Precipitation Trend Analysis of Upper Indus Basin Using Mann Kendall Method

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***Abstract*— Pakistan is one of the most water stress country of the world and its water resources is very prone to the changing climatic conditions. Any change in the physical processes of the universe may adversely affect the universe. Climate change due to global warming is the most glaring problem the world is facing today. Temperature and precipitation are the two main climatic factors governing the water resources of a locality in which temperature is the main climatic factor governing all climatic factors. This study is intended to investigate the trend in mean monthly precipitation data from 1980-2014 for five substations of the upper Indus basin using the Mann Kendall Mathematical Model. The study indicates seasonal increasing or decreasing trend in precipitation of time series data, considerable "wetness" is observed in summer and monsoon and "dryness" for all substations except for substation Chitral. In a nutshell, Upper Indus Basin will face more floods and droughts due to the projected increase and decrease in precipitation. These results show that it is dire need of the time to determine the impacts of climate change on the hydrology of the Upper Indus Basin and to devise certain policies for the proper utilization and management of the water resources.**

***Keywords*— Climate Change, Precipitation, Water Resources, Global Warming**

I. Introduction

Global warming is certain and the most glaring fact of the day and its ill effects are felt throughout the world either in the form of rising air temperatures or changing precipitation and melting of glaciers. These have led to the increase in discharge and a rise in sea level. Global warming is unequivocal and increasingly serious concern due to its recent acceleration.

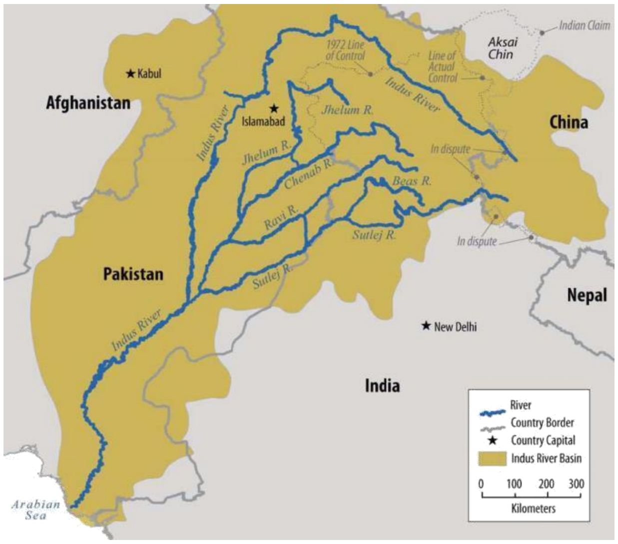
Pakistan is an agricultural country and it withdraws almost half of its water from melting water of the Himalaya-Karakoram and Hindukush ranges. Being an agricultural country, about 76% of its population live in the countryside [1]. The prosperity and lifestyle of the people of Pakistan depend largely on agriculture and highly of the Indus Basin Irrigation System. Any change in any of these water resources due to climate variability may affect the economy and food security of Pakistan.

Climate change is prevalent nowadays as, for instance, it has been found that Northern hemisphere were subjected to warming air temperatures since last 1400 years [2]. Such average globally warming air temperatures are variable and are not synchronous among different regions [3]. Similarly impacts of climate change differ considerably, on a local scale depending on exposure, the adaptive capacity of sectors of water, food and energy security [4]. Moreover, it is the dire need of the day to evaluate the prevailing climate state and water availability of Upper Indus Basin because the mountainous environment is highly susceptible to climate change and melt water is principal tool for controlling runoff
Dynamics in the Upper Indus Basin as, for instance, Authors in [5] have analyzed the trend in precipitation for four substations of UIB and found a significant increase in summer and winter while analyzing updated data for last three decades since 1980 suggested summer warming and winter cooling temperatures are less prevalent and clearly assessed for Gilgit and Bunji stations, respectively. It has been found that an increase in precipitation occurs in Chitral-Hindukush and Northwest Karakoram regions and decrease in precipitation over Himalayas within UIB though changes are insignificant [5].

