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Spatial and Temporal Analyses of Monthly Stream Flow Deficit Intensity in Gorganroud Watershed, Iran

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ABSTRACT: Drought is a complex natural phenomenon that can occur in any climate. Hydrologic drought in the river flow of arid and semi-arid areas causes serious shortages, threatens the quality of life, and impacts on the economy. Understanding this feature is then essential for the management of water resources. Hydrologic drought in the sense of deficient river flow is defined as the periods that river flow does not meet the needs of planned programs for system management. In the present study, changes in the monthly discharge of 14 hydrometric stations throughout the Gorganroud watershed over 30-year period (1980-2010) were studied. Then the deficit flow was determined based on threshold level method, and the results were analyzed. It was revealed that periods of severe shortages have happened in the very humid and semi-arid climates and the downstream of the study area, while longer periods (28 months) of low flows have occurred in the arid climate. The trend of severity and persistence in the central stations of the watershed was increasing. Also shortages occurred with greater frequency at the end of the study period, and river flow shortage during the years 1998-99, 2007-2008, 2008-2009 and 2009-2010 has occurred in most of the stations. So in these years, flow deficit has happened in 50, 85.9, 64.3 and 92.8 %of the stations, respectively.

Keywords: *Flow deficit, Threshold level, Trend, Zonation, Gorganroud*

1 INTRODUCTION

Hydrological drought is accompanied by the effect of periods of atmospheric fall deficiency on water resources supplying surface water or groundwater (discharge of rivers, reservoirs, lakes and groundwater) that affect water resources' systems, as well as water resources in addition to water reservoirs (Smith et al., 1992).Various indices have been presented for hydrological drought including Palmer Hydrological Drought Index (PHDI), Surface Water Supply Index (HWSI), and assessment of continuous periods in which river discharge is lower than the threshold level. In analyzing hydrological drought, the most appropriate method is threshold level method (Bayazidi and Saghafian, 2010). Threshold level is determined based on objectives and minimum flow indices.

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Studies in hydrologic drought on stream flow deficit include studies that assess flow for a season or in longer periods (Hisdal *et al.,* 2000). Kjeldsen *et al.*(2000) suggested hydrological droughts using threshold level in 10 Zimbabwean Rivers where the best distribution for analyzing continuity partial series and drought deficit volume is double exponential distribution. Zaidman *et al.*(2002) assessed the spatial and temporal development for a period of 40 years in Europe. Their results showed that the most intense and the longest droughts have occurred in South England and North France, respectively.Fleig *et al.* (2006) assessed hydrological drought globally. In this investigation, threshold level approach was used to extract drought characteristics. The results showed that the winter and summer droughts have to be analyzed separately. As the water remains for shorter time in the upper reaches of unregulated drivers than in the middle or lower reaches, drought intensity often varies with topographic location and time in the basin (Pandey *et al.,* 2008). Drought characteristics analysis in Awash River watershed (Ethiopia) hasbeen done previously by Edossa *et al.*(2010). They found that the most severe drought events occurred in the watershed in 1988 (May-June) and in 1998 (April-May). Use of threshold level approach has increased in recent years (Lorenzo-Lacruz *et al.,* 2012; Tokarczyk, 2013; Tomaszewski, 2011). Tomaszewski (2011) used 70% discharge (Q_{70}) in order to determine streamflow deficit periods and estimate streamflow deficit in Warta watershed based on threshold level. The results showed that the number of dry days per year during the study period follows an increasing trend. Lorenzo-Lacruz *et al.* (2012) analyzed the spatial and temporal variability of hydrological drought in the Iberian Peninsula, Spain, in the period 1945-2005. The results revealed that in most of the areas, the drought intensity had an increasing trend. Tokarczyk (2013) through classification of minimum flows and hydrological drought for NysaKłodzka river watershed in Poland,found that during the studied period, no intense drought has occurred. Several studies have assessed hydrological and meteorological droughts in Iran, for instance, Shahrokhvandi *et al.* (2009) in Khorram-Abad River watershed; Yazdaniand Ansari (2009) in Hamedan Province;Bayazidi and Saghafian (2010) the hydrometric station of Pole-Shalu, Kazeroun County watershed; and Malekinejad and Soleimanimotlagh (2011) in Chaghalvandy watershed, Lorestan Province. Geostatistical methods (Kriging, Co-Krigingand Inverse Distance Weighted (IDW)) have been used to meteorological drought zoning (Raiesi and Vafakhah, 2011), and it has been suggested that the Kriging method had the higher precision compared to the two other methods in zoning this type of drought.

It is now recognized that river low flows can lead to severe consequences in water quality and river ecological status (Whitehead et al., 2009).Navigation and power supply sectors can also be affected by low flows(Middelkoop *etal.,* 2001). In addition, during the streamflow deficit periods, particularly when there is no balance between supply and demand, the pressure on the river increases (Hebert *et al.,* 2003). Streamflow deficit condition is mainly influenced by regional climate, geology, soil, topography, vegetation, lakes, and marshes (Burn *et al.,* 2008; Smakhtin, 2001). Human activities such as irrigation and water harvesting can also affect the streamflow deficit (Hisdal *et al.,* 2001). All of these factors and conditions must be considered in the planning, design, construction, repairing and maintenance of different hydraulic structures and water resource systems. Also river flow deficit can also affect aquatic habitat by reducing the oxygen-carrying capacity, warming the water, and causing toxicity (Nemerow, 1991). All climatic zones of the world are at risk of drought. Thus this phenomenon may occur in any climate region. In this regard, applying adjustment programs, and relieving and compensation of damages are of high importance in sustainable agriculture as they can reduce greatly intense subsequent economic and social damages. Due to the limited water resources, management strategy is very important to enhance water use efficiency. 67% of the surface water resources of Golestan Province (about 828 million cubic meters) flow in the watershed, thus evaluating and predicting river outcome could determine the type of product, the cultivated area, and ultimately, reduce probable damage caused by drought or optimal use of wet condition. The present study is an attempt to recognize hydrological drought conditions in the Gorganroud watershed, and detect the presence or absence of streamflow deficiencies. It, finally, presents zoning of deficit volume in the watershed scale.

