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ORIGINAL ARTICLE

Precipitation and Runoff Forecasting and Analysis Using Stochastic Models (Case Study: Urmia Lake Catchment area)

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ABSTRACT
The basis of many decision makings in hydrological processes and decisions of exploitation of water resources is premised on time series analysis and forecasting. In this research, in order to provide a statistical model and then forecasting of precipitation status and the resultant runoff in the Urmia Lake catchment area, the time series models were used. For modeling, 42 – year monthly rainfall statistics (1970- 2010), and 42 – year monthly irrigation statistics (1970- 2010) were used. Seasonal Arima model, SARIMA (0,0,5)(1,1,2)12 for precipitation and SARIMA (1,1,5)*(1,1,2)12 for runoff, was identified as the best model to forecast flood for the next 12 years with the confidence level of 95 per cent. To recognize the accuracy of the processed pattern, residual analysis tests, residual independence hypothesis investigation and residual variance constant hypothesis estimation were used. The calculations indicated that the percentage changes in average monthly rainfall for the next 12 years, compared with the previous three rounds, has been -0.331 (1975-86), -9.7 (1987-98), 6.19 (1999-2010) per cent, respectively, and this is despite the fact that the percentage of changes for runoff is -96.08 (1975-86), -110.88 (1987-98), -18.67 (1999-2010) percent.**
** The negative sign indicates reduction and the positive sign shows increase compared with the previous round.*
Key Words: *Stochastic, Precipitation (Rainfall) and Runoff, Time Series*

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INTRODUCTION

The basis of many decision makings in hydrological processes and decisions of exploitation of water resources is premised on time series analysis and forecasting. As an instance, exploitation from dam reservoirs in real time requires knowledge of the estimated future inflows to the reservoir, which is feasible by river flow time series forecasting. In the science of statistics, the word "stochastic" is synonym with probability of random; however, in hydrology, this word is come to express a specific method for referring to a series of partly random time data, and, in fact, fills the gap between probabilistic methods in hydrology and deterministic hydrology (the basis of random variables are premised on time series) [1-8]. In this study, using precipitation and flood statistics of Urmia Lake catchment in the years 1968 – 2010 and exploiting stochastic techniques (time series), the amount of precipitation and flood is predicted and estimated for the next 12 years. Subsequently, the correlation between precipitation and runoff for contemporary and future years is compared. All the procedures for conducting this research have been performed using Minitab 16 software [9-11].

Factors Forming Time Series

1 – Trend (Tt)

Increasing or decreasing changes in the average value of a series is called trend.

2 – Seasonal Variations (St)

These are seasonal changes which occur at short-term intermittent periods (annual, seasonal, monthly or other time periods).

3 – Irregular Changes or Jump (Kt)

These changes are sporadic movements in a time series which do not follow a regular or certain pattern and are usually induced by unusual events that are unpredictable and difficult to work with in time series.

4 – Random Variable (ε_t)

Being random is due to the uncertain nature of time series changes. The randomness of a time series can be independent or self-dependent with one another. For statistical modeling, the most important stage is the modeling of the series' random part.

(1 $$X_t = T_t + S_t + K_t + \varepsilon_t$$

Fathabadi et al. [1] applied time series model and neural networks for the prediction of Taleqan River discharge and selected ARIMA (3,0,0)*(0,1,1) as an appropriate model for forecasting and demonstrated that the time series model reveals a better estimation than neural networks.

General Pattern of Box and Jenkins

Box and Jenkins have had a significant role in providing a general method for time series forecasting. They, with emphasis on differentiation, can make patterns for non-stationary series and the general category of ARIMA models is attributed to them. Recently, in order to analyze the changes of regional parameters, scientists have attempted the modeling and then simulating of these parameters. Modeling in families of ARMA, ARIMA and seasonal multiplicative ARIMA or SARIMA (Seasonal Autoregressive Integrated Moving Average), is one of the important and valid methods in the simulation of climatic parameters.

