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The Karkheh River Streamflow Forecast based on the Modelling of Time Series

Karim Hamidi Machekposhti [1], Hossein Sedghi [1], Abdolrasoul Telvari [2], Hossein Babazadeh [1]*

[1] *Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[1*] *Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran (h.sedghi1320@gmail.com)*

[2] *Department of Civil Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran*

[1] *Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

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ABSTRACT

Autoregressive integrated moving average (ARIMA) models are appropriate for the annual streamflows (annual peak and maximum and also mean discharges) of the Karkheh River at Jelogir Majin station of Karkheh river basin in Khuzestan province in western Iran, through the Box- Jenkins time series modelling approach. In this research among the suggested models interpreted from ACF and PACF, ARIMA(4,1,1) for all annual streamflows satisfied all tests and showed the best performance. The model forecasted streamflow for ten leading years showed the ability of the model to forecast statistical properties of the streamflow in short time in future. The SAS and SPSS softwares were used to implement of the models.

Keywords:

Hydrologic Time Series, Box-Jenkins Approach, ARIMA Model, Karkheh River.

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1. Introduction

The application of statistical hydrology in earlier days was restricted to surface water problems, especially for analyzing the hydrologic extremes such as floods and droughts. However, during past three decades, the statistical domain of hydrology with the advent of fast computing technology has broadened to encompass the problems of both surface water and groundwater systems. With such a broad domain, statistics has emerged as a powerful tool for analyzing hydrologic time series. The Box-Jenkins ARIMA model is the most commonly time series model in hydrologic time series modelling [1]. The ARIMA model has two general forms: ARIMA(p, d, q) and multiplicative ARIMA(p, d, q)×(P,D,Q) in which p and q are non-seasonal autoregressive and moving average, P and Q are seasonal autoregressive and moving average parameters, respectively. The other two parameters, d and D, are required differencing used to make the series stationary. Several researches have conducted about streamflows time series modelling in the world [2, 3, 4, 5, 6, 7, and 8].

2. Study Area

The Karkheh basin in west of the Iran, located in the central and southern regions of the zagros mountain range and its area is more than 50000 km2. In terms of the geographical coordination, this region has been extended between 46˚ 57′ - 49˚ 10′ E longitudes and 31˚ 48′ - 34˚ 56′ N latitudes. Water in the basin is mainly used for agriculture production, domestic supplies, and fish farming but also serves to sustain the environment. For the latter, a major concern is the sustainability of the Hoor-AlAzim swamp that is a Ramsar site located at the Iran–Iraq border. Among the stations located in Karkheh river basin, Jelogir Majin hydrometric station (station number 9 in Figure 1) with 58 years statistical period length from 1958-1959 to 2015-2016 were selected according to the appropriate spatial distribution and having sufficient data. This station is located at the upper reaches of the reservoir of Karkheh dam and is the supplier of the most water entering the dam reservoir and has the greatest impact on reservoir water dam. The plotted of natural data are shown in Figures 3-5. This data were taken from Iran Water Resources Management Organization (IWRMO). The Karkheh River with 900 km long is the third largest river in Iran based on annual average flow. The basin's climate is best described as Mediterranean, having mild/wet winters and hot/dry summers, with mean annual precipitation ranging from 150 mm in the southern arid plains to 750 mm in the northern mountains. The Karkheh River is directly connected to the Karkheh dam, the largest surface reservoir in the region, which has an important role in supplying water to the region.

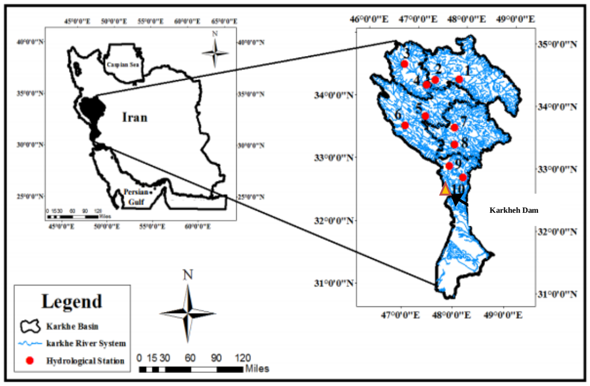

Figure 1. The Study area location.

