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The Application of Geostatistics on Drought-Severity Zoning: A Case Study of the Urmia lake Basin in Kurdistan

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Abstract: *Drought is one of the most important disasters that has affected many countries and leads to severe economic, social, political, and cultural problems, among others. The awareness, prediction and zoning of drought can considerably reduce the risk of this phenomenon. The purpose of this study is to identify the droughts that happened in the studied area and from that, try and predict upcoming incidents of drought. In this research, the Urmia watershed area, located in the east of the Kurdistan province was studied. By using the SPI index, the annual precipitation data of 30 synoptic stations were analyzed for the period of 1993 to 2013. By using simple kriging (SK), ordinary kriging (OK), and inverse distance method (IDW) with grades 1 and 2, the maps of drought intensity for the droughts that occurred in the Kurdistan province were prepared. The standardized precipitation index was used for each statistical year. The results showed that a higher percentage of statistical years are located in the mild and moderate class of drought. The study of the dry periods by using the SPI index showed that in recent years, while continuing to increase landwards, some of the intensity of the droughts has reduced. The most severe droughts occurred in the region in the years 1998, 1999, 2005, and 2008. According to the results, most of droughts occurred in the Hassan Abad station with 6 event and 12 months respectively.*

Keywords: *Geostatistics, Zoning, Drought, Urmia lake watershed, Kurdistan*

INTRODUCTION

Drought as a natural disaster has very deleterious effects on the ecological environment (Serrano et al, 2005). In addition to reducing the surface and groundwater resources and causing huge damages to irrigated and rain-fed agriculture; drought causes problems in the environment, in the natural resources, and in the local ecosystems. Drought with a time delay in the onset of the rainy season is associated with Intensity, duration and frequency of precipitation. Thus, in times of drought, due to these changes in weather conditions and the fact that in the growth stage, the presence of water, relative humidity and the temperature are the main physiological needs of plants, the plant communities are disturbed. There is reduced biodiversity. And thus, interference in plant growth as the first link of the food chain gradually affects other vital food chains (Saleh et al., 2006). Unfortunately, drought and the ways to deal with it have been neglected compared to the other natural disasters. The main reason behind this problem is a relatively long period of severe drought, compared to floods and earthquakes and the short-term consequences of their impacts and damages.

This phenomenon can occur in all climatic zones, but the characteristics and consequences in one climatic area can be different from another.

Drought is a temporary aberration and is different from dry weather, because the dry is limited to regions with low rainfall and is a permanent feature of climate. The destructive consequences of drought are far more than other natural disasters such as floods, hurricanes, earthquakes and so on.

The destructive effects of drought become apparent in a relatively long time, and thus, this phenomenon is less comprehensible and identifiable. In addition to the obvious damage that usually is caused to the crops, gardens, and animal husbandry, drought in extreme cases may even lead to famine and eventually, migration.

Reduced crop production and soil fertility, reduced quality and levels of surface water and groundwater, increased mortality of livestock and poultry, damage to aquatic ecosystems and wildlife, reduced water supplies, and increased temperature are examples of the effects of drought.

Previous studies have shown that among all forms of natural disasters, the damages caused by drought are the most severe. Therefore, a broad and comprehensive monitoring and early warning systems in areas prone to drought are inevitable and necessary.

Kurdistan, in terms of geographical location and climatic conditions, is located in an arid and semi-arid belt and is always faced with the problem of drought and water scarcity.

Kurdistan, unfortunately, in addition to the lack of rainfall (517mm annual rainfall is normal, in the past two decades, the annual rainfall has reduced by about 15% to 20% compared to normal climatic condition), has improper temporal distribution of precipitation (four months of rain in a year) and lop-sided spatial distribution of precipitation (the east region of province receives 27% of the total annual rainfall and west region receives 73% of the total rainfall). This situation exacerbates the problem of water crisis.

The adverse effects of drought are evident throughout the studied area. One of the consequences of the devastating drought of the past two decades is the challenge of water scarcity in the Gheshlagh watershed area. This study has been done in a watershed that is located in the eastern part of the Kurdistan province.

