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 Indicators, the driest years were: 1964, 1966, 1973, 1990, 2008 and 2010.

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

Introduction

Nowadays drought has become one of the most expensive natural disasters (Klaineet al, 2013). Drought is the result ofrainfall shortcoming and temperatureincreasing that may occur in eachkind of climatic conditions. It has different types such as: agricultural, hydrological and meteorologicaldrought. We payattention to rivers discharge in hydrological drought (Alizadeh,2008). Meteorological drought happens more than others,agricultural and hydrological droughts occur after that (Mahmoodi, 2001). Drought has a major impact on soil and vegetation coverand reduces agricultural 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.AkramHedayatidezfuli(2005)has studied drought using standard precipitation methods, percentdifference, deciles and Z standard precipitation method. Shehas concluded thatrainfall has increasedtoward the northeast because of height increasing. Rainfall didn't have a clear pattern in total area and the area had rainfall between its droughtsbecause of the large extentof differences.Zareaabyane(2004)has studied Hamadan drought with 60 percent threshold methods, percent of normal, rainfall classified and 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 wet. He believes for determining dry and wet years the SPI method is the best, because this method obeys normal distribution. Lashtizand(2004)in his research has studied Northwest droughts. Azizi(2008)has studied Iran droughts and their relationshipwithEl-Niño southern oscillation. Montazeri(2008)studiedZayanderoud basin with standardized precipitation. Celine Herweijer et al.(2008)reconstructed past climate with tree rings and found out that one unprecedented drought has occurred in medieval centurieswhile these droughts are related with Enso.Cook et al.(1997) studied drought in the westof USA with Palmer indicator, principal component analyses and point network. They found there is a relationship between 1930's drought and dust; and year 1700 was the driest year of USA. Khideretal.(2011)simulated the El Nino and medieval glacier era.It was collected from the sedimentary cores of Sulawesi sea, and there was heat in the western edge of the tropical Pacific. Results showed that Enso was the strongest and La Nina was more than El Ninoduring the Lia little ice. Hu Chiin(2001)in a study between 1470 and1997 showed that when the south China has drought conditions, there washumidity in northeast and this is a meridional variety. In this research, anomaly firstly happened in the northeast and then came toward the down latitudes.These events have happened in the USA too and it happens at 30 degree of northern latitude once every 10 years.Julien Aimaet al.(2013) have attempted to examine human influences on climate. Their model was wavelet,which showed a strong relationship between solar energy and El Nino at 200.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 accomplishedthemon theMay 21st, 22nd and 23rd. Their purpose was to estimate the relationship between sea surface temperature and rotational pattern 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 wave was notthe only drought factor.R Justin (2013)realized the relationship between western America humidity and drynessand the relationship of El Nino and southern,Arcticand high-latitudes oscillations by 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 oscillations and tree rings during the last millennium and they found that winter droughts agree with El Nino in Southeast but summer droughts totally obey internal factors. He found that tree rings of 20th century are wetter than those of last millennium and 21- year droughthasoccurredin the 16th century. In short term,rainfall increasesand evaporation does too. In short,when drought happens by human changes, rainfall and evaporation reduce.According to Paleoclimatology literature,it can be found out that past droughts had more variety. In other research,Woodhouseet al.(1998) studied United States droughts and reconstructed drought with usingtree rings. They found out that last millennium droughts of America arise from two patterns: pressure pattern of the northern hemisphere and ENSO teleconnection.

