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Impact Assessment of Hydroclimatic and Stochastic Variations on Water Stress of Jhelum River Flow Forecast

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Abstract: The hydrological system of a country significantly influences the ecological, agricultural and consequently the economic structure. Since, the accessibility of water resources has governed the power generation sector and agronomic establishments of the region like Pakistan. Moreover, Pakistan is sensitive in climatic variation and faces gradually higher threats regarding rainfall variability, floods and prolonged droughts. Sometimes, these climate change impact embedded with the high frequency and strength of extreme events caused by global warming. These extreme situations occur mostly in the hydrological phase that occurs because of the unexpected variations in temperature and rainfall. UN-ICC report pronounces that Pakistan is in top four unsafe countries that are undesirably affected by climate variability. The water stress Index established by Mallin Falkenmark conferred that Pakistan is in the list of countries that can face serious scarcity of water as its population is continuously increasing and water resources are shrinking. A perfect assessment of upcoming water resources under fluctuating climatic situations is significant for water resource availability and management. This study analyses the impact of hydroclimatic and stochastic conditions of river flow prediction and forecast of Jhelum River flow at Mangla station (second major reservoir of Pakistan, serve about 6 million hectares of cultivated area and generating 6% (about 1000MW) of the country's electrical power generation). Forecasting of river flow is helpful in understanding the prevailing situation of climate variations. The preliminary analysis of 34 years monthly data (Jan. 1976 to December 2010) of river flow, temperature and precipitation indicates that the precipitation of the seasonal and monsoon rainfall (June to September) is dominant on the yearly cycle. During these months the temperature rise is at its year maximums, so, the melting of snow/glaciers contributes a large amount of water in the natural river flow. The autocorrelation function (ACF) shows a strong seasonal variation of river flow, correlation analysis shows that the strong contribution of monsoon and orographic regular runoff is significant. To include the embedded periodic variation of the river flow, seasonal autoregressive moving average (SARIMA) will be used to predict and forecast the river flow. Additionally, the stepwise linear regression is applied to analysis the regular flow along with climatic variations by multiple linear regression show good results and will be helpful in forecasting of the river flow on monthly and annual basis. However, the reduce prediction and forecast accuracy shows that the inconsistence stochastic and hydroclimatic influenced river flows variation from the last 20 years, may be caused by Global and local impact. The results of this study are hoped to contribute considerably in current and future hydrological researches and studies, particularly in the Jhelum River flow at Mangla station of Pakistan.

Keywords: Hydroclimatic, Stochastic, Time Series, Jhelum River, Monsoon

1 Introduction

Pakistan is a state in which major portion of the economy is based on agriculture which requires a large quantity of water. The implementation of this requisite is done by the Indus River system (IRS) which comprises of Indus, Jhelum, Sutlej, Chenab and Ravi rivers. Pakistan's power generation zones and agronomic structure depends on the accessibility of water resources and a reliable forecast which helps to manage power generation of the country. The monsoon precipitation and melting of glaciers of the northern areas contributes a significant quantity of water to the IRS in summer season [1-2]. Whereas, in the winter season, water from melting of snow/glaciers, fountains and minimum precipitation (extensively lesser than the summer monsoon precipitation season) supports the lowest level of the river [3]. The average estimated flow of rivers on the basis of seasons is considered to be normal, however, unexpected variation in the regular flow due to sudden climate change can be seen on different occasions [4-5]. Sometimes, trivial variations in climate disturb the usual river flow causing droughts or flood situation which affects the populations in the riverine areas and the eco-hydrological system of the country. UN-ICC report pronounces that Pakistan is in the top four unsafe countries as it is unenviably affected by climatic variation and was the worst hit

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by the terrible flood in 2010 [6]. The severe deficiency of water in one and heavy flooding in other season produced by the coaction of these dynamics and put some inconsistency measured in the river flow at the inter-annual time scale.

Pakistan faces flood almost every year in its river system. Floods are usually initiated by substantial short duration of rainfall from the monsoon depression (either comes from the Bay of Bengal or from the Arabian Sea) in summer season [7]. The usual river flow is further intensified due to the melting of snow-glacier of mountain areas [8] due to hot summer seasonal high temperature. This extensive flow of water not only fulfil the demand of water of the country, but also sometimes becomes the reason of flood as there is no proper planning done regarding water management in the country. The flood becomes hazardous sometime due to above average monsoon/seasonal rainfall and temperature or because of unreliable and superseded forecasting. This causes an enormous damage to infrastructure, agricultural region, socioeconomic structure, the lives of human beings and livestock's. In 1992 Pakistan confronted a vilest flood of its history after 1959, when 1,045,000 cusecs flood devastate in Jhelum River at Mangla [7]. In September 1992, a five day spell of massive rainfall brought a devastating huge flood [7] at Mangla station. Their dangerous effects can be lessened by providing a reliable forecast in the respective areas.

The research regarding runoff behaviour and modelling of river flow has been done in past studies. Archer and Fowler [3], and Qureshi [9] forecasted the seasonal and collective discharge flow of Jhelum River with the impact of precipitation and temperature, while the relative importance of snow accumulation and monsoon rainfall data for estimating annual runoff is carried out by [10]. The potential impacts of climate variability on water discussed by Mahmood et. al. [11], whereas, Mahmood & Jia [12] examined the variation of climate using GCM (General circular model) while the effects of temperature on the runoff of the stream passing through the Jhelum river at Mangla station were examined by Yaseen et al. [13]. Moreover, the forecasting of the river flow using time series method carried out by Nigam et al. [14]. All these studies are based on analysing the behaviour of the river flow runoff and its modelling.

This paper will conduct hydrological modelling, prediction and forecasting of mean monthly river flow of Jhelum River at Mangla Dam utilising stochastic time series and Multiple linear regression (MLR) methods . Fig 1 describes the study area, the Jhelum River and watershed to Mangla reservoir. A reliable and improved prediction regarding floods can be supportive for water resource management at downstream locations and flood rescue departments as it can issue the warnings before the floods. Forecasting of river flow is also helpful in understanding the dominant condition of climate variations [6].

