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Water Poverty Index and its Changes Trend in Fasa Plain

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Abstract

Due to increasing population growth, inadequate management of surface and subsurface water resources, and the escalation of the water crisis in the coming years, will be inevitable. Therefore, it is necessary to provide scientific and multi-criteria indices capable of more precisely examining the status of surface and subsurface water resources. In this study, the water poverty index (WPI) based on five weighted components of resources, availability, capacity, consumption and environment of the Fasa plain during 2008-2018 were calculated and their trends were evaluated using parametric and nonparametric statistical tests (i.e. Mann-Kendall and Spearman). The results showed that the consumption component (0.47) and the capacity component had highest and lowest role in the WPI index. Trend analysis of the WPI index showed that the WPI based on the linear regression, Mann-Kendall and Spearman tests had a non- significant decreasing trend (with S= -0.01, Z_S= -1.03 and Z_D= -1.38, respectively). It is natural that the decrease in WPI values reflects an increase in the level of crisis in available water resources. Due to the downward trend of WPI index in the Fasa plain, proper scientific and practical management of water resources is essential to provide the enable long-term sustainable use of resources.

Keywords: Water Poverty Index, Change Trend, Parametric Tests, Nonparametric Tests, Fasa Plain.

1- Introduction

Water scarcity is one of the greatest challenges of the present century and one of the most critical issues in the next half century (Alessa et al. 2008; Mokarram et al. 2015). Proper and efficient management of available water resources, both surface and subsurface, followed by equitable development and protection of the environment without regard to the issue of water resources management is a serious challenge (Mishra and Singh, 2010; Brown and Matlock, 2011). Accordingly, assessing the status of water resources in the current situation as well as its future changes in order to identify the depth of the water crisis in each region and to assist in its proper management requires the use of appropriate and multi-criteria scientific indicators. So far, various indicators have been presented for assessing the water crisis in different parts of the world, such as the Falcon Mark index, the UN index, the International Water Management Institute index, the Water Security index, the Water Poverty index, etc, (Lawrence et al. 2002; Sullivan, 2002; Wurtz et al. 2019; Ray and Shaw, 2019; Shadeed et al. 2019).

In recent years, various researchers around the world have been investigating the status of water resources using the Water Poverty Index. For example, Talebi and Amini (2018) studied the dimensions of dehydration using a comparative analysis of water poverty index in Qom districts. The results of his research showed that the best approach to managing water poverty is to make the best use of available resources and capacities and to focus on the principles of planning rather than focusing on water resources expansion in different ways. Asiabi Hir et al. (2018) assessed the water poverty index in some Ardabil watersheds using the five components include resources, availability, capacity, consumption and environment. The results of his research showed that water poverty index is an effective and comprehensive tool for analyzing the availability of surface water resources and its relation to human and environmental needs. Huang et al. (2017) assessed the trend of changes in WPI for assessment of water stress and water management policies in China. The results of this paper indicated that the WPI had an increasing trend from 2003 to 2015 (non-significantly). Many researchers assessed the water poverty index around the world such as Panthi et al. 2019; Ray and Shaw, 2019; Maiolo and Pantusa, 2019; Liu et al. 2019 López-Álvarez et al. 2019; El-Gafy, 2018; Shakya, 2012.

Due to the importance of available water resources in the Fasa area due to the arid climate of the region, people's livelihoods are highly dependent on aquaculture professions such as agriculture, over-harvesting of groundwater resources, inappropriate temporal and spatial distribution of water resources with emphasis on precipitation and Consequently, the need for sound and scientific management of resources in this study was calculated by calculating water poverty index in Fasa plain based on five weighted components of resource component, availability, capacity, consumption and environment of its change trends using parametric and non-parametric statistical tests.

