Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 5, No. 1, p. 385-395, 2014
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Temporal trend calculation of di (drought index) and comparison of two methods of IDW and KRG as important spatial analysis tools

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Article published on July 12, 2014

Key words: Drought, drought index, temporal trend, spatial analysis, DI.

Abstract

Drought is one of the main natural causes of agricultural, economic and environmental damage. The objective of this study is to provide a comparative spatial analysis by using IDW and KRG methods in Taleghan Watershed in Iran with the view to identifying trends and onset of drought. Data-set is collected from 8 climatology station within the watershed from 1967 to 2008. After testing and if needed normalizing the data, they transformed to the DIP software for calculating the DI. In the second stage we used data in GS+ for assessing the spatial variability of DI Geostatic calculations. To increase certainty, we used cross validation and t-student test to make better decision in choosing best manner for mapping. As results of test, KRG had the highest accuracy compared to the others in making spatial maps. The lack of rain and abnormally dry weather that has happened in 1976 and 1988 was the same and the watershed has been exposed only in extremely dry condition. In addition, for wet period we observed a reverse condition i.e. the area and severity of wet in 2005 is weaker than 1994. In the map of 1994 we can see the extremely wet class in all parts of the watershed, while in the second peak year of wet period, there are moderate, severe and extreme conditions. We can indicate that KRG method for mapping the spatial distribution of climate condition by using the DI can end in a better map than that of IDW method.

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Introduction

The objective of the study is to provide:a)a comparative analysis of spatial and temporal variability of drought index in Taleghan with the view to identifying trends and onset of drought, b) assessment of accuracy of two methods IDW and Kriging for spatial analysis. It will quantify the relative effectiveness of DI and precipitation data as drought indices in the Taleghan regions. 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. In a study that has been done,the approach suggested by Stahl (2001) for modelling a regional drought index using atmospherical circulation pattern classification was implemented in France, a region not included in Stahl's original study. The relatively poor quality of the modelling results in calibration (small percentage of variance explained) lead to investigate a new clustering process that regroups weather types according to their association with rainfall or no rainfall, instead of being based on the occurrence of certain weather types during severe drought events. The results obtained are of the same order of magnitude as those obtained by Stahl in Europe during the calibration periods. Despite a modelling procedure that does not explicitly include any temporal dynamic (and in particular there is no accounting of the delay between the occurrence of a weather type and hydrological response of the basins), CP groups explain up to 25% of the temporal variability of RDI. In validation, most of the models are able to predict the summer 2003 drought.

Results of finding a research by Mihaela and *et a.,l* in 2009 indicated, although the DI drought index is very simple to calculate, the study pointed out that it is similar with the sc-PDSI that has a rather complicated calculating procedure. The comparison between the DI and sc-PDSI seasonal values for the period 1951–2002 for three stations in Romania indicate a similar behavior, only the sign of the indices being opposite. The same similarity was obtained for the first temporal component EOF of DI and sc-PDSI for the same period. Analyzing the first temporal component of the DI for each season, a tendency for dryness in spring and summer between 1999 and 2002 could be observed.

For summer, the period between 1970 and early 1980's appears as a persistent wet period, in concordance with the result obtained by Van der Schrier (2005) for sc-PDSI over the entire European region. The investigation of climatic change points was achieved by nonparametric statistical tests and for every detected point the signal-to-noise ratio was calculated. These methodologies were applied to the first temporal component series of the DI for each season. Several statistical significant change points: 1968, 1981 and 1986 for summer and 1970 for winter and autumn have been evidenced. The results will be used for studying climate changes in moisture availability in Romania by calculating DI from outputs of global models for climate changes using downscaling procedures.

Drought is one of the main natural causes of agricultural, economic and environmental damage (Whilhite *et al*, 1985; Bhuiyan *et al*, 2008). Droughts are apparent after a long period without precipitation, but it is difficult to determine their onset, extent and end. Thus, it is very difficult to objectively quantify their characteristics in terms of intensity, magnitude, duration and spatial extent. For this reason, much effort has been devoted to developing techniques for drought analysis and monitoring.

Drought is a complex natural phenomenon and has significant impacts on effective water resources management. In general, drought gives an impression of water scarcity due to insufficient precipitation, high evapotranspiration and over- exploitation of water resources or a combination of all above (Burton *et al.*, 1978; Wilhite, 1993).

