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Research paper

Simulation and Detecting Streamflow Fluctuations using Drought Severity Index

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ABSTRACT

In recent decades, amongst the natural disasters that affected human life on earth, the frequency of drought is higher than other disasters. A study region was selected with a desirable situation in terms of soil potential so that such potential was estimated to be 60 thousand hectares while the total area of water and dry farming lands is one-third of this potential. Therefore, the limiting agricultural development in this region was water restriction and there was practically no land restriction in agricultural development. Thus, in the current study, the need for water transferring in different levels of agricultural development was investigated in the form of a water transfer plan. Scenarios include implementing an artificial recharge plan as well as increasing the area under cultivation and irrigation efficiency to balance the aquifer. The results of the first scenario showed that to balance the groundwater, at least 45 million cubic meters of water must be transferred to the plain annually. The results of the scenario analysis indicated that the water transferred to plain, the area under cultivation can be increased up to 21000 hectares. The results of the third scenario showed that the pressurized irrigation plan could be developed up to 26000 hectares to increase the cultivation area.

Introduction

From the beginning of history, drought has been a part of climate change in our environment. Water shortage on the one hand, and excessive and improper use of water, on the other hand, is a critical threat for the environment, and water sources are of importance in a country like Iran that is one of the arid and semi-arid regions of the world, considering that it has also affected northern regions of the country (Hamlat et al., 2013). Rainfall status and water resources constraints and climate conditions in the country indicate the fact that there must be a plan for drought phenomena and its effects and consequences must be seriously addressed at the time of occurrence (Rahiz and New, 2014). Moreover, the need to increase water use efficiency in agriculture, modify consumption pattern and irrigation management and pay attention to water withdrawal must be taken into consideration (Vasiliades and Loukas, 2006). Aridity and drought are both the results of interaction between the natural environment and the community (Hoff et al., 2011). The drought phenomenon represents the various effects of the environment on the organisms, microorganisms, animals, and humans while the aridity has a general concept and is not used for environmental elements (Loukas et al., 2008).

Considering the proper management and decrease of drought consequences in the development of areas requires planning and implementation of preventive measures in response to drought phenomenon which requires the application of enough knowledge in drought forecasting. Hydrological drought indices are developed to provide a comprehensive image of water balance in a basin for optimal water management; some studies have been conducted in this regard (Tabari et al., 2013).

Tabari et al., (2013) used SDI for hydrological drought in the northwest of Iran during the 1975-2009 statistical period for simultaneous periods of 3, 6, 9, and 12 months at 14 hydrometric stations. The results of hydrological drought analysis based on SDI indicated that approximately all the stations experienced serious droughts during the period. Rahiz and New (2014) applied Drought Severity Index (DSI) at different time scales for precipitation and monthly runoff in order to evaluate the efficiency of drought index based on rainfall in the simulation of hydrological drought. The results showed that rainfall-based DSI can simulate the important hydrological drought occurrences such as stream-based DSI, and rainfall-based DSI usually presents the hydrological drought with a medium level better than a very severe level. Vasiliades and Lukas (2006) studied the relationship between the hydrological drought and weather in the selected basins in Greece. The results showed that the SPI index has a better relationship with the hydrological drought index in comparison with other indices (Vasiliades and Loukas, 2006).

Sayari et al., (2013) used three indices of ARI, PNPI, and SPI to monitor the drought in Kashfrood basin (Northeast of Iran). The results showed a slight increase in monthly rainfall, maximum and minimum monthly temperature as well as an increase in drought occurrence and its duration under both scenarios (Sayari et al., 2013). Duan and Mei., (2014) studied the drought variations from 1961-2000 and 2100-2061 using CSIRO-MK and CCCma-GCM models under three scenarios of emission in a basin in China. The results showed that with the increasing temperature even with a more stable perspective of meteorological drought in the future, hydrological and agricultural droughts can be considered greater threats to local water resources management (Duan and Mei, 2014).

Liu et al., (2012) utilized SPI, PDSI (Palmer Drought Severity Index), and SRI to rebuild the historical drought occurrences and estimate the risk of future drought for the drought-prone basin of Blue River under a possible variable climate (Liu et al., 2012). The results showed the three historical drought indices, indicating that more severe droughts are likely to occur over the next 90 years, especially in the late 21st century . Loukas et al., (2008) used the SPI index in different time scales of 3, 6, 9, and 12 months to evaluate the effect of climate change on the drought severity in a region in Greece. The results showed a considerable increase in annual drought severity in different time scales of SPI and more critical conditions under A2 scenario (Loukas et al., 2008).