3. Material and Methods

The Box and Jenkins modelling approach has three steps. Model identification is the first step. The second step is to estimate parameters and diagnostic checking, and the last step is to apply goodness of fit test. In this step, the model that seems to represent the behavior of the series is searched through autocorrelation and partial autocorrelation functions (ACF and PACF) for further investigation and parameter estimation [9].

After identifying models, we need to obtain efficient estimates of the parameters. Several methods are available for estimating parameters including Maximum Likelihood (ML), Conditional Least Squares (CLS) and Unconditional Least Squares (ULS). Among these methods, maximum likelihood and conditional least squares seems to be the best [1, 9]. The parameters should be statistically significant at α= p% and satisfy two conditions, namely stationary and invert ability for autoregressive and moving average models, respectively. The third step, Goodness of fit tests, verifies the validity of the model using some tools. The residuals of the model are usually considered to be time independent and normally distributed over time. The most common tests applied to test time, independence and normality, are the Portmanteau lack of fit test, the nonparametric Kolmogrov–Smirnov and Anderson–Darling tests [10]. The Statistical Analysis System (SAS) and Statistical Package for the Social Science (SPSS) softwares were used to for determinate of the best model for this series. The basic methodology of ARIMA development (Box and Jenkins modelling approach) is shown in Figure 2:

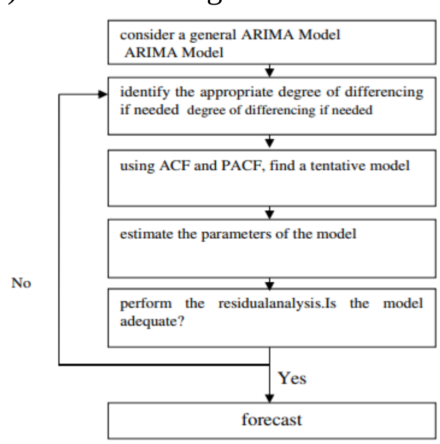

Figure 2. ARIMA model development.

4. Results

Befor to start of modelling, we must test the all series for normal distribution. In this study, the natural series have not normality therefore we gave Ln transformation of natural series (Tjelogirmajin in Figures 6-8). Plotting the observations of Ln natural data against time shows that there is increase trend for studied series. In this study, the Ln of natural series is not stationary and then has first differencing of Ln natural data to achieving stationary series (d=1. Therefore, the optimum level of differencing for the series was one and the d value used in the ARIMA model would be one (d=1). We try to fit an ARIMA model to the annual streamflow of the Karkheh River. We use annual streamflow such as peak and maximum and also mean discharge time series of this river in Jelogir Majin hydrometric station the period 1958-2005. Based on the ACF and PACF of the logarithmic series, three models are examined for further consideration. The first model is ARIMA(1,1,0), the second is ARIMA(1,1,1) and the third is ARIMA(4,1,1). All three models were suitable for modelling (Table 1). According to Akaike index (Table 2) the best model was ARIMA (4,1,1). The results of time independent and normal test of residuals show the adequacy of the three model estimated by CLS and ML methods. Therefore, the model ARIMA (4,1,1) for peak and mean discharge whose parameters are estimated by CLS method is the best model and the model ARIMA(4,1,1) for maximum discharge whose parameters are estimated by ML method is the best model. Figures 6-8 shows the model prediction and observed annual streamflow of the Karkhe River which match well together. The above selected model was then used for forecasting streamflow from 2006 to 2015 (Table 3). Comparing the observed and model forecasted streamflow indicates the same yearly variation for all series. This may imply the capability of the ARIMA model in forecasting.