Typically, when a drought event and resultant disaster occur, governments and donors follow impact assessments, and response, recovery and reconstruction activities, to return the region or locality to a pre-disaster state. All these activities are generally followed with the assessment of the past drought condition which is often carried out with a drought assessment tool. Although, in general people cope with drought impacts by taking recovery actions after any drought, the society can reduce drought vulnerability and therefore lessen the risks associated with droughts by making a future drought plan. Moreover, the likelihood of increasing frequency, duration and severity of droughts in Australia due to possible climate change impacts reinforces the need for future drought plans (Hennessy *et al*, 2008). Therefore, it is well recognized that preparedness for drought is the key to the effective mitigation of drought impacts which is becoming more important for water resources managers to handle the challenges in water resources management (Hennessy *et al*, 2008).

Materials and methods

Our study area, Taleghan, is located in one of the more variable and suitable regions for farming and grazing in Iran (Fi 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 ranglands resources is raising concern over long term sustainability. Taleghan is also a semi-arid area with a 41-year rainfall average of around 520 mm. Most rainfalls are in winter and spring.

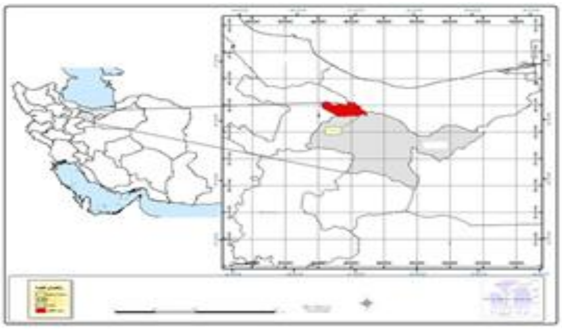


Fig. 1. Map of study area in Iran.

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 (Smakhin *et al*, 2004). In this research the DI has been used as a reference index for the identification of drought events.

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

In the second stage, we used data in GS+ to assess the spatial variability of D.I as Geostatic calculations. We analyzed the spatial relationship of SPI with Krigging and IDW and NDW by using GS+ (Zhao , 2010).We used the GIS to map the location of Taleghan Watershed.

The Decile Index

This method is a rather under-utilized drought indices but its simplicity makes it the most reasonable place to start. The Precipitation Deciles method was created by Gibbs and Maher (1967) 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. The simplicity of this index contributes to its downfalls, however, since there are a lot of variations that this index ignores. 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 (1967) 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 dividing into ten Deciles. Lastly, rank the time period of interest against the ranked data to see which Decile it falls within.

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 month period is in or above the eighth Decile (Kim *et al*, 2002) or as a supplemental rule suggested by Keyantash and Dracup in (2002), 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 (1967) and widely used in Australia (Coughlan, 1987) 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 Decileis 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.

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

The objective of the study is to provide: a)a comparative analysis of spatial and temporal variability of drought index in Taleghan with the view to identifying trends and onset of drought, b) assessment of accuracy of two methods IDW and Kriging for spatial analysis. It will quantify the relative effectiveness of DI and precipitation data as drought indices in the Taleghan regions. 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.

Results

After analysing data, we assessed the data-set in 3 stages: a) Time trend of SPI, b)Spatial Trend of SPI and c)comparison between three kinds of mapping i.e.Kriging, IDW and IDW by using cross validation.

Temporal Trend

As shown in graph 1,11 years of the total period are in 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 of rainfall, we observed that 18 years of 42 years are in severe drought condition while only 13 years are in wet condition.

Considerable finding in this graph (Fig 2) is related to the fact that in most cases, we can see a drought period coming after a wet condition. Therefore, it can be usual for forecasting the lack of rain in next years. It has high probability that in the next drought that may happen, condition of lack of rain may be worse and on the other hand, spatial distribution of the next wet period is likely to be only in normally or moderately wet classes. As shown in graph 1, the next dry period has started from 2006, and sharply has gone down toward worse condition.

