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Study of spatial and temporal rain and drought patterns in the south of Iran using TRMM

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Abstract

Droughts are one of the most damaging climatic phenomena, and the most complex natural hazard which affects the economy, agriculture, public health and environment in large areas. The aim of this study is to compare drought indicators derived from tropical rainfall measuring mission (TRMM) data in the south of Iran. Also the TRMM rainfall was considered, so as to investigate changes in the rainfall pattern over the area. In this study, five meteorological drought indices, including the standard precipitation index (SPI), deciles index (DI), z-Score, Standard Index of Annual Precipitation (SIAP) and Percent of Normal Precipitation Index (PNPI) derived from TRMM data at 0.25° × 0.25° spatial resolution are compared to monitor droughts in the South of Iran. The results showed that the SPI index was strongly correlated with other drought indices. The maximum relation of the SPI index with other drought indices was investigated, and the PNPI Index was found to have the most correlation, with a correlation coefficient of $R = 0.995$ and a coefficient of determination of $R^2 = 0.99$. Also a strong inverse relationship was observed between rain and longitude while altitude and latitude were found to be poorly related.

Keywords: Rain; Drought indices; South of Iran; TRMM

1. Introduction

Drought is a complex natural hazard and a major environmental disaster; which is characterized by a lack of precipitation (Su *et al*., 2003; Paulo *et al*., 2012; Gocic & Trajkovic, 2014). Drought is a climate extreme, linked with a high incidence in human development (Domínguez-Castro *et al*., 2008). As extreme climate events, droughts tend to grow in intensity frequency under global warming, especially in the semi-arid regions of the northern hemisphere (Zhang and Jia, 2013). Drought directly reduces water availability to plants, which in turn diminishes the productivity (yield) of crops, forestry and (grazed) rangeland. It also lowers surface and sub-surface water supplies, which may result in less arable land areas, and an increase in the mortality rate of livestock and wildlife Moreover, since economic sectors are closely interrelated, these indirect impacts may spread to other sectors of the economy that are well beyond the sector and area(s) experiencing drought (Salami *et al*., 2009).

Precipitation is a key parameter in the study of climate change as well as the variability, detection and monitoring of natural disasters such as drought. Precipitation datasets, which accurately record the amount and spatial variability of rainfalls, are critical for monitoring drought and a wide range of other climate factors. This poses a challenge in many parts of the world, which often have limited weather stations and/or historical data records (Zambrano *et al*., 2017). Precipitation, and the lack thereof, and there results, especially results such as droughts, vary on different temporal and spatial scales (Yousefi *et al*., 2014). Recently, the remote sensing of precipitation products of tropical rainfall measuring mission (TRMM) data has been used as an alternative to the data derived from meteorological stations and the monitoring of drought and flood. Therefore, the drought indices based on remote sensing that

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synthesize precipitation are developed and used to monitor the complex process of drought (Du *et al*., 2013). Accordingly, the aforementioned precipitation products have been employed in many researches involving drought monitors (Rhee *et al*,. 2010; Frolking *et al*., 2011; Son *et al*., 2012; Ezzine *et al*., 2014; Yaduvanshi *et al*., 2015; Sahoo *et al*., 2015; Hatmoko *et al*., 2016; Mozafari and Narangifard, 2016; Park *et al*., 2016 and 2017). Also, various studies on drought have been undertaken by researchers in Iran (Morid *et al*., 2006; Bajgiran *et al*., 2008; Karimpour Reyhan *et al*., 2009; Mozafari *et al*., 2011; Nosrati & Zareiee, 2011; Shahabfar *et al*., 2012; Moazami *et al*., 2013; Keshavarz *et al*., 2013; Keshavarz & Karami, 2014; Golian *et al*., 2015; Omidvar *et al*., 2016; Fatemi *et al*., 2017) and in the Middle East, Mediterranean (Zaitchik *et al*., 2007; Al-Dousari *et al*., 2008; Almazroui, 2011; Kaniewski *et al*., 2012; Nastos *et al*., 2013).

The aim of this study is to compare drought indices, including the standard precipitation index (SPI), deciles index (DI), z-Score, Standard Index of Annual Precipitation (SIAP) and Percent of Normal Precipitation Index (PNPI) derived from tropical rainfall measuring mission (TRMM) data in the south of Iran. Also, TRMM rainfall was considered to investigate variation in rainfall patterns over the study area.

2. Materials and Methods

2.1. Study area

The study area is located in the south of Iran in an area of about 594092 km^2 between 25°N to 32°N and 50°E to 63°E. The study area covers the six provinces of Kohgiluyeh and Boyer-Ahmad, Fars, Blusher, Hormozgan, Kerman and Sistan and Baluchistan.

