Original Research Article

Evaluation of meteorological drought index for drought assessment and mapping in Lorestan province in Iran

Abstract

Droughts are major natural disasters for many parts of the world. Dry areaswhere the precipitation pattern is markedly seasonal, or is otherwise highly variable, are themost susceptible. The Iranian Prairies are often subjected to drought, and it is sometimes catastrophic Therefore, understanding the drought conditions through the prediction and zoning of drought extents can considerably decrease the damaging risks of this phenomenon. This research has been done with statistical correlations of 5 meteorological drought indicators and monthly rainfall data of 15 synoptic and climatological stations in Lorestan province and its surrounding. Statistical years weren't the same and the statistical period is between 1951 to 2010 years. Drought events are determined with the use of indicators such as: Standardized Precipitation Indicator (SPI), percentage of normal indicator (PNI), deciles indicator (DI), Chinese Z indicator (CZI), Z standardized indicator (ZSI) and sequences. Dual correlation coefficients in all stations of this province showed relatively high values, According to these indicators, the driest years were: 1964, 1966, 1973, 1990, 2008 and 2010.

Key words: drought, drought indicators,Lorestan,monthly rainfall, zoning.

1. Introduction

Nowadays drought has become one of the most expensive natural disasters (Klaineet al, 2013). Drought is the result ofa shortfall in rain and high temperatures that may occur in anykind of climatic conditions. There aredifferent types such as: agricultural, hydrological and meteorologicaldrought. We payattention to rivers discharge in hydrological drought (Alizadeh,2008). Meteorological drought happens more than others,and this is followed byagricultural and hydrological droughts(Mahmoodi, 2001). Drought has a major impact on soil and vegetation coverand reduces the output ofagricultural products (Azizi, 2001). Unlike aridity, drought occurs in humid areas too

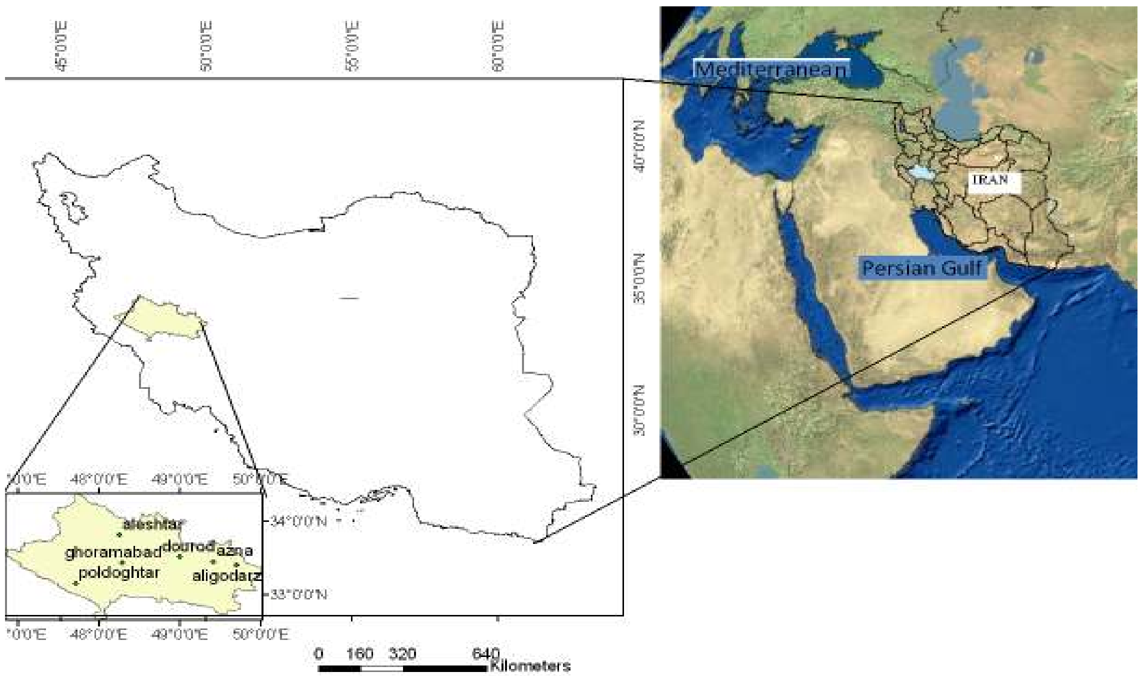
(Soltani et al, 2007).Although it is difficult to define and monitor drought, there are many methods for examiningit.Akram Hedayatidezfuli(2005)has studied drought using standard precipitation methods, percentdifference, deciles and Z standard precipitation method. Shehas concluded thatrainfall has increasedtoward the northeast because of topography. Rainfall didn't have a clear pattern in total area and the area had rainfallbetween droughtsresulting in strong interannaul variability.Zareaabyane(2004)has studied Hamadan drought with 60 percent threshold method (percent of normal)rainfall classifiedas a deviation of the mean.Precipitation time heterogeneity was a result of this research and there wasgenerally heavyrainfall in the winter and the lowestrainfall in the summer.Farajzadeh(2007) in his research has used Nietzsche method, SPI and DRI for evaluation and monitoring Northwest drought and wetperiods. He found thatfor determining dry and wet years the SPI method is the best, because this method uses thenormal distribution. Lashtizand(2004)in his research has studied Northwest Iran droughts. Azizi(2008)has studied Iran droughts and their relationshipwithEl-Niño Southern Oscillation (ENSO). Montazeri (2008)studied theZayanderoud basin with standardized precipitation. Herweijer et al.(2008)reconstructed past climate using tree rings and found out that one unprecedented drought hadoccurred in medieval centurieswhiledroughts in general are related with ENSO.Cook et al.(1997) studied drought in the westernUSA with thePalmer indicator, principal component analyses, and a datapoint network. They found there is a relationship between 1930's drought and dust; and the year 1700 was probablythe driest year in the USA. Khideretal.(2011)simulated theEl Niño and medieval glacier era.The recordwas collected from the sedimentary cores of Sulawesi sea, and there was heat in the western edge of the tropical Pacific. Results showed that ENSO variability was the strongest and La Niña was stronger than El Niñoduring the LIA (little ice age). Hu andChiin(2001)in a study betweenthe years1470 and1997 showed that when the south China has drought conditions, there washigherhumidity in northeast and this is a meridional variation.In this research,a dryanomaly first appeared in the northeast and then moved towardlowerlatitudes.These events have happened in the USA as well and drought happens at 30 degree of northern latitude or higheronce every 10 years.Emile-Geay? et al.(2013) have attempted to examine human influences on climate. Their model used wavelet transform techniques,which showed a strong relationship between solar energy and El Nino at 200(units?).However, human influences were short-term andjust on radiation. Kaplan etal.(1992)have attempted three tests at sea level following the unprecedented drought and heat in 1988. They accomplishedthemusing data from 21 – 23 May, 1988. Their purpose was to estimate the relationship between sea surface temperature and rotated Empirical Orthogonal Function patterns in the height fields of the northern hemisphere.All experimentswere performed very carefully but they were not like originalconditions because they were accomplished on the ocean surface,therefore sea surface temperature wave was notthe only drought factor.Justin(2013)realized the relationship between western America humidity and drynessand the relationshipof ENSO and arcticand high-latitudes oscillations by using tree rings. Siger et al.(2009) examineddrought in thesoutheast of the United States and the relationship between hydro climatology and human climate change. They predicted droughtwith usingrainfall,water leveloscillations, and tree rings during the last millennium and they found that winter droughts correlatewith El Niño in Southeast but summer droughts are caused by internal factors. He found thatthetree rings of 20th century are wetter than those of last millennium and 21- year droughthadoccurredin the 16th century. In short term,rainfall increasesand evaporation will follow. Thus,whendrought happens as a result of human influence, rainfall and evaporation reduce.According totthePaleoclimatology literature,it is implied that past droughts were more variable.In other research,Woodhouseand Overpeck.(1998) studied United States droughts and reconstructed drought with usingtree rings. They found out that last millennium droughts of America arise from two patterns: thepressure pattern of the northern hemisphere and ENSO teleconnections.

