	Survey
		Support of Charity	Under the support of charitable organizations (+)	Survey
		Health insurance	Access to health insurance (-)	Survey
		Infant and child mortality	Experience of infant and child mortality (+)	Survey
Adaptive Capacity	Social capital	Participation	Participation in formal and informal events (-)	Survey
		Trust	The level of trust (-)	Survey
		Social linkage and integrity	Level of social linkage and integrity (-)	Survey
		Responsibility	Level of responsibility (-)	Survey
	Human capital	Education	Level of education (-)	Survey
		Experience	Level of experiences (-)	Survey
		Skill	Level of skills (-)	Survey
		Training	Level of participation in training (-)	Survey
	Fixed capital	Infrastructure	Access to electricity, water and natural gas (-)	SCI[c]
		Service centers	Access to health centers, banks and shops (-)	SCI[c]
		Location	Distance from the city (+)	SCI[c]
		Agricultural equipment	Access to agricultural equipment (-)	Survey
		Credits	Access to credits (-)	Survey
		Land ownership	Agriculture land ownership (-)	Survey
		Livestock	Ownership of livestock (-)	Survey
	Natural capital	Water	Water quality (-)	ICWP[d]
		Soil	Soil erosion (+)	ICWP[d]
		Groundwater vulnerability	Susceptibility Index (SI)[e] (+)	ICWP[d]

[a]IWRM stands for Integrated Water Resource Management: Zayande Rud Project (Mohajeri et al., 2017)

[b]The last 10 years was considered prior to the research year i.e. 2017

[c]SCI stands for Statistical Center of Iran.[d] ICWP stands for Iran's Comprehensive Water Plan: Zayandeh Rud basin (ICWP, 2013)

[e]The Susceptibility Index (SI) is a parametric vulnerability method designed to evaluate the specific vertical vulnerability of groundwater to pollution caused, especially by agricultural activities (Goyal et al., 2021)

snowball sampling (Pittman et al., 2011). Finally, the interviewers' narratives were interpreted using open, axial, and selective codings, and the sub-categories and the core theme were chosen (Corbin & Strauss, 2014).

Sensitivity

Sensitivity (S) is the degree to which a system is modified or affected by perturbations (Adger, 2006). For assessment of sensitivity, we applied the Multidimensional Poverty Index (MPI) proposed by Alkire and Foster (2010, 2011) (AF method) to identify multiple deprivations at the household level in living standards, financial and socioeconomic status indicators. Each household in a given village is classified as sensitive or non-sensitive depending on the weighted number of deprivations that the household members experiences. Based on the AF method, we aggregated these data into the regional measure of the Multidimensional Sensitivity Index. This index permits comparisons both across regions, districts, as well as other key household and community characteristics.

Multidimensional Sensitivity Index which is referred to as S in this paper, measures sensitivity in d dimensions across a population of n individuals. The headcount (H) is the proportion of the households (n) who are sensitive. That is $H = q/n$, where q is the number of sensitive households. In order to estimate the intensity of sensitivity (A), the average deprivation share across sensitive households was calculated. Sensitivity was assessed by the following equation (for more details, see Appendix A):

$$S = H * A \quad (1)$$

According to the MPI index, equal weightings for both dimensions and indicators were applied. Four k-cutoffs i.e., 0.2, 0.25, 0.3, and 0.35, were applied to test the robustness of sensitivity ranking of districts according to the plausible values of the cut-offs in Alkire & Santos, 2014. These cut-offs mean that individuals or households are identified as sensitive if they are deprived in 20, 25, 30, and 35% or more of the weighted deprivation count (Alkire & Santos, 2014).

The sensitivity dimensions included living standards, financial resilience, and socioeconomic status. The housing, home appliance, and assets indicators were considered as the living standards status. Financial resilience consists of four indicators: ability to pay costs of basic needs, traveling, health and treatment, and on-time loan repayment. The key indicators of socioeconomic status are listed as follows: types of job, literacy of head of household, the use of charity support, access to health insurance, and the rate of infant and child mortality (Table 1). The data for sensitivity assessment were collected through 266 face-face interviews with the head of rural households by a structured questionnaire.

Adaptive capacity

Adaptive capacity (AC) is the ability of the system to cope with and adapt or recover from the effects of environmental hazards or policy change (Adger, 2006; Klenk et al., 2012; Smit & Wandel, 2006). Some researchers used natural, physical, financial, social, and human capitals to estimate adaptive capacity (Nazari et al., 2015; Nelson et al., 2010). Adaptive capacity also relates to the flexibility to substitute between the capitals in response to external stresses and shocks. For example, some farmers sold their agricultural machinery and home appliances (physical capital) due to the reduced production capacity under drought (Keshavarz et al., 2017). Loss of physical capital compounded with a declining financial capital reduces the adaptive capacity of rural areas at local and regional scales.

In this study, the financial and physical capitals were integrated into one category, namely fixed capital. The adaptive capacity indicator consists of four sub-components: social, human, natural, and fixed capitals. Social capital components included participation in formal and informal events, the level of trust, responsibility, social linkage, and integrity (Table 1). The human capital indicator consists of the level of education, experience, skill, and attendance in training. Fixed capital was referred to as access to infrastructures (i.e., electricity, water, and natural gas), service centers (i.e., health centers, banks, and shops), agriculture equipment, credits, distance from the city, and agricultural land and livestock ownership. Natural capital was divided into three indicators: water quality, soil erosion, and groundwater vulnerability (Table 1).

