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Comparison of temporal and spatial trend of SPI, DI and CZI as important drought indices to map using IDW Method in Taleghan watershed

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ABSTRACT

Drought is both a hazard and a disaster; a hazard because it is an accident of unpredictable occurrence, part of the naturally variable climate system; disaster because it corresponds to the failure of the precipitation regime, causing the disruption of the water supply to the natural and agricultural ecosystems as well as to other human activities. Drought definitions are many and often are equated with specific drought impacts on economic activities, ecosystems, and society and water management issues. The objective of this study is to provide a comparative spatial analysis by using IDW methods as one of important geospatial methods and temporal variability of drought index in Taleghan with the view to identifying trends and onset of drought. It will quantify the relative effectiveness of SPI, DI and CZI and precipitation data as drought indices in the Taleghan region as a unique and highly productive basin. Taleghan is also a semi-arid region with a 41-year rainfall average of around 520 mm. Most rainfalls are in winter and spring. Geographic information system (GIS), GS+, Excel and DIP are good tools for analyzing spatial location, interaction, structure and processes. In this research the SPI, DI and CZI has been used as reference indices for the identification of drought events. Data-set is collected from 8 climatology station within the watershed from 1967 to 2008. After testing and if needed normalizing the data, it was entered in Excel and after being saved as a text, it was transformed to the DIP software to calculate the SPI, DI and CZI. In the second stage, we used data in GS+ to assess the spatial variability of SPI, DI and CZI as Geostatic calculations. We analyzed the spatial relationship of SPI, DI and CZI with IDW by using GS+ only for yearly data. To increase the insurance, we used cross validation to make better decision in choosing the best method for mapping. To determine the degree of accuracy of maps, the cross validation between the three ways was analyzed. The R^2 factor was used as an important indicator to assess their accuracy. In the meanwhile, t-student test in 1% level was calculated to distinguish the significances.

Keywords: Drought, Drought Index, Temporal Trend, Spatial Analysis, DI, SPI, CZI, IDW

INTRODUCTION

Drought can basically be defined as a period of abnormally dry weather, which further results in a change in vegetation cover condition [5, 14]

Drought is a natural feature of climate and occurs in almost all climatic regions with varying frequency, severity and duration [17]. It can be defined as a temporary imbalance of water availability consisting of a persistent lower than average precipitation of uncertain frequency, duration and severity, of unpredictable or extremely hard to predict occurrence, resulting in diminished water resources availability [11].

Drought is both a hazard and a disaster; a hazard because it is an accident of unpredictable occurrence, part of the naturally variable climate system; disaster because it corresponds to the failure of the precipitation regime, causing the disruption of the water supply to the natural and agricultural ecosystems as well as to other human activities. Drought definitions are many and often are related with specific drought impacts on economic activities, ecosystems, and society and water management issues [1, 13, 16 and 18].

Vicente-Serrano et al in 2010 [15] used precipitation minus potential evapotranspiration (P–ET) to assess yearly changes in the degree of aridity, which they referred as aridification. Drought indices evaluate the departure of climate variables in a given time interval (month, season or year) from the “normal” conditions and are used as monitoring tools and operational indicators for water managers. Several drought indices have been developed, most of them based only on precipitation, some based on precipitation and evapotranspiration (ET), and others referring to runoff and vegetation conditions [5]. Keyantash and Dracup in 2002 [7] evaluated the performance and tractability of the most used drought indices, whereas Mishra and Singh in 2010 [10] reviewed drought concepts and compared drought indices.

Drought monitoring models and products assist decision makers in drought planning, preparation, and mitigation, all of which can play a role in reducing drought impacts [12].

Standardized Precipitation Index (SPI)
SPI was developed in Colorado by McKee et al in 1993 [9] and is based just on precipitation and, therefore, requires less input data and calculation effort than PDSI. A long-term precipitation record at the desired station is fitted to a probability distribution (e.g., gamma distribution), which is then transformed into a normal distribution so that the mean SPI is zero [3]. SPI may be computed with different time steps (e.g., 1 month, 3 months..., 48 months) and is reported to be able to identify emerging droughts sooner than the Palmer Index. The use of different time scales under the umbrella of the same index allows the effects of a precipitation deficit on different water-resources components (groundwater, reservoir storage, soil moisture, streamflow) to be assessed.

Positive SPI values indicate greater than mean precipitation and negative values indicate less than mean precipitation. Similarly, to the PDSI, SPI may be used for monitoring both dry and wet conditions. The “drought” part of the SPI range is arbitrarily split into “near normal” conditions (0.99 <SPI<-0.99), moderately dry (-1.0 < SPI < -1.49), severely dry (-1.5 <SPI<-1.99) and extremely dry (SPI < -2.0). 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.”

