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WATER HEALTH OF INDIAN HIMALAYAN REGION: ISSUES AND CONCERNS

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ABSTRACT

Climate change and socio-economic and demographic changes have put unprecedented pressure on water resources, leading to uncertain supplies, increased demands and higher risks of extreme events like floods and droughts. The rivers fed by snow-and-glacier-melt of the Himalayan region play an important role in providing water, specially during the lean season. A balanced understanding at the river-basin scale is needed if we are to arrive at a comprehensive understanding of the challenges and opportunities offered by the Himalayan waters. Overall, lack of high-altitude weather stations and long-term monitoring of snow and glacial-melt limits our ability to predict the long-term impacts of climate change on glaciers, but recent advances in remote sensing have provided information that was hitherto not available. Some studies have been carried out in the Indian Himalayan basins which depict clear trends in temperature, rainfall, snow cover area and discharge. Understanding the characteristics and trends of water related variables are crucial for sustainable water management. The purpose of this paper is to highlight various dimensions of Himalayan water resources and their management.

Keywords: *Himalayas, Glacier, Climate Change, Health, Melt runoff*

INTRODUCTION

The Himalayas are drained by 19 major rivers comprising of three major river systems, namely the Indus, the Ganges, and the Brahmaputra.The importance of these three river systems can be understood from the fact that these contribute more than 60% of annual runoff from all rivers of India and flow from these river systems sustains the lives of millions of people living downstream. These river systems consist of substantial contribution from snow and glacier-melt and hold immense potential as a freshwater source for our country. Because of significant snow and glacier contribution, average water yield of Himalayan Rivers is almost double of peninsular rivers. Himalayas have three well-defined hydrological regimes: monsoon dominated regime of north-eastern Himalayas and part of western Himalayas, snow dominated (due to western disturbances) regime of J & K and cold-arid regime of Ladakh.

Because of its geography, the Himalayan region is particularly vulnerable to the impact of climate change. The rise in mean temperature here has been higher than the global average, and this trend is expected to continue. Glacial retreat is one of the serious concerns in the Himalayas, and this is expected to affect timing, location, and volume of the stream flow. Melt runoff in the Himalayan river basins is highly significant. For example, glacier melt runoff provides about 40% of total streamflow in the Upper Indus basin and 10% in the Ganges basin (Immerzeel et al., 2010). Lutz et al. (2014)) projected an increase in runoff at least until 2050, caused primarily by increasing precipitation in the Ganges and Brahmaputra basins and accelerated melt from Indus basin. However, changes in seasonal flow and peak distribution may be more crucial than annual changes (Singh & Bengtsson, 2004).

With respect to precipitation, there are no consistent or statistically significant future projections for the region, although localized and seasonal trends have been observed (Shrestha, Wake, Dibb, & Mayewski, 2000). Precipitation is projected to increase by the end of century in the Indus (Immerzeel et al., 2010), Ganges (Kumar et al., 2011) and Brahmaputra (Immerzeel, W. 2008) basins, although the magnitude of change varies from basin to basin. In high-altitude areas, precipitation occurs as snow, which is then stored as glaciers, gradually generating melt runoff throughout the year. The temperature trends in Himalayas have been studied in parts by some researchers. The upper Indus basin shows an increasing temperature trend over the past 50–100 years, although trends are not homogeneous (Bhutiyani, Kale, & Pawar, 2007). In the Ganges basin, there is a consistent increase in temperature with altitude (You et al., 2010). The upper Brahmaputra basin also shows an increasing temperature trend over the last 50 years (Immerzeel, 2008) Most of the climate projections based on general circulation models and regional climate models suggest that the future will be consistently warmer.

In the Himalayan region, long-term ecological and hydrological database are unavailable and there is a need to properly design and operate hydro-meteorological networks and install automated instruments for long-term database development. Understanding of hydrological processes in Himalayan region for optimal utilization of water resources in the present and changed climate scenarios requires application of advanced modelling techniques in conjunction with advanced observations from remote sensing satellites and isotopic characterization. This paper highlights some important short and long-term water related issues in the Indian Himalayan region.

