AQUA
Water Infrastructure, Ecosystems and Society

AQUA — Water Infrastructure, Ecosystems and Society Vol 71 No 3, 433 doi: 10.2166/aqua.2022.112

Investigating the effects of climate change, drought, and agricultural sector policies on the trend of the water poverty index in Iran

Nabeallah Yazdi[a], Seyed Nematollah Mousavi[a,*], Abdol Rassoul Zarei[b] and Abdoulrasool Shirvanian[c]
[a] Department of Agricultural Economy, Agriculture faculty, Islamic Azad University, Marvdasht Branch, Marvdasht, Iran
[b] Department of Range and watershed management (Nature engineering), Faculty of Agriculture, Fasa University, Fasa, Iran
[c] Economic, social and extension research department, Fars Agricultural and Natural Resources Research and Education Center, AREEO, Shiraz, Iran
*Corresponding author. E-mail: seyed_1976mo@yahoo.com

ABSTRACT

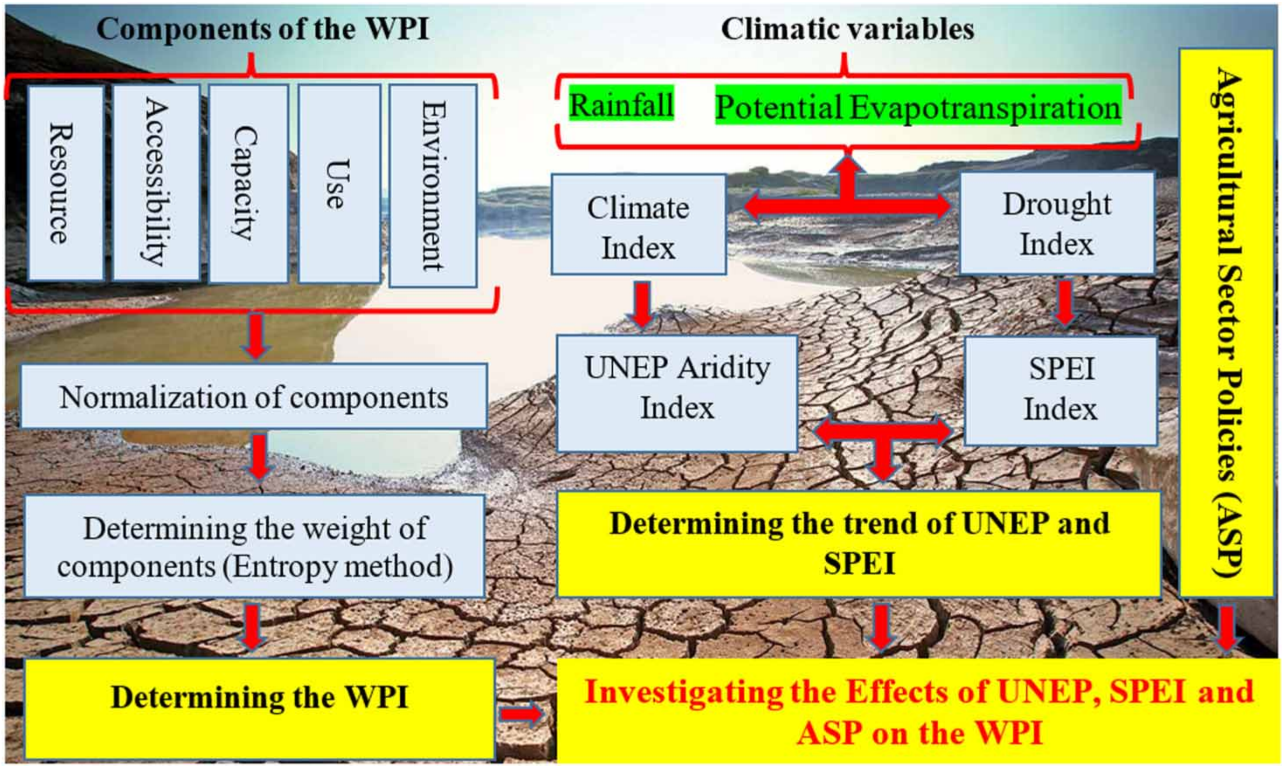
Since climate change, intermittent droughts with various severities, poor management and uncontrolled abstraction of water resources, and inattention to the balance of these resources have caused the water crisis in recent decades, it is vitally important to study the water scarcity, its changes in the future, and the effect of climate change and drought on the scarcity through appropriate management policies in the agricultural sector. To achieve this goal, the present study selected the Fasa plain in Iran and calculated its water poverty index (WPI) from 2008 to 2018 using parametric and non-parametric statistical tests. Also, the study calculated the correlation coefficient between the WPI and climate change and drought in the study area. It then evaluated the effects of water resources management policies in the agricultural sector on the poverty index. The results showed that water consumption had the greatest weight in calculating the WPI. The WPI has fluctuated between 0.297 and 0.678 in the Fasa plain, and the worst situation of water poverty was experienced in 2014. Despite its insignificance, the downward trend in the WPI showed that water resources management has become more unfavorable over time. Finally, it was concluded that the WPI in the Fasa plain was more dependent on drought than on climate change in the short term. Therefore, managing water resource consumption in this plain is vitally important, especially in drought conditions. The results also showed that reducing water consumption in the agricultural sector can significantly improve the WPI. Therefore, solving the water crisis in this plain, given the drought conditions and its future trend, requires policies improving water-use efficiency in the agricultural sector.

Key words: agricultural sector, climate change, Iran, water poverty index

HIGHLIGHTS

- Calculating the water poverty index and the trend of its changes during different years.
- Determining the correlation coefficient between the water poverty index and drought and climate indicators.
- Calculating the five major indicators in relation to the water poverty index.
- Evaluating water resources management policies on the poverty index.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water scarcity and water stress have become major global concerns over the past years. Increasing water demand due to population growth, urbanization, industrialization, expansion of agricultural activities, and economic growth are some reasons for water scarcity (Duc *et al.* 2021; Xiao *et al.* 2021a, 2021b, 2022; Yang & Usman 2021). In addition to the above-mentioned factors, there are some other parameters, such as climate change, drought, and inefficient water management policies, especially in the agricultural sector (Khadka *et al.* 2017; Salman *et al.* 2021; Stenzel *et al.* 2021) which play a significant role in assessing water stress accurately, determining the areas with water shortage, and developing effective management policies. Examining the current water resource situation and its future changes to identify the depth of the water crisis in each region and provide proper management plans requires the use of appropriate scientific multi-criteria indicators (Ray & Shaw 2019).