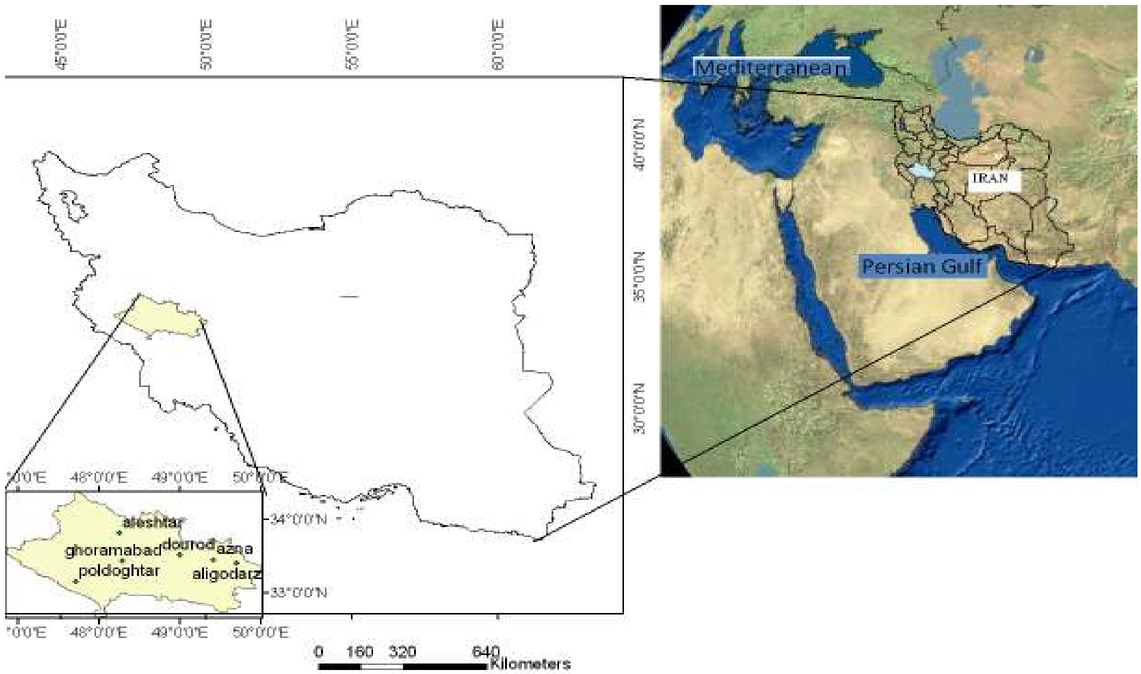
Materials and methods:

Geographical structure and nature situation

Lorestanis a province in western Iran in the Zagros Mountains. The population of Lorestan was estimated 1,716,527 in 2006. Lorestan covers an area of 28,392 km².Lorestanis located within Iran in 33.4871°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. inKhorramabad, 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 completely dry, but Khorramabad can expect 4 inches of rainfall equivalent in December and January.

Temperatures vary widely with the seasons and during day and night. InKhorramabad, summer temperatures typically range from a minimum of 12 °C (54 °F) to a hot maximum of 32 °C (90 °F). In the winter, they range from a minimum of -2 °C (28 °F) to a chilly 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 5 meteorological drought indicators and monthly rainfall data of 15 synoptic and climatological stations in

Lorestan province and its surrounding Table (1)shows the stations studied . Statistical years weren't the same and the statistical period is between 1951 to 2010 years.

Dip software was used for drought studying, so rainfall data of all stations were taken from the meteorology organization and homogeneity of data were evaluated with 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.

percent of normal precipitation: Table 2 ,This indicator has been edited(Michael J. Hayes)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 representing a particular season, to an annual or water year. Normal precipitation fora specific location is considered to be 100%.(Michael J. Hayes)

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

Table 3: drought classification and occurrence probability
of standardized precipitation drought indicator (Mackee et al1995)

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**

Table 3 ,Thisindicator has been edited byMackeeet al(1998). from Colorado University. 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 1 (Alizadeh, 2008).

SPI: Standardized precipitation indicator

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

σ!: Standard deviation of station rainfall data

3-3 deciles:

This method is a meteorological indicatorto monitor drought introduced by Gibbs and Maher. 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 10th decile 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

3-4 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

3-5: 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, so.8annualrainfalls= (X_0) and we get difference of annual rainfall to (X_0).Negative amounts of ($X-X_0$) represents a drought and its positive amounts represents wet (Alizadeh, 2008). In limited coordinates,however,that 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 sequence answer is negative and continues as long as sequence answer becomes positive.

Discussion and conclusion

Table 5 shows the correlation coefficient ofdrought indices in **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 Correlation	.977**	.994**	1	.994**	.998**	.994**
	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).							

2-4 Drought study with standardized precipitation indicator:

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

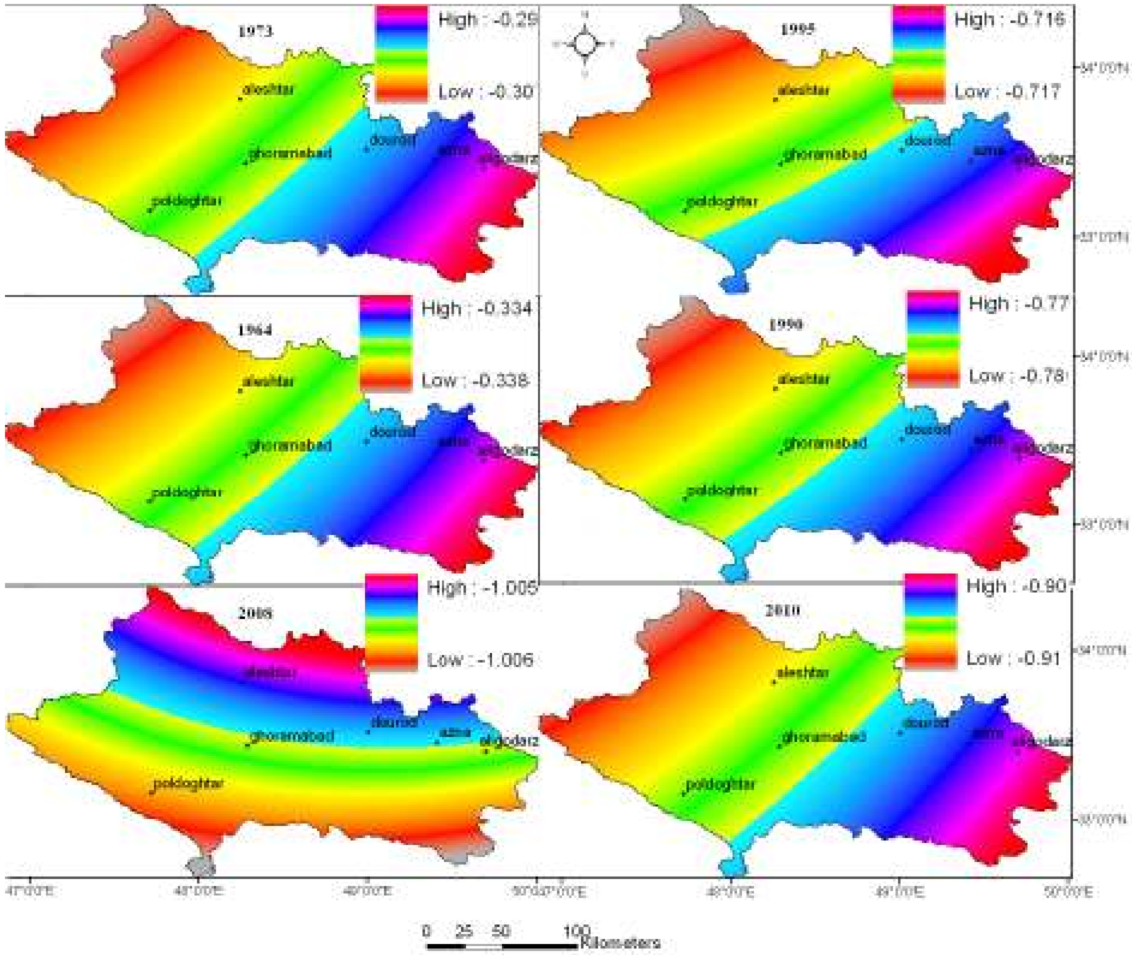


Figure 2: dry years were studied with standardized precipitation indicator in Lorestan Province

3-4 Drought study with decile indicator:

Although all indicators have high numerical correlation coefficient with each other without any classification but 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 8 classifications in standardized precipitation indicators and 5 classifications in deciles and due to this problem dry years are not the same in figures 2and 3. In terms of drought amount, two indicators aren’t equal, in 2008 the most parts of the province have experienced drought with standardized precipitation indicator whilewith decile indicator 1990 is most drought amount.