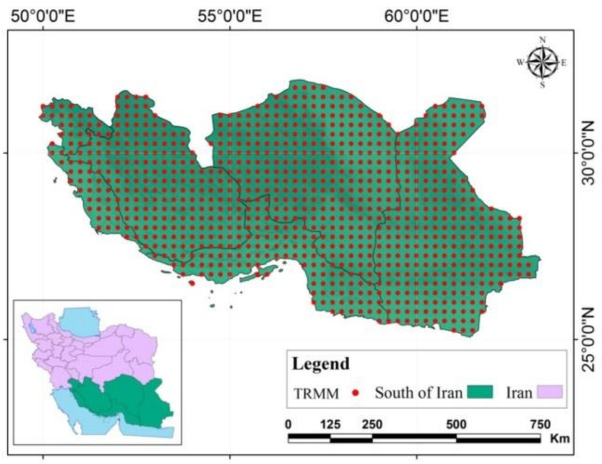

Fig. 1. Clipped TRMM dataset on a map of Southern Iran containing 867 grids with a resolution of 0.25°× 0.25°

2.2. Precipitation dataset

The tropical rainfall measuring mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development Agency (NASDA) of Japan. The objectives of TRMM are to measure tropical and subtropical precipitation and estimate its associated energy exchange. A number of precipitation-related sensors, such as the precipitation radar (PR), TRMM microwave imager (TMI), and visible and infrared radiometer system (VIRS) are on board TRMM (Kummerow *et al*., 1998; Almazroui, 2011). The TRMM satellite was launched in November 1997, and since then, several algorithms have been developed to estimate rainfall (e.g., Iguchi *et al*., 2000; Zhang & Jia, 2013). In this study, the precipitation dataset at a spatial resolution of 0.25° × 0.25° was used. It has covered the latitude band extending from 50° south to 50° north from 1998 to the present. This dataset is freely available at this address (http://disc2.nascom.nasa.gov).

In this study, the precipitation data of the seventh version of the TRMM satellite (3B43 V7) was used. The validation of satellite data in other studies (e.g. Rasuli *et al*., 2016; Varikoden *et al*., 2010; Almazroui, 2011; Al-Dousari *et al*. 2008; Erfanian *et al*. 2014; Shirvani and Fakhari Zade Shirazi; 2014;) indicates its efficiency, consistency and correlation with terrestrial data. Therefore, the use of TRMM's precipitation data, especially in the area of rainfall zoning, drought monitoring and other applications of meteorology and hydrology can be useful.

2.3. Drought indices

There are several indices to measure the deviation of precipitation from historically established norms for a given period of time. None of major indices are inherently superior to others in all circumstances, but some indices are better suited for certain applications (Monacelli *et al*., 2005). More than 150 drought indices have been developed (Niemeyer, 2008; Zargar *et al*., 2011). A large number of indices have been suggested and used for the detection and monitoring of meteorological, agricultural, hydrological and socio-economical droughts (Javan *et al*., 2016). Five drought indices selected for this study include, the standard precipitation index (SPI) proposed by (Mckee *et al*., 1993), the deciles index (DI), which was developed by Gibbs and Maher (1967), z-Score, the Standard Index of Annual Precipitation (SIAP) and the Precipitation Index Percent of Normal (PNPI).

2.3.1. Standard Precipitation Index (SPI)

Among all drought indices, SPI is the most popular, as it is widely used for the purpose of drought analysis around the world (e.g. Hayes *et al*., 1999; Raziei *et al*., 2009; Ibrahim *et al*., 2010; Mirabbasi *et al*., 2013; Nohegar *et al*., 2013: Fatemi *et al*., 2015; Omidvar *et al*., 2016). SPI is characterized by features such as statistical consistency, and the ability to describe both short-term and long-term drought impacts in different timescales of precipitation anomalies. The probabilistic nature of SPI allows its comparison in various locations (Mirabbasi *et al*, 2013). The Standard Precipitation Index (SPI) was used for identifying dry periods by way of statistical analysis (Eq. 1). This index was developed by Mckee *et al* (1993) based on the following equation:

$$SPI = \frac{P_i - \overline{P}}{SD} \quad (1)$$

Where, Pi is the precipitation in i*th* year, $\overline{P}$ is the average precipitation during the statistical period and SD is the standard deviation of the precipitation series. The positive values of the index shows that precipitation is above average while the negative values indicates varying intensities of drought (Table 1).

Table 1. Varying intensities of drought based on the Standard Precipitation Index

Standard precipitation index	Index value
2 and more	Extremely severe wet years
1.5 to 1.99	Severe wet years
1 to 1.49	Moderate wet years
-0.99 to 0.99	Normal
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 and less	Extremely severe drought

2.3.2. Standard Index of Annual Precipitation (SIAP)

The best method for transforming raw precipitation data into relative amounts is to divide the deviation of precipitation from the mean by standard deviation. In this regard, Khalili (1991, 1998) provided the standard index precipitation as followed for studying the process of dry and wet periods in Iran. In addition to the mean, this index considers the standard deviation. The SIAP may be negative (dry) or positive (wet) in some stations, which is due to the different pluvial systems in various parts of the country (Javan *et al*., 2016).
The values of SIAP can be computed using the following equation:

$$SIAP = \frac{P_i - \bar{p}}{SD} \quad (2)$$

Where Pi is the sum of precipitation in a given wet year, P is the average wet year precipitation, and SD is the standard deviation of the wet year precipitation (mm) (Bazrafshan and Khalili, 2013).

