Seasonal Prediction of Karoon Streamflow Using Larg-Scale Climate Indices

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Abstract

Water resources limitation in arid and semi arid regions on one hand and water demand increase on the other, have made the optimum utilization of existing water resources and systems necessary. In this context, researchers are trying to increase the accuracy and lag time of prediction by using various statistic and empirical models as well as different local and long-range variables in the last decades. Karoon River is the greatest and most important river in Iran because of agricultural water demand supply and hydroelectric power production. Therefore streamflow prediction of this river has considerable economical and social benefits. In this study the relationship between Karoon stramflow and monthly customary climate phenomena (ENSO, PDO and NAO) indices and rainfall data has been discussed. Also, to predict the dry season streamflow (April to August) in Poleshaloo hydrometry station, entrance to the Karoon3 Reservoir in the beginning of April, a multiple linear regression model based on principal component analysis (PCA) has been developed. The results indicate that Karoon River annual and seasonal water volume has a significant correlation with the PDO and SOI Indices. In addition, the explained model can predict streamflow with an accuracy of 20% mean absolute percentile error in verification period.

Key Words: Seasonal prediction, Multiple linear regression PCA, Climate Indices, Karoon River

Introduction

Identifying appropriate climatic variables and using them in development of long-term statistical model has been studied in this article to predict Karoon3 reservoir inflow in the south west of Iran. Lack of appropriate data (especially snow characteristics data in the mountainous regions), have increased the importance of identification of the long range and local climate indices such as sea surface temperature.

South west of Iran is a strategic region because of hydroelectric power production, agricultural and drinking water supplement. Karoon River watershed located in south west of Iran, in western hillside of Middle Zagros heights (29°5~32°55´N and 48°00´~52°03´E), is considered part of the Persian Gulf basin in Iran's hydrological divisions (Figure 1). According to De Martonne classification system, the climate of the watershed with 45231 km^2 area has a great diversity. Winter precipitation dominates this watershed with 44 percent of total annual rainfall.

Karoon is the biggest river in Iran and is so important, because of the hydroelectric power production, agricultural lands irrigation, supplement of drinking water in major cities and inter-basin water transfer. Therefore, inflow prediction of Karoon3 reservoir, especially in dry seasons, is important with regard to economic and social benefits and can be effective in planning, decision-making and management. In that manner, this article discusses the recognition of appropriate variables to predict April to August Karoon3 reservoir inflow (about 56 percent of total annual inflow) and offers regression based model to predict the streamflow volume.

In recent decades, rainfall prediction, based on long-range phenomena[1] and also the effective indices in local rainfall[2] has been done commonly in various parts of the world [Maeng et al. 2007, Kaiqin et al. 2007 and Soukup et al. 2009].

Various studies have been performed about the effect of climate phenomena on Middle East meteorological and hydrometric variables. Investigation of Barlow et al. (2002), shows coincidence between the ENSO negative phase (La Nina) and 1998 to 2001 drought in Middle East. Also, Cullen et al. (2002) indicated dependence of temperature, rainfall and streamflow variations in Middle East on North Atlantic oscillation phenomena. Pagano et al. (2003) reviewed the studies related to Middle East climate relativity to seasonal long-range climate phenomena, and concluded the wet (drought) condition tendency in El Nino (La Nina) term and also coincidence of NAO negative phase with hot, dry weather in Middle East.

Additionally, the effects of common climate indices on different regions' climate and employing these effects in predicting models, have been studied in various researches in Iran [Nazemossadat 1999 & 2001 and Ashouri et al. 2008]. Probing the relation between regional ocean-atmospheric variables and meteorological and hydrometric variables is common in western Zagros; among those we can mention the study of Persian Gulf SST effect on south and southwest

[1] such as NAO, ENSO and PDO
[2] such as SST, SLP and other atmospheric variables

of Iran [Nazemossadat 1998] and drought and wetness forecasting in this region by using local ocean-atmospheric variables such as pressure and temperature of adjusted seas surface [Karamouz et al. 2008].

