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Assessment of potential climate change impacts on drought indicators (Case study: Yazd station, Central Iran)

M.T. Dastorani[a*], A.R. Massah Bavani[b], S. Poormohammadi[c], M. H. Rahimian[d]

[a] *Associate Professor, Faculty of Natural Resources, Yazd University, Yazd, Iran*
[b] *Assistant Professor, Faculty of Agriculture, Abureyhan College, University of Tehran, Tehran, Iran*
[c] *MSc Graduatet, Yazd University, Yazd, Iran*
[d] *Research expert, National Salinity Research Center, Yazd, Iran*

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Abstract

This research studies the potential impact of climate change on future trend and changes of two well known drought indicators namely RDI and SPI in Yazd meteorological station, in central part of Iran. For this purpose, data of HadCM3 model that were resulted from GCM-runs based on the IPCC-SRES scenarios of A2 and B2 were acquired and analyzed for projection of daily T_{min}, T_{max} and precipitation for the projected period of 2010 to 2039. RDI and SPI drought indicators then were calculated and validated based on corresponding observations of historical period (1961-1990). Comparison of the results indicate that SPI and RDI of A2 scenario would have a negative trend along with the projected years, while these indicators tend to have positive trend when resulted from B2 scenario. The latter result demonstrates an increase of vulnerabilities based on up coming droughts.

Keywords: Climate Change; Drought; Yazd station

1. Introduction

Climate change is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC[1], 1992). This phenomenon is caused by greenhouse gasses, which affect the greenhouse properties of the earth's atmosphere. Emissions of greenhouse gasses have been increased since industrialization in the 1900s, due to increasing in fossil fuel burning. These gasses allow solar radiation to travel from the sun to the ground but prevent the reflected heat from the surface into the space. This causes to rise the earth's temperature, gradually (Takara et al., 2009)

It is expected that climate change would strongly affect the hydrologic cycle of water in future decades (Gedney et al, 2006, Milly et al, 2005). It will also have significant impacts on the availability of water, as well as the quality and quantity of water. Among the climatic variables, precipitation (P) and evapotranspiration (ET) have the great importance in long term changes of water resource (Piao et al, 2006). In this regard, many researchers predicted that climate change accelerates water cycles with more ET and increased precipitation (Betts et al, 2007, Oki and Kanae, 2006). But increased precipitation does not necessarily lead to sustainable water resources because less frequent but heavier precipitation may lead to extremely flood or drought occurrence (Andreadis and Lettenmaier, 2006). Therefore, it should be emphasized that to monitor and assess the impact of climate change on drought occurrence, ET and P should be considered together as two major climatic variables. In this regard, different drought indicators have been introduced and used at

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[*] Corresponding author. Tel.: +98 351 8210312,
Fax: +98 351 8210312.
E-mail address: mdastorani@yazduni.ac.ir

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[1] -United Nations Framework Convention on Climate Change

different parts of the World. These indices simplify complex interrelationships between many climate and climate-related parameters (Tsakiris et al., 2007). Among these, some indices are found better than others for especial uses. For example, the Palmer Drought Severity Index (PDSI) has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance. However PDSI is more relevant and suitable for large areas with uniform topography. The Standardized Precipitation Index (SPI) is another widely used drought index. It was first introduced by McKee et al. (1993) at Colorado State University. It is based on the consideration that each component of a water resources system reacts to a deficit in precipitation over different time scales. This index is uniquely related to probability and also is normally distributed, so it can be used to monitor wet as well as dry periods (Tsakiris et al., 2007). Another drought indicator is Reconnaissance Drought Index (RDI) that was first introduced in the coordinating meeting of MEDROPLAN[2] (Tsakiris 2004). This index is based both on precipitation (P) and potential evapotranspiration (ET). Since this index can be used under "climate instability" conditions, therefore, it would be suitable for study of climate change impacts on water scarcity and drought occurrence (Tsakiris et al., 2007). Kirono et al. (2011) study is an example of RDI application for characterization of Australian droughts under enhanced greenhouse conditions. In their study, RDI was applied to simulate climate variables from 14 GCMs performed for the IPCC 4th assessment report. The results showed a general increase in drought areal extent and frequency for most regions of the country. Karamouz et al.(2009)simulated the flood flow under climate change phenomenon using GCM models in Kajoo river basin located in arid and semi-arid region of south-east Iran.

