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Flow Regime Vulnerability Over Transboundary Rivers in Himalayas Region; A Case Study of the Neelum River Pakistan

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Abstract- The contradictory approaches to water sharing at regional and global scale has detrimental impacts on human (domestic and agricultural) and ecological demands. Economic activities have also been affected, including where livelihoods and survival depends upon agriculture. This study considers past and future flow trends and water availability in the Jhelum basin, focusing on the Neelum River. The Neelum River is largest tributary of Jhelum basin and is also an important transboundary river shared between Pakistan and India. To detect historical trends of flow data, Man Kendall and Sen's slope trend analysis were carried out, whereas the future projections in the flow regime were estimated using First Order Morkove stationary method. The analysis shows significant flow depreciation in the period between 1991 and 2013. The two stations were considered in this study Nusheri (Upstream) and Muzaffarabad (Downstream). At Nusheri station monthly and annual decreasing trends dominated (significant decline in the months of June, July and August) including the annual average declining rate of 3.386 cumecs per year. At Muzaffarabad station (downstream to Nusheri) the similar decreasing trends were dominated as were at the upstream, the overall annual average decline rate was 3.186 Cumecs per year The overall flow depreciation was estimated about14% by volume at both stations in the period of 1991 to 2013. The Pakistan has built Neelum-Jhelum hydropower and India has built Kishan Ganga hydropower project on the same river, therefore fair allocation of flow without curtailing water must be made to ensure water availability throughout the year in this river. This will also help to reduce long withstanding turbulence of Pak-India relations.

Keywords- Neelum-Jhelum, Transboundary, flow regime, water allocation, Man-Kendal, Sen's slope, Trend analysis, Future Projections. .

I. INTRODUCTION

According to Inter Government Panel on Climate Change (IPCC) fifth assessment report, an average global temperature has been risen by 0.84 ^{0}C since the beginning of this century and this temperature rise has substantially impacted on the global economy. [1]. The Himalayan region is one of the most vulnerable climatic region with regards to water availability [2, 3, 4, 5, 6,7], however, there is poor understanding of the hydrological response under climate change of this area due to a lack of crysopheric and hydro-meteorological data [8.] Hydrological response is primarily controlled by topographical and climatic conditions of the catchment and predicted by distributed, semi distributed and lumped modeling approaches. however hydrological modeling is difficult in this region due to data scarcity, inconsistency, inefficient measuring systems and lack of active management system [9,10]. The Indus is the one of largest rivers originating from Himalayas region, covering four countries Pakistan, Afghanistan, India and China, with catchment area of 966 000 Km^2. More than 60 percent of the catchment area of Indus rivers is located in Pakistan. The majority of the water of Indus River is carried by its eastern tributaries, the Neelum, Jhelum, Chenab, Sutlej and Ravi in descending order [11].

Pakistan is running an agriculture-based economy which is primarily controlled by water availability throughout the year in the Indus River [12, 13, 14]. Water sharing conflicts on the Indus River have been originating from 20th century, escalated with greater momentum after independence of both Pakistan and India in 1947. The fair allocation of water is governed by institutional polices at national as well as international level in transboundary basin [15, 16] and these policies are also modulating the adverse impacts of climate change on the water-based economy of Pakistan [17]. Water sharing in the Indus River basin has long history of contention between India and Pakistan [18]. These disputes gained greater momentum due to transitional status of Jammu and Kashmir state at the time of partition in 1947. After years of dialogues between the two riparian countries of Pakistan and India, the World Bank finally solved this problem by shaping Indus Water Treaty (IWT) [18]. IWT was established on three baselines: (1) Indus water is enough for requirements of India and Pakistan; (2) discussion will be made on all tributaries of Indus; and (3) technical aspects will be negotiated instead of political [19,20]. Finally, 20% of the total water from Indus is given to India through eastern tributaries (Ravi, Sutlej and Bias) and 80% to Pakistan through its western tributaries, including Chenab, Jhelum and Indus itself [21].

The World Bank, acting as an arbitrator, has also ensured the continuity of flow in western tributaries of the Indus river basin without any interruption. In this regard, water infrastructure was developed to overcome water loses in eastern tributaries of the Indus river downstream through dams and diversion canals [22; 23 24]. Consistent with the term "Respect for agreement", India is required to release a defined amount of water in western tributaries without alteration. But recently, water sharing disparities have been seen in the Jhelum river basin (Western Tributary of Indus), which comprises of four tributaries: Kunhar, Neelum, Poonch and Jhelum itself. A transboundary river basin dispute exists at the international level [25, 26, 27], and the water sharing dispute of Neelum River has attracted global attention over last decade when it was raised in the International Court of Justice (ICJ) where to attend Pakistan's claim that the 'Kisanganga' project is in violation of the IWT. Moreover, Pakistan emphasized that the water availability in Neelum river is essential for food and fiber of eastern region because existence of life is determined by this water. The ICJ determined that there must be the release of 9 cumecs continue flow from Jammu and Kashmir (India) towards Pakistan downstream in Neelum river to overcome water insecurity.

