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Assessment of meteorological drought using SPI in West Azarbaijan Province, Iran

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ABSTRACT: Assessment of drought is one of the most important steps in risk management of drought analysis. Drought is mostly the result of a decrease in precipitation in comparison with the mean value and would affect the quantities of soil moisture and water resources. The basis of drought indices is often based on measuring the deviation of precipitation values from long-term mean, during a specific period of time. The standard precipitation index (SPI) can be used for indicating the associated temporal and spatial variations. The aim of this research is the assessment of the characteristics such as intensity, frequency and duration of meteorological drought using SPI with 1, 3, 6, 12 and 24 months time scales in West Azarbaijan Province, Iran. The indices have been computed in various time scales for 38 gauging stations with 32 years record period in the study area and evaluated for the recent drought during 1998-2001. The results indicate that with an increase in return period and time scale, the duration of drought will be increased. Frequency of drought, with an increase in scale, will also be decreased linearly, but their durations show an increase. This index having temporal and spatial variations and is attributed as a suitable tool for analyzing drought for different hydrological purposes.@JASEM

Keywords: Meteorological Drought, Standardized Precipitation Index, Drought Management, West Azarbaijan Province.

Based on Palmer (1965), drought is defined as permanent and unusual deficit of moisture. In this definition, “permanent” refers to the beginning times of drought until the end of the duration. The word “unusual” refers to the deviations or fluctuation from usual average conditions. The basis of drought indices mostly depends on measurements as the deviations of precipitation values from the long-term mean value during a particular period of time. Linsly and Froysy (1987) described the drought definition as an amount of precipitation lower than the usual for a region and in a particular period of time (WMO, 1975). The value of a drought index is usually a value that in comparison with the original data has a great importance in facilitating the decisions of project managers (Hayes et al., 1999). Mckee et al. (1993) developed the precipitation standard index (SPI) in order to analyze and define the drought. The Colorado Climatic Centre and other national centers in the United States for reducing the drought intensity are the type of centers that use SPI for analysis of the present drought conditions.

The SPI characteristics make it possible for researchers to assign the intensity of drought or wet-year phenomenon in a particular time scale for all points of the world having rain gauging stations. SPI merely uses monthly precipitation data. It is basically designated to specify the deficit of precipitations in various time scales. These time scales reflect the drought specific effects on the ability to access different water resources. The soil moisture conditions react toward precipitation short-term abnormalities, while groundwater, river flow and reservoir storage are affected by precipitation long-term abnormalities. For all of these reasons, Mckee et al. (1993) first used this index for 3, 6, 12 and 24 months time scales and then Edwards and Mckee (1997) described that having monthly precipitation data time series for each location, SPI can be calculated for previous months (one to 24 months). Morid et al (2006) compared seven meteorological indices for drought monitoring in Iran and showed that SPI is able to detect the onset of drought, its spatial and temporal variation consistently, and it may be recommended for operational drought monitoring in the Tehran Province.

Iran is frequently hit by recurring droughts. The most recent drought of 1998–2001 was the worst in the last 30 years with rainfall deficits consistently exceeding 60% of the mean annual rainfall in most of the country. The severity of this drought placed an extreme strain on water resources, livestock and agriculture. The Iranian Emergency Agency reported that 278 cities and 1050 villages had been affected. Also, the crops from a rainfed area of 4 million ha as well as those from an irrigated area of 2.7 million ha were completely destroyed. The total agricultural and livestock losses by the year 2001 were estimated to be US$2.6 billion. Eighteen out of the 28 provinces of the country were affected, but the impact of the drought differed throughout the country and some of the provinces were more hit than others (Fahmi, 2001; Mir Abolghasemi et al., 2001).