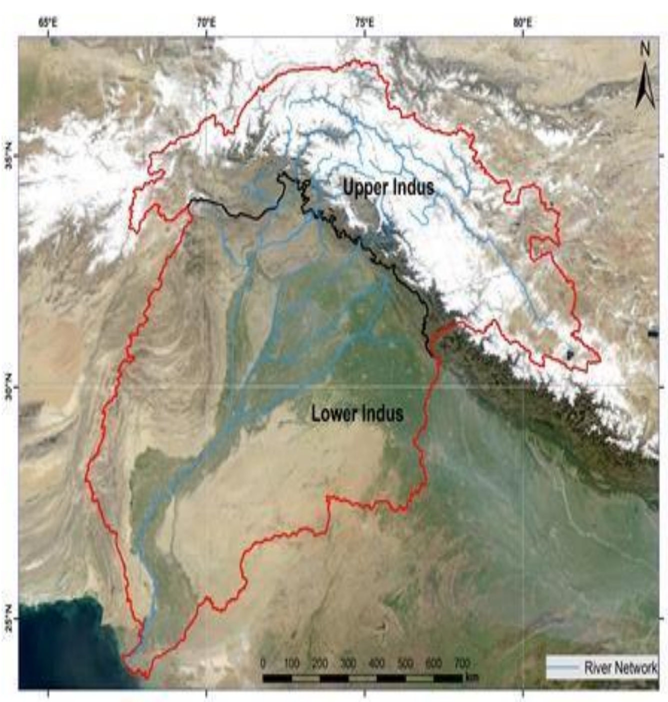
Owing to the climate change fingerprints in UIB, a non-parametric Mann Kendall test is applied over the time series data to investigate the trend. This study will be very useful and will pave the way for impact assessment and will serve as an important knowledge for the water resource managers and policy makers in this region.

II. STUDY AREA

The Indus Basin spreads over an area of 1.1 million sq. km and is shared by Afghanistan, China, India and Pakistan. The Karakoram and Himalaya mountain ranges guard the north and Northeast of Pakistan while the Hindu Kush mountain range guards the northwestern frontiers of the country. The main river originates at the lake Knangalo river in the Tibetan plateau, China and include water form Swat, Chitral, Gilgit, Hunza, Shyok, Shigar, Indus, Shingo, Astore, Jhelum, Chenab, Kabul, Ravi, Beas and Sutlej are draining parts of India, China, Afghanistan and Pakistan. Recent cases are shown and analyzed.



The Upper Indus Basin is resting on Hindus Kush-Himalayan and Karakoram ranges with an area of 289000 sq.km. The Indus Basin ranks among the most important for human dependence, directly or indirectly. The basin is preponderant in the sense that it provides water for sectors like agriculture, domestic use, industrial use and energy production for people living therein. The Indus Basin is fed by seasonal precipitation and two biggest natural reservoirs i.e. snow and glaciers. These basins have features like distinct hydrological regimes, which are linked with the main source (snow and glaciers) of the meltwater generation.



III. LITERATURE REVIEW

Tahir A. A in [6] worked on the impact of climate change on snow and ice and hydrological regime in UIB.

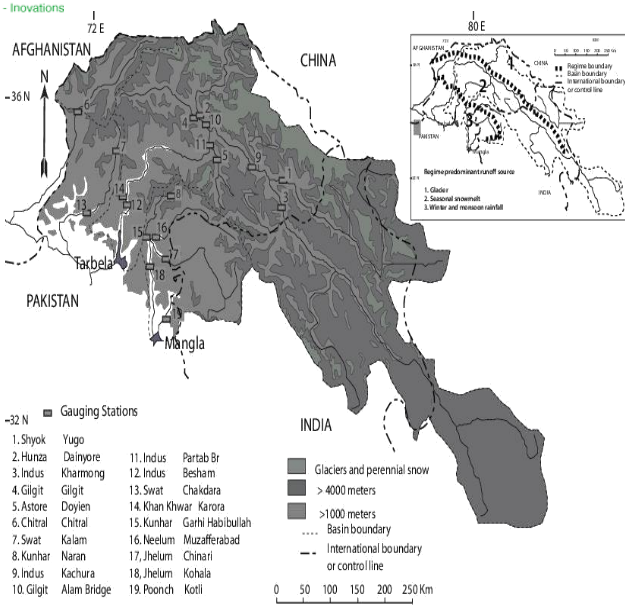
It is opined that snow cover change has direct relation with summer mean temperatures and hence results in a high stream flow. Salik et.al. in [4] evaluated that local impacts of climate change differ considerably depending on their susceptibility, adaptive capacity for sectors of water, food and energy security. In view of the report delivered by Khattak et.al. in [7] found winter warming and summer cooling trend for a period (1967-2005).

