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Assessing Impact of Climate Change on Surface Water Resources in Dal Catchment

Mir Bintul Huda[1], Akhoon Asrar[2] and Nasir A Rather[1]

[1]Department of Civil Engineering, NIT Srinagar, J&K, India.

[2]Department of Agricultural Engineering, IARI, Delhi, India.

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ABSTRACT

Research and investigation was carried out on "Assessing the impacts of climate change on Surface Water Resources of Dal Catchment". Two catchments of Dal Lake viz. Dachigam and Telbal were selected for the study purpose; since the two alone contribute about 80% to the waters of Dal Lake. The stream discharges and climatic data were obtained for the previous 20 years. The three main variables of study were 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 5 year moving averages; which revealed the increasing trend in the temperature and the stream discharge, while a decreasing trend was visible in the precipitation. The trend of the three parameters was in accordance with the global climatic and hydrological findings. Further, to analyze the findings, Mann-Kendal's test was used to ascertain the results. As per this test, discharge displays a significant trend over the given period of study at 5% significance levels with a p-value of 0.006; temperature also indicates a significant trend at 10% significance level with a p-value of 0.086 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 given study concluded that there was an adverse effect of the climate change on the catchment of the Dal Lake.

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.

In recent usage, especially in the context of environmental policy, climate change usually refers to changes in modern climate. It may be qualified as anthropogenic climate change, more generally known as global warming or anthropogenic global warming.

The observed warming over several decades due to rising atmospheric carbon dioxide (CO_2) and other green house gases has been associated with the change in number of components of hydrological cycle and 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 snow melt fed rivers and ice related phenomena in the rivers and lakes have been observed.

As the climate warms throughout 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 simulations 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 area 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 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 resources 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.

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. The present study was taken as a small initiative on this front. The catchment of world famous Dal Lake which is mainly glacier fed taken up for the study and the impact assessment due to climate change on surface water resources of this catchment was done.

Impact assessment of climate change on various water resources and watersheds has been successfully carried in various parts of the globe. But, it was found that no such scientific study has been taken up for the Dal lake and its catchment, thus, necessitating a preliminary assessment of the area in this field. Further Dal Lake is an important tourist destination and backbone of the tourism industry in Kashmir, so,

Tele:

E-mail addresses: nasir_11phd13@nitsri.net

demanding research in all fields concerning it, for proper planning and implementation of conservation measures.

Methodology

The present study was taken to assess the impact of climate change on various hydro meteorological variables of the catchment of Dal Lake and detect trends in them over last twenty years. When attempting to detect trends in a natural series, an investigator must be cognizant of the inherent variability of hydrologic time series (Burn, 1994) as Askew (1987) indicates that there is a difficulty associated with differentiating between natural variability and trends. This argues for a rigorous procedure for detecting trends.

Description of Study Area

Location: The catchment of Dal Lake was taken as the study area which is located in the state of J&K. The state of Jammu & Kashmir is situated in the north western Himalayan region lying between 27^0 17' to 37^0 N latitude and $74^0 18'$ to $80^0 23'$ E longitude. The Kashmir valley comprises the temperate zone of the state and covers a total of 1.6 Mha. The region is endowed with abundant precipitation, intense solar radiation and favorable temperature and above all fresh water lakes, wetlands, and tarns.

Dal Lake is an urban valley lake situated between $34^0 5'$ to $34^0 6'$ N latitude and $74^0 8'$ to $74^0 9'$ E longitude, at an altitude of 1583 m and is the second largest lake in the state of J&K.

A perennial inflow channel, Telbal channel, enters the lake from the north and supplies about 80% of water to the lake. Towards the south-east side, an outflow channel drains the lake water into the tributary. The maximum depth of the lake is 6 m and a mean depth of 1.4 m. the normal range of annual water level fluctuation is 0.7 m and the length of the shore line of the lake is surrounded by high mountains on one side and by an urban area on the other side. The total catchment area of the Dal Lake works out to be 337.17 km^2.From computation of runoff point of view, the Dal catchment has been divided in following sub-catchments:

i. Telbal catchment comprising of Dachigam (catchment A) and Telbal (catchment B)
ii. Lake Hillside (catchment C)
iii. Srinagar North (catchment D)
iv. Srinagar Centre (catchment E)
v. Dal Lake (catchment F)

Catchment A – Dachigam: This is the largest catchment and drains via the Dachigam Nallah and the Telbal Nallah, the latter being the main stream flowing into Dal Lake and is the main carrier of silt load into the Lake.