2 Materials and methods:

2.1 Geographical structure and nature situation

Lorestan is a province in western Iran in the Zagros Mountains (Fig. 1). The population of Lorestan was estimated at 1,716,527 in 2006. Lorestan covers an area of 28,392 km².Lorestan is located within Irancentered at about33.4871°N 48.3538°E.

Its climate is generally sub-humid continental with winter precipitation, a lot of which falls as snow (Köppen *Csa*). Because it lies on the westernmost slopes of the Zagros Mountains, annual precipitation in Lorestan is among the highest anywhere in Iran south of the Alborz Mountains. in Khorramabad, the average annual precipitation totals 530 millimetres (21 inches) of rainfall equivalent, whilst up to 1270 millimetres (50 inches) may fall on the highest mountains. The months June to September are usually verydry, but Khorramabad can expect 4 inches of rainfall equivalent in December and January. Temperatures vary widely with the seasons and during day and night. In Khorramabad, summer temperatures typically range from a minimum of 12 °C (54 °F) to a maximum of 32 °C (90 °F). In the winter, they range from a minimum of -2 °C (28 °F) to a maximum of 8 °C (46 °F).



Figure(1)The geographical position area, Lorestan in Iran

Table (1)Geographical location of study the stations in and around the province			
x	y	h	station
49.41	33.45	1871.9	Azna
48.25	33.81	1567.2	Aleshtar
49.7	33.4	2022	Aligodarz
49.86	31.85	767	Iezeh
49.88	31.51	710	Baghmalek
47.71	33.15	713.5	Poldoghtar
48.28	33.43	1147.8	Khoramabad
50.36	32.96	2290	Daran
49	33.51	1522.2	Dourod
48.38	32.4	143	Dezful
48.8	32.5	485	Sardasht
48.41	32.26	82.9	Safiabad

48.71	32.08	59	Keshtkar
50.81	31.51	1580	Lordegan
48.51	32.78	450	Mazoo

This research has been done with statistical correlations of five meteorological drought indicators and monthly rainfall data from 15 synoptic and climatological stations in Lorestan province and its surroundings.Table (1)shows the stations studied . Statistical years weren't the same and the statistical analysiscovers the period from1951 to 2010.

Dip software was used for the drought study, so therainfall data of all stations were taken from the meteorology organization and homogeneity of data were evaluated with a run test examination and missing data were reconstructed by proportions method and at last were entered to the software and droughts were identified.At the next stage one database was developed includinglatitude and longitude and monthly droughts. This database was used in GIS software.

The data in Table 2 were edited by (The National Drought Mitigation Center-NDMC)The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Percent of normal is also easily misunderstood and gives different indications of conditions, depending on the location and season. It is calculated by dividing actual precipitation by normal precipitation -- typically considered to be a 30-year mean -- and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months

Table 2: percent of normal indicator classification

class	**PNI quantities**	**PNI Rating**
slight drought	**70-80 percent**	**1**
moderate drought	**55-70 percent**	**2**
intense drought	**40-55 percent**	**3**
very intense drought	**less than 40**	**4**

Less than -2	-1.99 to -1.5	-1.49 to -1	-0.99 to 0	0 to 0.99	1 to 1.49	1.5 to 1.99	More than 2	**SPI amount**
Infra dry	Very dry	Slightly dry	Almost normal dry	Almost normal wet	Slightly wet	very wet	Ultra wet	**Event description**
0.028	0.04	0.0919	0.3413	0.3413	0.0919	0.04	0.0228	**Occurrence probability**

representing a particular season, to an annual or water year. Normal precipitation fora specific location is considered to be 100%.(M. J. Hayes, NDMC, personal communication)

In Table 3, we followed Mackeeet al(1998).The SPI indicator is for the lack of rainfall measurements from various sources. SPI is calculated in each area based on the long-term statistics and for a specific period. To do this,the following formula is used: SPI= ((rainfall in specific period -same period rainfall mean)/standard deviation).Since SPI has been standardized, it's usable for wet and dry climates and the results are comparable fora specific period. According to this method, when SPI is continuously negative and reduces to -1 or less,there is drought period and when SPI becomes positive, there isn’t any. SPI cumulative amounts show the drought intensity and magnitude. Classificationof SPI amounts is in Table 3 (Alizadeh, 2008).