There is plenty of literature already available on the hydrological response with reference to climate change [28, 29, 30, 31, 32, 33] in Indus River basin [34, 35], but only few studies are available in the Jhelum basin [36]. It is important to note that mostly transboundary water allocation agreements are based on suppositions of hydrological response of basins rather than deterministic approaches [37]. Therefore, statistical approaches can provide a better understanding of historical as well as future flow regimes. There are many parametric trend test including t-test, Linear regression test, F-test and non-parametric tests Kruskal-Wallis, Sen's Slope Estimator and Man Kendall methods available and are widely used to assess temporal trends of hydrological data in river basins due to conceptualization of trends and methodology design.

This paper presents a comprehensive detail on trend analysis based on observational flow data at two stations in Neelum river. The widely-used Man-Kendall and Sen's slope methods were adopted to estimate trends in historical flow records as these two methods give reliable results of temporal trend analysis. To estimate future projected flow series, The Markov chain first order was used. It is important to estimate the trends analysis and future flow variations in the Neelum River as it is a largest tributary of Jhelum basin, contributing more than 40 percent flow to Mangla Dam [38] and its catchment distribution on both side. This study will also set basis to future water trade-off between riparian countries to maintain the storage and operational water demands.

II. METHODOLOGY

2.1. Study Area

The River Neelum lies between 73^0 to 76^0 east and 32^{0}to 36^0 north between the riparian countries of India and Pakistan, along the line of control (LOC) in Kashmir region. This river originates from the Kishna lake in Kashmir, in the Himalayan ranges, and enters Pakistan in Azad Jammu and Kashmir at Taobat. It then flows to Muzaffarabad District and merges with Jhelum river at Muzaffarabad bridge. The Neelum river is a major contributor of the Indus basin in the eastern and northeastern part of Pakistan and is the largest tributary of Jhelum basin. Mangla reservoir, the second largest dam of Pakistan, is located on Jhelum river. The Neelum River provides 40 % of total flow to Mangla dam. This dam provides irrigational water to 6 million hectares and supports 1000 MW of electricity, which is 6% of the installed capacity of Pakistan [39] (Fig.1).

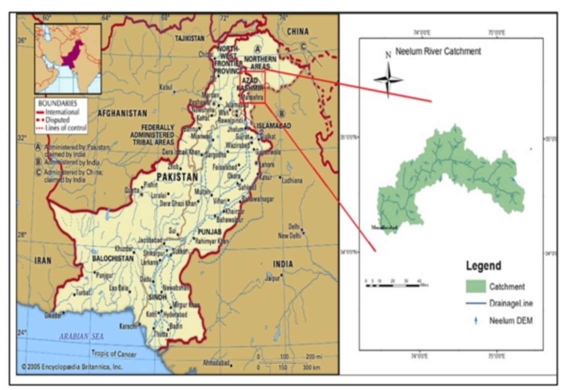

Figure.1. Study area River Neelum, Pakistan

2.2. Data Source

In this study available flow records from 1991 to 2013 at two gauging stations of River Neelum (Nusheri and Muzzafarabad) were used for analysis, shown in figure (1). In Pakistan, flow measurement is made by Water and Power Development Authority (WAPDA) and Surface Water Hydrology Project (SWHP). In this study we have acquired data from SWHP.

The detail flow measuring methods and their accuracy used by WAPDA was given by Archer [39]. In this study flow data of two station Nusheri (upstream) and Muzaffarabad (Downstream) was used for trend analysis.

2.3. Trend Analysis

The methodology of this study comprises of baseline flow data analysis and its possible future impacts on water availability. Firstly, data was tested to autocorrelation and it was found that there is no need to auto correlate. In order to assess the temporal changes, trend analysis was carried out using nonparametric Mann-Kendall test [40, 41] at daily, monthly and annual scale for each station. To visualize the linear change rate Sen's slope [42] was applied. At 0.05 (5%) confidence interval the false discovery rate was controlled. It was not likely to reject all null hypotheses more than 5%. The Mann Kendal methodology elaborated as follows.