2- Materials and Methods

Study Area

Fasa plain is geographically located at 53° 28 ´ to 53° 54´ east and latitude 28 ° 48´ to 29 ° 7´ west with an area of 840.21 square kilometers (Figure 1). The study area is climatically dry with an average rainfall of 289.01 mm per year, average temperature of 19.42 ° C and average altitude of 2040 meters above sea level (Bahrami et al. 2019).

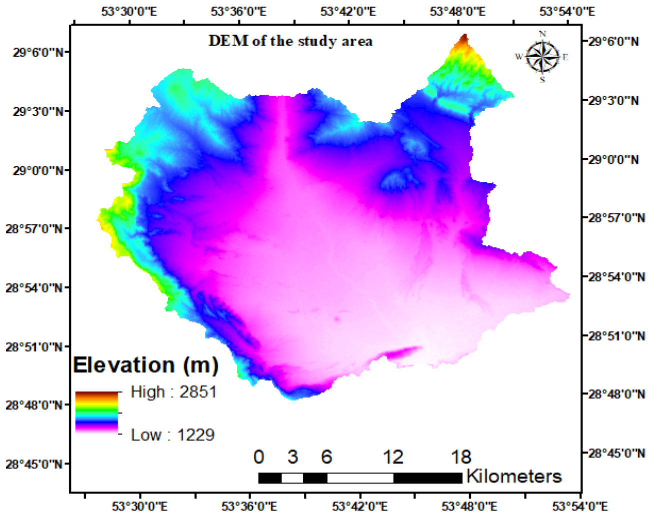

Fig1. Geographical position and elevation map of the study area

3- Method

Water Poverty Index

Water poverty index (WPI) is based on five weight components including resources, availability, capacity, consumption, and environment (Eq. 1).

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

Where R is the resource component, A is the availability component, C is the capacity component, U is the consumption component, E is the environmental component, and W is the weight of each component.

WPI after normalization will range from 0 to 1 with zero indicating a critical state of water resources and 1 favorable status of water resources.

Water poverty index components

Resource component (R)

This component determines the extent of natural access to water resources in the study area. Indicators used in this component include the accessibility index and the variability index. According to Asiabi Hir et al. (2018), this component is expressed in equation (2):

$$R = W_{R1} R_1 + W_{R2} R_2 \quad (2)$$

Where R_1 is the index of accessibility, R_2 is the index of variability, W_{R1} and W_{R2} are the weights of the R_1 and R_2 indices, respectively.

The accessibility index is calculated by combining the criteria of annual rainfall, water resources per capita from adjacent basins, and groundwater resources per capita using equation 3 (Rajabi-Hashjin and Arab, 2006):

$$R_1 = W_{R11}R_{11} + W_{R12}R_{12} + W_{R13}R_{13}$$
(3)

Where R_1 Accessibility index, R_{11}, R_{12} and R_{13} are annual rainfall criterion per capita, water resource benchmarks from adjacent basins per capita and benchmark of groundwater resources per capita, respectively, W_{R11}, W_{R12} and W_{R13} are weight criteria R_{11}, R_{12} and R_{13}, respectively, .

In equation (3):

$$R_{11} = \frac{X_i}{POP} \times 100$$
(4)

$$R_{12} = \frac{S_i}{POP} \times 100$$
(5)

$$R_{13} = \frac{U_i}{POP} \times 100$$
(6)

Where X_i is the amount of annual rainfall (mm), S_i is the volume of water inputs to the basin from adjacent basins (m^3 per year), U_i is the volume of groundwater resources (m^3 per year) and POP is the total population of the study area.

Also, the index of variability can be calculated by combining the criteria of rainfall variations, temperature variations and radiation variations using equation (7):

$$R_2 = W_{R21}R_{21} + W_{R22}R_{22} + W_{R23}R_{23}$$
(7)

Where R_2 variability index, R_{21}, R_{22} and R_{23} are the rainfall change criteria, temperature change criterion and radiation change criterion, W_{R21}, W_{R22} and W_{R23}, respectively, are the weight of the criteria R_{21}, R_{22} and R_{23}.