SPI: Standardized precipitation indicator

$\bar{P}i$: Station rainfall mean in millimeters

σ!: Standard deviation of station rainfall data

2.2 deciles:

This method is a meteorological indicatorto monitor drought introduced by Gibbs and Maher(year?). In this method, theamounts ofrainfall distribution were organized from the smallest to the largest and divided into 10 sections. The first decile represents 10 percent of rainfall and 10thdecile shows 100 percent of rainfall. Table 4is compiled based on this indicator.

Table 4: drought classification based on deciles

9-10	7-8	5-6	3-4	1-2	Deciles classification
Severe wet	Moderate wet	Normal situation	Moderate drought	Severe drought	Situation description

2.3 Chinese Z Indicator (CZI), Z6standardizedindicator (ZSI):

CZI indicator isthe cube rootofWilson-Hilbert (?).Assuming that the rainfall data follows Pearson distributiontype three, the indicator is calculated as follows:

J: month CS: coefficient of skewnessΦj: standard variable X_j: monthly rainfall σ: standard deviation of the rainfall data $\boldsymbol{\sigma^2}$: variance of the monthly rainfall data $\bar{\boldsymbol{X}}$: monthly rainfall average

2.4: normal threshold climatic indicator or sequences:

In this indicator,the mean of annual or seasonal rainfalls and one threshold are considered (Abiyane, 2004). Rainfall threshold for drought (X_0) is usually 75 to 80 percent of the annual rainfall average, so0.8* annual rainfall= (X_0) and we get difference of annual rainfall to (X_0).Negative amounts of (X-X_0) represents a drought andapositive amounts represents a wet year(Alizadeh, 2008). In limited coordinates,however,where the horizontal axis is the number of statistical years and the vertical axis is specified to the statistics obtained from the sequences, wet and dry years can be shown graphically.Therefore, the downward histograms indicate drought and the upward histograms indicate wet. Drought statistical periods begin when the sequence is negative and continues until the sequence becomes positive.

3. Discussion

Table 5 shows the correlation coefficient ofdrought indices for the**Khoramabad** station. The maximumcorrelation is between normal percentage and number Z that it is 100 percent. The minimumcorrelation is between deciles and precipitation indicator.The results of the 36 stations and their surroundings revealthat CZI-SPI, DI-PN-ZSI indicators have very high correlation with each other in all examined stations.

Table 5correlation coefficient results for meteorological drought indicators inKhoramabadstation

		di	pn	spi	zsi	czi	Test sequences
di	Pearson Correlation	1	.980**	.977**	.980**	.981**	.980**
	Sig. (2-tailed)		.000	.000	.000	.000	.000
	N	55	55	55	55	55	55
pn	Pearson Correlation	.980**	1	.994**	1.000**	.999**	1.000**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
	N	55	55	55	55	55	55
spi	Pearson	.977*	.994**	1	.994**	.998**	.994**

	Correlation	*					
	Sig. (2-tailed)	.000	.000		.000	.000	.000
	N	55	55	55	55	55	55
zsi	Pearson Correlation	.980**	1.000**	.994**	1	.999**	1.000**
	Sig. (2-tailed)	.000	.000	.000		.000	.000
	N	55	55	55	55	55	55
czi	Pearson Correlation	.981**	.999**	.998**	.999**	1	.999**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
	N	55	55	55	55	55	55
Test sequences	Pearson Correlation	.980**	1.000**	.994**	1.000**	.999**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	55	55	55	55	55	55
**. Correlation is significant at the 0.01 level (2-tailed).							

3.1Drought study with standardized precipitation indicator:

Maps were drawn for all years with thestandardized precipitation indicator.The driest yearsare shown in figure 2.According to this index, years2008 and 2010 are drier than others.