MATERIALS AND METHODS

In this research, using 42 – year monthly precipitation – runoff statistics (1968 – 2010), first the next 12 years of these two parameters in Urmia Lake catchment area are forecasted and afterwards, by comparing the predicted values with the real data, the correlation between precipitation – runoff will be obtained.

The studied region has been demonstrated in figure number (1).

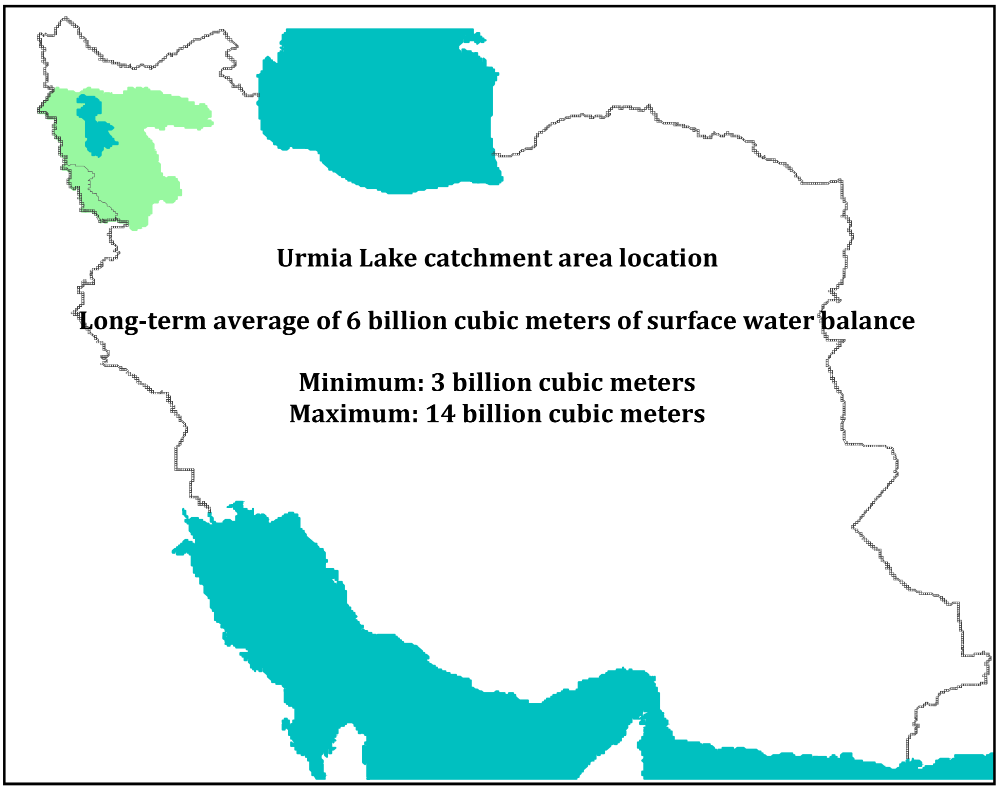

Figure 1: Urmia Lake Catchment Area Location

In order to study time series, in the first step, the static variance of the data under study should be evaluated through Bartlett & Levene's test. The work basis in this test (with confidence level of usually 95%) is the variance test. At the confidence level of 95 per cent, if the p-value of Bartlett & Levene's test is

less than 0.05, the data is non-stationary in variance and abnormal. For making the data variance static, Box-Cox transformation is used.
At the next stage, in order to make static and eliminate the trend and seasonal changes, the seasonal and non-seasonal differentiation is used. To determine the seasonal and non-seasonal differentiating rates, autocorrelation plot or variance minimization is utilized.
In order to determine seasonal and non-seasonal moving average and autoregressive degrees (P, Q, p, q), PACF and ACF charts, obtained from differentiated data set, are applied.
After identifying the appropriate model or models for data, in order to recognize the best model, the two following methods are used, which are complementary:
The analysis of the residuals of the fitted model and Perth-Mantoux test for the detection of random or uncorrelated residuals.
Analysis of the models that have more parameters (over fitting).
(If several appropriate models have been detected, Akaike's criterion is used)
In the end, forecasting is conducted, using the most fitting model. Comparing the predicted data with the last three 12-year rounds (on a monthly basis), degree of dependence of these two values for the precipitation and runoff of the intended catchment is obtained.