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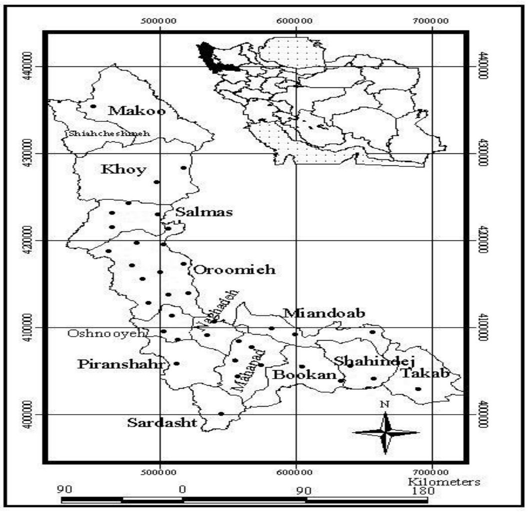
MATERIALS AND METHODS

SPI approach: SPI was developed in Colorado by McKee et al (1993), is based on the probability distribution of precipitation and requires less input data and calculation efforts then PDSI, and is reported to be able to identify emerging droughts sooner than Palmer Index. The basis of SPI approach is the calculating probabilities of precipitation for each time scale. In a general point of view, for analyzing the precipitation data in monthly scale during a record period (preferably 30 years or more), it is required to form total precipitation time series in an ideal scale. The main problem in this case is fitting an appropriate statistical distribution on a particular time series. Tom (1996) realized that gamma distribution fits well for some climatological data such as precipitation time series (Edward and Mckee, 1997). To obtain experimental accumulation probabilities, first precipitation data will be arranged as ascendant then the value of experimental probabilities. For an easy access to Z or SPI values, it is better to use Abramowitz and Stegun approximate, (quoted from Edward and Mckee, 1997) this approximation transform the accumulation possibilities to standard normal random variant. Actually SPI is a standard variant that shows diversion values upper or lower than average. Different applications of SPI including: 1) Drawing SPI series (in each time scale) in a chart is a good index of drought phenomenon in a particular place, 2) SPI can be used for spatial analysis of drought, so makes it possible to compare different stations in various climatic regions ignoring differences between their normal precipitations 3) SPI can be calculated for short time scales (for example, one month) and 5) By studying drought, it is possible to analyze frequency and duration of different values of SPI.

Methods: The recording data of monthly precipitation of 38 stations, in Azarbaijan province (Fig. 1) based on long-term recording data, defect of data and suitable transmittal with joint length of record period duration, which is 32 years (1972-2003) have been selected. The SPI calculation in different time steps (e.g. 1, 3, 6, 12, 12 and 24 month) for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and Mckee, 1997). Table 1 shows the classes of SPI. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Similarly to the PDSI, SPI may be used for monitoring both dry and wet conditions. A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again. The positive sum of the SPI for all the months within a drought event is referred to as "drought magnitude".After calculating the intensity of drought, the duration of drought in each scale was elicited and TDF (Time scale-Duration-Frequency) curves was drawn, based on different return period. The average duration of drought intensity (ADI) based on number or duration of months that faced continuously with drought and dividing by DM (Drought Magnitude), were calculated (Mckee et al., 1995). Four meteorological stations (Oromieh, Miandoab, Mahabad and Khoi) with 40 years record period, which are located in different climate were selected for experiment and analysis of SPI with different time scales.



Fg 1. A schematic map of the West Azarbaijan Province showing the location of the stations.

Table 1. Categorization of SPI values into classes

Values	Class	Symbol	SPI
3	Extremely wet	EW	≥2
2	Severely wet	SW	1.5 to 1.99
1	Moderately wet	MW	1 to 1.49
0	Normal	N	-0.99 to 0.99
-1	Moderately dry	MD	-1 to -1.49
-2	Very dry	VD	-1.5 to -1.99
-3	Extremely dry	ED	≤-2

Mapping the most intensive recent drought 1998-2001: For regional studying and mapping of the drought, the precipitation recording data of 38 stations were used, (with 32 years record period), and at final stage a special studying was done on the recent intensive drought 1998-2001. For assessment and mapping of the drought, these maps have been prepared. The map of drought 1998-2001 in different time scales. The map of longest duration. The map of drought return periods regarding duration. The map of the most intensive drought regarding duration.