In the present research it has been tried to assess the impact of climate change on SPI and RDI as two main drought indicators. In this study data of GCM-runs for the Third Assessment Report (TAR) based on the IPCC[3]-SRES scenarios would be acquired as well as observed data of Yazd meteorological station, a hyper arid region in central part of Iran. The main objective of this study is to evaluate the potential impacts of climate change on SPI and RDI and consequently drought trend in future projected decades (2010-2039) under different scenarios (A2 and B2). Potential impacts are all the impacts that may occur given a projected change in climate, without considering adaptation. The A2 scenario corresponds to pessimistic future with higher population growth, lower GDP growth, and fragmented and slower technological change. B2 emission scenario represents a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions (Nakicenovic and Swart, 2000). In fact, A2 and B2 are the most frequently used emission scenarios in the world (IPCC, 2010). Results of the study would help decision makers to plan for avoiding or reducing vulnerabilities about future water scarcities in the region.

2. Materials and methods

2.1. Study site

The study site is Yazd meteorological station in Yazd province, central part of Iran. It has been located in $31^o\ 54^'$ north latitude and $54^o\ 24^'$ east longitude (Figure 1) in Yazd city. Climatic condition in study site is hyper arid with annual precipitation of about 60 mm and potential evapotranspiration more than 3500 mm. In this area, water shortage is a real problem limiting agricultural as well as most of the industrial activities. Due to low precipitation and high evapotranspiration, this area is very sensitive to drought.

2.2. Methodology

In this study three main sources of data were used which are as fallows:

1- Historical daily temperature and precipitation data of Yazd meteorological station from 1961 to 1990 (T_{min}, T_{max} and P)

2- Projected monthly data of HadCM3 for projected period of 2010 to 2039 (T_{min}, T_{max} and P), that were resulted from GCM-runs for the Third Assessment Report (TAR) based on the IPCC-SRES scenario of A2.

3- Projected monthly data of HadCM3 from 2010 to 2039 (T_{min}, T_{max} and P), based on scenario of B2**.**

Figure 2 illustrates the procedure for study the impact of climate change on SPI and RDI as two main drought indicators.

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[2] -Mediterranean Drought Preparedness and Mitigation Planning

[3]-Intergovernmental Panel on Climate Change

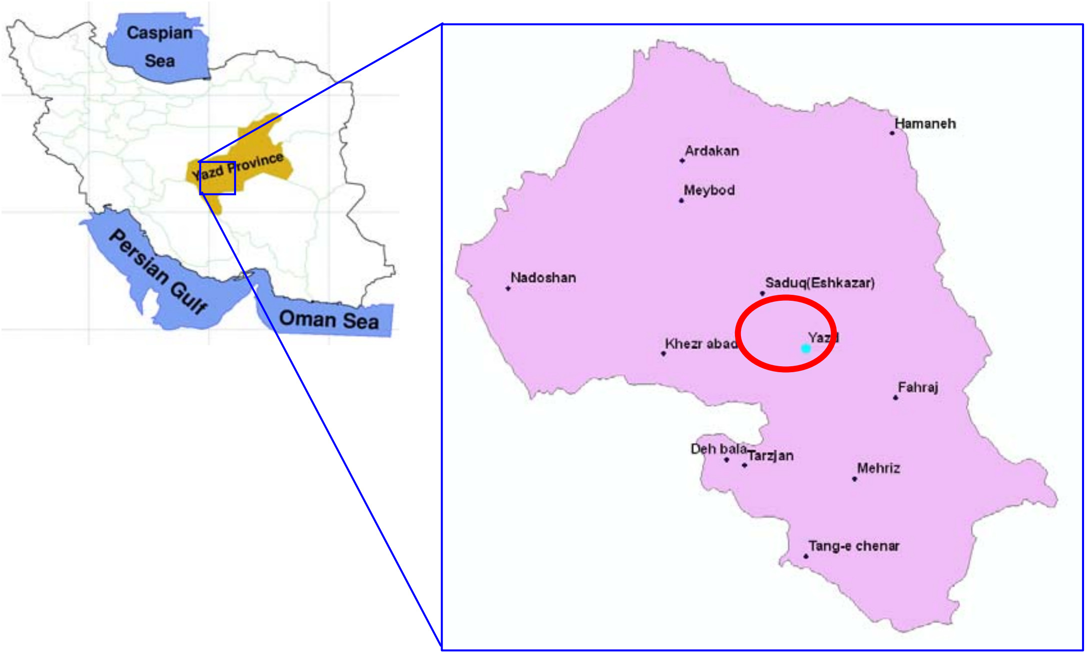


Fig. 1. Geographical location of Yazd meteorological station in Yazd-Ardakan plain, located in Yazd province, central part of Iran