The climate of the area is semi-arid with low rainfall and low surface water, such that the uncontrolled exploitation of groundwater has caused a drop in the water level in the plains. The harmful effect of drought on vegetation is visible and is an important factor in increasing the number of forest and pasture fires.

(Ameri et al,2010) studied the drought phenomenon of Kerman province by using the percentage of precipitation over a 30-year period for total rain gauge stations. The results showed that the radial function interpolation method for mapping the intensity of the drought is more suitable than other interpolation methods.

(Moradiet al,2011) evaluated and predicted the severity, duration, frequency and extent of drought in Fars province, by using the standardized precipitation index (SPI) of 26 stations, over a period of 32 years (1968-1999). The results this study showed that the most severe drought occurred in the Gozun station and the longest drought happened in the Pole-Khan station. The results also showed greater sensitivity of the southern and central regions to the effects of drought. The results of the drought duration map in different periods of time showed that the drought in the southern province had more intensity and duration than other regions.

(Eyvaziand Mosaedi, 2011) used the standardized precipitation index over a period of 25 years and nine different courses (including eight monthly and one annual period) for monitoring and spatial analysis of meteorological drought in Golestan province.

These studies used the interpolation definitive methods (IDW, GPI, RBF) and geostatistical (kriging) method. Based on the results, the interpolation methods, kriging, and RBF at different periods showed better results for zoning of drought severity.

Materials and Methods

The Urmia lake basin is located in the northwest of Iran. On the north, it is limited to the basin of Aras River; on the east, it is limited to the Sefidrood river watershed; on the west, it is limited to the Zab watershed and the border between Iran and Turkey; and finally, on the south, it is limited to the Sirvan river basin. This basin has the longest border with the Aras river basin (410km) and the shortest border with Iraq (about 33km).

Until 2001, the hydraulic structures made for utilization of the water resources of the rivers leading to Urmia Lake were limited to the Bukan dam on the Zarinehroud, Mahabad dam and Hasanlu dam out of the Godarchay river, the Alavian dam on the Sufi Chayriver and finally, the Nahad dam on the Ajichai river.

The Urmia lake basin is considered to be a Grade 1 basin and has an area of approximately 51,876 square kilometres. The catchment area is located in the East Azerbaijan province, West Azerbaijan, and Kurdistan (Fig. 1).

In this study, the part of the Urmia lake basin located in the north-west of Kurdistan province was studied, with an area of 5320 square kilometres. In this area, 83% of Saqez city, 9% of Divandarreh city, 4% of Baneh city and 5.3% of Marivan city are located.

In total, 11.2% of the entire Urmia lake basin is located in the Kurdistan province. The climate of this region is semi-arid with low rainfall and the potential of surface water is poor, such that the uncontrolled exploitation of groundwater caused a drop in the water level in the plains of the province.

One of the problems that always exist in the analysis of regional statistics is the number of different statistical years for the stations that are mostly related to their founding year.

It is possible that the data of one station is related to a dry period and data of the other station related to a rainy period. Thus, it is necessary to select a common time base so that the wet and dry periods are factored in. Due to this, 30 years were selected as the common time base that is relatively suitable for the study and the analysis of rainfall data.

The analysis of drought for rain gauge stations was done by using the standardized precipitation index (SPI). The annual precipitation data was entered in the DIP software prepared by (Moradiet al,2011): the SPI values of the data were calculated.

Since the SPI point information in stations isn't enough for drought monitoring and spatial and regional developments, the interpolation methods are needed. The interpolation methods used in this research include inverse distance weighting (IDW) method and types of kriging models.

Semivariogram is the most basic tool in geostatistics to describe the spatial relationship of a variable. A semivariogram is a vector quantity that shows the spatial correlation and the similarity between the measured points in terms of square differences between two points due to their direction and distance.

By increasing the distance between the sample from which the following amounts of variable tahthave little effect at nearby points and by increasing the distance between adjacent points, the variogram doesn't change significantly.