To date, SPI is finding more applications in southwest Asia than other drought indices due to its limited input data requirements, flexibility and simplicity of calculations (Smakhtin and D. A. Hughes. 2004)

The Decile Index
This method is a rather under-utilized drought index but its simplicity makes it the most reasonable place to start. The Precipitation Deciles method was created by Gibbs and Maher in 1967 [4] to obtain a consistent assessment of the meteorological situation for regions where precipitation averages were inadequate. This index is favourable because it is easy and relatively quick to compute. Also, the only data it requires as an input is long term precipitation values, which is not difficult to come across. Some of these deficiencies include the inability for the Decile ranges to accurately represent the drought situations in areas where precipitation patterns depend heavily on seasonality and difficult to understand patterns when constructed as a time series.

Gibbs and Maher in 1967 [4] proposed that these Decile values be computed on an annual basis. By nature, droughts do not usually last this long of a time scale, typically their duration is on the order of months. Also, as mentioned before, some of the drought events will be lost or smoothed out when the averaging period is so long. This simple index could not be used for drought prediction because of its dependence on observed data but it does a very good job at giving a general idea about the current hydrometeorological state of the regions.

Computations

As promised, the computations for this index are very basic and thus do not require the use of extensive lists of equations. First, the long term precipitation data set must be sorted, starting with the wettest amount and decreasing to the driest. Next, this sorted set needs to be divided into ten Deciles. In table 1, the categories and truncation levels of the Precipitation Deciles is represented. According to this method, a drought ends when: 1) the previous month's precipitation puts the three month total in or above the fourth Decile, 2) the summed precipitation for the previous three months period is in or above the eighth Decile [8], or, as a supplemental rule suggested by Keyantash and Dracup [7], if the summed precipitation surpasses the first decile for every month in the drought then the drought can be considered concluded. This last rule was formed because this index makes it possible for the first rule to be prompted quite easily by receiving insignificant amounts of precipitation during a period where that area receives little to no precipitation.In this approach suggested by Gibbs and Maher in [4] and widely used in Australia [1] monthly precipitation totals from a long-term record are first ranked from highest to lowest to construct a cumulative frequency distribution. The distribution is then split into ten parts (tenths of distribution or Deciles). The first Decile is the precipitation value not exceeded by the lowest 10% of all precipitation values in a record. The second Decile is between the lowest 10 and 20% etc. Comparing the amount of precipitation in a month or several months' period with the long-term cumulative distribution of precipitation amounts in that period the severity of drought can be assessed. Decile Indices (DI) are grouped into five classes, two Deciles per class. If precipitation falls into the lowest 20% (Deciles 1 and 2), it is classified as "much below normal". Deciles 3 to 4 (20 to 40%) indicate "below normal" precipitation, Deciles 5 to 6 (40 to 60%) give "near normal" precipitation, 7 and 8 (60 to 80%) – "above normal" and 9 and 10 (80 to 100%) are "much above normal" (McMahon, 1986).

Table 1: Category and Value of Drought for SPI

Deciles Index			
DI Rank	**Deciles**	**Category**	**value**
1	%10 <	Very much below normal	-4
2	10 to 20	Much below normal	-3
3	20 to 30	Below normal	-2
4	30 to 40	Slightly below normal	-1
5	40 to50	Normal	0
6	50 to60	Normal	0
7	60 to70	Slightly above normal	1
8	70 to 80	Above normal	2
9	80 to 90	Much above	3
10	%90>	Very much above normal	4

China Z-Index (CZI) and Z-Score

China-Z Index (CZI) and Modified China-Z Index (CZI) have been used by many scientists to monitor moisture conditions across their country or their case study area.

The CZI is based on the Wilson-Hilferty cube-root transformation [6]. Assuming that precipitation data follow the Pearson Type III distribution, the index is calculated as:

$$CZI_j = \frac{6}{C_s}\left(\frac{C_s}{g}\varphi_j + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6} \quad (1)$$

$$C_s = \frac{\sum_{j=1}^{n}\left(x_j - \bar{x}\right)^3}{n \times \sigma^3} \quad (2)$$

$$\varphi_j = \frac{x_j - \bar{x}}{\sigma} \quad (3)$$

Where*j* is the current month, $C_s$is coefficient of skewness, *n* is the total number of months in the record, φ_j is standard variant, also called the Z-Scores, and x_j is precipitation of *j* month. Wu *et al*. (2001) attempted to reduce the differences between the SPI and MCZI, but they concluded that the overall differences between these two indices reduce significantly as it is between the SPI and CZI.