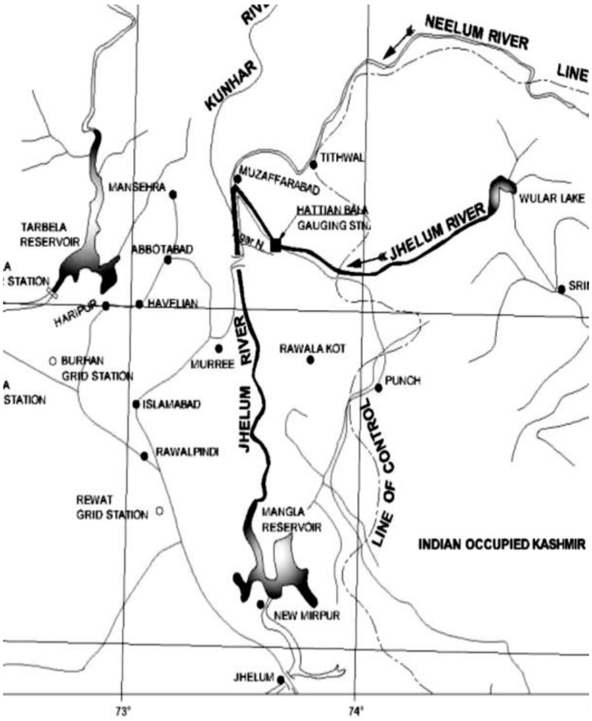


Figure 1 Study area of Jhelum River

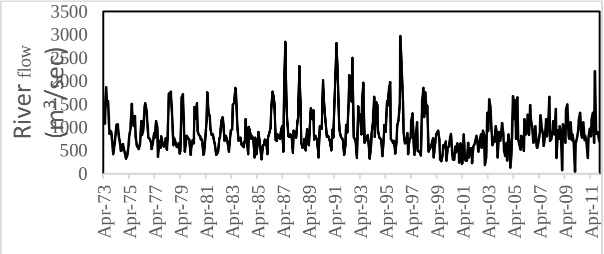


Fig 2 Time series plot of Jhelum River (Apr., 1973 to Dec., 2011)

2 Data and Methodology

This paper consider monthly data of precipitation and temperature for the duration of January 1976 to December 2010, collected from Pakistan meteorological department (Fig. 3 & 4). And of river flow data of the same epoch collected from Sind irrigation department (Fig. 2). After conducting preliminary analysis, stochastic time series modelling of SARIMA (Seasonal Auto-regressive Integrated Moving Average) will be used to predict and forecast the river flow. Moreover, further investigation provides the relation of Hydroclimatic variations with the seasonal river flow. This has been promptly accommodated by MLR modelling, using stepwise method. The consequent suggested models of MLR provide good results and will be helpful in forecasting of the river flow on monthly and annual basis.

The precipitation of the cities contributes the river flow throughout the year as concurrent rainfall runoff and as time delayed temperature dependent snowmelt runoff (Table 1, Fig. 3). On the basis of the annual sum of precipitation values (Table 1) of Murree, Islamabad and Kotli show substantial rainfall whereas Sialkot shows reduced rainfall. In the monsoon season (June, July, August and September months), almost every city collects the bulk amount of yearly precipitation (Fig. 3 & 5a).

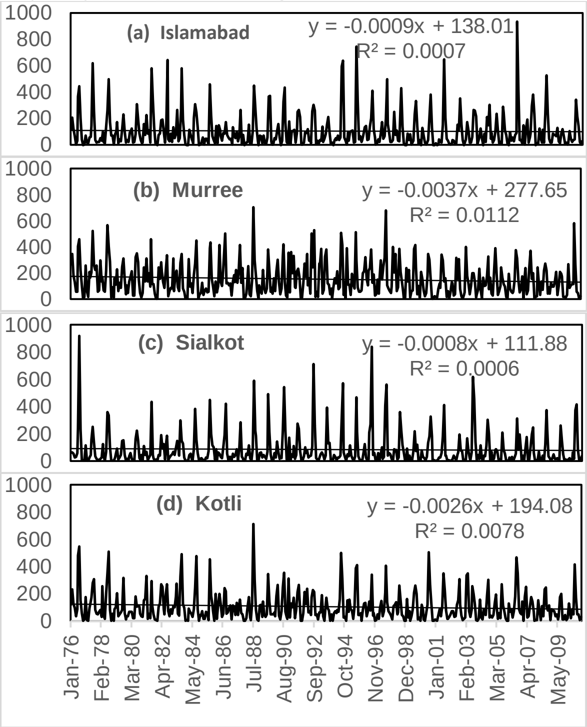
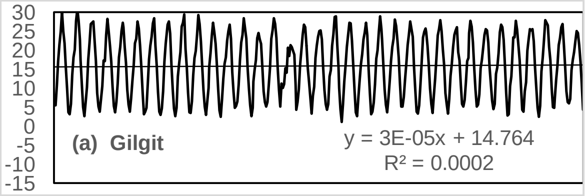


Figure 3 Time series plot of rainfall (Jan 1976 to Dec 2010) (a) Islamabad (b) Murree (c) Sialkot and (d) Kotli. Overall reduction in the rainfall observed by the negative slop values of the each trend line equation. Moreover, it is also observed that low frequency of the small and large rainfall events since 1994 as compared to 1976 to 1994 duration