In equation (8):

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

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

$$R_{23} = \frac{SO_i}{0.3} \times 100$$
(10)

Where P_i is the coefficient variation of annual rainfall (based on the ratio of average precipitation and standard deviation of it), T_i the coefficient variation of annual temperature (based on the ratio of average temperature and standard deviation of it) and SO_i is the coefficient variation of sunshine of the study area.

Availability component

This component is determined using the three indices of water supply, availability to health, and arable land using equation (11) (Asiabi Hir et al. 2018; Rajabi-Hashjin and Arab, 2006):

$$A = W_{A1}A_1 + W_{A2}A_2 + W_{A3}A_3$$
(11)

In equation (11):

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

$$A_2 = \frac{Xw}{POP} \times 100$$
(13)

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

Where: A_1, A_2 and A_3, respectively, water supply index, health access index and arable land index, W_{A1}, W_{A2} and W_{A3}, respectively, by weight of indices A_1, A_2 and A_3, X_S population of people with access to safe drinking water and hygienic, Xw population of access to sanitary and Cu area of arable land in the study area, Re domestic water resources in the study area.

Capacity component

This component has two indicators of water per capita or water allocation per person per year and per capita index of agricultural land allocated per person per year and is calculated using the equation 15 (El-Gafy, 2018; Cho and Ogwang, 2014):

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

In equation (15):

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

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

Where C_1 and C_2 are the index of water reserve per capita or amount allocated per person per year, and the index of agricultural land per capita of arable land per year, respectively, W_{C1} and W_{C2} are weight of C_1 and C_2 indices, respectively, D_i is the total volume of water reservoirs in the study area (m^3 per year) and Z_i is the total area of agricultural land available in the study area.

Consumption component

This component has two indices of consumption of domestic water per capita and consumption of agricultural water per capita and is calculated by using the equation 18 (Asiabi Hir et al. 2018):

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

In equation (18):

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

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

Where U_1 and U_2 are water use index per capita and agricultural water consumption per capita, , respectively, W_{U1} and W_{U2} , respectively, by weight of indices U_1 and U_2, P_i volume of water consumed in the household in the study area (m^3 per year), K_i total area of irrigated agricultural land and SUM are the total area of agricultural land available in the study area.

Environmental component

This component is determined by the environmental stress index based on the amount of chemical fertilizer used in the region per year using the equation 21 (Talebi and Amini, 2018).

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

Where L_i is the amount of fertilizer used in the area per year and SUM is the total area of available agricultural land in the study area.

Then, in order to scale the data of all components as well as the water poverty index (normalization), the equation 22 was used:

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

Where X_i is the value of each components and indices, X_{min} is the minimum value of each of the components and indices, and X_{max} is the maximum value of each of these components and indices.

Determine the weight of indicators and components

The entropy weighting method was used to determine the weight of the components and indices (Valmohammadi and Firoozeh, 2010; Nastaran et al., 2016):

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j}$$
(23)

Where W_j is the weight of the component or index of j, D_j is the degree of deviation from the information in component or index of j.

Investigation of the Changes Trends in Water Poverty Index

The Parametric (linear regression slope) and nonparametric (Mann-Kendall and Spearman tests) statistics were used to study the trend of changes in water poverty index during 2008-2018 (Zarei et al., 2016; Zarei et al. 2015; Nosrati and Zareiee, 2011).

Mann–Kendall trend test

The Mann–Kendall test statistic (Zs) is calculated using equation 24:

$$Z_s = \begin{cases} \frac{s-1}{\sqrt{\sigma^2(s)}}, & \text{if} \quad S > 0 \\ 0, & \text{if} \quad S = 0 \\ \frac{s-1}{\sqrt{\sigma^2(s)}}, & \text{if} \quad S < 0 \end{cases}$$
(24)

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$
(25)

Where as n is number of data points, x_i andx_j are the data values in time series i and j (j >i),

Positive values of Z_s indicate increasing trends while the negative Z_s show decreasing trends. If $|Z_s|$ > 1.96 than trend of changes is significant at 0.05% level.