Vulnerability assessment

Table 1 presents the sub-components and indices of three main components of the research: exposure, sensitivity, and adaptive capacity. It should be noted that a minus sign showed the indicators which have an inverse correlation with vulnerability in parenthesis, and the indicators which have a positive correlation with vulnerability were shown by a plus sign which means that a higher value makes a higher vulnerability.

Data were collected from different scales and units; however, all components were analyzed at the district level. In order to standardize all data into a uniform scale, below conversion was used (UNDP, 2015; Keshavarz et al., 2017):

$$\text{Normalized indicator value} = \frac{\mathit{Original\ Value} - \mathit{Minimum\ Value}}{\mathit{Maximum\ Value} - \mathit{Minimum\ Value}} \tag{2}$$

The resultant number is between zero and one.

Regarding the aggregation rule for constructing a composite index, United Nations Development Programme (UNDP) has applied the geometric mean instead of the arithmetic mean for Human Development Index since 2010 (UNDP, 2015). In this approach, higher achievement in one dimension does not linearly compensate for low achievement in another dimension. In fact, the geometric mean reduces substitutability between dimensions (UNDP, 2015).

The final vulnerability index was calculated based on both the geometric mean (Talukder et al., 2017; UNDP, 2015) and the arithmetic mean (Gbetibouo et al., 2010; Heltberg et al., 2010; Shukla et al., 2017) as following equations, respectively:

$$V_g = (E * S * AC)^{1/3} \tag{3}$$

$$V_a = \frac{E + S + AC}{3} \tag{4}$$

where V_g represents the geometric mean, V_a represents the arithmetic mean, E represents exposure, S represents sensitivity, and AC represents adaptive capacity. We considered the inverse correlation between adaptive capacity and vulnerability by converting AC to 1-AC in mean calculations.

Result and discussion

Exposure

The average precipitation in study areas is less than 100 mm/year, and the agricultural sector depends entirely on the Zayandeh Rud River. The irrigation requirement is supplied directly from the surface water and indirectly from the groundwater pumping. The effect of water scarcity on rural areas is divided into two climatic and non-climatic shocks.

Climatic exposure

From a climatic point of view, the results of studies on average temperature and precipitation changes and the effects of climate change on these parameters during the last 10 years prior to 2017 (year of study) were used. The findings of Otroj (2013) on the groundwater level trend in Isfahan province showed that anthropogenic effects are most likely to be responsible for water shortage rather than rainfall reduction. Raziei et al. (2014) also found no statistically negative trends for rainfall in this region. However, the newer studies about climate change impacts on the temperature and precipitation have indicated an increasing trend in temperature and a decreasing trend in precipitation at an annual scale across the basin. The reduction in winter snowfall would lead to a decrease in basin runoff and would significantly affect the renewable and available water resources (Nasri & Modarres, 2019; Rahmani Fazli & Salehian, 2017). However, climate change plays a role in the inconstancy of basin water resources (Rahmani Fazli & Salehian, 2017); all six districts have been influenced equally (Eslamian et al., 2017).

Non-climatic exposure

In general, the individuals who had been interviewed were unanimous about the significant effects of human-made factors on water scarcity. The results showed that a high degree of exposure to water scarcity belongs to rural areas that directly depend on the river. These districts named Bon-Rood, Jolgeh, and Markazi expose to water scarcity with 0.82, 0.78, and 0.75 scores, respectively. Surprisingly, exposures of J. Sofla J. Olya and Koohpayeh (0.25, 0.04, and 0.19) are less than those which have direct access to the river. The farmers of these areas participated financially in canal reconstruction for their irrigation systems in recent agricultural development planning; however, they have often used groundwater.

Miss/poor governance was identified as the core theme, and the categories include fragmentation and lack of coordination, policy incoherence, and centralization (Table 2). Iran has become increasingly caught in hydrological, political, and capability constraints (Collins, 2017). Understanding the impact of Iran's socio-political situation on water governance is necessary to identify non-climatic factors that affect water scarcity exposure in study areas. The persistence of these challenges indicates that water scarcity is a symptom of a more significant problem relating to the effects of Iran's oil-rent state context and the lack of state capacity that results from the inadequate development of modern state in Iran (Karl, 1997; Katouzian, 2012; Yousefi, et al., 2021).

Oil rents have changed the decision-making framework in Iran, and spending has become the key mechanism of stateness. Oil rent revenues have altered the state's function by growing bureaucracy and power centralization at the national level, whereas the public sector lacks the capacities for effective policy formulation and implementation. Additionally, oil rents have created the illusion that the country's path to economic development is without major impediments, and massive spending has become a model for the economy, with little regard for environmental restrictions. The illusion of water abundance and self-sufficiency strategy along with international sanctions, have exacerbated policy incoherence and worsened the water crisis (Madani, 2020; Yousefi et al., 2021). Over the last half-century, the construction of the Zayandeh Rud dam and water transfer tunnels, as well as access to pumping technology and cheap energy, have resulted in human overexploitation of the ecosystem and a dramatic increase in water demand due to the development of agricultural lands and energy/water-intensive industries (Yousefi et al., 2021).

Sensitivity

The results of sensitivity components show that in living standards, Koohpayeh and Jolgeh districts gained the maximum and the minimum scores (0.36 and 0.19), respectively. Both these two districts have the highest scores for financial resilience (Fig. 2). In terms of socioeconomic status, J. Olya has the highest score of 0.28 due to a high concentration of elderly people living in large part of this district with low socioeconomic conditions. The J. Sofla district obtained the minimum scores in financial and socio-economic status, which means a lower sensitivity than other districts. In general, a lower living standard and financial resilience have a greater impact on sensitivity than socioeconomic indicators (Fig. 2).