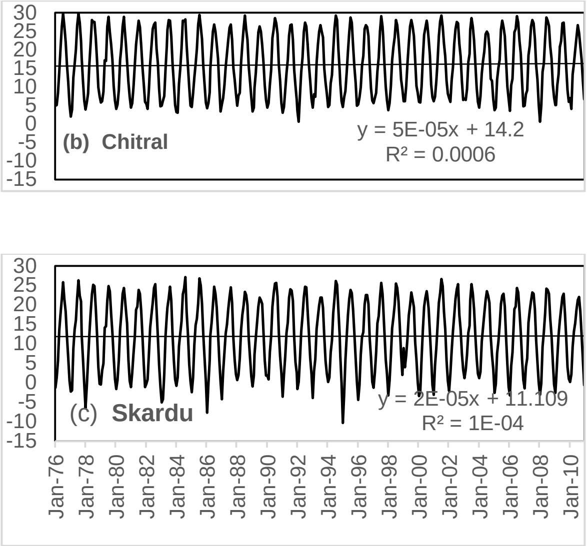


Figure 4 Time series plot of temperature (Jan 76 to Dec 10) (a) Chitral.(b) Gilgit and (c) Skardu. All three graph shows very low rising trend as mention with the slop value of the trend line. During 1993 to 2004 it shows some annual minimum and maximum variations narrowing (i.e. due to raising trend in the minimum temperature) temperature. From 2004 on words the avg. annual mean temp reduce some level with reduced annual min max range

Moreover, it is observed that Kotli, Murree and Islamabad collects some precipitations in winter season (Fig. 5a). The intensity and annual pattern (illustrates the twelve-month cycle) of temperature of Chitral, Gilgit, Skardu (Fig. 4 & 5b) supports the regional regular snow-glacier melts runoff [15]. These seasonal/annual variations of rainfall and temperature influence the regional river flow can be analysed by ACF and PACF analyses. The ACF analysis of Jhelum River flow (Fig. 2) shows a strong seasonal variation along with some dominant early lag values (Fig. 6a) identify the existence of autoregressive and order of moving average components. Likewise, the PACF plot (Fig. 6b) helps to identify the order of autoregressive and existence of moving average components. It is very supportive in finding the seasonal autoregressive integrated moving average SARIMA models [1]. The cross-correlation analyses shows that the local temperature (Chitral, Gilgit, Skardu) has significant influence on the river flow (Table 2, Fig. 7b), however, precipitation (Table 2, Fig. 7a) demonstrate less influential.

Table 1 Preliminary Analysis of precipitation (mm) and temperature (°C) of different cities

Mean Monthly Temperature				Sum of monthly precipitation			
	Chitral	**Gilgit**	**Skardu**	**Islamabad**	**Kotli**	**Murree**	**Sialkot**
Annual Sum				44400.90	43858.10	63582.60	35083.40
Mean	16.016	15.883	11.920				
Median	16.100	16.300	12.600	56.60	69.15	119.00	38.80
Mode	26.3	21.1	12.9	0.00	0.00	0.00	0.00
Standard Deviation	8.238	8.030	8.988	132.97	110.21	128.92	126.91
Sample Variance	67.857	64.474	80.790	17682.00	12145.85	16619.85	16106.39
Minimum	0.600	1.100	-10.300	0.00	0.00	0.00	0.00
Maximum	29.800	30.700	27.100	935.20	711.00	704.30	917.60

Table 2 Correlation of mean monthly river flow at Jhelum River with Precipitation and Temperature of different cities

Jhelum River flow at Mangla station	Precipitation cities				Temperature cities		
	Islamabad	**Kotli**	**Murree**	**Sialkot**	**Gilgit**	**Skardu**	**Chitral**
	0.189	0.195	0.213	0.231	0.410	0.414	0.412

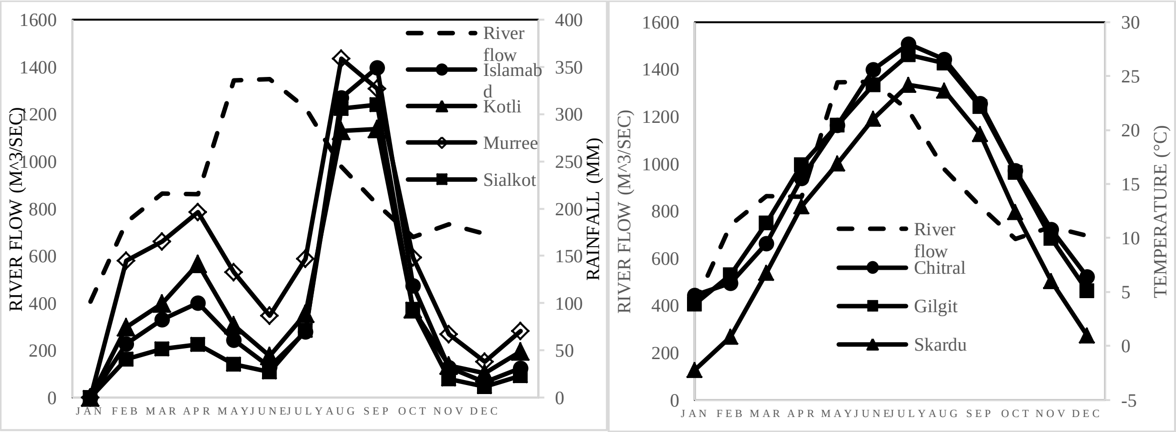


Figure 5 Seasonal plot of Jhelum River with (a) sum of annual precipitation (b) Mean monthly temperature

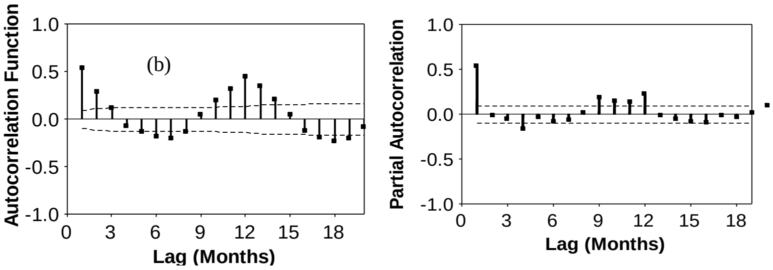


Fig. 6 Jhelum River flow (a) ACF and (b) PACF plot

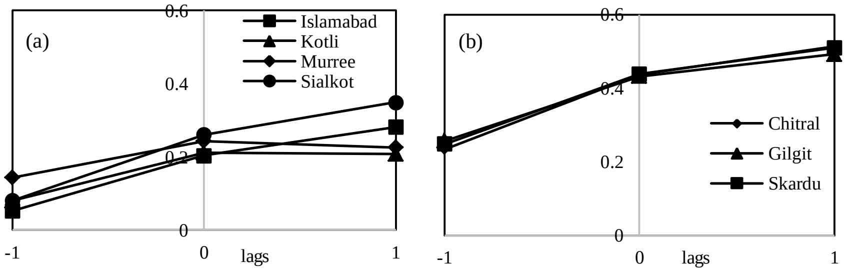


Figure 7 CC analysis of Jhelum river flow with (a) precipitation and (b) temperature