Spearman's Rho test

The Spearman's Rho test statistic (Z_D)is expressed as follows:

$$Z_D = D\sqrt{\frac{n-2}{1-D^2}}$$
(26)

$$D = 1 - \frac{6\sum_{i=1}^{n}(R(X_i)-i)^2}{n(n^2-1)}$$
(27)

Where $R(X_i)$ is the rank of the observation, X_i in the time series and n is the length of the time series. Positive values of Z_D indicate increasing trends while negative Z_D show decreasing trends. If $|Z_s|$ > 2.08 than trend of changes is significant at 0.05% level.

Linear regression method

The slope of linear regression indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. A linear regression line has an equation of the form:

$$Y = a + bx$$
(28)

Where as x is the explanatory variable, Y is the dependent variable, b is the slope of the line and a is the intercept.

4- Results

Components of water poverty index

The results of the resource component calculations showed that the value of accessibility index in this component fluctuate between 0 in 2018 to 0.219 in 2017 (Figure 2 and Table 1). On the other hand, the value of variability index varied from 0.221 in 2011 to 0.538 in 2010.The final result of calculating the resource component after applying the weight of the indices (weight of both accessibility index and weight variability was 0.5) evaluated in this component showed that the value of this parameter has a range of variation between 0.165 in 2018 to 0.361 in 2010 (Figure 2 and Table 1).

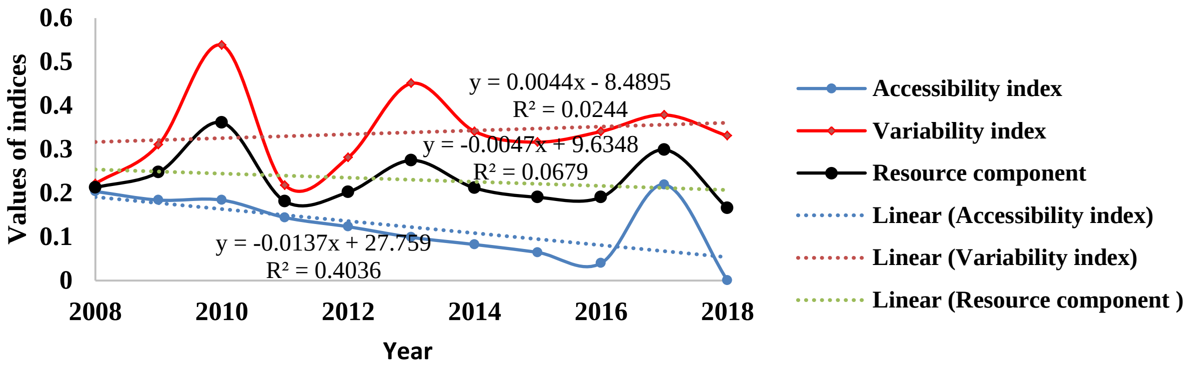

Fig 2. Values of accessibility and variability indices and resource component

Table 1. Values of WPI components in Fasa plain from 2008 to 2018

Year	Resource	Availability	Capacity	Consumption	Environmental
2008	0.213	0.000	1.000	0.954	0.643
2009	0.247	0.010	0.823	1.000	0.655
2010	0.361	0.013	0.694	0.985	0.863
2011	0.181	0.025	0.524	0.913	0.685
2012	0.202	0.333	0.431	0.839	1.000
2013	0.275	0.641	0.341	0.604	0.935
2014	0.211	0.949	0.218	0.000	0.798
2015	0.190	0.962	0.156	0.276	0.863
2016	0.190	0.975	0.049	0.840	0.000
2017	0.299	0.987	0.236	0.841	0.143
2018	0.165	1.000	0.000	0.790	0.030