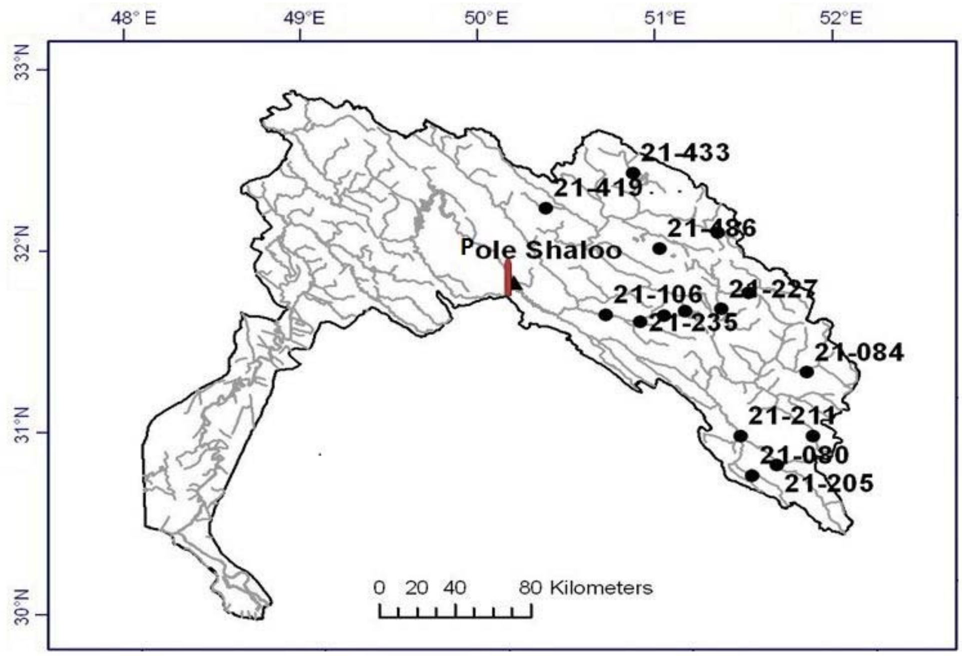

Figure 1. Location of Karoon3 reservoir, Poleshaloo hydrometric station and considered rain stations in Karoon Watershed

Data and Methodology

Meteorological and hydrological data has been used in this study in a 28-year period from 1977 until 2004, including the Karoon3 reservoir inflow in Poleshaloo Station, monthly rainfall in 15 rain stations over the watershed (Table 1) and SOI, PDO and NAO indices monthly values. Hydrometric and rainfall data have been taken from Khoosestan Water & Power Authority and climate Indices have been obtained from Climate Diagnostic Center (http://www.cdc.noaa.gov).

The purpose of this research is to recognize the suitable climate variables from aforementioned data set and exploit them in statistic model to predict the April to August Karoon3 reservoir inflow in the beginning of April. Therefore relationship between Karoon3 reservoir inflow in April to August and monthly values of meteorological and climatic variables prior to April has been studied by correlation analysis. Variables with correlation coefficient significance at 95% confidence level or higher have been considered as input variables of the modeling. According to the time series length (28 years), 95% confidence level is $r = \pm 0.37$.

Table 1- List of rain stations used in this study

Station code	Station	Latitude (N °)	Longnitude (E °)	Elevation (m)
21433	Shahr-e-kord	32.32	50.83	2050
21431	Zarindokht	31.53	50.95	1750
21436	Alooee	31.55	51.07	2100
21235	Lordegaan	31.5	50.82	1580
21092	Broojen	31.97	51.28	2140
21106	Menj	31.55	50.63	1430
21227	Soolegaan	31.55	51.27	2140
21419	Biregaan	32.15	50.33	2176
21486	Avargaan	31.9	50.95	2285
21423	Tangzaraaloo	31.63	51.43	2210
21084	Hanaa	31.18	51.72	2620
21217	Dehkadeshahid	30.83	51.73	2220
21205	Shahmokhtar	30.68	51.52	1730
21080	Sepidaar	30.63	51.38	2100
21211	Battari	30.85	51.33	1560

Results

- *Potential influencing variables*

The characteristics of the annual streamflow volume (in million-cubic meters), monthly streamflow distribution and autocorrelation function of AMJJA streamflow in Poleshaloo station have been plotted in Figure 2.

