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Multivariate and Cluster Analysis of Hydrologic Indices: A Case Study of Karun Watershed, Khuzestan Province, Iran

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ABSTRACT

Hydrological droughts usually affect large areas and minimum river flow is an appropriate index for the study of hydrological droughts. are commonly used for analyzing multivariate data? This study considered 35 hydrological indicators which were divided into 5 groups, including amplitude, duration, frequency, timing, variability, that characterized the various flow regime characteristics. Factor analysis and principal component analysis were used to calculate the hydrological indices for 14 stations of Karun watershed, Iran, and analyze the main components (PCAs). Then, the main components, the most important parameters of the Karun domain, which included A2, A4, D3, D5, V1, F and T, were determined and based on these indices, they were grouped by cluster analysis.

Hydrological indicators were divided 6 groups which most of them near PC1 which then follow PC2 but at least of them follow other PC. The only group has positive axis include: D6, A2, A1 that Station 7 and 13 near it. Three groups hydrological indicators have positive PC2 and one group also negative and positive PC2.two groups has negative PC2.two groups of hydrological indicators has positive and 4 groups of hydrological indicators has negative.

Keywords: *Cluster Analysis, Component Analysis, Hydrological Drought, Hydrological Index*

INTRODUCTION

Drought is a natural and repetitive climatic phenomenon. It occurs in virtually all parts of the world. However, its characteristics vary from one watershed to another. During hydrological droughts, river flow and water in lakes and reservoirs behind dam's decrease and groundwater table also drops.

Hydrological regime characteristics are essential for the assessment of river health and for water resource management (Puff et al. 1997). Therefore, it is hypothesized to develop an indicator that specifies the range (magnitude), duration, frequency, timing and diversity of natural hydrologic events of the regime. More than 200 indicators are currently available to describe hydrologic regimes, of which about 70 are related to low flows. These indicators have been developed with different perspectives. The rapid rise of hydrological indicators from 32 reported by Richter et al. (1996) to 171 reported by Olden and Puff (2003) and finally to 261 reported by Monk et al. (2006) has complicated evaluation and resource management. Therefore, water resources managers combined a few indicators in a well-defined framework, which would help sustain management. Bonaiya (2009) presented a feature of river's natural regime in eastern Canada. Using 175 river flow events from five eastern provinces of Canada, Deleg et al. (2011) described a wide range of flow characteristics, such as magnitude (amplitude) and frequency of low flows, using multivariate analysis. They developed regional regression equations for a number of low flow indicators, which, as a function of drainage area, were used to compare flow regimes of different provinces and regions. Khazaei et al. (2003) analyzed hydrological droughts in Gharehso River basin and concluded that the index of drought incidence decreased with decreasing probability of occurrence. Nathan and McMahon (1990) conducted a regional analysis of minimum flows in 184 sub-basins in Australia, using multivariate correlation analysis, cluster analysis, and principal component analysis. Samiei, Zahtabian, and colleagues and Biabanaki compared multivariate regression and low flow indexes, and found the regression method to be better. It seems that due to the use of more watershed characteristics in determining regional equations, more accurate estimates of flow are obtained by multivariate regression method.

The objective of this study is to employ several new hydrological indicators in Karun watershed, Iran, and identify the most relevant hydrologic indices for low flows, identify similarities and regional differences by using multivariate statistical analysis, and use cluster analysis for hydrologic indices.

Materials and Methods

Study Area

Karun watershed is located between 30-00 and 34-05 northern latitudes and 48-00 and 30-52 eastern longitudes, and covers parts of 7 provinces of Isfahan, Khuzestan, Chaharmahal and Bakhtiari, Fars, Kohgiluyeh and Boyer Ahmad, and Lorestan and Central. The watershed is partly in the basin of the Persian Gulf and the Oman Sea and consists of two large rivers Karun and Dez that join together at the Shaloo bridge and form Great Karun. The altitude in the area varies from 0 to more than 4,400 meters. The lowest point of the area is the southern margin of the Persian Gulf, and the highest elevation is in the Zardukh and Dena Mountains.