The trend of dry and wet years can be determined as follows:

Table 2. Standard index of annual precipitation (SIAP) drought category (Sadat Noori *et al*., 2013)

SIAP value	Classification
≥ 0.84	Extremely wet
0.52 to 0.84	Wet
- 0.52 to 0.52	Normal
- 0.84 to - 0.52	Dry
≤ - 0.84	Extremely dry

2.3.3. Percent of Normal Precipitation Index (PNPI)

The PNPI is a simple measurement of precipitation for a given location. The identification of drought trend by PNPI provides a descriptive analysis of a single region or a single season. This index can be calculated for a variety of timescales (a single month, a number of months representing a particular season, and annual or water years). The PNPI for any given location is estimated at 100% (Javan *et al.*, 2016). This index is calculated according to the following equation:

$$PNPI = \frac{Pi}{P} \times 100 \qquad (3)$$

Where Pi is actual precipitation and P is normal precipitation (Sayari *et al.*, 2013).

Table 3. PNPI values for classes of drought severity (Willeke *et al.*, 1994)

PNPI	Class
−0.25 < PNPI ≤ 0.25	Normal
−0.52 ≤ PNPI < −0.25	Light drought
−0.84 ≤ PNPI < −0.52	Moderate drought
−1.28 ≤ PNPI < −0.84	Severe drought
PNPI ≤ −1.28	Extreme drought

3. Results and Discussion

3.1. On-site analysis of drought

The calculated drought and rain indices are presented in Table 4. Fig 2 shows a comparison of both rain indices and SPI. In Figure 3, a comparison of time series of drought indices for the base period (1998–2013) is shown.

In this section, drought indices were compared using the Matrix plot and the Pearson Correlation method. The Pearson correlation coefficient (R^2) for the SPI versus Z Index, SIAP index, DI index and PNPI index were computed in the study area at a confidence level of 99%. The results suggested that the SPI index was positively related to other drought indices (fig 4 and 5). The strongest correlation between SPI and other drought indices (PNPI Index) was observed at a correlation coefficient of R=0.995 and a coefficient of determination of R2=0.99.

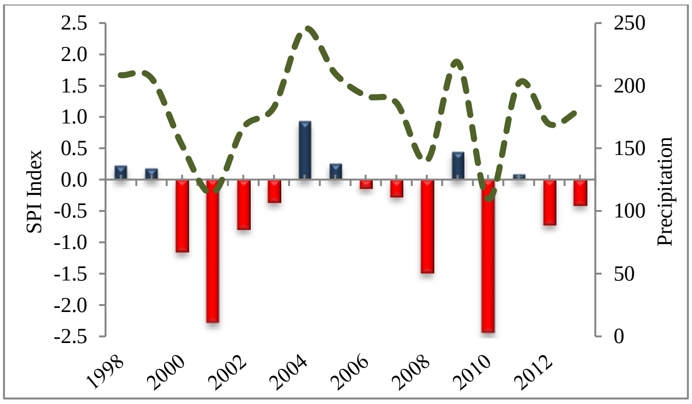

Fig. 2. Diagram of SPI annual changes and annual precipitation

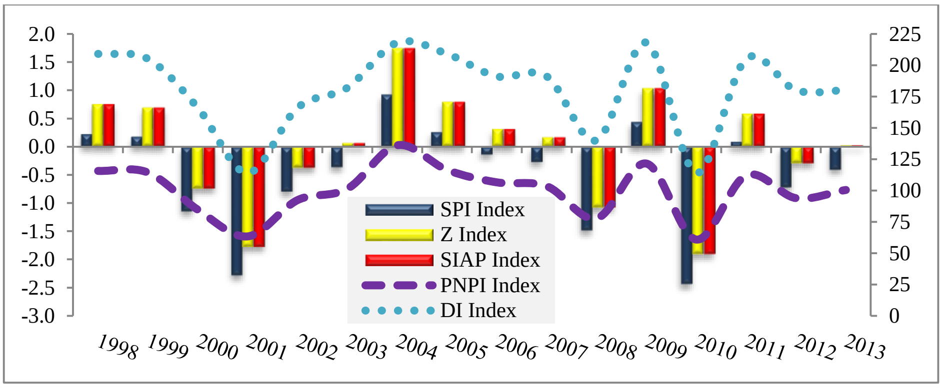

Fig. 3. Comparison of drought indices time series for the base period (1998–2013)

Table 4. Drought indices, category and rain

year	Rain	SPI Index	Drought Severity	Z Index	Drought Severity	DI Index	Drought Severity	PNPI Index	Drought Severity	SIAP Index	Drought Severity
1998	208.28	0.23	Near normal	0.76	Moderately Wet	209	Above normal	116	Normal	0.76	Wet
1999	205.98	0.18	Near normal	0.69	Moderately Wet	205	Slightly above normal	114	Normal	0.69	Wet
2000	152.46	-1.14	Moderately dry	-0.75	Moderately Dry	166	Below normal	85	Normal	-0.75	Dry
2001	114.11	-2.28	Extremely dry	-1.78	Severely Dry	114	Extremely below normal	63	Moderate drought	-1.78	Severely dry
2002	166.30	-0.79	Near normal	-0.37	Near Normal	166	Below normal	92	Normal	-0.37	Normal
2003	182.57	-0.36	Near normal	0.06	Near Normal	182	Normal	101	Normal	0.06	Normal
2004	245.19	0.92	Near normal	1.75	Very Wet	218	Extremely above normal	136	Normal	1.75	Very wet
2005	209.70	0.26	Near normal	0.79	Moderately Wet	209	Above normal	116	Normal	0.79	Wet
2006	191.84	-0.14	Near normal	0.31	Near Normal	191	Normal	106	Normal	0.31	Normal
2007	186.31	-0.27	Near normal	0.16	Near Normal	191	Normal	103	Normal	0.16	Normal
2008	140.04	-1.48	Moderately dry	-1.08	Moderately Dry	140	Well below normal	78	Slight drought	-1.08	Severely dry
2009	218.81	0.44	Near normal	1.04	Moderately Wet	218	Well above normal	121	Normal	1.04	Very wet
2010	109.53	-2.43	Extremely dry	-1.90	Severely Dry	114	Extremely below normal	61	Moderate drought	-1.90	Severely dry
2011	201.84	0.09	Near normal	0.58	Moderately Wet	205	Slightly above normal	112	Normal	0.58	Wet
2012	169.13	-0.72	Near normal	-0.30	Near Normal	180	Slightly below normal	94	Normal	-0.30	Normal
2013	180.89	-0.40	Near normal	0.02	Near Normal	180	Slightly below normal	100	Normal	0.02	Normal