INDICATORS OF HIMALAYAN WATER HEALTH

The key input variables that affect the water resources from the Himalayas include precipitation from rainfall and snowfall, glaciated area in the region and its contribution to the water resources, glacial lakes and their status, hydro-meteorological variables (particularly temperature) which affect the nature of precipitation and melting of snow and glaciers, quantum of virgin river flows generated from the rainfall and snow/glacier-melt along with their spatial and temporal distribution, quantum of virgin sediment flow generated from rainfall and snow/glacier-melt processes along

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with their spatial and temporal distribution, and the quality of the generated flows in the rivers.

In view of the water related data and their sources, a few indicators have been identified to judge the status of health of the Himalayan region as given below:

a) Trend of precipitation and its spatial distribution in different time scales (monthly, seasonal, annual)

b) Trend of meteorological variables, especially temperature, and its spatial distribution in different time scales (monthly, seasonal, annual)

c) Snow cover area and its spatial and temporal distribution

d) Characteristics of glaciers and glacial lakes (area, mass balance etc.) and their advancement/retreat

e) River flow in the region and its spatial and temporal distribution

f) Sediment flow in the region and its spatial and temporal distribution

g) Quality of surface and groundwater

Status & Trends of the Water-related Indicators of Himalayan health

Some of the trends for the specified indicators are discussed below.

Precipitation

A number of studies have been carried out to estimate the trend of precipitation in different river basins in the Himalayas. Data series of different length have been used. A few figures are illustrated here to show the long-term trends. Most of these figures are self-explanatory showing the name of the station and the period of record used in the estimation of the trend.

For the Kashmir region in general, the annual precipitation and number of rainy days show a decreasing trend, though the rate of decrease vary considerably for different stations (Kumar et al., 2013). As can be observed, some exception to these trends have also been observed with different period of observation as is the case of precipitation trends at Srinagar station in Kashmir.