Bocchiola and Diolaiuti in their research [8] suggested that summer cooling and winter warming trends are no longer prevalent and is assessed only for Gilgit and Bunji stations for (1980-2009). However an increase in precipitation is observed over Chitral, Hindu Kush and Karakoram while a decrease in greater Himalayas. Penas have found in [9] a generalized increase in Tmax and Tmin in winter, pre monsoon by applying different statistical tools over 37 meteorological stations in Pakistan.

Mahmood and Babel in [10] studied the possible impacts of climate change on the water resources and Kunhar River Basin, Pakistan. Temperature and precipitation data for a period (2011-2099) were obtained under A2 and B2 scenarios and analyzed for future stream flow and determined an overall increase of 1.92°C-3.15°C in temperature and 5%-11% in precipitation. Khalida Khan and Muhammad Yaseen investigated in [11], sixteen stations of UIB with Mann Kendall test and the Sen's Slope method indicated there is an upsurge of annual maximum and mean temperature for the period (1961-2011).

IV. SELECTED REGION

The Upper Indus Basin covers an area of about 289000 sq.km and having a very sparse network of meteorological stations that mostly lies within the Pakistan political boundary, where five substations of UIB are selected, i.e Chitral, Skardu, Gilgit, Astore and Gopiz. Field monthly data of precipitation for 35 years, i.e. (1980-2014) were collected from Pakistan Meteorological to investigate the trend within UIB.



V. METHODLOGY

A. Trend Analysis

A trend simply means what seems to be going around at any given time. In statistical terms, it is defined as the change in the values of a parameter, whether increases or decreases, getting better or worse.

Methods for Trend Analysis

Following are the methods that can be used for trend detection;

I. Mann Kendall test

II. Sen's Slope test

III. Cusum's test

B. Mann Kendall Test

The Mann Kendall test is a non parametric test and does not require the data to be normally distributed. Moreover, it has very low sensitivity to abrupt breaks due to inhomogeneous time series. It is usually preferred when various stations are taken in a single study.

C. Computational Procedure

According to this test, the null hypothesis H_0 assumes that there is no trend and this is tested against the alternative hypothesis H_1, which assumes that there is a trend. The computational procedure for the Mann Kendall test considers the time series of n data points and X_i and X_j as two subsets of data where i= 1, 2, 3,…, n-1 and j= i+1, i+2, i+3,…., n. Each data value of I series is compared with all the subsequent values of j series. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if a data value from a later time period is lower than the data value from an earlier time period, the statistic S is decremented by 1. The sum of all such increments and decrements yields a final value of S.

The Mann Kendall S statistic is computed as follows;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i) \;\ldots\ldots\; (1)$$

$$Sgn(x_j - x_i) = \begin{Bmatrix} +1, \rangle (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, \langle (x_j - x_i) \end{Bmatrix}$$

Where X_i and X_j are the annual values in years.

Mann Kendall test Statistics(S):

The resultant Mann Kendall test statistic shows how strong the trend in precipitation is and whether it is increasing or decreasing.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (i)(i-1)(2_i+5)}{18} \;\ldots(2)$$

Where t_i denotes the number of ties to extent i.

Tied Group (ti):

These are those values which are repeated in a data set. The summation term in the numerator is used only if the data series contain tied values. The standard test statistic Z_S is calculated as follows;

$$Z_c = \begin{Bmatrix} \dfrac{S-1}{\sqrt{Var(S)}} \\ 0, S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, S\langle 0 \end{Bmatrix} \;\ldots\ldots\ldots(3)$$

Mann Kendall Test Statistic (Zs):

The test statistic indicates the significance of the trend. It takes only those values which are significant as a trend for a certain significance level. Indeed, this test statistic is used to test the null hypothesis, H_0. If Z_S is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (e.g. 5% with $Z_{0.025}$ = 1.96) then the null hypothesis is invalid implying that the trend is significant.