The null hypothesis of no trend was assumed H0 that explain independent and identically distributed data series states that the data series otherwise trend exists with hypothesis H1The MK “S” statistics define in general way is given in equation

$$S = \sum_{i=n}^{n-1} \sum_{j=i+1}^{n} (y_j - y_i) \qquad \text{Equation (1)}$$

y_j is sequential data series and n for data extents

$$sgn(y) = \begin{cases} 1 \; if \; y > 0 \\ 0 \; if \; y = 0 \\ -1 \; if \; y < 0 \end{cases} \qquad \text{Equation (2)}$$

2.4. Future Change

After satisfactory trend analysis of baseline data from 1991 to 2013, the future flow change projection was made through data generation procedure, in lieu of future availability of irrigation water. For this purpose, first order Markove Chain method was used including Lag1 correlation procedure shown in equation 1

$$Q_{j+1} = \bar{Q} + \rho 1 (Q_j - \mu_Q) + \bar{Q} Sd_Q (\sqrt{1 - \rho 1^2}) \qquad 1$$

Where Q_{j+1} new discharge, $\bar{Q}$ is an average discharge, Q_t is preceding discharge value of given month, Sd_Q is standard deviation and $\rho 1$ is LAG1 correlation.

III. RESULTS

3.1. Trends at Upstream Nusheri

The objective of this paper was to evaluate flow depreciation in terms of historical and future patterns.

At both stations the analysis showed negative trends in historical as well as in future projected flow series ie reducing flows. The overall declining trends were dominant in all monthly, seasonally and annually flows. The maximum decrease in monthly flows was 16.915 cumecs/yr in June and minimum decrease was seen 0.294 cumecs/yr in November. The maximum decline was seen in June; this may be due to surplus effect of Monsoon rains, which affects flow volume in the entire Jhelum basin. We have included the monthly, seasonal average and annual analysis of flow time series varied from 1991 to 2013, but daily analysis was not incorporated due to significant uncertainty, frequency, complexity, and smoothness issues. An average flow declining rate from January to March (JFM) was 0.296 cumecs/yr, April to June (AMJ) 9.201 cumecs/yr, July to September (JAS) 4.864 cumecs/yr and October to December (OND) 0.032 cumecs/yr, respectively. The annual average flow declining rate was 3.386 cumecs/yr. (Table.1 & Figure 3).

Table 1 Shows detail of Mankendall Coefficient tau, Statistical significance p and Sen's slope analysis of flow data series at Nusheri station from 1991 to 2013

Month	Tau	P value	Sen’s Slope
Daily	-0.043	< 0.0001	-0.003
Jan	-0.058	0.710	-0.218
Feb	-0.076	0.620	-0.313
Mar	-0.120	0.427	-1.291
Apr	-0.087	0.568	-2.21
May	-0.167	0.264	-6.239
Jun	-0.243	0.102	-16.915
Jul	-0.342	0.021	-11.285
Aug	-0.250	0.092	-4.204
Sep	-0.109	0.472	-1.604
Oct	-0.105	0.487	-0.335
Nov	-0.036	0.823	-0.294
Dec	0.029	0.862	0.214
JFM	-0.054	0.728	-0.296
AMJ	-0.301	0.042	-9.201
JAS	-0.243	0.102	-4.864
OND	-0.011	0.960	-0.032
ANN	-0.236	0.112	-3.386

Note: Flow series data are in cumecs

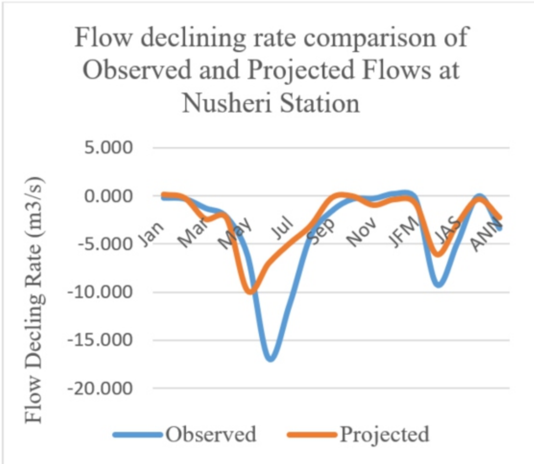

Figure.3 Comparison between observed and Projected flow declining rate at Nusheri, River Neelum, Pakistan

