Severity – Area – Frequency curves of drought and wet periods

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Abstract
Occurrence of extreme climatological events such droughts and wet periods an cause substantial damage to the eco-system. Although such events are regional in nature. They are measured at point scale. As such, it is required to study the spatial distribution of extreme events. Severity – Area- Frequency (SAF) curves are one of the tools to characterize regional scales. A number of methods exit to drive the SAF curves. We used a medium range time series based on SPI drought/wet index to study SAF in Razavi & Southern Khorasan provinces in Iran. Also, maps of probability of drought occurrence were derived. The results indicated that drought periods occur locally in higher frequencies while only sever low frequency droughts may spread over the whole region.

Key words : *SPI, Severity- Area- Frequency, Drought, Wet, Iran.*

1-INTRODUCTION

Droughts are long–term hydro-meteorological events affecting vast regions and causing significant non-structural damages. Droughts are costliest natural disaster in the world and affect more people than any other natural disaster (Whilhite, 2000). Meteorological drought is considered the first ring in the chain of droughts and is analyzed in water resource planning and management studies. Main drought characteristics include the onset, termination time, severity and frequency (Loukas and Vasiliades , 2004) .

Numerous drought indices have been proposed to quantify droughts. The most commonly used meteorological drought indices are Palmer drought severity index (PDSI) (Palmer, 1965), deciles (Gibbs and Maher, 1967), and the standardized precipitation index. The SPI quantifies the precipitation deficit for multiple time scales and reflects the impact of droughts on the availability of different types of water resources. Wetter and drier climates can be represented in the same way by the SPI, because it is a normalized index (Loukas and Vasiliades , 2004) .

Regional drought analysis is useful for declaring the drought condition or determining the drought intensity during a particular year (Shin and Salas, 2000). One of most useful methods to assess drought in a region is the drought severity–area–frequency (SAF) curves, which was proposed by Henriques and Santos (1999). They obtained the area of influence of each station using the Thiessen polygon method and constructed the SAF curves using the drought severity from the synthetic precipitation series. The Thiessen method, however, does not properly consider the spatial distribution of rainfall data.

Loukas and Vasiliades (2004) used SPI for the identification and the assessment of drought events. The observed monthly precipitation data were spatially distributed into 212 grids of 8×8 km over the Thessaly region, Greece, by a simple Multiple Linear Regression (MLR) model**.** The precipitation grid data were then used for the estimation of the SPI time series. A practical method for developing annual and monthly drought severity-aerial extent-frequency (SAF) curves was proposed. They believed that SAF provides useful information to characterize a regional drought event and to plan the water resources management in semi-arid regions. Kim and Valdés (2002) investigated the temporal and spatial characteristics of droughts to provide
a framework for sustainable water resources management in a semi-arid region. Using the PDSI as an indicator of drought severity, the characteristics of droughts were examined in the Conchos River Basin in Mexico, an important basin to both the United States and Mexico. The temporal and spatial characteristics of the PDSI were used to develop a drought intensity - areal extent - frequency curve that could assess the severity of a regional drought in the basin. The analysis of the PDSI suggested that the Conchos River Basin had a severe drought in the 1990s, which the basin has not experienced before. Based on this analysis, the drought that occurred in the 1990s has an associated return period of about 80 to 100 years over the basin.

In this study, the regional drought in north eastern Iran is analyzed and drought SAF curves are developed. More advanced geostatistical techniques are applied to estimate regional drought variables corresponding to each return period. Thin Plate Smoothing Splines (TPSS) used in this study is a mathematically elegant model for surface estimation that has been progressively developed over the last decade. The model smoothes the data through minimizing the function, which combines the mean-square residuals and the roughness of the signal surface (Zheng and Basher, 1995).

2-STUDY AREA

The study area covers two provinces: Razavi and South Khorasan. The region is mountainous in the north while southern part is flat. The climate is generally arid and semi-arid so that the degree of dryness increases southward. Precipitation data of some 30 stations including synoptic, climatology, and daily raingages within the region and those of 11 stations in the proximity were collected. The synoptic and climatology stations are run by the National Meteorological Organization while the daily raingages are handled by the Ministry of Energy. Figure 1 shows the study area and the distributions of the stations. The common record length of the stations spans from 1965 to 2000 which is adequate for studies drought.