As it is shown, the average annual inflow to Karoon3 reservoir is about 11000MCM and the AMJJA includes 56 percent of annual streamflow. Correlation analysis between AMJJA and seasonal streamflow in the prior fall and winter, shows that winter streamflow volume has significant correlation with AMJJA streamflow.

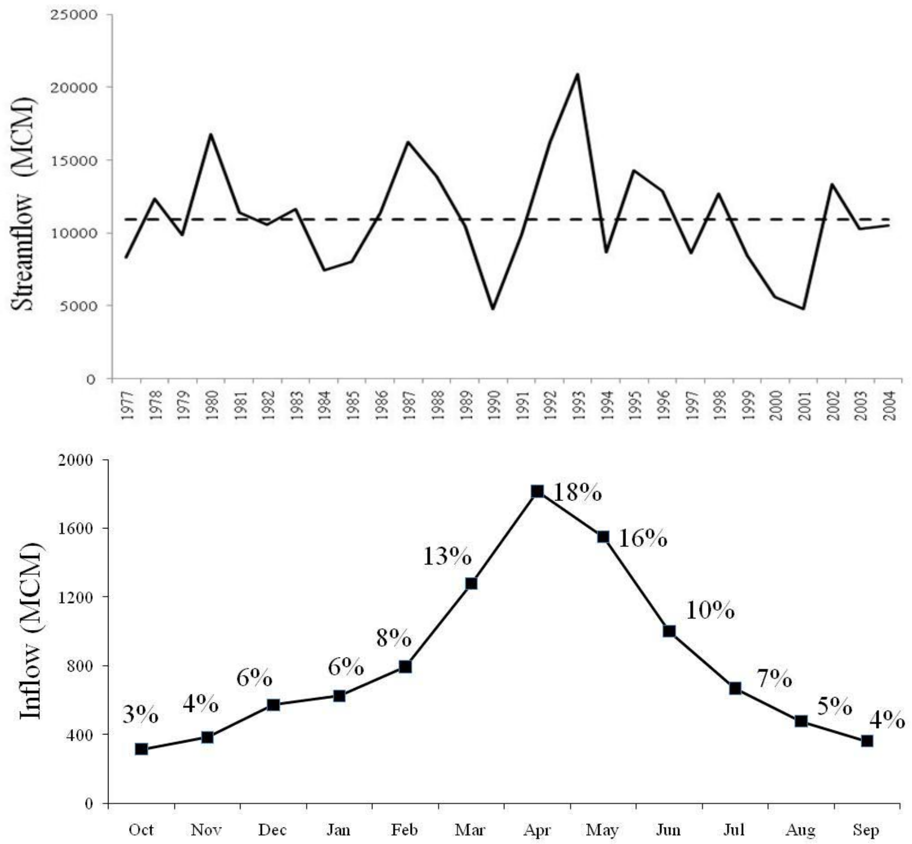

Figure 2. Characteristics of streamflow in Karoon3 reservoir, Poleshaloo Station: (a) Annual streamflow (b) Monthly streamflow distribution

Figure 3 shows correlation coefficient between AMJJA streamflow volume and monthly teleconnection indices. This figure shows that PDO has significant correlation with streamflow (especially in October) and SOI in fall has inverse correlation with streamflow. It shows that NAO index has no significant relationship with Karoon streamflow.

In Table 2, the simultaneous effect of the PDO and ENSO phases on annual inflow of Karoon River has been shown. The ratio of average inflow in different phases of these phenomena to the average of long-term annual inflow has been computed. As is clear, simultaneous occurrence of El Nino and PDO warm phase, leads to obvious increasement in annual inflow of Karoon3 reservoir (23% in average).

