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Regional Analysis of Streamflow Drought: A Case Study for Southwestern Iran

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***Abstract*—**Droughts are complex, natural hazards that, to a varying degree, affect some parts of the world every year. The range of drought impacts is related to drought occurring in different stages of the hydrological cycle and usually different types of droughts, such as meteorological, agricultural, hydrological, and socio-economical are distinguished. Streamflow drought was analyzed by the method of truncation level (at 70% level) on daily discharges measured in 54 hydrometric stations in southwestern Iran. Frequency analysis was carried out for annual maximum series (AMS) of drought deficit volume and duration series. Some factors including physiographic, climatic, geologic, and vegetation cover were studied as influential factors in the regional analysis. According to the results of factor analysis, six most effective factors were identified as area, rainfall from December to February, the percent of area with Normalized Difference Vegetation Index (NDVI) <0.1, the percent of convex area, drainage density and the minimum of watershed elevation that explained 90.9% of variance. The homogenous regions were determined by cluster analysis and discriminate function analysis. Suitable multivariate regression models were evaluated for streamflow drought deficit volume with 2 years return period. The significance level of regression models was 0.01. The results showed that the watershed area is the most effective factor with high correlation with deficit volume. Also, drought duration was not a suitable drought index for regional analysis.

***Keywords*—**Iran, Streamflow drought, truncation level method, regional analysis.

I. Introduction

DURING the (2000 to 2003) period, droughts in south Asia affected more than 100 million people with severe impacts felt in Western India, Pakistan, Afghanistan and Iran. Only in Iran water levels in 36 reservoirs dropped by 45% during this period, Of the rural population, 60% were affected, 2.8 million tons of wheat were destroyed, more than 800,000 animals died from lack of water and fodder, 8.4 million hectares of orchards and crops were lost and 9.6 million hectares of forested land endangered [1].

The extent of drought impacts is related to drought occurring in different stages of the hydrological cycle. Different types of droughts are usually distinguished.

The origin is meteorological drought, which is defined as the deficit in precipitation. An agricultural drought relate to soil moisture deficit, which may reduce agricultural production and increase the probability of forest fires. It can further develop into a streamflow drought defined as the deficit in surface water and groundwater, reducing water supply for drinking, irrigation, industrial and hydropower needs. A discussion of different drought definitions can be found in [3] and [20].

The truncation level method defines droughts as periods during which the streamflow is below a certain truncation level [21]. This drought event definition fulfils the above criteria and is selected for this study. This method has been used for point drought analysis in some previous researches (e.g. [24] - [12]-[18]- [4]-[16]).

Regional analysis of droughts can be performed via studying spatial patterns of point drought or alternatively studying regional characteristics of the drought [17]-[19]-[6]-[7]-[23]. Hisdal and Tallaksen [9] estimated the regional streamflow drought characteristics by truncation level, Empirical Orthogonal Functions (EOF) and Kriging method interpolation. Another method for regional analysis is studying effects of climatic, physiographic, geologic and vegetation on hydrologic indices. Nathan and McMahon [14] regional analyzed the low flow in 184 catchments by multivariate regression, cluster analysis and principle component analysis (PCA) in Australia. Nutzmann and May [15] provided a model to determinate river discharge and indicated that streamflow drought is controlled by base flow and groundwater level. Longobardi and Villani [13] studied the effects of climatic, topographic, geologic and soil properties on base flow index (BFI) as a characteristic of low flow and concluded that geologic factor exerted highest impact on BFI.

In the present study regional streamflow drought characteristics are analyzed. A drought event definition applicable to stream flow time series, and of direct relevance to the water industry and to environmental demands, is adopted.

II. Study Area and Data

Southwestern Iran extending from $30^{\circ},20'$ to $34^{\circ},56'$ N latitude and $46^{\circ},06'$ to $52^{\circ},30'$E longitude that include comprises Karoon, Dez and Karkhe basins. This area has Mediterranean climate type with wet winters and dry summers. Lowland area receives surface water Zagros

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tributaries and has great potential for agricultural activities.