The Karun watershed has a total area of 6,71,212 square kilometers and is bounded northwards by the watershed area of the rivers Gharacheh, Saveh, Golpayegan and Zayandehrud, by the western part of the Karkheh River basin, from the east to the Venus River, Maroon and Jarahi Rivers. About 69% of the area is mountainous and 31% plain and foothills. Generally, the amount of sediment in the watershed of the Great Karun branches ranges from 28 to 1800 tons / km in a year, and is variable in the Ghar Aghaj River in the outskirts and the Dokoh River upstream of the basin. In the outskirts of the Dez River in the north of the basin, which is from the highlands, erosion is in low to moderate amount, with a value of less than 300 tons per square kilometer that is one of areas with moderate erosion and in some areas (Seyyed Shahid Abbaspour) it is high.

Methods

Selection of Hydrometric Stations

For describing the characteristics of normal flow regime in two watersheds of Karun, daily average flow at 14 hydrometric stations located in 4 provinces was selected. The statistical period of data was more than 30 years. Table 1 shows the characteristics of hydrometric stations selected in the Karun watershed.

Selection and Calculation of Hydrological Indicators

There are more than 200 hydrological indicators, of which 67 are directly related to low flows. In addition, four other indicators (average daily flow, average daily flow, annual average annual average and annual flow coefficient) due to their potential relationship with low-flow regimes were considered as part of low-flow regime. From these 71 hydrological indicators, we selected 35 indicators and we calculated them. All of the variables used in Table 2 were divided into five groups to identify the various characteristics of flow regime, including:

Amplitude, Duration, Frequency, Timing, Variability and Average of total data

Principal Component Analysis (PCA)

Component decomposition is a multivariate method that reduces the number of variables to several components and provides a summary of the main data. The higher the internal correlation between the variables is the lower the number of constructed components will be. One of the ways of component analysis is the component weighting matrix. There are many reasons for the importance of component analysis. First, this method separates properties that are dependent on other properties. Secondly, by increasing the number of variables, the multi-variable regression equation is increasingly uncontrollable, which can be reduced by using component analysis (Khorasanzadeh,1375)

Flow Regime Classification

Flow regime classification offers the source for hydrologic and ecologic educations. Bunn and Arthington (2002) posed four guiding principles regarding the effect of flow regimes on aquatic biodiversity. Streamflow is a convenient quantity for classification purposes because it integrates the effects of most landscape features into a single measureable 'characteristic' (Likens et al., 1977). There is no limit to the quantity of hydrological parameters that have been developed to define the diverse features of the flow regime.

The variables were divided into three categories. They include catchment descriptor, flow variability and intermittency.

Catchment Descriptor

The flow per unit catchment area (MAAN) for each station, well-defined as the ratio of mean annual runoff to the catchment area upstream of the station was used as a catchment descriptor. The flashiness index was introduced a new measure of flow variability. The baseflow (ML1) refers to the water that enters streams by flowing through the groundwater system, rather than directly over the surface of the land. The nature of water dynamic between the aquifer and the river is widely used in defining the river type.

Hydrologic classification based on baseflow is also very common.

Extent of Intermittency:

The median annual number of zero flow days (DL6) was determined for each station and used to assess every measures of flow variability were used. This is calculated as the standard deviation of all the daily flow values, divided by the mean annual flow. The predictability value (TA1), which ranges from zero to one, comprises two components – flow constancy (TA2) and flow contingency (Colwell, 1974). For example, a stream with relatively uniform flow throughout the year may have a predictability value near one due to the constancy component (i.e. TA2/TA1 value is high).

Alternatively, a stream with highly variable seasonal flow may also have a high predictability value if similar flow occurred with a consistent periodicity (i.e. high contingency value). The flashiness index was introduced in this study as a new measure of flow variability.

The term flashiness reflects the frequency and rapidity of short term changes in stream flow (Baker et al, 2004). Stream flashiness is the stream flow response to storms. Streams that rise and fall quickly are considered flashier than those that maintain a steadier flow (Fongers et al., 2007).