The valley catchment begins above the vegetation line in the Himalayan foothills at an elevation of 4500 m and has very steep sides, characteristic of the region. The Nallah is a steep, fast flowing boulder bed stream. At the outlet of the catchment the Dachigam Nallah flow is diverted to the irrigation canals in Catchment B (Telbal), the Harwan Reservoir (irrigation water storage) and the water treatment plant at Harwan. The balance continues to flow down the Nallah, which is then called the Telbal Nallah. At times of flood when the Nallah is carrying a large silt load the reservoir is by-passed.

Catchment B – Telbal: This catchment discharges into the Dal Lake via the Telbal and a number of other small streams. The catchment begins in the foothills which being south facing has been denuded by burning off and over-grazing. From the base of the steep hills to the Lake the gently sloping ground is extensively used for paddy fields which are dissected by a system of irrigation canals.

Catchment C – Lake Hillside: This catchment drains into the Dal Lake via a number of small streams around the east and south sides of the Lake. Around the Lake foreshore the land slopes very gently and is used for gardens, orchards and paddy fields. Beyond this the land rises very steeply to 1000 m above the Lake. The steep exposed slopes in the main do not support any vegetation though in some areas over-grazing has contributed to denudation.

Catchment D – Srinagar North: This catchment drains into Nagin Lake and directly into the Amir Khan Nallah, which is one of the outlets from Dal Lake via Nagin Lake. The catchment contains outer suburbs of Srinagar City and is also extensively cultivated with gardens and paddy fields.

Catchment E – Srinagar: This catchment drains into the southwest corner of Dal Lake via a number of channels. The catchment is almost fully urbanized and includes the central part of Srinagar City. The topography is flat.

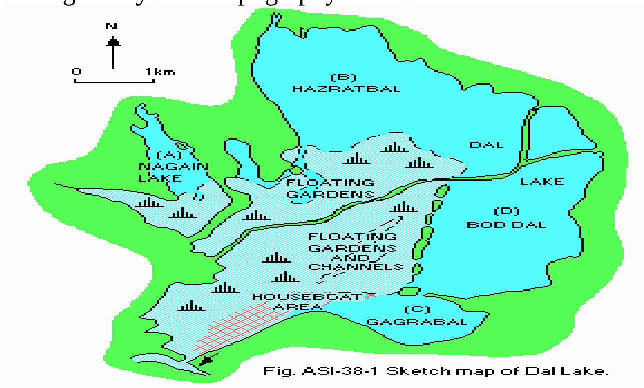

Fig 1. Sketch of Dal Lake

Catchment F – Dal Lake: This is the catchment formed by the Lake itself and includes open water, floating gardens, and marsh and land areas within the Lake. RITES conducted the bathymetry survey during 1999-2000. Based on bathymetry survey, the details of Dal Lake interior are summarized below in table 2.

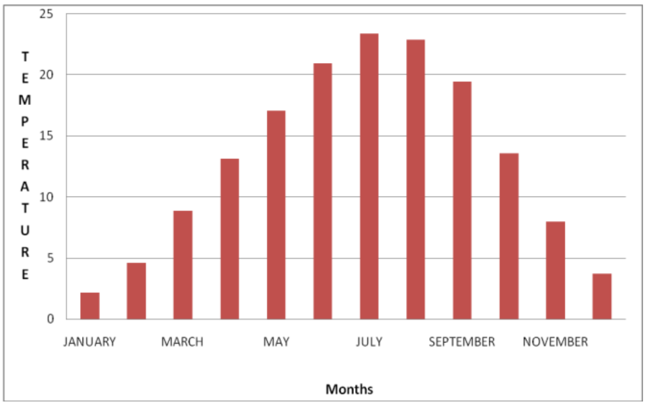

Fig 2. Lake

Topography: The study area is located among high mountains of the mighty western Himalayas. The variation in altitude is vast, ranging from 5500 feet to 14000 feet above mean sea level. Due to this vast variation, the watershed is very clearly demarcated into an upper and lower region. The terrain ranges from gently sloping grasslands to sharp rocky outcrops and cliffs. Part of the watershed lies above the tree line and this area displays its own kind of natural beauty with bare rock mountains and crevices.

Climate: The climate of the area is temperate sub-humid type, characterized by two distinct seasons, winter and summer.