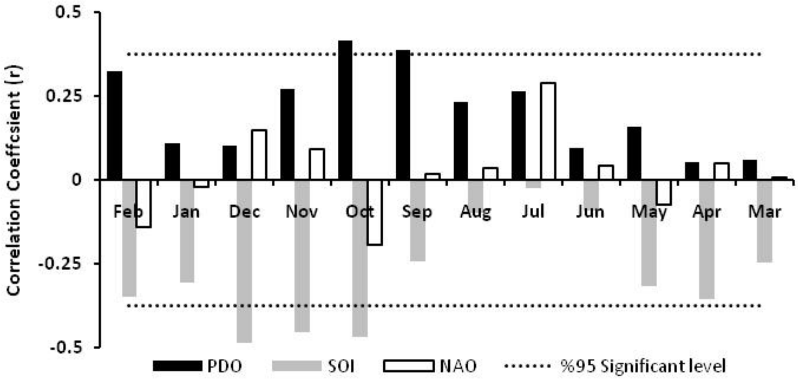

Figure 3. Correlation coefficient between AMJJA stream-flow and climate indices in prior months

Table 2. The ratio of average inflow in different phases of ENSO and PDO to the long-term average annual inflow

ENSO	La Nina		Neutral		El Nino	
PDO	Negative PDO	Positive PDO	Negative PDO	Positive PDO	Negative PDO	Positive PDO
Q/Q_{avr}	0.74	0.70	0.90	0.84	1.09	1.23

- *Forecast model*

The development of seasonal prediction models based on a multiple linear regression is very simple and popular in many regions. We use this framework to develop the forecast models. Regression models in general can be written as: [Mndenhall and Sincich, 1994]

$$y_i = b_0 + b_1 x_{i,1} + b_2 x_{i,2} + \ldots + b_k x_{i,k} + e_i \qquad i = 1 \text{ to } N \tag{1}$$

Where y_i is the dependent variable (AMJJA streamflow in this paper) in year i, x_is are the predictor variables, b_o is constant value and b_k is the k^{th} variable coefficient, e_i refers to the model error (difference between observed and estimated values) and N is the total number of observations.

Linear regression is based on the assumption that the independent variables are not significantly correlated. When highly intercorrelated predictors are used in a multiple linear regression model, multicollinearity can become the cause of statistically uncertainty and impermanent estimates of regression coefficients and numerical inaccuracies in computing the estimates of the model's coefficients.

One of the more advanced regression models is the regression based on principal component analysis (PCA). PCA is one of the statistical techniques which changes a dependent set of variables into an independent one. By using PCA, the original data set can be transformed into linear combinations of the original variables to create a new set of variables or principal components (PCs) which are independent of one another.

In any forecast model, it is essential that the model be developed on a subset of the data and then be independently tested on a different subset of the data not used in the model calibration. The prediction equation with a number of statistics which was used to measure the forecast performance in calibration and verification period has been shown in Table 3. They include the coefficient of determination, the root-mean-square error (RNSE), the mean absolute percentile error (MAPE), and the bias. In addition, in Figures 4 and 5, time series and scatter plots of observed values and estimated values are shown.

Table 3. Stepwise regression models for prediction of Karoon3 reservoir inflow in Poleshaloo station (1977-2004)

Model	Calibration				Verification			
	R^2	RMES	MAPE (%)	bias	R^2	RMES	MAPE (%)	bias
$Y = 2639 + .62*X_1 + .46*X_2 + 8.1*X_3 + 411*X_4 - 495*X_5$	0.64	1376	0.21	-79	0.74	965	0.20	456

Y = AMJJA Streamflow Volume in PoleShaloo Station (MCM)

X_1 = JFM Streamflow Volume in PoleShaloo Station (MCM)

X_2 = Raifall in 21-433 Rain Station in December (mm)

X_3 = Raifall in 21-205 Rain Station in March (mm)