Table 2: Category and Value of Drought for CZI

Standardized Precipitation Index		
CZI Rank	CZI values	Category
1	2 and above	Extremely wet
2	1.5 to 1.99	Very wet
3	1 to 1.49	Moderately wet
4	-0.99 to 0.99	Near normal
5	-1 to -1.49	Moderately dry
6	-1.5 to -1.99	Severely dry
7	-2 and less	Extremely dry

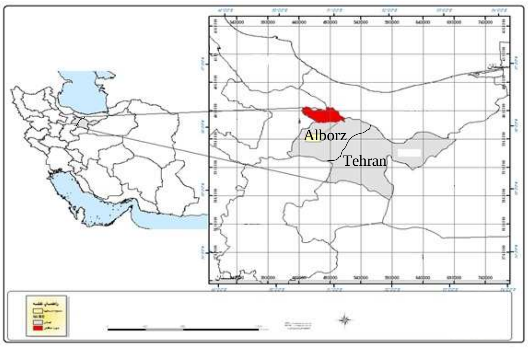
The objective of this study is to provide a comparative spatial analysis by using IDW as one of important geospatial methods and temporal variability of drought index in Taleghan with the view to identifying trends and onset of drought. It will quantify the relative effectiveness of SPI, DI and CZI and precipitation data as drought indices in the Taleghan region. The results from this comparison will hopefully serve as timely scientific input for policy makers in Taleghan and international organizations for sustainable water resources development and management in Taleghan.

MATERIALS AND METHODS

Study area

Taleghan is located in one of the more variable and suitable regions for farming and grazing of Iran (Figure 1). A unique and highly productive basin, Taleghan is home to thousands of inhabitants with exceptional biodiversity. The impact of both climate and anthropogenic factors on Taleghan Basin is substantial. Access to freshwater from both surface and groundwater resources have been hampered. Increasing pressure on groundwater and rangelands resources is raising concern over long term sustainability. Taleghan is also a semi-arid - with a 41-year rainfall average of around 520 mm. most rainfalls are in winter and spring.

Figure 1: Map of study area in Iran



Datasets and methodology

Geographic information system (GIS), GS+, Excel and DIP are good tools for analyzing spatial location, interaction, structure and processes, because hydrometeorological data are spatially distributed (Smakhtin and D. A. Hughes. 2004, p 32). In this research the SPI, DI and CZI has been used as reference indices for the identification of drought events.

Data-set collected from 8 climatology station within the watershed from 1967 to 2008. After testing and if needed normalizing of the data, they entered in Excel and after saving as a text, transformed to the DIP software for calculating the SPI as Monthly, Yearly and 3, 6, 9, 12, 24 and 48 Monthly Moving Average (MMA), DI and CZI.

In the second stage we used data in GS+ for assessing the spatial variability of SPI, DI and CZI as Geostatic calculations. We analyzed the spatial relationship of SPI, DI and CZIwith IDW by using GS+ only for yearly data [19].To increasing the insurance, we used crass validation for making better decision for choosing best manner for mapping.

RESULTS AND DISCUSSION

After analysing data, we assessed the data-set in 3 stage, a) time trend of SPI, DI and CZI, b)spatial analysis of SPI, DI and CZI in peak years of drought and wet and c)comparison between three kind of drought indices in mapping through IDW by using cross validation.

1-**Time Trend**

1-1: SPI

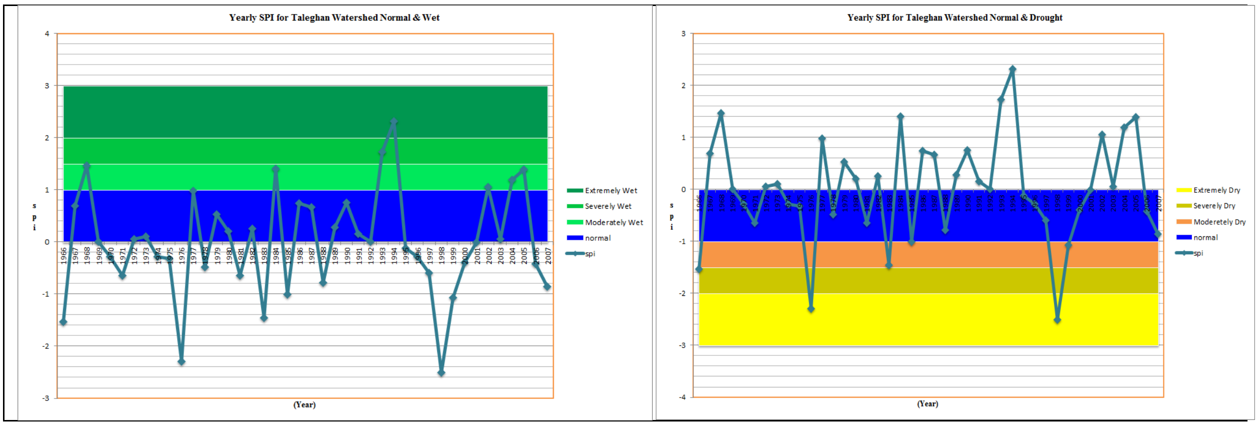
As shown in below Graph 1, 23 years of period located in the lower level of normal (<0) toward to the droughts region. There were only 19 years upper than normal (>0) to wet ones. Despite of more than 560 mm rainfall average, this can be important and considerable. In the watershed with this amount of rainfall we can see there are 3 years of 42 years in severely and extremely wet while only there are 4 years in against point (Dry category).