TABLE 1. AREAS OF DIFFERENT LAND USES IN DAL CATCHMENT

Land use class	Area in km^2
Bare grounds	160.97
Dense forest	52.02
Built-up/unclassified	45.44
Open Forest	34.15
Lakes/Shadows	33.49
Snow	9.25
Degraded Forest	1.85
Total	337.17

TABLE 2.DAL LAKE INTERIOR DETAILS

S.No	Land portion	Area in km^2
1.	Dal Lake	13.39
2.	Nagin	0.79
3.	Small water bodies	0.82
4.	Channels	1.10
5.	Floating Gardens	2.41
	Total	18.51

TABLE 3. MEAN ANNUAL DISCHARGE, MEAN ANNUAL TEMPERATURE, ANNUAL RAINFALL AND THEIR 5 YEAR MOVING AVERAGE

YEAR	Mean annual discharge	5-year moving average	Mean annual temperature	5-year moving average	Annual rainfall	5-year moving average
1990	0.875775		13.84664		973	
1991	1.048108		12.08208		719.5	
1992	0.841667	0.994017	12.4743	12.84605	1056.8	946.34
1993	1.115	1.045345	12.78144	12.53916	908.7	979.16
1994	1.089533	1.059547	13.04577	12.60604	1073.7	1052.88
1995	1.132417	1.058007	12.31222	12.59949	1137.1	984.92
1996	1.119117	0.996007	12.41649	12.6622	1088.1	940.86
1997	0.833967	0.9491	12.44153	12.81616	717	815.06
1998	0.805	0.822867	13.09498	13.11032	688.4	680.54
1999	0.855	0.745285	13.81557	13.422	444.7	561.54
2000	0.50125	0.779077	13.78304	13.6078	464.5	542.64
2001	0.731208	0.897597	13.97486	13.59498	493.1	574.64
2002	1.002925	0.96752	13.37055	13.55063	622.5	622.48
2003	1.3976	1.174428	13.03089	13.35406	848.4	701.3
2004	1.204617	1.28826	13.59383	13.28243	683.9	806.76
2005	1.535792	1.383367	12.80018	13.33327	858.6	797.7
2006	1.300367	1.404627	13.61672	13.38967	1020.4	769.16
2007	1.478458	1.474707	13.62471	13.32382	577.2	754.8
2008	1.5039	1.433252	13.31292	13.45563	705.7	738.88
2009	1.555017		13.26458		612.1	
2010	1.328517		13.45922		779	

TABLE 4. KENDALL CORRELATION MATRIX FOR DIFFERENT VARIABLES OF THE STUDY

Variables	Mean Annual Discharge	Mean Annual Temp	Annual Rainfall
Mean Annual Discharge	1	-0.105	0.143
Mean Annual Temp	-0.105	1	-0.486
Annual Rainfall	0.143	-0.486	1

The winter is from November to February and summer is from March to October.

Temperature: The Dachigam catchment area has dramatic climatic diversity. The mean annual temperature is about 13.15°C. Average maximum and minimum temperatures are 19.7°C and 7.6°C respectively. The month of July was observed to be hottest with mean monthly temperature of 23.38°C and January was the coldest month with mean monthly temperature of 2.14°C.

Rainfall: The rainfall is highest in the months of March and April. The mean annual rainfall of the area was found out to be 784.4 mm. Snowfall is common in the months of January and February.

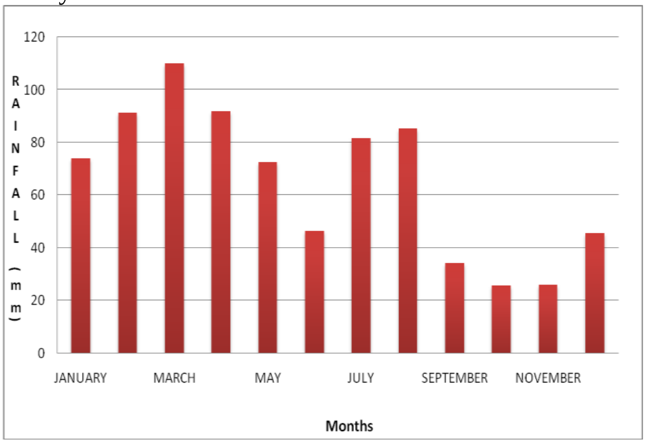

Fig 3. Mean Monthly Rainfall over 20 Years of the Catchment of Dal Lake

Variables of the study

The first step was to choose the variables to be investigated for the present study. Stream flow was chosen as it tends to reflect an integrated response for the catchment area as a whole. Hydrologic variables are important indicators of climate change. These variables tend to reflect climatic change and can help in understanding the relationships between hydrology and climate. Numerous studies have suggested different variables for detecting climate change. Pilon et al. (1991) suggested stream flow variables, while Anderson et al. (1992) considered mean, low and high flow regimes for climate change investigation. Burn and Soulis (1992) suggested studying a large number of hydrologic variables since climate change is expected to affect various variables in different ways.