Hamlat et al., (2013) conducted a study to evaluate and analyze the present balance and forecast the future and also, to analyze the possible scenarios in the western watershed of Algeria using the WEAP model. The results showed that urban demand for the considered scenarios is provided; however, in the agriculture sector, its consumption can only be met by transferring water. Harma et al., (2012) modeled the surface water flow of Okanagan basin located in the British Colombia state of America using the WEAP model. Considering the biological and social conditions, land uses and urban demand, they showed that the available surface storage systems cannot supply the urban demand with respect to the normal rainfall by 2050. In addition, in two scenarios of climate change and vegetation, the available resources will face deficiency to meet the agricultural and urban needs (Harma et al., 2012). Hoff et al., (2011) studied the Jordan River Basin which has a severe shortage in water resources. The results showed that climate and socio-economic changes are the key drivers of water shortage in the basin.

Considering that the researchers of the country focus on the investigation of the effect of climate phenomena on precipitation and temperature variables, less attention has been paid to the rivers' streamflows. Given the importance of studying the streamflow of river as one of the most effective and comprehensive hydrological variables as well as the lack of such studies with the emphasis on the drought severity in studying the streamflows of Iran, the current study investigated and studied the variations and fluctuations of streamflows in drought conditions using WEAP model. In general, the present study aims to explore the trend resulted from climate change, detect the fluctuations resulted from climate phenomena (climate variability) and interpret the causing reasons for each.

Material and Methods

The study area is located in the south of Kerman Province and is in the range of 31 degrees and 22 minutes to 31 degrees and 38 minutes of northern latitude and 50 degrees and 58 minutes to 51 degrees and 16 minutes of eastern latitude. According to previous studies, the area of this plain is 231 km^2. Zone tectonics follows the trend of the Iranian and Arabian plates, and most of the folds are oriented northwest-southeast and most of the faults in the region are parallel to the main Zagros fault.

June to July is the hottest month and December to January is the coldest period of the plain. The absolute minimum temperature recorded over the past 30 years was minus 32 degrees Celsius and the maximum absolute temperature was 47 degrees Celsius. The mean annual precipitation is 500 millimeter and the mean annual evaporation potential of the basin is 1800 millimeter.

The latest statistics of water resources of plain and its comparison with those of previous years indicate that the number of groundwater wells has increased sharply and reached from 112 rings in 1976 with the annual discharge of 24 million cubic meters to 719 rings with the annual discharge of 133 million cubic meters in 2007. The stone of the plain's floor in the northern and eastern part of this fault was limestone which plays a significant role in the recharge of the underground water reservoir of the place, which is located under the drainage basin.

The irrigated area under cultivation is 12321 ha and water use efficiency has been varied from 30 to 50 % in this plain and according to the composition of the region's crop pattern, the net irrigation water requirement of the plain is 7500 cubic meters per hectare based on the Penman-Monteith method. Considering the present irrigation efficiency (41.5%), the annual gross irrigation water requirement of lands is 18000 cubic meters per hectares (Table 1).

Table 1. Distribution of monthly discharge of wells, springs, and aqueducts

Month	23 September-22 October	23 October- 21 November	22 November- 21 December	22December- 20 January	21 January- 19 February	20 February-19 March	20 March- 20 April	21 April- 21 May	22 May-21 June	22 June-22 July	23 July-22 August	23 August-22 September	Total
Well's monthly discharge (%)	5	3	2	0.3	0.3	0.4	11	14	16	16	17	15	100
Aqueduct's monthly discharge (%)	6.5	5.5	5.5	5.3	5.3	7.2	12	14	12.5	10	8.2	8	100
Spring's monthly discharge	9.6	6.7	6.9	6.9	6.9	7.5	8.9	9.8	9.6	9.5	9.4	8.3	100

To study the groundwater fluctuations, the statistics of water level data of 14 observation wells measured from September 1992 to September 2008, which was 16 water years in total, were used (Table 2). Moreover, Table 3 shows the resultant of variation of groundwater level over 16 years.