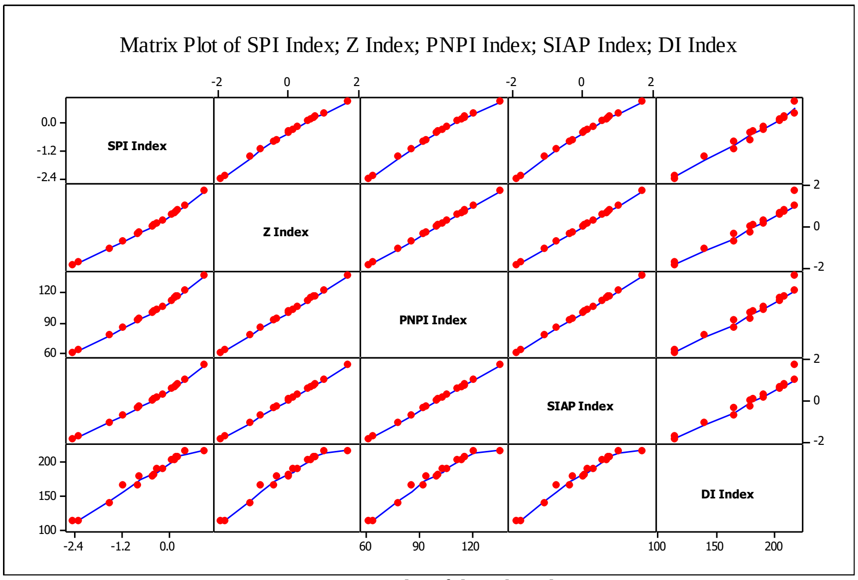

Fig. 4. Matrix plot of drought indices

Table 5. Pearson Correlation between SPI and other drought indices

Correlations					
	SPI Index	Z Index	SIAP Index	DI Index	PNPI Index
SPI Index	1	.995**	.995**	.987**	.995**
Z Index	.995**	1	1**	.976**	1**
SIAP Index	.995**	1**	1	.976**	1**
DI Index	.987**	.976**	.976**	1	.976**
PNPI Index	.995**	1**	1**	.976**	1

**. Correlation is significant at the 0.01 level (2-tailed).

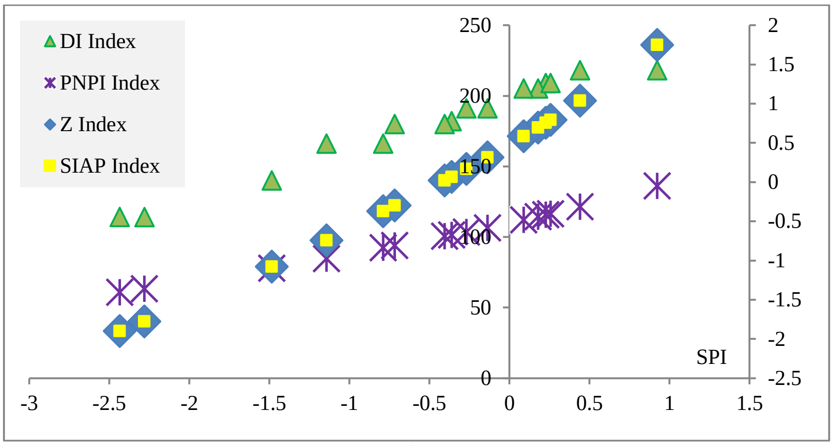

Fig. 5. Dispersion diagram of SPI and other drought indices

The maps of annual precipitation in 2004 for drought severity (near normal) and in 2001 for drought severity (extremely dry), which were derived from TRMM data, are drawn using GIS software, as shown in Figs. 6 and 7). According to Fig. 6, the highest rainfall was received in 2004 in the west of the study area (717-1181 mm), while the minimum rainfall was recorded in the eastern parts of Kerman and Sistan and Baluchistan provinces (11-126 mm). Also, a strong inverse relationship was found between rain and longitude along with a poor positive relationship between altitude and latitude (Figs. 8 and tab. 6). Based on the findings, the maximum rainfall was recorded in Kohgiluyeh and Boyer-Ahmad province in 2001 (545-912 mm) and the lowest rainfall (5-76 mm) was observed in the east of Kerman province, the south of Fars province, and in Hormozgan and Sistan and Baluchestan provinces (Fig. 7).

