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Prediction of Annual Inflow to Karkheh Dam Reservoir using Time Series Models

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Abstract: The optimal exploitation of water from a dam reservoir requires a comprehensive knowledge of future availability of water resources. In this case the amount of water that will be available in the future is important. Also, we need to examine the flows at the dam from a short-term perspective. This is necessary to avoid overflowing and to minimize damage. In order to facilitate forecasting of the water resources, many different techniques have been developed through the years. In this paper, using annual mean flow data (since 1958-2005) obtained from Jelogir Majin hydrometric station at Karkheh River (upstream of Karkheh dam), an Auto Regressive Integrated Moving Average (ARIMA) model, for prediction of annual mean inflow to Karkheh dam reservoir was accomplished. On the basic of comparison the results of the model with measured data, the performance of ARIMA (4,1,1) model by Conditional Least Square (CLS) estimation parameter method is acceptable. The SAS and SPSS softwares were used to implement of the models.

Keywords: ARIMA, Reservoir, Time Series Model, Inflow Prediction, Karkheh Dam

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1. Introduction

Increased need to water resources with proper quantity and quality besides possessing temporal and spatial distribution adapted with operation needs required engineers and investigators of water sources to make more efficient managerial systems for hydrosystems. It is needless telling that accuracy in predicting the streams of forthcoming periods has valuable effect on the efficiency of decision support systems for operating the reservoir. Prediction includes approximating the future situation of a parameter with 4 dimensions: quality, quantity, space and time [5]. Regarding to the statistics in Iran, it seems that time series models are acceptable variants for developing the flow prediction model. The basic theory for developing mentioned models is that the future is a reflection of past and any statistical relation that could be found in the historical statistics can be generalized to the future. The main development of time series models and their concepts resulting in vast application of these models, were conducted by Box and Jenkins (1970 & 1976). The method used by these investigators was later called Box-Jenkins method and attracted the hydrologists. Musa (2013) studied flow discharge from the Shiroro river (since 1990-2011) by an Autoregressive Moving

Average model (ARMA) and analyzed with three different models namely; Autoregressive (AR), Autoregressive Moving Average (ARMA) and Autoregressive Integrated Moving Average (ARIMA) models. Based on the model analysis and evaluations, proper predictions for the effective usage of the flow from the river for farming activities and generation of power for both industrial and domestic us were made. It also highlights some recommendations to be made to utilize the possible potentials of the river effectively [4].

Shakeel et al. (1993) applied time series modelling of annual maximum flow of river Indus at Sukkur India. They find that ARIMA(2,1,1) was appropriate for these series [5]. Srikanthan et al. (1983) used time series models to analize annual flow of Australian streams. Autocorrelation and partial autocorrelation functions were applied to determine the appropriate form of Box-Jenkins time series models [6]. Stojković et al. (2015) studied stochastic structure of annual discharges of large European rivers. They suggested that the stochastic flows simulated by the model can be used for hydrological simulations in river basins [7]. In another study, Vijayakumar and Vennila (2016) suggested that ARMA(2,4) is the best model for generated annual inflow of Krishnagiri Reservoir in the state of Tamilnadu, India [8]. Hamidi Machekposhti et al. (2017) forecasted inflow of Karkheh dam at Iran by time series models and found that the ARIMA models are suitable for predicting of annual inflow series [2]. Adeli et al. (2015) used stochastic models to produce artificial time series and inflow prediction in Talog dam reservoir in Khuzestan province at Iran. The results of modelling showed that ARMA(2,3) was the best in comparison with the other models [1]. Similar research results indicate the ability and advantage of time series models to predict the flow of the river.

In this study, we used time series models such as ARMA and ARIMA models to predict Karkheh river flow at the entrance to Karkheh dam reservoir in Jelogir Majin hydrometric station.

1.1. Case study

Here we use a time series model for predicting the annual inflow to Karkheh dam reservoir. Karkheh dam is the largest dam construction in Iran. This is built on Karkheh river, the third largest river in Iran with 900 kilometer in length. It is in the Northwestern province of Khuzestan, the closest city being Andimeshk. It is 127 meter (417 ft) high and has a reservoir capacity of 5.9 billion cubic meter. This dam is located in geographic longitudinal and transversal 46˚ 57′ - 49˚ 10′ E and 31˚ 48′ - 34˚ 56′ N, respectively. The reservor shows different uses:

i) To Control the devastating floods of Karkheh stream;
ii) To Regulate the water for irrigation usage and;
iii) To Provide required force for power supply.