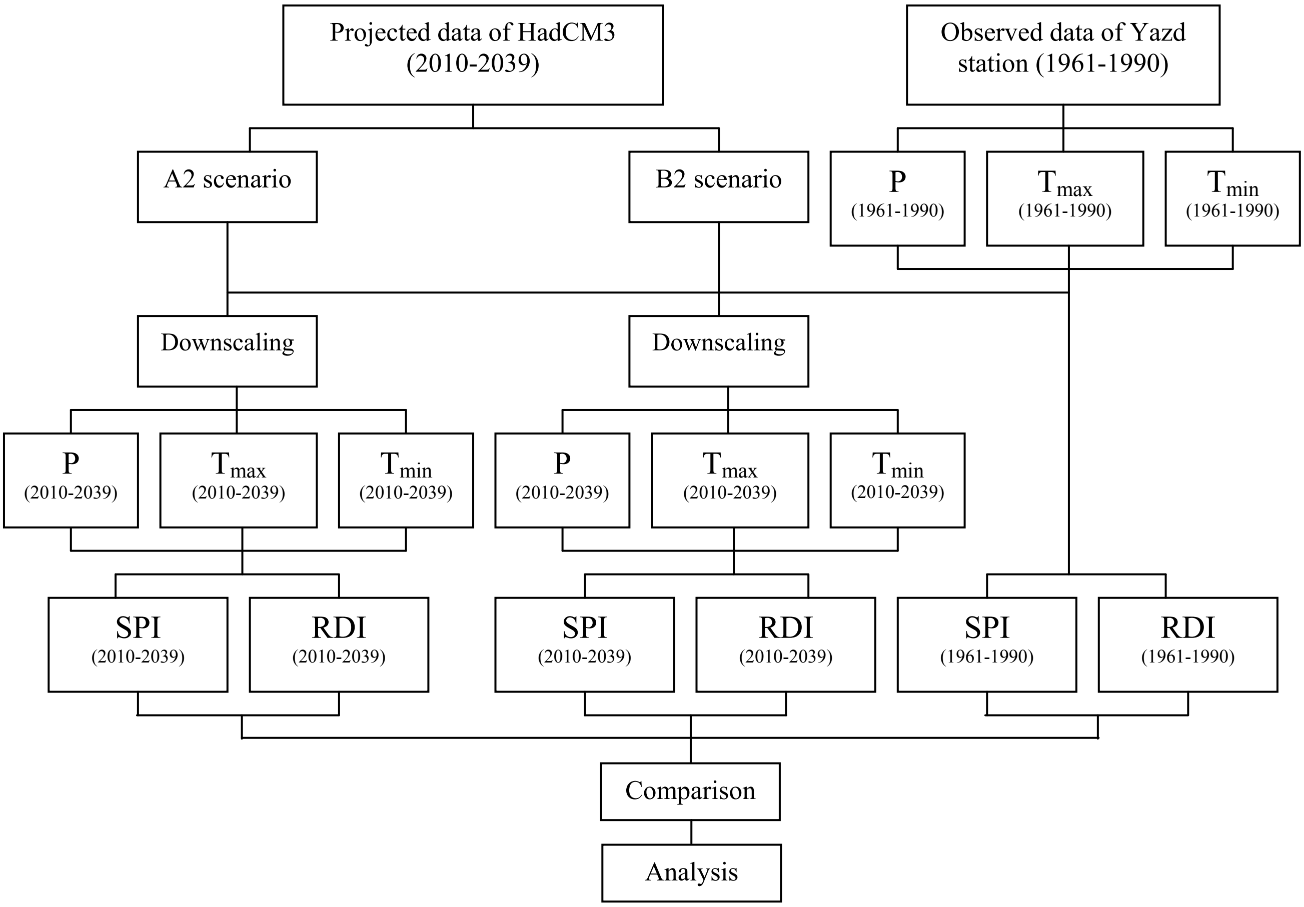


Fig. 2. Proposed methodology for study of climate change impacts on drought indictors (RDI and SPI) at projected period (2010-2039)

2.3. Downscaling

Downscaling is a procedure that derives local or regional scale information from larger scale data like GCM model outputs (Bates et al., 2008 and Giorgi et al., 2001). Two main methods that have been adopted and used are dynamical and statistical downscaling approaches. The statistical downscaling methods generally develop statistical relationships to relate the large scale atmospheric variables to local climate variables. These methods mainly include weather pattern based approaches, regression methods and stochastic weather generators. In all cases, the quality of the downscaled product depends on the quality of the driving model (Bates et al., 2008). In this study the stochastic approach was used for downscaling of daily data of HadCM3 for projected period of 2010 to 2039 with the help of ClimGen software capabilities (Massah Bavani, 2006). These data were included T_{min}, T_{max} and P. For monthly temperature for example:

$$\Delta T_{GCM,i} = \overline{T}_{GCM\,(2010-2039),i} - \overline{T}_{GCM\,(1961-1990),i} \quad (1)$$