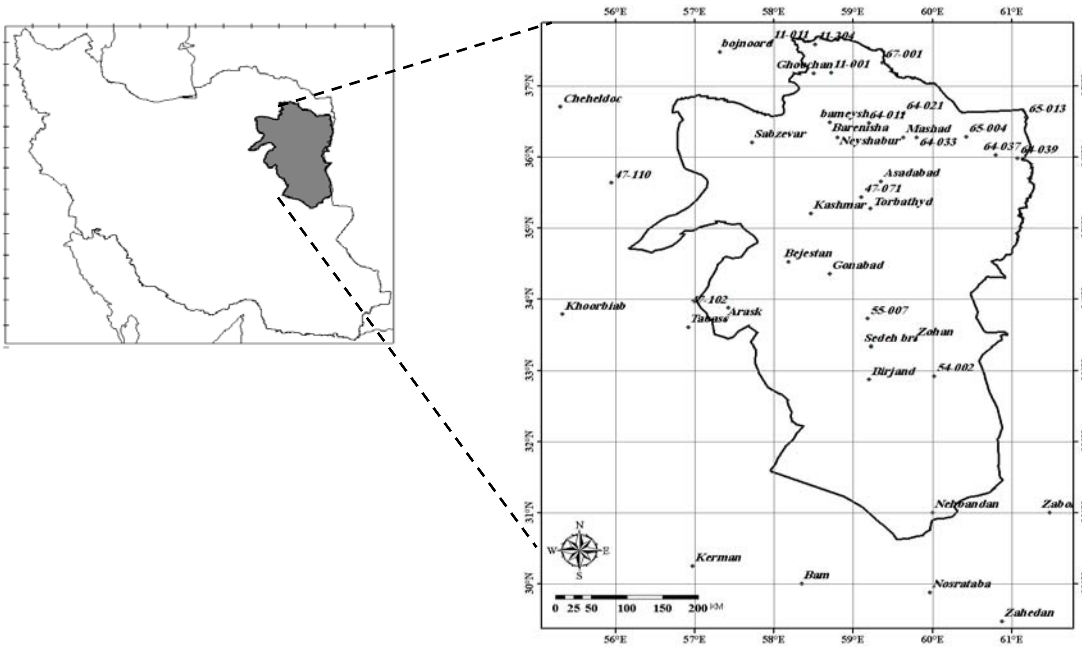

Figure 1: study area and the distributions of the rain stations

3- METHODOLOGY

Derivation of SAF (Severity-Duration-Frequency) in the area was carried out as follows. First, an appropriate drought monitoring (historical) index must be selected. Many drought indices have been proposed to date, for instance, Palmer Drought Severity Index (PDSI), Deciles Index, China-Z index (CZI), and the well-known Standardized Precipitation Index (SPI) (McKee et al., 1993). The SPI was chosen for this study because of its simplicity and being based solely on the accessible precipitation data. The SPI is calculated from precipitation monthly record by first fitting the gamma probability distribution function and then transforming into a normal distribution so that the mean SPI is set to zero (McKee et al. 1993; Edwards and McKee, 1997). Positive and negative SPI values indicate wet and dry conditions, respectively. Table 1 shows various SPI classes. The SPI may be computed with different time scales (e.g. 1 month, 3 months, etc.).

After the SPI monthly time series is computed for each station, drought maps are generated. A number of interpolation methods exist for mapping. To name a few, Thiessen Polygons, inverse distance, and geostatistical methods are in common practice. Some studies have compared and indicated that Thin Plate Smoothing Splines (TPSS) are suitable for spatial analysis of SPI in the eastern part of Iran. Therefore, this method was chosen for mapping SPI in the study region.

Table 1: SPI classes

Class	SPI
Extremely wet	≥2
Very wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Normal	-0.99 to 0.99
Moderately dry	-1.0 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	≤-2

In the next step, all 36 12-month September SPI maps are classified into several clusters. The area covered by each SPI category is calculated and the best probability distribution function is fitted to the area values. If the area turns out to be zero in any year-category, a very small figure is assigned. The areas associated with different return periods are determined from the probability distribution function. It is noted that the average of SPI value in each category represents the drought\wet degree in that particular category. In the end, the families of SAF curves corresponding to different return periods are constructed by plotting area (in percent of whole region) vs. average SPI in each category.

Furthermore, in order to classify the study area on the basis of drought occurrence probability, the September 12-month SPI time series at stations are analyzed based on Weibul statistics. As such, the drought occurrence probability is calculated at point scale and then mapped.

4- RESULTS

Figure 2 shows an example of 12-month SPI time series at one of the stations. Similar time series have been derived for other stations. In most stations in the region, several severe droughts such those in 1966, 1971, 1995, and the developing 2000 are observed which was consistent with field reports. Note that the observation of such severe drought on the basis of SPI time series is at point scale and may not hold for the whole region. This point will be further elaborated in the spatial analysis of droughts.