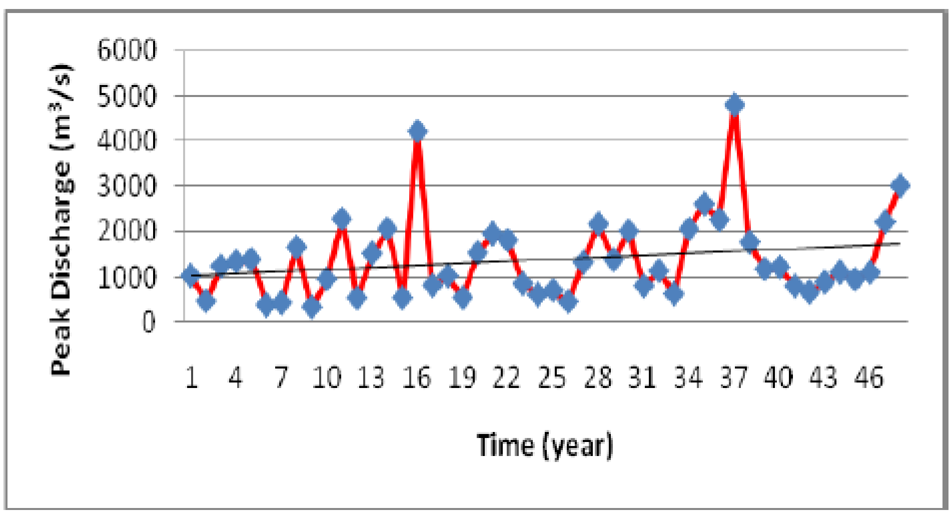

Figure 3. Original annual peak streamflow (Discharge) time series.

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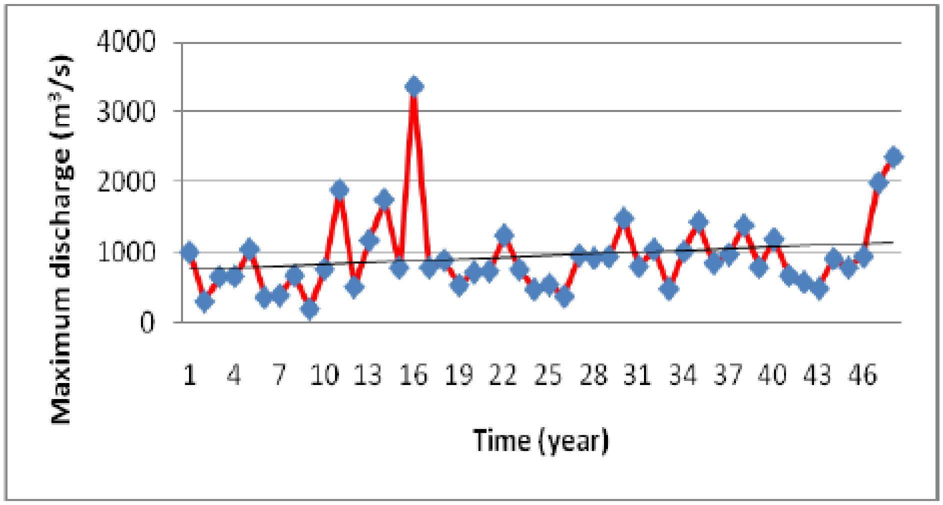

Figure 4. Original annual maximum streamflow (Discharge) time series.