3.2. Trends at downstream Muzaffarabad

Muzaffarabad station is located downstream from Nusheri, just before merging into Jhelum river. As expected, analysis for Muzzafarabad shows similar results as were show at the upstream Nusheri site. Although additional water from rainfall between Nusheri and Muzzafarabad was available, a declining trend prevailed. The annual average flow declining rate was 3.186 cumecs /yr and in monthly flow analysis shows the maximum decline rate 13.198 cumecs /yr in the month of July (Table 2). The seasonal declining rates of flow were in January to March (JFM) 0.304 cumecs /yr, April to June (AMJ) 8.065 cumecs /yr, July to September (JAS) 7.062 cumecs /yr and October to December (OND) 0.411 cumecs /yr, respectively (Table 2 & Figure.4). Daily flow series analysis was also not included in the analysis for Muzarrarabad. The annual average declining rate was estimated 3.186 cumecs/yr.

Table 2 Shows detail of Mankendall Coefficient tau, Statistical significance p and Sen's slope analysis of flow data series at Muzaffarabad station from 1991 to 2013

Month	Tau	P value	Sen's Slope
Daily	-0.028	0.000	-0.002
Jan	0.024	0.895	0.066
Feb	0.032	0.853	0.23
Mar	0.079	0.616	1.559
Apr	-0.071	0.653	-1.763
May	-0.174	0.256	-7.215
Jun	-0.206	0.178	-11.925
Jul	-0.222	0.146	-13.198
Aug	-0.174	0.256	-3.757
Sep	-0.127	0.412	-1.97
Oct	-0.170	0.267	-0.65
Nov	-0.048	0.771	-0.092
Dec	-0.087	0.579	-0.283
JFM	0.055	0.731	0.304
AMJ	-0.238	0.119	-8.065
JAS	-0.214	0.161	-7.062
OND	-0.099	0.526	-0.411
ANN	-0.170	0.267	-3.186

Note: Flow series data are in cumecs

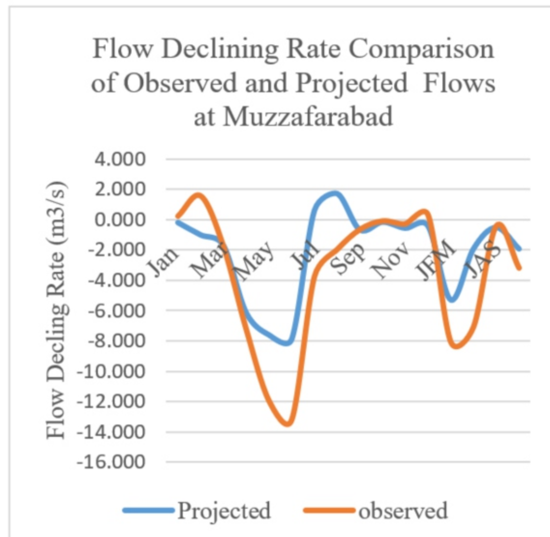

Figure.4. Comparison between observed and Projected flow declining rate at Muzaffarabad, River Neelum, Pakistan

3.3. Future Flow Projection

In order to assess future change, trend analysis was also done for an extended data series. The results are similar to observed flow outcomes in terms of declining flow rate. The maximum average declining rate in projected flow was observed 0.417 cumecs /yr and minimum 0.004 cumecs /yr at Nusheri (upstream) station (Figure. 5). The declining trend was also prevalent in the predicted flow series at Muzaffarabad (downstream), with minimum flow reduction 0.391 cumecs /yr and maximum 0.029 cumecs /yr, respectively (Figure. 6). At present, the flow scenarios moving towards reducing end but uncertainty is always associated with future projections due to changes in temperature and precipitation pattern.

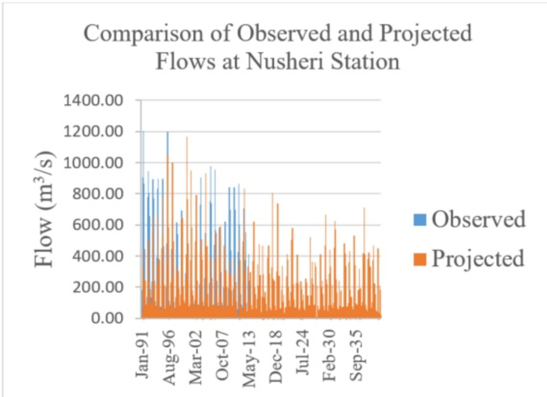

Figure.5. Comparison between observed and Projected flow at Nusheri station, River Neelum, Pakistan