Significance Level (α):

Significance level (α) shows the rigidity of our result i.e significance level of (α = 0.5%) shows that the result will Be 99.5% free from any error.

VI. RESULTS & DISCUSSION

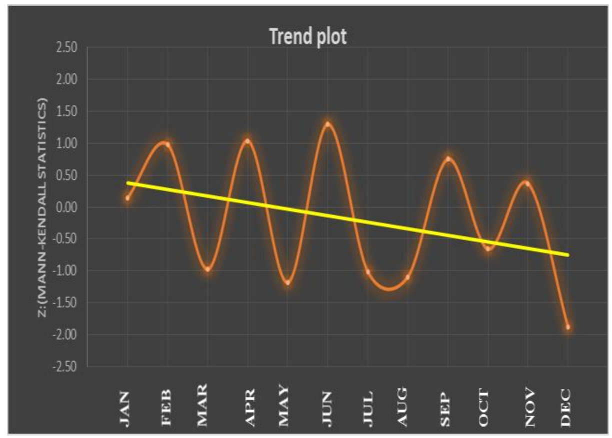
The Mann Kendall test results for the selected substations of (Chitral, Skardu, Gilgit, Astore & Gopiz) are shown below; These results are graphically explained as follows;

Station	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Astor	Z	1.75	1.38	2.72	1.73	1.71	2.66	0.62	0.64	-1.85	1.36	0.74	1.09
	Critical Z Value,	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96
	H_0 hypothesis	Accept	Accept	Reject	Accept	Accept	Reject	Accept	Accept	Accept	Accept	Accept	Accept
	Trend, ±	No	No	Yes(+)	No	No	Yes(+)	No	No	No	No	No	No
Chitral	Z	0.14	0.98	-0.98	1.04	-1.19	1.30	-1.02	-1.10	0.75	-0.66	0.37	-1.89
	Critical Z Value,	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96
	H_0 hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
	Trend, ±	No	No	No	No	No	No	No	No	No	No	No	No
Gilgit	Z	0.60	0.43	-0.71	0.02	0.32	2.11	-0.44	1.33	2.30	0.63	0.00	0.39
	Critical Z Value,	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96
	H_0 hypothesis	Accept	Accept	Accept	Accept	Accept	Reject	Accept	Accept	Reject	Accept	Accept	Accept
	Trend, ±	No	No	No	No	No	Yes(+)	No	No	Yes(+)	No	No	No
Gupis	Z	-3.39	-2.59	0.73	0.63	1.38	2.63	2.24	-0.17	0.70	3.58	-0.97	-4.80
	Critical Z Value,	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96
	H_0 hypothesis	Reject	Reject	Accept	Accept	Accept	Reject	Reject	Accept	Accept	Reject	Accept	Reject
	Trend, ±	Yes(-)	Yes(-)	No	No	No	Yes(+)	Yes(+)	No	No	Yes(+)	No	Yes(-)
Skardu	Z	0.98	1.69	-0.49	0.72	-0.98	-0.11	-0.35	2.35	1.76	-0.80	-0.79	0.03
	Critical Z Value,	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96	±1.96
	H_0 hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Reject	Accept	Accept	Accept	Accept
	Trend, ±	No	No	No	No	No	No	No	Yes(+)	No	No	No	No

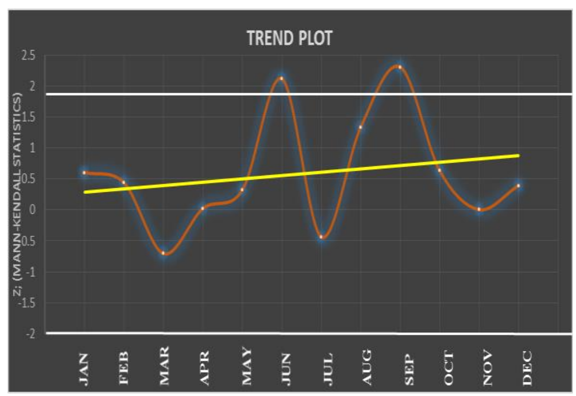
The table, shows the value of Z_S, calculated for Five substations of UIB after analysis of monthly data using Mann Kendall test. This value of Z_S is then compared with Z_{cr} for 5% significance level, which comes out to be ±1.96. If the value of Z_S is greater than the value of Z_{cr}, this implies an increasing trend and vice versa, and leading to the rejection of null hypothesis H_0 . While if the value of Z_S lies in range of Z_{cr} i.e ±1.96, leads to the acceptance of the null hypothesis, which means no trend over there.