Figure 3 shows the sensitivity index calculated by Eq. 1 for four cut-offs. The increase in cut-off values reduces the sensitivity of districts. The districts' rankings are stable and robust except for the cut-off value higher than 0.3 in Markazi, Bon-rood, and J. Sofla which sensitivity lines cross each other. However, there are no significant differences among the sensitivity index of these three districts in cut-off > 0.3. It means that one district is unambiguously less sensitive than another regardless of whether households are required to be deprived in 20% or 35% of the weighted indicators (Alkire & Santos, 2). Therefore, we estimated the vulnerability index across districts based on cut-off = 0.3.

The results of the headcount of sensitivity (H), the intensity of sensitivity (A), and sensitivity index (H*A) for a cut-off of 0.3 are illustrated in Fig. 4. The number of sensitive households is significantly different across districts (Fig. 4). J.Olya has the maximum number of sensitive households (H = 0.63), and J. Sofla (H = 0.18) has the least number. This means that 63 percent of households in J. Olya and 18 percent of households in J.Sofla are sensitive. The intensity of sensitivity across districts is not very different, ranging from 0.37 (Bon-Rood) to 0.45 (J. Olya) (Fig. 4). However, the S value, which is the product of multiplying H by A, has a larger range from 0.07 (J. Sofla) to 0.28 (J. Olya), aligned with the sensitive household numbers. As mentioned above, a large portion of the J. Olya district was populated by elderly people with low socioeconomic conditions, which has led to the maximum sensitivity score. Jolgeh was ranked second in the sensitivity index, which is due mainly to financial resilience, according to Fig. 2. Farmers own lands smaller than 0.5 ha in this district, and rural residents have difficulty finding a second job.

Table 2 Main non-climatic exposures

Theme	Categories	Concepts	Open coding
Poor governance	Fragmentation and lack of coordination	Separated measures of organizations; miss-management; not taking the work and interests of other relevant stakeholders into consideration (inform and/or consider); miss-allocation; illegal water extraction; agricultural development in upstream	Orchards farming has developed in the mountains in upstream (Isfahan or Chaharmahal-o-Bakhtiyari provinces) due to the wrong planning of the government and … Unfortunately, each province decides separately. The agricultural organization assigns national ranges to the new farmers, and the regional water company in Chaharmahal-o-Bakhtiyari authorizes water extraction upstream, so these problems happen … Lack of integrated management in distribution and water consumption and no law enforcement on optimum crop pattern leads to vulnerability…
	Policy incoherence	Conflict of policy aims; short term perspective in planning; lack of attention to environmental water requirement (Gavkhoni wetland); lack of monitoring and enforcement	One party alone cannot manage the river and water resources, and inclusive involvement of people is needed for planning … The water right belongs to prior farmers and people who live in the east. According to Sheikh Bahaei Tomar share scroll from many years ago, we have water rights. These water rights should not have been sold to industry or anywhere else … It is one result of water extraction in upstream and direct pumping to their orchards without a permit; these lead to losing water-right of east of Isfahan in downstream …
	Centralization	Lack of independent rural development director; top to down planning; lack of rural participation in decision making; limited NGOs, developing water transfer by decision-makers in center	The decision about the river is made in Tehran, and we have no role…

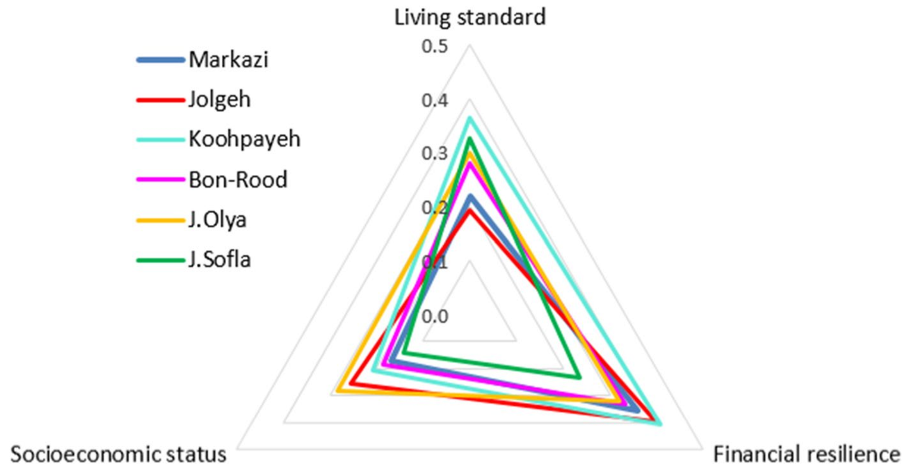

Fig. 2 Different deprivations of six districts

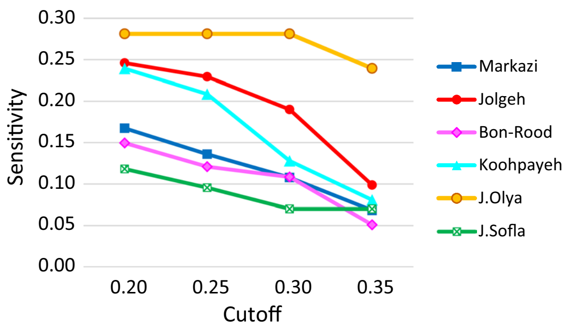

Fig. 3 Sensitivity index of districts for different cut-offs

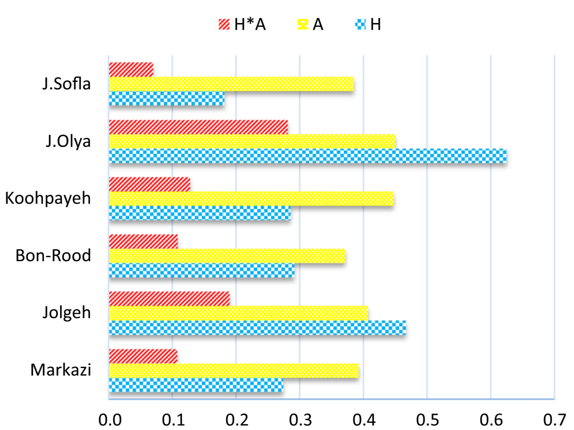

Fig. 4 Average Intensity (A), head count (H) and sensitivity (S = H*A) to water scarcity