By the way we can extract that there are about 4 important period of drought and wet period in this time. In the other hand there two points peak of extremely dry (1976, 1998) with more than SPI <-2 while in against of it, we see only one peak point of extremely wet with SPI>2 (1994) in whole period. This as well as shown the variability and unreliability of rain in this watershed that located in the one of the important place in the country. Otherwise we found that often after a wet period, there was a drought period. First wet period belongs to 1967 to 1969, while the next drought period has followed in 1974 to 1976 and sameness the wet period of 1992 to 1995 has come with 1996 to 2000 as another drought period.

Another important finding relate to the years of two major drought period. As shown in the graphs, the first period of drought has taken along only 3 years between 1974 to 1976, while the second ones were with 5 years between 1996 to 2000. Therefore except severity of drought, the time of drought too has shown considerable increasing.

The colors that are shown in below graphs are same with the 2D and 3D maps in next sessions.

Graph 1: Yearly SPI for Taleghan watershed 1966-2007 (Left: Wet Period, Right: Drought Period)



1-2: DI

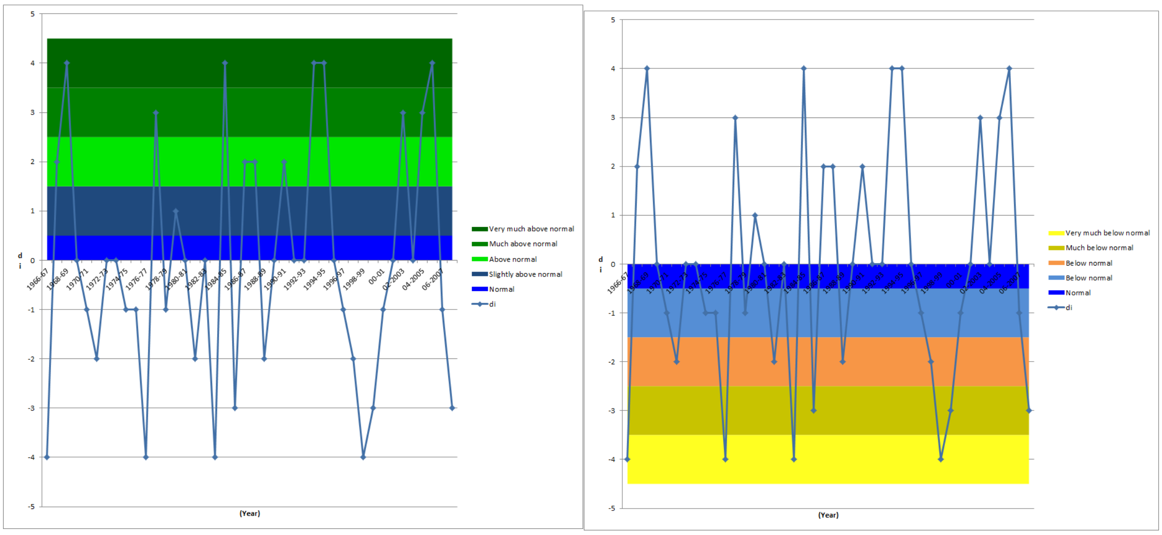
As shown in the following Graph 2, 11 years of period are located in the normal condition (-0.5<DI<0.5), 13 years in wet condition (DI>0.5) and 18 years in dry condition (DI<-0.5).

Despite more than 500 mm, we observed that 18 years of 42 years are in worse condition while 13 years are in wet condition.