Figure 1 shows the study area location. The average inflows to Karkheh dam from 1958 to 2005 in Jelogir Majin hydrometric station (upstream of Karkheh dam) are shown in Figure 2. Data was provided from Iran Water Resources Management Organization (IWRMO).

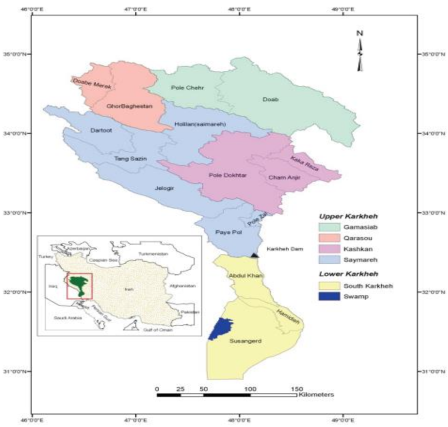


Figure 1. The study area location

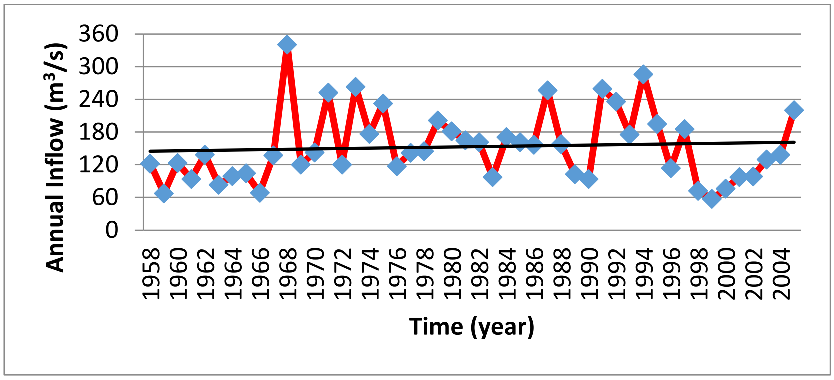


Figure 2. Time series for the annual inflow to Karkheh dam reservoir

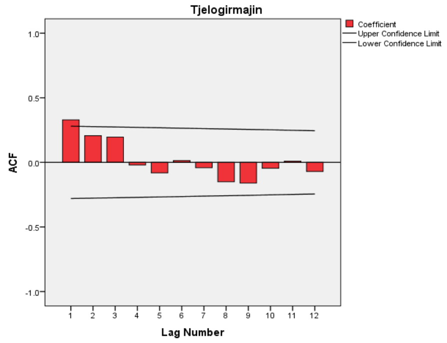
2. Methods

Method of this study is conducted by time series analysis, one of these methods called ARIMA method or Box-Jenkins model or (p,d,q) model. In any (p,d,q) model, p indicates the number of autoregressive, q is the number of mobile mean and d is the order of non-seasonal differencing as well as indicating the number of orders needed for attaining the series to a kind of statistical balance. In the first stage, the analysis of initial values of p, d and q is determined by Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF). By accurately studying the ACF and PACF charts and their components, the general view for presence of time series with trend and their properties are obtained. Then in the second stage, it is examined if p and q values, indicating the autoregressive and mobile mean, remain in the model or must be removed from. In the third stage, it is reviewed whether the residual values, residual error are random and with normal distribution or not. In this case, one can say that this model enjoys proper fitness. A special type of non-seasonal models indicating the proper results and adapted to the general structure of ARIMA models according to Box-Jenkins (1976) called non-seasonal model. This model is ARIMA (p,d,q). Then for ideal model, it must be used models for testing the model and compared among them to select best model for prediction.

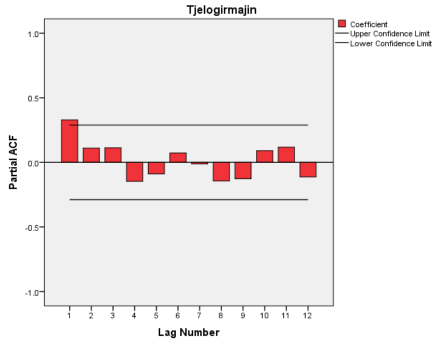
During time series analysis or generally in data analysis, it may be used several proper model for indicating a given data set. When applying the ARIMA model, the Akaike Information Criterion (AIC) has higher accuracy and it acts better comparing two ARIMA model for selecting the best fitting function. In this study there was used ARIMA and AIC test for modelling the inflow to reservoir and studying their effects on each other. According AIC test any model with minimum AIC value is suitable for prediction. After determining the type of model and its parameters as well as determining the proper AIC value, for validating the model, crop years 2006 to 2015 were considered as control and actual values were compared with predicted values.