In Iran, water is mainly used in the agricultural sector (Nouri *et al.* 2019). The agricultural sector accounts for 92% of water consumption in Iran, which is much higher than the global average (62%) (Mohammad Jani & Yazdan 2014). Therefore, water resources management policies in the agricultural sector can effectively reduce water scarcity and its consequences. Climate change in Iran has shown itself in the form of increasing droughts and a shortage of water resources (Nazari *et al.* 2018). Therefore, it is vitally important to study the scarcity of water resources (i.e., water stress) and its future changes and evaluate the consequence of climatic variables and drought with and without appropriate management policies in the agricultural sector of Iran.

To achieve this goal, it is necessary to define climatic, drought, and water scarcity indicators. In the study of climate, the United Nations Environmental Program (UNEP) index has been one of the most widely used indicators in different parts of the world (Kimura & Moriyama 2019; Zarei *et al.* 2019a, 2019b). It has been adopted to determine the climatic situation in various studies (Meslier & DiRuggiero 2019; Moghimi & Zarei 2021; Yang *et al.* 2019; Bahrami *et al.* 2020; Zarei & Mahmoudi 2021c). For example, Zarei *et al.* (2019b) showed that the UNEP index is more accurate in determining different regions' climatic conditions than the modified De Martonne index. Nouri & Bannayan (2019) examined the trend of changes in the spatial and temporal pattern of the climate index in Iran based on the UNEP index from 1966 to 2012 and found that the index had a downward trend.

Another highly recommended index, which is internationally used in examining droughts and determining their severity and frequency, is the Standardized Precipitation Evapotranspiration Index (SPEI) (Abbasi *et al.* 2019; Alwan *et al.* 2019). It has been employed to determine drought conditions in various studies (Polong *et al.* 2019; Starks *et al.* 2019; Wang *et al.* 2019). In the following, some studies are mentioned that have employed this index. For example, Abbasi *et al.* (2019) have studied and predicted drought in the west of Lake Urmia; Polong *et al.* (2019) have studied drought's temporal and spatial patterns in Kenya, and Ye *et al.* (2019) have studied drought's spatial and temporal conditions in Northeast China.

So far, various indicators have been presented to study the scarcity of water resources in different parts of the world, including the Falcon Mark Index, the United Nations Index, the International Water Management Index, the Water Security Index, and the Water Poverty Index (WPI; Ray & Shaw 2019; Shadeed *et al.* 2019; Wurtz *et al.* 2019). Many efforts have been made to develop various indicators, methods, and options for quantitative assessment of water stress in the current conditions and its future changes at the regional and national levels (Sullivan *et al.* 2006). Water resources-related indicators contribute to water adequacy, help ensure food safety and population needs, and are helpful tools for policymakers in water resources management (Koyratty *et al.* 2021; Ladi *et al.* 2021; Mishra *et al.* 2021).

Unlike many indicators, the WPI deals with various aspects affecting the management and development of water resources. It is an effective and comprehensive tool that analyzes the existence of surface water resources and their relationship with human and environmental needs. Due to the unfavorable quantitative and qualitative conditions of water resources, the WPI has been proposed as a multi-criteria and more comprehensive index in the study of water resources (Asiabi Hir *et al.* 2018).

The WPI has been conceptualized differently in various studies comparing the status of water resources in different regions and countries (Sullivan *et al.* 2003, 2006; Panthi *et al.* 2019; Maiolo & Pantusa 2019; Ray & Shaw 2019; Chen *et al.* 2020; Khadka & Pathak 2021; Koirala *et al.* 2020). For example, the WPI has been calculated 56 using remote sensing techniques for the environmental component, namely the semi-arid San Luis Potosí region of Mexico, reflecting the strong resource management conflict. Koirala *et al.* (2020) assessed water stress in 27 areas of the Koshi River Basin in Nepal using the WPI. They selected 12 indicators from the five main components of the poverty index and found that the degree of water poverty in this basin ranged from low to moderate. Chen *et al.* (2020) argued that water resources on Taiwan's Strait Island are scarce according to the calculated WPI. They also concluded that policies for developing water resources, improving water storage, and controlling groundwater resources could reduce water stress. Khadka & Pathak (2021) examined the correlation between groundwater potential and the WPI in the Midhill region of Nepal and realized that the index is lower than the national level, and the potential of groundwater resources is directly correlated with the WPI.

An international literature review shows that the WPI in the current situation and its trend in the future has not yet been analyzed under climate change, drought, and the application of water resources management policies in the agricultural sector. Therefore, this research has been tried to apply a novel and inventive approach to examine the climate conditions, drought situations, and management policies and their relationship with the WPI. It can be claimed the present study has tried to cover the following objectives: it wants to (a) determine the climatic conditions of the study area during the period under evaluation, (b) evaluate the drought situation of the study region from 2008 to 2018, (c) calculate the WPI in the Fasa plain based on five weight components including resources, accessibility, capacity, use, and environment, and (d) assess the correlation between the WPI and climatic conditions and drought situation (with and without the application of water resources management policies) from 2008 to 2018.

2. STUDY AREA

The study area consists of the Fasa plain in Fars province, which is located at east longitude of 53°28′–53°54′ and north latitude of 28° 48′–29° 07′ with an area of 840.21 km^2 (Figure 1). It is one of the large plains of Fars province located 100 km away from the south of Shiraz. This plain is also situated at an average of 2,040 meters above sea level and has a dry climate with an average rainfall of 289.01 mm/year and an average temperature of 19.42 °C. It is mountainous in the east and is covered with forests and rangeland areas in the east and west. The agricultural and urban lands are mainly located in the central regions of the plain. The Fasa plain does not have a permanent river, and water is mainly extracted from groundwater for various sectors such as agriculture and drinking. The bedrocks in the mountainous regions are mainly comprised of dolomite