The elevation varies from zero in lowlands to over 4000 m in mountains. Moisture from the Mediterranean Sea, Persian Gulf, Red Sea and Northern Atlantic Ocean is the source of precipitation. Zagros mountains face to the prevailing moisture systems [11]. The daily discharge series of 54 hydrometric stations was included in this study. These data were made available by Iranian Water Resource Management Organization. Fig. 1 shows the geographic location of the study area in relation to the country Iran as well as stream flow stations.

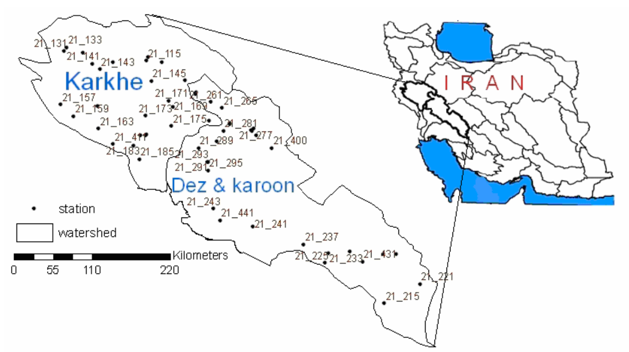

Fig. 1 The network of hydrometry stations in study area

III. Methodology

A. Threshold Level Method

The threshold level method introduced by Yevjevich [21] based on theory of runs defines droughts as periods during which the water supply is lower than the current water demand. Yevjevich [22] later simplified this method by applying a constant demand that was represented by a threshold level, Q_α, thus droughts are defined as periods during which the stream flow is below the threshold level.

Based on the run theory a run is the period between two consecutive crossings of the truncation level and it delineates a drought event. The run length then explains the duration of the drought event and the run sum describes the cumulative deficit volume. The drought characteristics include deficit volume or severity, V_i, duration, d_i and the start of drought t_i as illustrated in Fig. 2.

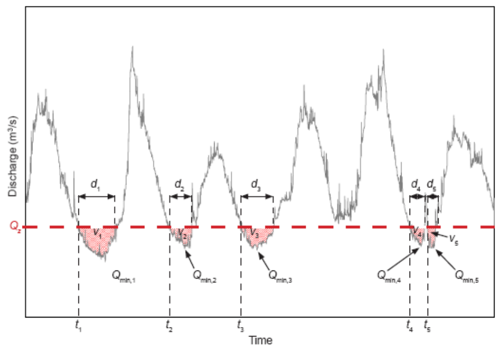

Fig. 2 Illustration of common hydrological drought characteristics (after Fleig et al. 2006)

The threshold level should represent the lower boundary to "normal" condition and is set to a percentile of the daily flow duration curve (FDC), e.g. the 70- percentile flow (Q_{70}), which represents that flow exceeded 70 percent of the time.

Minor droughts have short duration and small deficit volume and should be reduced in an extreme value analysis. Dependent droughts can occur during long–term periods of low discharge when divide the period of low discharge into several drought events. There are three different pooling procedures; moving verage (MA), sequent peak algorithm (SPA) and the inter event time criterion (IT- Criterion). They were compared and discussed in [19]-[8]-[4].

Based of IT- Criterion two dependent droughts are pooled if they occur less than a critical number of days, t_c, apart, i.e. $t_i \le t_c$.

The duration of pooled drought is defined from the starting (first) day of the first pooled event to the last day of the last pooled event.

$$d_{pool} = d_i + d_{i+1} + t_i \tag{1}$$

where d_i and d_{i+1} are the duration of events i and i+1, respectively. In references [19] and [4] recommend that $t_c = 5day$. The pooled drought deficit volume of the pooled events is as follows:

$$V_{pool} = V_i + V_{i+1} \tag{2}$$

The minor droughts are excluded when their deficit volume is smaller than a certain coefficient (%) multiple by maximum observed deficit volume ($V_i \le \alpha \times V_{\max}$). The value of α must be from 0.5 to 1%.