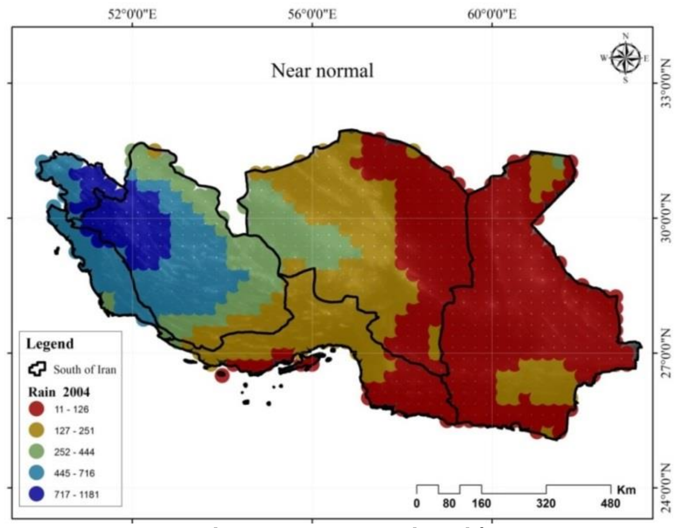

Fig. 6. Annual precipitation in 2004 derived from TRMM

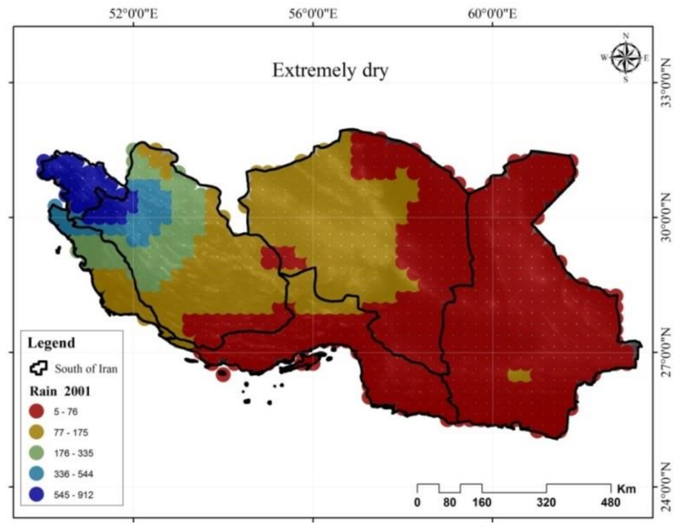

Fig. 7. Annual precipitation in 2001 derived from TRMM

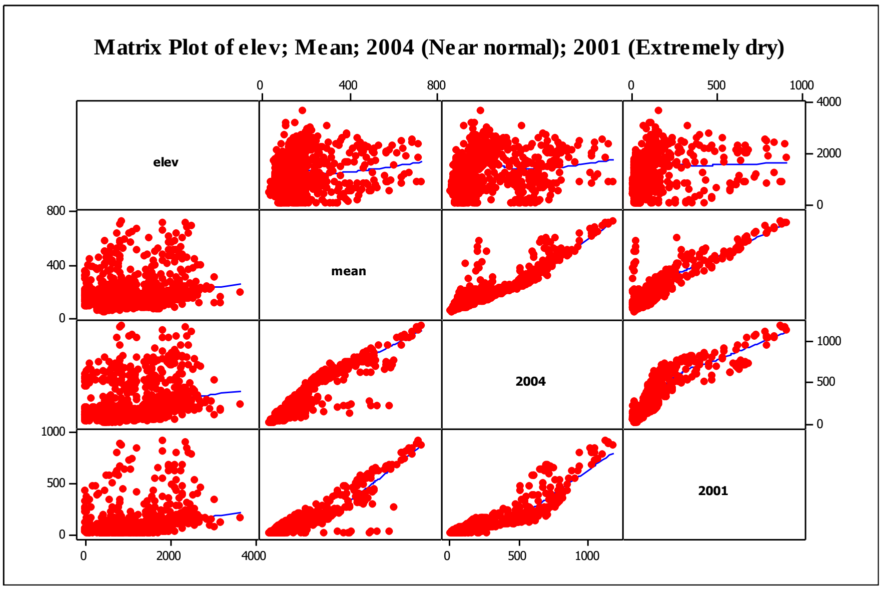

Fig. 8. Relationship between rain and longitude and relationship between altitude and latitude

Table 6. The results of Pearson Correlation

	Latitude	Longitude	Elev	mean	2001	2004
Latitude	1	-.352**	.459**	.251**	.336**	.303**
Longitude	-.352**	1	-.225**	-.694**	-.828**	-.852**
mean	.251**	-.694**	.212**	1	.915**	.890**
Elev	.459**	-.225**	1	.212**	.295**	.229**
2001	.336**	-.828**	.295**	.915**	1	.944**
2004	.303**	-.852**	.229**	.890**	.944**	1