Considerable finding in the Graph 2 is related to the fact that in most cases we can see a drought period comes after the wet condition. In the meanwhile, contrary to every peak wet year (DI>3), there is abnormally dry weather (DI<-3). Therefore it can be usual to forecast the lack of rain in next years. It has high probability that in the next drought going to happen, the condition of lack of rain may be worse and on the other hand, in the next peak year of wet period spatial distribution of wet will be only in the normal or moderately wet. As shown in graph 1, the next dry period has started from 2006, and sharply has gone down toward worse condition. The important peak years of drought are 1976 and 1998;On the other hand, 1994 and 2005 are peak years of wet.

The colors that are shown in the following graphs are the same with the 2D and 3D maps in next sessions.

Graph 2: Time Trend of DI (Drought Index) 1966-2007



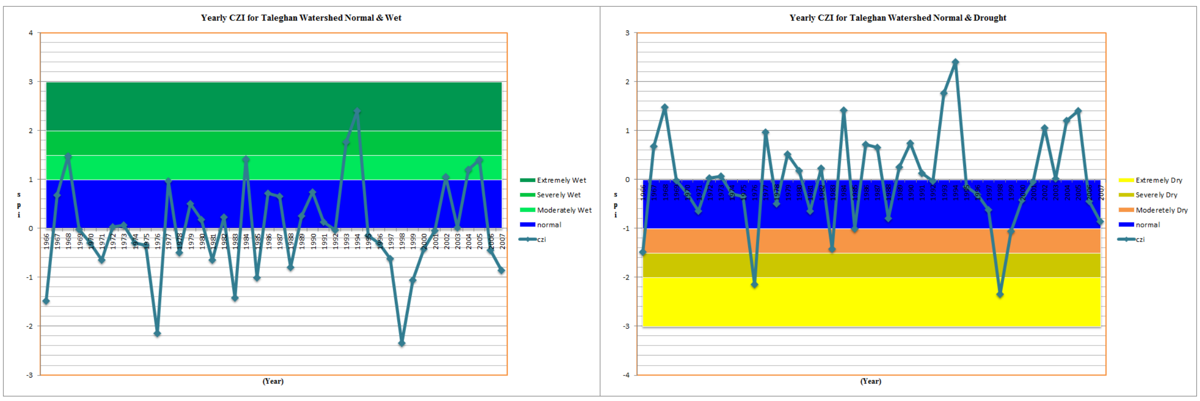
1-3: CZI

As seen in Graph 3, 29 years of period are located in the level of normal (-0.99<CZI<0.99), 7 years upper than normal (CZI>0.99) toward wet condition and 6 years lower than normal (CZI<-0.99) toward drought conditions. In the watershed with this amount of rainfall, as it can be seen, there is1 years of 42 years in extremely wet while only there are 2 years in extremely dry condition.

In the meantime, it can be concluded that there are about 4 important periods of drought and wet period in this time. On the other hand, there are two extremely dry peak points (1976, 1998) with more than CZI<-2 while, we see only one peak point of extremely wet with CZI>2 (1994) in the whole period. First wet period belongs to 1967-1969, while the next drought period has followed from 1974 to 1976 and similarly, the wet period of 1992 to 1995 has come with 1996 to 2000 as another drought period just like SPI and DI as a whole.

The colors that are shown in the following graphs are the same with the 2D and 3D maps in next sessions.