The TPSS method was applied to generate 36 September 12-month SPI maps. Figures 3 and 4 represent maps of two years with extreme drought in the whole study area. Figure 5 shows the percentage of area under each SPI category extracted from Figures 3 and 4.

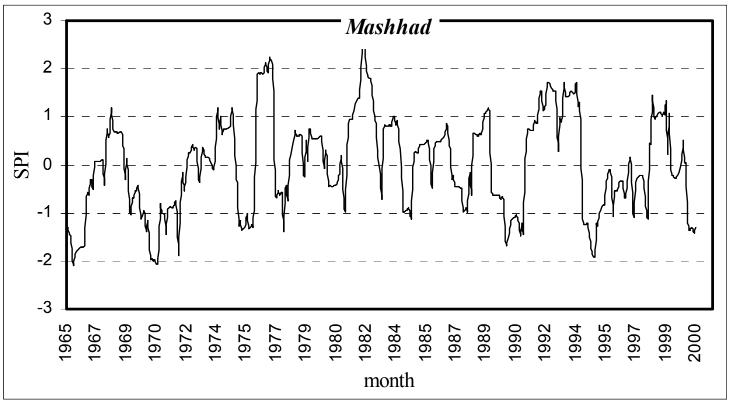

Figure 2: 12-month September SPI 1965-2000 time series for Mashhad station

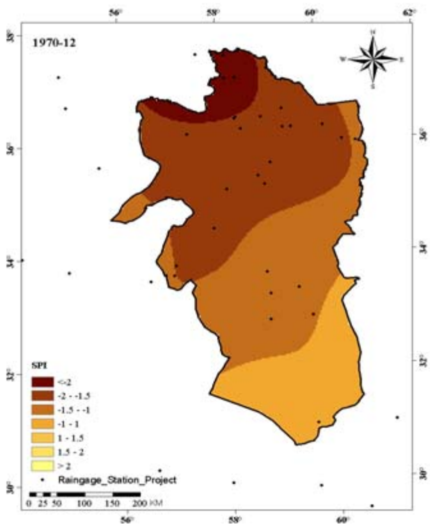

Figure 3: september 1970 drought map

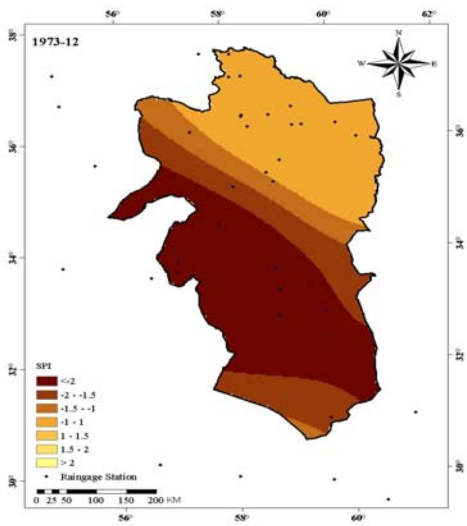

Figure 4: september 1973 drought map

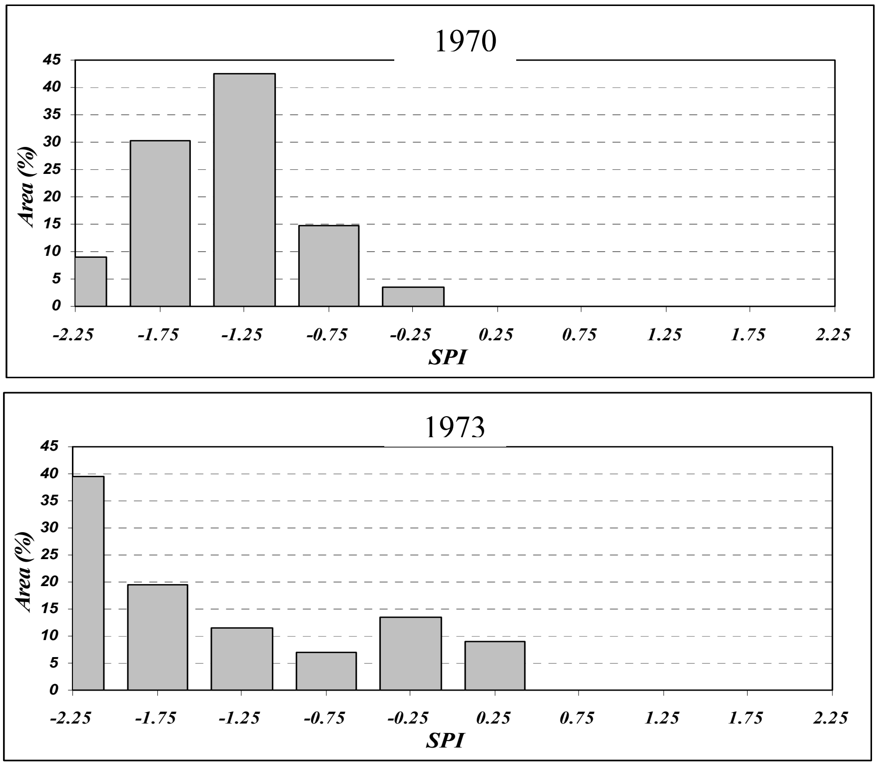

Figure 5: percentage of each SPI category in 1970 (top) and 1973 (bottom).

Figure 6 shows the time series of percentage area in different SPI category in the whole study period. A few years experience no drought in any portion of the region while normal conditions prevail in most parts of the region throughout the study period.

The most severe drought in terms of both magnitude and area covered corresponds to 1973 where about 40% of area experienced droughts of SPI less than -2.25. In the same year, some 20% of area faced SPI in the (-2 to -1.5) range. The 2-parameter Gamma distribution function was the best in fitting the probability distribution of drought area. So, this is used as dominated distribution. Table 2 shows the area under each average SPI category for various return periods. Negative values indicate drought conditions.

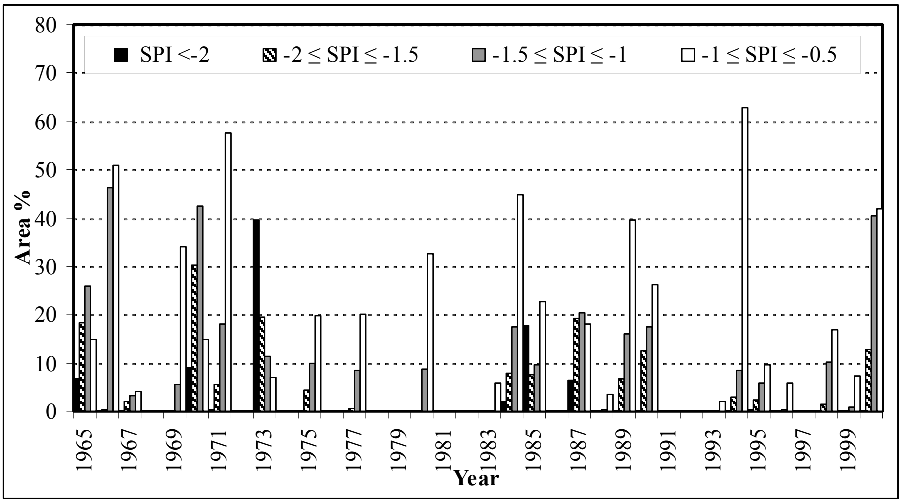