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusions

In the current study, five meteorological drought indices including SPI, DI, z-Score, SIAP and PNPI, which were derived from the tropical rainfall measuring mission (TRMM) data in the South of Iran during 1998–2013 period, were used. First, the time-series of drought indices were constructed for the 1998–2013 period based on monthly mean rainfall values to determine drought categories. According to the results, drought indices were relatively similar. For example, 2004 was a rainy year with an average rainfall of 245 mm, and all drought indices indicated wet conditions for this year (SPI Index: near normal, Z Index: extremely wet, DI index: well above normal, PNPI index: normal, SIAP index: extremely wet). Also in 2010 (low rainfall) with an average rainfall of 109 mm, drought severity indices were almost identical (SPI Index: extremely dry, Z index: severely dry, DI index: well below normal, PNPI index: moderate drought, SIAP index: severely dry). The results of drought monitoring in the South of Iran using SPI suggested a severe drought in 2001 and 2010, and moderate drought in 2000 and 2008. The results of the Z index showed severe drought in 2001 and 2010, moderate drought in 2000 and 2008, near normal condition in 2002, 2003, 2006, 2007, 2012 and 2013, moderately wet in 1998, 1999, 2005 and 2011 and extremely wet in 2004. Also, the SPI index was positively related to other drought indices. The strongest relation between the SPI index and other drought indices was with the PNPI Index, at a correlation coefficient of R = 0.995 and a coefficient of determination of R2 = 0.99. Finally, based on the findings, a strong inverse relationship was found between rainfall and longitude while altitude and latitude were found to be in a poor positive relationship.

The use of TRMM satellite data is recommended for proper drought monitoring (Du *et al*., 2013; Zhang and Jia, 2013). Also, the results of another study (Hatmoko *et al*., 2016) showed that Meteorological Drought Index derived from TRMM provides more accurate results compared to APHRODITE for SPI of 3 to 12 months, except for SPI 1 month. Nevertheless, the hydrological drought index obtained from TRMM yields superior result.

The efficiency of TRMM satellite data, especially in southern Iran and Fars province, for monitoring drought, has been confirmed in several studies (Erfanian *et al*., 2014; Shirvani and Fakhari Zade Shirazi, 2014; Rasouli *et al*., 2016).

References

Al-Dousari, A., A. Ramdan, A. Al Ghadban, 2008. Site-specific precipitation estimate from TRMM data using bilinear weighted interpolation technique: An example from Kuwait. Journal of arid environments, 727; 1320-1328. doi:10.1016/j.jaridenv.2007.12.013

Almazroui, M., 2011. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009. Atmospheric Research, 99; 400-414. doi:10.1016/j.atmosres.2010.11.006.

Bajgiran, P. R., A. A. Darvishsefat, A., Khalili, M. F. Makhdoum, 2008. Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran. Journal of Arid Environments, 72; 1086-1096. doi:10.1016/j.jaridenv.2007.12.004.

Bazrafshan, J., A. Khalili, 2013. Spatial Analysis of Meteorological Drought in Iran from 1965 to2003. Desert, 18; 63-71.

Domínguez-Castro, F., J. I., Santisteban, M., Barriendos, R. Mediavilla, 2008. Reconstruction of drought episodes for central Spain from rogation ceremonies recorded at the Toledo Cathedral from 1506 to 1900: A methodological approach. Global and Planetary Change, 63; 230-242. doi.org/10.1016/j.gloplacha.2008.06.002.

Du, L., Q., Tian, T., Yu, Q., Meng, T., Jancso, P., Udvardy, Y. Huang, 2013. A comprehensive drought monitoring method integrating MODIS and TRMM data. International Journal of Applied Earth Observation and Geoinformation, 23; 245-253. doi.org/10.1016/j.jag.2012.09.010.

Erfanian, M., S. Kazempour, H. Heidari, 2016. Calibration of TRMM satellite 3B42 and 3B43 rainfall data in climatic zones of Iran. Physical Geography, 48; 287-303. DOI: 10.22059/jphgr.2016.59370.

Erfanian, M., N. Vafaei, M. Rezaeianzadeh, 2014. A New Method for Drought Risk Assessment by Integrating the TRMM Monthly Rainfall Data and the

Terra/MODIS NDVI Data in Fars Province, Iran. Physical geography, 46; 93-108. DOI: 10.22059/jphgr.2014.50621.

Ezzine, H., A. Bouziane, D. Ouazar, 2014. Seasonal comparisons of meteorological and agricultural drought indices in Morocco using open short time-series data. International Journal of Applied Earth Observation and Geoinformation, 26; 36-48. doi.org/10.1016/j.jag.2013.05.005.

Fatemi, M., K. Omidvar, E., Mesgari, M. Narangifard, 2017. Spatial analysis and investigation of Tele-connection patterns with drought in central Iran. Journal of the Earth and Space Physics, 42; 49-61.

Fatemi, M., K. Omidvar, K. K. Hatami Bahman Beiglou, M. Narangifard, 2015. Using Principle Component Analysis in Identifying Synoptic Patterns of Wet Periods in Central Iran. J Earth Sci Clim Change. 6:309. doi:10.4172/2157-7617.1000309.

Frolking, S., T. Milliman, M. Palace, D. Wisser, R. Lammers, M. Fahnestock, 2011. Tropical forest backscatter anomaly evident in SeaWinds scatterometer morning overpass data during 2005 drought in Amazonia. Remote Sensing of Environment, 115; 897-907. doi.org/10.1016/j.rse.2010.11.017.

Gibbs, W.J., J.V. Maher, 1967. Rainfall Deciles as Drought Indicators. Bureau of Meteorology bulletin No. 48; Commonwealth of Australia, Melbourne, VIC, Australia.

Gocic, M., S. Trajkovic, 2014. Spatiotemporal characteristics of drought in Serbia. Journal of Hydrology, 510; 110-123. doi.org/10.1016/j.jhydrol.2013.12.030.