Table 2. Coordinates and area of Piezometric wells

Piezometer Number	UTM		Height above sea level (m)	Piezometer area
	x	y		
1	407829	3387140	1833.84	12.624
2	410904	3383827	184.13	8.498
3	410754	3386822	1836.17	10.685
4	408285	3388663	1833.27	7.872
5	413039	3390287	1843.51	11.112
6	414189	3382173	1869.32	6.815
7	414622	3388089	1841.08	5.962
8	414829	3383328	1872.58	7.532
9	414766	3379780	1912/73	8.150
10	404005	3388810	1834.2	7.250
11	406754	3390181	1838.19	6.31
12	405466	3396695	1899.5	6.945
13	405787	3392008	1853.22	12.144
14	409341	3392732	1845.06	15.179

Table 3. The Resultant of groundwater level variations in alluvial aquifer

Row	Water year	Groundwater level variations (meter)
1	2002-2003	2.71
2	2003-2004	-3.59
3	2004-2005	0.19
4	2005-2006	-0.84
5	2006-2007	-1.66
6	2007-2008	1.27
7	2008-2009	-2.13
8	2009-2010	-3.62
9	2011-2012	-6.19
10	2012-2013	3.6
11	2013-2014	-.072
12	2014-2015	1.14
13	2015-2016	-.088
14	2016-2017	4.81
15	2017-2018	2.30
16	2018-2019	-10.33
Total variations		-14.33

Due to the completion of discharge information and recharge of the aquifer in the water year of 2017-2018, the balance of groundwater is provided based on the information and statistics of 2017-2018 water year. Due to the bedrock of the area and its outcrop in the plain margins, there is no water exchange between this basin and the adjacent basins and the recharge of this part is considered to be zero. The mean annual precipitation is calculated as 500 millimeters. By considering the 34% of penetration in alluvial aquifer, 23.12 million cubic meter accounts for penetration of precipitation. The volume of agricultural return flow is 26.6 million cubic meters. The volume of return flow from spring to the aquifer is 1.26 million cubic meters.

Considering the bedrock of the region and its outcrop in margins of plain, there is no water exchange between this basin and adjacent basins and the recharge of this region is considered to be zero. The total volume of discharge of alluvial aquifer of through wells (643 rings) is estimated to be133 million cubic meters. Considering that the depth level of static was higher than 3 meters, therefore, the values of evaporation and transpiration of groundwater were considered zero in the water-balance equation. Drainage through the river is considered zero. The volume variations of the groundwater reservoir is calculated 78 million cubic meters over 16 years.

Model description

Using WEAP model to Simulate Groundwater Reservoirs

WEAP model uses arc-node structure to model the basin. In the present study, different nodes are used for modeling including drinking water and agriculture demand sites, environmental need, hydrometer station and various arcs used in modeling include Water transmission network from water supply sources to demand sites, water return network, and different domains of the river.

The present study aims to investigate the groundwater reservoirs in drought conditions on the fluctuations of the rivers leading to the basin using the WEAP model. In order to achieve this goal, 2017 year was selected as the base year; then, scenarios were evaluated over a 30 year period (2017-2047) by the WEAP model. During this 30 year period, the required data of the model were determined based on the statistics of the 2019-2020 period. Required data of groundwater reservoirs were available in a 15-year period (2006-2020); therefore, model calibration was conducted in this period.

Considering the drought condition in this study, the mean of drought periods data as data for future years (simulation period) is considered to determine the simulation period data. It must be mentioned that before the formation of the input file of the model, data of the available hydro-climatology station (precipitation of basin) were tested homogenously and completed and rebuilt using the regression method.

It is required to calibrate the model after estimation and determining the required parameters. Model calibration was conducted in the 2005-2019 period in which the data and information of plain were available. WEAP model calibration is conducted using changing parameters including aquifer hydraulic conductivity, aquifer specific yield, horizontal distance and rain penetration coefficient in the plain. The base of calibration for groundwater is the observed volume of the aquifer for each month during the simulation period and its comparison with the observed value. The volume is obtained by the water level of the aquifer in each month using piezometers.

In the present study, the scenarios are based on the plans under implementation and study which are artificial recharge plan and water transfer plan from upstream. Characteristics and general conditions of scenarios are presented in Table 4.