RESULTS AND DISCUSSION

Table 2 shows the characteristics of drought in 1 and 12 month time scales. Result show that the most intensive drought values had occurred in 1966, 1989 and 1999. The SPI values with 1 month time scale shows more diversity and intensity, whereas SPI with 12 month time scale shows values with less diversity and intensity.Considering ADI, DM values and also durations, the longest duration is in Oromieh station with 45 months, and the shortest one in Makoo station with 9 month duration. These stations also had maximum and minimum value of DM, respectively.

Table 2. The characteristics of extreme droughts using SPI time-scales in West Azarbaijan province

Station	Extreme observed value of SPI						Extreme duration-severity		
	SPI-1	Year	Month	SPI-12	Year	Month	Duration	DM	ADI
Khoy	-2.88	1966	Nov	-2.05	1989	Aug	14	-32.64	-2.33
Mahabad(Syn)	-2.54	1992	Dec	-2.16	1987	Sep	23	-35.76	-1.55
Miandoab	-2.6	1983	Nov	-3.04	1999	May	33	-48.84	-1.48
Oroomieh	-2.7	1999	Dec	-2.41	1999	May	45	-75.38	-1.68
Takab	-2.7	1998	Nov	-2.12	1999	June	13	-24	-1.85
Sardasht	-2.11	1996	July	-2.22	1989	Sep	11	-16.74	-1.52
Piranshahr	-3.38	1989	Oct	-1.77	1999	May	13	-20.39	-1.57
Kahriz	-1.96	1980	Mar	-2.39	1988	Aug	14	-26.98	-1.93
Mahabad(Cli)	-2.5	1999	Sep	-2.11	1999	Dec	23	-35.5	-1.54
Makoo	-2.47	1998	May	-1.83	1989	Aug	9	-11.9	-1.32
Ghooshchi	-2.44	2000	Nov	-3.23	2001	July	37	-77.17	-2.09
Evaghooli	-2.23	1998	Dec	-1.64	2001	Apr	10	-14.4	-1.46

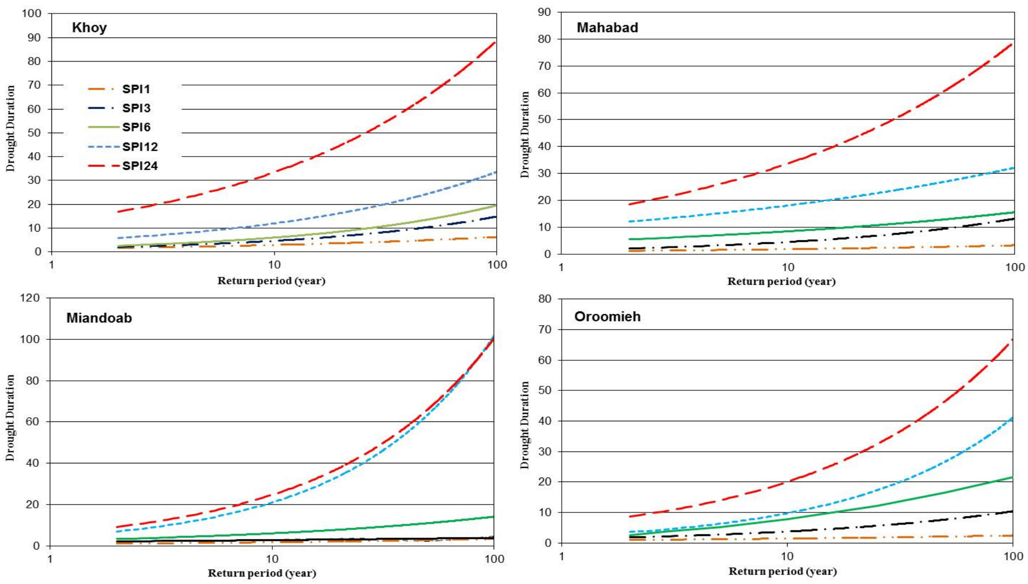


Fig 2. Graphs of time scale – duration – frequency with different return periods in selected stations.