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

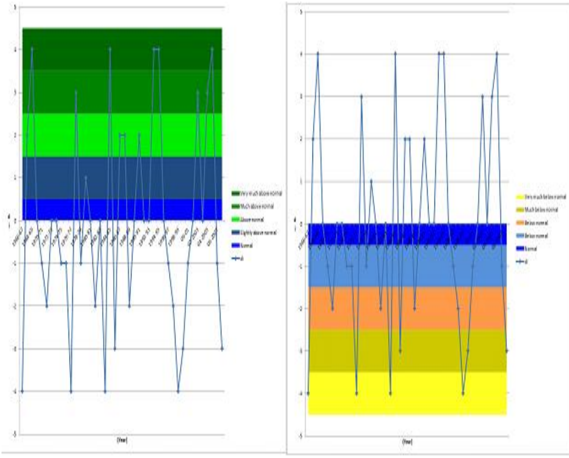


Fig. 2. Time Trend of DI (Drought Index) 1966-2007.

Spatial Trend

2D and 3D map of IDW

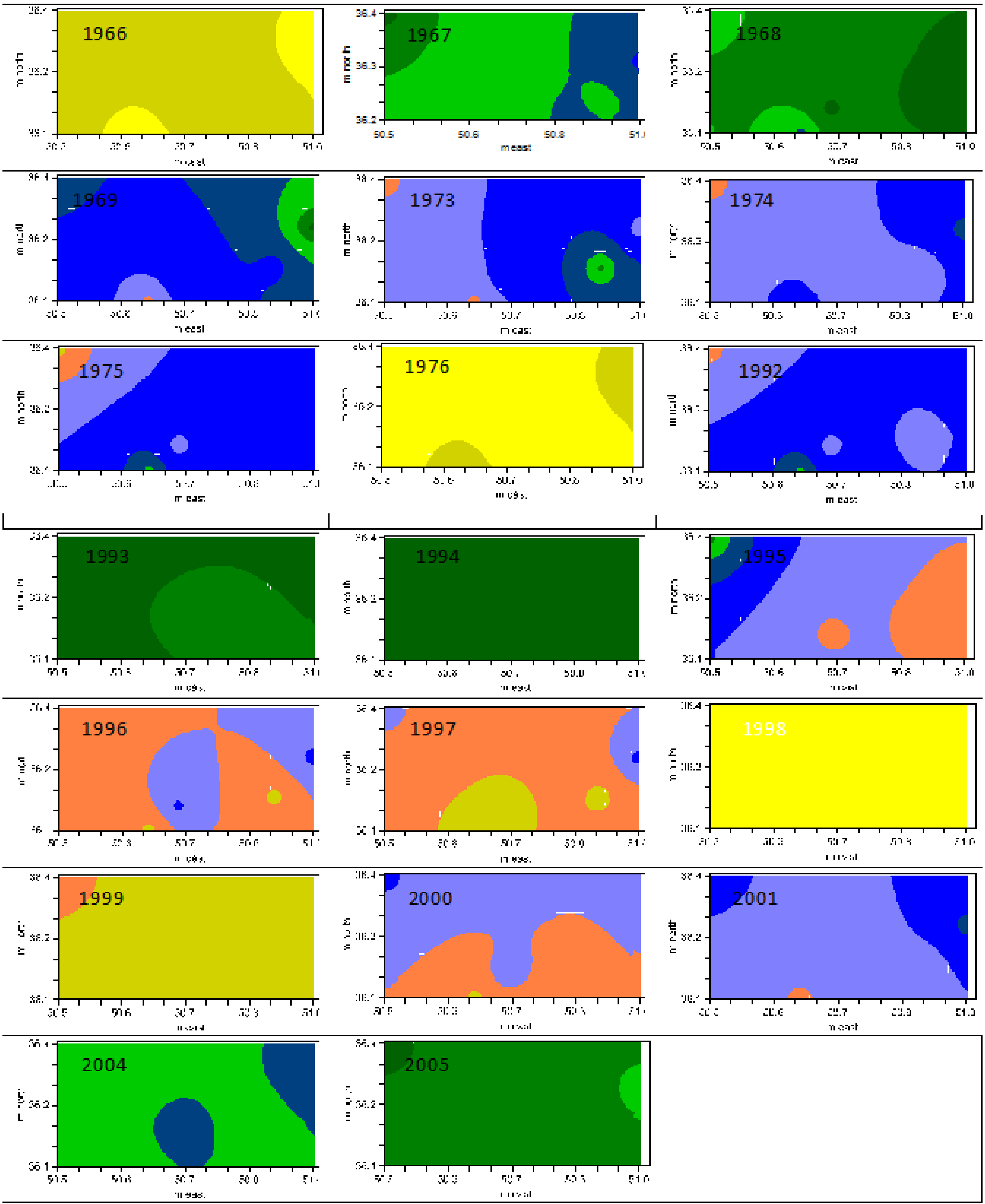
Additionally, in order to guide the results toward a good deduction, we decided to determine more important and substantial period of dry and wet stipulation. Therefore, after analysing the amounts of DI and graphs, we chose these periods: 1966-1969, 1992-1995, and 2004-2005 as wet period and 1973-1976, 1996-2001 as drought period (Table 2 and 3).