Adaptive capacity

As shown in Fig. 5, the natural capital has a wide range in six districts compared with other capitals. The maximum score belongs to Koohpayeh (0.55), followed by Markazi (0.5). The Koohpayeh district is located in a mountainous area where water and soil conditions are suitable. The lowest natural capital is 0.12 occurred in Bon-Rood. Severe soil erosion and salty groundwater are evident in this district. The values of human and social capitals are almost similar (0.43–0.53), with a maximum difference of 0.1 among the districts. The highest human capital belongs to J.Sofla where households have more experience of dealing with a water shortage because they have never had direct access to the river, which has increased their adaption to water scarcity. J.Olya and Koohpayeh have similar experiences in terms of not having direct access to the river; however, their human capital has been reduced due to their lower education and training levels. The lowest fixed capital (financial and physical capitals) belongs to both Koohpayeh and Bon-Rood, with a score of 0.34. However, Koohpayeh has the maximum natural capital, and the score of fixed capital falls primarily due to the highest distance to the city compared with other districts. The highest fixed capital score (0.53) belongs to the Markazi district. Bon-Rood has the lowest adaptive capacity (0.34) due to the most inadequate natural capital (Fig. 5 and 6). J. Sofla, Koohpayeh, and Markazi showed the highest adaptive capacities, 0.46, 0.47, and 0.48, respectively.

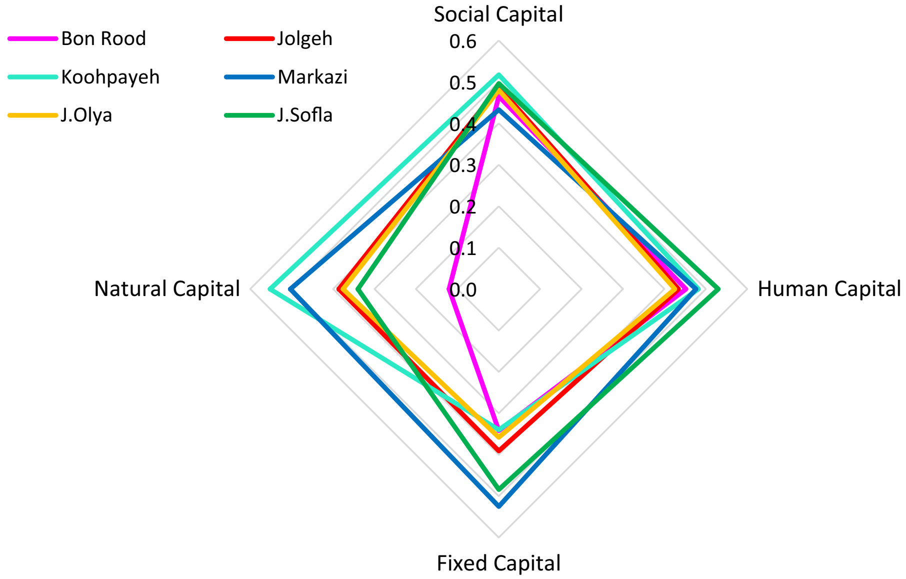

Fig. 5 Sub-components of adaptive capacity to water scarcity in six districts

Vulnerability index

Figure 6 illustrates components of vulnerability to water scarcity in six districts. The highest differences among values of components across districts are related to the exposure index. Climate factors have led to the inconstancy of basin water resources (Rahmani Fazli & Salehian, 2017); however, all six districts have been influenced equally (Eslamian et al., 2017). In fact, non-climatic factors have created different exposures to water scarcity in six districts. Poor water governance has had the most contribution to creating vulnerability. During interviews, informed people mentioned factors such as economic pressure, inflation, and inappropriate policies that led to increased vulnerability in rural areas; however, these issues exist for all people at the national level.

Table 3 shows vulnerability values calculated by arithmetic and geometric means. The vulnerability values calculated by geometric mean are more than arithmetic ones. It can be seen that different averaging approaches resulted in different vulnerability rankings of districts. The geometric-mean vulnerability (V_g) ranking is as follows: Jolgeh (0.44), Bon-Rood (0.39), Markazi (0.35), Koohpayeh (0.23), J.Olya (0.21) and J.Sofla (0.19). The arithmetic-mean vulnerability (V_a) ranking is as follows: Bon-Rood (0.53), Jolgeh (0.52), Markazi (0.46), J.Olya (0.30), J.Sofla (0.29), and Koohpayeh (0.28). In both averaging approaches, Jolgeh, Bon-Rood, and Markazi scores are significantly higher than the scores of J.Olya, J.Sofla, and Koohpayeh. The areas that had direct access to the river (Jolgeh, Bon-Rood, and Markazi) were more vulnerable than those that never had direct access to the river. Koohpayeh, J.Olya, and J.Sofla have low exposure and high adaptive capacity; however, J.Olya had the most sensitivity score.