Based on the results, the values of capacity, access, consumption and environment components varied between 0 and 1. The maximum and minimum capacity of this component was calculated in 2008 and 2018, respectively. Regarding the accessibility component, the highest and lowest values occurred in 2018 and 2008, respectively. The results showed that the maximum and minimum values for consumption component were calculated in 2009 and 2014, respectively. However, the highest and lowest amount of environmental component occurred in 2012 and 2013 (Figures 3, 4, 5 and 6 and Table 1). Fluctuations in components over different years appear to be highly dependent on variability of effective parameters in the short run such as climate change especially parameters affecting drought and wet season such as rainfall, evapotranspiration, etc.

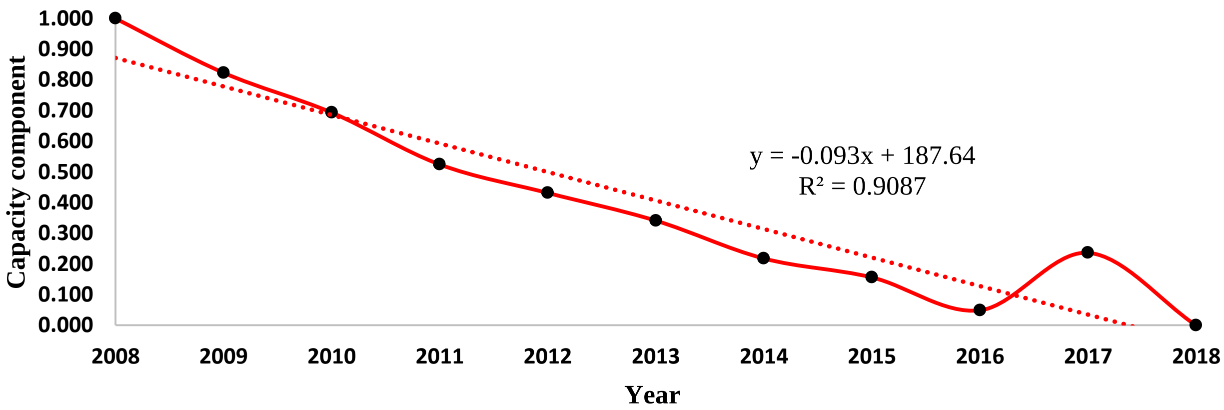

Fig 3. Capacity component during 2008-2018

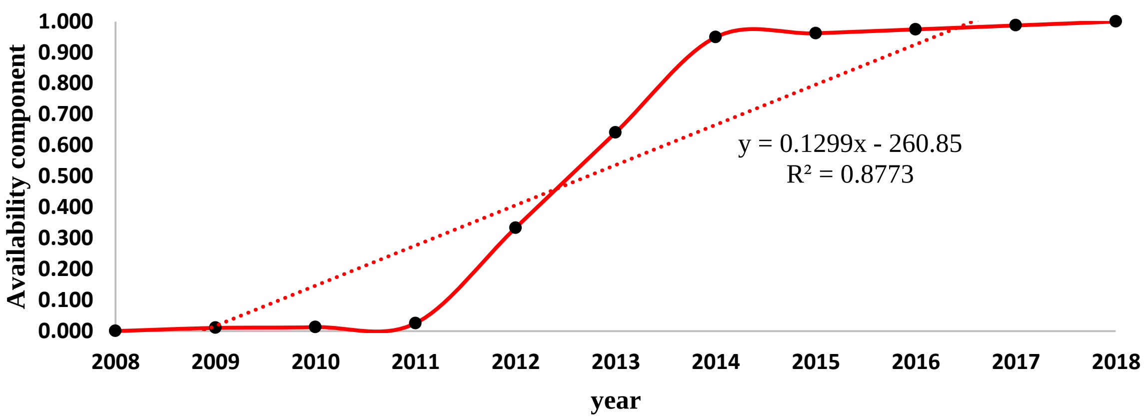

Fig 4. Availability component during 2008-2018

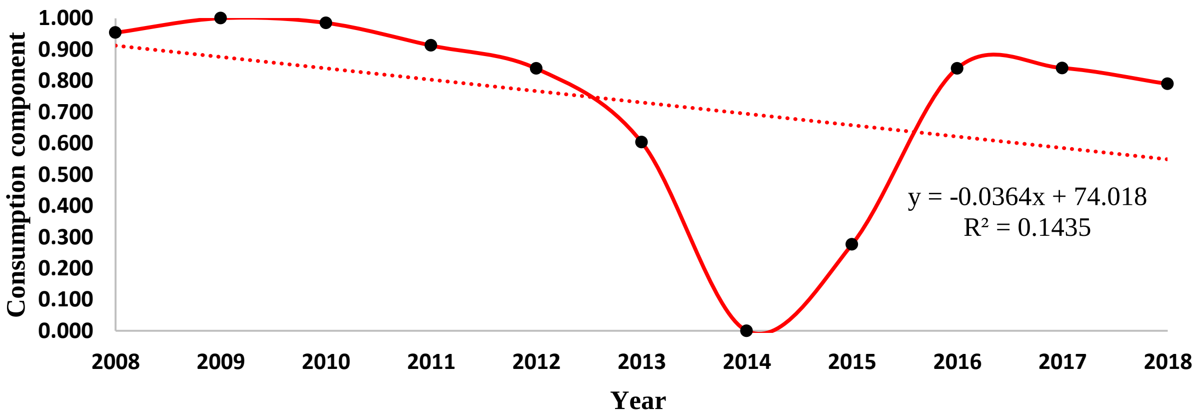

Fig 5. Consumption component during 2008-2018