Table 3. Relative frequencies (%) of different wetness categories detected by five time-scale of SPI during 1963-2003

Mahab	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPI-24**
Extremely dry	0.4	1.5	4	1.5	1.1
Very dry	2.1	2.9	6.5	4.5	9
Moderately dry	6.5	8.6	12.8	15.8	9.4
Normal	70.6	73.2	64.4	63.3	65.4
Moderately wet	13.5	7.1	8.6	7	2.4
Severely wet	4.4	4.6	5.5	7	11.8
Extremely wet	2.5	2.1	1.7	0.9	0.9
Miandoab					
Extremely dry	2.3	1.9	1.7	1.7	4.4
Very dry	1.9	1.3	2.3	3.3	3.9
Moderately dry	7.7	7.7	5.4	5.6	5.3
Normal	70.4	72.1	73.3	66.5	72.2
Moderately wet	9.4	9	10.2	15.8	6.1
Severely wet	6.3	5.6	5	4.8	7.4
Extremely wet	2.1	2.5	2.1	2.3	0.7
Oroomieh					
Extremely dry	1.9	2.3	2.5	2.1	4.6
Very dry	2.7	4.8	6.3	6.3	3.5
Moderately dry	7.1	11.3	10.4	13.3	9.0
Normal	75.2	64.2	64.4	60.8	69.0
Moderately wet	6.5	10.0	9.4	9.0	4.8
Severely wet	4.2	5.2	4.8	5.6	5.8
Extremely wet	2.5	2.3	2.3	2.9	3.3
Khoy					
Extremely dry	2.1	2.1	3.5	0.2	0
Very dry	3.3	3.5	4.0	4.2	4.7
Moderately dry	7.5	11.9	7.7	12.3	13.8
Normal	69.8	67.1	67.5	64.8	65.9
Moderately wet	10.4	8.8	12.5	12.7	10.4
Severely wet	5.6	4.4	3.3	4.6	4.3
Extremely wet	1.3	2.3	1.5	1.3	1.0

By analyzing the TDF curves (Fig. 2) it is clear that with increase of return period and length of time scales, drought duration will increase. It means that longer durations have low probability of occurrence or longer return periods. In order to observe ADI regionally and the mapping of ADI values, was done in the region (Fig. 3) that the intensite of drought has occurred as -2.4 in the center of region. The intensity is manifested as drought kernels. By studying the comparative frequency of SPI in different time scales, during 40 years record period, it became clear that maximum frequency is at the normal level and there is no particular procedure in different time scales (Table 3). The maximum frequency is observed at Oromieh station with 75.2% in 1 month time scale, in a normal class. Considering the characteristic of drought duration in different time scales and different return periods, various maps can be drawn. The sample of these maps in 12 month time scales and with 5 and 25 years return period is presented in Fig. 4. Result shows that counter lines related to duration with 25 years return period is the higher values compared with 5 years return period. Maximum values of drought duration with 12 month time scale, and 5 years return period, with value of 18 month is seen in the center and south of the province, whereas for 25 years return period, 22 months duration in center, and 18 months duration in the south of the region is seen which can be useful in future predictions drought at the region.

Assessment of recent drought in the period of 1998-2001 based on different time scales of SPI: Among years of drought, the drought happened in 1998-2001, as most important and intensive drought years have been examined. The results of comparative frequency of these indices are showed in Fig. 5. The values of SPI in 1 month time scale in Oromieh station was 83.3% which shows “Normal” situation and 0% which shows “Extremely Dry” situation. Whereas in 24 month time scale it is almost 4.1% “normal” and 45.8% for ED.