Finally, using the best model, the mapping and statistical interpolation of droughts was done for all statistical years.

The kriging interpolation method is an accurate estimator that is used to obtain the best linear unbiased estimation. The best linear unbiased estimator must have the minimum variance of estimated error.

In this study, the evaluation of the methods and the selection of the best model were performed using the GS + software. Then, using the best model, zoning and drought interpolation was performed for all statistical years.

Results and Discussion

The number and severity of drought

Based on the results of the research, on a 12-month time scale, at all stations except Darreh Gavan, Qabaghlu, Khor-khoreh of Saqez, Mirdeh, Sooteh and Tilekouh, drought was very severe. According to the results, in 1988-1989, 1989-1990, 1990-1991, 1991-1992, 1998-1999, 1999-2000, 2008-2009, 2013-2014 water years, most of the stations saw the occurrence of moderate and severe drought.

The geostatistical results

To select the suitable interpolation method, choosing the best semi-variogram function to fit the data is necessary. It is noteworthy that in this study, four spherical, Gaussian, linear and exponential semivariograms have been used. The characteristicsof the geostatistical methods used are presented in Table 1. After selecting the desired semivariogram functions for each of the indicators, the suitable interpolation methods were selected and according to this, the zoning of drought was performed with the GS + and ArcGIS10.2 softwares.

The results of drought zoning in the study area

The best method of interpolation was determined by using the geostatistical methods and by using the ARCGIS10.2 software, drought zoning was done for each statistical year. Then, by comparing it with the values of the SPI table, drought and wet conditions of each year were determined. Then, the percentage of each part of the area that was under any particular drought conditions was identified. The results of the drought mapping over 30 years showed that 95% of the total area is under normal conditions.

The impact of drought on water resources

In this study, the water level dataderived from the hydrometric stations of study area was used to evaluate the effect of drought on the water resources. To determine the climatic elements and the fluctuations in the water levels of the piezometeric wells, regression and Pearson correlation coefficient was used.

The significance level in Saqez, Mirdeh and Qahr Abad is less than 0.05. So, there was a significant relationship between river flow and drought. The correlation coefficient in Saqez station is close to one. Thus, there is a significant and positive correlation between the periods of drought and the wet year with water resources (river discharge).

The results of drought zoning

As mentioned, one of the strategies for the study of drought and its devastating effects is the monitoring and mapping of drought severity using drought indices and interpolation methods, including the geostatistical approaches.

In this study, to estimate the severity of drought in the region for the statistical period, the intensity of the drought was calculated by using the SPI index for all stations.

The zoning maps indicated that from 1984 to 1987 were wet and normal years. Drought engulfed the entire region in 1988 and generally, 33 severe droughts have occurred since.

This situation continued until 1993; from 1994 to 1997, the extent of severe and average droughts reduced and the extent and severity of normal and near-normal droughts increased.

Since 1998- 1999 the droughts increased and between 2000 and 2007 the wet year risedand the situation is closer to normal conditions. The area faced the peak of the drought in 2008 and again between 2009 and 2012, the drought severity reduced sharply, with wet years and the condition was closer to normal.

The results of the last few months of 2013 statistics represent an increase of drought. The studies conducted showed that a higher percentage of statistical years experienced mild to moderate class of drought. Similar results were reported by (Yazdaniet al, 2006) and (ZareAbyanehet al, 2006).

The study of the dry periods by using the SPI index in the region showed that in recent years, while the continuity of droughts increased, the severity has reduced. (Ansari and Davari, 2007), who studied the droughts in the Khorasan province, and (Heidari and Yazdani, 2008) arrived at similar results. In general, we found a drought occurred every few years. Severe droughts occurred in the region in the years 1988, 1989, 1991, 1998, 1999, 2008, and 2013. According to the results, most of the droughts occurred in the Rahim Abad station with nine incidences of drought on the scale of 12 months.