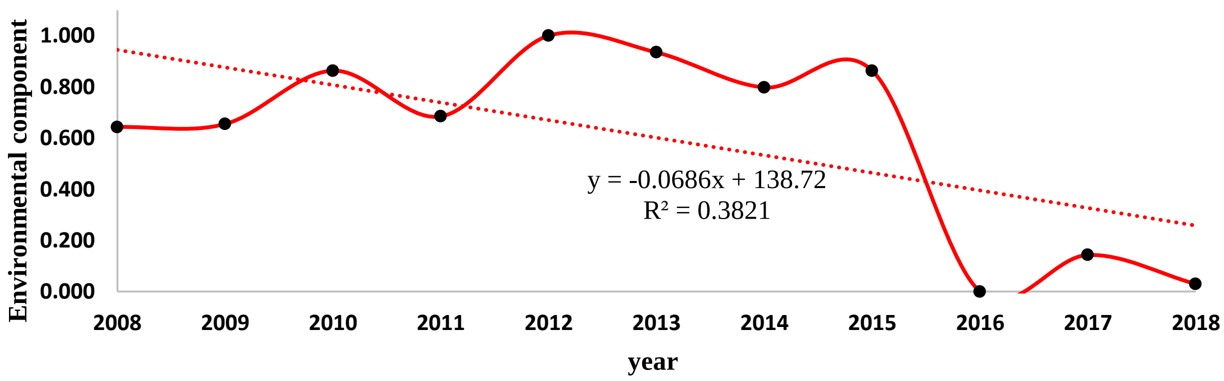

Fig 6. Environmental component during 2008-2018

Weight of components of water poverty index

The results of the entropy model in order to determine the component weights in order to establish the component composition and calculate the final water poverty index under study showed that the components of consumption, source, environment and access and capacity were the highest weights, respectively. The investigated components have the WPI index determination. The component weights are presented in Table (2).

Table 2. Weight of components of WPI

Components	Resource	Availability	Capacity	Consumption	Environmental
Weight	0.246	0.140	0.000	0.474	0.140

Water poverty index (WPI)

The results of the calculations related to the water poverty index by applying the weight of the components examined in the WPI specific calculation showed that the water poverty index fluctuated between 0.678 in 2010 and 0.227 in 2014. This indicates that the critical level Water resources have reached their minimum values in 2010 and their maximum in 2014 (Table 3).