These results are graphically explained as follows;

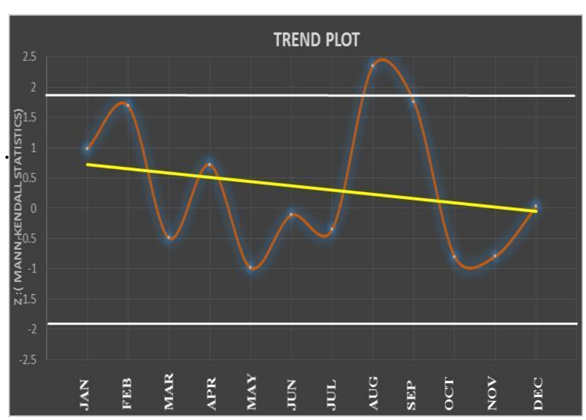
1. **Chitral**



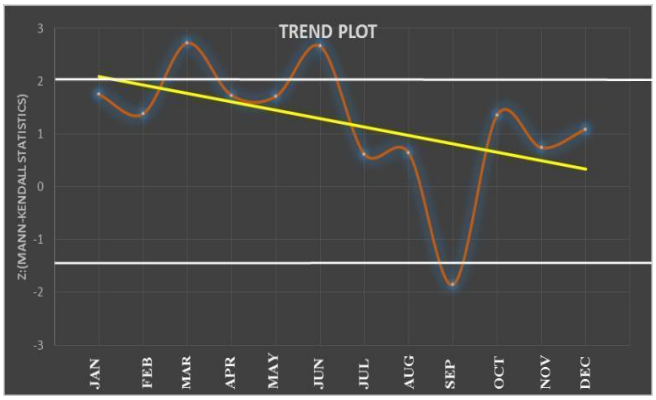
2. **Gilgit**



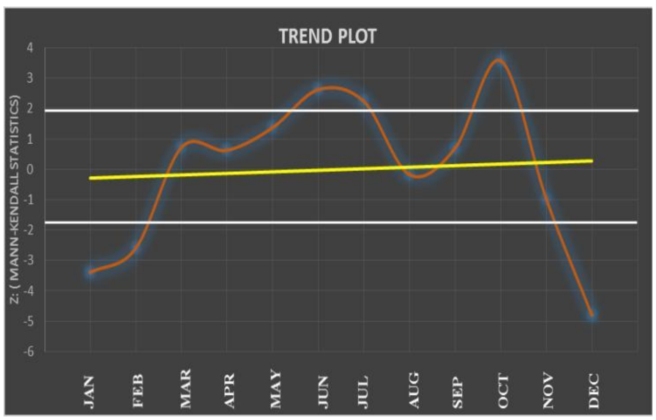
3. **Skardu**



4. **Astore**



5. **Gopiz**



The above figures give the graphical representation of a trend for each substation of the Upper Indus Basin. These graphs show a significant trend if the values of the Mann Kendall Statistic go beyond the range specified for a significance level α = 5%. All the substations show significant trends wherever the "Red Line" surpasses the range "White Line", however the substation Chitral is showing no trend. The "Yellow Line" is a linear trend line showing the future scenario for all substations. The substations Chitral, Skardu and Astore will show the decreasing trend in the near future while the substations Gilgit and Gopiz show the increasing trend in near future.

VII. CONCLUSIONS & RECOMMENDATIONS

4.1 Conclusions:

It is found that most of the sub stations of Upper Indus Basin show a clear sign of the trend, i.e either "increasing" or "decreasing" for a mean monthly precipitation data ideally(1980-2014) for 35 years. Such precise response of increase or decrease in precipitation at monthly scale is averaged out on a seasonal time scale for five substations of the Upper Indus Basin, which are as follows;

Chitral

It is noted from the analysis that substation Chitral is showing no trend for all four seasons (summer, autumn, winter, spring) i.e neither "Dryness" nor "Wetness". However the trend line (yellow) is indicating –ve trend in near future. It means that the total amount of precipitation will decrease in future.