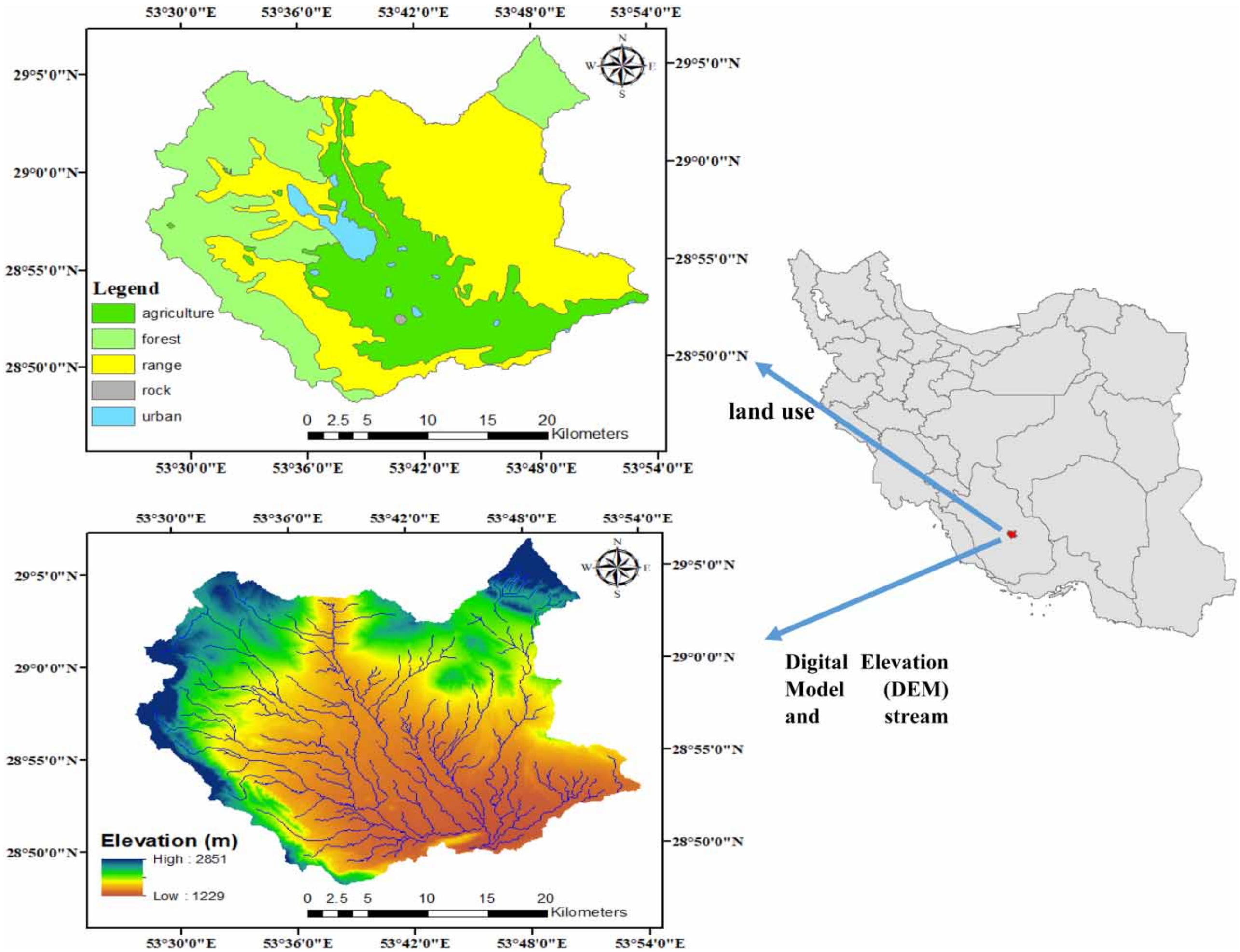


Figure 1 | Land use, digital elevation model (DEM), and stream network maps of the study area.

and calcite, while the surface of the plain consists of Quaternary deposits (i.e., mainly gravel, sand, sandy loam, and clay). In the bed of this plain, agricultural and livestock activities are the axis of the livelihood economy of the local people; in other words, over 80% of the rural population and about 20% of the urban population of Fasa are engaged in agricultural activities and animal husbandry. The dependence of these activities on water resources, the lack of proper management of water abstraction in farms, and the impact of climate change and drought on water resources in this plain have caused the focus on water resources management. Accordingly, this study tries to calculate the WPI in the Fasa plain.

3. MATERIALS AND METHODS

The WPI was adopted to determine the status of water resources in the Fasa plain based on five weight components, namely, resources, accessibility, capacity, use, and environment. According to Sullivan *et al.* (2003), Sullivan & Meigh (2007), and Ty *et al.* (2010), their mathematical relation is as follows:

$$\mathrm{WPI} = W_R R + W_A A + W_C C + W_U U + W_E E \quad (1)$$

where R is the resource, A is the accessibility, C is the capacity, U is the use, E is the environment, and W is the weight of each component. This index has a range of changes between zero and one in terms of quantity, representing that *zero* is the critical condition of water resources, and *one* is the optimal condition of water resources.

3.1. Components of the WPI

3.1.1. Resource

This component determines the extent of natural access to water resources of the Fasa plain. Its indicators include the accessibility index and the variability index, expressed as follows:

$$R = W_{R1}R_1 + W_{R2}R_2 \tag{2}$$

where R_1 is the accessibility index, R_2 is the variability index, and W_{R1} and W_{R2} are the weights of the R_1 and R_2 indices, respectively. In Equation (1), the accessibility index shows the population pressure on existing water resources. This index is a combination of three criteria, including the per capita annual rainfall criterion in the Fasa plain (R_{11}), the per capita criterion of incoming water resources from the adjacent basins (R_{12}), and the per capita criterion of groundwater resources of the plain (R_{13}) and it was calculated using the following equation:

$$R_1 = W_{R11}R_{11} + W_{R12}R_{12} + W_{R13}R_{13} \tag{3}$$

$$R_{11} = \frac{X_i}{\mathrm{POP}} \times 100 \tag{4}$$

$$R_{12} = \frac{S_i}{\mathrm{POP}} \times 100 \tag{5}$$

$$R_{13} = \frac{U_i}{\mathrm{POP}} \times 100 \tag{6}$$

where W_{R11}, W_{R12}, and W_{R13} are the weights of R_{11}, R_{12}, and R_{13}, respectively. X_i is the annual rainfall in the Fasa plain, S_i is the volume of water sources entering the Fasa plain basin from adjacent basins, U_i is the volume of groundwater resources in the Fasa plain, and POP is the total population living in this plain.