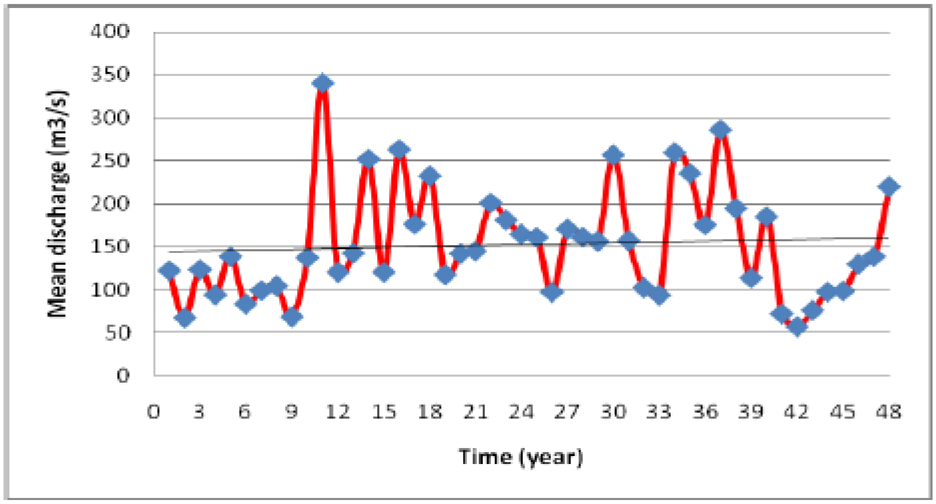

Figure 5. Original annual mean streamflow (Discharge) time series.

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Table 1. Result of parameter estimation for the selected model.

Parameter	Estimation Method	Type (Order) and Values of Parameters ARIMA(p,1,q)	Absolute Value of t	Probability of t	Stationary Condition	Invertibility Condition
Annual Peak StreamFlow	ML	P(1) = -0.48656 Q(0)	-3.81	0.0001	Satisfy	
	CLS	P(1) = -0.48713 Q(0)	-3.78	0.0005	Satisfy	
	ULS	P(1) = -0.49708 Q(0)	-3.88	0.0003	Satisfy	
	ML	P(1) = 0.10744 Q(1) = 0.93539	0.66 10.87	0.5104 0.0001<	Satisfy	Satisfy
	CLS	P(1) = 0.11274 Q(1) = 0.96723	0.69 15.99	0.4926 0.0001<	Satisfy	Satisfy
	ULS	P(1) = 0.12820 Q(1) = 0.99998	0.84 3.35	0.4072 0.0001<	Satisfy	Not Satisfy
	ML	P(4) = -0.3317 Q(1) = 0.86679	-2.25 9.89	0.0243 0.0001<	Satisfy	Satisfy
	CLS	P(4) = -0.33489 Q(1) = 0.86679	-2.19 13.48	0.0339 0.0001<	Satisfy	Satisfy
	ULS	P(4) = -0.36065 Q(1) = 0.89524	-2.4 11.84	0.0208 0.0001<	Satisfy	Satisfy
Annual Maximum StreamFlow	ML	P(1) = -0.51759 Q(0)	-4.14	0.0001<	Satisfy	
	CLS	P(1) = -0.49304 Q(0)	-3.84	0.0004	Satisfy	
	ULS	P(1) = -0.52951 Q(0)	-4.23	0.0001	Satisfy	
	ML	P(1) = 0.14873 Q(1) = 0.92809	0.86 8.16	0.3922 0.0001<	Satisfy	Satisfy
	CLS	P(1) = 0.230274 Q(1) = 0.97512	1.46 28.55	0.1501 0.0001<	Satisfy	Satisfy
	ULS	P(1) = 0.17543 Q(1) = 0.99999	1.13 3.35	0.2631 0.0016	Satisfy	Not Satisfy
	ML	P(4) = -0.26820 Q(1) = 0.74897	-1.71 6.36	0.087 0.0001<	Satisfy	Satisfy
	CLS	P(4) = -0.26824 Q(1) = 0.69253	-1.7 5.76	0.0964 0.0001<	Satisfy	Satisfy
	ULS	P(4) = -0.27556 Q(1) = 0.85681	-1.66 8.77	0.1031 0.0001<	Satisfy	Satisfy
Annual Mean StreamFlow	ML	p(1) = -0.41932 q(0)	0.13457	-3.12	0.0018	Satisfy
	CLS	p(1) = -0.41473 q(0)	0.13576	-3.05	0.0037	Satisfy
	ULS	p(1) = -0.42872 q(0)	0.13480	-3.18	0.0026	Satisfy
	ML	p(1) = 0.36414 q(1) = 0.99994	0.15423 52.247	2.36 0.02	0.0182 0.9847	Satisfy
	CLS	p(1) = 0.34486 q(1) = 0.96630	0.15246 0.04271	2.26 22.62	0.0286 0.0001<	Satisfy
	ULS	p(1) = 0.35777 q(1) = 0.99998	0.14375 0.29826	2.49 3.35	0.0166 0.0016	Satisfy
	ML	p(4) = -0.1636 q(1) = 0.66032	0.15570 0.12124	-1.5 5.45	0.2933 0.0001<	Satisfy
	CLS	p(4) = -0.17507 q(1) = 0.68987	0.15914 0.11569	-1.1 5.96	0.2771 0.0001<	Satisfy
	ULS	p(4) = -0.18146 q(1) = 0.68935	0.15870 0.11617	-1.14 5.93	0.2589 0.0001<	Satisfy