Table 4. General characteristics and conditions of scenarios

Scenario	Description
SI	Implementing the water transfer plan with annual transitional volumes of 40, 45, and 50 million cubic meter
SII	Implementing a transfer plan with the volumes of 150, 100, 175, and 200 million cubic meters per year and determining the maximum increase in the area under cultivation in each transfer so that the plain does not face dehydration.
SIII	Implementing the transfer plan with different volumes and implementing the pressurized irrigation plan and determining the maximum increase in the area under cultivation in each transfer so that the plain does not face dehydration.
SIV	Implementing the artificial recharge plan of 10 million cubic meters per year, complete implementation of water transferring plan (200mcm) and full implementation of pressurized irrigation systems

Results and Discussion

Calibration

In the best situation of model calibration (Calibration with the lowest calibration error percentage), the calibration parameters obtained for plain are presented in Table 5. The monthly storage capacity of aquifer calculated using model and observation in the best situation of calibration is presented in the graph of Fig. 1. It must be mentioned that when a specific yield of the plain is considered 4 percentage, the model error is the least. Therefore, this value was applied as the specific yield. Furthermore, the results showed that on average, 45.5 million cubic meters of precipitation per year are used for aquifer recharge which is 93.5% less than the amount of annual withdrawal.

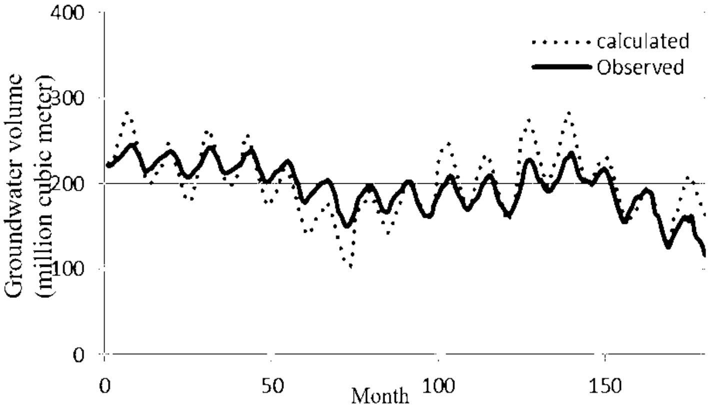

Figure1. Aquifer storage in two modes of simulation and observation in the best situation of calibration monthly.

Table 5. Characteristics of the best mode of calibration of WEAP model

No	Parameter Description
1	Final storage capacity of aquifer (MCM)
2	Water volume in aquifer in 2006 (MCM)
3	A percentage of precipitation which is used for aquifer recharge.
4	Mean annual aquifer withdrawal during the calibration period (MCM)
5	Specific yield coefficient of plain (%)
6	Mean absolute value of model error in calibration period (%)

Scenario analysis

Scenario I

This scenario assumed the implementation of water transfer plan from upstream with different transitional volumes with average values of 40, 45, and 50 million cubic meters per year and its effect on the water balance of groundwater of plain. Despite the average transfer of 40, 45, and 50 million cubic meters per year, the water balance of plain will be still negative and the storage volume of the aquifer will be decreased by 4 percent at the end of the simulation period in comparison to the beginning of the period. Therefore, to balance the groundwater balance of plain, annually, 45 million cubic meters of water must be transferred from upstream.

Scenario II

Transferring water from upstream with different annual values is considered in this scenario and the maximum increase in area under cultivation in each transfer is investigated to prevent plain from dehydration. In all of the cases, the percentage of the water supply of agricultural lands, development, and present, is maintained at 85% (i.e. admitting the 15% of less irrigation). Considering that the outputs obtained are detailed, it was then tried to summarize the results in a graph. Thus, Fig. 2 is presented. The value of aquifer storage capacity during the simulation period in four transferring modes of 150,100, 175, and 200 million cubic meters per year.