B. Frequency Analysis

Annual Maximum Series (AMS) of drought derived from time series of daily discharge based on threshold level (Q_{70}) method as discussed above. The distribution of the drought deficit volume and duration AMS in a given time interval, [0,t], e.g. one year, $F_t(x)$, is stated based on, the distribution model of the number of droughts combined with the distribution function of the magnitudes of all events within the time interval, $H_t(x)$:

$$F(x) = \Pr(Z_t = 0) + \sum_{k=1}^{\infty} H^k(x) \Pr(Z_t = k) \tag{3}$$

Where Z_t is the number of drought events and $\Pr(Z_t = k)$ is the probability of k events during the time interval [4]. The Nizowka software is used for extraction and analysis of droughts [10].

Minor droughts were excluded with $\alpha = 0.5\%$ and dependent droughts were pooled with $d_{\min} = 5$ days and $t_c = 3$ days. Several probability distributions, including

Gamma, Weibull, Log-Normal, Johnson, Gumbel and Generalized Pareto, fit to series of deficit volume and duration by applying the method of maximum likelihood. Also, the Pascal and Poisson distributions applied for the event numbers.

χ^2- goodness of fit test was used to examine different distributions at 0.05 significance level [5] . The return period of drought characteristics (deficit volume and duration) calculated by:

$$T = \frac{1}{1 - F(x)} \tag{4}$$

C. Regional Analysis

Regional analysis is a method to estimate the hydrological characteristics of ungauged basins with no data. The relation between dependent and independent variables is established by multivariate regression models.

Dependent variables include hydrological indices and characteristics such as flow duration quantiles, floods of different return periods, low flow and hydrological drought indices. Independent variables may involve geological, physiographic, climatic and land cover factors. In this research, some 35 independent variables which were included for the study of regional hydrological drought are main river slope, main river length, watershed length, watershed slope, mean elevation, watershed perimeter, watershed area, total length of rivers, minimum elevation, drainage density, percent of concave area, steady or convex areas, percent of area under snow melt line in different months (March, April, and May), percent of areas in different aspects (including flat, northwest, north, northeast, east, southeast, south, southwest, and west), percent of area with various ranges of NDVI (<0.1, 0.1-0.25, 0.25-0.4, and >0.4), average annual rainfall, cumulative rainfall depth in December-February, December-March, December-April, and December-May periods.

Factor analysis attempts to identify factors that explain the formation of correlations within a set of observed variables. Varimax rotation and principal component methods were used in this research.

Cluster analysis was used to grouping the watersheds into homogenous classes. Hierarchic method starts with the calculation matrix of distances between individuals. Each individual first forms a group with one number. The groups that are 'close' together are merged. Several ways to define 'close' include nearest neighbors, furthest neighbor linkage, group average linkage and Ward's method. Ward's method with squared Euclidean distances was used in this study.

By discriminate function analysis, it is possible to separate two or more groups of individuals, given measurement of several variables related to these individuals. An approach to discriminate is based on Mahalanobis distances. The Mahalanobis distances of individuals to group centers can then be calculated and each individual can be allocated to the group that it is closest to. Another method is canonical discriminate functions that involve taking a linear combination of variables for separating groups. Second method employed in this study.

A regression model predicts the value of a dependent variable with one or more independent variables. In this research, independent variables are geological, physiographic, climatic, and land cover factors. Dependent variables are hydrological drought indexes including drought deficit volume and duration. Step wise regression is a technique for choosing the variables to be included in a multiple regression model.

IV. Results

In each one of the 54 hydrometric stations in the study area, drought periods were determined based on 70% threshold level. Frequency analysis on annual maximum series of duration and deficit volume was performed. Suitable distribution wasn't found for five stations. Thus, the number of stations was decreased to 49 for further analysis. In most stations, the most sever and longest droughts occurred during 2000-2003 period. For the regional analysis, deficit volume and duration of 2-year return period were determined as the regional model dependent variables "Figs. 3 and 4".