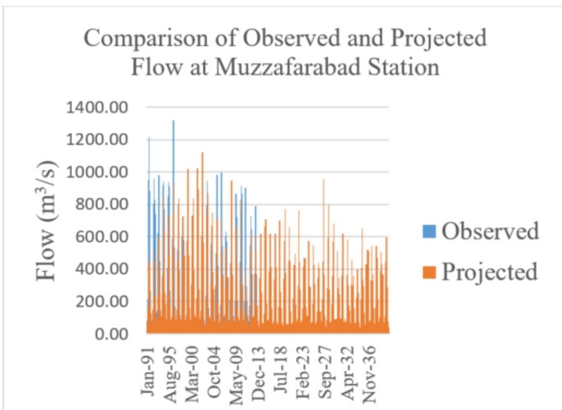

Figure.6. Comparison between observed and Projected flow at Muzzafarabad, River Neelum, Pakistan

IV. Discussion

Table 1 & 2 shows trends analysis results including Tau, statistical significance p and Sen's slope values. The more detail is also given in figure 5 and 6, all results daily, monthly seasonally and annually shows declining trends at both station Nusheri at upstream and Muzaffarabad at downstream. More than 90% trends are negative and leading towards reduction of flows in entire flow series from 1991 to 2013. Similar trends were also reported by Rashid Mehmood (2017) in this region. This declining will cause serious implication to Mangla reservoir operation and management as the Neelum river is the largest tributary of Jhelum basin. It carries more than 40% of the total flow of the Jhelum basin [39] thus any change in Neelum River flow can harm downstream water demands as well as bilateral relations. The main focus of this study was to evaluate the flow continuity, trend analysis and future projections for the Neelum river using data from two sites, upstream at Nusheri and downstream at Muzaffarabad. The analysis demonstrated declining flow pattern in all seasons including summer and winter. The annual declining flow rate was estimated 3.386 cumecs and 3.186 cumecs per year at both stations which shows flows are reducing largely on annual basis. In the monthly flows declining rate varies between 16.915 cumecs and 0.214 cumecs per year at Nusheri and between 13.198 cumecs and 0.23 cumecs per year at Muzaffarabad, respectively. The minimum declining rate was found in the winter season, which may be due to less snow melting and consequently low runoff generation. The summer season depicted maximum flow declining, due to additional runoff generation from Monsoon rains and higher snow melting rate (Table.1 and Table 2). An overall average decline was estimated 14% by volume which shows clear picture of future reduction of flows. Although this declining pattern of flows is not only resulted due to climate change, land use changes and industrial growth but also due to man-made structures on this river. An overall tendency of decreasing flow will trigger irrigation complexities downstream as Mangla dam provides water for agricultural purposes. A fair water sharing mechanism may reduce subsequent water-based tensions and provide a step forward towards a more efficient flow redistribution system between riparian and also need to increase efficiencies of their internal irrigations system [4]. Both external and internal water sharing mechanism can give better results in terms of water availability. Both countries need to focus on their internal water sharing policies to use water in efficient ways till the settlement of these water redistribution challenges.

V. Conclusions

In this study temporal trends of flow series were analyzed using non-parametric Man-Kendall and Sen's slope method. We have found that the seasonal, annual and projected future scenarios were all showing a declining pattern, which will create significant water management challenges in this region. At the upstream Nusheri station, the mean annual flow reduction was 3.386 cumecs per year. At the downstream Muzaffarabad station, the average annual decline was 3.186 cumecs per year. The seasonal trends were also depicting negative results. The decrease in both summer and winter season will risk water availability in this basin and put an extra pressure on the Mangla Dam water regulation process. Because the population downstream is reliant on an agriculture, much depends upon Mangla water releases. To compensate this water imbalance, we need to reconsider efficient irrigation system internally by both Pakistan and India as well as external water trade-off between the riparian countries in order to meet irrigational demands of people living downstream. This study reveals flow declining pattern in the Neelum river basin but extensive research is required to explore the exact reasons behind this flow declining pattern, either this is due to climate change at global or regional level or due to land use changes or anthropogenic reasons.

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Authorship and Contribution Declaration

Sr.#	Author-s Full Name	Contribution to Paper	Signature
1	Mr. Muhammad Waqar (Main/principal Author)	Proposed topic, basic study Design, methodology and manuscript writing	
2	Prof. Dr. Sajid Rashid Ahmad (2nd Author)	Literature review & Referencing, and quality insurer	
3	Dr. Asif Khan (3rd Author)	Statistical analysis and Results interpretation	