The geostatistical results

After determining the severity of the droughts, according to the routing and the study of the semivariogram, the best model was fitted to the annual data of drought severity. Then, the SPI index was selected as the best method for interpolation of drought severity, which is the lowest error value and the amount of G% is positive. Among the interpolation methods, simple kriging, ordinary kriging, and inverse distance method have been used for the interpolation. The results showed that by using the SPI index, in most of the statistical years, the inverse distance method was preferred to the geostatistical methods (kriging).

The evaluation results of the different methods showed that, for the above index, the inverse distance method with the power of 2 has more accuracy and the least variance than others. As a result, the inverse distance method with the power of 2 is the most suitable interpolation method for mapping of drought in the studied region in all statistical years, with the exception of 1984, 1988, 1995, 1996, 1997, 2003, 2004, 2009, 2010, and 2011.

The priority of certain inverse distance in the interpolation of drought severity reflects the fact that this procedure can be a strong interpolation method. Also, (Mohammadi and Shamsipour, 2005), in the assessment of drought and its impact on the groundwater in Hamedan plain, found the IDW method with the least root of average error to the best interpolation method (among IDW, kriging and RBF) for the desired area. Also, the incompatibility of the results for the interpolation method for each of the statistical years is concluded by other studies, including (Moradiet al,2011).

Although the eastern region has less rain than the western region, the extent and severity of drought are more in the western region occasionally. This suggests that drought occurs in every region and climate, Therefore, by studying maps based on geostatistical methods in annual time period, a specific spatial pattern was not detected in the area.

(Rahdan, 2014), in a study entitled "Comparison of some zoning methods for the spatial analysis in Isfahan province" didn't recognize a clear pattern of spatial expansion for starting, developing and ending the drought in Isfahan province. Based on these results, more than one moisture condition has prevailed in the province.

The results of the impact of drought on water resources

Based on the results obtained from the SPI index, the study area has faced different drought and wet year periods with varying intensity over a period of 30 years; these changes have affected the water resources (discharge). During this period of 30 years, 23 years have been close to normal (neither wet and nor dry). Two years have been wet years, and five have been drought years. The periods of drought in the area are longer than the wet periods. This can indicate that the study area is located in a region with an arid climate.

One of the consequences of droughtis the impact on water resources. In this regard, by calculating the correlation coefficient between the river discharge and SPI, the impacts of drought on surface water resources were shown for each station. The results suggest that the droughts in the studied period had affected the water resources.

In the months with drought, the water level had been lower than the average and during the wet periods, the water level had been higher than the average. The results of the Pearson correlation between the droughts and the water stations showed a significance level (sig) less than 0.05. This means that in general, the wet conditions and the droughts affected the water resources (discharge), particularly in Saqez station over the 30-year period. The results of the relationship between the water level and the SPIin the long-term, shown with the correlation coefficient between the SPI and the water level, is consistent with the researches results of (Kanget al, 2009) which evaluated drought and its effects on water levels in the agricultural lands of Australia. The results are also consistent with the findings by (Caloieroet al, 2015) in the region of Calabria, and (MohammadiGhaleNaiet al, 2011) in the Saveh aquifer.

As drought is not the only cause of declining water levels in the studied area, there being other influencing factors, it is recommended that this huge and valuable water resource, Urmialake, be protected with proper plan and management. If the use of water resources in the study area is not limited and balanced, in the near future, water will be scarce in this region, which has a history of several thousand years of human settlement.

Following the occurrence of drought as an integral feature of the region and the increasing demand for water resources in the various fields of agriculture, industry and drinking simultaneously, combined with a steady decline in the water table, we should expect dire situations for water resources in the near future. The alternating periods of drought in the region, make it more and more clear that there is the necessity of strong leadership in water resources usage, especially during the drought periods.

In the study area, like many parts of the country, rainfall is less than the global average. The indiscriminate use of water resources causes quickly severe and quick imbalance. In this case, the recovery and return to normal conditions will be almost impossible.