Where, $\overline{T}_{GCM\,(1961-1990),i}$ and $\overline{T}_{GCM\,(2010-2039),i}$ are mean monthly temperatures (T_{min} or T_{max}) that were resulted from different scenarios (A2 and B2) for baseline (1961-1990) and projected (2010-2039) periods in month i. In fact ΔT illustrates differences between monthly temperatures of past and future periods under A2 or B2 scenarios. To estimate temperatures of projected period in site scale resolution ($T_{(2010-2039),i}$), monthly observed data of temperature were acquired ($\overline{T}_{observed(1961-1990)}$) and added to $\Delta T_{GCM,i}$ of that corresponding month:

$$T_{(2010-2039),i} = \overline{T}_{observed(1961-1990),i} + \Delta T_{GCM,i} \quad (2)$$

These monthly temperatures (T_{min} or T_{max}) then were converted to daily values via the ClimGen software capabilities. Some similar procedure was used for production of daily precipitations for 2010 to 2039:

$$\Delta P_{GCM,I} = \frac{P_{GCM\,(2010-2039),i}}{P_{GCM\,(1961-1990),i}}$$

(3)

$$P_{(2010-2039),i} = \overline{P}_{(1961-1990)} * \Delta P_{GCM,i}$$

(4)

Where, $\Delta P_{GCM,i}$ is ratios of projected and baseline monthly precipitations, those were resulted from HadCM3 under different scenarios. $\overline{P}_{(1961-1990)}$ is monthly mean observed precipitation for Yazd meteorological station, while $P_{(2010-2039),i}$ is corresponding monthly mean downscaled precipitation for projected period. ClimGen also was used for generation of daily precipitation, as well as temperature downscaling procedure (Massah Bavani, 2006).

2.4. RDI and SPI drought indicators

In the current study, drought assessment was achieved using the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) for the Yazd meteorological station. SPI that uses daily precipitation (P) quantifies the precipitation deficit for different time scales (3, 6, 12, 24 and 48 months) and reflect the impact of drought on the availability of water resources. In this study yearly time scale was selected as a common hydrologic cycle. RDI, apart from P, also incorporates potential evapotranspiration (ET). It calculates the aggregated deficit between the evaporative demand of the atmosphere and precipitation. Also RDI can show the effects of climate instability conditions (Tsakiris and Vangelis, 2005) which can be a result of climate change. In this study, estimation of ET has been accomplished through Hargerives-Samani method which uses both maximum and minimum temperatures, in a daily basis (Table1).

Table 1. Classification of SPI and RDI indices

SPI / RDI value	class
2.00 and more	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Wet
-0.99 to 0.99	Moderate (normal)
-1.49 to -1.00	Dry
-1.99 to -1.50	Very dry
-2.00 and less	Extremely dry

3. Results and discussion

Table 2 shows differences between observed (1961-1990) and estimated (2010-2039) monthly T_{min}, T_{max} and P under A2 and B2 scenarios. These differences have been illustrated as ΔT_{min}, ΔT_{max}, and ΔP, respectively. Annual averages of ΔT_{min} and ΔT_{max} are 1.5 and 1.2 for A2 scenario, while these differences are 1.1 and 1.0 for B2 scenario, respectively. It seems that more increase of temperature would be probable under A2 scenario compared with B2 scenario. Precipitation as more effective variable, shows different trends compared with temperature. This parameter has increased under A2 scenario, rigorously; in contrast, it has decreased under B2 scenario, slightly.

Table 2. Differences of monthly predicted (2010-2039) and observed (1961-1990) T_{min}, T_{max} and P values under A2 and B2 scenarios

Month	A2			B2		
	ΔT_{min}	ΔT_{max}	ΔP	ΔT_{min}	ΔT_{max}	ΔP
Jan	1.1	0.5	6.4	1.4	1.7	-1.7
Feb	1.1	1.3	3.9	0.0	-0.3	-0.8
Mar	1.1	1.6	1.4	1.0	1.4	0.4
Apr	1.8	2.0	4.3	1.7	1.5	-2.5
May	1.5	1.1	0.2	1.0	1.7	3.8
Jun	1.2	0.5	1.8	0.8	1.1	0.1
Jul	1.8	1.1	1.6	2.7	1.3	-0.1
Aug	1.7	1.0	0.4	0.9	0.6	0.0
Sep	1.4	0.7	2.9	1.7	0.9	0.1
Oct	1.8	1.9	2.9	1.1	1.7	-0.7
Nov	1.7	1.7	1.0	0.9	0.1	1.0
Dec	1.5	1.2	3.8	0.3	0.3	-0.9
Average	1.5	1.2	30.5	1.1	1.0	-1.3

