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Assessing the impact of climate change on surface water resources of Wular Lake

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Abstract
Research and investigation was carried out on "Assessing the impacts of climate change on Surface Water Resources of Wular Lake". The discharge of river Jhelum at Asham Inlet was obtained of the previous 21 years, and formatted to a pre-requisite form. Also the climatic data viz. temperature, precipitation, etc. were obtained from the metrological station. The three main variables of study were used as discharge, temperature and precipitation; discharge being the response variable with respect to the remaining two. Trend lines were established for each of the variables with the help of the moving averages of 5 years; which revealed the increasing trend in the temperature and the decreasing trend in the discharge and the precipitation. The trend of the three parameters was in accordance with the global climatic and hydrological findings. Further, to analyse the findings, Mann-Kendall's tests was used to ascertain the results. As per this test, temperature indicates a significant trend at 10% significance level with a p-value of 0.0494 while the precipitation could not reveal any significant trend over the limited time frame of study even at 10% significance level, which could be a result of the seasonal dimension to it. The discharge displayed a no trend over the given period of study at 5% significance levels. Further Kendall correlation test was done on the three variables of study; a significant correlation between mean annual temperature and annual rainfall was found, the magnitude of correlation coefficient being 0.46. A significant correlation was found between the annual rainfall and the mean annual discharge and correlation coefficient value of 0.65 was observed. Also a weak correlation was found between mean annual discharge and mean annual temperature; the coefficient value was found to be – 0.6190. The results are in accordance with the global findings which depict rising global temperatures and decreasing precipitation. The given study concluded that there was an adverse effect of the climate change on the catchment of the Wular Lake as visible by the various tests.

Keywords: Climate Change, Precipitation, Discharge, Kendall test, Discharge Fluctuation, Time series analysis

Introduction
Climate change is a long term change in the statistical distribution of weather patterns over periods of time that range from decades to millions of years.it may be a change in the average weather conditions or a change in the distribution of weather events with respect to an average e.g. greater or fewer extreme weather events. Climate change may be limited to a specific region or may occur across the earth.

Global warming is one of the major climate changes that have direct impact on redistribution of water resources on the earth. The observed warming over several decades due to rising atmospheric carbon dioxide (co2) and other greenhouse gases has been associated with the change in number of components of hydrological cycle systems such as increasing atmospheric water vapor content, increasing evaporation, changing precipitation patterns, intensity and extremes; reduced snow cover; and changes in soil moisture and runoff (Huntington, 2006). The frequency of heavy precipitation events has increased over most areas. There have been significant decreases in water storage in mountain glaciers and northern hemisphere snow cover. Shifts in the amplitude and timing of runoff in glaciers and snowmelt fed rivers and ice related phenomena in the rivers and lakes have been observed.

As the climate warms through the twenty first century, glaciers and ice caps are projected to lose mass owing to dominance of summer melting over winter precipitation increase. Based on simulation of eleven glaciers in various regions, a volume loss of 60% of these glaciers is projected by 2050 (Schneeberger *et al*., 2003) thus reducing water availability during warm and dry periods in regions supplied by melt water from major mountain ranges. Globally, the areas of land classified as very dry has more than doubled since 1970s (IPCC Technical paper IV, June 2008). These trends are predicted with a high degree of confidence to continue and accelerate during the current century.

The consequences of climate change may alter the reliability of current water management systems and water-related infrastructure. Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs.

The climate of Kashmir has also witnessed a change over the past decades somewhat in similar fashion as rest of the world, with precipitation decreasing over years especially its distribution during a particular season. Besides, the state is rich in fresh water resource making it more vulnerable to climate change as there are abundant evidences that fresh water resources have the potential to be strongly impacted by the climate change with wide ranging consequences for human societies and ecosystem. The world famous Wular Lake located in north Kashmir valley which is mainly Jhelum River fed would be a victim of climate change.