It seems that the continuous monitoring of drought and strong monitoring of the water harvesting, especially during severe and prolonged droughts, is very necessary to prevent a sharp drop in the water level in the region. It can be done with optimizing water use in various sections, especially agriculture. Also, according to the snowy basin, studying the climatic conditions affecting snowmelt in the basin and providing a snowmelt-runoff model for a better understanding of the basin can be effective for the management of the existing water resources.

Regarding the surface supply of water, to reduce the pressure on the underground resources, using storage procedures via the construction of dams and water channels simultaneously can reduce the trend of declining groundwater levels. Watershed management and protection activities can increase the infiltration coefficient in the basin and consequently, will cause water resources, especially groundwater to recharge.

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Table 1. Semi-variogram models specifications and the fitted model on it in 30 statistical years

Suitable interpolation method based on the RMSE	RMSE	Proportion	Sill(co+c)	Naggest(co)	Model	Year
IDW	0.0519	0.79	0.1	0.02	Exponential	1983
Ordinary kriging	0.59	0.74	0.54	0.13	Spherical	1984
IDW	0.501	0.50	0.54	0.27	Gaussian	1985
IDW	0.68	0.52	0.9	0.4	Gaussian	1986
IDW	0.04	0.50	0.22	0.11	Gaussian	1987
Simple kriging	6.21	0.99	1.78	0.001	Spherical	1988
IDW	0.58	0.50	2.32	1.16	Gaussian	1989
IDW	0.56	0.50	1.73	0.83	Gaussian	1990
IDW	1.87	0.50	1.7	0.8	Gaussian	1991
IDW	0.08	0.50	0.38	0.19	Gaussian	1992
IDW	20.6	0.50	6.16	3.08	Gaussian	1993
IDW	0.18	0.50	0.64	0.23	Gaussian	1994
Ordinary kriging	0.93	0.15	0.24	0.018	Spherical	1995
Ordinary kriging	0.18	0.50	0.64	0.23	Exponential	1996
Simple kriging	2.24	0.73	1.33	0.02	Spherical	1997
IDW	0.421	0.98	0.64	0.02	Spherical	1998
IDW	0.567	0.50	.04	0.52	Gaussian	1999
IDW	0.056	.05	0.32	0.16	Gaussian	2000
IDW	0.078	0.50	0.44	0.22	Gaussian	2001
IDW	3.24	0.50	1.93	0.96	Gaussian	2002
Simple kriging	0.15	0.50	0.63	0.12	Spherical	2003
Simple kriging	0.126	0.38	0.58	0.28	Spherical	2004
IDW	0.08	0.63	0.25	0.09	Spherical	2005
IDW	2.40	0.50	1.66	0.83	Gaussian	2006
Simple kriging	1.64	0.501	0.49	0.23	Gaussian	2007
IDW	0.96	0.50	1.49	0.74	Gaussian	2008
Simple kriging	0.26	0.72	0.58	0.16	Spherical	2009

IDW	0.10	0.81	0.74	0.13	Exponential	2010
Simple kriging	0.106	0.64	0.32	0.12	Spherical	2011
Simple kriging	0.25	0.67	0.45	0.14	Spherical	2012
IDW	0.233	0.501	0.67	0.33	Gaussian	2013

Table 2. percent of the overall drought

Row	**Drought/ wet year**	**Area (in square meters)**	**The area than the total (%)**
1	Severe drought	93212970	1
2	Moderate drought	21284620	2
3	Normal	4659864570	95
4	The average wet year	94411700	2

Table 3. The results of Pearson correlation and linear regression between droughts and piezometer wells water level

Qahr Abad		Mirdeh		Saqez		Alton	
Correlation coefficient	significant factor	Correlation coefficient	significant factor	Correlation coefficient	significant factor	Correlation coefficient	significant factor
0.492	0.02	0.532	0.04	0.968	0.000	0.154	0.1