The index of variability (R_2) indicates climate variability and is calculated by combining the criteria of precipitation changes (R_{21}), temperature changes (R_{22}), and radiation changes (R_{23}) (Hamouda *et al.* 2009) as follows:

$$R_2 = W_{R21}R_{21} + W_{R22}R_{22} + W_{R23}R_{23} \tag{7}$$

$$R_{21} = \frac{P_i}{0.3} \times 100 \tag{8}$$

$$R_{22} = \frac{T_i}{0.3} \times 100 \tag{9}$$

$$R_{23} = \frac{\mathrm{SO}_i}{0.3} \times 100 \tag{10}$$

where W_{R21}, W_{R22}, and $\mathrm{W}_{\mathrm{R23}}$ are the weights of criteria R_{21}, R_{22}, and R_{23}, respectively. P_i is the coefficient variation of annual rainfall, T_i is the coefficient of change of annual temperature, and SO_i is the coefficient of radiation change in the study area.

3.1.2. Accessibility

The accessibility indicates adequate access to a sufficient amount of safe and hygienic drinking water. This component was obtained from three indicators of water supply index (A_1), health access index (A_2), and arable land index (A_3) (Asiabi Hir *et al.* 2018) as follows:

$$A = W_{A1}A_1 + W_{A2}A_2 + W_{A3}A_3 \tag{11}$$

$$A_1 = \frac{X_S}{\mathrm{POP}} \times 100 \quad (12)$$

$$A_2 = \frac{X_w}{\mathrm{POP}} \times 100 \quad (13)$$

$$A_3 = \frac{\mathrm{Cu}}{\mathrm{Re}} \times 100 \quad (14)$$

where W_{A1}, W_{A2} and W_{A3} are the weights of these indicators, respectively. X_S is the population with access to safe and hygienic drinking water, X_w is the population with access to sanitation, Cu is the area of arable land, and Re is the internal water resources in the Fasa plain.

3.1.3. Capacity

It shows the effectiveness of the ability of residents in managing water. It also has two indicators: the annual average water storage or the amount of water allocated to each person ($C1$) and the annual average agricultural lands or the amount of arable land allocated to each person ($C2$). It is calculated (El-Gafy 2018) as follows:

$$C = W_{C1}C_1 + W_{C2}C_2 \quad (15)$$

$$C_1 = \frac{D_i}{\mathrm{POP}} \times 100 \quad (16)$$

$$C_2 = \frac{Z_i}{\mathrm{POP}} \times 100 \quad (17)$$

where W_{C1} and W_{C2} are the weights of mentioned indices, respectively. D_i is the total water volume in the reservoirs of the existing dams, and Z_i is the total area of agricultural lands in the Fasa plain.

3.1.4. Use

In relation to the component of use, water use has been considered for domestic and agricultural purposes and this component examines the amount of water use and the type of water resources exploitation. Accordingly, this component has two indicators: per capita household water use (U_1) and per capita agricultural water use (U_2):

$$U = W_{U1}U_1 + W_{U2}U_2 \quad (18)$$

$$U_1 = \frac{P_i}{\mathrm{POP}} \times 100 \quad (19)$$

$$U_2 = \frac{K_i}{\mathrm{SUM}} \times 100 \quad (20)$$

where W_{U1} and W_{U2} are the weights of these indices, P_i is the volume of water used in the household sector, K_i is the total area of irrigated agricultural land, and SUM is the total area of agricultural land in the Fasa plain.

3.1.5. Environment

This component was determined based on the amount of chemical fertilizer per unit area of agricultural land in the Fasa plain, and it was used as an indicator of environmental stress or pressure applied to the ecosystem:

$$E = \frac{L_i}{\mathrm{SUM}} \times 100 \quad (21)$$

where L_i is the amount of chemical fertilizer and SUM is the total area of agricultural land in the Fasa plain.

3.2. Normalization of criteria, indicators, and components

Each criterion, indicator, and component expressed in Equations (1)–(21) are measured using their units. Despite the various units of measurement of criteria, indices, and components, their algebraic sum in the mentioned equations is not possible;

therefore, it is necessary to unify or, in other words, to normalize equations to enable integration in them. In this respect, the following equation was used:

$$Np = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (22)$$

where X_i, X_{min}, and X_{max} are the value, the minimum, and the maximum of each component, indicator, and criterion, respectively.

3.3. Determining the weight of criteria, indices, and components

The entropy weighting method was used to determine the weight of components, indices, and criteria. In this method, first, the probability distribution is determined (Equation (23)), after that, the entropy index is determined (Equation (24)), and then the deviation of information is determined in each index (Equation (25)). Finally, weights were calculated using the amount of deviation from the information (Equation (26)).

$$\text{Prob}_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (23)$$

$$E_j = -\frac{1}{Ln(m)} \sum_{i=1}^{m} (\text{Prob}_{ij} \times Ln(\text{Prob}_{ij})) \quad (24)$$

$$D_j = 1 - E_j \quad (25)$$

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \quad (26)$$

where Prob_{ij} is the probability of occurrence of ith value in the component, index, or criterion of jth, r_{ij} is the frequency percentage of each value in this component, index, or criterion, E_j is the entropy index of jth, D_j is the amount of deviation from the information in jth, and W_j is the weight of jth.

3.4. Climate index

The UNEP drought index was employed to assess the annual climatic conditions (Zarei *et al.* 2019b; Zarei & Mahmoudi 2021a, 2021b). It is calculated based on the ratio of annual rainfall (P_i) to annual potential evapotranspiration (PET_i) (UNEP 1992) as follows:

$$\text{UNEP index} = \frac{P_i}{\text{PET}_i} \quad (27)$$

In the above equation, the Penman–Monteith FAO equation was used to calculate the potential evapotranspiration (Allen *et al.* 1998). Based on the UNEP method, climatic condition classes are presented in Table 1.

3.5. Drought index

The SPEI was used to assess the annual drought situation. It is based on precipitation and potential evapotranspiration. First, the difference between precipitation (P) and potential evapotranspiration for the i month was obtained from the following equation:

$$D_i = P_i - \text{ETP}_i \quad (28)$$

In this equation, D values at different time scales were obtained from the following equation:

$$D_n^k = \sum_{n=o}^{K-1} P_{n-1} - \text{ETP}_{n-i} \quad (29)$$

where k is the desired time scale (months), and n is the desired month in the calculation. Other variables are already defined.