Despite the threats faced by the state due to climate change and its ecological fragility, very less work has been done to ascertain the impact on various environmental components. Also, it was found that no scientific study has been taken up for impact assessment of climate change on various water resources and watersheds, thus, necessitating a preliminary assessment of the area in this field. The present study was taken as a small initiative on this front.

Materials and methods

The present study was taken to assess the impact of climate change on various hydro meteorological variables in the catchments of Wular Lake and identify trends for these variables over last twenty one years.

Study Area

Location

Wular Lake is located 34 km northwest of Srinagar city at an altitude of 1,530 m and between 34 20’ N latitude and 70 24’ E longitude. It is elliptical in shape with a maximum length of 16 km and breadth of 7.6 km. The lake is surrounded by high mountainous ranges on the north eastern and north-western sides, which drain their runoff through various nallahs, prominent being Erin and Madhumati. Wular is a shallow lake with a maximum depth of 5.8m. As per the Directory of Wetlands of India (MoEF, 1990), the area of the lake is 189 sq. km.

The Wular Catchment comprises of the following sub catchments

i. Wular 1 (catchment A)
ii. Erin (catchment B)
iii. Madhumati (catchment c)
iv. Wular 2 (catchment D)
v. Ningli (catchment E)
vi. Gunder (catchment F)