Wet period

The first wet period has started from 1966 (worse condition) and gone up until 1969, so that in 1968 as the year the whole watershed was exposed to a good distribution of rainfall, we can see that most part of region is in severely and extremely wet condition.

In the second wet range that started from 1992 to 1995, 1994 has been displayed as peak year, as in the whole watershed, the extremely wet condition is seen. In the last wet period that occurred during 2004 – 2005, the greatest area belongs to the severely wet class that has been accompanied with moderately and extremely wet class in small parts. Again, we see that severity of humid condition decreased significantly in comparison to previous wet period. Important finding in 3D map is related to this fact that the area located toward the north has been exposed to the moist condition.

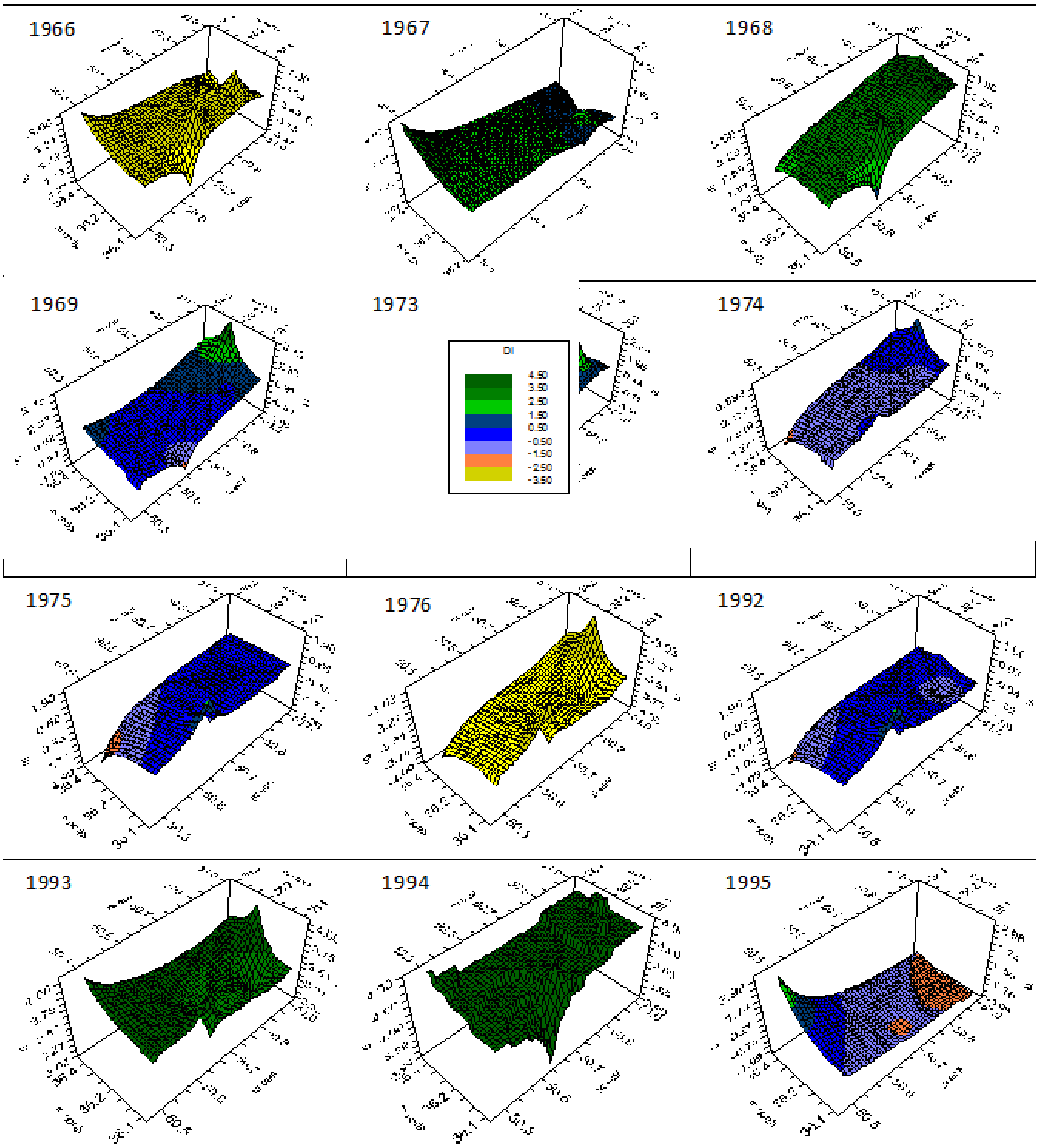
Table 2. 2D map of IDW in Taleghan Watershed for selected years between 1966 to 2007.