Monthly distributions of observed and predicted ET and P as two main climatic variables have been shown in figures 3 and 4 for A2 and B2 scenarios, respectively. As shown in those figures, observed precipitation decreases until August (moves to zero in June, July, August and September) and increases thereafter. The midseason months for rainfall are January to March; by April almost two-thirds of the annual rainfall has accumulated. For ET, it is observed that the monthly pattern of ET is well organized in a clear simple bell (sinusoidal) shaped pattern. June was found as the peak month with ET of about 6 mm per day, potentially. Projected evapotranspiration follows the same trend but with rare increases of values in almost all months. Also, differences between A2 and B2 scenario results for ET seem to be negligible.

For precipitation, however, significant differences can be found between observed and projected monthly P, as well as the A2 and B2 scenario results. Amongst these, difference between observed and projected precipitation seems to be more significant for A2 scenario (with increase of 30 mm per year in 2010-2039 period) compared with B2 results.

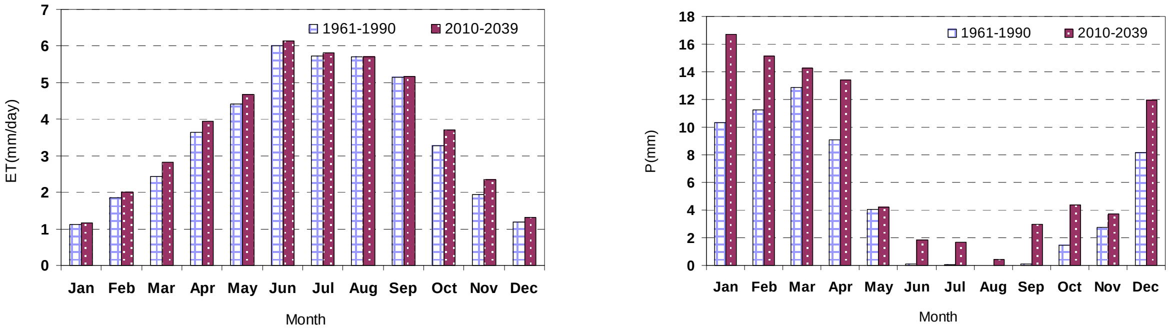


Fig. 3. Monthly distributions of observed and projected evapotranspiration (ET) and precipitation (P) at Yazd meteorological station under A2 scenario