Figure 6: percentage area covered by droughts of different SPI severity

Table 2: area (in km^2) covered by each SPI category for various return periods

SPI	T= 2 yr	T =5 yr	T=10 yr	T=20 yr	T=25 yr	T=50 yr	T=100 yr
<-2	8	3594	11033	21945	26113	40889	58203
-1.75	2696	13761	24934	37769	42198	56766	72441
-1.25	9268	31040	50143	70829	77776	100148	123615
-0.75	19788	53413	80663	109138	118541	148413	179237
-0.25	23064	49666	69391	89154	95546	115519	135707
0.25	33394	66981	91168	115057	122728	146557	170465
0.75	26832	63882	92483	121699	131240	161283	191945
1.25	8669	33777	56997	82717	91448	119794	149827
1.75	440	8657	20324	35516	41051	60012	81398
2<	12	1267	3572	6829	8056	12361	17349

Figure 7 shows the SAF drought and wet curves in Razavi and South Khorasan provinces. As it is shown, drought by short return period and high degree cover only small areas.

For instance, droughts of 2- and 5-year return periods in the -1 SPI range are expected to cover around 10 to 30 percent of the whole region, respectively. This is while droughts with 20- and 50-year return periods can cover 50 and 75 percent of area in the same SPI (-1) range, respectively. Thus, very small parts of region may be affected by severe droughts (high return periods and/or more negative SPI values). Although a drought of 100-year return period dominates around 90% of whole area, it will be only a near-normal drought of SPI being greater than -0.5.