Dry period

1976 is the apex of drought for the duration of 1973-1976. In this year, condition of drought appears so severely and extremely dry, that large area of the watershed has been affected by it. On the contrary, in the second period of drought that happened during 1996-2001, in 1998 as the driest circumstances, extreme drought spread in whole watershed. We cannot see other classes of drought in the map. On the other hand, drought in comparison to the latest dry year has increased sharply (Table 2 and 3).

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



2D and 3D map of KRG

Wet period

As a whole, events in all years are the same as IDW map, but there are some differences between them. Although peak year of first wet period is like that of IDW in 1968, distribution of conditions is more reasonable in IDW method than KRG, despite the fact that most parts of region are in severely and extremely wet conditions in KRG method like IDW.

In the second wet range that started from 1992 to 1995, 1994 has been displayed as peak year, so that in the entire watershed, the extremely wet stipulation has been seen which is exactly what has happened in IDW map. In the last wet period that has occurred in 2004 – 2005, although shape of distribution of wet categories is similar to the IDW as a whole, the map shows distortion in it. Again it is obvious that severity of humid condition decreases significantly in comparison to previous wet period. Important finding in 3D map is related to this fact that the area located toward the north has been exposed to the moist conditions (Table 4 and 5).

Table 4. 2D map of KRG in Taleghan Watershed for selected years between 1966 to 2007.