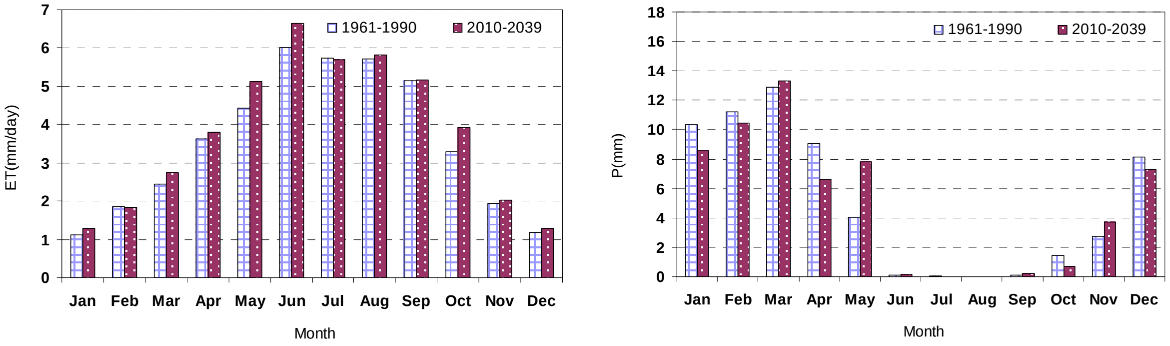
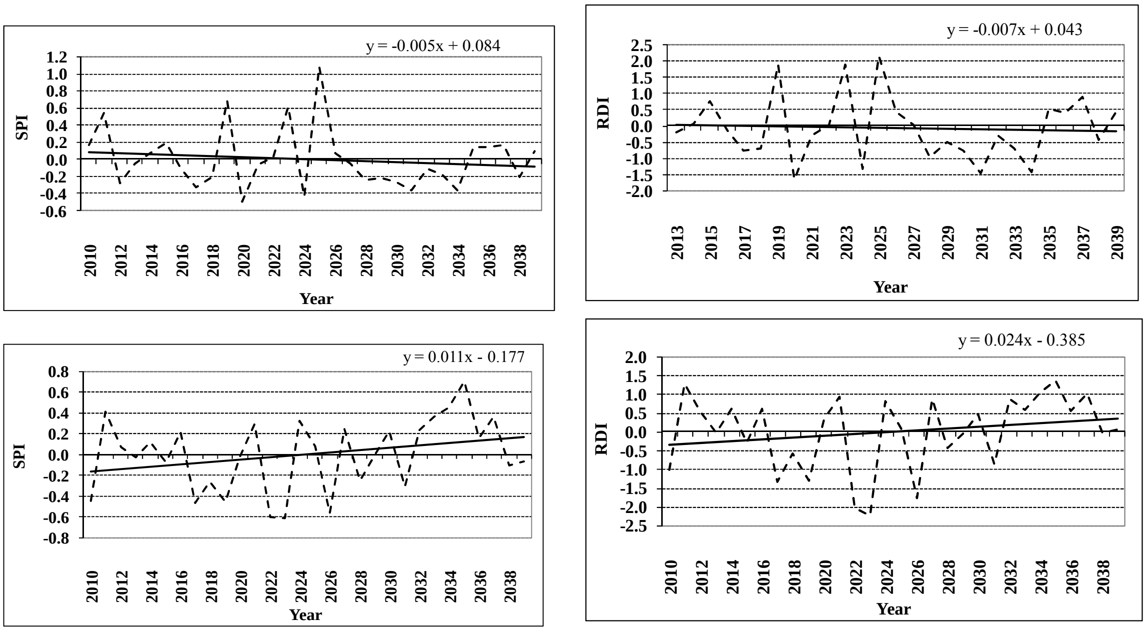


Fig. 4. Monthly distributions of observed and projected evapotranspiration (ET) and precipitation (P) at Yazd meteorological station under B2 scenario

As the main purpose of this study, potential impacts of climate change on drought indicators were investigated. As mentioned before, RDI and SPI have been introduced as two practical and well known indices for characterization of droughts at different parts of the world. Figure 7 shows overal trends of projected SPI and RDI in Yazd meteorological station for projected period (2010-2039) under A2 and B2 scenarios, separately. This figure illustrates that SPI and RDI of A2 scenario would have a negative trend along with the projected years, while these indicators tend to have positive trend when resulted from B2 scenario.



(a) (b)

Fig. 7. Overal trend of predicted SPI and RDI in Yazd meteorological station for projected period (2010-2039) under (a) A2 and (b) B2 scenarios

Also comparisons between previous and future values for RDI and SPI were accomplished. Figures 5 and 6 represent annual amounts of these indicators for baseline and projected periods, which were resulted from GCM-runs based on SRES scenarios of A2 and B2, respectively.