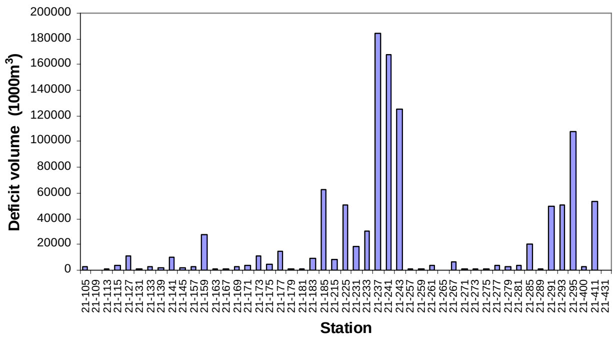

Fig. 3 2-year deficit volume off all stations

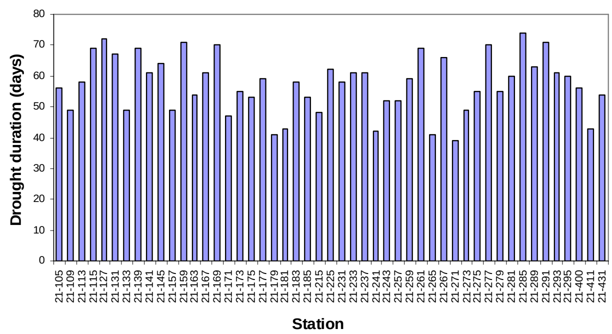

Fig. 4 2-year drought duration of all stations

The 2-year deficit volume had a range about 131 to $180000 m^3$ and the 2-year drought duration also varied from 41 to 74 days.

Performing factor analysis on 35 factors mentioned earlier, these first components with eigen value greater than one explained 43.3, 25.8, 9.3, 5.1, 4.1 and 3.2 % of variance respectively. Therefore the total variance explained by the first six components was 90.9 %.

In the next step, the first six components were rotated by Varimax method. The results showed that *watershed area, total rainfall depth from December to February, the percentage of watershed area with NDVI<0.1, the percentage of convex areas, drainage density*, and *minimum elevation* had the highest correlation with the first six components. In order to determine hydrologically homogenous regions, the hierarchical cluster analysis was applied and the method of furthest neighbor yielded best results. The homogenous watersheds were determined based on maximum Euclidean distance of 12.

The discriminate analysis showed that *watershed area, percentage of watershed area with NDVI<0.1,* and *the percentage of convex areas* were the main discriminative variables between groups The map of hydrologically homogenous regions is shown in Fig. 5.

At this stage, the stepwise regression analysis was carried out with six independent variables, and two dependent variables, i.e. deficit volume and drought duration. The GLS[1] method was applied in order to determine the model parameters. No suitable relation was found for drought duration in homogenous regions. Hence, only deficit volume regional regression models were established. Coefficient of determination (R^2) and standard error (Se) was calculated and the best model was selected with a significance level of α=0.01, as shown in Table I.

All regional models in homogenous regions were significant in 0.01 level and had acceptable R^2 with low standard error. The value of R^2 for all models in homogenous regions was higher than that of models for the whole region.

By applying multivariate regression method, suitable 2-year deficit volume models were derived at 0.01 significance level individual homogeneous regions as well as the entire region. The deficit volume models involved *watershed area* and *total rainfall depth from December to February.* Chalise et al. [2] also found that the average annual rainfall is the most effective factor on stream flow in Himalaya. While [15] concluded that the hydrological drought in Germany was controlled by base flow and downfall of groundwater level. The main conclusions of this study as follows:

- The deficit volume and duration regional maps confirmed meaningful differences between northern and southern portions as well as upstream and downstream watersheds.
- The 2-year deficit volume regional models in the majority of homogenous regions were dependent on *watershed area* and *total rainfall depth from December to February.*
- No regional model could be established for hydrological drought duration due to no fit of statistical distributions on drought duration.