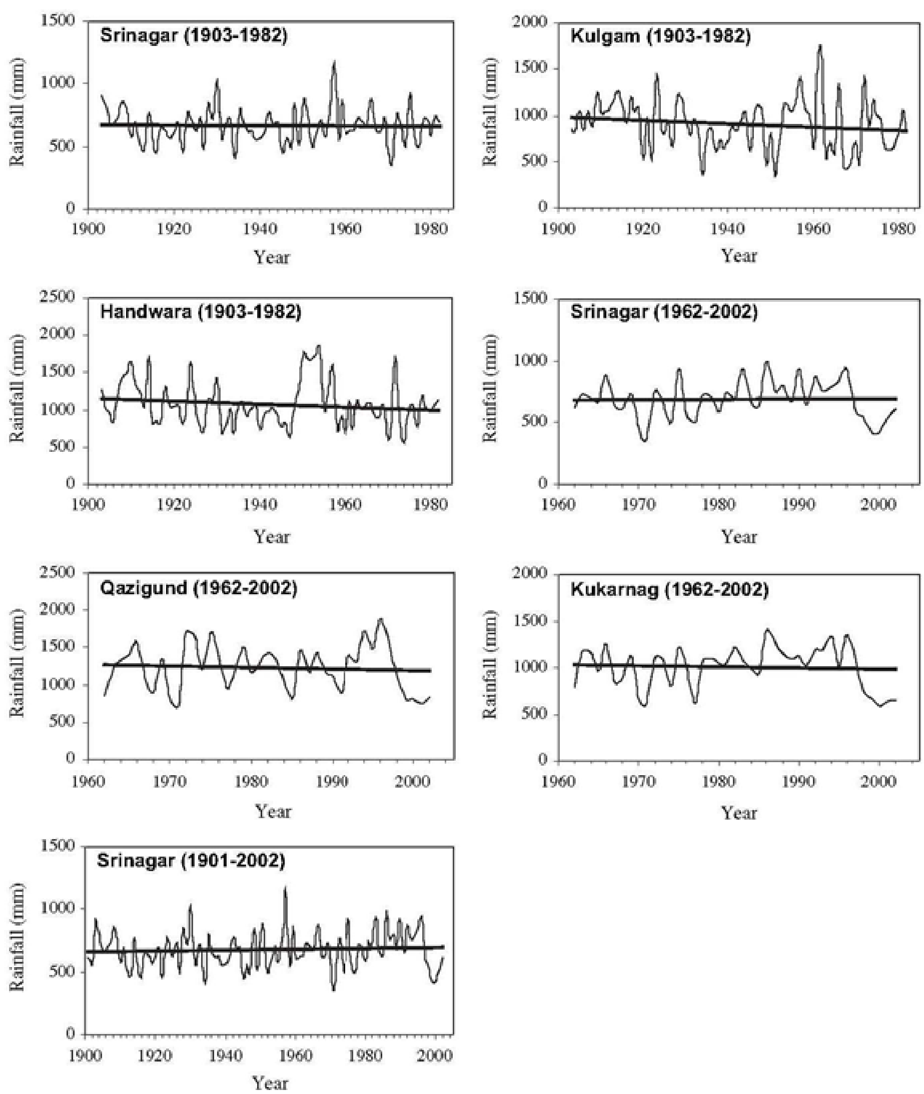

Fig.1: Linear trend in annual rainfall at different stations in Kashmir Valley (Source: Kumar et al., 2013)

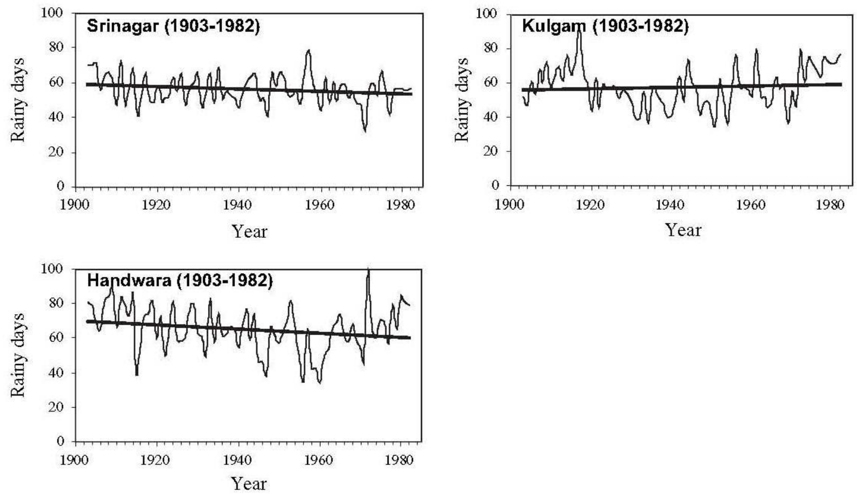

Fig. 2: Annual rainy days at different stations in Kashmir Valley (Source: Kumar et al., 2013)