2.1 SARIMA Method

Stochastic hydrological models are very worthy in grasping the long term variations and especially time series analysis is very significant for hydrological modelling [14]. The hydrological data are usually autocorrelated therefore the, time series stochastic modelling is significant in exploring the self-regressed sequential values of the variables at different lags. This is possible only when mean and variance are unchanged *i.e.* persistent. The time series ARIMA model involves an autoregressive process (AR), the *I* component is the differencing, and to accommodate the self-regressed (AR) prediction error moving average (MA) is utilized. The ARIMA (*p*, *d*, *q*) model involves three parameters *p*, *d* and *q* for representation of order of AR, I and MA processes respectively. To capture the seasonality of the data series the seasonal ARIMA (SARIMA) model is used. This study utilizes the SARIMA method adopting Box & Jenkins approach [16], for the modelling of Jhelum river flow. The SARIMA model gives worthy results because of their self-regressed and proficient seasonal adaptability. An improved forecasting can secure the environment, health, increase the security of food and water & power generation management. It can also provide benefits to the strategies of national power management through timely indications about shortfall or excess of water regarding hydropower sources [6].

2.1.1 Model Selection

The SARIMA modelling consists of three steps, the identification, estimation and adequacy of the model [14-16]. The river flow data from April 1973 to Dec. 2005 is utilized for modelling and Jan. 2006 to Dec. 2011 will be utilized for forecasting. For the identification step, analyse the ACF plot of Jhelum river indicating a sharp exponential decay shows existence of a autoregressive relation. Moreover, number of significant early lag spikes of ACF plot (Fig. 6a) indicates the order of moving average (*q*) component and the same of PACF (Fig. 6b) indicates the order of the autoregressive component (*p*). The differencing component (*d*) appears whenever it is required to stationary the data series, generally, the river flow series are stationary series. The annual seasonal behaviour shows in Fig. 6a suggested as a SARIMA model $(p, d, q) \times (P, D, Q)_s$, where *p*, *d*, *q* and *P*, *D*, *Q* are the autoregressive, differencing and moving average components of simple and seasonal (*s* period) respectively.

$$\eta(B)\, \Delta^a\, \alpha(B^s)\, \Delta^A{}_s\, \Theta_t = \gamma(B)\, \mu(B^s)\, \mathcal{E}_t$$

where *B* is Backward Shift operator and equal to $B\Theta_t = \Theta_{t-1}$

and Δ is differencing operator $\Delta = 1 - B$

The other terms are defined as:

$$\eta(B) = (1 - \eta_1 B - \eta_2 B^2 - \ldots\ldots\ldots\ldots\ldots\ldots - \eta_n B^n)$$

$$\gamma(B) = (1 - \gamma_1 B - \gamma_2 B^2 - \ldots\ldots\ldots\ldots\ldots\ldots - \gamma_p B^p)$$

$$\alpha(B^s) = (1 - \alpha_1 B^s - \alpha_2 B^{2s} - \ldots\ldots\ldots\ldots\ldots - \alpha_n B^{ns})$$

$$\mu(B^s) = (1 - \mu_1 B^s - \mu_2 B^{2s} - \ldots\ldots\ldots\ldots - \mu_p B^{ps})$$

where η, γ, α, μ are the parameters of autoregressive, moving average, seasonal autoregressive, and a moving average of degree *n*, *p*, *ns* and *ps* respectively. The error ($\mathcal{E}_t$) is a random process having constant variance, zero mean and white noise. *A* and *a* are seasonal and non-seasonal differencing degrees. Once the model is suggested it will be utilized to perform the parameter estimation using E-Views software. Subsequently, the statistical tests of the predicted model based on *R*-squared, Adjusted *R*-squared, Akaike Information Criterion and Durbin Watson (DW) Statistics (Table 3) gives the three models are selected having most appropriate values of the statistics in all.

The first model is SARIMA $(1, 0, 0) \times (1, 0, 1)_{12}$ with R-squared = 0.481,

adjusted R-squared = 0.478 and DW = 2.022 (Table 3), defined in equation as

$$(1 - \eta_1{}^1 B^1)\, (1 - \alpha_1{}^1 B^{12})\, \mathrm{M}^1{}_t = (1 - \mu_1{}^1 B^{12})\, \mathcal{E}^1{}_t$$

Or

$$\mathrm{M}_t{}^1 = \alpha_1{}^1\, \mathrm{M}^1{}_{t-12} + \eta_1{}^1\, \mathrm{M}^1{}_{t-1} - \eta_1{}^1 \alpha_1{}^1\, \mathrm{M}^1{}_{t-13} + \mathcal{E}_t{}^1 - \mu_1{}^1\, \mathcal{E}^1{}_{t-12}$$

Where, $\mathrm{M}^1{}_t$ represents the first model at Mangla station. Moreover, η is the coefficient of AR component, α is the coefficient of seasonal AR while μ is used for the seasonal MA component.