[1] Generalized Least Squares

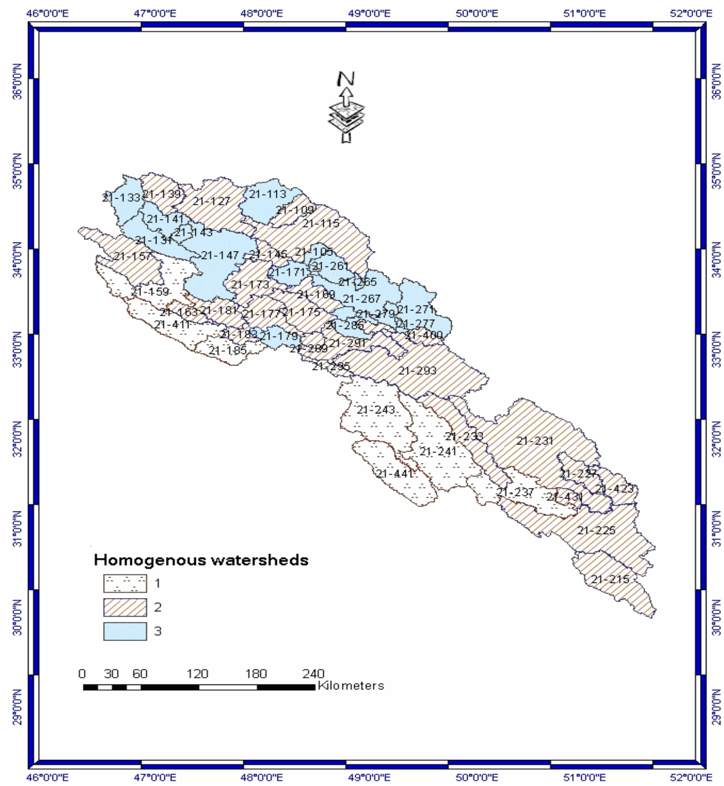

Fig. 5 The map of hydrological homogenous regions

TABLE I
REGIONAL REGRESSION MODELS FOR 2-YEAR DROUGHT DEFICIT VOLUME (DV_2)

Regions	Regional regression models	R^2	Se
1	$LogDV_2$=-2.632LogDD+3.595	0.95	0.06
	$LogDV_2$=-3.572LogDD-0.348Log R_{d-f}+3.876	0.99	0.02
2	$LogDV_2$=0.892LogA+3.397Log R_{d-f}-7.278	0.84	0.29
3	$LogDV_2$=0.64LogA+3.438 Log R_{d-f}-6.486	0.85	0.24
All region	$LogDV_2$=0.817LogA+1.1	0.66	0.46
	$LogDV_2$=0.886LogA+1.775Log R_{d-f}-3.309	0.78	0.38

DV_2: 2- year drought deficit volume (1000m^3)
A: watershed area (km^2)
DD: drainage density (km/km^2)
R_{d-f}: total rainfall depth from December to February (mm)

REFERENCES

[1] L. Abdullaev, and K. Jumaboev, (2004) “Water Management and Drought Mitigation Strategies: Application of IWMI experience for CAC region”. Www. IWMI.org.

[2] S.R. Chalise, S.R. Kansakar, G. Rees, K. Croker, and M. Zaidman, “Management of water resources and low flow estimation for the Himalayan basins of Nepal”, Journal of Hydrology, No. 282, Issues 1-4, 2003, pp. 25-35.

[3] J.A. Dracup, K.S. Lee, and E.G. Paulson, “On the definition of droughts,” Water Resources Research 16 (2), 1980, pp. 297–302.

[4] A.K. Fleig, L.M. Tallaksen, H. Hisdal, and S. Demuth, “A global evaluation of streamflow drought characteristics,” Hydrology and Earth System Sciences sions, vol. 10, 2006, pp.535–552.

[5] C.T. Haan, “Statistical Methods in Hydrology,” Ames, Iowa: The Iowa State University Press, 1977, pp. 130-160.

