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 R² = 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 subsurface 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
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; Frohling et al., 2011; Son et al., 2012; Ezzine et al., 2014; Yaduanshi 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 & 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 km² 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°](http://disc2.nascom.nasa.gov)

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:

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

Where, $P_i$ 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>
<thead>
<tr>
<th>Standard precipitation index</th>
<th>SIAP value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely severe wet years</td>
<td>≥ 0.84</td>
</tr>
<tr>
<td>Moderate wet years</td>
<td>0.52 to 0.84</td>
</tr>
<tr>
<td>Normal</td>
<td>-0.52 to 0.52</td>
</tr>
<tr>
<td>Severe drought</td>
<td>-0.84 to -0.52</td>
</tr>
<tr>
<td>Extremely severe drought</td>
<td>≤ -0.84</td>
</tr>
</tbody>
</table>

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:

$$\text{SIAP} = \frac{P_i - \overline{P}}{SD}$$  (2)

Where $P_i$ 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>
<thead>
<tr>
<th>SIAP value</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 0.84</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>0.52 to 0.84</td>
<td>Wet</td>
</tr>
<tr>
<td>-0.52 to 0.52</td>
<td>Normal</td>
</tr>
<tr>
<td>-0.84 to 0.52</td>
<td>Dry</td>
</tr>
<tr>
<td>≤ -0.84</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>
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:

\[ PNPI = \frac{P_i}{P} \times 100 \]  

Where \( P_i \) 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)

<table>
<thead>
<tr>
<th>PNPI</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-0.25 &lt; PNPI \leq 0.25)</td>
<td>Normal</td>
</tr>
<tr>
<td>(-0.52 \leq PNPI &lt; -0.25)</td>
<td>Light drought</td>
</tr>
<tr>
<td>(-0.84 \leq PNPI &lt; -0.52)</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>(-1.28 \leq PNPI &lt; -0.84)</td>
<td>Severe drought</td>
</tr>
<tr>
<td>PNPI \leq -1.28</td>
<td>Extreme drought</td>
</tr>
</tbody>
</table>

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 \( R^2=0.99 \).
Table 4. Drought indices, category and rain