The second model is SARIMA $(1, 0, 2) \times (1, 0, 1)_{12}$ with R-squared = 0.485

adjusted R-squared = 0.480 and DW = 1.984 (Table 3), defined in equation as

$$(1 - \eta_1{}^2 B^1)\, (1 - \alpha_1{}^2 B^{12})\, \mathrm{M}^2{}_t = (1 - \gamma_1{}^2 B^1 - \gamma_2{}^2 B^2)\, (1 - \mu_1{}^2 B^{12})\, \mathcal{E}^2{}_t$$

Or

$$M^2_t = \alpha_1^{\,2}\, M^2_{t\text{-}12} - \eta_1^{\,2}\, M^2_{t\text{-}1} + \eta_1^{\,2}\, \alpha_1^{\,2}\, M^2_{t\text{-}13} + \mathcal{E}^2_t - \gamma_1^{\,2}\, \mathcal{E}^2_{t\text{-}1} - \gamma_2^{\,2}\, \mathcal{E}^2_{t\text{-}2} - \mu_1^{\,2}\, \mathcal{E}^2_{t\text{-}12} + \mu_1^{\,2}\gamma_1^{\,2}\, \mathcal{E}^2_{t\text{-}13} - \mu_1^{\,2}\gamma_2^{\,2}\, \mathcal{E}^2_{t\text{-}14}$$

Above equation represents the second model M^2_t of Mangla station. Similarly, the third model is SARIMA (2, 0, 1) × (1, 0, 1)$_{12}$ having R-squared = 0.493, adjusted R-squared = 0.488 and DW = 2.011 (Table 3), defined in equation as

$$(1 - \eta_1^{\,3}B^1 - \eta_2^{\,3}B^2)\,(1 - \alpha_1^{\,3}B^{12})\, M^3_t = (1 - \gamma_1^{\,3}B^1)\,(1 - \mu_1^{\,3}B^{12})\, \mathcal{E}^3_t$$

Or

$$M^3_t = \alpha_1^{\,3}\, M^3_{t\text{-}12} - \eta_1^{\,3}M^3_{t\text{-}1} + \eta_1^{\,3}\alpha_1^{\,3}M^3_{t\text{-}13} - \eta_2^{\,3}\alpha_1^{\,3}M^3_{t\text{-}14} + \mathcal{E}^3_t - \mu_1^{\,3}\mathcal{E}^3_{t\text{-}12} - \gamma_1^{\,3}\mathcal{E}^3_{t\text{-}1} + \gamma_1^{\,3}\mu_1^{\,3}\mathcal{E}^3_{t\text{-}13}$$

All the above equations are representing the time series SARIMA models.

Table 3 The Time Series SARIMA prediction indicators of selected models of Jhelum River flow at Mangla Station (Jan. 1976- Dec. 2005) and its forecast efficiency indicators (Jan. 2006- Dec. 2010).

	SARIMA models and prediction indicators					**SARIMA forecast and its efficiency indicators**		
S. No.	**SARIMA Model**	**R- Squared**	**Adjusted R- Squared**	**Akaike Criterion**	**Durbin Watson**	**Correlation**	**SSE**	**MSE**
1	(1, 0, 0)×(1, 0, 1)$_{12}$	0.48	0.48	14.450	2.022	0.41	9885291.7	137295.7
2	(1, 0, 2)×(1, 0, 1)$_{12}$	0.49	0.48	14.452	1.984	0.41	10120819.8	140566.9
3	(2, 0, 1)×(1, 0, 1)$_{12}$	0.49	0.49	14.439	2.011	0.43	9461322.5	131407.3

2.1.2 Proficiency of the Model

The prediction results of all three models (Table 3) shows that SARIMA (2, 0, 1)×(1, 0, 1)$_{12}$ appear to be the best among the three selected model relative to prediction indicators, R-squared 0.49, Akaike criterion 14.439 and DW statistics of 2.011. The prediction residuals ACF and PACF correlograms (Fig. 10c) show no significant serial correlation that provide the_adequacy of this model. The prediction results are not so good because of the inconsistency of the time variation of the river flow data series, especially after 1997 (Fig. 2). So, the time series methodology does not completely describe the hydrological variation of the Jhelum River like the Indus river flow at the Tarbela station result presented in Hassan & Ansari [1]. This may also observed from Jhelum river flow ACF plot has sharp roll off (in early lag values Fig. 6a). In comparison with the same of the Indus river flow at Tarbela station [15] shows sustainable roll off pattern (Fig. 9), ([15] the reference there in Fig. 8). Formally, both ACF plots look alike, however, if applying linear trend line fits (in early lag values) on both ACF plots then the ACF of Jhelum river shows a sharp decay (unsustainable) whereas the trend line of ACF of Tarbela station shows a sustainable decreasing, or shows slightly nonlinear roll off behaviour. This may support the more autoregressive dependence of the previous values.

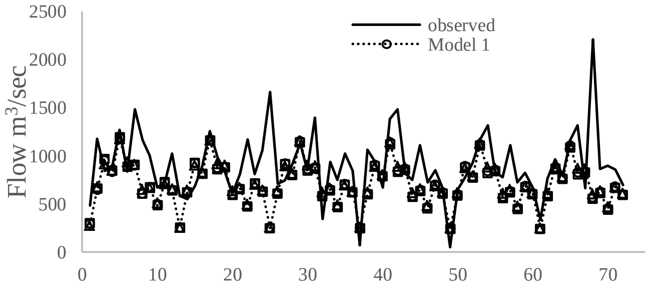


Figure 8 Time series plot of observed and forecasted river flow using SARIMA models

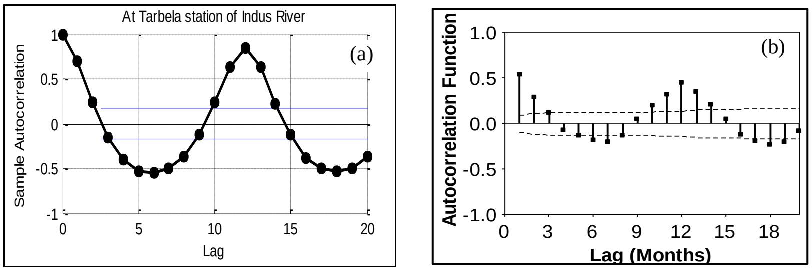


Figure 9 Comparison of ACF of (a) Indus River flow (Hassan & Ansari, 2015) at Tarbela with (b) Jhelum river flow at Mangla