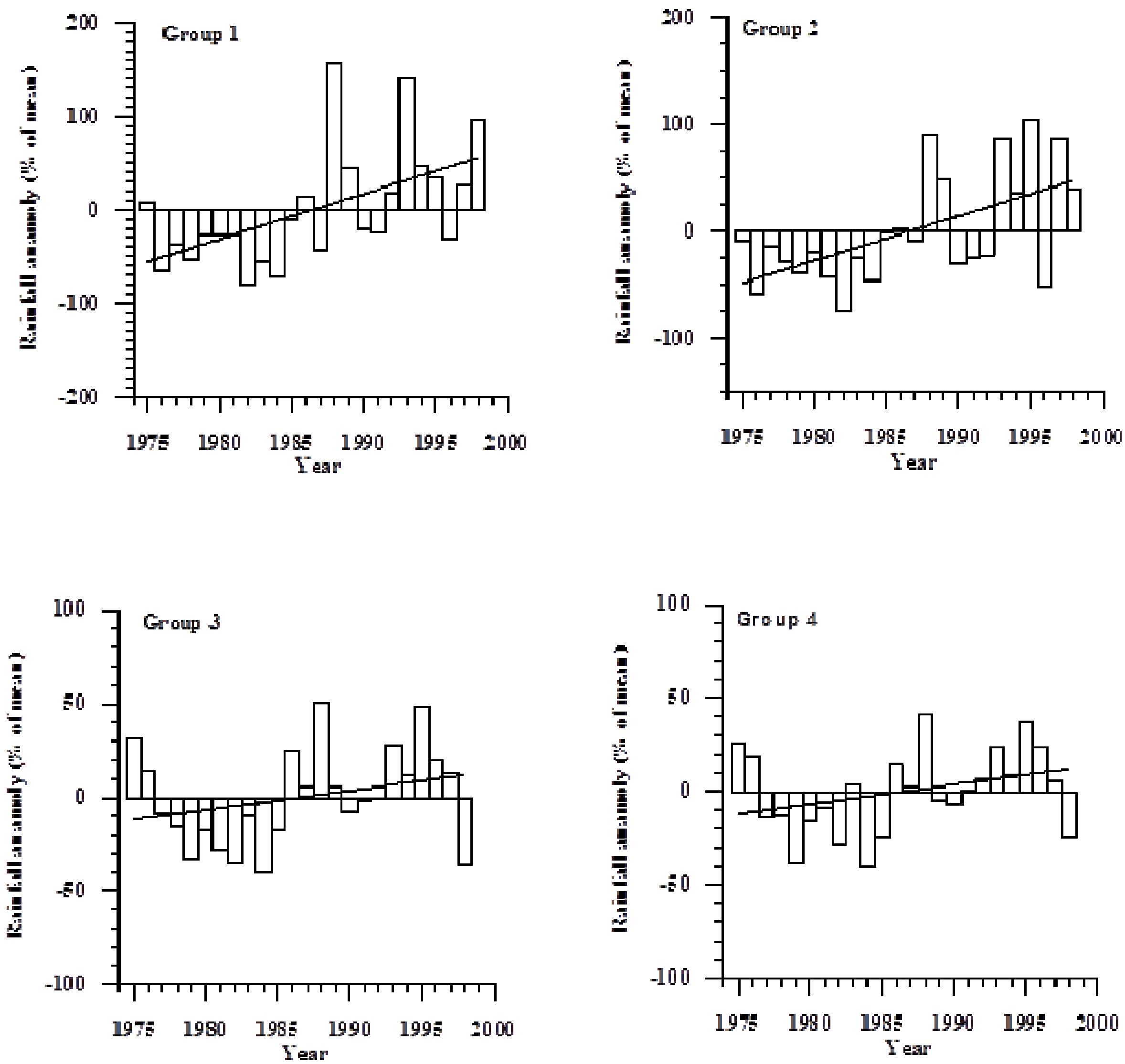

Fig. 3: Trends of annual rainfall at different stations in Chenab basin (Source: Arora et al., 2013)

There are around 14 precipitation stations in Chenab basin and they have been clubbed in different groups to get regional trend. All the groups in Figure – 3 show increasing precipitation trend in the basin as seen from the observations from 1975 to 2000 (Arora, et. al. 2003).

In the Satluj basin, spatial variation of z-statistics of the trend analysis of precipitation has been plotted in Figure – 4. z-statistics shows the confidence in establishing the trend of a variable in a particular region. Values with 1.96 indicates the increasing (+) or decreasing (-) trend with 95% confidence (Arora et al., 2013). More is the z-statistics, higher is the degree of confidence in establishing a trend and values lesser than 1.96 are not assumed to signify any established trend. Thus, most of the region in Satluj basin (except for area close to Rakcham) does not show any established trend in precipitation.