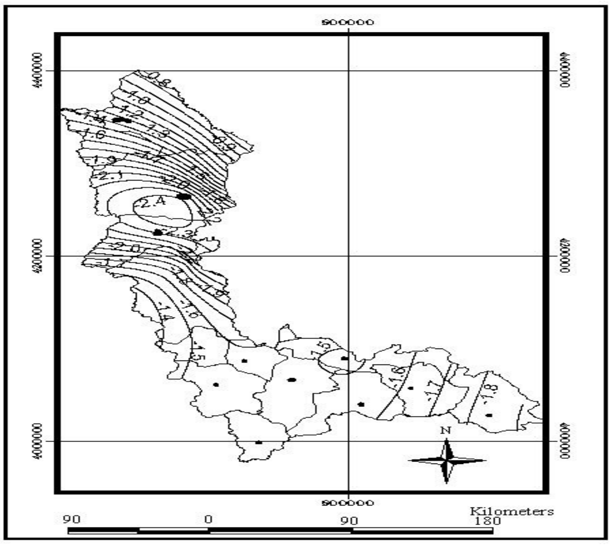


Fig 3. The map of extreme drought severity of the SPI with time scale 12-month during 1963-2003.

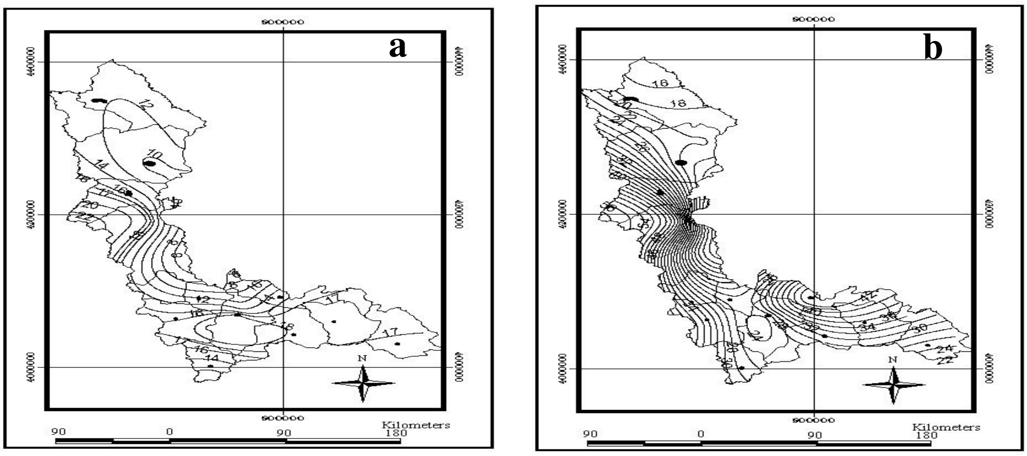


Fig 4. The map of the SPI with time scale 12-month and return period 5-year (a) and 25-year (b) during 1963-2003 in the West Azarbaijan province.