RESULTS AND DISCUSSION

Based on the conducted calculations by miniTab16 software, the best detected models for Urmia Lake catchment area are tables (1) and (2), respectively.

Table 1 – Calculated parameters for precipitation

Coefficients / Detected Model	P	d	q	P	D	Q
SARIMA (1,1,5)*(1,1,2)12	1	1	5	1	1	2

Table 2 – Calculated parameters for runoff

Coefficients / Detected Model	P	d	q	P	D	Q
SARIMA (0,0,5)*(1,1,2)12	0	0	5	1	1	2

By fitting the above models to data and analyzing the residuals using Perth-Mantoux test, the following results (tables 3 and 4) were achieved:

Table 3 – Parameters of the fitted models for precipitation

Comparison Parameters	SARIMA (0,0,5)*(1,1,2)12			
Lag	12	24	36	48
Chi-Square	4.7	16.9	29.6	41
Degree Of Freedom	4	16	28	40
P-Value	0.324	0.393	0.384	0.427

Table 4 – Parameters of the fitted models for runoff

Comparison Parameters	SARIMA (1,1,5)*(1,1,2)12			
Lag	12	24	36	48
Chi-Square	3.4	20.2	34.2	43.9
Degree Of Freedom	4	16	28	40
P-Value	0.339	0.165	0.160	0.271

In Perth – Mantoux test, if both of the following conditions are met, the model is deemed appropriate:

First condition: when the value of the obtained Chi – Square statistic is more than its corresponding value in the Chi-Square table, H0 hypothesis is rejected based on the randomness of the fitted model data, i.e. the data is correlated (non-random).
Second condition: the obtained P – Value must be larger than α value (error percentage) which usually equals 0.05.
The results of residual analysis of the selected fitted model for precipitation and runoff are given in figures 2 and 3.