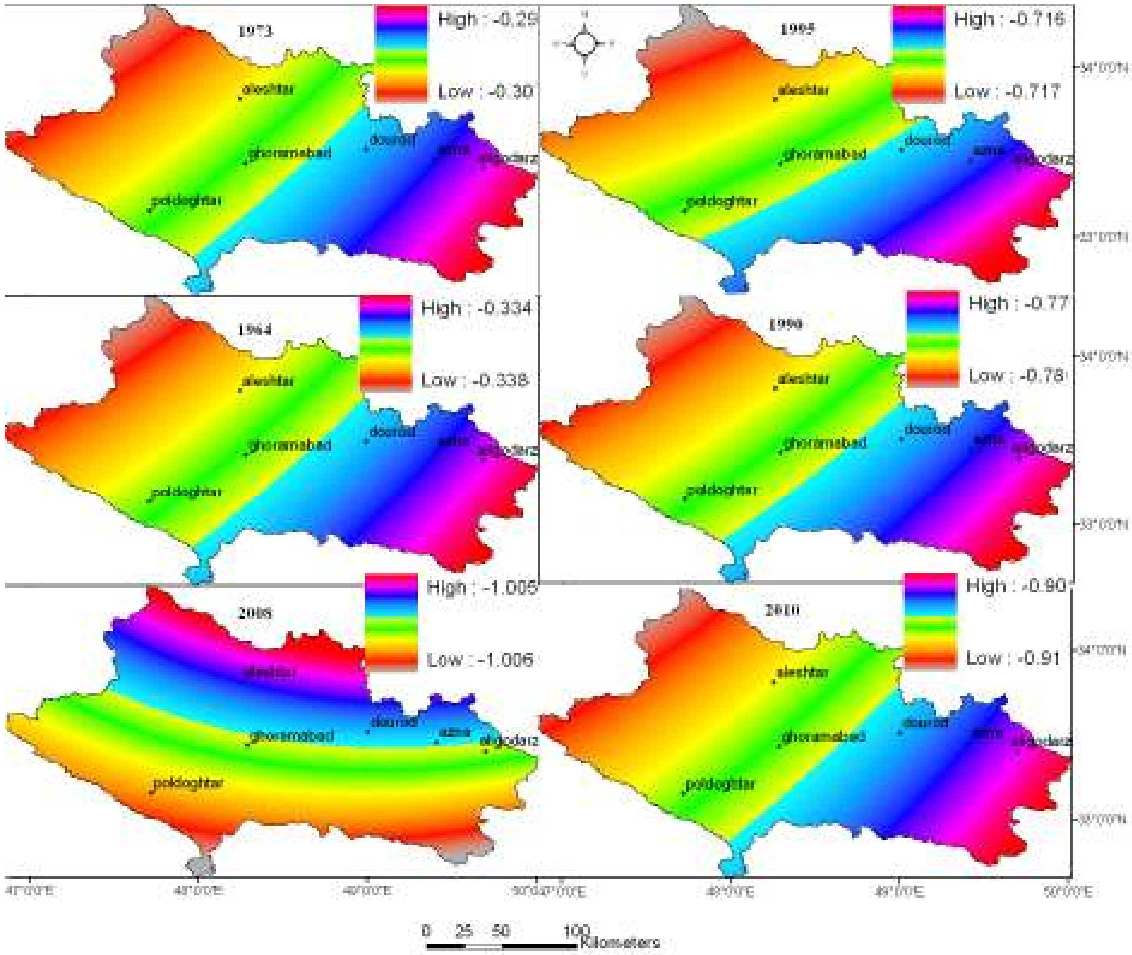


Figure 2: Dry years studied using the standardized precipitation indicator in Lorestan Province

3.2Drought study using the decile indicator:

Although all indicators have high numerical correlation coefficient with each other without any classification, in Cluster analyses they aren't in the samecategory. Itreveals that the levels of these indicators are not well-defined or are notcoordinated with each other. There are eight classifications for the standardized precipitation indicators and five classifications in deciles,thus dry yearsare not the same in Figures2and 3. In terms of drought intensity, thetwo indicators aren’t equal, in 2008 the most parts of the province have experienced drought with standardized precipitation indicator whileusing the decile indicator 1990 is most drought amount.

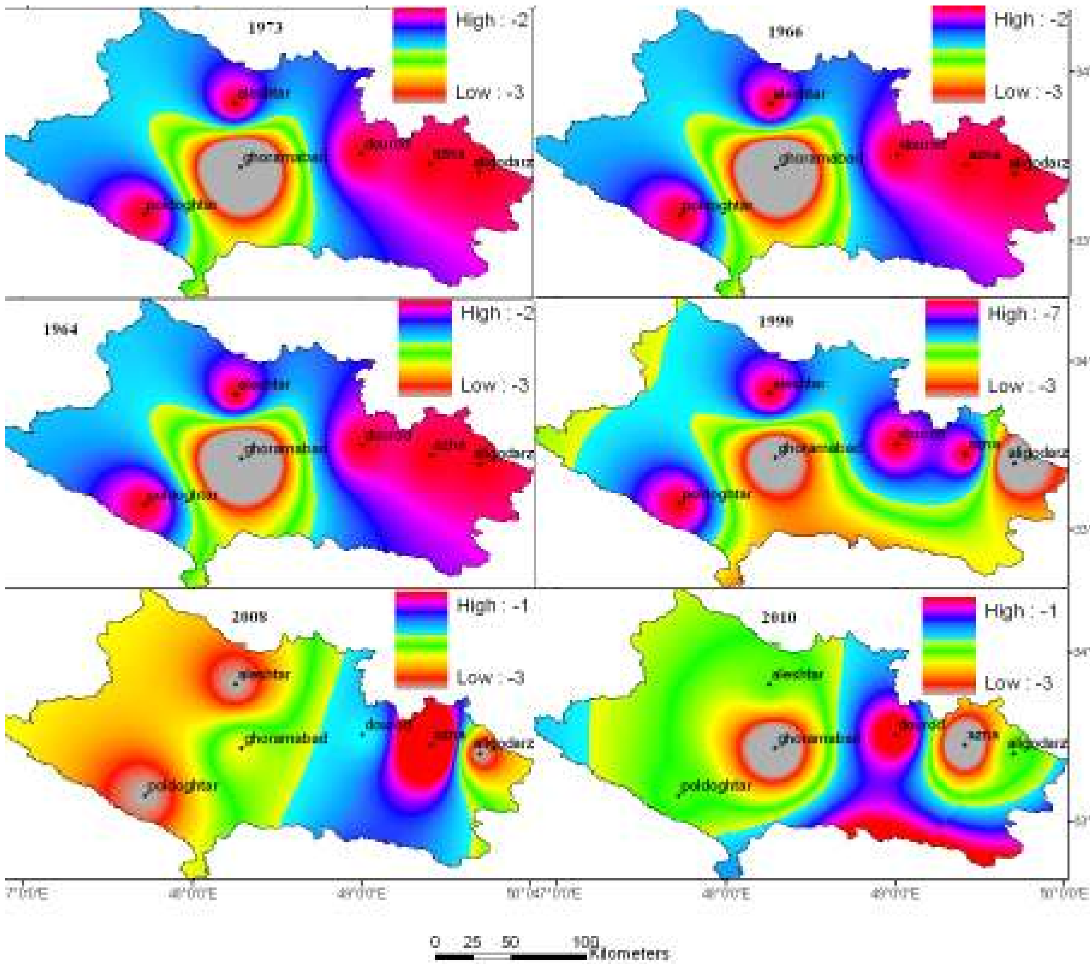


Figure 3: As in Fig. 2 except using deciles

3.3Study of drought with sequence indicator:

Chart 3 has been drawn with sequence test. This test is derived froma histogram in which negative amounts show drought and positive ones show wetyears. In this histogram dry years are: in the 1950's: 1954 and 1958; in the 1960's: 60, 66 and 68; in the 1970's: 76 and 78; in the 1980's: 80, 84 and 86; in the 1990s: 92, 94 and 96, and in2000's most yearsshow a negative value. Positivehistograms can be observed in thedecades 50, 70 and 90 in which wet years have been reduced and dry years have been increased. Figure 4shows dry years with sequence indicator. There isn't a special classification for this indicator but in this figure purple red colorsshow drought and wet respectively. The driest year is 2010 and the wettest year is 2006. Figure 6 shows amount and intensityofdrought.