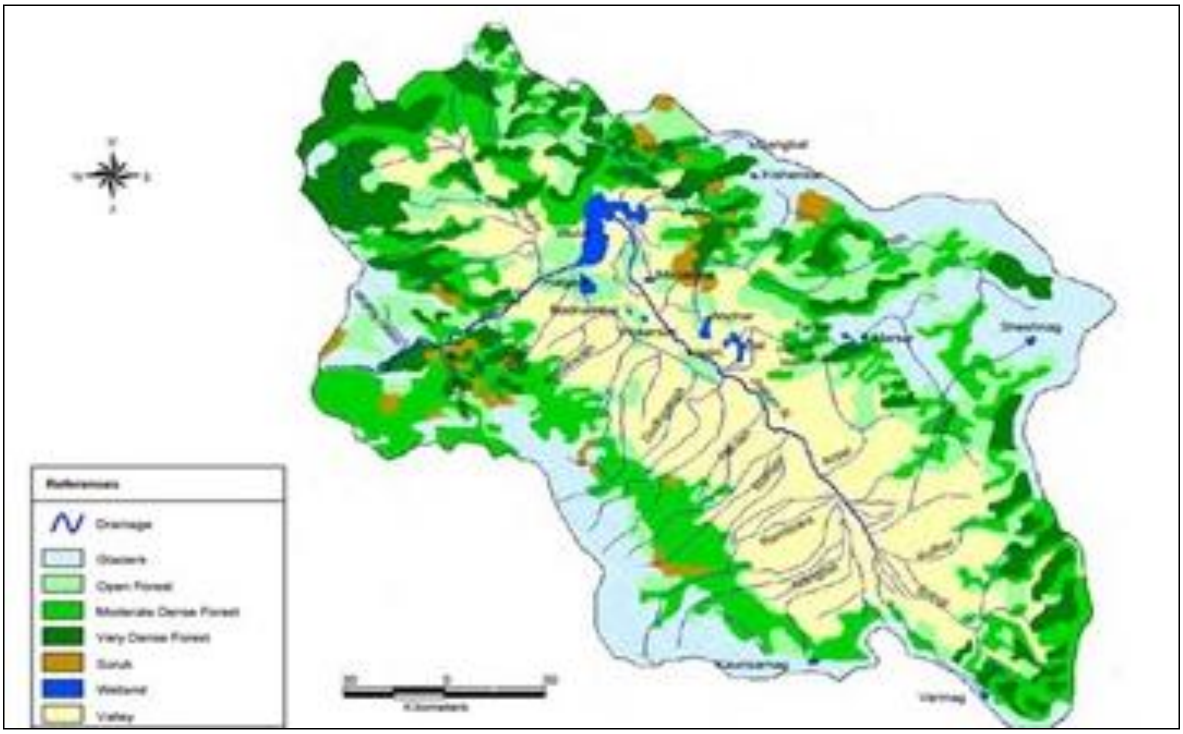

Fig 1: An overview of the wular catchment

- **Climate**

The Climate of the area is temperate sub-humid type, characterized by two distinct seasons, winter and summer. The winter is from November to February and summer is from March to October. The Wular catchment area has dramatic climatic diversity. The average mean annual temperature is about 13.99 ^{o}C. Average maximum and minimum temperatures are 19.7 ^{o}C and 7.6 ^{o}C respectively. The month of July was observed to be hottest with mean monthly temperature of 23.4 ^{o}C and January was the coldest month with mean monthly temperature of 2.1 ^{o}C as shown in Fig. No. 2. The rainfall is highest in the months of March and April. The mean annual rainfall of the area was found to be 758.93mm. Snowfall is common in the months of January and February. The pattern of mean monthly rainfall over past 21 years is shown in Fig 3.

- **Variables Studied**

Stream flow was chosen as one of the variable as it tends to reflect an integrated response for the catchment area as a whole. The other variable of the study are temperature and precipitation

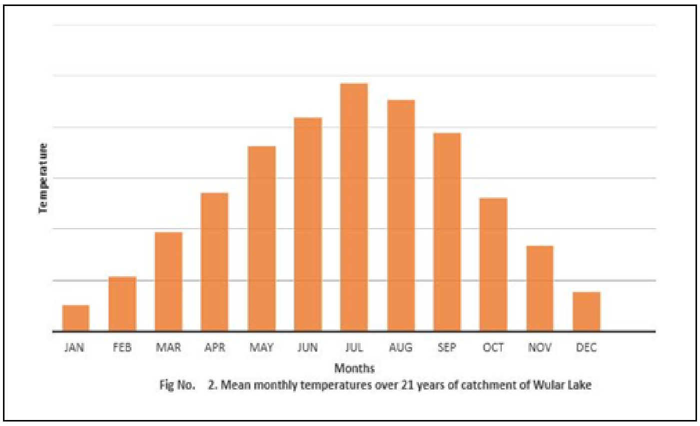

Fig 2: mean mean monthly temperatures over 21 year catchment of Wular Lake

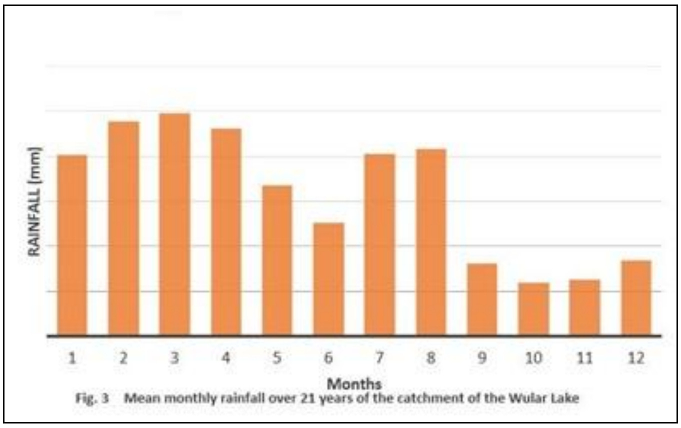

Fig 3: Mean monthly rainfull over 21 year of the catchment of the wular Lake

- **Moving Averages**

After arranging the hydro-meteorological data into annual averages, moving averages were calculated using Microsoft Excel software. The moving averages tends to eliminate any type of fluctuations by ironing them out. To iron out a type of fluctuation through moving averages means to remove their influence.

In general the method of moving averages consist of taking the arithmetic mean of the Y values for a certain time span (number of years or of the other time periods) and placing it at the center of their time span. Then, we repeat the procedure by dropping the yearly figure of the Y value, adding on the figure directly following the last figure we had previously added; thus we move the time span and its center forward by one year; then we compute and place a new average. We continue until we exhaust the series. In this study, 5 year moving averages were calculated for detecting trends in all the variables.