2 MATERIALS AND METHODS

2.1 Study area

Being located at 56º 28´-54º 00´ E and 36º 35´-37º 48´ N, the investigated watershed represents diverse climatic conditions because of proximity to the northern slopes of the eastern Alborz mountain range in the having west rainy fronts, humidity from the Caspian Sea and effects of temperature variations imposed by Turkmenistan Desert. Rainfall increases from the north to south and from the east to west of the watershed area. Average rainfall varies greatly in different parts of the watershed, ranging from 202 mm in Pas-Poshteh to 903 mm in Rabat Qareh-Bil. Similarly, the annual temperature is highly variable in different parts of the watershed ranging from 0 °C in the Alborz heights to more than 17.5 ° C in the northeast part of the watershed. Stratigraphy of the region is classified to Paleozoic formations and units, Mesozoic formations, and Cenozoic formations. Cenozoic units are much expanded in the studied watershed comprising quaternary deposits. Comprising about 48% of Golestan Province area, the Gorganroud watershed has 17 main branches. Gorganroud River is one of the most important rivers in northeast of Iran, which originates from Aladagh mountain ranges in Bojnourd County and reaches the sea near Torkaman port (southeast part of the Caspian Sea). In this investigation, 14 gauging stations in the Gorganroud watershed with a common base statistic of 30 years (1980-2010) were selected. Characteristics of the selected stations and their location map are given in Table 1 and Figure 1.The climate of the region was specified through Domarten method.

2.2 Data quality control

Needed data including the discharge data of all gauging stations of the Gorganroud watershed were collected from Iran Water Resources Management Company (IWRMC). Based on the statistics obtained from IWRMC, there are 78 hydrometric stations at the study area. Of these, 14 stations with a common period of 30-years statistics were selected. The statistics of all stations were confirmed by applying various methods such as simultaneously theoretical comparison of different stations' statistics, controlling extreme values (very high or very low), and controlling the missing data. Then the existing statistics were evaluated for homogeneity.

Table 1: Characteristics of hydrometric stations used in this study

Code	Station	Latitude	Longitude	Elevation(m)	Climate	Land use
12-001	Tangrah	55º 16´	37º 59´	330	Humid	Forest-Rangeland
12-005	Tamar	55º 29´	37º 28´	132	Semi-humid	Rangeland
12-007	Galikesh	55º 27´	37º 15´	250	Semi-humid	Forest- Dry farming
12-013	Lazoreh	55º 23´	37º 13´	190	Humid	Forest- Dry farming
12-017	Nodeh	55º 16´	37º 03´	280	Humid	Forest- Rangeland
12-019	Araz-Kuse	55º 08´	37º 13´	35	Semi-humid	Irrigated farming
12-021	Ramian	55º 08´	37º 01´	200	Humid	Forest
12-031	Bagheh-Salian	54º 45´	36º 54´	20	Humid	Forest
12-033	Taghi-Abad	54º 38´	36º 52´	100	Very humid	Forest
12-037	Agh-Ghala	54º 27´	37º 01´	-12	Semi-arid	Dry and Irrigated farming
12-039	Basir-Abad	54º 10´	37º 01´	-21	Semi-arid	Dry and Irrigated farming
12-063	Haji-Ghoshan	55º 21´	37º 24´	45	Semi humid	Dry farming- Rangeland
12-071	Zaringol	54º 57´	36º 52´	280	Humid	Forest
12-083	Sarmo	54º 49´	36º 49´	500	Humid	Forest

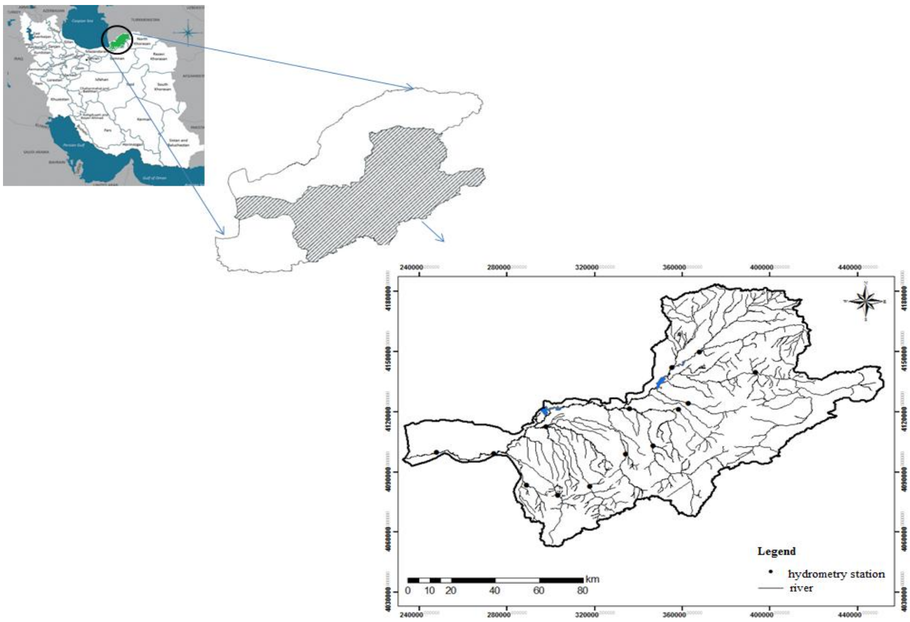

Figure 1: Geographical location of the Gorganroud watershed in the study area

In this research, the run test was applied to assess the homogeneity of discharge data. In this test, the existing statistics were sorted and their median was determined. Then each of the values was compared to median value, and number of values higher/lower than median and number of runs were determined. The optimum limit of sum of the number of sequences could be obtained using standard tables at different probability levels. Also homogeneous data series could be determined based on the number of observations and sum of sequences.