[6] A.G. Henriques, and M.J.J. Santos,. “Regional drought distribution model,” in Physics and chemistry of the earth. Part B. Hydrology, oceans and atmosphere, European water, 1999.

[7] H. Hisdal, K. Stahl, L.M. Tallaksen, and S. Demuth, "Have streamflow droughts in Europe become more severe or frequent?," International Journal of Climatology vol. 21, 2001, pp.317–333.
[8] H. Hisdal, and L.M. Tallaksen, (Eds) "Drought event difention," ARIDE Technical Report No.6, University of Oslo, Norway, 2000.
[9] H. Hisdal, and L.M. Tallaksen, "Estimation of regional, meteorological and hydrological drought characteristics: a case study for Denmark," Journal of Hydrology, vol. 281, 2003, pp. 230–247.
[10] W. Jacubowski, and L. Radczuk, NIZOWKA2003 Software, Agricultural University of Wroclaw, Poland, 2003.
[11] Jamab Engineering consultants Company, "The report of Iran Water comprehensive plan," Iran water Resources Management Organization publication, 2000, pp. 30–85.
[12] R.T. Kjeldsen, A. Lundrof, and D. Rosbjerg, "Use of a two-component exponential distribution in partial duration modeling of hydrological drought in Zimbabwean rivers," Hydrological science journal, vol. 45(2), 2000, pp. 285-298.
[13] A. Longobardi, and P. Villani, "Baseflow index regionalization analysis in a Mediterranean area and data scarcity context: Role of the catchment permeability index," Journal of Hydrology, vol. 355(1-4), 2008, pp. 63-75.
[14] R.T. Nathan, and T.A. McMahon, "Identification of homogeneous regions for the purpose of regionalization," Journal of Hydrology, vol. 121, 1990, pp. 217-238.
[15] G. Nutzmann, and S. Mey, "Model-based estimation of runoff changes in a small lowland watershed of north-eastern Germany," Journal of Hydrology, vol. 334(3-4), 2007, pp. 467-476.
[16] Z. Radic, and V. Mihailovic, "Development of monitoring system for Serbia hydrological droughts analysis," Serbia Water National Program "Hydrological bases of water resources and international cooperation ". NPV – 21A, 2005.
[17] Z. Sen, "Regional drought and flood frequency analysis: theoretical consideration," Journal of Hydrology vol. 46, 1980, pp. 265–279.
[18] L.M. Tallaksen, "Streamflow drought frequency analysis," in Drought and Drought Mitigation in Europe, J.V. Vogt and F. Somma Ed. Kluwer Academic Publishers, the Netherlands, 2000, pp.103-117.
[19] L.M. Tallaksen, and H. Hisdal, "Regional analysis of extreme streamflow drought duration and deficit volume," in FRIEND'97-Regional Hydrology: Concepts and Models for Sustainable Water Resource Management, A. Gustard, S. Blazkova, M. Brilly, S. Demuth, J. Dixon, H. Van Lanen, C. Llasat, S. Mkhandi, and E. Servat, Ed. IAHS Publication vol. 246, 1997, pp. 141–150.
[20] D.A. Wilhite, and M.H. Lantz, "Understanding the drought phenomenon: the role of definitions," Water International vol. 10 (3), 1985, pp. 111–120.
[21] V. Yevjevich, "An objective approach to definition and investigations of continental hydrologic droughts," Hydrology Papers 23, Colorado State University, Fort Collins, USA, 1967.
[22] V. Yevjevich, "Methods for determining statistical properties of droughts," in Coping with droughts, V. Yevjevich, L. da Cunha, and E. Vlachos, Ed. Colorado, Water Resources Publications, 1983, pp. 22-43.
[23] M.D. Zaidman, H.G. Rees, and A.R. Young, "Spatio-temporal development of streamflow droughts in north-west Europe," Hydrology and Earth System Sciences, vol. 5(4), 2001, pp. 733–751.
[24] E. Zelenhasi´c, and A. Salvai, "A method of streamflow drought analysis," Water Resour. Res., vol. 23(1), 1987, pp. 156–168.