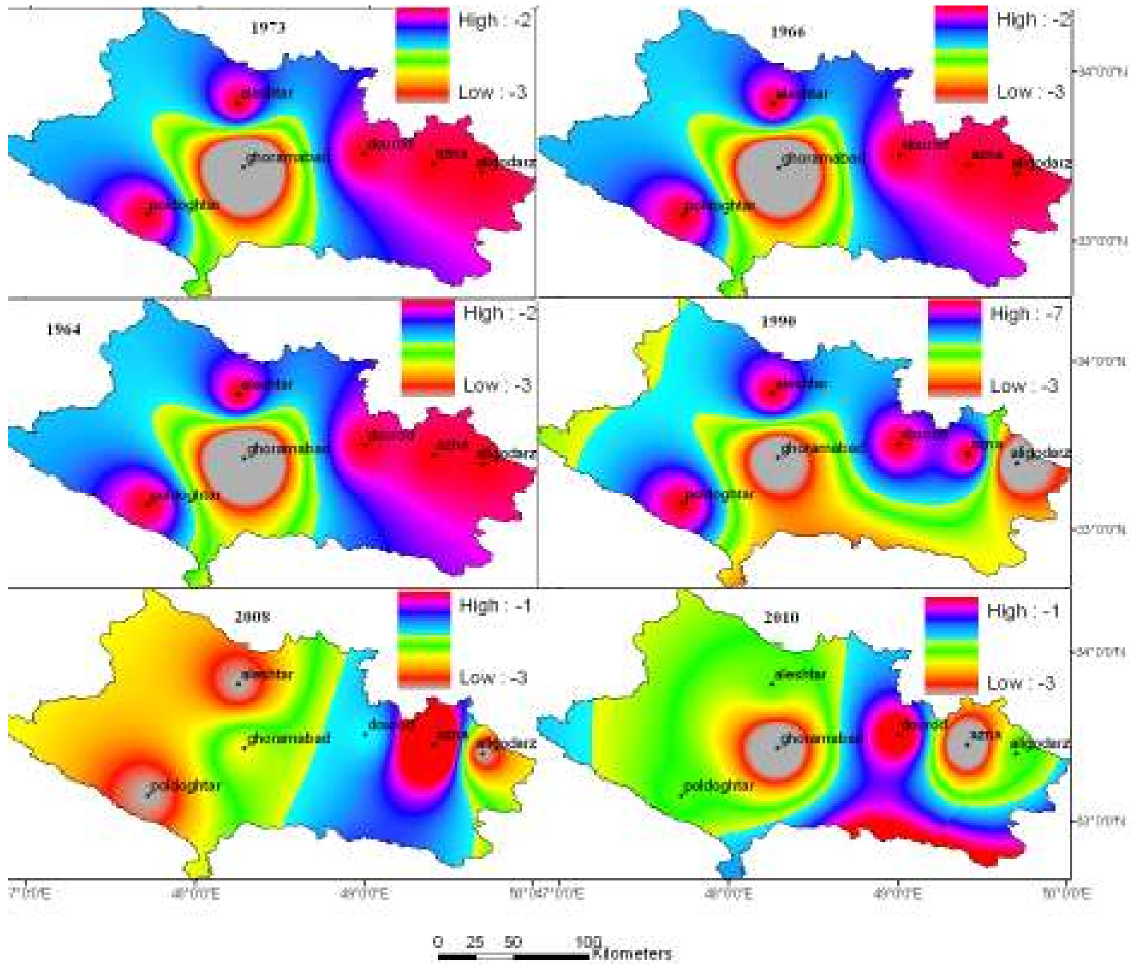


Figure 3: study of dry years in Lorestan province with deciles

4-4 study of drought with sequence indicator:

Chart 3 has been drawn with sequence test. This test is drawn on a histogram in which negative amounts show drought and positive ones show wet. In this histogram dry years are: in the fifties: 1954 and 1958; in the sixties: 60, 66 and 68; in the seventies: 76 and 78; in the eighties: 80, 84 and 86; in the nineties: 92, 94 and 96, and in2000 century the most years show negative amount. Upward histograms can be observed in thedecades 50, 70 and 90 in which wet years have been reduced and dry years have been increased. Figure 5 shows dry years with sequence indicator. There isn't 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.

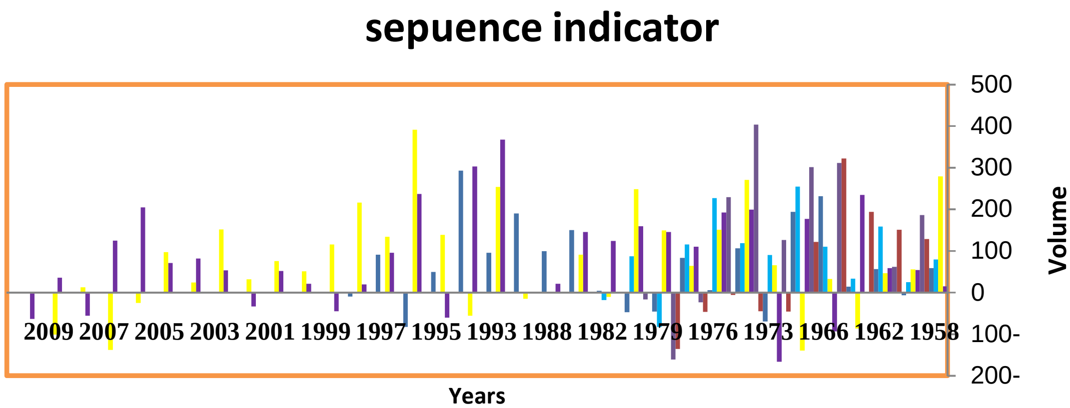


Chart 3: evaluation of drought with sequence indicator in some selected stations,