ML: Maximum Likelihood CLS: Conditional Least Square ULS: Unconditional Least Square

Table 2. Goodness of fit statistic.

Parameter	ARIMA model	Estimation Method	Akaikc's Statistic
Annual Peak StreamFlow	(1,1,0)	ML	103.4247
		CLS	103.4469
		ULS	103.4316
	(1,1,1)	ML	95.2824
		CLS	93.1350
		ULS	-
	(4,1,1)	ML	90.8381
		CLS	88.8680
		ULS	91.0387
Annual Maximum StreamFlow	(1,1,0)	ML	84.185
		CLS	84.9952
		ULS	84.1939
	(1,1,1)	ML	79.7781
		CLS	79.6182
		ULS	-
	(4,1,1)	ML	77.7478
		CLS	78.8943
		ULS	78.1438
Annual Mean StreamFlow	(1,1,0)	ML	57.72
		CLS	57.845
		ULS	57.725
	(1,1,1)	ML	53.275
		CLS	53
		ULS	53.275
	(4,1,1)	ML	52.706
		CLS	52.238
		ULS	52.766

Table 3. Forecasts from period 2006-7 to 2015-16.

Period	Forecast		
	Annual Peak StreamFlow	Annual Maximum StreamFlow	Annual Mean StreamFlow
2006-7	1451.13	1234.6	138.9
2007-8	1384.65	1176.4	132.5
2008-9	1091.6	962.1	130.9
2009-10	983.980	919.2	120.7
2010-11	1256.52	1091.7	130.8
2011-12	1276.4	1106	131.9
2012-13	1382.16	1167.2	132.2
2013-14	1431.11	1181.7	134
2014-15	1318.57	1128.3	132.2
2015-16	1311.6	1099.4	132

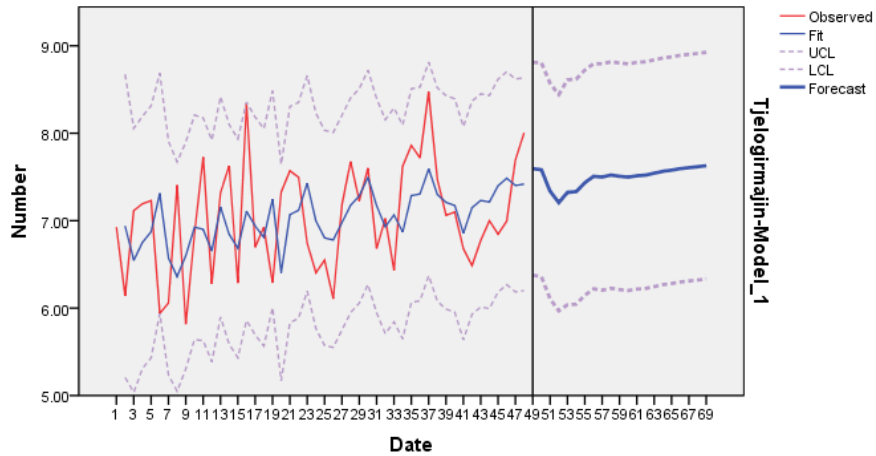

Figure 6. Observed and model prediction of peak streamflow of Karkheh river.