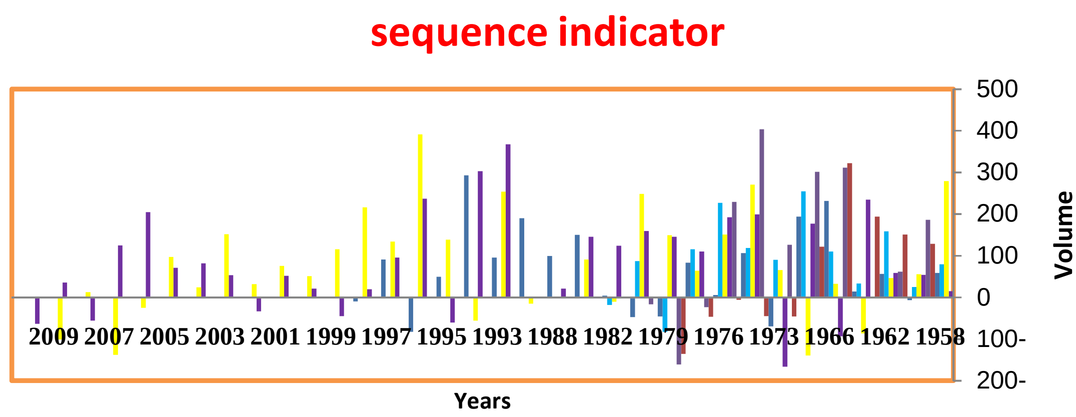


Chart 3: evaluation of drought with sequence indicator in some selected stations,

Table 6examines drought with sequence indicator				
	During periods of drought	Amount of drought	Drought Severity	The most severe drought
Azna	5	-277	-282	-146
Iezh	2	-428.3	-430.3	201.4
Baghmalk	2	-192.4	-194.4	156.7
Daran	2	-93.1	-95.1	47.7
Dezful	6	-368.3	-374.3	-138
Keshtkar	4	-115.492	-119.492	-53.12
Mazo	7	587.6	580.6	-238

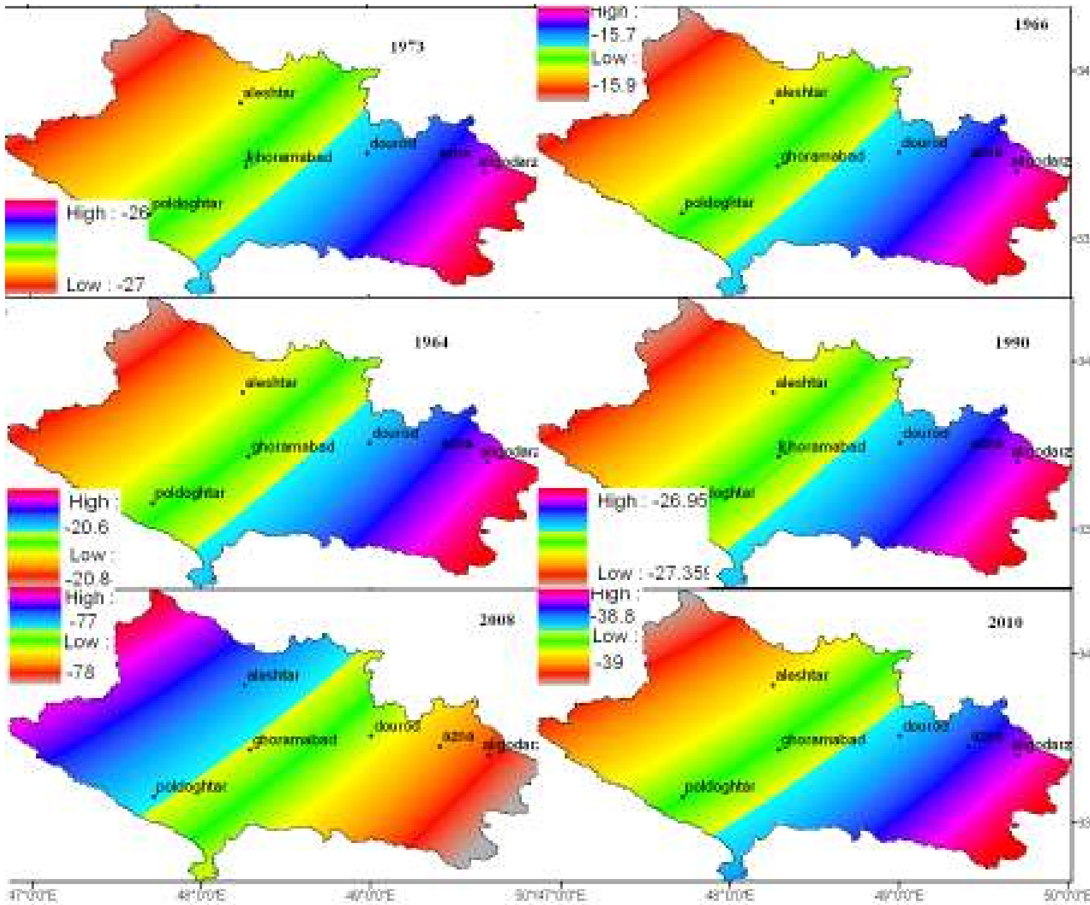


Figure 4: As in Fig. 2, except for using the sequence indicator.