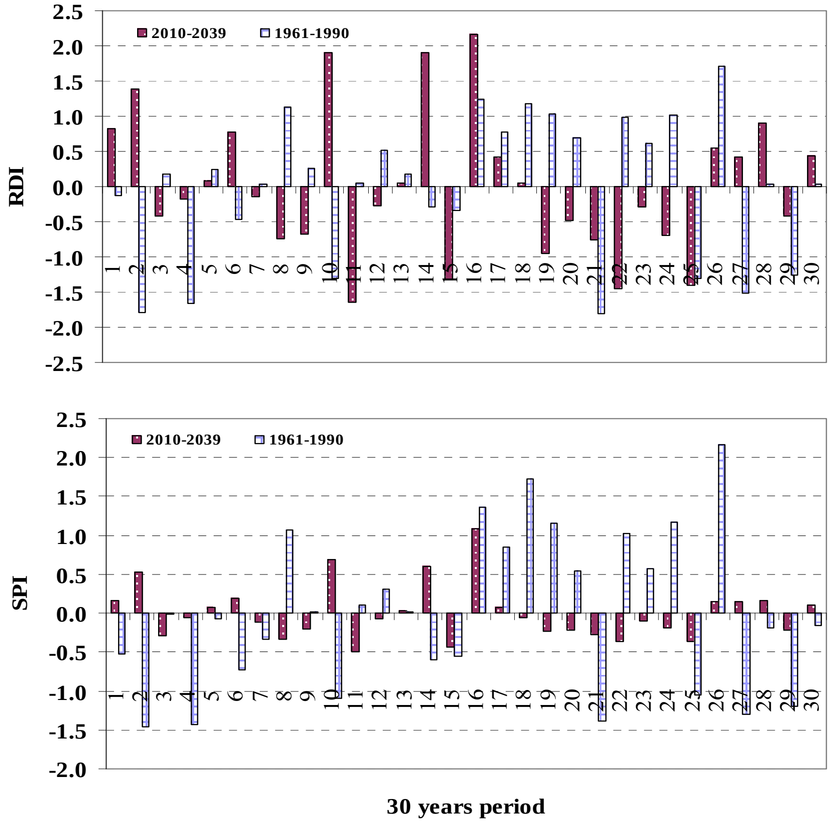


Fig. 5. RDI and SPI for observed data of yazd meteorological station (1961-1990) and also their projected values for future 30 years period (2010-2039) under A2 scenario

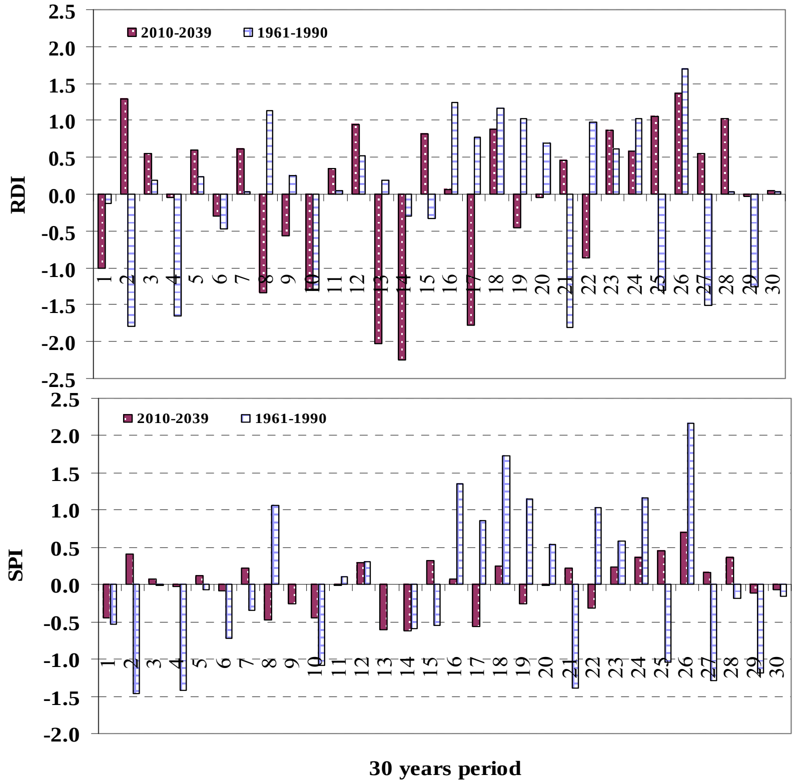


Fig. 6. RDI and SPI for observed data of yazd meteorological station (1961-1990) and also their projected values for future 30 years period (2010-2039) under B2 scenario

These figures illustrate considerable changes in fluctuations of dry and wet spells. Comparisons show that projected SPI fluctuations are lower than those that were resulted for the baseline. While, the RDI fluctuations seems to be high compared with their corresponding baseline values. For this reason, extreme dry or wet spells often can be found in the projected RDI simulations.

4. Conclusion

Results of the study indicate different impacts of climate change on drought indicators. The B2 scenario based results say that climate change has a serious and effective impact on drought severity and period in this hyper arid region and intensifies water shortage during the next three decades. While, the A2 scenario based results illustrate a positive trend of drought indicators with a decline in the impact of climate change on regional water resources. It seems that the ability to quantify future changes of climatic variables (ET and P) and their impacts on drought indicators is limited by some uncertainties. These uncertainties almost arise from the range of socio-economic aspects of scenarios, the range of climate model projections for a given scenario, the downscaling procedure to local scales, impacts assessments and feedbacks from adaptation and mitigation activities (see Deepashree and Mujumdar, 2010, for more description). However, it is necessary for the water authorities to take the opposed results into account, and have applicable water resources management strategies to be able to deal with these problems in the coming decades. Decision makings also should be accomplished with especial considerations to the uncertainties that almost appear in the results.

References

Andreadis K. M. and D. P. Lettenmaier, 2006, Trends in 20th century drought over the continental United States, Geophysical Research Letters, Vol.33, L10403

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008, Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 p.