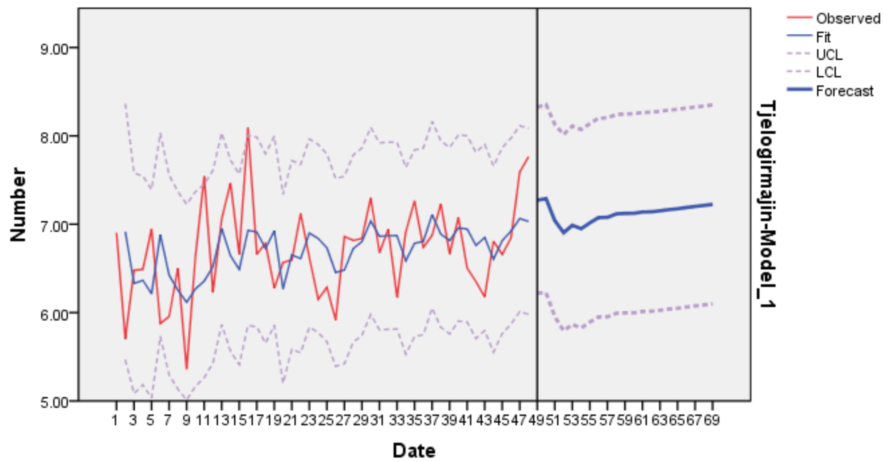

Figure 7. Observed and model prediction of maximum streamflow of Karkheh river.

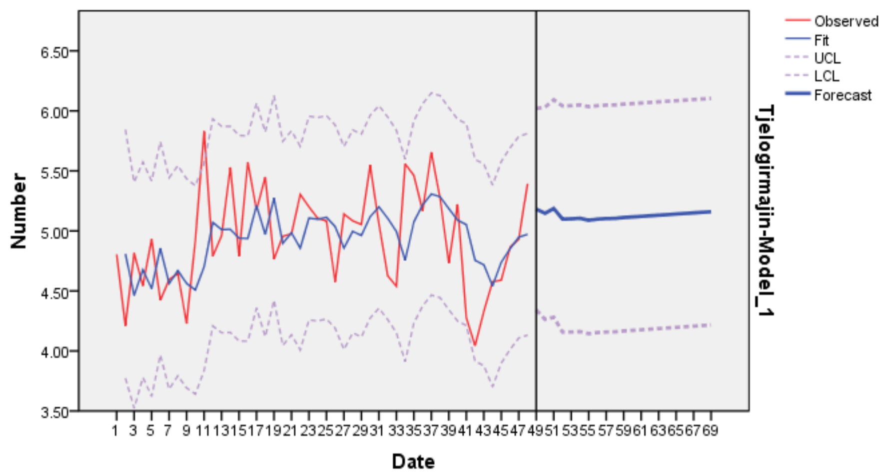

Figure 8. Observed and model prediction of mean streamflow of Karkheh river.

5. Conclusions and Discussions

In this research, we attempted to forecast Karkheh river streamflow in Jelogir Majin station (upstream of Karkheh dam reservoir) in Karkheh river basin at Iran using time series modelling (ARIMA models). The ARIMA model has a better performance than other ARMA stochastic model because it makes time series stationary, in forecasting. The model ARIMA (4,1,1) was fitted to annual streamflow in this river. Accepted model in this station give us ten years predicted along with their 95% confidence interval that can help decision makers to establish strategies, priorities and proper use of water resources in this river at Iran. The ARIMA models are suitable for short term forecasting because the ARMA family models can model short term persistence very well. These models are a finite memory model, thus it does not fare well in long term forecasting. The significant ACF and PACF functions with high order can be caused by factors such as area good vegetation and water from snowmelt. The good vegetation of the region and the forest causes water retention in the soil surface layer and delay in the rise in surface runoff. As well as vegetation reduces the power and erodibility destroyed by a severe storm (intense rain events happening across the region) and runoff from the storm drainage system seems to cause significant delays.

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