The geometric mean is used to avoid concerns related to interaction and compensability between dimensions (Tate, 2012). Poor performance in any dimension or indicator is directly reflected in the resultant mean value (Talukder et al., 2017). Therefore, we analyzed the results based on the geometric mean. Nevertheless, differences between the two averaging approaches were not significant. Koohpayeh, J.Olya, and J.Sofla have close scores. The maximum difference in their vulnerability score is 0.04 by the geometric mean and 0.02 by the arithmetic mean. The vulnerability ranking of Jolgeh and Bon-Rood changed by two methods; however, the differences in scores are low.

Strategies for vulnerability reduction

Rural household poverty, poor water governance, and political and social limitations have amplified the impacts of water scarcity for dwellers of study

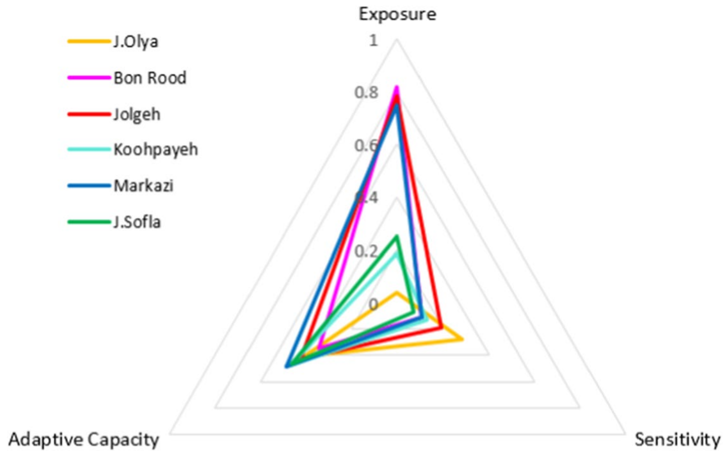

Fig. 6 Components of vulnerability to water scarcity in six districts

areas. To reduce their livelihood vulnerability, the government should support introducing adaptation approaches to mitigate farm-level losses, such as crop diversification, cultivation of drought-tolerant crop varieties, and resource conservation and management practices. Policymakers should provide farm families with access to alternative livelihood skills and credit facilities to transform into non-farm occupations (Keshavarz et al., 2017). Governments also require suitable supportive policies to ensure farmers' financial viability (Nazari et al., 2015). Technological developments in the capture, storage, and efficient use of water provide further opportunities for adaptation (Gawith et al., 2015). It was found that the vulnerabilities to water scarcity are not equally distributed across the districts, nor are they driven by the same factors. Therefore, adaptation and resilience in each district require different strategies. Some adaption techniques, such as modern irrigation systems like tape irrigation, were adopted in some parts of the study area.

Table 3 Vulnerability to water scarcity calculated by arithmetic (V_a) and geometric (V_g) means

Districts	V_a	V_g
Markazi	0.46	0.35
Jolgeh	0.52	0.44
Bon-Rood	0.53	0.39
Koohpayeh	0.28	0.23
J.Olya	0.30	0.21
J.Sofla	0.29	0.19

Conclusion

This study assessed vulnerability to water scarcity in six rural areas of Isfahan County, which have been influenced by severe water scarcity in the recent 15 years due to the drying up of the Zayandeh Rud River, the primary source of irrigation water. A mixed and integrative methodology was used to assess vulnerability. According to the results, the vulnerability varied across the districts depending on the different levels of exposure, sensitivity, and adaptive capacity of households. In general, poor water governance was the main cause of exposure to water scarcity. The main aspects of poor water governance in study areas were: a combination of power centralization and weak coordination, policy incoherence, and lack of implementation capacity. In the study area, these deficiencies are evident in no rule of law and the lack of control regarding water withdrawals, particularly from wells, weak institutional capacity for coordination, and no changes in the status quo plans and strategies to address challenges.

Although rural areas have had access to basic needs and infrastructures, the lack of turnover or cash flow has caused economic difficulties. Living standards and financial resilience contribute to sensitivity more than socioeconomic factors. The differences in adaptive capacity across rural areas have been created mainly by different natural capitals. Villages located downstream have lost their natural capital due to water-quality degradation caused by river drying up and groundwater overexploitation. The districts that had direct access to the Zayandeh Rud River were more vulnerable to water scarcity than those that had never had direct access to the river due to the more exposure and less experience in dealing with water shortage. Each region requires different strategies and measures for developing adaptation and resilience pathways. However, there is increasing evidence of maladaptation. The lack of enabling conditions can hardly be addressed within the one sector alone and is more related to the socio-political-economic context of countries that require structural transformation.

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Conflicts of interest
The authors declare that they have no conflict of interest.

References

Adger, W. N. (2006). Vulnerability. *Global Environmental Change, 16*(3), 268–281.

Alkire, S., Santos, M. E. (2010). Acute multidimensional poverty: A new index for developing countries. OPHI, Paper NO. 38.

Alkire, S., & Foster, J. (2011). Understandings and misunderstandings of multidimensional poverty measurement. *The Journal of Economic Inequality, 9*(2), 289–314.

Alkire, S., & Santos, M. E. (2014). Measuring Acute Poverty in the Developing World: Robustness and Scope of the Multidimensional Poverty Index. *World Development, 59*, 251–274.

Anonymous (2021). Thousands of Iranian farmers protest against severe water shortages,| Euronews. 2021, November 20. available at: https://www.euronews.com/2021/11/20/thousands-of-iranian-farmers-protest-against-severe-water-shortages

Bijl, D. L., Biemans, H., Bogaart, P. W., Dekker, S. C., Doelman, J. C., Stehfest, E., & van Vuuren, D. P. (2018). A global analysis of future water deficit based on different allocation mechanisms. *Water Resources Research, 54*(8), 5803–5824.