<table>
<thead>
<tr>
<th>Year</th>
<th>Rain</th>
<th>SPI Index</th>
<th>Drought Severity</th>
<th>Z Index</th>
<th>Drought Severity</th>
<th>DI Index</th>
<th>Drought Severity</th>
<th>PNPI Index</th>
<th>Drought Severity</th>
<th>SIAP Index</th>
<th>Drought Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>208.28</td>
<td>0.23</td>
<td>Near normal</td>
<td>0.76</td>
<td>Moderately Wet</td>
<td>209</td>
<td>Above normal</td>
<td>116</td>
<td>Normal</td>
<td>0.76</td>
<td>Wet</td>
</tr>
<tr>
<td>1999</td>
<td>205.98</td>
<td>0.18</td>
<td>Near normal</td>
<td>0.69</td>
<td>Moderately Wet</td>
<td>205</td>
<td>Slightly above normal</td>
<td>114</td>
<td>Normal</td>
<td>0.69</td>
<td>Wet</td>
</tr>
<tr>
<td>2000</td>
<td>152.46</td>
<td>-1.14</td>
<td>Moderately dry</td>
<td>-0.75</td>
<td>Moderately Dry</td>
<td>166</td>
<td>Below normal</td>
<td>85</td>
<td>Normal</td>
<td>-0.75</td>
<td>Dry</td>
</tr>
<tr>
<td>2001</td>
<td>114.11</td>
<td>-2.28</td>
<td>Extremely dry</td>
<td>-1.78</td>
<td>Severely Dry</td>
<td>114</td>
<td>Extremely below normal</td>
<td>63</td>
<td>Moderate drought</td>
<td>-1.78</td>
<td>Severely dry</td>
</tr>
<tr>
<td>2002</td>
<td>166.30</td>
<td>-0.79</td>
<td>Near normal</td>
<td>-0.37</td>
<td>Near Normal</td>
<td>166</td>
<td>Below normal</td>
<td>92</td>
<td>Normal</td>
<td>-0.37</td>
<td>Normal</td>
</tr>
<tr>
<td>2003</td>
<td>182.57</td>
<td>-0.36</td>
<td>Near normal</td>
<td>0.06</td>
<td>Near Normal</td>
<td>182</td>
<td>Normal</td>
<td>101</td>
<td>Normal</td>
<td>0.06</td>
<td>Normal</td>
</tr>
<tr>
<td>2004</td>
<td>245.19</td>
<td>0.92</td>
<td>Near normal</td>
<td>1.75</td>
<td>Very Wet</td>
<td>218</td>
<td>Extremely above normal</td>
<td>136</td>
<td>Normal</td>
<td>1.75</td>
<td>Very wet</td>
</tr>
<tr>
<td>2005</td>
<td>209.70</td>
<td>0.26</td>
<td>Near normal</td>
<td>0.79</td>
<td>Moderately Wet</td>
<td>209</td>
<td>Above normal</td>
<td>116</td>
<td>Normal</td>
<td>0.79</td>
<td>Wet</td>
</tr>
<tr>
<td>2006</td>
<td>191.84</td>
<td>-0.14</td>
<td>Near normal</td>
<td>0.31</td>
<td>Near Normal</td>
<td>191</td>
<td>Normal</td>
<td>106</td>
<td>Normal</td>
<td>0.31</td>
<td>Normal</td>
</tr>
<tr>
<td>2007</td>
<td>186.31</td>
<td>-0.27</td>
<td>Near normal</td>
<td>0.16</td>
<td>Near Normal</td>
<td>191</td>
<td>Normal</td>
<td>103</td>
<td>Normal</td>
<td>0.16</td>
<td>Normal</td>
</tr>
<tr>
<td>2008</td>
<td>140.04</td>
<td>-1.48</td>
<td>Moderately dry</td>
<td>-1.08</td>
<td>Moderately Dry</td>
<td>140</td>
<td>Well below normal</td>
<td>78</td>
<td>Slight drought</td>
<td>-1.08</td>
<td>Severely dry</td>
</tr>
<tr>
<td>2009</td>
<td>218.81</td>
<td>0.44</td>
<td>Near normal</td>
<td>1.04</td>
<td>Moderately Wet</td>
<td>218</td>
<td>Well above normal</td>
<td>121</td>
<td>Normal</td>
<td>1.04</td>
<td>Very wet</td>
</tr>
<tr>
<td>2010</td>
<td>109.53</td>
<td>-2.43</td>
<td>Extremely dry</td>
<td>-1.90</td>
<td>Severely Dry</td>
<td>114</td>
<td>Extremely below normal</td>
<td>61</td>
<td>Moderate drought</td>
<td>-1.90</td>
<td>Severely dry</td>
</tr>
<tr>
<td>2011</td>
<td>201.84</td>
<td>0.09</td>
<td>Near normal</td>
<td>0.58</td>
<td>Moderately Wet</td>
<td>205</td>
<td>Slightly above normal</td>
<td>112</td>
<td>Normal</td>
<td>0.58</td>
<td>Wet</td>
</tr>
<tr>
<td>2012</td>
<td>169.13</td>
<td>-0.72</td>
<td>Near normal</td>
<td>-0.30</td>
<td>Near Normal</td>
<td>180</td>
<td>Slightly below normal</td>
<td>94</td>
<td>Normal</td>
<td>-0.30</td>
<td>Normal</td>
</tr>
<tr>
<td>2013</td>
<td>180.89</td>
<td>-0.40</td>
<td>Near normal</td>
<td>0.02</td>
<td>Near Normal</td>
<td>180</td>
<td>Slightly below normal</td>
<td>100</td>
<td>Normal</td>
<td>0.02</td>
<td>Normal</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Latitude</th>
<th>Longitude</th>
<th>Elev</th>
<th>mean</th>
<th>2001</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3.52°</td>
<td>.459°</td>
<td>.251°</td>
<td>.336°</td>
<td>.303°</td>
</tr>
<tr>
<td>mean</td>
<td>-2.25°</td>
<td>.212°</td>
<td>1</td>
<td>.915°</td>
<td>.890°</td>
</tr>
<tr>
<td>2001</td>
<td>-2.25°</td>
<td>.212°</td>
<td>1</td>
<td>.295°</td>
<td>.229°</td>
</tr>
<tr>
<td>2004</td>
<td>-1.94°</td>
<td>.229°</td>
<td>.890°</td>
<td>.944°</td>
<td>1</td>
</tr>
</tbody>
</table>

**. 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 $R^2 = 0.99$. 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


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