3. Results and Discussion

Time series diagram for inflow to Karkheh dam reservoir indicated in Figure 2. ACF and PACF diagrams have drawn in Figure 3 to determine the initial model. The regular non-seasonal changes are indicated by these diagrams. The series are not static and show non-seasonal changes.



(**a**)



(**b**)

Figure 3. Diagram for (**a**) ACF and (**b**) PACF of time series of annual inflow to Karkheh dam reservoir

Consequently, the variability of time series will be increased over the time, therefore, data series is not static in variance and it could become static by Box-Cox method. The Maximum Likelihood (ML), Conditional Least Square (CLS) and Unconditional Least Square (ULS) methods are used to estimate the model parameters. The result of values for the parameters estimation of three selected models (1,1,0), (1,1,1) and (4,1,1) show in Table 1. This table shows that all three models are suitable for modelling this data. Therefor we select the best model with Akaike Information Criterion (AIC). For verifying the model we used ACF and PACF diagram for residuals of inflow to dam reservoir in Figure 4 where the auto correlations were in the range of zero and the assumption for independency and stochastic data was accepted.

Also result of auto correlation check of residuals for data is given in Table 2. The goodness of fit statistic for this data is in Table 3. Finally, the best model for predicting the values of inflow to Karkheh dam reservoir is ARIMA (4,1,1) which estimate by CLS method. Forecasting of annual mean flow from period 2006 to 2015 came in Table 4 and the correlation between actual values and predicted values indicated in Figures 5 and 6.

Table 1. Result of parameter estimation for the selected models

Parameter	Estimation Method	Type (Order) and Values of Parameters ARIMA(p,1,q)	Std. Error	Absolute Value of t	Probability of t	Stationary Condition	Invertibility Condition
Mean Annual Flow	ML	p(1) = -0.41932	0.13457	-3.12	0.0018	Satisfy	
		q(0)					
	CLS	p(1) = -0.41473	0.13576	-3.05	0.0037	Satisfy	
		q(0)					
	ULS	p(1) = -0.42872	0.13480	-3.18	0.0026	Satisfy	
		q(0)					
	ML	p(1) = 0.36414	0.15423	2.36	0.0182	Satisfy	
		q(1) = 0.99994	52.247	0.02	0.9847		Not Satisfy
	CLS	p(1) = 0.34486	0.15246	2.26	0.0286	Satisfy	
		q(1) = 0.96630	0.04271	22.62	0.0001<		Satisfy
	ULS	p(1) = 0.35777	0.14375	2.49	0.0166	Satisfy	
		q(1) = 0.99998	0.29826	3.35	0.0016		Not Satisfy
	ML	p(4) = -0.1636	0.15570	-1.5	0.2933	Satisfy	
		q(1) = 0.66032	0.12124	5.45	0.0001<		Satisfy
	CLS	p(4) = -0.17507	0.15914	-1.1	0.2771	Satisfy	
		q(1) = 0.68987	0.11569	5.96	0.0001<		Satisfy
	ULS	p(4) = -0.18146	0.15870	-1.14	0.2589	Satisfy	
		q(1) = 0.68935	0.11617	5.93	0.0001<		Satisfy

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

Table 2. Result of autocorrelation check of residuals

Parameter	ARIMA Model	Estimation Method	To Lag	Df	Chi-Square	Pr>Chi Square	Adequacy for Modelling
Mean Annual Flow	ARIMA(1,1,0)	ML	6	5	8.04	0.1540	Satisfy
			12	11	11.80	0.3792	
			18	17	17.84	0.3990	
			24	23	26.29	0.2875	
		CLS	6	5	7.87	0.1636	Satisfy
			12	11	11.83	0.3764	
			18	17	17.88	0.3963	
			24	23	26.24	0.2898	
		ULS	6	5	8.08	0.1517	Satisfy
			12	11	11.87	0.3733	
			18	17	17.97	0.3906	
			24	23	26.52	0.2771	
	ARIMA(1,1,1)	CLS	6	4	3.17	0.5296	Satisfy
			12	10	4.99	0.8920	
			18	16	8.33	0.9386	
			24	22	11.96	0.9583	
	ARIMA(4,1,1)	ML	6	4	2.98	0.5618	Satisfy
			12	10	6.31	0.7883	
			18	16	11.02	0.8082	
			24	22	16.88	0.7699	
		CLS	6	4	3.1	0.5416	Satisfy
			12	10	7.19	0.7074	
			18	16	11.74	0.7617	
			24	22	17.32	0.7455	
		ULS	6	4	3.01	0.557	Satisfy
			12	10	6.34	0.7858	
			18	16	10.94	0.8134	
			24	22	16.57	0.7866	