2.3 Using threshold level method to estimate streamflow deficit

Among the most common methods for analysis of streamflow deficit is runs theory used by Yevjevich et al. (1967). In this method, a discharge value (Q) is selected as the threshold level so hydrological drought occurs when the discharge is lower than the selected threshold. Streamflow deficit starts when the discharge falls below the threshold value, and continues until it reaches above the threshold. In this method, each streamflow deficit period is characterized by the volume, duration and intensity of deficiency. Deficit intensity and volume are among the most common drought features that have been addressed in most of the studies on streamflow deficiency(Fleig *et al.*, 2006; Hisdal *et al.*, 2004). The mentioned threshold may be constant or variable (monthly, seasonal or yearly) (Fleig *et al.*, 2006; Gustard and Demuth, 2008).In the present study, the threshold level was considered to be fixed, and 30-year median of discharge in each station was regarded as the threshold level. In each station, the median was calculated, and discharge deficit value was determined by subtracting the median from the observed discharge in each month;then this value was converted into volume deficit according to the number of days in each month. In order to determine the continuity of each period, the number of consecutive months with discharge lower than threshold value was determined as the continuing streamflow deficit in that period. Drought intensity (severity) in each period for all studied stations was extracted when the deficit volume was divided by the continuity.

2.4 Preparing Severity-Duration–Frequency (SDF) curves

Using median index and after extracting droughts with duration di, n-months droughts were extracted from complete series of droughts. Then appropriate distribution was selected based on Kolmogorov-Smirnov test, and the continuity value (n) was considered to be 1, 2, 3, 4, 5, 6, 7 and 9 months. Kolmogorov-Smirnov test is used to assess whether distribution of a sample follows a specific distribution. Kolmogorov-Smirnov test is applied when the number of samples is not large enough (Mosaedi *et al.*, 2009). To determine the best distribution function, statistical distributions including two-parametric Gamma, Weibull, two-parametric log-normal distribution, Johnson, dual exponential and Generalized Pareto(GP) distributions were used(Zelenhasić and Salvai, 1987). It is worth noting that no statistical distribution can have a good fit completely on the observed data, and selecting an optimal distribution is done according to comparison of the results of goodness of fit test distribution.

2.5 Mann–Kendall test

This test, which was first presented by Mann (1945)and then developed by Kendall (1948), is one of the most common non-parametric methods of time series trend analysis. This method is recommended for two reasons: 1) it is applicable for non-normal, incomplete and seasonal data, and 2) it has the greatest inherent ability to analyze data(Xu et al., 2010). Also the test is more appropriate to determine the hydrologic time series trend compared to other tests (McBean and Motiee, 2006). The Mann-Kendall (MK) test was used to detect a significant trend in streamflow deficit intensity and duration.

3 RESULTS AND DISCUSSION

3.1 Results of applying threshold level and determining dry periods

After conducting quality control for time series, the curve of discharge variations against time was depicted for all hydrological stations. By conducting the required assessments, the median threshold level was considered as the basis for extracting the stream flow deficit

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periods. The threshold level for different stations is shown in Table 2.The highest (5.776 m^3s^{-1}) and lowest (0.172 m^3s^{-1}) median values were belonged to Agh-Ghala and Taghi-Abad stations, respectively. Averages of continuity of stream flow deficit calculated for different stations are also given in Table 2.Accordingly, maximum continuity (5.29 months in each deficit period) belonged to Galikesh station while minimum continuity (3.4 months in each deficit period) was in Taghi-Abad station. The streamflow deficit values in different regional stations varied from 178 months in Tangrah station to 189 months in Ramian station but the average for the whole watershed was 180.6 months. The number of streamflow deficit events occurred in the watershed was 43 events in average with the highest number (53) and the lowest (34) for Taghi-Abad and Galikesh stations, respectively. At all stations, the maximum continuity of the stream flow deficit periods occurred in 2009-2010 and 2010-2011 years. The highest continuity of stream flow deficit (28 months) belonged to Agh-Ghala and Basir-Abad stations that occurred during the last years of the period.

Table 2: Stream flow deficit properties in the study area

Station	Median (CMS)	Number of events	Total duration (month)	Mean duration (month)	Maximum deficit (m^3/month)	Maximum duration (month)
Tangrah	0.567	42	178	4.24	**1395**	**5**
Tamar	1.127	49	180	4.09	**2728**	**1**
Galikesh	1.806	34	180	5.29	**3188**	**5**
Lazoreh	1.373	40	179	4.48	**2810**	**5**
Nodeh	1.841	45	180	4	**3281**	**2**
Araz-Kuse	3.156	38	181	4.79	**7412**	**2**
Ramian	0.478	48	189	3.73	**1102**	**6**
Bagheh-Salian	1.248	41	180	4.39	**3222**	**1**
Taghi-Abad	0.172	53	180	3.40	**444**	**1**
Agh-Ghala	5.776	39	180	4.62	**15064**	**4**
Basir-Abad	5.741	39	180	4.62	**15187**	**9**
Haji-Ghoshan	1.198	50	180	3.6	**3015**	**5**
Zaringol	1.314	44	180	4.09	**2282**	**6**
Sarmo	0.812	43	181	4.53	**2173**	**9**