Betts R. A., O. Boucher, M. Collins, P.M. Cox, P.D. Falloon, N. Gedney, D. L. Hemming, C. Huntingford, C. D. Jones, D. M. H. Sexton, and M. J. Webb, 2007, Projected increase in continental runoff due to plant responses to increasing carbon dioxide, Nature, Vol.448, pp. 1037-1041

Deepashree R., P.P. Mujumdar, 2010, Hydrologic drought prediction under climate change: Uncertainty modeling with Dempster–Shafer and Bayesian approaches, Advances in Water Resources 33 (2010) 1176–1186.

Giorgi, F., B.C. Hewitson, J.H. Christensen, M. Hulme, H. von Storch, P.H. Whetton, R.G. Jones, L.O. Mearns, and C.B. Fu, 2001, Regional climate information - evaluation and projections. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge and New York, pp. 581-638.

Guttman, N.B., 1998: Comparing the Palmer Drought Index and the Standardized Precipitation Index. J. Amer. Water Resour. Assoc., 34, 113-121.

Guttman, N.B., 1999. Accepting the Standardized Precipitation Index: A calculation algorithm. Journal of the American Water Resources Association, 35(2), 311-322.

Gedney N., P. M. Cox, R. A. Betts, O. Boucher, C. Huntingford, and P. A. Stott, 2006, Detection of a direct carbon dioxide effect in continental river runoff records, Nature, 439, pp. 835-838.

IPCC, 2010, IPCC-DDC GCM Data Archive, available in: http://www.mad.zmaw.de/IPCC_DDC/html/ddcgcmdata.html

Kanellou E., C. Domenikiotis, and N. R. Dalezios, 2009, Mapping of the Reconnaissance Drought Index (RDI) based on Remote Sensing and GIS over Greece, Geophysical Research Abstracts, Vol. 11, EGU2009-8464-1.

Karamouz M., M. Fallahi, S. Nazif and A. Ahmadi, 2009, Long lead flood simulation using downscaled GCM data in arid and semi-arid regions: A case study, Journal of Desert, V. 14 No. 2, pp 185-196.

Kirono D. G. C., D.M. Kent, K.J. Hennessy, F. Mpelasoka, 2011, Characteristics of Australian droughts under enhanced greenhouse conditions: Results from 14 global climate models, Journal of Arid Environments 75 (2011), pp. 566-575.

Massah Bavani A.R., 2006, Risk assessment of climate change and its impacts on water resources, Case study: Zayandeh Roud basin, PhD thesis, Tarbiat Modarres University, Iran. P. 189 (in Persian).

McKee, T.B., N.J. Doesken, and J. Kleist, 1995. Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology, American Meteorological Society, Jan 15-20, 1995, Dallas TX, pp. 233-236.

McKee TB, NJ. Doesken, J. Kleist, 1993, the relationship of drought frequency and duration to time scales, Proceedings of the 8th Conference on Applied Climatology; 17–22 January 1993, American Meteorological Society, Boston, pp. 179-186.

Milly P. C. D., K. A. Dunne, and A. V. Vecchia, 2005, Global pattern of trends in streamflow and water availability in a changing climate, Nature, 438, pp. 347-350.

Nakicenovic, N., Swart, R., 2000. Emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, p. 612.

Oki T. and S. Kanae, 2006, Global hydrological cycles and world water resources, Science, Vol.313, pp. 1068-1072.

Pashiardis S., S. Michaelides, 2008, Implementation of the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) for the regional drought assessment: A case study for Cyprus, European Water 23/24: 57-65.

Piao S., P. Friedlingstein, P. Ciais, N. de Noblet-Ducoudre, D. Labat, and S. Zaehle, 2006, Changes in climate and land use have a larger direct impact than rising CO2 on global river runoff trends, Proceedings of the National Academy of Sciences, Vol.104, No.39, pp. 15242-15247

Takara K., S. Kim, Y. Tachikawa, E. Nakakita, 2009, Assessing Climate Change Impact on Water resources in the Tone River Basin, Japan, Using Super-High-resolution Atmospheric Model Output, Journal of Disaster ResearchVol.4, No.1.

Tsakiris G, 2004, Meteorological Drought Assessment. Paper prepared for the needs of the European Research Program MEDROPLAN (Mediterranean Drought Preparedness and Mitigation Planning), Zaragoza, Spain.

Tsakiris G., H. Vangelis, 2005, establishing a drought index incorporating evapotranspiration, European Water 9/10: 3-11.

Tsakiris G., D. Pangalou, H. Vangelis, 2007, Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI), Journal of Water Resource Management, 21:821–833.