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

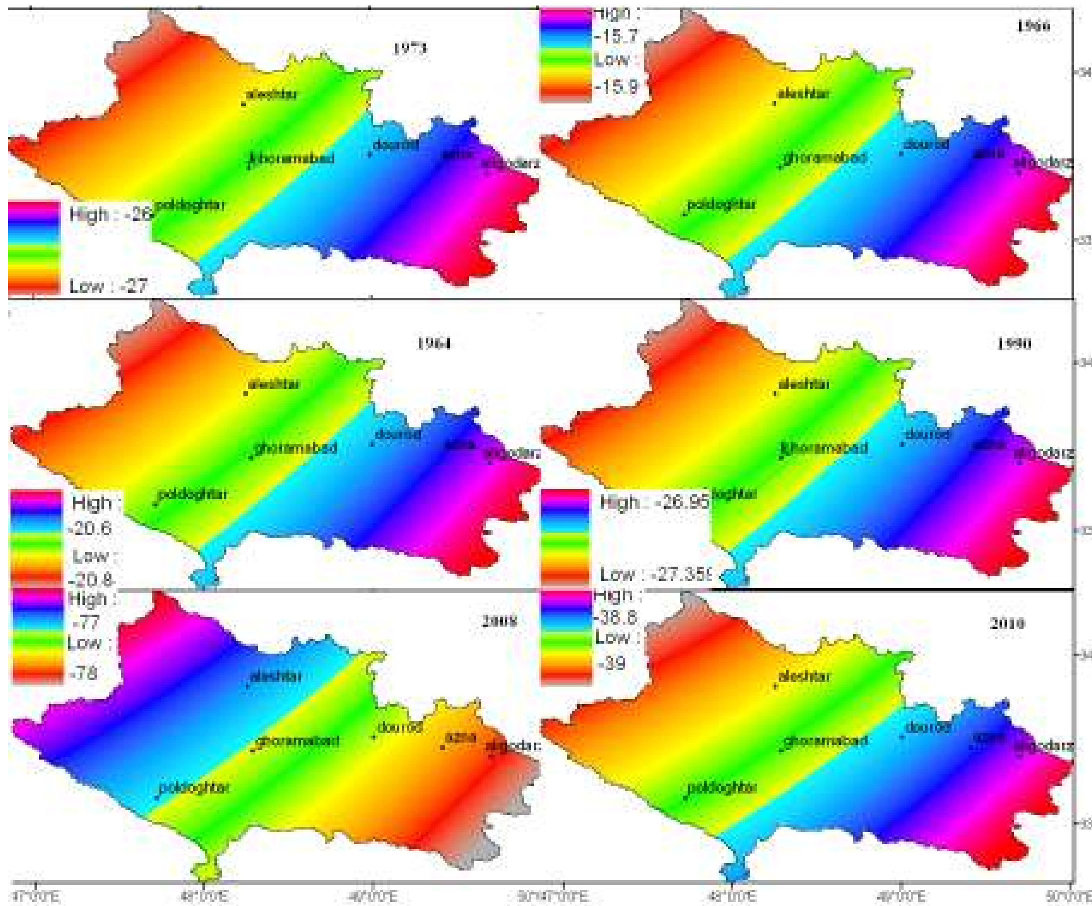


Figure 4: study of drought intensity and amount with sequence indicator, by the authors.

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 waspredominated. 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