Stream flow is used as one of the variables herein because of the spatially integrated hydrologic response that they provide. The other variables of the study are temperature and precipitation.

Data Sources

The meteorological data required for the current study was obtained from Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar. The stream flow data was taken from Department of Soil Conservation, Magarmal Bagh, Srinagar.

Data Processing

The need of arrangement and purpose of data processing was to obtain monthly averages and also annual means as the source agency had provided daily meteorological data and was not in a proper order and format. The discharge data was obtained in a rough form and was hand written and therefore necessitated proper processing.

The meteorological data was first arranged into chronological order. The temperatures were converted into monthly averages from 1990 to 2010. Annual averages temperatures were also calculated. All this was done using MS-Excel 2003. The same procedure was applied to precipitation data but instead of averages, total monthly and annual values were calculated. The stream flow data was obtained as monthly averages from the source agency.

Moving Averages

After arranging the hydro-meteorological data into annual averages, moving averages were calculated using Microsoft Excel software. The moving average 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.

If we iron out cyclical fluctuation from annual data through a moving average, then the moving average for each year represents trend, since annual data do not show seasonality and irregular variations are usually inconsequential in such data.

In general, the method of moving average consists of taking the arithmetic mean of the Y values for a certain time span (number of years or of other time periods), and placing it at the centre of the 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 centre forward by one year; then we compute and place a new average. We continue until we exhaust the series.

Statistical Tests

Two statistical tests were applied in this study for analyzing the time series of all variables for trend. The first test, called Mann-Kendall test is 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 applications (Hirsch et al., 1982; Gan, 1992). The Mann-Kendall test statistic is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i=1}^{n} Sgn(X_j - X_i)$$

Where X_i and X_j are the sequential data values, n is the data set record length and

$$Sgn(\theta) = +1 \begin{Bmatrix} +1 \\ 0 \\ -1 \end{Bmatrix} \quad \text{if } \theta>0, \theta=0, \theta<0$$

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.

The distribution of the test statistic is generated in this work by a permutation approach (Robson et al., 1998). The Mann-Kendall statistic, S is calculated for each of a large number of different random orderings (permutations) of the data set. The test statistic for the original data set is then compared to the distribution of the test statistic obtained from the permutated data sets and a significance level is estimated from this distribution. The rationale behind this approach is that under the null hypothesis of no trend in the data each ordering of the data set is equally likely. Therefore, the null distribution of the test statistic can be estimated from the permutation approach. This approach can be applied with any statistical test for trend.

The non parametric robust estimate of the magnitude of the slope, β, determined by Hirsch et al.(1982) is given by

$$\beta = \text{Median} \frac{[(X_j - X_i)]}{[(j-i)]} \quad \text{for all } i < j$$

The second statistical test applied in this study is Kendall τ method. It is also a non parametric method for testing the correlation (Kendall, 1938; Sprent, 1980). This method is used to test the correlation between runoff, precipitation and temperature. Both these tests were conducted using XLSTAT Version 2011.2. Software.

Results and discussions

Description of Study Area

The catchment area of Dal Lake was selected as the area of our study. Dal Lake is an urban lake situated in the Srinagar city of the state of Jammu and Kashmir, between 34°5' to 34°6' North latitude and 74°8' to 74°9' East longitude, at an altitude of about 1583 m.

The total catchment area of Dal Lake is about 337.17 km^2. 80% of the inflow to the lake is contributed by Telbal channel in the north, which is a perennial channel. On the basis of runoff computation, the catchment is divided into a number of sub-catchments. The catchments of Dachigam and Telbal constitute about 234.17 km^2 of the total catchment and are the major water supplier to the lake, with the numeric value approximating to about 80% of the total inflow.

The study was based on the discharge fluctuations of this major inflow stream, which could clearly reflect the broader picture of the lake catchment as a whole.