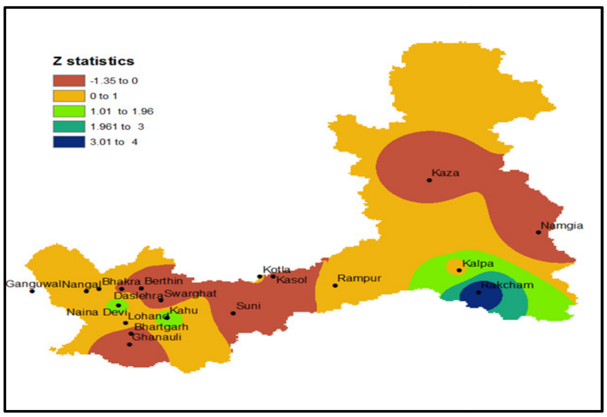

Fig. 4: z-statistics of trends analysis of annual precipitation in Chenab basin (Source: Arora et al., 2013)

Similarly, the trends of annual and seasonal rainfall at various stations in Uttarakhand region have been estimated by Singh and Mal (2014) as can be seen in Figure – 5.Trend values with < 95% confidence level have been treated to have statistically insignificant trend. The figure indicates the magnitudes of trends estimated using Sen's slope method. On the *x*-axis, different seasons and year (aggregate of all seasons) have been plotted through bars, while the *y*-axis indicates trend values (mm per year). 1 cm on *y*-axis indicates 9 mm/year of trend magnitude.

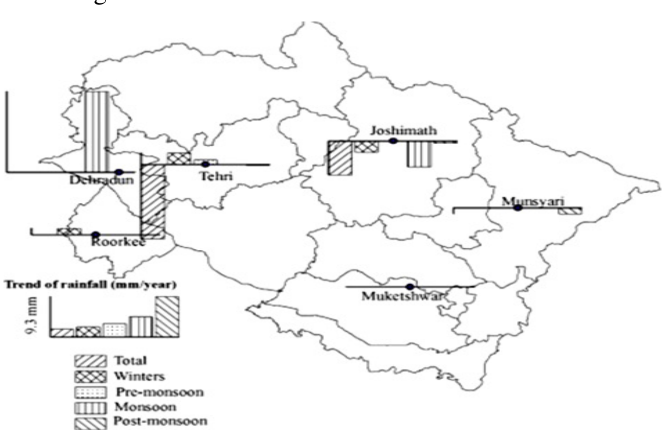

Fig. 5: Trends of precipitation in Uttarakhand State using Sen's Slope method (Source: Singh and Mal., 2014)

Shrestha *et al.* (2012) have prepared a pan-Himalayan view depicting the widespread trends of seasonal and annual precipitation (in mm per year) in different eco-regions of the Himalaya. In most of the Himalayan arc, the authors predict that precipitation in the fall and winter seasons is declining though reverse trend is observed in summer season. Further, the annual precipitation is also showing an increasing trend (with varying magnitude) except in extreme north-eastern part of the Himalaya.

Temperature

In addition to the precipitation, trends in temperature variation from the past records have also been estimated in different studies for different regions. Some of the salient aspects for different river basins are presented below.

Ren et al. (2017) have estimated grid-averaged trends in the annual mean temperature in the Hindu-Kush Himalayan region over more than last 100 years (1901 – 2014). The authors observe that increasing temperature trend is clearly visible, though with different magnitude, in different regions. The z-statistics of the temperature trend in the Satluj basin (Arora et al., 2013) is plotted in Fig. 6 which shows warming trend in the south-east part of the basin only. Similarly, the variation of temperature during 1975 – 1990 at Sirshi (Arora et al., 2003) in the Chenab basin shows a rising trend as shown in Fig. 7.

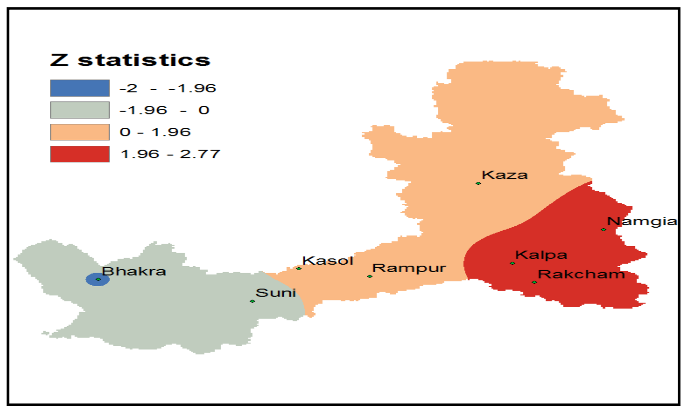

Fig. 6: Spatial trends of temperature in the Satluj river basin ***(Source: Arora et al., 2013)***