One approach to quantifying flashiness was proposed by Baker et al (2004) by the means of the flashiness index (R-B Index 1). stream intermittency. This index was widely used in river classification taxonomy (e.g Matthews, 1988)

$$R - B\ Index = \frac{\sum_{i=1}^{n} |q_{i-1} - q_i|}{\sum_{i=1}^{n} q_i}$$

in which i is the day number, qi and qi-1 are the discharges on day i and day i-1, respectively. This index measures the path length of flow oscillations for data from gaged streams. Longer paths correlate with flashier streams, while more constant flows have shorter path lengths. Values for the R-B Index could theoretically range from zero to two. It would have a value of zero if the stream flow were absolutely constant. Its value increases as the path length, and flashiness, increase.

Multivariate cluster analysis of the selected hydrologic variables was then used to identify groups of stream sites with similar flow regimes.

Relationship between Flow and Watershed Features

Linear correlation coefficient between the flow features defined by the PCs extracted from the PCA and the watershed characteristic was designed so as to regulate the watershed descriptors that are for the source of flow regime variation.

Cluster Analysis

The number of components that should be used in analysis plays an important role. All components with a specific value greater than one are preserved. As shown in Table 3, the first and second components of the Karun watershed were 77.01% and 14.87% of the variance of 35 variables, respectively. In general, two components for the Karun watershed were 88.81% of the variance of variables. According to Tables 3 it was concluded that the two components must be rotated.

After analyzing the components, we categorized the components as follows:

Hydrological indices had a high positive correlation with very close angles. Indicators that had angular positions of about 180 degrees had a high negative correlation, and those indicators with an angle of 90 degrees were weakly correlated. In order to group the variables in this study, the input method was used. In this method, the average of each variable within each cluster was computed and the average of the clusters was calculated for viewing the square of Euclidean distance. The clustering method was applied using hydrologic indices and watershed stations. In order to identify the homogeneous regions and the necessity of using them in preparing the model, cluster analysis was used by the hierarchical clustering method (Moghadam and colleagues, 1373). Therefore, considering the knowledge of stations and their characteristics, it was decided to choose the best clustering method.

Results and Discussion

STATGRAPHICX software was used for analyzing the main components of 35 variables at 14 selected stations in the region.

Table 3 shows the results of extraction analysis of the initial components, in which the special values of variables 1 to 35, which were more important, was presented. The total sum of the variance of variables in analysis was equal to the number of variables. A special value, the variance level of the variables based on a component, was equal to or greater than zero and could be larger than the total variance. The percentage of variance of the variables based on components, as shown in Table 3, was equal to the special value divided by the total number of variances of the variables varied by 100; for example, the special value was related to the first component of 26.95 and the total percentage of variances for the first component was 26.95 divided by 35 times 100, that is, 77.77.

After grouping with the rotating component matrix, we identified the most important indicators in each domain. The matrix of the rotated component is shown in Table 4; this matrix shows component loads that correlations between each of the variables and components are for a varimax rotation. The ratio of the variance of each rotating component in most of the sources is the relative importance of each component. The components in each column in Table 4 represent the internal solidarity of each other and the only variables with the highest correlation with the first and second components were selected.

The first component, based on Table 4, shows 77.01% of the variance in the Karun area, meaning the variables had a weighing load for this component. According to the varimax table 3 from each set, each of the variables that had the greatest impact on the components was selected.

We chose the first set of A4 because it had the greatest impact on the first component, we selected the second set of A2s because it had the greatest effect on the second component, we selected the third set of D5 for its maximum effect on the second component, the fourth set F and T together. Because we chose at least one variable from each group, we selected the fifth set of V1 and selected the final set of D3 because it had the greatest impact on the first component.