Various factors have been studied in assessing stream flow deficit conditions. Smakhtin (2001) considered the geology among the most important natural factors affecting the stream flow deficit phenomenon. In fact, in stream flow deficit conditions, the base flow is one of the most important components, which is dependent on the geology of the region, and particularly on the permeability of underlying layers. Permeability of underlying layers is another factor that contributes to recharge the ground water, and in periods without rainfall, it provides river discharge. Much of the rainfall in the watershed occurs in December to April. Therefore, soil permeability can play an important role in providing base flow in months without rainfall; it can further increase the groundwater resources and provide river discharge in months without rainfall. The results of this study showed that in stations located at areas with forest or rangeland land use, the average continuity of stream flow deficit has been lower. Dense root systems in rangelands cause penetration of more water into the soil, and also tree roots improve water infiltration routes in the soil; for this reason, the

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base flows in the river even in periods without rainfall. In forest land uses, the root system, organic matter and litter increase water penetration and water holding capacity of the soil. So in forest land uses, surface runoff is lower, runoff time is longer, and continuity of stream flow deficit is lower as compared to other land uses (Chang, 2012). The obtained results correspond to the results of Grandry et al. (2013) in Wallonia watershed, Belgium.

The highest number of months with stream flow deficit in October occurred in Tangrah station (28 months), in November occurred in Galikesh and Zaringol stations (24 months), in December occurred in Galikesh and Zaringol stations (24 months), in January occurred in Zaringol station (23 months), in February occurred in Zaringol and Tangrah stations (15 months), in March occurred in Basir-Abad station (12 months), in April occurred in Basir-Abad and Agh-Ghala stations (9 months),in May occurred in Agh-Ghala station (13 months), in June occurred in Nodeh station (25 months), in July occurred in Nodeh, Araz-Kuseh and Agh-Ghala stations (29 months), in August occurred in Basir-Abad station (28 months), and in September occurred in Araz-Kuseh station (28 months).

3.2 Results of Severity-Duration–Frequency (SDF) curves

The appropriate distribution that best fits to the different continuities at each station was determined. To do this, six distributions including Gamma, Weibull, log Normal, Johnson, double exponential and GP were fitted on the stream flow deficit intensity time series data of 1, 2, 3, 4, 5, 6, 7 and 9 months in the selected stations. Kolmogorov–Smirnov test was used to determine the best distribution. The results of frequency analysis showed that in water deficit intensity, the Weibull distribution had the highest correspondence. This result is consistent with those of Bashirzadeh *et al.* (2011) in Lorestan Province, Kaznowska *et al.* (2011) andShahrokhvandi*et al.* (2010); however, it is different from the findings of Fleig *et al.* (2006) Kjeldsen *et al.* (2000) Tokarczyk *et al.* (2005) and Grandry (2013). Tokarczyk *et al.* (2005) showed that log-normal and GP distributions had the best fitness on the stream flow deficit data of Orda watershed, Poland. Also Fleig *et al.* (2006) found that log-normal and GP distributions are the best fitted ones to the stream flow deficit data in Linderborg River, Denmark.

According to the selected statistical distributions of the stations, SDF curves were depicted for different stations. It is to be noted that due to the small number of low deficit events, estimation of events with high return periods (100 and 500) is accompanied with some uncertainties. The reason is that in spite of the long statistical periods of 30 years, what the theory predicts does not take place in reality due to the low number of observations. In Sarmo and Galikesh stations, SDF curve was not depicted because of the low number of stream flow deficit events with marked continuities. So, eventually, SDF curves were depicted for 12 selected stations in the studied watershed that are shown typically for Tangrah station in Figure 2. In all the studied stations, SDF curves follow an increasing trend. In Basir-Abad, Agh-Ghala and Zaringol stations and in low continuities, the stream flow deficit volume was low but, in high continuities, it followed an exponential trend. In the studied hydrometric stations and in low continuities, the stream flow deficit volume was higher, and the volume increasing slope decreased with increasing continuity.

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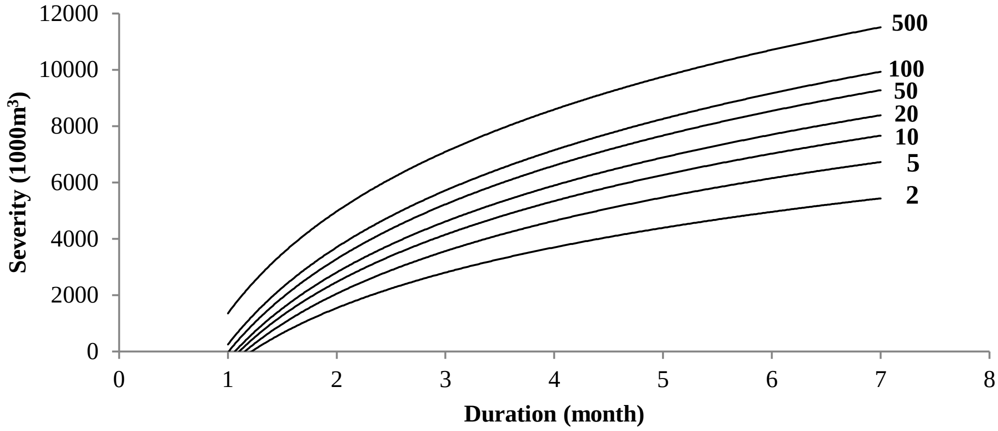

Figure 2: SDF curves for Tangrah station

3.3 Results of Mann-Kendall test

Mann-Kendal test on data shows that the in most of the studied stations, the stream flow deficit intensity does not follow a significant increasing or decreasing trend; only in Nodeh, Ramian, Zaringoil, and Sarmo stations, there was a significant increasing trend at 95% confidence level (Table 3). In the mentioned stations, stream flow deficit intensity has increased sharply in recent years. Also only in Lazoreh, Nodeh, Ramian, and Sarmo Mohamadabad stations, stream flow deficit continuity had an increasing trend; in recent years, this increase has been remarkable. Figure 3 shows the temporal variability of stream flow deficit intensity for the four selected stations as samples. These stations are located at different parts of the study area.