Data

The details of the annual mean discharge, temperature and rainfall along with their 5-year moving averages are given in the Table 3. The trend test was done on the organized set of data to assess the impact of climate change over the Dal catchment over a period of last 20 years. The results of the trend analysis are discussed as follows:

Variables

Air Temperature: The ambient temperature data were plotted against time frame of the study area from year 1990 to 2010 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 Dal catchment at the rate of 0.058°C per year i.e. 0.58°C per decade. The rising trend in the mean temperature over the Dal catchment is shown, along with the annual air temperature since 1990, in fig.4.1. 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 = 0.568
Kendall's tau = 0.276
p-value (Two tailed) = 0.086
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 8.61%. In this case, the null hypothesis can be 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 over the past 20 years.

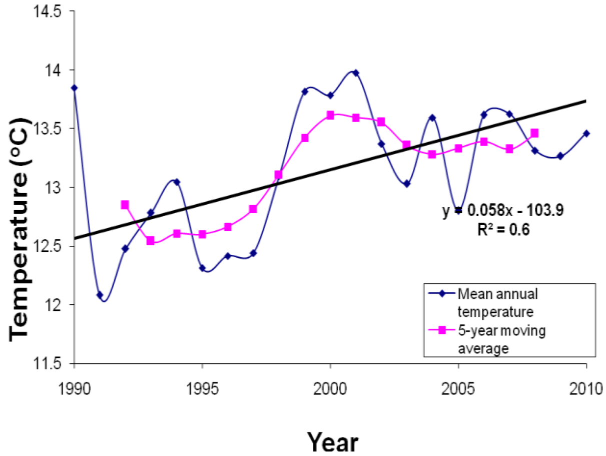

Fig 4. Trend of Temperature in the Dal Catchment

Rainfall: The annual rainfall data were plotted against time frame of the study area from year 1990 to 2010 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 16.78 mm per year. The average annual rainfall of the Dal catchment was found to be 784.4 mm. The falling trend in the rainfall is shown along with the annual rainfall from 1990-2010, in fig. 2. 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 20 years over the Dal catchment.

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

Standard deviation = 215.239
Kendall's tau = -0.238
p-value (Two tailed) = 0.142
alpha = 0.05

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.

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 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 temperature data indicates that no trend is visible in the rainfall series over the past 20 years.

Discharge: An idea about the discharge pattern over a year for the Dal catchment was revealed from the graph plotted between mean monthly discharges versus time in months. The streams are dry during the months of January, February and December, and is maximum in the month of June and then follow a decreasing pattern.

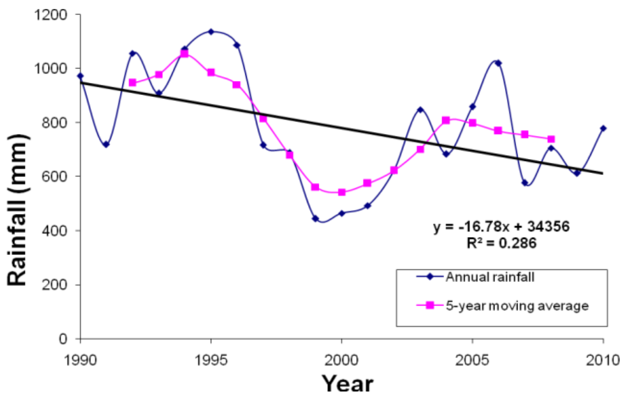

Fig 5.Trend of Rainfall of the Dal Catchment.

The graph is shown in the fig.3. The discharge data were plotted against time frame of the study area from year 1990 to 2010 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 rising trend was observed in the mean annual discharge of catchment into the Dal at the rate of 0.030 m^3/s per year. The rising trend in the mean annual discharge along with the mean annual discharges since 1990 is shown in fig. 3. The increasing trend of the discharge of the catchment of Dal lake can be attributed to the rising trend of ambient temperature of the Dal catchment which accelerates the glacier melting.

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

Standard deviation = 0.295
Kendall's tau = 0.429
p-value (Two tailed) = 0.006
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 lower 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 0.62 %. In this case, the null hypothesis can be rejected and alternative hypothesis can be accepted.

Hence, the result of the trend test on the discharge data indicates that a trend is visible in the discharge series over the past 20 years.