Based on the analysis of main components for the domain, we selected the most important indicators according to Table 5, where the highest and lowest values weare related to the following stations:

Cluster Analysis of Stations in the Karun Area

In this study, cluster analysis using the station ward method based on Euclidean distance was used as a similarity criterion. Results of cluster analysis based on hydrologic indices for 14 hydrometric stations are presented in Figure 1. Based on cluster results, hydrometric stations were divided into three groups. The first group related to the hydrometric station 1 (Batari), the second group related to hydrometric stations 7, 13, 14, respectively (Dams getvand, Bamde & Mollasani, the third group related to hydrometric stations 2, 3, 4, 5, 6, 8, 9, 10, 11 and 12, respectively (Shahid, Kata, Vana'i, Sulgan, Armand, Patavweh, Kamandan, Darreh Takht, Cham Chit and Sepid Dasht stations). In the first group, the A4 index had made station 1 different from other stations. In the second group, the A2 index had caused similarity between stations. The third group, the V1, F, and T indices, had caused similarity between stations.

Conclusion

This study was carried out to analyze hydrologic indexes for investigating minimum flow regimes in Karun watershed. A total of 14 stations were selected from among the hydrometric stations. Using the information of the Dubai station, they were coded using MATLAB software and hydrological indicators were obtained for the Karun area for a period of 34 years from 1390-1357. On the hydrological indices for each station, PCA analysis was performed using STATGRPHICS statistical software. First, we extracted the initial component, so the special value in deciding the number of components that should be used in the next analysis was important. To determine the number of components, all components with a specific value greater than one were preserved. In general, two components for the Karun domain accounted for 88.81% of the variance percentage of variables. Then, we grouped components. Thus, six subsets were selected in the Karun area. After grouping using the rotational component matrix, we identified the most important indices in the domain. After analyzing the main components, the most important indicators identified in the Karun basin were A2, A4, D3, D5, V1, F and T. Then, the grouping of stations based on the most important hydrologic indices was obtained by examining dentograms and taking into account the maximum Euclidean distance of eighty, three homogeneous groups were obtained.

The first group was related to the hydrometric station 1 (BATARI), which meant that the A4 indicator had a different station 1 than the other stations. The second group was related to hydrometric stations 7, 13, and 14, where the A2 indicator generated similarity between stations. The third group was related to hydrometric stations 2, 3, 4, 5, 6, 8, 9, 10, 11 and 12, with V1, F and T indices creating similarity between the stations.

PC1 is 70.36% more than PC2 then 82.18% more than other PC. PC 2 11.55% more than other percent. According to table 3 the JOlOGIR station has the highest values in the hydrological indices A1, A11, A12, D6 and the Firozan station has the lowest values in the hydrological indices F1, D6, A12, A11, A1 and the highest values in the hydrological indices V1. The POL SHAWER station has the lowest values in the hydrological indices T1, V1 and the highest values in the hydrological values T1. According to the Figure 1. T1, various from D4, D5, or F1 and A11 has 180 degrees' difference. T1 has almost 90 degrees as equal as A9, A12, A10 and it has lesser than 90 degrees from A8, A13.D6. A 11 without T1 closely another component has almost lesser than 90 degrees.

Table1. *The characteristics of hydrometric stations selected in the Karun watershed*

AMSL (m)	Latitude (N)	Longitude (E)	Longitude (E)	AMSL (m)	Latitude (N)	Longitude (E)	Station Name
1970	55.37	48.36	Venayi	970	33.13	48.53	Sepid dasht
2086	31.38	51.14	Sulegan	1290	33.23	48.58	Cham Chit
1082	31.40	50.46	Armand	20	31.41	48.41	Bamdej
100	32.15	48.49	Sade Gatvand	18	31.35	48.53	Mallasani
1560	30.57	51.15	Pataveh	1560	30.51	51.15	Batari
2050	33.18	26.49	Kamandan	2250	30.50	51.44	Dehkade Shahid
1820	33.23	49.23	Dare Takht	1550	31.10	51.15	Kata