X_4 = PDO in October

X_5 = SOI in December

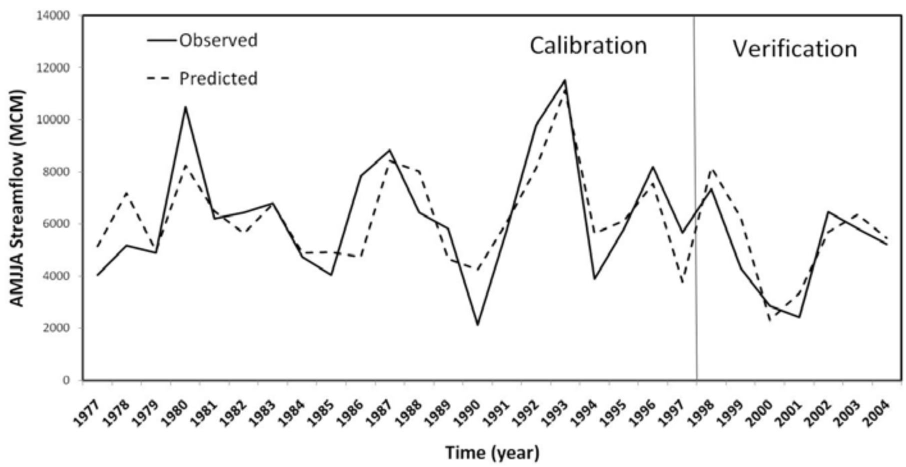

Figure 4. Comparison between estimated values (dotted lines) and observed AMJJA streamflow values (solid lines)

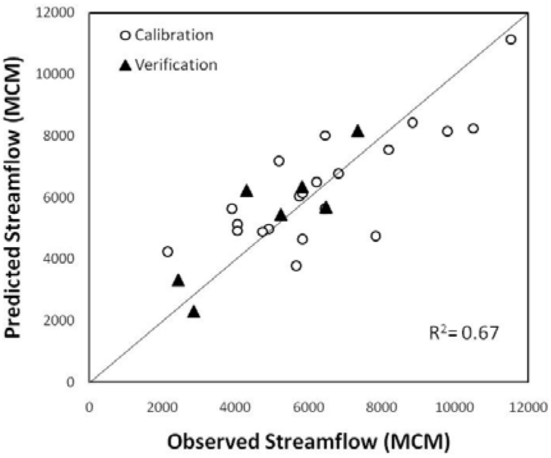

Figure 5. Scatter plot of estimated and observed AMJJA streamflow values

Conclusions

Basin hydroclimatic information such as streamflow and precipitation was used in traditional predictions. One-point-measures usually are not up to date, in some basins are not enough, have been quite imperfect and sometimes are not even available.

The main goal of this study was the prediction of dry season streamflow volume in Karoon3 reservoir in the beginning of April, using large-scale climate indices and investigating the relationship between Karoon River inflow and large scale phenomena such as ENSO, PDO and NAO.

Ocean-atmospheric climate indices are simply available and updated. Because of the fact that local climate variability is the result of pre-existing atmospheric circulation conditions, a longer lead time should be expected when using these variables in forecasts.

In Karoon3 watershed, winter rainfall encompasses half of annual rainfall and considering snow characteristics data may have an important role in the accuracy level of prediction models. Deficiency of available snowpack information causes to apply the available and considerable ocean-atmospheric variables in this study. Correlation analysis demonstrates that the prior annual streamflow has no significant correlation with AMJJA streamflow volume, but monthly rainfall in some stations and winter inflow do. It was found that SOI in fall and PDO in October have significant correlation with streamflow volume, but NAO index has no significant correlation with Karoon3 reservoir streamflow volume. Simultaneous occurrence of El Nino and PDO warm phase, leads to obvious increasement in annual inflow of Karoon3 reservoir.

A multiple Linear Regression model was developed for prediction of streamflow volume. Model verification showed good consistency between the estimated and observed values. Applying almost 5 variables in this model is an advantage, but regression models are not stationary with time and will have to be constantly monitored. Therefore, performance of different statistical and empirical models can be compared to select the best framework. Considering the non-linear relationships between dependent and independent variables, other related factors such as soil moisture and various available atmospheric variables should be applied for further study to increase the accuracy of prediction. The mechanism involved in the correlations explained in the article could be profitable in atmospheric general circulation models (GCM) or regional climate models (RCM).

Acknowledgment

This work was supported by Khoosestan Water & Power Authority. The writers acknowledge and thank all specialists in Environmental and Water Resource Center of Sharif University of Technology for their useful comments.

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