Table 6demonstrates the examination of drought with sequences indicator. In this table duration, amount, intensity and the most severecharacteristics of drought are shown.The common dry years are: 1990 and 2001 to 2010, it means that in the most years of century 2000 drought haspredominated. Drought value obtained from sum of negative values in a dry period can represent dry amountof a station in that period.Mazo station with a period of 5 years and amount of -784.4had the longest period. But the most severe drought of a period can show the best result because this amount shows which period and station have experienced the most severe drought. The most severe drought is related to Mazu station with amount of -238 that drought period was 5 years and amount of the most severe (-151.8), Mazu

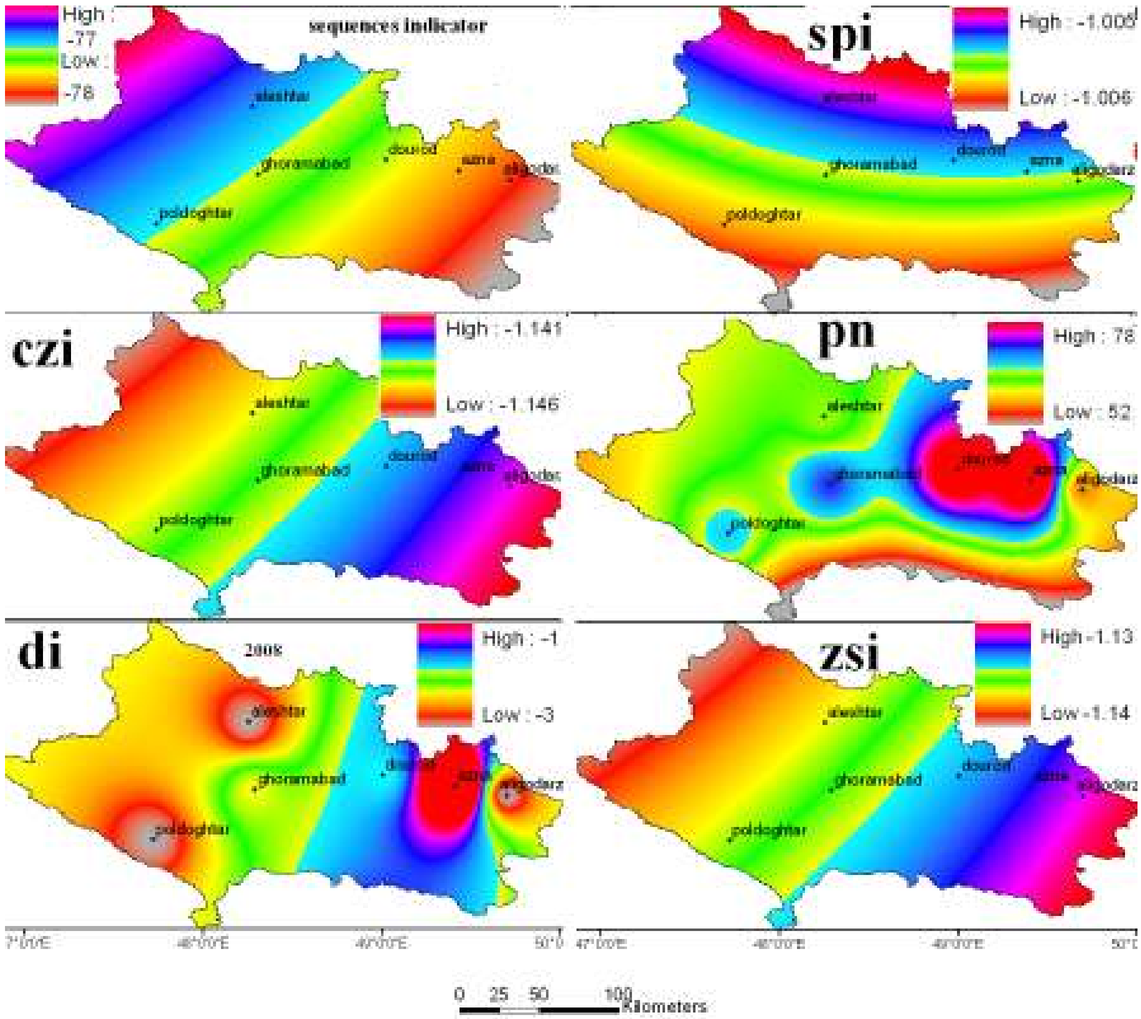


Figure 5: comparative study of Lorestandrought in 2008

3.4 comparative study of drought:

The year 2008shows up with all of the indicators revealing that this year is dry. In spite of the different classification system of the indicators, there is a little difference between maps for that year.

5- conclusion:

Climate change is one of the most important subjects in the world today. One of the first impacts of climate change is the prolongation and intensification of drought in some parts of the world.Iran is classified as one of the dry zones of the world andthe scarcity of water resources isaserious threat that requires special attention. Thus, drought is an important issue for Iran. In this article the following results areobtained; the correlation coefficient is very high between drought indicators, drought amount and duration have increased in recent years and the most severe and widespread drought has happened in Lorestan.The average monthly drought index was 4.5. Extensive droughts have occurred in 1960s,1990s, and1995 and 1996 wereconsidered dry years. The correct and efficient way of using water can save us from water scarcity and drought crisis. Watershed management can help us in this field. If any dam construction is performedcarefully and correctly, it can solve many problems of water scarcity. For instance, GotvandOlya dam has been built on salt domes sothat not only was the water problem not solved,but nowa new environmental crisis is taking place.Intensifying droughts require more attention to water resources in the recent years, especiallysince river discharge reductions will affect water quality. If climate changes are anthropogenic, we will have to waituntil Karun and Arvand has lost its quality, because Arvand is the only navigable river in Iran and it has a key role in the creation of natural outlooksfor tourist attraction. Management and planning for this water resource should be placed at the top of all programs.