Table2. *Introduction of Hydrological Indicators*

Mean of total data	A1
Median of total data	A2
Mean of minimum values of flow in January per total record	A3
Mean of minimum values of flow in February per total record	A4
Mean of minimum values of flow in Mars per total record	A5
Mean of minimum values of flow in April per total record	A6
Mean of minimum values of flow in May per total record	A7
Mean of minimum values of flow in June per total record	A8
Mean of minimum values of flow in July per total record	A9

Mean of minimum values of flow in August per total record	A10
Mean of minimum values of flow in September per total record	A11
Mean of minimum values of flow in October per total record	A12
Mean of minimum values of flow in November per total record	A13
Mean of minimum values of flow in December per total record	A14
7-day minimum	D1
30-day minimum	D2
90-day minimum	D3
Mean of 7-day minimum flow per year	D4
Mean of 30-day minimum flow per year	D5
Mean of 90-day minimum flow per year	D6
Minimum flow of 7-day mean divided by median of total record	D7
75 percent continuity curve divided by median of total record	D8
90 percent continuity curve divided by median of total record	D9
7-day minimum divided by median of total record	D10
30-day minimum divided by median of total record	D11
90-day minimum divided by median of total record	D12
coefficient of variations in monthly minimum discharges per year	V1
coefficient of variations in 7-day minimum flow per year	V2
coefficient of variations in 30-day minimum flow per year	V3
coefficient of variations in 90-day minimum flow per year	V4
coefficient of variations in monthly minimum discharges from July to September per year	V5
coefficient of variations in duration of occurrence of flow below threshold value equal to 25 percentile	V6
Standard deviation of ratio of mean 7-day minimum to mean daily flow per year	V7
Mean from the number of day in which the minimum flow is occurred	T1
Mean number of flow occurrence with the flows below threshold value equal to 25 percentiles to record total flow	F1

Table3. *Extraction of the initial component in PCA analysis in the Karun watershed*

Components	Eigen Values	Variance Percentage	Cumulative Percentage	Components	Eigen Values	Variance Percentage	Cumulative Percentage
1	26.95	77.01	77.01	19	16e-1.88	0	100
2	5.20	14.87	91.88	20	16e-1.68	0	100
3	2.10	6.02	97.90	21	16e-1.39	0	100
4	0.44	1.26	99.17	22	16e-1.008	0	100
5	0.20	0.58	99.76	23	17e-9.15	0	100
6	0.069	0.19	99.96	24	0	0	100
7	0.010	0.029	99.98	25	0	0	100
8	0.002	0.008	99.99	26	0	0	100
9	0.0008	0.002	99.99	27	0	0	100
10	0.0003	0.001	100	28	0	0	100
11	0.00001	0	100	29	0	0	100
12	16e-9.27	0	100	30	0	0	100
13	16e-60.7	0	100	31	0	0	100
14	16e-7.22	0	100	32	0	0	100
15	16e-5.62	0	100	33	0	0	100
16	16e-2.66	0	100	34	0	0	100
17	16e-2.36	0	100	35	0	0	100
18	16e-2.19	0	100				

Table4. *Rotational Matrix in the Karun Area*

Components	Primary Components		Components C	Primary Components	
	1	2		1	2
A1	0.08	0.39	D5	-0.02	0.43
A2	0.06	0.41	D6	0.02	0.43
A3	0.18	-0.06	D7	-0.19	-0.01
A4	0.19	-0.05	D8	-0.19	-0.01

A5	0.18	-0.07	D9	-0.19	-0.01
A6	0.18	-0.06	D10	-0.19	-0.01
A7	0.18	-0.04	D11	-0.19	-0.01
A8	0.18	-0.05	D12	-0.19	-0.01
A9	0.18	-0.07	V1	-0.19	-0.01
A10	0.18	-0.08	V2	-0.19	-0.01
A11	0.18	-0.07	V3	-0.19	-0.01
A12	0.18	-0.08	V4	-0.19	-0.01
A13	0.18	-0.06	V5	-0.19	-0.01
A14	0.18	-0.06	V6	-0.19	-0.01
D1	-0.17	-0.11	V7	-0.19	-0.01
D2	-0.16	-0.15	F	-0.03	0.04
D3	-0.15	-0.17	T		
D4	-0.06	0.41			