Table 3: Results of Mann-Kendall test on the intensity and continuity of stream flow deficit data

Station	Severity		Duration	
	Significant level	Sen's slope	Significant level	Sen's slope
Tangrah	0.13	42.82	0.80	0
Tamar	0.89	7.71	0.70	0
Galikesh	0.18	144.74	0.86	0
Lazoreh	0.07	214.78	0.02	0.09
Nodeh	0.05	154.78	0.02	0.07
Araz-Kuse	0.65	128.14	0.29	0
Ramian	0.00	86.1	0.01	0.07
Bagheh-Salian	0.24	78.97	0.90	0
Taghi-Abad	0.09	10.73	0.26	0
Agh-Ghala	0.5	295.68	0.93	0
Basir-Abad	0.57	387.03	0.76	0
Haji-Ghoshan	0.38	40.91	0.73	0
Zaringol	0.00	143.71	0.09	0.05
Sarmo	0.00	182.20	0.00	0.13

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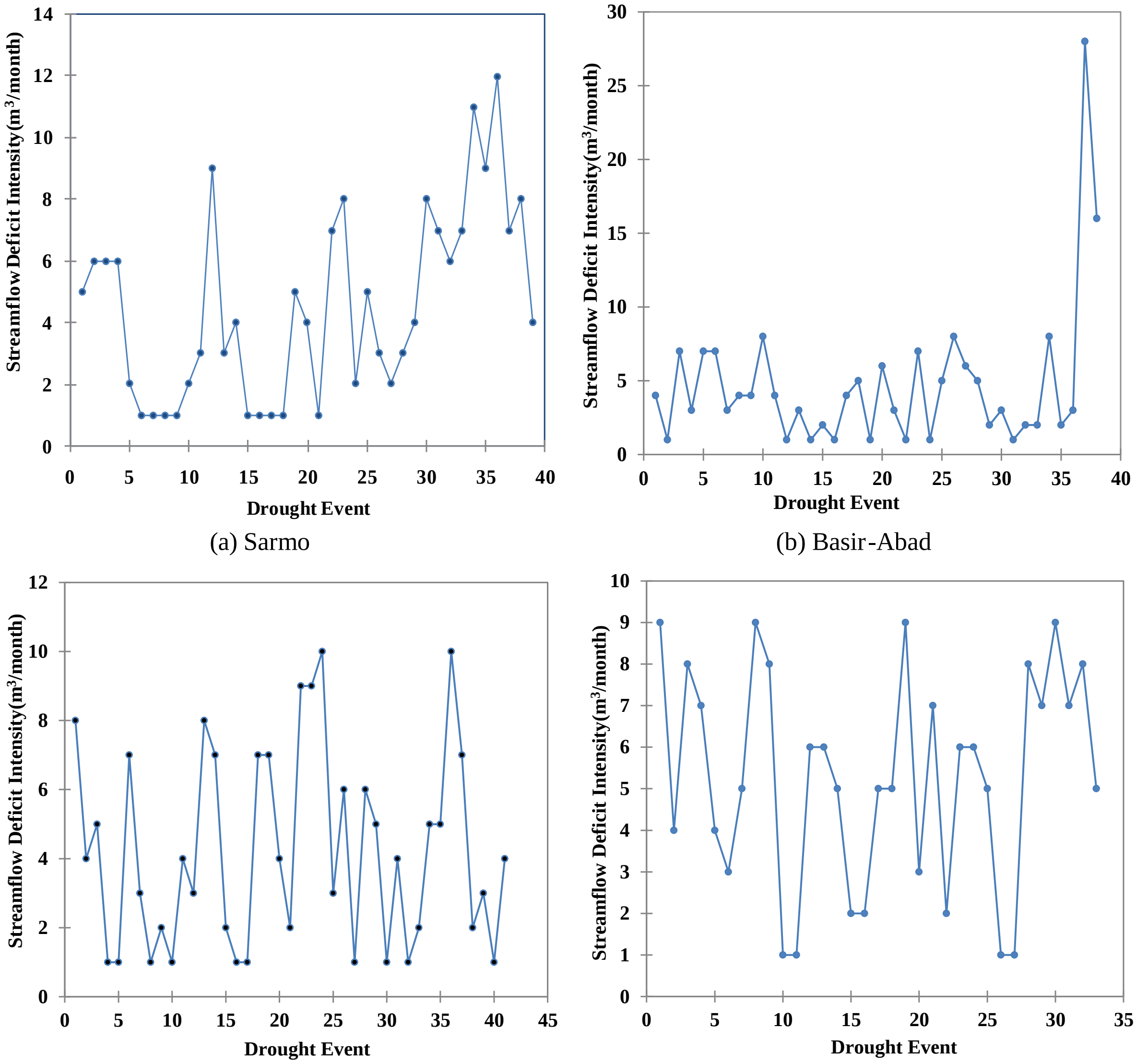

(a) Sarmo (b) Basir-Abad

(c) Galikesh (d) Tangrah

Figure 3: Temporal variability of stream flow deficit intensity for the four selected stations (1980-2010).

3.4 Results of stream flow deficit volume zonation

Years with stream flow deficit in the Gorganroud watershed are not similar in different stations. Therefore, it is necessary to identify dry years in each station. After plotting monthly discharge variations against time and depicting curves, the times with stream flow deficit were determined. Years with stream flow deficit were more frequent at the end of the period so that in most stations, the stream flow deficit occurred in the years 1998-1999, 2007-2008, 2008-2009, and 2011-2012, and 50%, 85.9%, 64.3% and 92.8% of the stations were faced to stream flow deficit, respectively. Thus, these years were selected for zoning. Also the average of stream flow deficit volume events occurred in 30-years period was assessed, and thereby zoning of stream flow deficit volume was carried out. Kolmogorov-Smirnov test was used to assess the data normality. The results showed that the data were not normally distributed. In order to normalize the data, Johnson transformation software was then used. Zonation maps of the stream flow deficit in the Gorganroud watershed are presented in Figures 4 to 8. These maps are zoned based on a percentage of median in which the river had flowed in the related year or period.