Graph 3: Time Trend of CZI in 1966-2007



1-Spatial trend analysing 2D and 3D Mapping by using IDW for SPI, DI and CZI

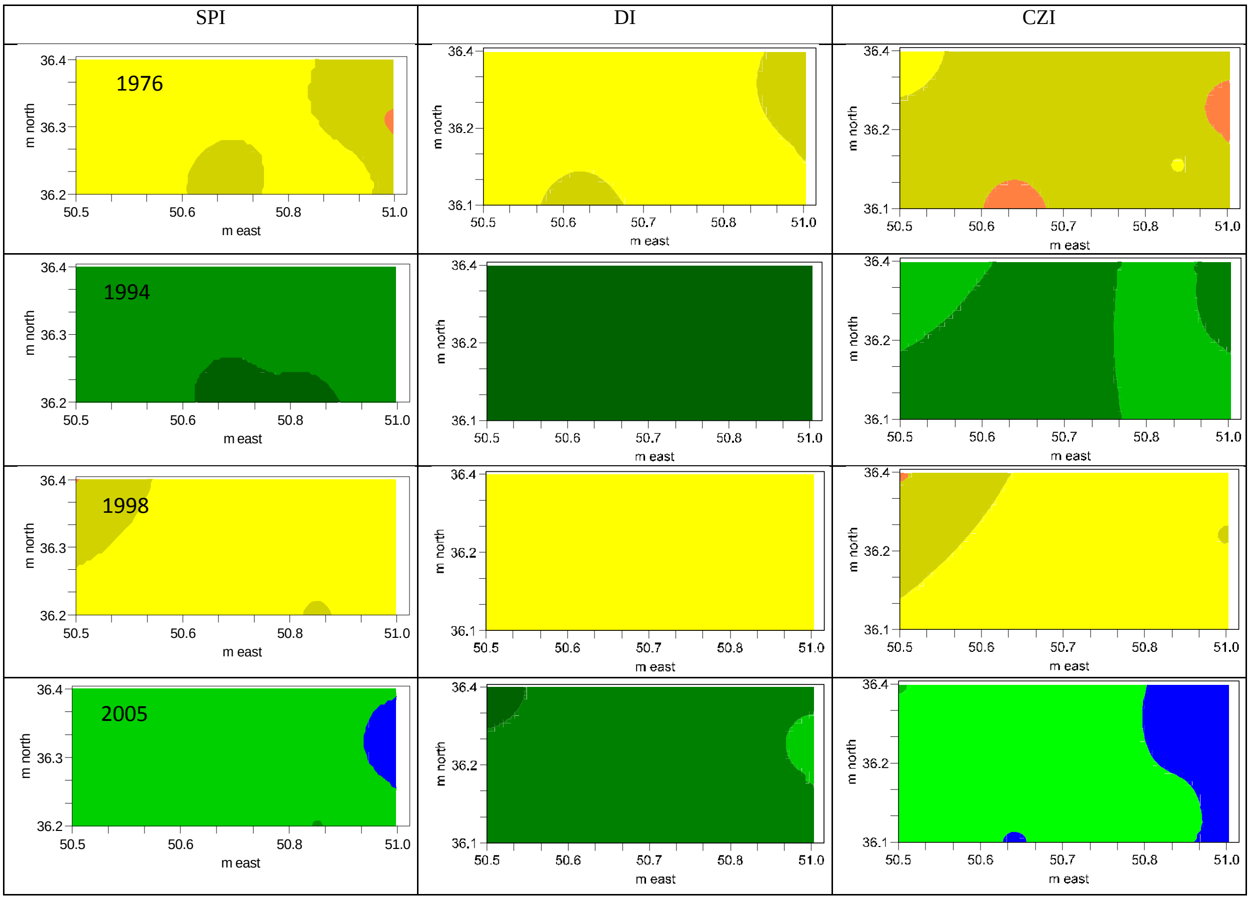
2-1: Drought peak years

In the first dry range that started from 1973 to 1976,as has been shown in table 3 and 4, 1976 has been displayed as peak year. In SPI method, it can be seen that the whole watershed has been exposed to moderate, severe and extreme drought and as a result, the most parts of it are extremely dry and then severely dry and finally moderately dry, while in CZI we see the same condition about category of drought with this difference that progress of severe drought is maximum and in the next steps come extremely and moderately dry conditions. On the other hand, we found that in DI, there are only 2 categories: severe and extreme drought. Distribution of extreme drought condition in the watershed is more than severe drought condition (table 3 and 4).

In the second period of drought that happened during 1996-2001, in 1998 as the driest circumstance, the SPI map shows the extremely dry condition encompassed a great area of the region and the severely dry condition is ranked after it. There is a very small part in the watershed as moderately dry, but it is hardly seen. Distribution of classes in CZI as a whole are like SPI, but amounts of moderate and severe drought extension are bigger than SPI. Contrary to those methods, in DI manner, there are only extremely drought situation in the whole watershed. We cannot see other kinds of drought in the map (Table 3 and 4).

One common finding in all maps is the fact that severity of drought in second year i.e. 1998, increased much more than the first peak year. On the other hand, lack of rainfall in last year was distinguishable. If another dry peak year is going to happen in the future, it might be worse than the last condition in 1988 (Table 3 and 4).

Table 3: 2D map of IDW in Taleghan Watershed for selected years between 1966 to 2007