Table 1 | Classification of climatic conditions and drought severity based on the UNEP and the SPEI, respectively

Class number	Climatic conditions	UNEP range	Class number	SPEI range	Drought class
1	Humid	>0.65	1	≥2	Extremely wet
2	Sub-humid	0.5–0.65	2	1.50–1.99	Severely wet
3	Semi-arid	0.2 to ≤0.5	3	1–1.49	Moderately wet
4	Arid	0.05 to ≤0.2	4	−0.99 to 0.99	Near normal
5	Hyper arid	≤0.05	5	−1 to −1.49	Moderate drought
			6	−1.5 to −1.49	Severe drought
			7	≤− 2	Extreme drought

A three-parameter distribution is needed to calculate the drought index to cover the negative D values. And it seems that the logarithmic logistic function properly fits the time series of data at different time scales. The cumulative probability function of the *D* data series is based on the logarithmic logistic function as follows:

$$F(X) = \left[1 + \left(\frac{\alpha}{X - \gamma}\right)\right]^{-1} \tag{30}$$

where α is the scale parameter, and γ is the main parameter for *D* values in the range between γ and ∞. Based on the SPEI, different drought classes are presented in Table 1.

3.6. Investigating the correlation between the WPI and UNEP and SPEI

At this stage, the correlation between WPI and SPEI and UNEP was, first, calculated based on the Equation (31) from 2008 to 2018. After that, the significant level of the calculated coefficient was investigated according to the Fisher table with a freedom degree of $n - 2$.

$$R = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sqrt{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}} \tag{31}$$

where x and y are the variables under study, and n is the number of data.

Then, the water consumption reduction scenarios in the agricultural sector were presented as a policy approach of policymakers in water resources management to examine the different water resources management policies on the WPI. These scenarios can be played by improving irrigation efficiency through new irrigation technologies and appropriate water transfer systems, cultivating crops that require less water, increasing the use of varieties of drought-resistant crops, and applying low irrigation. Therefore, the impact of water consumption reduction scenarios as the output of appropriate water resources management policies on the WPI is measured using Equation (20).

In this study, the required meteorological data was prepared by the Iran Meteorological Organization. Information about the total volume of water reservoirs of dams, information on water resources (surface and groundwater), incoming and outgoing water, and water consumption in different sectors were provided by the Fasa Water Organization. Statistics of the population and their accessibility to safe drinking water were prepared by the urban and rural water supply department and the central health department of Fasa. Information on agricultural parameters and fertilizers was obtained from the Agricultural Jihad Organization of Fasa.

4. RESULTS AND DISCUSSION

4.1. Trend of WPI components

The resource component is obtained from the total weight of the two indicators of accessibility and variability, considering the same weight for both indicators. The results showed that the value of the calculated resources component ranged from 0.165 to 0.361, and the average value of this component was 0.230 during the years under study (Table 2; Figure 2). The highest and lowest values of the resource component belong to 2011 and 2018, respectively. The value of the resource component for different areas was estimated at 0.61 in Lopez-Alvarez *et al.* (2020), 0.40 in Koirala *et al.* (2020), and more than 0.60 in Chen *et al.* (2020). Comparing the value of the resource component of the study area with other areas shows that the Fasa plain is not in a good position in terms of available water resources.

Figure 3 shows that accessibility had an ascending trend from 2008 to 2018 and reached one in 2018. Therefore, it can be understood that access to safe and healthy agricultural water has been facilitated in the Fasa plain from 2008 to 2018. The high value of the accessibility component has also been proven in other studies, showing the improvement of facilities and technological advances in transportation and health infrastructure around the world (Maiolo & Pantusa 2019; Ray & Shaw 2019; Chen *et al.* 2020; Khadka & Pathak 2021; Koirala *et al.* 2020).

Table 2 | Normalized values of WPI index components in the Fasa plain during 2008–2018

	Components				
Year	**Environmental**	**Water use**	**Capacity**	**Availability**	**Resources**
2008	0.643	0.954	1	0.000	0.213
2009	0.655	1	0.823	0.000	0.247
2010	0.863	0.985	0.694	0.013	0.361
2011	0.685	0.913	0.524	0.025	0.181
2012	1	0.839	0.431	0.333	0.202
2013	0.935	0.604	0.341	0.641	0.275
2014	0.798	0.000	0.218	0.949	0.211
2015	0.863	0.276	0.156	0.962	0.190
2016	0.000	0.840	0.049	0.975	0.190
2017	0.143	0.841	0.236	0.987	0.299
2018	0.030	0.790	0.000	1	0.165
Average	0.601	0.731	0.406	0.535	0.230

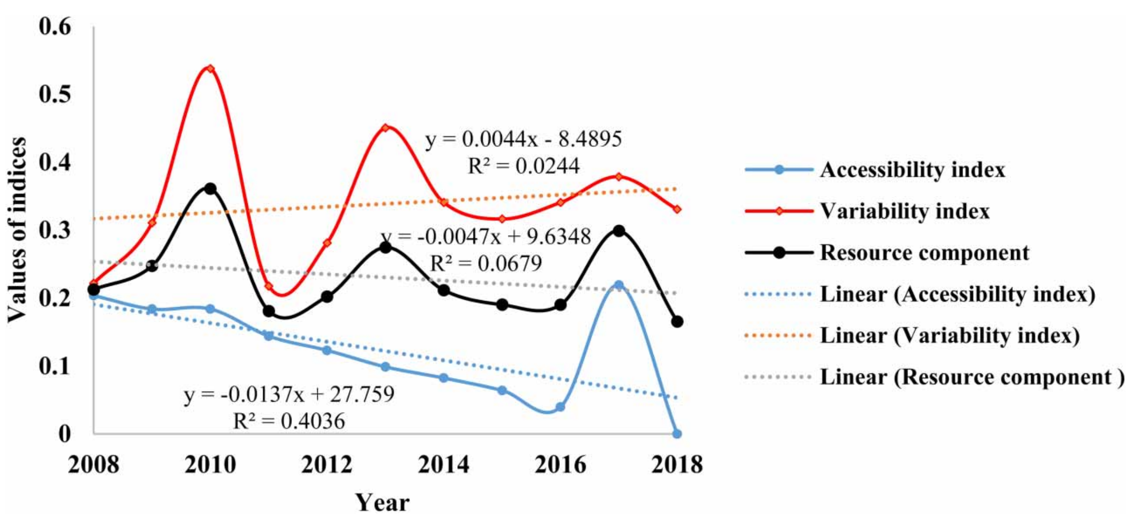


Figure 2 | Values of accessibility and variability indices and resource component.