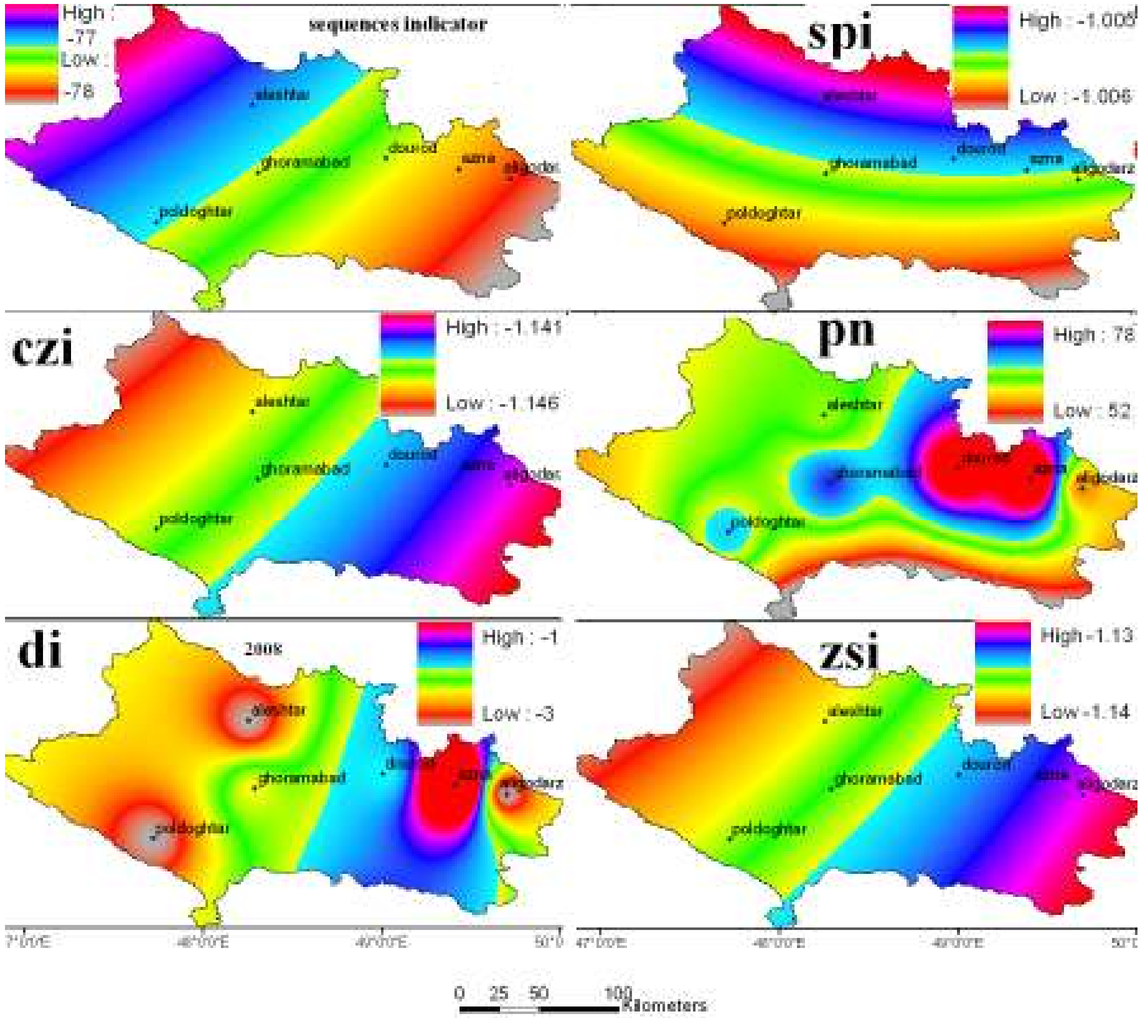


Figure 5: comparative study of Lorestandrought in 2008

5-4 comparative study of drought:

Year 2008 was studied with all of the indicators whichreveal that this year is dry. Due to different classification of the indicators, there is a little difference between maps.

5- conclusion:

Climate change is one of the most important subjects in the world today. The first effect of climate change is the drought prolongation and intensification in some parts of the world. Iran is on the dry zones of the world and scarcity of water resources isaserious threat that requires special attention andDrought is a huge issue for Iran . In this article the following results areobtained: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.Average Drought amount was 4.5 month. Extensive droughts have occurred in 1960s,1990s, 1995 and 1996 are considered 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 so not only any problem isn't solvedbut also a new environmental crisis is taking place. Droughts intensifying require more attention to water resources in the recent years, especially rivers discharge reducing will affect water quality and if climate changes are associated with our self-seeking changes, we will have to waituntil Karun and Arvand has lost its quality,BecauseArvand 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