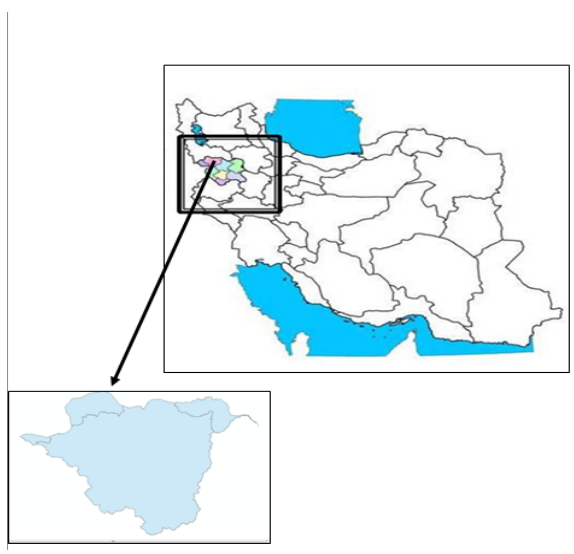

Fig. 1. Location of studied area in the country

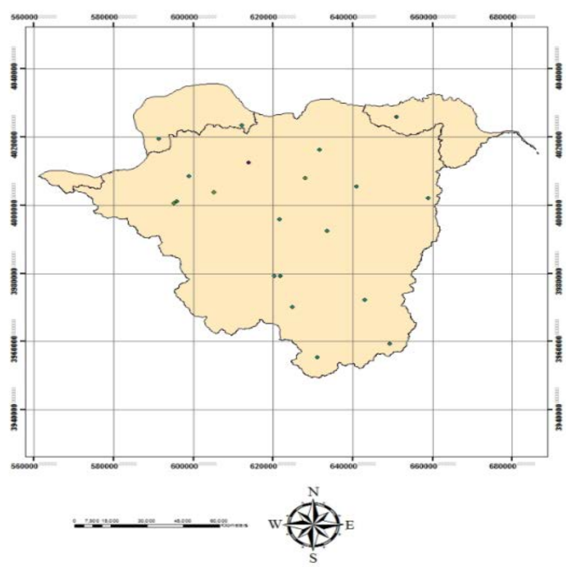

Fig 2. Map of the study area stations

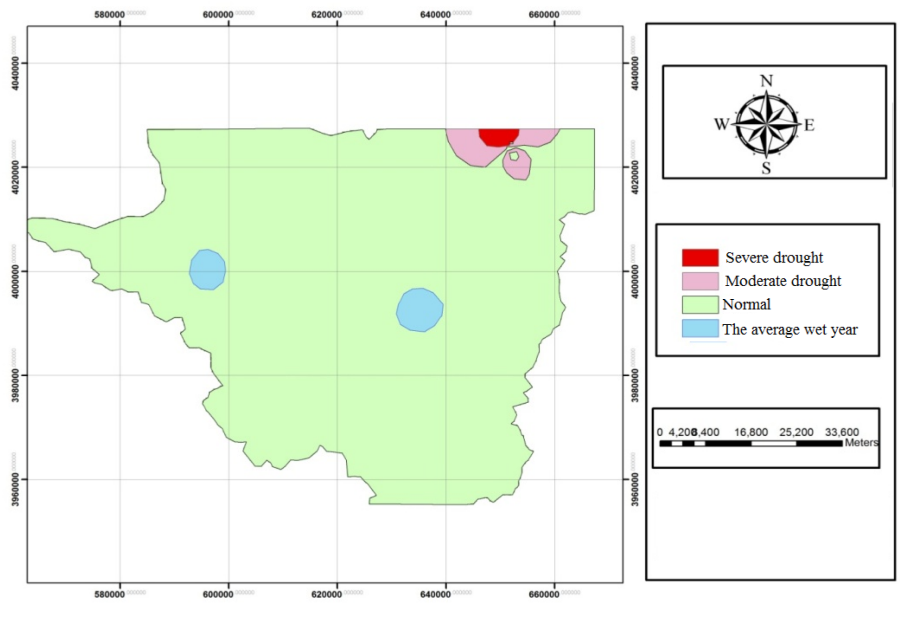

Fig 3. General zoning of drought in the study area