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

Table 3. Goodness of fit statistic

Parameter	ARIMA model	Estimation Method	Akaikc's Statistic
Mean Annual Flow	(1,1,0)	ML	103.4247
		CLS	103.4469
		ULS	103.4316
	(1,1,1)	CLS	93.1350
	(4,1,1)	ML	90.8381
		CLS	***88.8680***
		ULS	91.0387

Table 4. Forecasts from period 2006-7 to 2015-16 for mean annual inflow

Period	Forecasted	Observed
2006-7	139	135
2007-8	133	131
2008-9	131	128
2009-10	131	130
2010-11	127	125
2011-12	132	127
2012-13	132	131
2013-14	134	
2014-15	132	
2015-16	132	

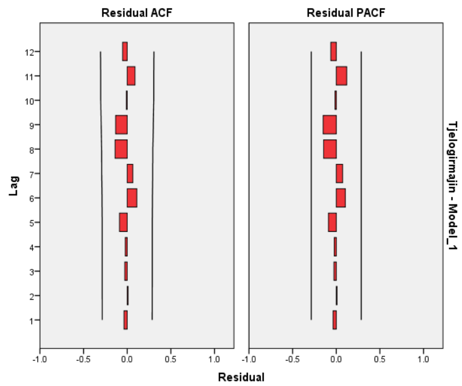


Figure 4. Autocorrelogram of residual series parameter

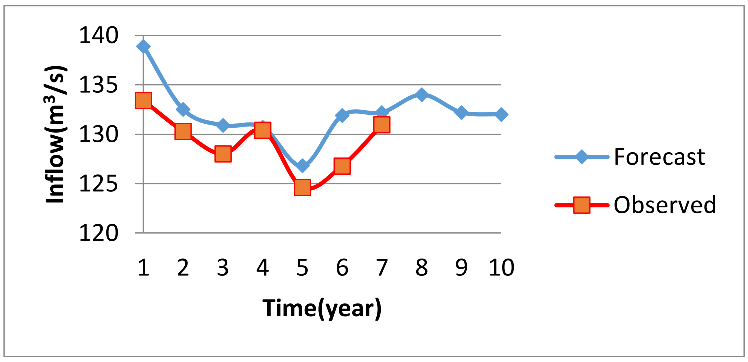


Figure 5. Comparison of forecasted and observed annual inflow (2006-2015)

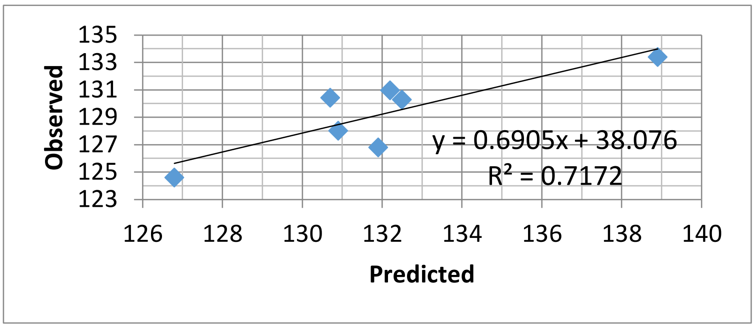


Figure 6. Correlation between actual values and predicted values of annual inflow to dam reservoir

4. Conclusions

Recognizing fluctuations of inflow during statistical period and predicting them are necessary for planning. Results from reviewing the annual average inflow with reviewing the diagrams indicated that:

• In order for predicting the studied parameters, there was used Box-Jenkins model and finally they assessed by providing final model. The correlation coefficient between predicted and observed annual inflow to Karkheh dam reservoir obtained about 0.72. Therefore, considering the higher accuracy of model, it culd be used for anticipating the annual mean inflow.

• ARIMA (4,1,1) model was the best model for annual average inflow to dam reservoir and it has lower Akaike vales than other models (AIC=88.89).

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