Table 3. WPI in 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		

Trend of changes in water poverty index

Investigation of the trend of changes in water poverty index and its components in Fasa plain during 2008-2018 indicated that based on all statistical methods used (Spearman, Mann-Kendall and linear regression) among all studied components, only availability component had an increasing trend (non-significant) which could be due to the increase in people's standard of living and subsequently to increased access to health over time, increased arable land affected by rangeland degradation and conversion. They will be affected by technological advances in arable land as well as the ease of water supply (Table 4). Other components studied by all methods have a decreasing trend, including capacity component changes according to all statistical methods, consumption component changes according to spearman method and environmental component changes according to regression method. The linearity at the 5% level is significant (Table 4).

The results of the trend of changes in the water poverty index indicated that this indicator is decreasing (non-significant) overtime during the period under study (Table 4). Although the trend of changes in WPI is not statistically significant, But the results can be a kind of alarm regarding the status of available water resources as well as the need for scientific and practical management of available water resources. Naturally, water resources management is more important in sectors that are more dependent on water, such as agriculture and drinking.

Table 4. Trend of changes in WPI and components of it in Fasa plain during 2008- 2018

WPI and components	S	Ps	Zs	Pm	Z_D	Psp
Resource	-0.005	0.523	-0.981	0.876	-1.216	0.229
Availability	0.130*	0.012	3.125*	0.021	4.589*	0.011
Capacity	-0.093*	0.023	-2.941*	0.043	-4.213*	0.021
Consumption	-0.036*	0.048	-1.781	0.113	-2.112*	0.041
Environmental	-0.069*	0.034	-0.681	0.641	-1.201	0.227
WPI	-0.010	0.366	-1.031	0.312	-1.380	0.223

Note. *. Trend of changes is significant at 0.05% level, S is the slope of linear regression, Zs is the Mann-Kendal Statistic, Z_D is the Spearman Rho statistic, Ps is the p-value of Slope of linear regression, Pm is the p-value of Mann-Kendal Statistic and Psp is the p-value of Spearman Rho statistic.

The results showed that among the components of WPI only Availability component had increasing trend during 2008-2018. It seems, increasing the quality of people's lives, increasing the level of public health and increasing access to safe and sanitary water are the main causes of increasing trend of Availability component. On the other hand, increasing population, decreasing arable land (with good quality), decreasing ground water, reducing water per capita, increasing use of fertilizers, climate change, increasing water consumption in the home sector, low levels of water use efficiency in agriculture, etc, are the main causes of decreasing trend in other components of WPI and WPI.

5- Conclusion

The results showed that the poverty index in the study area fluctuated between 0.678 to 0.297 during the under-evaluation time period (2008-2018) and the trend of its changes during the years under study was a decreasing trend. Therefore, it can be concluded that this indicator is in a more critical condition during the years under review than it was in previous years (the beginning of the period under review). On the other hand, the results based on water poverty index showed that over the years studied, the status of water resources management in supply and demand of these resources has been in poorer condition over time. In this regard, based on the results of the study, more than any other component that has contributed to this challenge, is the consumption component. Accordingly, it seems that the most important measure to reduce the challenge of water poverty in the Fasa plain is to focus on water management. Since water consumption is in the economic approach to demand, it is imperative that, instead of using unsuitable management tools, demand management in the Fasa plain be adjusted to accommodate water consumption. On the other hand, it is suggested that using improved irrigation systems, plant mulches, using windbreakers, using the plant varieties with low water requirements, modification of water consumption patterns in the drinking sector, etc. try to help increase water productivity and reduce pressure on water resources.

6- Acknowledgment

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7- Conflicts of Interest

No potential conflict of interest was reported by the authors.

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