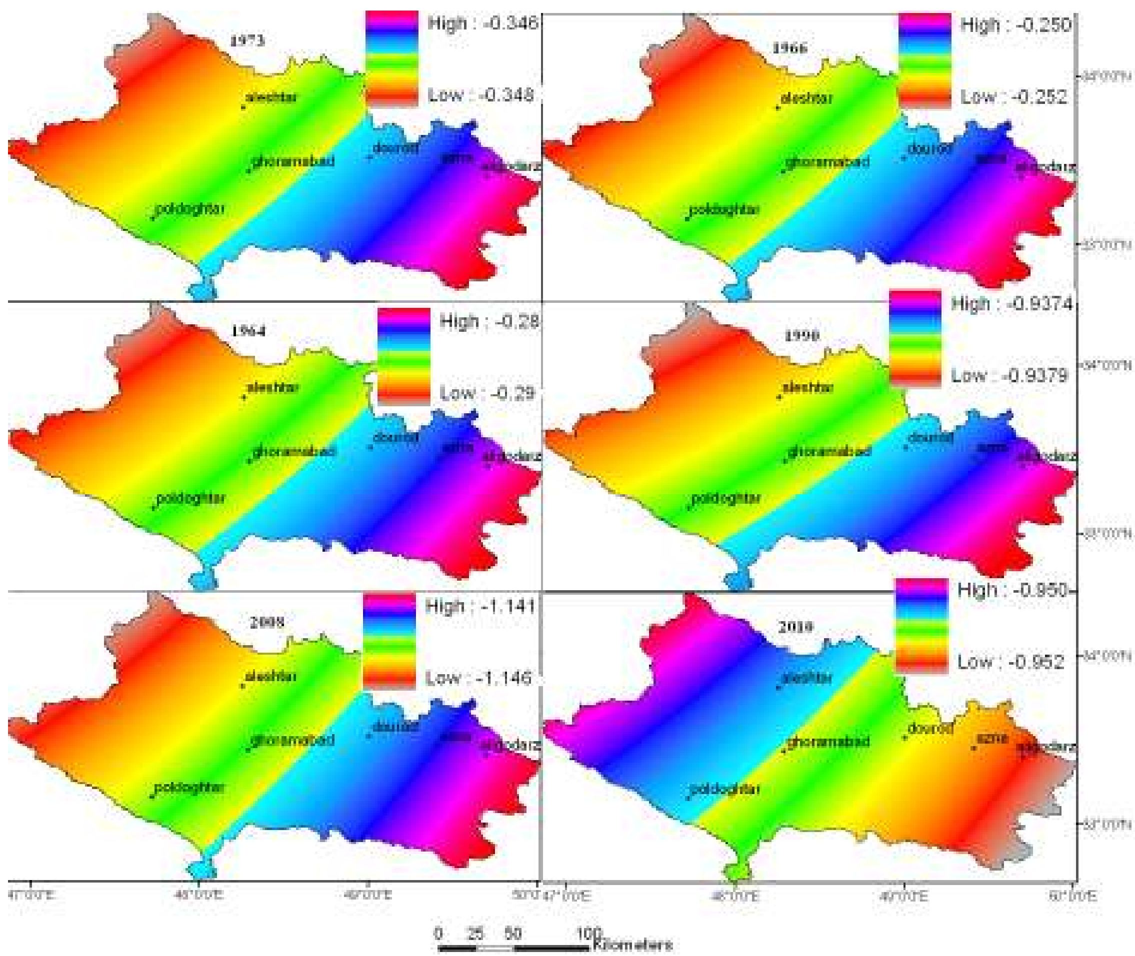

Figure 6: study of dry years in Lorestan with Czi

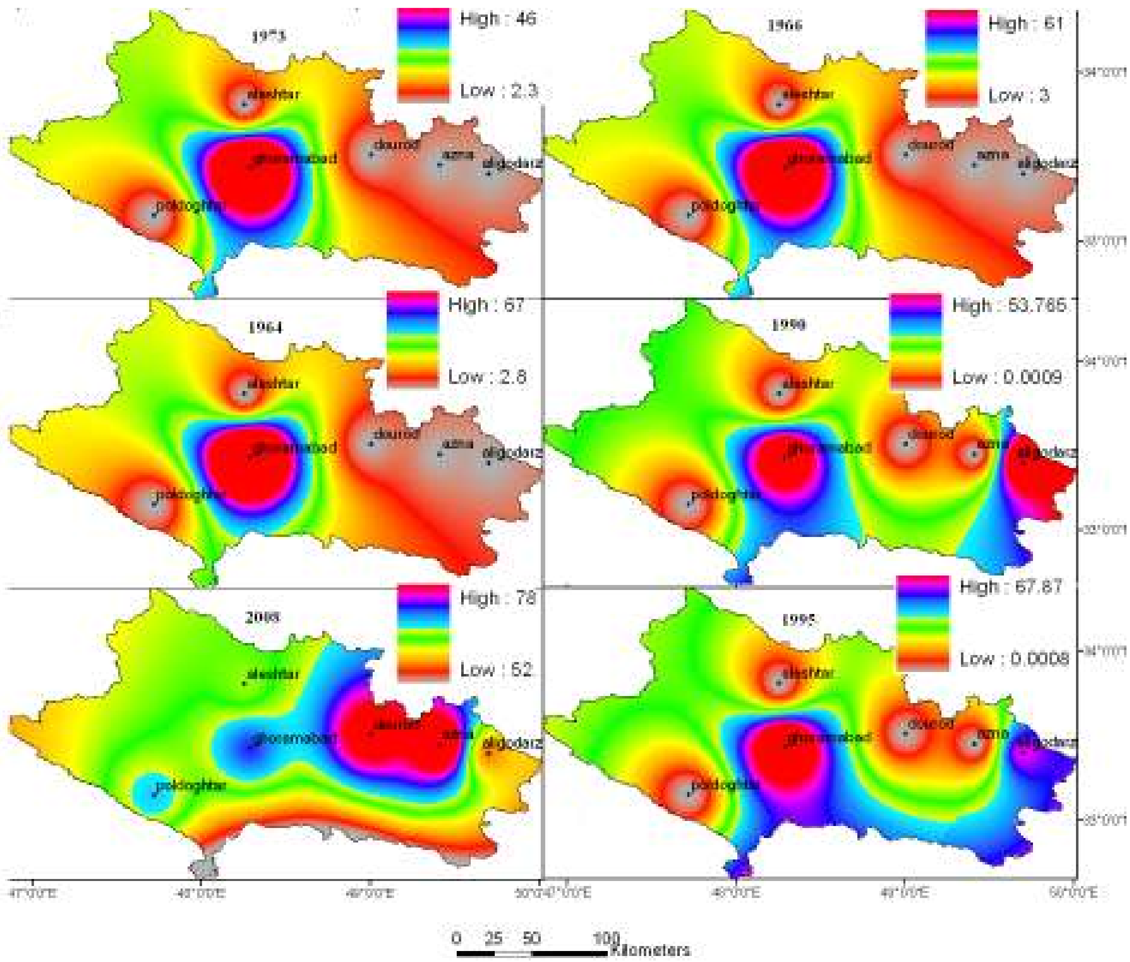

Figure 7: study of dry years in Lorestan with pni