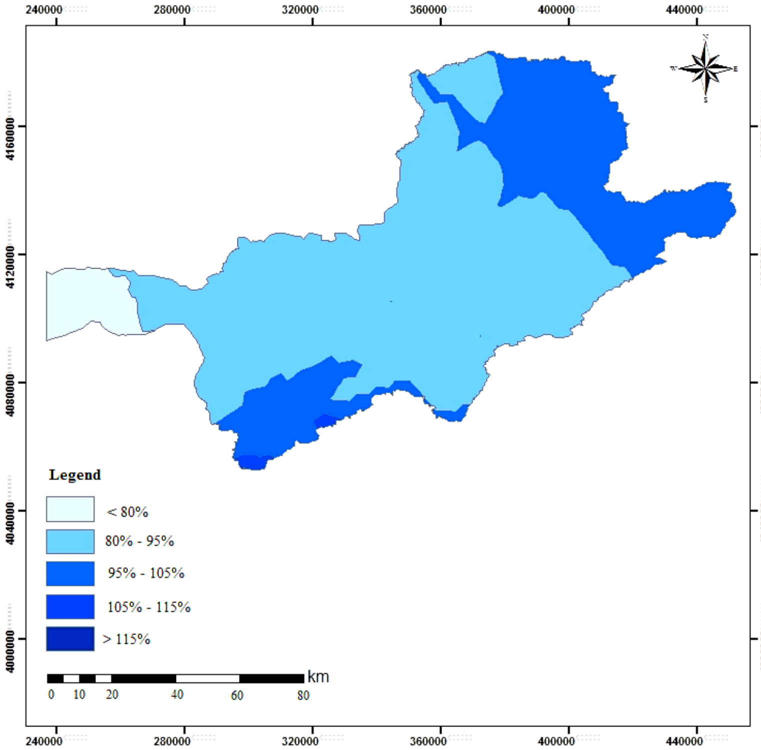

Figure 4: Map of the spatial distribution pattern of stream flow deficit volume in 1998-1999.

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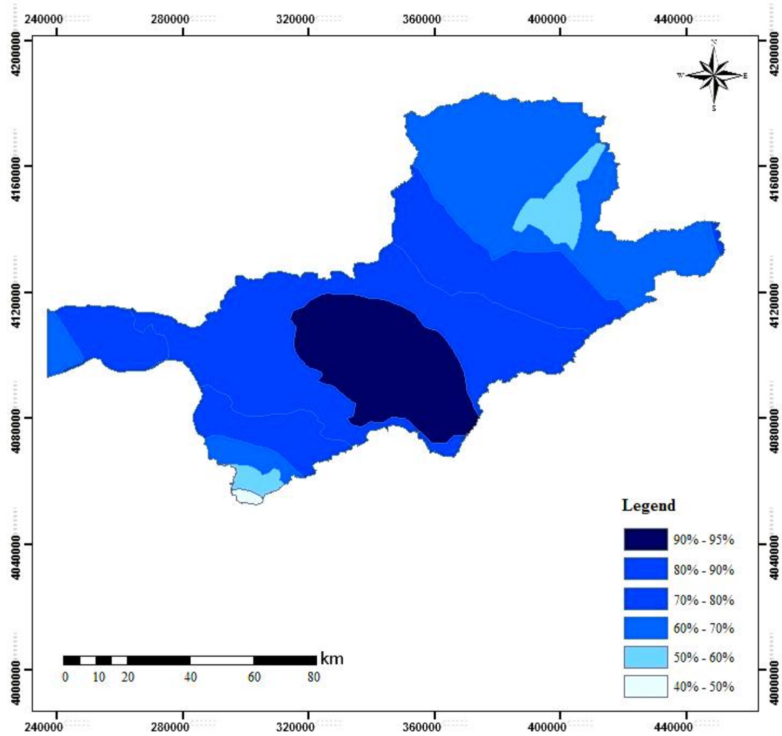

Figure 5 Map of spatial distribution pattern of stream flow deficit volume in 2007-2008

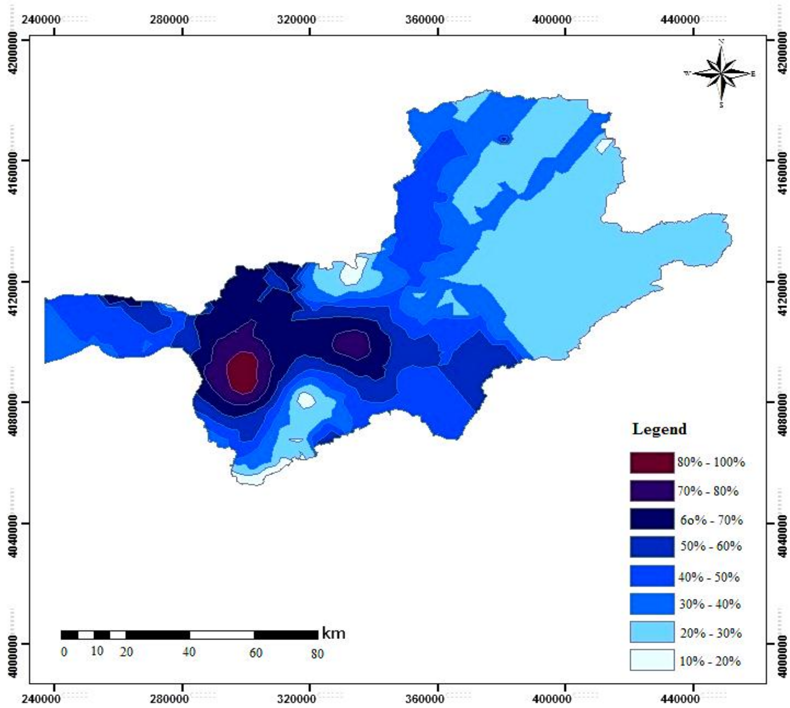

Figure 6: Map of the spatial distribution pattern of stream flow deficit volume in 2008-2009.