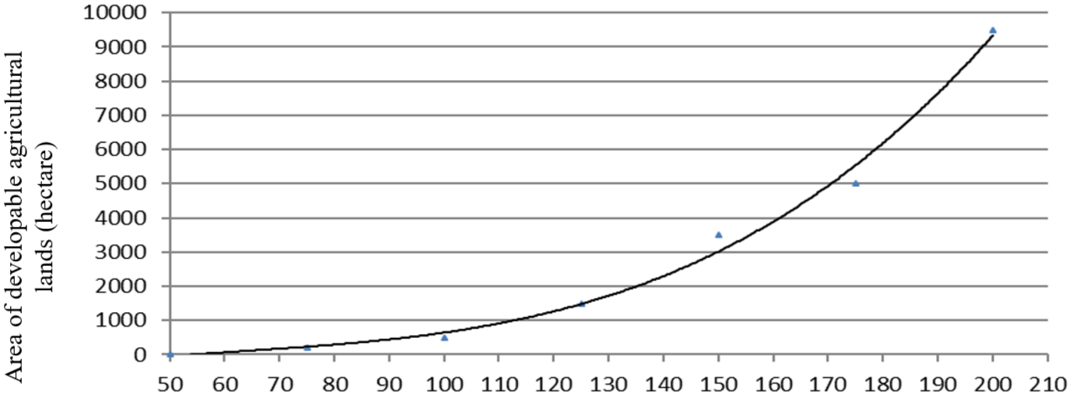

Figure 2. The area of developable agricultural lands in different values of transitional water plan

Scenario III

In this scenario, the model is implemented with different capacities of water transfer to the plain and different levels of agricultural development in the region (which is estimated that the total potential of agricultural lands is more than 60000 hectares). In all the aforementioned cases, it is assumed that all of the agricultural lands (including current and development) must be pressurized irrigation and the percentage of the water supply of all agricultural lands including current lands and development is maintained at the level of 85 (i.e. admitting 15% less irrigation). As in Scenario S-2, the results obtained are summarized in a graph. Therefore, Fig. 3 is presented. The amount of storage volume of the aquifer during the simulation period in 4 modes of transferring with the volumes of 100, 150, 175, and 200 million cubic meters per year can be seen in Fig.4.

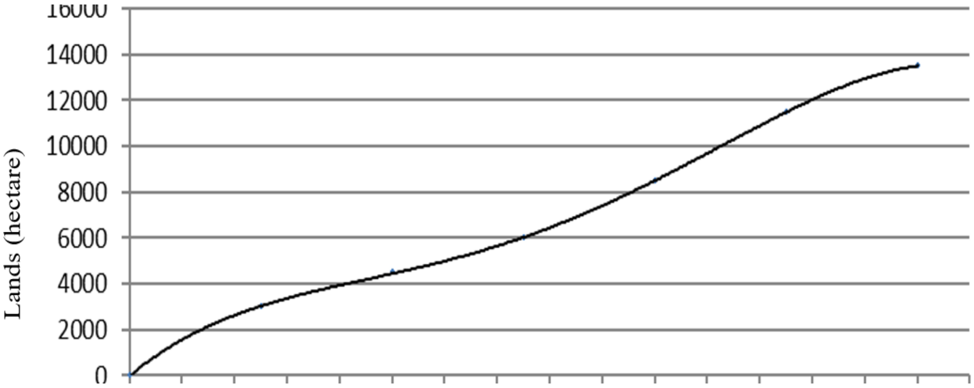

Figure 3. The area of developable lands in different values of transitional water plan along with the implementation of the pressurized irrigation systems.

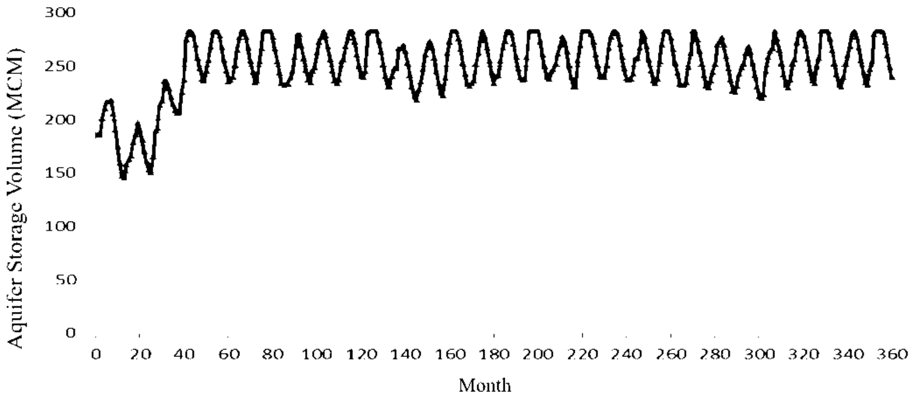

Figure 4. Variations of aquifer storage in the 30-year period of withdrawal (S III with the annual transfer of 200 MCM and increase in area under cultivation up to 26000 hectares) from 2018 to 2047.