- **Statistical Tests**

Two statistical tests were applied on all hydro-climatic variables for analysing temporal trends and testing the correlation. The first test, called Mann-Kendall test was used to test the non-linear trend. Mann-Kendall test was originally devised by Mann (1945) as a non-parametric test. This test was found to be an excellent tool for trend detection by other researchers in similar application (Hirsch *et al*. 1982; Gan, 1992) [7]. The Mann-Kendall test statistic is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i)$$

Where n is the number of observations and x_j is the j^{th} observation and sgn (ɵ) is the sign function which can be defined as follows:

$$\mathrm{sgn}(\theta) = \begin{cases} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{cases}$$

The Mann-Kendall test has two parameters that are important to trend detection. These parameters are the significance level that indicates the trends: strength and the slope magnitude estimate that indicates the direction as well as the magnitude of the trend.

Results and discussions

The outcome of Mann-Kendall trend test and Kendall tau correlation test for different variables are discussed as follows:

- **Temperature**

The ambient temperature data were plotted against time frame of the study area from year 1993 to 2014 along with the five year moving average curve in order to evaluate the trend in the variation in temperature recorded for the catchment of study. The rising trend was observed in the mean annual air temperature over the Wular at the rate of 0.041 °C per year i.e. 0.41 °C per decade. The rising trend in the mean annual temperature over the Wular from 1993 to 2013 is shown in Fig.4.

An annual mean global warming of 0.4 to 0.8 °C has been reported since the late nineteenth century (IPCC, 1998). Pant and Kumar (1997) reported the rise in the seasonal and the annual surface temperature over India at the rate of 0.57 °C per century using the data for 1881-1997.

The Mann-Kendall trend test was applied, which computed the various indicative values as below:

- Standard deviation = 0.5089
- Kendall's tau = 0.3143
- P-value (Two tailed) = 0.0494
- Alpha = 0.1

For the purpose of interpretation, two hypotheses are put forward:

1. Null Hypothesis, stating that there is no trend in the temperature series.
2. Alternative Hypothesis, stating that there is a trend in the series.

At 10% significance levels, the computed p-value is lower than the significance level alpha (0.1). The p-value signifies that the risk of rejecting the null hypothesis in the case of its being true is just 4.94%, in this case, the null hypothesis can he rejected and alternative hypothesis can be accepted.

Hence, the result of the trend test on the temperature data indicates that a trend is visible in the temperature series at 10% significance level over the past 21 years.