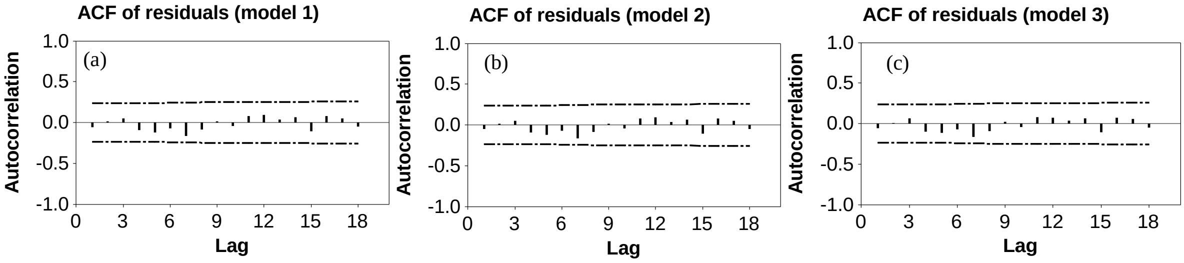


Figure 10 ACF of residuals of SARIMA (a) model 1, (b) model 2 and (c) model 3

2.1.3 Forecasting through Time series models

Time series SARIMA suggested three models that are selected for forecasting purpose (Table 3). Like the prediction results (Table 3) forecasting indicators shows some conventionally less efficient results which shows the maximum correlation of only about 0.43 (Table 3) with SARIMA $(2, 0, 1)\times(1, 0, 1)_{12}$. Moreover, the time series plots of the considered rainfall stations since 1994, shows overall decreasing annual linear trend (Fig. 3), with low frequency of the small and large rainfall events as compared to 1976 to 1994 period. This may be one of the cause of inconsistent and reduce river flow of Jhelum River since 1997 (Fig. 2).

2.2 Multiple Regression River flow Analysis

The monthly and annual seasonal river flow of Jhelum is analysed and predicted through regression analysis at Mangla station. The first step is estimating the parameters and checking of the adequacy of the model.

Since river flow is analysed in view of climatic variability and many parameters of statistical correlation, to assess the relationship, between the dependent and independent variables. The linear regression can be written as

$$U = a + bV + e$$

where, U and V are dependent and independent variables respectively, a and b are the parameters of regression and e is the error. The MLR models are suggested by employing the stepwise regression method, that generates different combination of MLR models. Among these the best suitable models are selected based on the parameters p-values, and predictions R-squared, adjusted R-squared and Durbin Watson values. In this section, impact of precipitation and temperature on river flow is performed followed by stepwise linear regression which is applied to the monthly data of Jhelum River flow.

2.2.1 Model Selection Techniques

Monthly data of Jhelum river flow is analysed through many MLR models among these, this paper considers only one model (Eq. 1) as criteria defined as above and the value of R-squared, adj. R-squared and D.W statistics (Table 4).

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 \; P_{t-2}^{Mur} - \alpha_3 T_{t-1}^{Skr} - \alpha_4 P_{t-2}^{Sia} + \alpha_5 T_{t-1}^{Gil} \quad (1)$$

where, α is the coefficient of the parameters, $Y_{t\text{-}1}$ is the average river flow at lag-1, P_{t-2}^{Mur} and P_{t-2}^{Sia} is the sum of precipitation of Murree and Sialkot at lag-2 also T_{t-1}^{Skr} and T_{t-1}^{Gil} is the mean temperature of Skardu and Gilgit at lag-1. The precipitation and temperature have maximum influences (correlation) on river flow at two and one month lag respectively, so, appropriate variables are selected with different lag values.

Table 4 The prediction indicators values of MLR monthly model selected for river flow (Jan. 1976- Dec. 2005) and forecast efficiency indicators, (Jan. 2006- Dec. 2010)

MLR monthly models and prediction indicators				**forecasted and its efficiency indicators**				
Selected Model	**R-squared**	**Adj. R-squared**	**Durbin-Watson**	**Forecasted river flow**	**SSE**	**MSE**	**RMSE**	**Correlation**
$Y_t = \alpha_1 Y_{t-1} + \alpha_2 P^{Mur}_{t-2} - -\alpha_3 T^{Skr}_{t-1} - \alpha_4 P^{Sia}_{t-2} + \alpha_5 T^{Gil}_{t-1}$	36.86%	36.14%	2.066	$\hat{Y}_t$	7422298	123705	351.7172	0.126

2.2.2 Forecasting through selected model

The forecasting of the river flow (60 data point values) is performed by using Eq. 1 as shown in Fig. 12. The correlation between observed and forecasted river flow is only 0.126 (Table 4) because the observed time series data is not consistent with the data range utilised for the parameter estimation of the model (Fig. 2). Moreover, Fig. 11 of Quantile-Quantile plot shows a good relation between observed and forecasted river flow. This shows If the data point's worm follow the linear line they have from same distribution.

The climate modelling and the impact of climate changes on Jhelum River flow is also analysed by Akhter et al. (2015, 2016 & 2017) by using MLR and ANN techniques, they confirmed that the climatic variations in Jhelum River are drastically changing that is the biggest problem in predicting and forecasting the river flow. As the precipitation is continuously decreasing and temperature is increasing rapidly. Since they worked on the Jhelum River climatic data from Indian side, they have better results of their models [17-19]. Although the ACF and PACF of the MLR forecasting errors shows some spikes at initial lag values above the standard error bars which indicates that some dominating time varying components are remaining to be considered in the model.