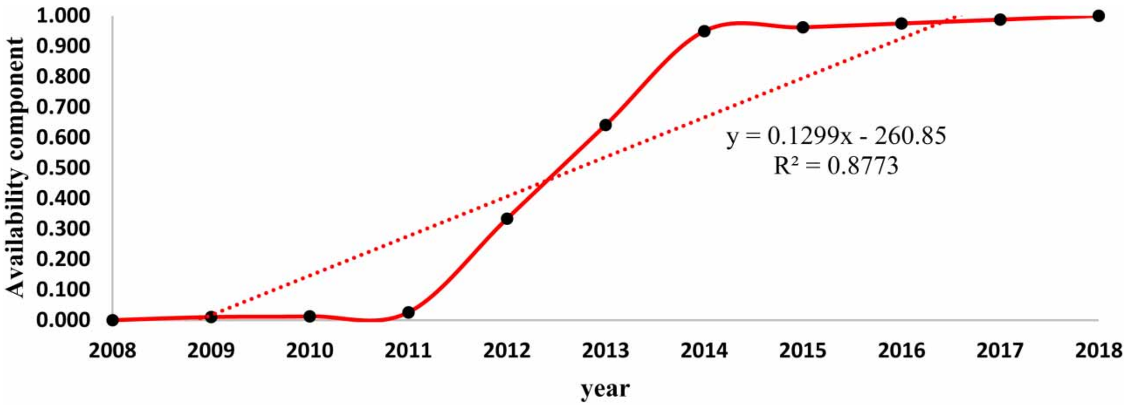


Figure 3 | Capacity component during 2008–2018.

Unlike the accessibility, there was a descending trend in the capacity from 2008 to 2018 (Figure 4), indicating that the Fasa plain's residents' ability to manage water resources has decreased over time. A review of various studies shows that the capacity value is estimated to be higher than 0.50 (Hawrami & Shareef 2020; Koirala *et al.* 2020; Lopez-Alvarez *et al.* 2020) in some studies and less than 0.50 in others.

The use component had a downward trend until 2014 and then had an upward trend (Figure 5). The average value of this component was obtained to be 0.73 for the Fasa plain during the studied years (Table 2). Its normalized value varies from 0 to 1. A comparison of the calculated value of the use in this study with the value of this component in other studies (Maiolo & Pantusa 2019; Panthi *et al.* 2019; Ray & Shaw 2019; Chen *et al.* 2020; Khadka & Pathak 2021; Koirala *et al.* 2020) shows that the level of water consumption is high in the Fasa plain.

The results showed the environment is almost declining and fluctuates wildly during the years under study (Figure 6). The average value of this component is 0.60 during the years under study (Table 3). This component is estimated between 0.20 and 0.60 for different regions of the Strait Island in Taiwan (Chen *et al.* 2020). The value of this component proved that the use of chemical fertilizers is high in the Fasa plain.

4.2. Calculation of the WPI

The weight of importance of different components was calculated using the entropy model to measure the WPI, which was obtained from the weight composition of the components. Table 3 shows that the highest and lowest weights of importance are related to the use and capacity, respectively. The results of the WPI calculated in Table 4 show that the WPI fluctuated between 0.678 in 2011 and 0.273 in 2015 (Table 4). Therefore, it can be understood that the shortage of water resources (i.e., water stress) has reached its minimum in 2011 and its maximum in 2015. The average WPI of the Fasa plain is equal to 0.562 during the study years. A review of the literature shows that the WPI in most arid and semi-arid regions is between 0.4 and 0.7

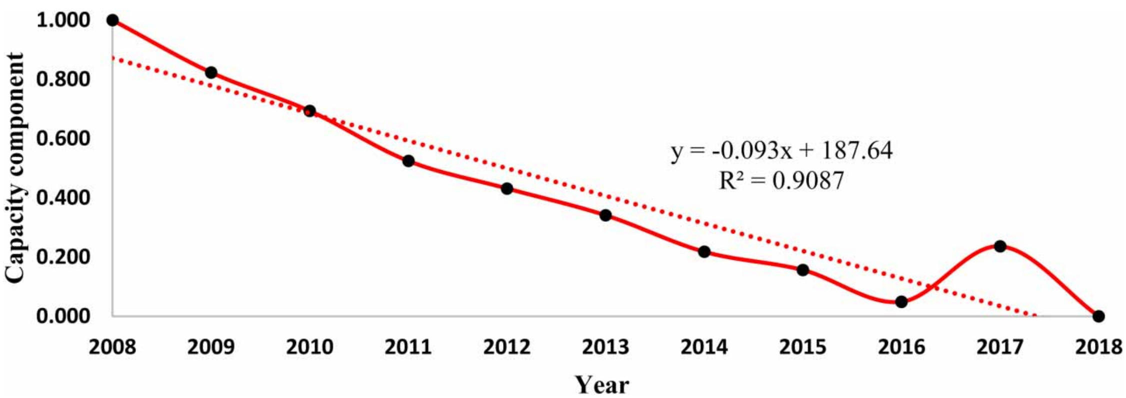


Figure 4 | Availability component during 2008–2018.

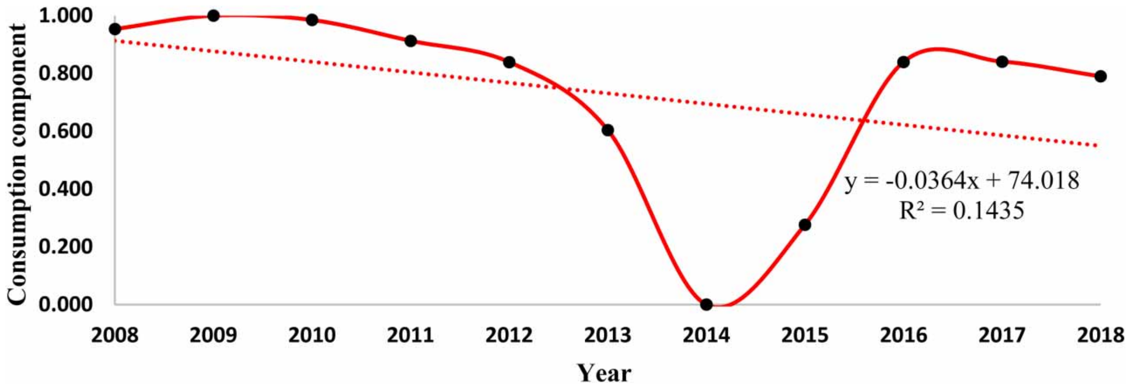


Figure 5 | Consumption component during 2008–2018.