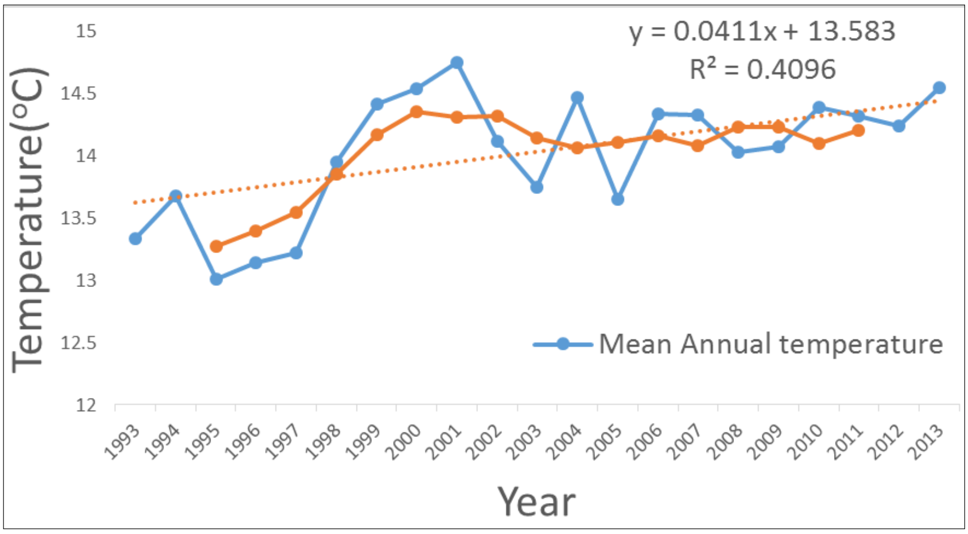

Fig 4: Trend of temperature in the catchments of Wular Lake

- **Rainfall**

The annual rainfall data were plotted against time frame of the study area from year 1993 to 2014 along with the five year moving average curve in order to evaluate the trend in the variation in rainfall recorded for the catchment of study. A falling trend was observed in the rainfall at the rate of 6.06 mm per year. The average annual rainfall of the Wular Lake was found to be 758.93 mm. The falling trend in the rainfall is shown along with the annual rainfall from 1993-2013, in Fig. 5. In the IPCC report, the globally Averaged precipitation is projected to increase. But, at the regional scale both increases and decreases are projected (IPCC, 2001). In the present study, the falling trend of almost 2.13% per year in the precipitation was observed over the past 21 years over the Wular Lake.

The Mann-Kendall trend test was applied, which computed the various indicative values as below:

- Standard deviation = 207.3187
- Kendall's tau = -0.1333
- P value (Two tailed) = 0.4209
- Alpha = 0.05

For At 5% significance levels, the computed p-value is greater than the significance Level alpha (0.05). The p-value signifies that the risk of rejecting the null hypothesis in the case of its being true is just 42.09 %. In this case, the null hypothesis cannot be rejected and alternative hypothesis cannot be accepted. Hence, the result of the trend test on the temperature data indicates that no trend invisible in the rainfall series at 5% significance level over the past 21 years.

For the purpose of interpretation, two hypotheses are put forward:

1. Null Hypothesis, stating that there is no trend in the rainfall series.
2. Alternative Hypothesis, stating that there is a trend in the rainfall series.

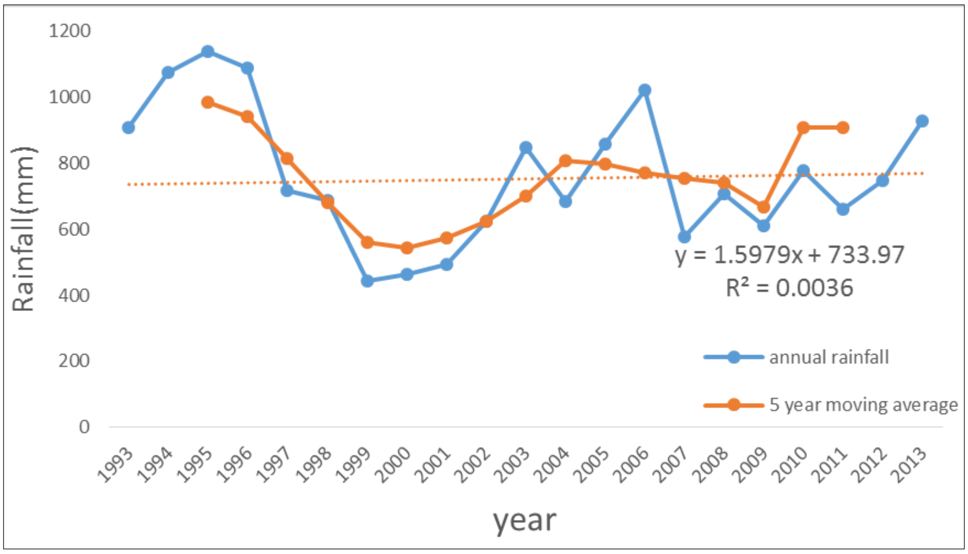

Fig 5: Trend of rainfall in the catchments of Wular Lake

- **Discharge**

An idea about the discharge pattern coming from the river Jhelum over a year for the Wular catchment was revealed from the graph plotted between mean monthly discharges versus time in months. The Jhelum flows into the Wular all through the year and discharge is maximum in the month of June and then follows a decreasing pattern. The graph is shown in the Fig. 6. The discharge data were plotted against time frame of the study area from year 1993 to 2013 along with the five year moving average curve in order to evaluate the trend in the variation in discharge recorded for the catchment of study. A decreasing trend was observed in the mean annual discharge coming into Wular Lake from river

Jhelum at Asham. The decreasing trend in the mean annual discharge along with the mean annual discharges since 1993 is shown in Fig. 6.