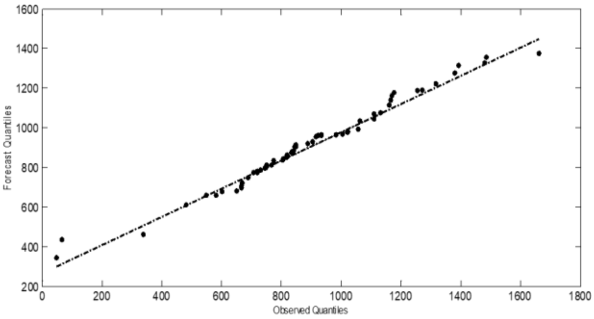


Figure 11 Q-Q plot of the forecasting of monthly river flow data with observed data

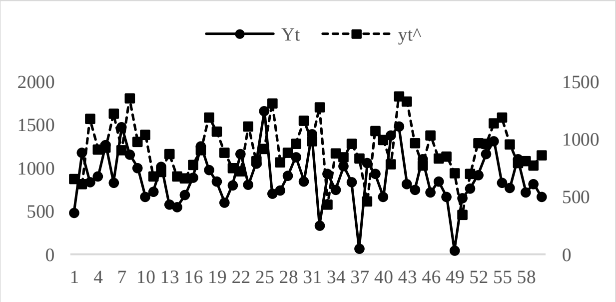


Figure 12 Time series plot of the forecasting of monthly river flow with observed data

2.2.3 Annual seasonal River flow Analysis

The annual seasonal pattern of river flow (Fig. 5a) from January 1976 to December 2005 shows a maximum monthly flow behaviour in May, June, July and August. This happened because in the month of April and May melting of snow/glaciers started (as accumulated in the winter precipitation) due to the pre-summer and pre-monsoon. Moreover, forthcoming June, July and August are the monsoon months in which seasonal & monsoon rainfall also contributes with this flow. Seasonal and monsoon rainfall and snow/glacier melting in May, June, July and August (MJJA) months, are the reason of the intensified river flow (Fig. 5a). This vigorous increased in flow during MJJA of the river causes sometimes hazardous floods.

2.2.4 Modelling and Forecasting

To explore the relation between influencing climatic data of MJJA and the seasonal maximum river flow, this study utilizes stepwise techniques for MLR method. This method provides a model that can help to forecast the river flow using the climatic data of MJJA. The model representing the river flow using precipitation and temperature is given below.

$$Q_M = \beta_S^{1} P_{S,M} + \beta_S^{2} T_{S,M} + \beta_S^{3} Q_{S,M}$$

Whereas, the variables Q, P and T represent the average annual flow in m^3s^{-1}, precipitation in millimetres and temperature in °C respectively. The M and S represent the respective month and the station of the selected parameters and β_S^1, β_S^2, β_S^3 are the coefficients of precipitation, temperature and river flow respectively. The following four suggested models show the impact of climatic factors on river flow.

$Q_{May} = \beta_1^{1} Q_{Apr} + \beta_2^{1} T_{G, Apr}$
$Q_{June} = \beta_2^{1} P_{Mur, Mar} + \beta_2^{2} Q_{May}$
$Q_{July} = \beta_3^{1} P_{Isl, Mar} + \beta_3^{2} Q_{June}$
$Q_{Aug} = \beta_4^{1} P_{Isl, May} + \beta_4^{2} P_{Mur, May} + \beta_4^{3} Q_{Jul}$

Since snowfall occurs in the winter season, and starts melting in the months of April, May, June and July as the temperature rises around 20°C (Fig. 5b). A rapid increase of river flow can be observed in MJJA months, which further followed by the western monsoon rainfall (Fig. 5a) that also contributes river flow but their impact is less than melting of glaciers.

The Table 5 representing that the values of R-squared, is above 90% shows that annual can easily explain by the MLR method. After parameters estimation and model analysis all four models are utilised for forecasting the river flow. The graphs of forecasted river flow (Fig. 13) and the values of SSE, RMSE, MSE (Table 5) shows that the selected models are adequate. Fig. 13a represent forecast for the month of May are the most prominent among the other months. Therefore, it can be concluded that the MLR utilizing local climatic factors may be suitable to forecast the annual seasonal flow. However, the problem of efficiency of the forecast remains same as for the time series as discuss in the previous sections. However, the prediction accuracy of the model is better than the time series method (R-squared values ranging from 90% to 93%, Table 5). However, for the forecast range (Jan. 2006- Dec. 2010) the inadequate performance of the model shows that observed flow data has inconsistency relating to the prediction or a parameter estimation data range (Jan. 1976- Dec. 2005). The overall performance of the prediction/model is good, nevertheless, the forecast results shows some inconsistence performance due to the decreasing regional precipitation (Fig. 3), temperature (Fig. 4) and river flow (Fig. 2)

Table 5 The MLR models of annual seasonal river flow with prediction indicators (Jan. 1976- Dec. 2005) and forecast efficiency indicators, (Jan. 2006- Dec. 2010)

	models and prediction indicators				**forecasted and its efficiency indicators**			
S.No.	**SELECTED MODELS**	**R-squared**	**Adj. R-squared**	**Durbin-Watson**	**Forecasted river flow month**	**MSE**	**RMSE**	**SSE**
01	$Q_{May} = \beta_1^{1} Q_{April} + \beta_2^{1} T_{Gigit, April}$	93.1%	92.5%	1.75	$\hat{Q}_{May}$	35344	497	247410
02	$Q_{June} = \beta_2^{1} P_{M, Mar} + \beta_2^{2} Q_{May}$	90.6%	89.9%	1.99	$\hat{Q}_{June}$	240219	1297	1681530
03	$Q_{July} = \beta_3^{1} P_{I, Mar} + \beta_3^{2} Q_{June}$	91.6%	90.9%	2.36	$\hat{Q}_{July}$	315981	1487	2211865
04	$Q_{Aug} = \beta_4^{1} P_{Isl, May} + \beta_4^{2} P_{Murree, May} + \beta_4^{3} Q_{July}$	92.1%	91.1%	1.82	$\hat{Q}_{Aug}$	176755	1112	1237283