Figure 8 shows the spatial distribution of drought occurrence probability for the study area. State of drought in this figure corresponds to SPI less than -1, i.e. moderate, severe, and extreme drought conditions. The drought state probability in the study region varies from 5% to 25%. The most part of the region may be affected by droughts in 15% to 20% of the time. The risk of drought occurrence is higher by moving away from the center of the region. This figure helps in locating drought prone areas for priority planning in the context of drought risk management.

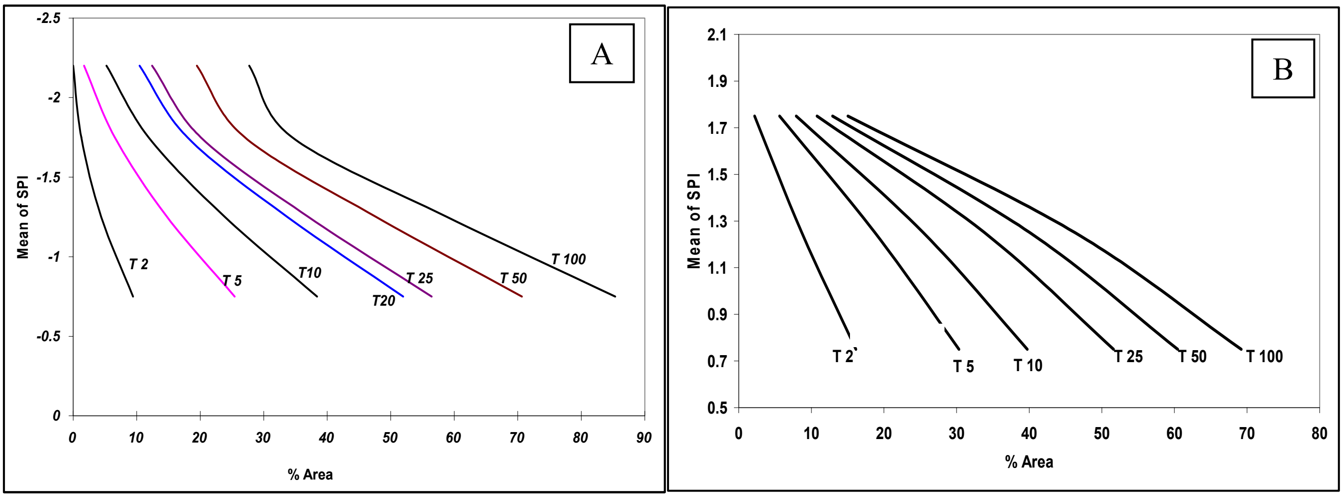

Figure 7: SAF diagram in Razavi and South Khorasan A) for drought, B) for wet

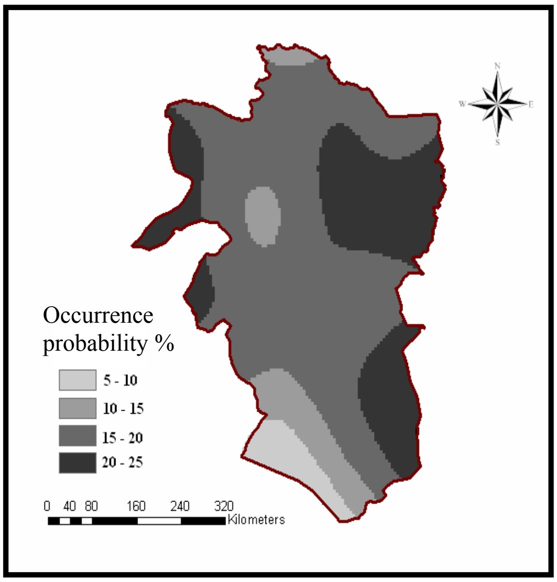

Figure 8. drought occurrence probability

5- CONCLUSION

In this paper, spatial characteristics of droughts\wets were studied in two provinces located in northeast of Iran based on the commonly used standard precipitation index (SPI) on the 12 months time scale. This was carried out by plotting the September 12-month SPI maps during the study period. Accordingly, the area under various drought severity categories was identified upon which frequency analysis was conducted. Then, severity-area-frequency curves were extracted for the region. It was shown that only droughts of high return period (eg. 100 years) may dominate the region. However, very severe droughts can influence smaller areas.

Moreover, drought occurrence probability map was plotted using TPSS interpolator. The probability varied from 5 to 25%. A good portion of the region in east and southeast had above 20% chance of drought probability. Central parts are less subject to drought occurrences.

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