The Mann-Kendall trend test was applied, which computed the various indicative values as below:

- Standard deviation= 2228.1304
- Kendall's tau = -0.2381
- P-value (Two tailed) = 0.1415
- Alpha = 0.05

For the purpose of interpretation, two hypotheses are put forward:

1. Null Hypothesis, stating that there is no trend in the discharge series.
2. Alternative Hypothesis, stating that there is a trend in the discharge series.

At 5% significance levels the computed p-value is higher than the significance level alpha (0.05). The p-value signifies that the risk of rejecting the null hypothesis in the case of its being true is just 14.15 %. In this case, the null hypothesis cannot be rejected and alternative hypothesis cannot be accepted.

Hence, the result of the trend test on the discharge data indicates that no trend is visible in the discharge series at 5% significance level over the past 21 years.

- **Correlation**

The trend analysis was followed by the correlation tests for assessing the inter dependence of the three parameters. The Kendall correlation was used and the results obtained were in the form of a correlation matrix (Kendall), given as under:

Table 1: Kendall correlation matrix for different variables of the study

Variables	Mean Annual Discharge	Mean Annual temperature	Annual Rainfall
Mean Annual Discharge at Asham	1	-0.6190	0.6476
Mean Annual temperature	-0.6190	1	-0.4571
Annual Rainfall	0.6476	-0.4571	1

The Kendall correlation matrix for different variables of the study as shown above indicates that there is a significant correlation between mean annual temperature and annual rainfall over a period of twenty one years from 1993 to 2013. The magnitude correlation coefficient between these two variable is 0.46 and is negatively correlated which revealed that over a period of twenty one years there is a rise in mean annual temperature values and corresponding annual rainfall has a decreasing value over the period of past 21 years.

A significant correlation was found between the annual rainfall and the mean annual discharge. This finding can be explained on the basis that rainfall has effect on the Jhelum flow into Wular Lake. Also a weak correlation was found between mean annual discharge and mean annual temperature. This depicts that there is no direct effect of temperature on river Jhelum's discharge into Wular Lake.

Conclusions

The present study was conducted with the prime objective of investigating the impact of climate change on Jhelum's input feeding Wular Lake. The data regarding the variables of study was processed as per the requirement of the study. The mean annual temperatures of last 21 years were plotted against time along with the 5-year moving average. There was a rising trend observed in the mean annual air temperatures over the Wular Lake at the rate of 0.041°C per year i.e. 0.41°C per decade. The annual rainfall data was also analysed for the trend by plotting total annual precipitation against time. The falling trend in the rainfall was observed from 1993-2013 with the magnitude of almost 6.06mm per year. The mean annual discharge at Asham inlet showed a decreasing trend when plotted with time for last 21 years at the rate of 179.28 m^3/s per year.

The following conclusions could be drawn from the current study:

i. There is rising trend in the ambient temperature from 1993 to 2013 of the Wular Lake at 10% significance level as the computed p-value (0.0494) is lower than a (0.1).

ii. The average annual rainfall of the Wular Lake was found to be 758.93 mm. No significant trend was observed in the rainfall over the past 21 years.

iii. Mann Kendall trend test for mean annual discharge at Asham Inlet over past 21 years revealed no trend ascertained at 5% level of significance. The decrease stream discharge is at the rate of 179.28 m^3/s per year.

iv. The trends are in accordance with the global findings which depict rising global temperatures and decreasing precipitation.

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