Golian, S., O. Mazdiyasni, A. AghaKouchak, 2015. Trends in meteorological and agricultural droughts in Iran. Theoretical and Applied Climatology, 119; 679-688. DOI 10.1007/s00704-014-1139-6.

Hatmoko, W., W. Seizarwati, R. Vernimmen, 2016. Comparison of TRMM Satellite Rainfall and APHRODITE for Drought Analysis in the Pemali-comal River Basin. Procedia Environmental Sciences, 33; 187-195.

Hatmoko, W., W. Seizarwati, R. Vernimmen, 2016. Comparison of TRMM Satellite Rainfall and APHRODITE for Drought Analysis in the Pemali-comal River Basin. Procedia Environmental Sciences, 33; 187-195.

Hayes, M. J., M. D. Svoboda, D. A., Wilhite, O. V. Vanyarkho, 1999. Monitoring the 1996 drought using the standardized precipitation index. Bulletin of the American Meteorological Society, 80; 429-438. http://disc2.nascom.nasa.gov

Ibrahim, K., W. Z. W. Zin, A. A. Jemain, 2010. Evaluating the dry conditions in Peninsular Malaysia using bivariate copula. ANZIAM Journal, 51; 555-569.

Javan, K., M. R. Azizzadeh, S. Yousefi, 2016. An Investigation and assessment of meteorological drought in Lake Urmia Basin using drought indices and probabilistic methods. Natural Environment Change, 2; 153-164.

Kaniewski, D., E. Van Campo, H. Weiss, 2012. Drought is a recurring challenge in the Middle East. Proceedings of the National Academy of Sciences, 109; 3862-3867.

Karimpour Reyhan, M., Y. Esmaeilpour, A. R. M. E. N., Malekian, N., Mashhadi, N. Kamali, 2009. Spatio-Temporal Analysis of Drought Vulnerability using the Standardized Precipitation Index (Case study: Semnan Province, Iran). Desert, 14; 133-140.

Keshavarz, M., E. Karami, 2014. Farmers' decision-making process under drought. Journal of Arid Environments, 108; 43-56. doi.org/10.1016/j.jaridenv.2014.03.006.

Keshavarz, M., E. Karami, F. Vanclay, 2013. The social experience of drought in rural Iran. Land Use Policy, 30; 120-129. doi.org/10.1016/j.landusepol.2012.03.003.

Mckee, T.B., N.J, Doesken, J, Kleist, 1993. The relationship of drought frequency and duration to time scales, In: Proc. 8th conference on applied climatology. January 17-22; 179- 184.

Mirabbasi, R., E. N. Anagnostou, A., Fakheri-Fard, Y., Dinpashoh, S. Eslamian, 2013. Analysis of meteorological drought in northwest Iran using the Joint Deficit Index. Journal of Hydrology, 492; 35-48.

Moazami, S.,S. Golian, M.R. Kavianpour, Y. Hong, 2013. Comparison of PERSIANN and V7 TRMM Multi-satellite Precipitation Analysis (TMPA) products with rain gauge data over Iran. International journal of remote sensing, 34; 8156-8171. doi.org/10.1080/01431161.2013.833360.

Monacelli, G., M. C. Galluccio, M. Abbafati, 2005. Drought assessment and forecasting. Drought within the context of the region VI.

Morid, S., V. Smakhtin, M. Moghaddasi, 2006. Comparison of seven meteorological indices for drought monitoring in Iran. International journal of climatology, 26; 971-985. DOI: 10.1002/joc.1264.

Mozafari, G. A., M. Narangifard, 2015. The Vegetative Cover Deterioration Due to the Droughts on the Mulla Sadra Watershed and Application of Remote Sensing Techniques in Its Monitoring. Water Engineering, 8; 1-14.

Mozafari, G.A., Y. Khosravi, E. Abbasi, F. Tavakoli, 2011. Assessment of geostatistical methods for spatial analysis of SPI and EDI drought indices. World Applied Sciences Journal, 15; 474-482.

Nastos, P. T., J. Kapsomenakis, K.C. Douvis, 2013. Analysis of precipitation extremes based on satellite and high-resolution gridded data set over Mediterranean basin. Atmospheric Research, 131; 46-59. doi.org/10.1016/j.atmosres.2013.04.009

Niemeyer, S., 2008. New drought indices. Options Méditerranéennes. Série A: Séminaires Méditerranéens, 80, 267-274.

Nohegar, A., M. Heydarzadeh, A. Malekian, 2013. Assessment of Severity of Droughts Using Geostatistic Method (Case Study: Southern Iran). Desert, 18; 79-87.

Nosrati, K., A. R. Zareiee, 2011. Assessment of meteorological drought using SPI in West Azarbaijan Province, Iran. Journal of Applied Sciences and Environmental Management, 15; 563-569.

Omidvar, K., M. Fatemi, M. Narangifard, K. Hatami Bahman Beiglou, 2016. A Study of the Circulation Patterns Affecting Drought and Wet Years in Central Iran. Advances in Meteorology, doi.org/10.1155/2016/1843659.

Omidvar, K., M. Fatemi, M., Narangifard, K. Hatami Bahman Beiglou, 2016. Assess circulation pattern of drought periods using SPI (case study: central Iran). International Journal of Geo Science and Environmental Planning, 1, 31-43.