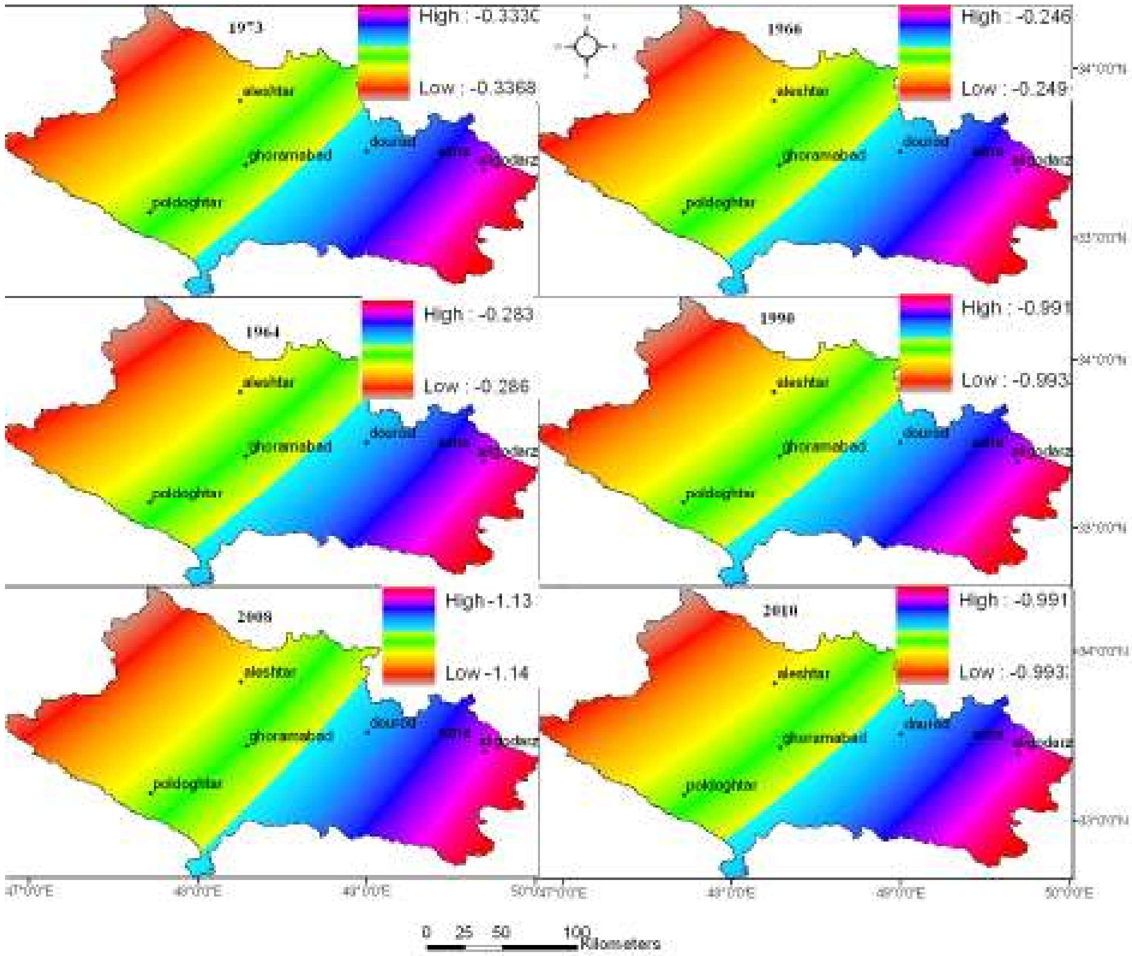

Figure 8: study of dry years in Lorestan with zsi

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