Spatial mapping of drought 1998-2001: For better understanding of SPI performance in different time scales, which can be get the spatial condition of changes in the situation of drought. The maps of drought for the period 1998-2001 were drawn. The analysis of these sketches show the flexibility of this different time scales. Drought patterns with monthly time scales in October and November are shown in Fig. 6. It is obvious that a moisture condition in October is going to change suddenly with dry conditions of November (It should be noted that Iran's wet years begins at October and there is no precipitation at summer). As you see passing the October through November, the drought pattern has been changed and this change cause changing the normal class and moderating dry to VD class. But considering the fact that the SPI values in monthly time scale are so transitive and have several positive and negative values, which can not be just rely on the results based on these data, and more time scales should be surveyed. Fig. 7 shows the drought pattern with 3, 12 and 24 months, time scale. It shows that by increasing the length of time scale, the extension of drought will increase. As in 24 month, time scale, the MD drought extension is too much more than ED, compared with 3 or 12 months, time scales. The SPI in short-term, time scales, face problems with zero values and most of the SPI values which are extracted with this index are of great and positive values, which are not matched with expected values. An other problem of using this index is that if there is no precipitation in a particular month, during the record period or in other word the data were be zero, then the SPI can't analyze the data and it can't nominate the situation of drought or wet year in all duration and the same month. This case is not solvable even with taking into consideration long-term time scales, because it is possible that no precipitation is recorded for several continuous months. In these cases it has been recommended that long-term time scales, such as 12 month or more should be considered or the other indices should be surveyed. The period 1998-2001 was the most important drought period of the region under study which had one or more classes of dry. A general result of drought patterns maps show that the south and center of this province had experienced these recent droughts more than other places, and these place have potential to become desert and destroy the lands.

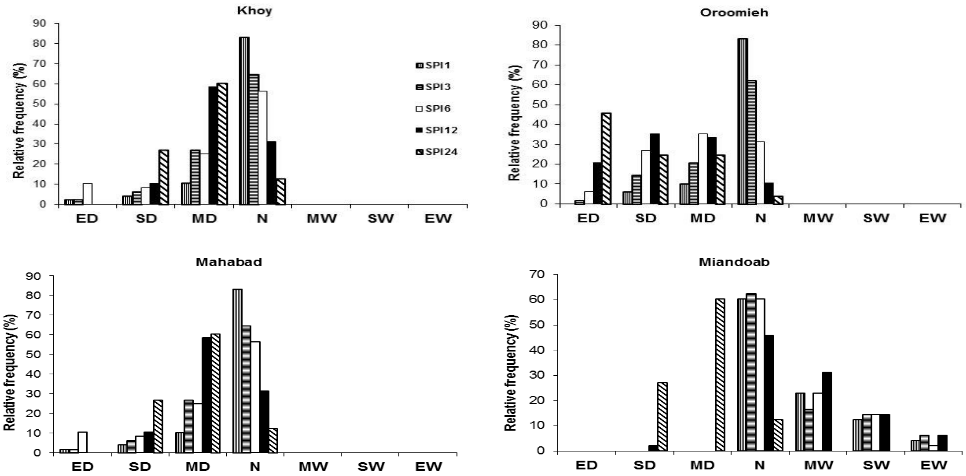


Fig 5. Histograms of the drought frequency classes of the SPI for the selected stations in 1998-2001. The symbols are described in Table 1.

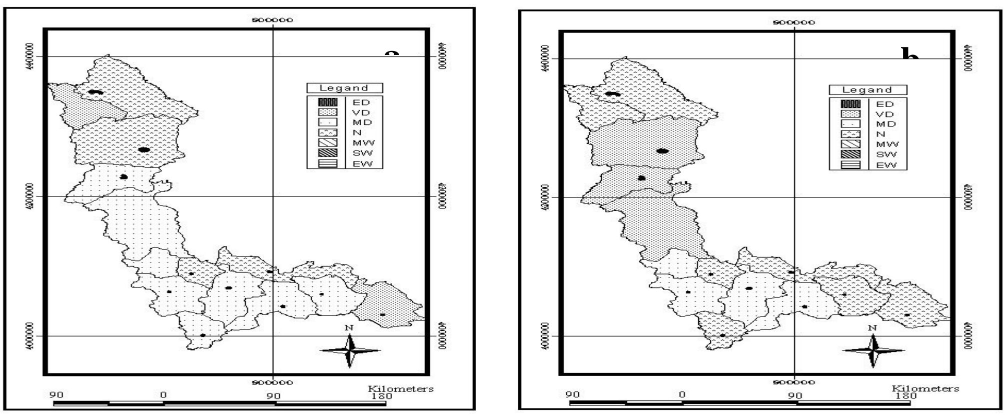


Fig 6. Drought classes of the SPI during October 1998 (a), and November (b) 1998 in the West Azarbaijan Province. The symbols are described in Table 1.