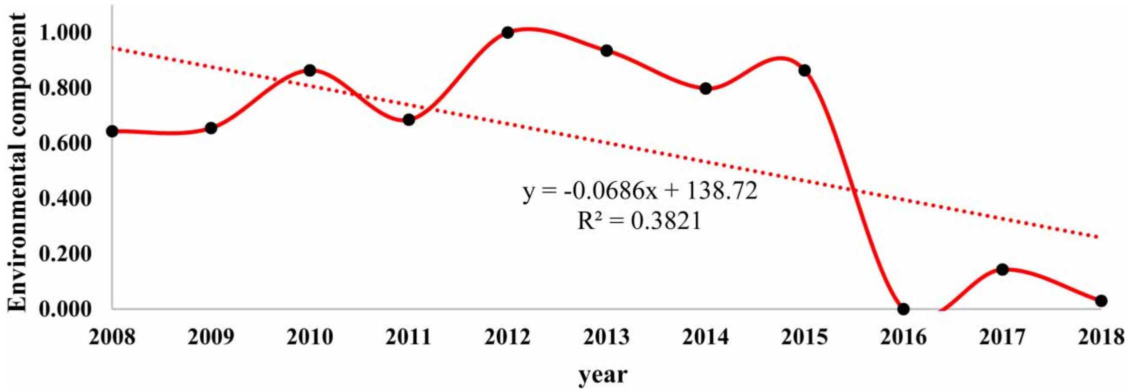


Figure 6 | Environmental component during 2008–2018.

Table 3 | Calculated weight for WPI index components

Component	Environmental component	Water use	Capacity	Availability	Resources
Weight	0.140	0.474	0.000	0.140	0.246

Table 4 | WPI in the Fasa plain during 2008–2018

Year	WPI	Year	WPI
2008	0.594	2014	0.297
2009	0.626	2015	0.434
2010	0.678	2016	0.581
2011	0.576	2017	0.630
2012	0.634	2018	0.559
2013	0.575		

(Maiolo & Pantusa 2019; Ray & Shaw 2019; Chen *et al.* 2020; Hawrami & Shareef 2020; Khadka & Pathak 2021; Koirala *et al.* 2020).

The study of changes in the WPI and its components in the Fasa plain was presented using different statistical methods, as shown in Table 5. According to all statistical methods, namely, Spearman, Mann–Kendall, and linear regression, the results

Table 5 | Results of the trend of changes in the WPI and its components during 2008–2018

Components and indicators	Spearman's dtatistics	Mann–Kendall test	Slope of regression Line
Resource component	−1.216	−0.981	−0.005
Availability component	4.589*	3.125*	0.130*
Capacity component	−4.213*	−2.941*	−0.093*
Use component	−2.112*	−1.781	−0.036
Environmental component	−1.201	−0.681	−0.069*
WPI	−1.380	−1.031	−0.010

*The trend of changes at the 5% level is significant.

showed that the accessibility component has a significant upward trend, which can be due to the improvement of people's living standards, higher access levels to health, more arable lands as a result of the destruction of pastures and their conversion into agricultural land, and the ease of supplying the required water as a result of technological progress (Table 5). In addition, the capacity has a significant downward trend based on all the methods indicating the reduced effectiveness of residents' ability to manage water resources over time. The changes in the WPI is descending and meaningless; however, despite its statistical insignificance, this decline is an alarm regarding the critical situation of water resources available for drinking and agricultural use in the coming years. Naturally, this issue highlights the need for the scientific and appropriate management and control of water resources in the study area.

4.3. Calculation of the UNEP climate index

Based on the UNEP climate index results, the best and worst years were 2016 and 2017, with index values of 0.279 and 0.027, respectively, in terms of climatic conditions (Figure 7). Studies have shown that this index has an insignificant upward trend in the period under review.

4.4. Calculation of the annual SPEI drought index

Based on the SPEI calculated in the statistical period under review, the most severe drought occurred in 2017 (with the SPEI equal to −3.29), while the most severe wet year (with the SPEI equal to 3.483) occurred in 2016. Studies showed that this index had an insignificant downward trend in the period under study (Figure 8).

4.5. Correlation coefficient between the WPI and UNEP and SPEI

The correlation coefficient between the WPI and UNEP and SPEI in Table 6 showed that the correlation with drought is more significant than the correlation with climate. The correlation coefficient between the WPI and UNEP and SPEI is 0.039 and 0.414, respectively, affected by the short-term effects of drought on water resources. However, climate is a long-

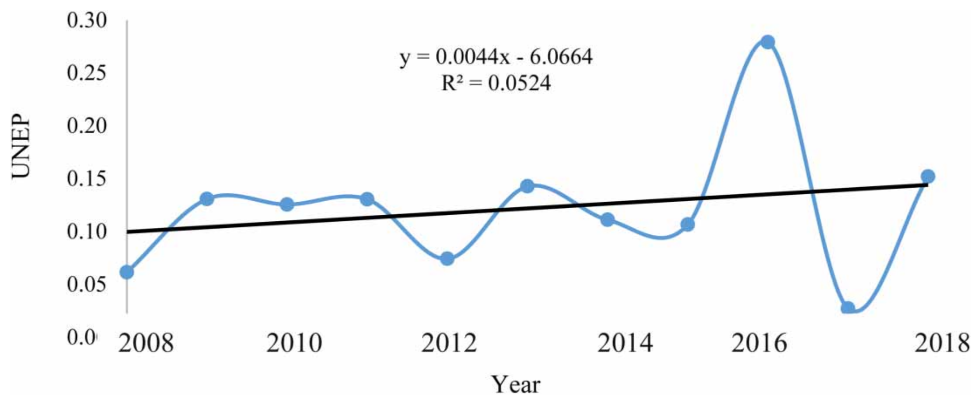


Figure 7 | UNEP climate Index during 2008–2018.