Table5. *The Most Important Indicators in the Karun Area*

Lowest Value in Station	Highest Value in Station	The Most Important Hydrologic Indexes
Chamchit (0.18)	Bamdej (168)	A2
Kamndan (0.5)	Batari (377.94)	A4
Sulegan (0)	Batari (128.17)	D3
Kamandan (0.51)	Bamdej (97.77)	D5
Vanaei sarab sefid (0.29)	Sulegan (1.11)	V1
Sulegan (44.5)	Dehkade shahid (5768.5)	F
Kamandan (120.88)	Sulegan (241.29)	T

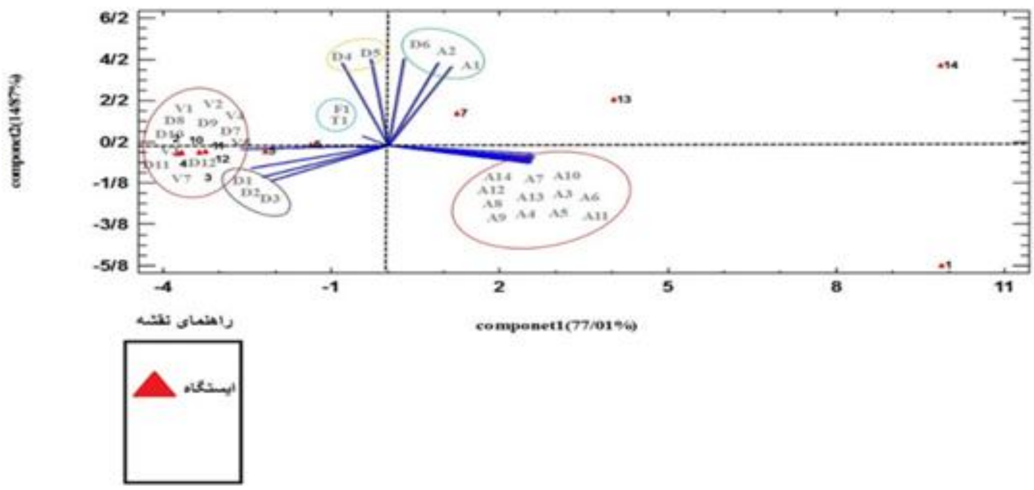

Figure1. *Six subsets are selected in the Karun area*

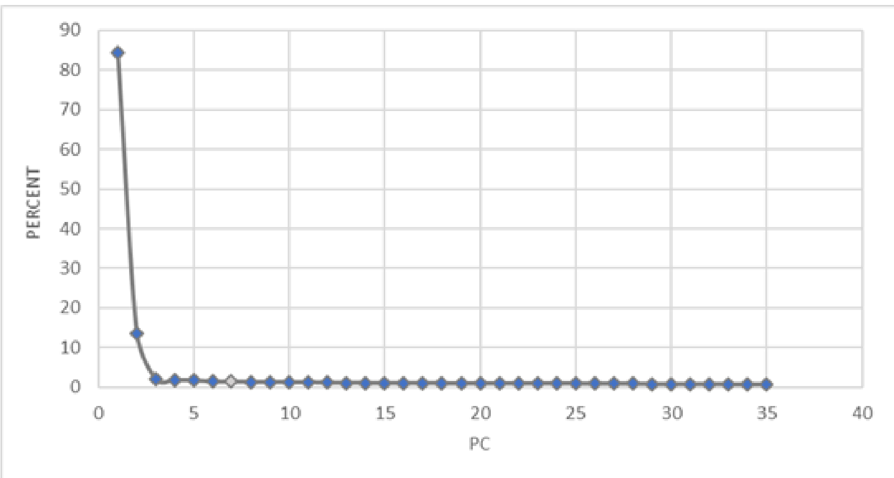

Figure2. *Scree plot*

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