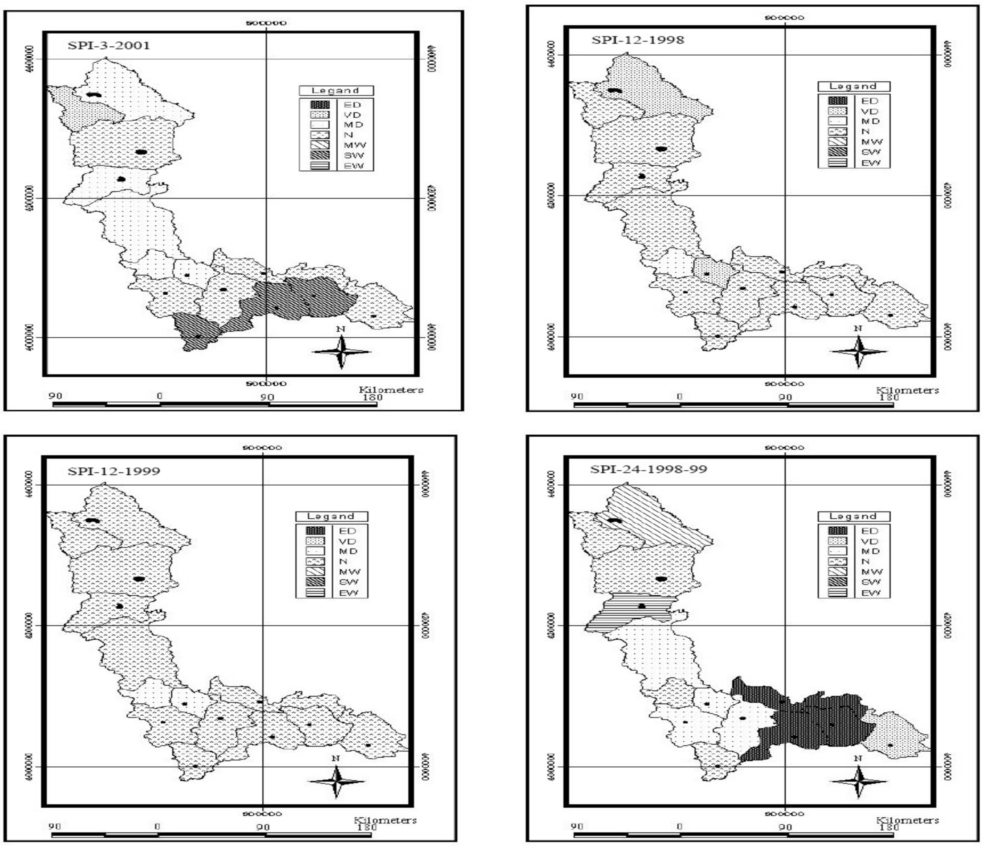


Fig 7. Drought classes of the SPI in different time scales during 1998-2001 droughts in the West Azarbaijan province. The symbols are described in Table 1.

Conclusion: In this research with the aim of assessment, analysis and application of SPI for meteorological drought in the West Azarbaijan Province in Iran, the long-term and short-term time scales of this index have been calculated. Duration, magnitude, intensity average of drought has also been surveyed. Duration of dry months with different return period have been surveyed and mapped. The results show that short-term, time scales, as regional, can't be useful. But long-term, time scales have suitable ability and flexibility in presenting drought patterns.By using this index which can be make an estimate and use different time scales based on management goals. Also which can be identify regions with more sensitivity through drought, and recognize those region that have ability to change into desert and destroy lands, and take action in management of water resources and prevent damages resulting it.

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