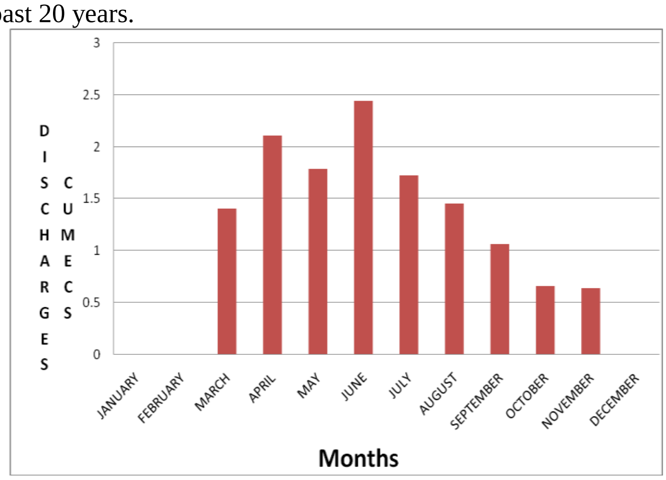

Fig 6. Mean Monthly Discharge Over 20 Years of catchment of dal lake

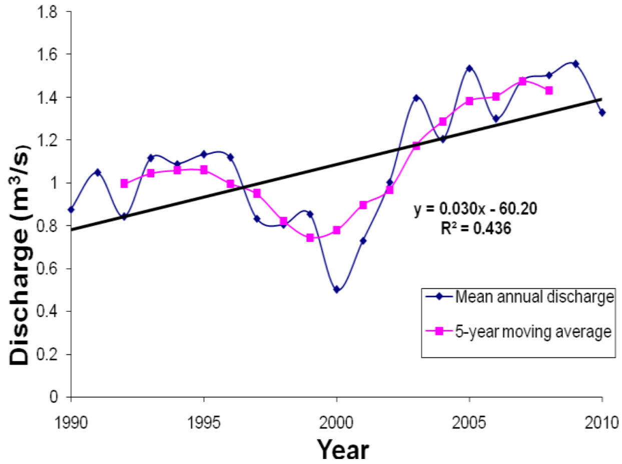

Fig 7. Trend of Discharge of the Dal Catchment

Kendall Correlation

The trend analysis of the three parameters, i.e. discharge, temperature and rainfall was done which indicated the trend of the series with respect to the time. 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:

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 1990 to 2010. The magnitude of correlation coefficient between these two variable is 0.48 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 weak correlation was found between the annual rainfall and the mean annual discharge. This finding can be explained on the basis that rainfall has least effect on the stream flows in Dal catchment and the flows is generally governed by glacier melting in upper reaches of the catchment. 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 stream discharges of Dal catchment, however, the rising trend of discharge can be attributed to the indirect effect of temperature i.e. glacier melting due to rising temperatures.

Conclusions

The present study was conducted with the prime objective of investigating the impact of climate change on streams feeding Dal lake. Therefore, catchment area of Dal Lake was chosen as the area of our study. The total catchment area of Dal Lake is about 337.17 km^2. Only Dachigam and Telbal catchments were selected for the study for simplification as it constituted about 234.17 km^2, the major portion of the Dal catchment. Two government agencies viz. JKLAWDA and Soil Conservation Department were approached for obtaining data. LAWDA provided the details about the Dal catchment while SCD gave stream discharge data. The metrological data of Stream discharge, ambient temperature and precipitation were taken from division of Agronomy, SKUAST-K. as the variables of the study. 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 Dal catchment at the rate of 0.058°C per year i.e. 0.58°C per decade. The annual rainfall data was also analyzed for the trend by plotting total annual precipitation against time. The falling trend in the rainfall was observed from 1990-2010 with the magnitude of almost 2.13 % per year. The mean annual stream discharges showed an increasing trend when plotted with time for last 21 years at the rate of 0.030 m^3/s per year.

The following conclusions could be drawn from the current study:

- There is rising trend in the ambient temperature of the Dal catchment at 10% significance level as the computed p-value (0.086) is lower than α (0.1).
- The average annual rainfall of the Dal catchment was found to be 784.4 mm. A falling trend was observed in the rainfall at the rate of 16.78 mm per year
- Mann Kendall test for mean annual stream discharges over past 21 years revealed a rising trend ascertained at 5% level of significance. The increase in stream discharge is at the rate of 0.030 m^3/s per year.
- The trends are in accordance with the global findings which depict rising global temperatures, decreasing precipitation and accelerated melting of glaciers resulting in increased stream flows.

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