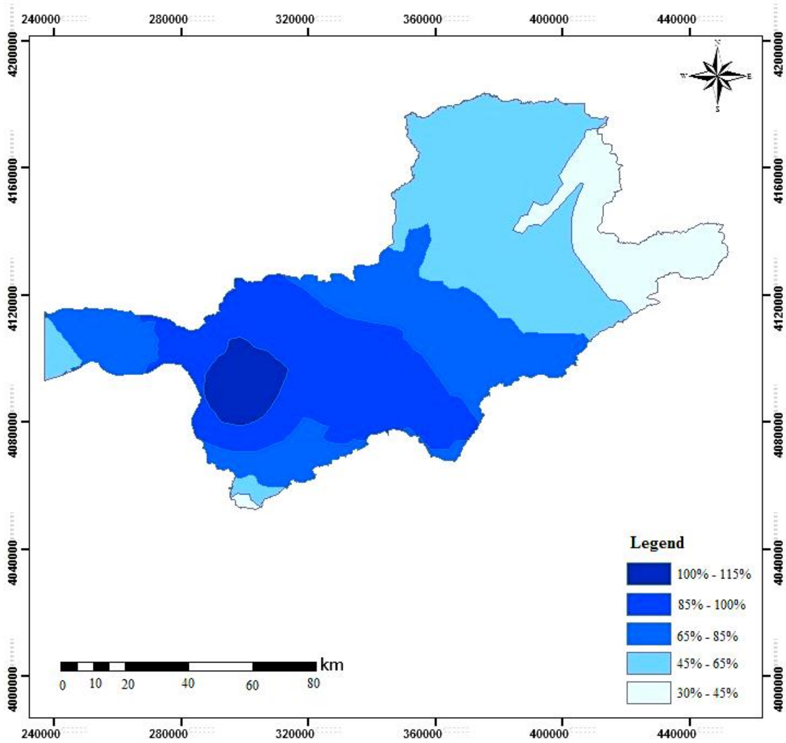

Figure 7: Map of the spatial distribution pattern of stream flow deficit volume in 2011-2012.

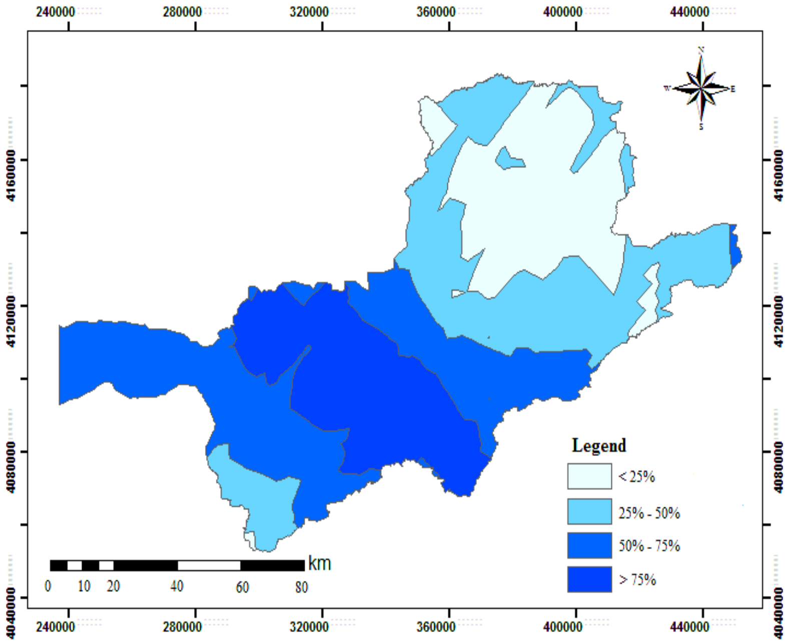

Figure 8: Map of the spatial distribution pattern of stream flow deficit volume in a 30-years period.

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According to the results, Basir-Abad station in 1998-1999, 2008-2009 and 2001-2012 and 2007-2008 years and Bagheh-Salian station in 2007-2008 year had the highest stream flow deficit volume. In order to avoid interpolation problems in the boundary of watershed, 8 stations outside the boundary line of the watershed were added to the studied stations (Hisdal *et al.*, 2003). Comparison ofthe maps of the spatial distribution pattern revealed that the spatial distribution patterns of stream flow deficit volume in 2008-2009 and 2011-2012 have some similarities. Zoning map of the average of 30-years stream flow deficit volume (Figure 8) shows that the stream flow deficit volume increases from the center of the Gorganroud watershed to the marginal areas. This result is different from that of Bazrafshan et al. (2011) who found that this type of drought across Golestan Province decreases from the west to the east. This can be explained by human activities, such as exploitation from the rivers.

3.5 Results of statistical analysis

In order to compare the mean intensity and continuity of stream flow deficit in different climates, stations and places, and to assess the presence or absence of significant differences between them, nested or sequential statistical test were used. Based on this test, averages of stream flow deficit intensity in different climates and places (upstream and downstream) were significantly different but there was no significant difference in each region when comparing the different stations. Also the comparison between the continuity averages of stream flow deficit in the Gorganroud watershed climates, as well as the stations of each climate and each place showed no significant differences.

After confirming significant differences between the mean intensity of stream flow deficit in different climates and places, Duncan’s test was used to find out the state of differences (Tables 4 and 5). Based on the test results, in very humid and semi-arid climates, stream flow deficit intensity is higher than in humid climate; however, there was no significant difference between semi-humid and other climates in this regard. On the other hand, stream flow deficit intensity in the downstream of the study area is higher than in the upstream. This can be explained by human activities, such as exploitation from the rivers.