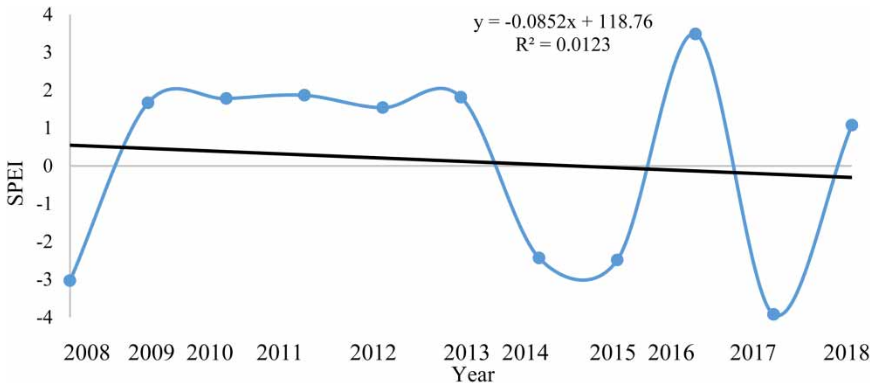


Figure 8 | SPEI drought index during the years 2008–2018.

Table 6 | Correlation coefficient between the studied indicators in the statistical period in the Fasa plain

	SPEI	UNEP index	WPI index
WPI index	–	–	1
UNEP index	–	1	0.039
SPEI index	1	0.732*	0.414*

*The correlation coefficient at the 5% level is significant.

term phenomenon and its effects in the short term (11-year period under study) are not very tangible. Therefore, drought is a factor affecting the WPI; however, the effect of climate change on the WPI is not proven in the period under review (i.e., a short period).

4.6. Calculation of the WPI by applying water resources management policies in the agricultural sector

Agricultural policymakers can reduce water consumption in agriculture by applying appropriate policies to encourage farmers to improve irrigation efficiency through new irrigation technologies and water transfer systems, cultivating crops that require less water, using more varieties of drought-resistant crops, and poor irrigation. In the present study, three water consumption reduction scenarios (10, 15, and 20%) were applied in the agricultural sector of the Fasa plain with the help of policies such as improving irrigation efficiency through the use of new irrigation technologies, and their effects on the WPI were investigated (Table 7). The results showed that the application of irrigation efficiency improvement policies in the agricultural sector of the Fasa plain could increase the average WPI during the years under study. Therefore, the WPI was 0.594, 0.622, and 0.659 with applying water consumption reduction scenarios of 10, 15, and 20%, respectively. The percentage change of the WPI for scenarios of 10, 15, and 20% of water resources consumption reduction compared to the case without using scenarios is equal to 5.69, 10.68, and 17.26%, respectively. This finding shows that as the decrease in water consumption intensifies, the rate of increase in the WPI has become close to the rate of decrease in water consumption. Therefore, further water resources reduction can significantly increase the WPI and solve the water crisis in the Fasa plain.

Finally, the results showed that water consumption management is the most critical measure for reducing water poverty in the Fasa plain, especially in the agricultural sector. As water consumption is in the field of demand in terms of the economic approach, so it is necessary instead of using grammatical tools, demand management in the Fasa plain should be on the agenda to adjust water consumption. According to the results, the WPI quickly depends on drought than climate change. Therefore, it can be understood that drought, despite climate change, will have adverse effects on the water crisis in the Fasa plain in a short time. To this end, it is necessary to use water management policies in the agricultural sector to reduce water consumption and mitigate the unfavorable situation of the water crisis under drought conditions. The results showed that policies of water consumption reduction in the agricultural sector could significantly improve the WPI.

Table 7 | WPI with and without the application of water resources management policies

Year	WPI without change in policies	WPI by applying water resources management policies		
		10% reduction in water consumption	15% reduction in water consumption	20% reduction in water consumption
2008	0.594	0.636	0.669	0.716
2009	0.626	0.679	0.727	0.797
2010	0.678	0.723	0.774	0.837
2011	0.576	0.614	0.645	0.689
2012	0.634	0.666	0.697	0.734
2013	0.575	0.601	0.622	0.650
2014	0.297	0.309	0.322	0.344
2015	0.434	0.450	0.461	0.473
2016	0.581	0.611	0.636	0.664
2017	0.630	0.661	0.686	0.713
2018	0.559	0.586	0.605	0.627
Average	0.562	0.594 (5.69%)	0.622 (10.68%)	0.659 (17.26%)

Therefore, it is necessary to reduce farmers' water consumption and solve the water crisis of the drought conditions by teaching agricultural ways such as using new irrigation technologies and proper water transfer systems to farms to increase farmers' water consumption efficiency and effectiveness.

5. CONCLUSIONS

This study investigated the effects of climate change, drought, and water resources management policies in the WPI and found that the WPI varied from 0.297 to 0.678 in the study area from 2008 to 2018, while its average was 0.562. Therefore, it can be concluded that the region has a moderate water crisis. The trend of different WPI components from 2008 to 2018 showed that the accessibility had a significant upward trend (at the 5% level), and the capacity had a significant downward trend (at the 5% level). The upward trend of accessibility is due to the ease of access to the required water due to the advancement of technology, high level of access to health, and more arable lands due to the destruction of pastures, turning them into farmland over time. The declining trend of capacity also shows that residents' ability to manage water resources has decreased over time. On the other hand, the downward trend of the WPI, despite its insignificance, showed that the situation of water resources management has been in a more unfavorable situation over time. The results showed that the use has played a more significant role in the occurrence of this challenge than other components.

ACKNOWLEDGEMENTS

The authors thank the Iranian Meteorological Organization, the Water Organization of Fars, and the Agriculture Jahad Fars Organization for their cooperation in providing the necessary data.

AUTHOR CONTRIBUTIONS

The participation of authors includes the data collection, analyzing the results, and writing the article.

ETHICS APPROVAL

The authors confirm that this article is original research and has not been published or presented previously.

FUNDING

No funds, grants, or other support were received.

CONFLICT OF INTEREST

The authors have no conflict of interest. Also, the authors certify that they are not affiliated with or involved with any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this paper.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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First received 20 August 2021; accepted in revised form 18 February 2022. Available online 2 March 2022