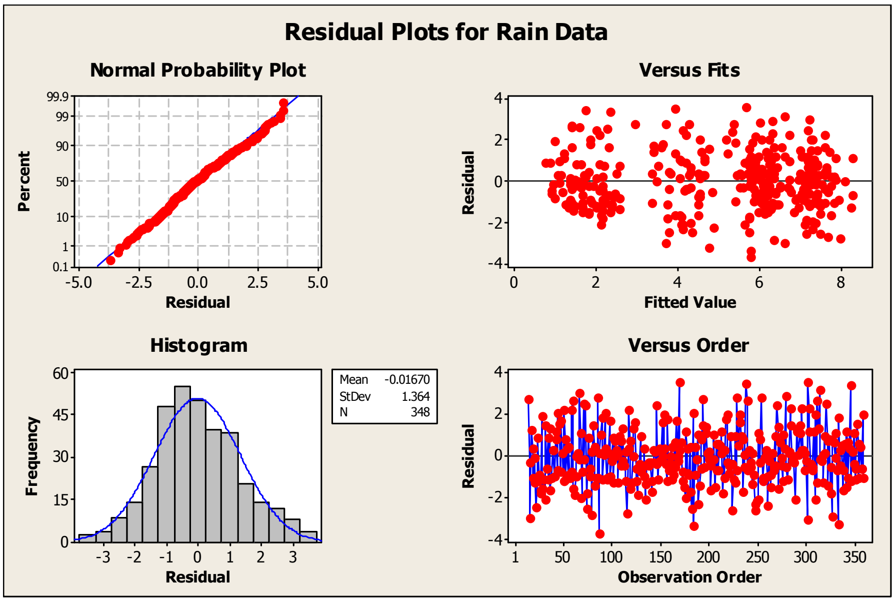

Figure 2 – Residual analysis of the precipitation fitted model

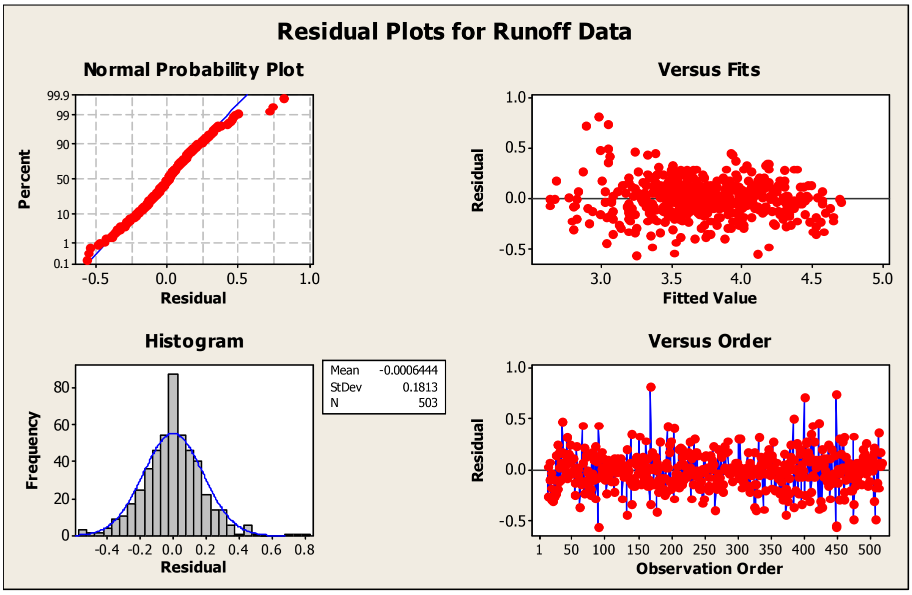

Figure 3 – Residual analysis of the runoff fitted model

The comparisons of monthly average of the forecasted data and that of the last three 12-year rounds for precipitation and runoff have been provided in tables 5 and 6.

Table 5 – Comparing change percentage of available data (three rounds) with the forecasted data for precipitation (cm)

forecasted	54-65	66-77	78-89
26.85	26.94	29.74	25.28
Change percentage	-0.33	-9.71	6.19

Table 6 – Comparing change percentage of available data (three rounds) with the forecasted data for runoff (cm^3)

forecasted	54-65	66-77	78-89
238.17	467.02	502.26	282.65
Change percentage	-96.08	-110.88	-18.67

CONCLUSION AND SUGGESTIONS

Tables 5 and 6 demonstrate the change percentage of monthly average of precipitation and runoff for the available and forecasted data. It is observed that in the last two rounds (years 1975 – 98), with increase and decrease of precipitation, the runoff rate also increases and decreases (direct correlation) and this value has severely declined for the most recent round, since with 3 millimeter decrease in precipitation, the runoff rate has also decreased to 200 million cubic meter, which is indicative of disturbance in the natural trend of Urmia Lake catchment area. Moreover, the 12-year forecasting for precipitation and runoff (on a monthly basis) reveals that the precipitation rate in the next 12 years will increase to 6.19% compared with the last 12 years and that the runoff rate will decrease to 18.67%. The assessments indicate that precipitation increase has no impact on runoff increase. Factors such as construction of large dams for water storage and preventing water below catchment areas from draining into the lake, climate change phenomenon, phenomena such as successive droughts in the past few years and indiscriminate harvesting of surface water for agriculture can be searched. To deal with these problems, there is no alternative but to apply coherent and unified management of available water resources.

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