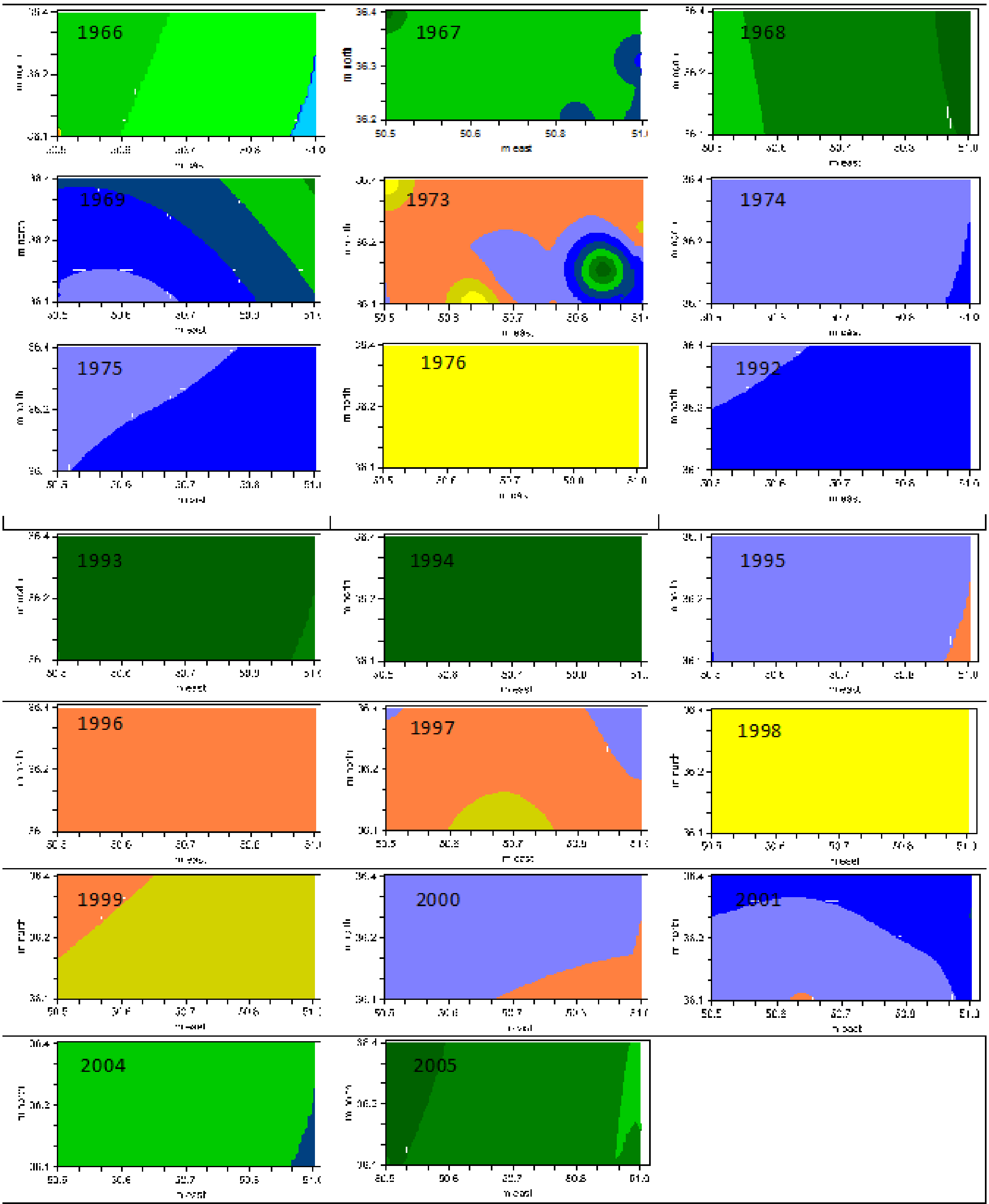
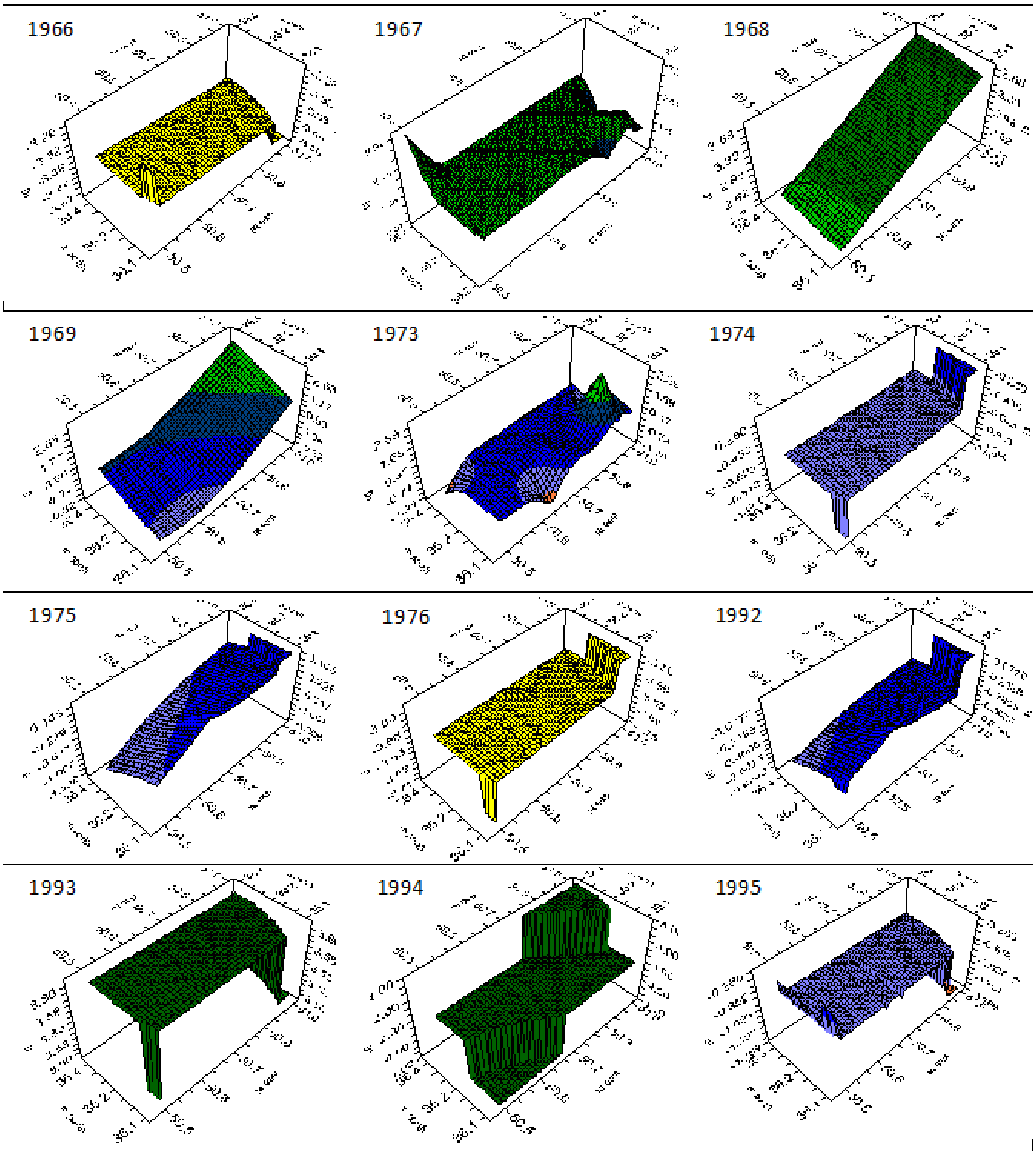