Gilgit

Considerable "wetness" or a +ve trend is detected at substation Gilgit in summer season (Jun-Sep). In these months due to increase in precipitation, there are greater chances of floods in the rivers of this sub basin. However, no significant trend is detected in Spring, Autumn and Winter. While the trend line dictates the total increase in the precipitation of Gilgit in future.

Skardu

The trend plot for Skardu shows that climate change will cause an increase in heavy rainfall i.e a +ve trend in the summer however, no trend is noticed during other seasons. But the trend line depicts an opposite scenario that precipitation will decrease in future i.e. Skardu will face "Dryness" in near future.

Astore

It has been noted that there is a +ve trend at Astore in the seasonal months of spring and summer while negative trend have been observed in the seasonal months of autumn. But the overall trend is negative.

Gopiz

It is concluded that at substation Gopiz, -ve the trend have been observed in the seasonal months of winter while +ve trend is noted in the seasonal months of summer and autumn. However, no trend is detected in spring.

This study reveals that UIB is going to face problems like floods and food security due to significant trend in precipitation. Indeed, it would create many problems for the policy makers, water management authorities and disaster management authorities if they ignore the climate change fingerprints in UIB. So there is a dire need for effective planning of water resources owing to "increase" or "decrease" in precipitation.

4.2 Recommendations:

Extreme weather and climate events, interacting with exposed and vulnerable human and natural systems, can lead to disasters. So opportunities for managing risks of weather and climate related disasters exist or can be developed at any scale, which are as follows;

- Build a clean energy economy by investing in efficient energy technology, industries and approaches.
- Expand the use of renewable energy and transform our energy system.
- The best way to minimize human effects on earth is that government should make a law and do some activities to stop urbanization which is the basic cause of global warming.
- Reduce tropical deforestation and its associated global warming emissions.
- The government needs to institute a major paradigm shift that promotes more judicious use of water. This entails more aggressive water infrastructure maintenance regimes, more water conserving technologies and methods such as drip irrigation and raising awareness among the public about the importance of conservation.

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REFERENCES

[1] P & D, 2001 A report of planning and Development, Government of Pakistan.

[2] IPCC, 2001. Climate Change 2001: The scientific basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A., (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

[3] Yue S, Hashino M (2003). Long term trends of annual and monthly precipitation in Japan. Journal of the American Water Resources Association **39**: 587–596.2003.

[4] Salik, K. M., Jahangir, S., Zahdi, W. Z., and Hasson, S.: Climate change vulnerability and adaptation options for the coastal communities of Pakistan, Ocean & Coastal Management, under review article # OCMA-D-14-00289, 2015.

[5] David R. Archer, Hayley J. Fowler. Spatial and Temporal variation in precipitation in the Upper Indus Basin,global teleconnections and Hydrological Application, Hydrology and Earth Sciences, **8**(1), 47-61 (2004).

[6] Tahir, A.A., Chevallier, P., Arnaud, Y., Neppel, L and Patrick Wagon Hydro-meteorological Investigation in the central Karakoram Ranges -Pakistan, Poster presented at the conference ―Water in mountain areas. Better observations for better forecasting". Lyon, France (2011).

[7] Khattak, M. S., Babel, M. S., and Sharif, M.: Hydrometeorological trends in the upper Indus River Basin in Pakistan, Clim. Res., **46**, 103–119, doi10.3354/cr00957, 2011.

[8] Bocchiola D., and Diolaiuti, G.: Recent (1980–2009) evidence of climate change in the upper Karakoram, Pakistan, Theor Appl Climatol, **113**:611–641, 2013.

[9] A. Penas, 2015 Analysis of recent Changes in Maximum and Minimum Temperatures in Pakistan.

[10] Mahmood & Babel, 2016 Potential impacts of Climate Change on Water Resources in the Kunhar River Basin, Pakistan.

[11] Khalida Khan, Muhammad Yaseen, 2015 Detection of river flow trends and variability analysis of upper indus basin, Pakistan.