Bruno Soares, M., Gagnon, S., & A., & M. Doherty, R. (2012). Conceptual elements of climate change vulnerability assessments: a review. *International Journal of Climate Change Strategies and Management, 4*(1), 6–35.

Canadell, J.G., P.M.S. Monteiro, M.H. Costa, L. Cotrim da Cunha, P.M. Cox, A.V. Eliseev, S. Henson, M. Ishii, S. Jaccard, C. Koven, A. Lohila, P.K. Patra, S. Piao, J. Rogelj, S. Syampungani, S. Zaehle, and K. Zickfeld, 2021: Global Carbon and other Biogeochemical Cycles and Feedbacks. In *Climate Change 2021*: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 673–816, doi:https://doi.org/10.1017/9781009157896.007.

Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid, (2022): *Water*. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

Castro, A. P., Taylor, D., & Brokensha, D. W. (2012). *Climate Change and Threatened Communities: Vulnerability*. Practical Action Publishing.

Collins, G. (2017). *Iran's looming water bankruptcy*. Houston: Baker Institute for Public Policy of Rice University.

Corbin, J., & Strauss, A. (2014). *Basics of qualitative research: techniques and procedures for developing grounded theory*. SAGE Publications.

Dakurah, G. (2021). How do farmers' perceptions of climate variability and change match or and mismatch climatic data? *Evidence from North-West Ghana Geojournal, 86*(5), 2387–2406.

Dasgupta, P., Morton, J., Dodman, D., Karapinar, B., Meza, F., Rivera-Ferre, M. G., Vincent, K. E. (2014). Rural areas in: climate change 2014–impacts, adaptation and vulnerability. In: *part A: global and sectoral aspects. contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change*). Cambridge University Press: Cambridge. 613–657.

Deepali Goyal, A. K., & Haritash, S.K. Singh. (2021). A comprehensive review of groundwater vulnerability assessment using index-based, modelling, and coupling methods. *Journal of Environmental Management, 296*, 113161. https://doi.org/10.1016/j.jenvman.2021.113161

Delazeri, L. M. M., Da Cunha, D. A., & Oliveira, L. R. (2021). Climate change and rural–urban migration in the Brazilian Northeast region. *GeoJournal., 87*, 1–21.

Devkota, R. P., Pandey, V. P., Bhattarai, U., Shrestha, H., Adhikari, S., & Dulal, K. N. (2017). Climate change and adaptation strategies in Budhi Gandaki River Basin, Nepal: A perception-based analysis. *Climatic Change, 140*(2), 195–208.

El Kharraz, J., El-Sadek, A., Ghaffour, N., & Mino, E. (2012). Water scarcity and drought in WANA countries. *Procedia Engineering, 33*, 14–29.

Ensor, J., & Berger, R. (2009). *Community-based Adaptation and Culture in Theory and Practice* (pp. 227–239). Thresholds, Values, Governance, Cambridge University Press.

Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., Vincent, K., Adam, H. N., Brooks, N., & West, J. J. (2021). Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development, 141*, 105383. https://doi.org/10.1016/j.worlddev.2020.105383

Eslamian, S., Safavi, H. R., Gohari, A., Sajjadi, M., Raghibi, V., & Zareian, M. J. (2017). Climate Cange Impacts on Some Hydrological Variables in the Zayandeh Rud River Basin, Iran. *Reviving the Dying Giant* (pp. 201–217). London: Springer.

Eze, J. N., & Onokala, P. C. (2021). Pattern of household vulnerability to desertification in Yobe state. *Nigeria Geojournal*. https://doi.org/10.1007/s10708-021-10395-5

FAO & World-Bank. (2018). *Water management in fragile systems: building resilience to shocks and protracted crises in the Middle East and North Africa*. FAO and World Bank.

Fellmann, T. (2012). The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. In: Proceedings of a Joint FAO/OECD Workshop on building resilience for adaptation to climate change in the agriculture sector, Rome, Italy, 23–24 April, 2012, pp. 37–61 http://www.fao.org/docrep/017/i3084e/i3084e.pdf

Field, C. B., Barros, V. R., Dokken, D., Mach, K., Mastrandrea, M., Bilir, T., Genova, R. (2014). IPCC, 2014: Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. In: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Füssel, H. M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change, 17*(2), 155–167.

IPCC (2022). Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press: Thresholds.

Gawith, D., Hill, D., & Kingston, D. (2015). Determinants of vulnerability to the hydrological effects of climate change in rural communities: Evidence from Nepal. *Climate and Development*. https://doi.org/10.1080/17565529.2015.1067184

Gbetibouo, G. A., Ringler, C., & Hassan, R. (2010). Vulnerability of the South African farming sector to climate change and variability: An indicator approach. *Natural Resources Forum, 34*(2010), 175–187.

GSI- The Geological Survey and Mineral Exploration of Iran. (2019). Production and presentation of earth sciences data. Online access: https://www.gsi.ir/fa/map

Heltberg, R., & Bonch-Osmolovskiy, M. (2010). *Mapping vulnerability to climate change*. The World Bank.

Hofste, R. W., Reig, P., & Schleifer, L. (2019). *17 Countries, home to one-quarter of the world's population, face extremely high water stress*. Washington: World Resources Institute.

ICWP (2013). Iran's Comprehensive Water Plan: Zayandeh Rud basin, Yekom Consulting Engineers Co., Ministry of Energy, Tehran

IFAD. (2016). Rural Development Report: Fostering inclusive rural transformation. the International Fund for Agricultural Development (IFAD), Rome, Italy, September 2016, 378.