Table 5. 3D map of KRG in Taleghan Watershed for selected years between 1966 to 2007.



Dry period

In the peak years of drought period in KRG maps, i.e. 1976 and 1998, in contrast to the IDW maps, only one category of drought is visible. In this method of mapping, the whole watershed has been shown as entirely extremely dry area. The maps display that there are worse conditions in all area in all peak years. To better understand and come to a conclusion, only after investigation of cross validation between IDW and KRG, it is possible to say which map shows better feedback (Table 6).

Cross validation

To determine the degree of accuracy of maps, the cross validation between the two methods was analysed. The R^2 factor was used as the important implement to assess accuracy between them. Furthermore, we calculated t-student test in 1% level to distinguish the significances. Results of R^2 have been displayed in table 6. As the findings of the computations, three methods can be compared together (Table 6).

Results of IDW and KRG

Findings display a high difference between IDW and KRG methods. So, the results of t-student test show significant difference even in 1% level of probability. Therefore, it can be inferred that KRG method for mapping the spatial distribution of climate conditions by using the DI can result in better mapping contrary to IDW method (Table 6).

Table 6. calculated R^2 for three kinds of mapping. Manner.

year	*IDW*	*KRG*	*year*	*IDW*	*KRG*	*year*	*IDW*	*KRG*	*year*	*IDW*	*KRG*	*year*	*IDW*	*KRG*	*year*	*IDW*	*KRG*	*year*	*IDW*	*KRG*
1966	0.92	0.99	1969	0.19	0.03	1975	0.69	0.91	1993	0.86	0.99	1996	0.97	0.99	1999	0.93	0.1	2004	0.88	0.99
1967	0.44	0.99	1973	0.40	0.94	1976	0.43	0.76	1994	0.46	0.80	1997	0.45	0.43	2000	0.70	0.98	2005	0.32	0.1
1968	0.31	0.05	1974	0.63	0.99	1992	0.70	0.99	1995	0.62	0.99	1998	0.46	0.17	2001	0.24	0.1			

Conclusion

First and important finding of this study corresponds with the way of mapping. As the results of tests indicate, KRG method, in this case, had the highest accuracy compared to the others in making spatial maps especially in this method of drought index. Therefore, this method can be suitable for this situation and will be based on for discussing and concluding the findings.

The lack of rain and abnormally dry weather that has happened in 1976 and 1988 was the same and the watershed has been exposed to extremely dry conditions.

Moreover, for wet period, we observed a reverse condition. The area and severity of wet conditions in 2005 is weaker than 1994. In the map of 1994, an extremely wet condition can be observed in all parts of the watershed, while in the second peak year of wet period, there are moderately, severely and extremely wet conditions.

The results indicate that KRG method for mapping the spatial distribution of climate condition by using the DI can lead to better maps compared to IDW method.

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