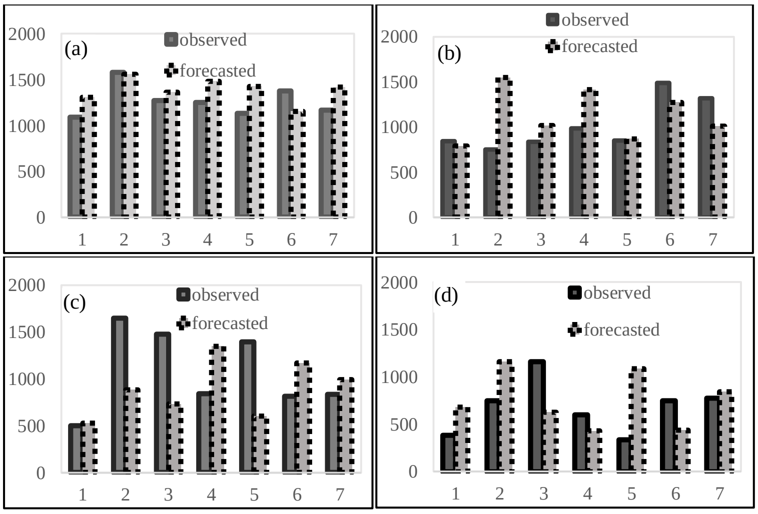


Figure 13 A comparison of observed and MLR forecasting of (a) Q_{May} (a) Q_{June} (c) Q_{July} (d) Q_{Aug}

3. Result and Discussions

This paper considers the time series modelling and forecast of the Jhelum River flow along with the impacts and variations of climate MLR method. The analysis of precipitation of the cities likely to be a good correlation (Table 2, Fig. 5a) with the river flow, especially during the winter months (January–to-April), but, it is of low rainfall season on the overall annual cycle. Moreover, the correlation of rainfall with river flow show very low values (Fig. 7a) may be due to phase difference between seasonal river flow and rainfall pattern (Fig. 5a). This is may be due to overall decreasing of river flow and the regional rainfall (Fig. 2 & 3).

Since the melting of snow/glaciers also contributes to base flow of the Jhelum River, therefore, the intensity of temperature may sometimes supply the surplus water locally, particularly in pre-monsoon season (Fig. 5b). The high correlation of Skardu shows that its temperature's impact is more than the other cities (Table 2) . It is because the Skardu is surrounded by the glaciers having highest altitudes. Whereas the cross-correlation analysis of river flow with precipitation shows that the impact of seasonal monsoon precipitation are better than orographic rainfall (as mention above) but temperature dependency is prominently visible regularly (Fig. 7).

To model and forecast the river flow using Stochastic Time Series SARIMA method suggested three models after checking through several criteria. The prediction of the model explain about 50% (R-squared = 0.49), moreover, the forecasting describes the observed data of only 43% which shows less efficient results. This may be due to the overall decreasing rainfall annual linear trend (Fig. 3) from 1941, with low frequency of the small and large events as compared to 1976 to 1994 period. This may cause inconsistencies and reduce river flow of Jhelum River since 1997 (Fig. 2). However, the best model explains approximately 43% of future forecasts.

The MLR modelling method is applied to Jhelum river flow on annual seasonal and monthly basis. One monthly and four annual seasonal models are selected through MLR after testing through the several criteria. Selected models generate the forecast of the river flow. The problem of efficiency of the forecast remains same as for the time series. Moreover, the prediction accuracy of the monthly model is 36%, and of annual seasonal is about 90% to 93% (R-squared values : Table 5) which is better than the time series method. However, for the forecast range (Jan. 2006- Dec. 2010) the inadequate performance of the model shows that observed flow data has inconsistency relating to the prediction or a parameter estimation data range (Jan. 1976- Dec. 2005). The overall performance of the prediction/model is good, nevertheless, the forecast results shows some inconsistence performance. However, the four annual seasonal MLR models gives good results of explaining the river flow approximately 92%. Moreover, due to the global climatic changes, water sources have been affected regionally since the last three decades. Many areas of the Jhelum River, are famous regarding their insubstantial rainfall, high rate of vaporization, reduced storage capacity due to high sedimentation rate and insufficient water renewable assets especially in summer season.

This problem of predictability and forecast are enhance due to the dominance of Indian control of the shared river flow of Jhelum. They release less water during drought years and recessionary period of the river flow annually, discharge more water during flood, especially extreme monsoon months (MJJA) flow to protect their dams. So, huge quantity of water is sometime available on the Pakistani side and shows good correlation of temperature and rainfall with the river flow. But the rest of the time Pakistan has to suffer with not only the climatic variation, but also with the political influences. These political influence may enhance the deficiency in the actual stochastic and seasonal variations of the river flow, which is the most important factors for SARIMA and MLR model and forecast.

4. Conclusion

This study investigated the climatic variations and their effects on Jhelum river flow. The Mangla station has its worth because it not only provides the water for agricultural use, but also it is a major source of generating electricity in Pakistan. The modelling and forecasting of Jhelum River flow is represented through SARIMA and MLR methods. The annual monsoon seasonal model of MLR shows good results, as compared to the other methods outcome.

The forecasting of river flow through these models is helpful in planning and water management. However, this happens before 1994, around and after this year the climatic situations are changing very rapidly and prediction and forecasting is becoming almost a challenge as the time passes. Moreover, due to the global climatic changes, water sources have been affected regionally since the last three decades. Many areas of the Jhelum River, are famous regarding their insubstantial rainfall, high rate of vaporization, reduced storage capacity due to high sedimentation rate and insufficient water renewable assets especially in summer season. The problem in predictability and forecast are enhancing somehow, due to the dominance of Indian control of the shared river flow of Jhelum. They release less water during drought years and recession period and discharge more water during flood, especially extreme monsoon months (MJJA) flow to protect their dams. The reliable forecasting not only can adopt the massive catastrophes before time, but also it will support flood rescue departments as it can issues the warnings before the floods. A trustworthy and healthier prediction regarding floods can be supportive for the management of downstream location, population and water resources. Forecasting of river flow is also helpful in understanding the prevailing situation of climate variations. Moreover, it can be concluded that these types of modelling and forecasting are significant for the present and forthcoming water resource and power generation managements.

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