Inkani, A. I. (2015). Households' vulnerability and adaptation to water scarcity in rural areas Katsina state, Nigeria (Doctoral dissertation, University of Nairobi).

Karl, T.L., 1997. The Paradox of Plenty: Oil Booms and Petro-states. University of California Press.

Katouzian, H., 2012. Iranian History and Politics: The Dialectic of State and Society. Routledge.

Keshavarz, M., Karami, E., & Vanclay, F. (2013). The social experience of drought in rural Iran. *Land Use Policy, 30*(1), 120–129.

Keshavarz, M., Maleksaeidi, H. & Karami, E. (2017). Livelihood vulnerability to drought: A case of rural Iran. *International Journal of Disaster Risk Reduction, 21*, 223–230. https://doi.org/10.1016/j.ijdrr.2016.12.012

Klenk, N., Reed, M. G., & Mendis-Millard, S. (2012). Adaptive capacity in Canadian model forest communities: A social and regional analysis. In M. S. Beaulieu & R. N. Harpelle (Eds.), *Pulp Friction: Communities and the Forest Industry in a global perspective.* Waterloo: Laurier University Press.

Loghmani Khouzani, S. T., Kirschke, S., Yousefi, A., & Liedl, R. (2022). The effect of policy incoherence on the emergence of groundwater-related subsidence phenomena: a case study from Iran. *Water International, 47*(2), 181–204.

Madani, K., (2020). How International Economic Sanctions Harm the Environment. *Earth's Future.* 8: e2020EF001829.

Maddison, D. (2007). *The Perception of and Adaptation to Climate Change in Africa*. Herndon: World Bank Publications.

Maghrebi, M., Noori, R., Bhattarai, R., Mundher Yaseen, Z., Tang, Q., Al-Ansari, N., & Madani, K. (2020). Iran's Agriculture in the Anthropocene. *Earth's Future.* 8(9), e2020EF001547

Mavhura, E. (2019). Systems analysis of vulnerability to hydrometeorological threats: An exploratory study of vulnerability drivers in Northern Zimbabwe. *International Journal of Disaster Risk Science, 10*(2), 204–219. https://doi.org/10.1007/s13753-019-0217-x

McCubbin, S., Smit, B., & Pearce, T. (2015). Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change, 30*, 43–55.

McDowell, G., Ford, J., & Jones, J. (2016). Community-level climate change vulnerability research: Trends, progress, and future directions. *Environmental Research Letters, 11*(3), 033001.

Mohajeri, S., & Horlemann, L. (2017). *Reviving the dying giant: Integrated water resource management in the Zayandeh Rud catchment*. Springer.

Mubaya, C. P., Njuki, J., Mutsvangwa, E. P., Mugabe, F. T., & Nanja, D. (2012). Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia. *Journal of Environmental Management, 102*, 9–17.

Müller Schmied, H., Cáceres, D., Eisner, S., Flörke, M., Herbert, C., Niemann, C., & Döll, P. (2021). The global water resources and use model WaterGAP v2. 2d: Model description and evaluation. *Geoscientific Model Development, 14*(2), 1037–1079.

Nasri, M., & Modarres, R. (2019). Hydrologic drought change detection. *Natural Hazards Review*. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000301

Nazari, S., Rad, G. P., Sedighi, H., & Azadi, H. (2015). Vulnerability of wheat farmers: Toward a conceptual framework. *Ecological Indicators, 52*, 517–532.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S., & Nidumolu, U. (2010). The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. *Environmental Science & Policy, 13*(1), 18–27.

Otroj, A. 2013. Assessment of drought and anthropogenic impacts on groundwater resources in Zayandeh Rud basin. In: Master thesis. Isfahan University of Technology: Isfahan, Iran.

Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., & Pandey, V. P. (2016). Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal. *Regional Environmental Change, 16*(4), 1121–1132.

Pittman, J., Wittrock, V., Kulshreshtha, S., & Wheaton, E. (2011). Vulnerability to climate change in rural Saskatchewan: Case study of the Rural Municipality of Rudy. *Journal of Rural Studies, 284*(27), 83–94. https://doi.org/10.1016/j.jrurstud.2010.07.004

Priest, J., & Blaikie, N. (2019). *Designing Social Research: The Logic of Anticipation*. Wiley.

Qaisrani, A., Awais, U. M., Siyal, G. E. A., & Salik, K. M. (2018). What Defines Livelihood Vulnerability in Rural Semi-Arid Areas? Evidence from Pakistan. *Earth Systems and Environment., 2*, 455–475. https://doi.org/10.1007/s41748-018-0059-5

Qin, Y., Mueller, N. D., Siebert, S., Jackson, R. B., AghaKouchak, A., Zimmerman, J. B., & Davis, S. J. (2019). Flexibility and intensity of global water use. *Nature Sustainability, 2*(6), 515–523.

Raber, W., Jafari Berenji, P., Reyhani, M. N., Mohajeri, S., & Horlemann, L. (2017). Vulnerability analysis of farmers in the Roodasht Region, Iran. *Reviving the Dying Giant* (pp. 175–193). London: Springer.

Rahmani Fazli, A., & Salehian, S. (2017). The effects of Temperature and Precipitation changes on the occurrence of water resources instability in Zayandeh Rud Basin. *Arid Regions Geographic Studies, 8*(29), 52–68.

Rao, K., Ndegwa, W. G., Kizito, K., & Oyoo, A. (2011). Climate variability and change: Farmer perceptions and understanding of intra-seasonal variability in rainfall and associated risk in semi-arid Kenya. *Experimental Agriculture, 47*(2), 267–291.