Table 4: Statistical results of comparison of stream flow deficit intensity and continuity in different climates and places

Climate	**Average of severity (1000 m^3/month)**	**Average of duration (month)**
Very humid	1.753±0.21 [a]	3.39±0.88 [a]
Humid	1.479±0.42 [b]	4.19±0.36 [a]
Semi-humid	1.58±0.351 [ab]	4.22±0.48 [a]
Semi-arid	1.685±0.41 [a]	4.62±0.72 [a]

Table 5: Statistical results of comparison of stream flow deficit intensity and continuity in different places

Place	**Average of severity (1000 m^3/month)**	**Average of duration (month)**
Upstream	1.539±0.04 [a]	4.11±0.28 [a]
Downstream	1.685±0.08 [b]	4.61±0.72 [a]

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Overall, during the investigated period, stream flow deficit has occurred throughout the watershed, and in each year, stream flow deficit has been observed at least for one period. This result is consistent with that of Mosaedi *et al.* (2009) who suggested that no region in Golestan Province has been free of drought. Stream flow deficit in the semi-humid and semi-arid areas of the watershed is more than in other regions. In other words, different parts of the watershed have a different susceptibility to stream flow deficit that is consistent with the findings of Eslamian *et al.* (2012) who studied hydrologic drought in the Karkheh watershed.

4 CONCLUSIONS

This study was carried out to analyze the monthly river stream flow deficit in the Gorganroud watershed. After identification of 78 hydrometric stations, 14 stations were selected and after confirming homogeneity and validity of the data, statistical errors were reconstructed. The monthly discharge variation curves against time were depicted for all the selected stations. The index of threshold level was used to determine dry periods. According to the present statistics and statistical period, median discharge of 30 years at each station was selected as threshold level. The results showed that the number of periods with stream flow deficit varies at different stations, and Taghi-Abad and Galikesh stations with 53 and 34 stream flow deficit periods had the highest and the lowest stream flow deficit events, respectively. The highest continuity of the stream flow deficit period belonged to Agh-Ghala and Basir-Abad stations with 28 months continuity. The stream flow deficit volume data in this watershed at most of the stations follow the Weibull distribution. Intensity and continuity trend of the stream flow deficit were assessed in all stations. It was revealed that stream flow deficit continuity was increasing only in Lazoreh, Nodeh Khormalou, Ramian, and Samo stations, and there was no significant trend for the other stations. Similarly, stream flow deficit continuity was increasing only in Nodeh, Ramian, Zaringol and Samo stations, and there was no significant trend for the other stations. Zonation of the stream flow deficit volume in the Gorganroud watershed was carried out using Kriging method as well as the statistics of 22 hydrometric stations within and outside of the watershed. The results of zoning the stream flow deficit volume indicated that stream flow deficit volume is lower in humid and very humid climates compared to semi-humid and semi-arid climates. Statistical analysis of the stream flow deficit intensity data in different climates and different climates of the watershed indicated that there were no significant differences between different climates in terms of stream flow deficit continuity. However, semi-arid and very humid climates had the higher stream flow deficit intensity as compared to semi-humid climate, while there was no significant difference between humid climate and other climates.

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تجزیه و تحلیل شدت کمبود ماهانه جریان رودخانه‌ای در حوزه‌ی آبخیز گرگانرود

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چکیدهخشک‌سالی پدیده طبیعی پیچیده‌ای است که در هر اقلیمی می‌تواند به وقوع بپیوندد. در مناطق خشک و نیمه‌خشک خشک‌سالی هیدرولوژیک در قالب کمبود جریان رودخانه‌ای باعث خطرات جدی زیست‌محیطی، افت کیفیت زندگی و تأثیر بر اقتصاد می‌شود. آگاهی از ویژگی‌های این پدیده برای مدیریت منابع آب ضروری است. خشکسالی هیدرولوژیک در قالب کمبود جریان رودخانه به‌عنوان دوره‌ای که جریان رودخانه تقاضای نیازهای برنامه‌ریزی شده را برای مدیریت سیستم برآورد نمی‌نماید تعریف می‌شود. در پژوهش حاضر با ترسیم نمودار تغییرات دبی ماهانه در مقابل زمان در ۱۴ ایستگاه آب‌سنجی حوزه آبخیز گرگانرود در طول دوره آماری ۳۰ ساله (۱۳۸۹-۱۳۵۹) دوره‌های کمبود جریان با استفاده از روش حدآستانه استخراج و نتایج مورد تجزیه و تحلیل قرار گرفت. شدیدترین دوره‌های کمبود جریان در اقلیم‌های خیلی مرطوب و نیمه خشک و رودخانه‌های واقع در پایین‌دست منطقه مورد مطالعه رخ داده است و طولانی‌ترین دوره‌های کمبود جریان در اقلیم نیمه‌خشک به مدت ۲۸ ماه بوده است. روند شدت و تداوم کمبود جریان تنها در ایستگاه‌های مرکزی حوزه آبخیز صعودی بود. سال‌های وقوع کمبود جریان در پایان دوره دارای فراوانی بیشتری می‌باشند و در سالهای ۷۸-۱۳۷۷، ۸۷-۱۳۸۶، ۸۸-۱۳۸۷ و ۹۰-۱۳۸۹ در اکثر ایستگاه‌ها کمبود جریان اتفاق افتاده است. به طوری که در این سال‌ها به ترتیب در ۵۰، ۸۵/۹، ۶۴/۳ و ۹۲/۸ درصد ایستگاه‌ها کمبود جریان مشاهده شده است.

کلمات کلیدی:کمبود جریان، حد آستانه، روند، پهنه‌بندی، گرگانرود

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