Park, S., J. Im, E., Jang, J. Rhee, 2016. Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. Agricultural and Forest Meteorology, 216; 157-169. doi.org/10.1016/j.agrformet.2015.10.011.

Park, S., J. Im, S., Park, J. Rhee, 2017. Drought monitoring using high resolution soil moisture through multi-sensor satellite data fusion over the Korean peninsula. Agricultural and Forest Meteorology, 237; 257-269. doi.org/10.1016/j.agrformet.2017.02.022.

Rasouli, A.A., M. Erfanian, B. SariSarraf, K, Javan. 2016. Comparative evaluation of TRMM estimated rainfall amounts and rainfall recorded by ground stations in Lake Urmia Basin. Journal of Geographic Space, 54; 195-217.

Raziei, T., B. Saghafian, A. A., Paulo, L. S., Pereira, I. Bordi, 2009. Spatial patterns and temporal variability of drought in western Iran. Water Resources Management, 23; 439-455.

Rhee, J., J. Im, G. J. Carbone, 2010. Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. Remote Sensing of Environment, 114; 2875-2887. doi:10.1016/j.rse.2010.07.005.

Sadat Noori, S. M., K. Ebrahimi, A. M., Liaghat, A. H. Hoorfar, 2013. Comparison of different geostatistical methods to estimate groundwater level at different climatic periods. Water and Environment Journal, 27; 10-19.

Sahoo, A. K., J., Sheffield, M., Pan, E. F. Wood, 2015. Evaluation of the tropical rainfall measuring mission multi-satellite precipitation analysis (TMPA) for assessment of large-scale meteorological drought. Remote Sensing of Environment, 159; 181-193. doi.org/10.1016/j.rse.2014.11.032.

Salami, H., N. Shahnooshi, K. J. Thomson, 2009. The economic impacts of drought on the economy of Iran: An integration of linear programming and macroeconometric modelling approaches. Ecological Economics, 68; 1032-1039. doi.org/10.1016/j.ecolecon.2008.12.003.

Sayari, N., M. Bannayan, A. Alizadeh, A. Farid, 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.

Shahabfar, A., A. Ghulam, J. Eitzinger, 2012. Drought monitoring in Iran using the perpendicular drought indices. International Journal of Applied Earth Observation and Geoinformation, 18; 119-127. DOI: 10.1016/j.jag.2012.01.011.

Shirvani, A., E. Fakhari Zade Shirazi, 2014. Comparison of ground based observation of precipitation with TRMM satellite estimations in Fars Province. Journal of Agricultural Meteorology, 2; 1-15.

Son, N. T., C. F. Chen, C. R. Chen, L. Y. Chang, V. Q. Minh, 2012. Monitoring agricultural drought in the Lower Mekong Basin using MODIS NDVI and land surface temperature data. International Journal of Applied Earth Observation and Geoinformation, 18; 417-427. doi.org/10.1016/j.jag.2012.03.014.

Su, Z., A. Yacob, J., Wen, G., Roerink, Y., He, B., Gao, C. Van Diepen, 2003. Assessing relative soil moisture with remote sensing data: theory, experimental validation, and application to drought monitoring over the North China Plain. Physics and Chemistry of the Earth, Parts A/B/C, 28; 89-101. doi:10.1016/S1474-7065(03)00010-X.

Varikoden, H., A. A. Samah, C. A. Babu, 2010. Spatial and temporal characteristics of rain intensity in the peninsular Malaysia using TRMM rain rate. Journal of hydrology, 387, 312-319. doi:10.1016/j.jhydrol.2010.04.023

Werick, W. J., G. E. Willeke, N. B. Guttman, J. R. M., Hosking, J. R. Wallis, 1994. National drought atlas developed. Eos, Transactions American Geophysical Union, 75; 89-90.

Yaduvanshi, A., P. K. Srivastava, A. C. Pandey, 2015. Integrating TRMM and MODIS satellite with socio-economic vulnerability for monitoring drought risk over a tropical region of India. Physics and Chemistry of the Earth, Parts A/B/C, 83, 14-27. doi.org/10.1016/j.pce.2015.01.006.

Yousefi, Y., J. Masoompour Samakosh, 2014. Temporal-Spatial Variability of the Severest Dry Spells in the North-West of Iran. Desert, 19; 17-25.

Zaitchik, B. F., J. P. Evans, R. A., Geerken, R. B. Smith, 2007. Climate and vegetation in the Middle East: interannual variability and drought feedbacks. Journal of Climate, 20; 3924-3941. DOI: 10.1175/JCLI4223.1.

Zambrano, F., B. Wardlow, T. Tadesse, M. Lillo-Saavedra, O. Lagos, 2017. Evaluating satellite-derived long-term historical precipitation datasets for drought monitoring in Chile. Atmospheric Research, 186; 26-42. doi.org/10.1016/j.atmosres.2016.11.006.

Zargar, A., R. Sadiq, B., Naser, F. I. Khan, 2011. A review of drought indices. Environmental Reviews, 19; 333-349. doi:10.1139/A11-013.

Zhang, A., G. Jia, 2013. Monitoring meteorological drought in semiarid regions using multi-sensor microwave remote sensing data. Remote Sensing of Environment, 134; 12-23. doi.org/10.1016/j.rse.2013.02.023.