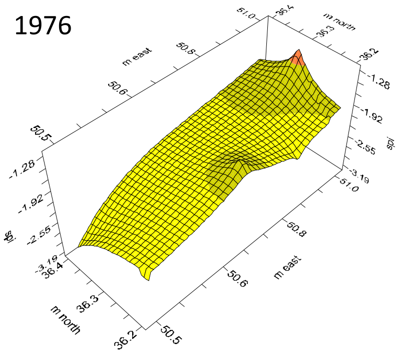
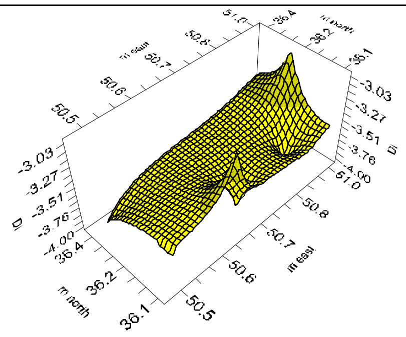
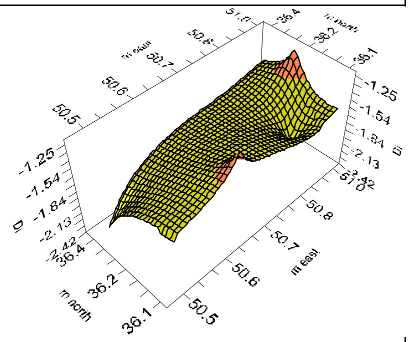
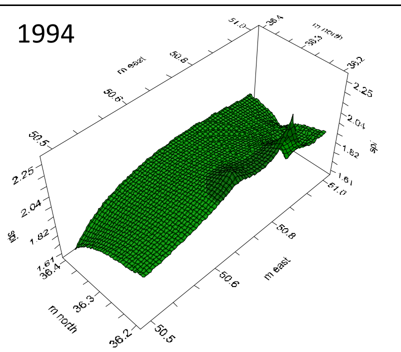
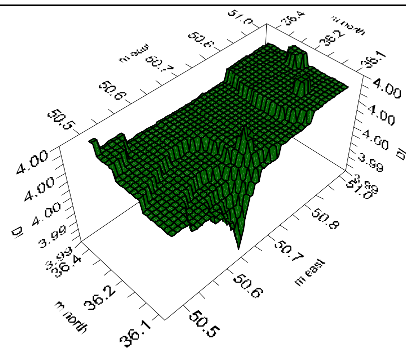
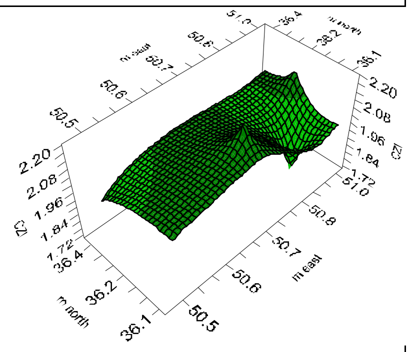
2-2: Wet peak years
As displayed in table 3 and 4, first wet peak year, 1994 was selected. In this year in maps of SPI and CZI, there are two classes of wet; extremely and severely wet, but the area of extreme wet in CZI map is more than SPI map. In DI map, the whole watershed has been located in extremely wet.

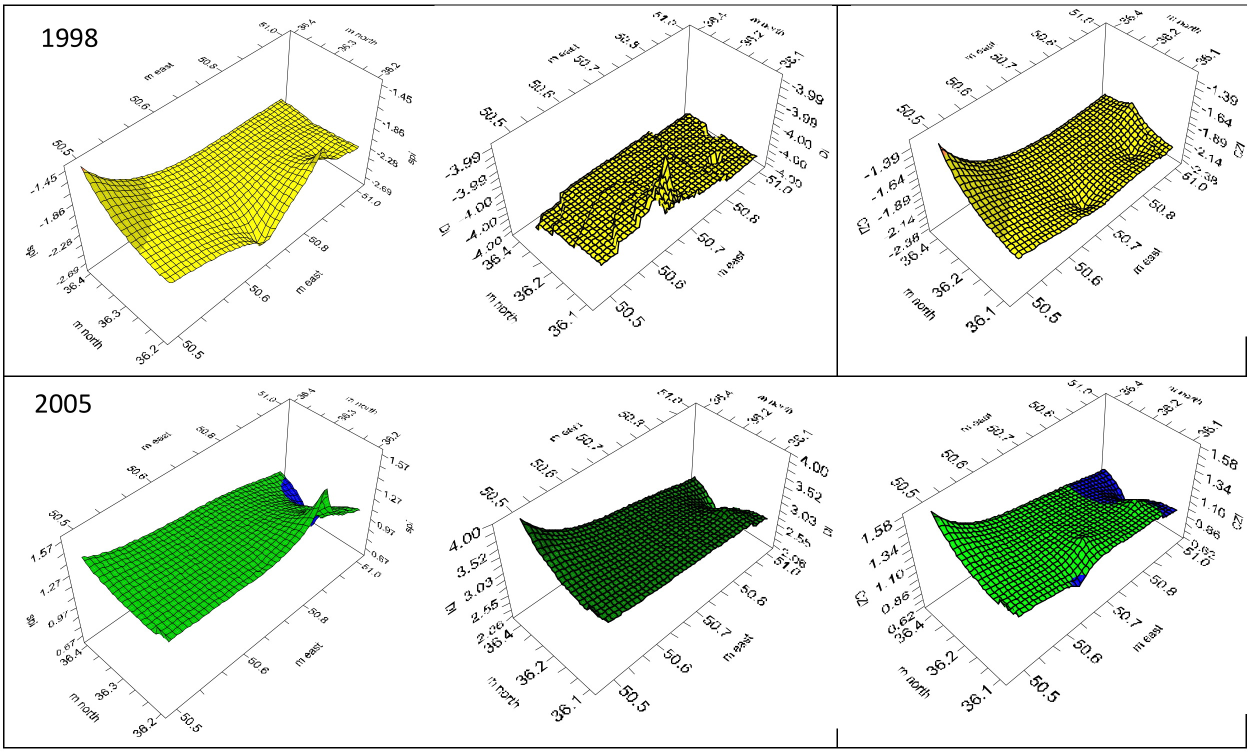
On the other hand, considering the ID, the best situation in the watershed has been appeared. And the entire area has gained maximum rainfall in extreme class, CZI and SPI come next related to the amount of rain that fall in the region, so in CZI more than half of the region is located in extremely wet and the condition for SPI is reverse.