Scenario IV

In this scenario which is the last one, it is assumed that all the management measures of water supply and demand for sustainable development to be done. These measures include the recharge with 10 million cubic meters per year on average, full implementation of water transfer plan and full implementation of pressurized irrigation systems to reach the plain's efficiency up to 65%.

Investigating the soil moisture using long-term meteorological data indicates that the value of soil moisture has been decreased in the northern parts of the basin since 1978. If the value of Ws (soil moisture) from 1963 to 1975 is compared with the values of recent years, the decreasing trend of moisture value following the recent droughts will be indicated. The situation in the western part of the basin is slightly different than the northern parts. In this area, soil moisture has been increased in January in the recent decade, unlike the last year. Furthermore, according to the values obtained from the Surface Drought Index, the amount of runoffs indicates that considering the values of precipitation and evaporation in the basin surface, the amount of runoff during the year has been trivial and the trend of runoff was a decreasing trend over the past 20 years.

Conclusion

The results show that the most impacts of recent droughts have been on surface soil moisture, groundwater and surface runoffs of the basin. Investigations on the variables dependent on the climate changes show that the increase in the value of groundwater discharges due to the recent droughts has considerably emerged in different parts of the basin. The amount of water shortage in the soil of different levels of basin following the discharge of groundwater and their level drop is considerable. This deficiency has been very severe during the dry years and sometimes during the year. In the western parts of the basin, the severity of deficiency has been less. Field studies indicate that the formation of some geomorphologic forms, such as surface erosion at skirt surfaces, creation and development of ditches and the occurrence of landslides, have been directly linked to changes in climate and hydrological features of the area. In the studied area, the occurrence of landslides in the skirts adjacent to the river bed in recent years has been significantly increased one of the main reasons of which is the removal of vegetation from the surface of skirts. The occurrence of landslides led to the accumulation of the hillside materials in valleys' bedside; finally, by the entrance of runoffs in the times of full of water, it has led to the increase in the sedimentary load of runoffs. Most of the lands under cultivation in the studied area are either located in the slope surfaces adjacent to the valleys or in the surfaces of floodplains and/or in the adjacent of steep walls of valleys.

Conflict of interest

The authors declare that they have no conflict of interest.

References

DUAN, K. & MEI, Y. 2014. Comparison of meteorological, hydrological and agricultural drought responses to climate change and uncertainty assessment. *Water resources management,* 28**,** 5039-5054.

HAMLAT, A., ERRIH, M. & GUIDOUM, A. 2013. Simulation of water resources management scenarios in western Algeria watersheds using WEAP model. *Arabian Journal of Geosciences,* 6**,** 2225-2236.

HARMA, K. J., JOHNSON, M. S. & COHEN, S. J. 2012. Future water supply and demand in the Okanagan Basin, British Columbia: a scenario-based analysis of multiple, interacting stressors. *Water Resources Management,* 26**,** 667-689.

HOFF, H., BONZI, C., JOYCE, B. & TIELBöRGER, K. 2011. A water resources planning tool for the Jordan River Basin. *Water,* 3**,** 718-736.

LIU, L., HONG, Y., BEDNARCZYK, C. N., YONG, B., SHAFER, M. A., RILEY, R. & HOCKER, J. E. 2012. Hydro-climatological drought analyses and projections using meteorological and hydrological drought indices: a case study in Blue River Basin, Oklahoma. *Water resources management,* 26**,** 2761-2779.

LOUKAS, A., VASILIADES, L. & TZABIRAS, J. 2008. Climate change effects on drought severity. *Advances in Geosciences,* 17**,** 23-29.

RAHIZ, M. & NEW, M. 2014. Does a rainfall-based drought index simulate hydrological droughts? *International journal of climatology,* 34**,** 2853-2871.

SAYARI, N., BANNAYAN, M., ALIZADEH, A. & FARID, A. 2013. Using drought indices to assess climate change impacts on drought conditions in the northeast of Iran (case study: Kashafrood basin). *Meteorological Applications,* 20**,** 115-127.

TABARI, H., NIKBAKHT, J. & TALAEE, P. H. 2013. Hydrological drought assessment in Northwestern Iran based on streamflow drought index (SDI). *Water resources management,* 27**,** 137-151.

VASILIADES, L. & LOUKAS, A. Hydrological drought evaluation with the use of meteorological drought indices. Geophysical Research Abstracts, 2006. 04468.