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Enclosure

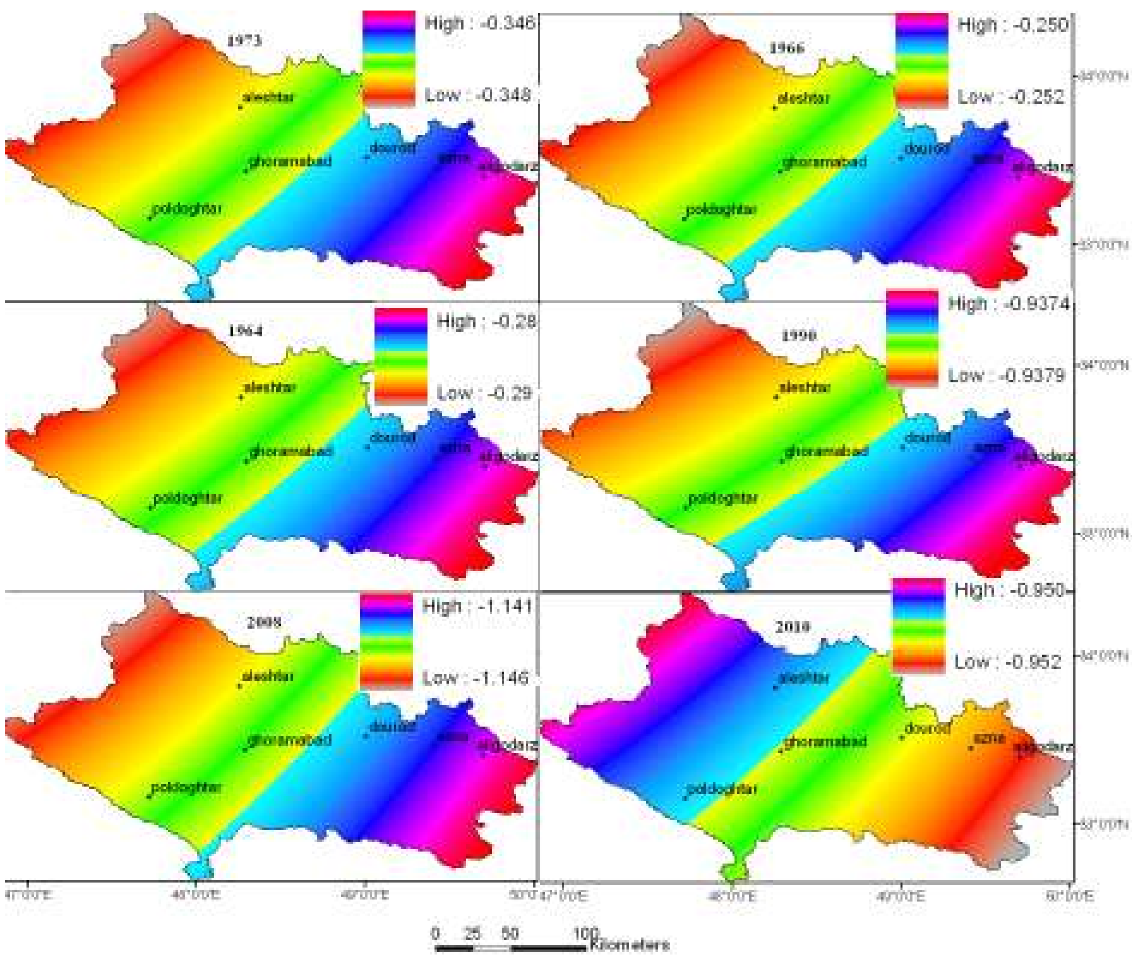

Figure 6: As in Fig 2, except using the CZI

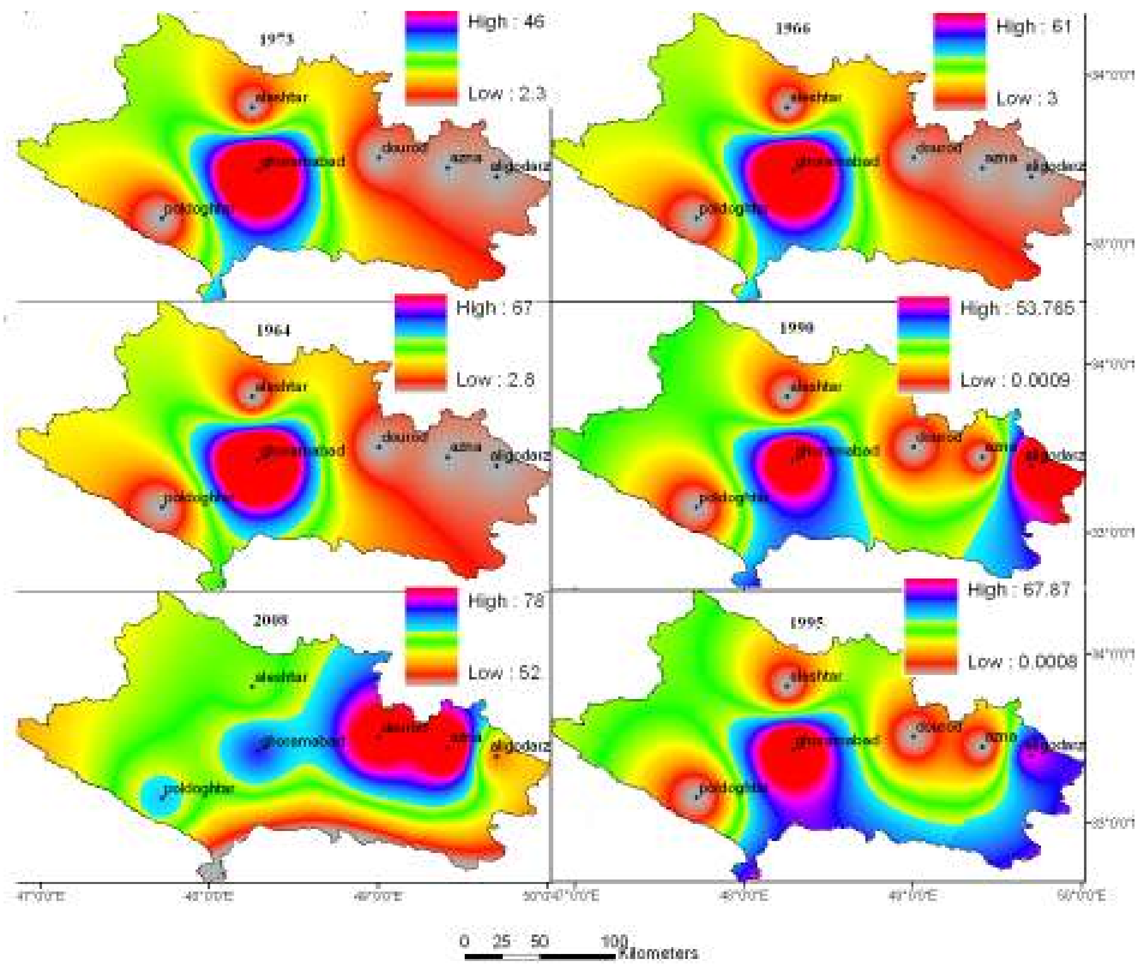

Figure 7: As in Fig. 2, except using the PNI.

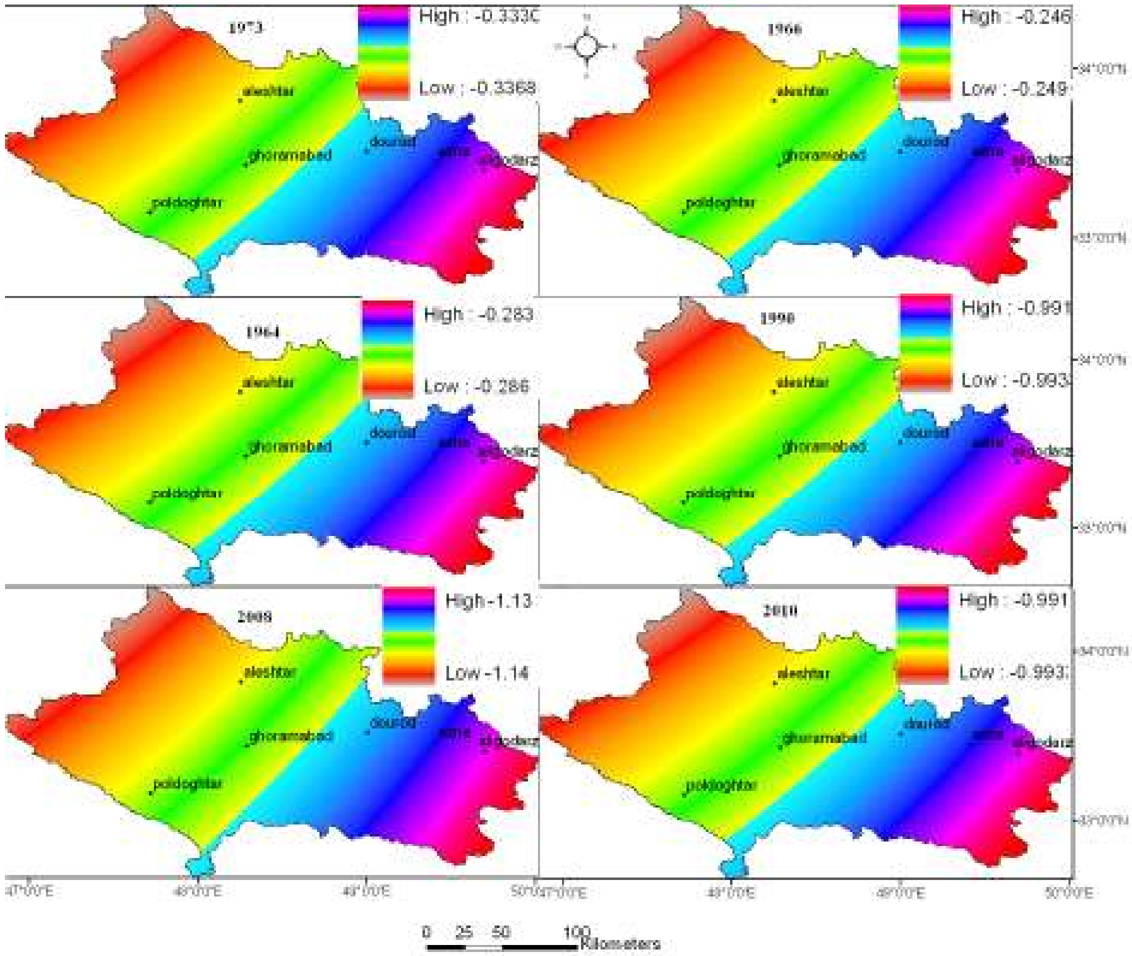

Figure 8: As in Fig. 2, except using this ZSI.

Is this a Table?

The most humidmonths.								
JAN.	FEB.	MAR.	APR.	MAY	OCT.	NOV.	DEC.	mean
1958	1965	1979	1964	1992	1953	1988	1958	1993
1978	2004	1983	1988	1970	1973	1989	1975	1969
2009	1980	1973	1997	1955	1977	1990	1996	1957
2003	2010	1955	1983	1952	1962	2002	1966	1994
1959	1971	2001	1993	2002	1982	1985	1977	1954
The driest months								
JAN.	FEB.	MAR.	APR.	MAY	OCT.	NOV.	DEC.	mean
1956	1972	1961	1951	1979	1979	1969	1981	1973
1986	1999	1998	1961	1987	1986	1955	1987	1990

1993	1982	1999	1996	1971	1964	1986	2006	1966
1984	1995	1984	2002	2005	1983	1995	1988	2010
1969	1958	1992	1966	1962	1981	2007	1960	1995