Second selected wet year is 2005. In all the maps, although watershed has been located in wet period, we can see only in ID map asmall area exposed to good rainfall and it is in extremely wet class and rest of the watershed is located in severely wet. In SPI and CZI map all the region has two category of wet: normal and moderately wet (Table 3 and 4).

As a whole,it can be said that in proportion to prior wet year, in this year amount of rainfall decreases sharply and although the watershed has gained rainfall more than normal, condition of rainfall in this year as a wet year is not satisfactory (Table 3 and 4).

Table 4: 3D map of IDW in Taleghan Watershed for selected years between 1966 to 2007

SPI	DI	CZI
1976 		
1994 		



1-Cross validation

To determine the degree of accuracy of maps, we analyzed cross validation between the three ways. We used R^2 factor as important means to determine their accuracy. Meanwhile, we calculated t-student test in 1% level to distinguish the significances. Results of R^2 have been displayed in table 7. Based on the findings of the computations, we can compare three methods together (Table 5).

3-1: SPI and DI

Results show that there is a significant difference between SPI and DI in 1 and 5 % levels. It means that the maps produced by SPI are more reliable than ID maps. These maps can be usedto analyse and probably forecast the events which might happen in the future (Table 5).

3-2: SPI and CZI

Results show that there is not any significant difference between SPI and CZI in 1 and 5 % level. It means that the maps extracted by SPI and CZI have the same feasibility for analysing and probably forecasting the events which might happen in the future (Table 5).

3-3: ID and CZI

Results show that there is a significant difference between CZI and DI in 5 % level. It means that the maps produced by CZI like SPI are more reliable than ID maps. Again, these maps are more reliable to analyse and probably forecast the events which might happen in the future (Table 5).

Table 5: calculated R^2 for three kinds of drought indices for important period of drought and wet

year	SPI	DI	CZI	year	SPI	DI	CZI	year	SPI	DI	CZI	year	SPI	DI	CZI	year	SPI	DI	CZI
1975	0.62	0.69	0.93	1992	0.75	0.70	0.81	1995	0.69	0.62	0.78	1998	0.92	0.46	0.99	2002	0.93	0.24	0.89
1976	0.85	0.43	0.74	1993	0.84	0.86	0.45	1996	0.99	0.97	0.86	1999	0.88	0.93	0.85	2004	0.66	0.88	0.79
1977	0.79	0.81	0.79	1994	0.71	0.46	0.69	1997	0.80	0.45	0.81	2000	0.87	0.70	0.79	2005	0.90	0.32	0.56

CONCLUSION

First and important finding of this study is related to the way of drought index accomplished by IDW mapping as spatial analysis method. As a result of test, in mapping with IDW, SPI has revealed the best correlation; MCZI and DI are placed after it respectively. We can use SPI as a reliable tool to forecast the next event in comparison to the other two methods.

The lack of rain and abnormally dry weather that has happened in the first dry peak year compared to the last one which happened in 1998, was moderate as a whole, while as we see in 1998 the severity of dry condition is worse. It is likely that the next dry year will be in more catastrophic condition than 1998.

The same situation for wet period is seen but in reverse direction. It means that the amount of rainfall decreases sharply in the second wet year. Although the watershed has gained rainfall more than normal, condition of rainfall in this year as a wet year is not satisfactory.

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