Räsänen, A., Juhola, S., Nygren, A., Käkönen, M., Kallio, M., Monge, A. M., & Kanninen, M. (2016). Climate change, multiple stressors and human vulnerability: A systematic review. *Regional Environmental Change, 16*(8), 2291–2302.

Raziei, T., Daryabari, J., Bordi, I., Modarres, R., & Pereira, L. S. (2014). Spatial patterns and temporal trends of daily precipitation indices in Iran. *Climatic Change, 124*(1), 239–253.

Schipper, E.L.F., A. Revi, B.L. Preston, E.R. Carr, S.H. Eriksen, L.R. Fernandez-Carril, B. Glavovic, N.J.M. Hilmi, D. Ley, R. Mukerji, M.S. Muylaert de Araujo, R. Perez, S.K. Rose, and P.K. Singh, (2022): Climate Resilient Development Pathways. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

SCI- Statistical Center of Iran. (2014). National Census of Agriculture (2014). Retrieved from https://www.amar.org.ir

SCI- Statistical Center of Iran. (2016). Iran Population and Housing Census 2016.

Shojaei, P., Gheysari, M., Myers, B., Eslamiyan, S. S., Shafieiyoun, E., & Esmaeili, H. (2017). Effect of different land cover/use types on canopy layer air temperature in an urban area with a dry climate. *Building and Environment, 125*, 451–463. https://doi.org/10.1016/j.buildenv.2017.09.010.buildenv.2017.09.010

Shukla, R., Chakraborty, A., & Joshi, P. K. (2017). Vulnerability of agro-ecological zones in India under the earth system climate model scenarios. *Mitigation and Adaptation Strategies for Global Change, 22*, 399–425.

Singh, C., Iyer, S., New, M. G., Few, R., Kuchimanchi, B., Segnon, A. C., & Morchain, D. (2021). Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Climate and Development*. https://doi.org/10.1080/17565529.2021.1964937

Smit, B., Burton, I., Klein, R., & Wandel, J. (2000). An anatomy of adaptation to climate change vulnerability. *Climatic Change, 45*, 223–251.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282–292.

Srivastava, S., Mehta, L., & Naess, L. O. (2022). Increased attention to water is key to adaptation. *Nature Climate Change, 12*(2), 113–114.

Stojanov, R., Duží, B., Kelman, I., Němec, D., & Procházka, D. (2017). Local perceptions of climate change impacts and migration patterns in Malé. *Maldives the Geographical Journal, 183*(4), 370–385.

Talukder, B., Hipel, K.W. and VanLoon G.W. (2017). Developing composite indicators for agricultural sustainability assessment: Effect of normalization and aggregation techniques. *Resources,* 6(66). https://doi.org/10.3390/resources6040066

Tate, E. (2012). Social vulnerability indices: A comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards, 63*, 325–347.

Teng, Y., Zhan, J., Liu, S., Agyemanga, F. B., Li, Z., Wang, C., & Liu, W. (2022). Integrating ecological and

social vulnerability assessment in Qinghai Province, China. Physics and Chemistry of the Earth, Parts A/B/C, 103115.
Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., & Martello, M. L. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences, 100*(14), 8074–8079.
UNDP (2015). Training Material for Producing National Human Development Reports. UNDP Human Development Report Office. March 2015.
Unks, R. R., King, E. G., Nelson, D. R., Wachira, N. P., & German, L. A. (2019). Constraints, multiple stressors, and stratified adaptation: Pastoralist livelihood vulnerability in a semi-arid wildlife conservation context in Central Kenya. *Global Environmental Change, 54*, 124–134.
Vedwan, N., & Rhoades, R. E. (2001). Climate change in the Western Himalayas of India: A study of local perception and response. *Climate Research, 19*(2), 109–117.
Vo, T. A. N., & Tran, T. K. (2022). Climate change and rural vulnerability in Vietnam: An analysis of livelihood vulnerability index. Human and Ecological Risk Assessment: An International Journal, 1–28.
WHO (2021). Progress on household drinking water, sanitation and hygiene 2000–2020: five years into the SDGs, World Health Organization.
Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. A., & Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change, 28*, 325–336.
World Bank (2022). Water Matters Resilient, Inclusive and Green Growth through Water Security in Latin America (English). Washington, D.C. : World Bank Group. Available at: https://documents1.worldbank.org/curated/en/099450103222231166/pdf/P1668950059b6e0af0bc670ffe759af1487.pdf
World-Bank, 2017a. Beyond Scarcity: Water Security in the Middle East and North Africa. The World Bank.
Yiridomoh, G. Y., Sullo, C., & Bonye, S. Z. (2021). Climate variability and rural livelihood sustainability: Evidence from communities along the Black Volta River in Ghana. *GeoJournal, 86*(4), 1527–1543.
Yousefi, A., Knieper, C., & Pahl-Wostl, C. (2021). Restoring the dying river: Addressing the political causes of water shortage in the Zayandeh Rud basin. *Iran. German Development Institute (DIE).* https://doi.org/10.23661/bpx.2020
Yousefi, A., Knieper, C., & Pahl-Wostl, C. (2022). *Top-down command of the state and ineffective coordination: Effects of the rentier state context on the water governance of the Zayandeh Rud basin*. Environmental Science and Policy (under review).
Zarafshani, K., Maleki, T., & Keshavarz, M. (2020). Assessing the vulnerability of farm families towards drought in Kermanshah province. *Iran Geojournal, 85*(3), 823–836.
Ziaei, L. (2020). Zayandeh Rud River basin: A region of economic and social relevance in the central plateau of Iran. In S. Mohajeri, L. Horlemann, A. Besalatpour, & W. Raber (Eds.), *In Standing up to Climate Change* (pp. 91–105). Springer.

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