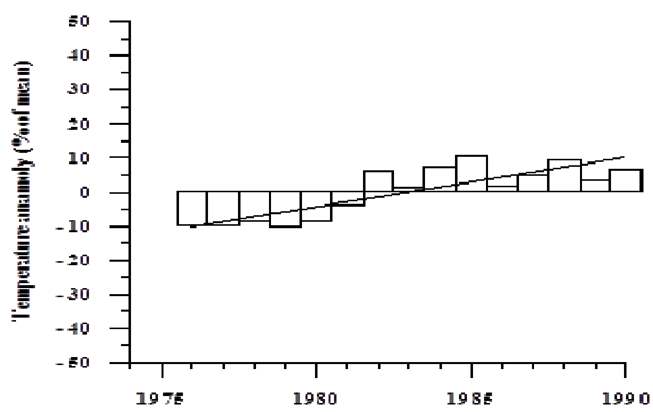

Fig. 7: Mean annual temperature variation at Sirshi in the Chenab river basin ***(Source: Arora et al., 2003)***

Shrestha et al. (2012) have prepared a pan-Himalayan view depicting the widespread trends of seasonal and annual temperature (degree C per year) in different eco-regions of the Himalaya. The authors estimate spatial temperature changes over the Himalaya that are represented for different weather seasons considering different classified Himalayan ecological zones. It is inferred that increase in temperature is more pronounced in the spring season in the western part of Himalaya (Central to western part) while the increase in more pronounced in the winter season in Central to Eastern part of Himalaya. On the annual scale, temperature is shown to rise over the entire Himalayan arc.

Snow cover area

In terms of water resources, snow cover is an important input to the Himalayan cryosphere which significantly affects the temporal water availability in the Himalayan rivers. A number of studies have been carried out to find the snow cover variation in different Himalayan basins using the remote sensing observations. Data of different sensors, based on availability, with varied resolutions have been used. The trends presented by Gurung et al. (2011), as shown in Figure 8, indicate consistent or slightly increasing trends of snow cover areas in eastern and western parts of Hindukush Himalaya while decreasing trends are observed in central part.

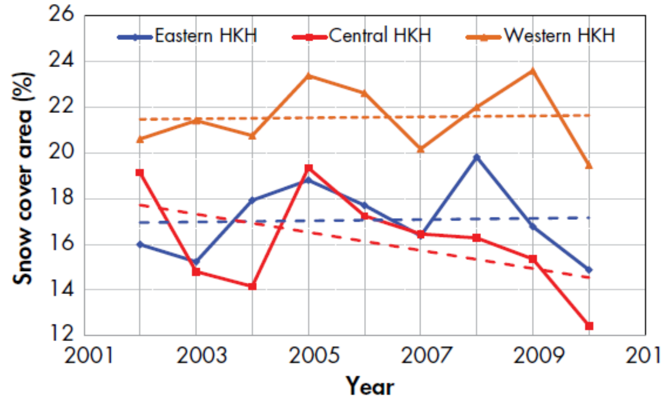

Fig. 8: Trend of SCA in different HKH regions using MODIS data (Gurung et al., 2011)

Similar observations have been recorded for the snow cover areas in the Alaknanda and Bhagirathi basins (SAC, 2016) as shown in Fig. 9 and 10.

Some trends on temperature and snow cover area (2002 – 2012) in the Brahmaputra basin have been reported by (Barman and Bhattacharjya, 2015) as presented in Figure – 11. Though the temperature is observed to be rising in all seasons, the snow cover area is seen as rising in January and falling in all other seasons (may be because of higher temperature and early snow melt).

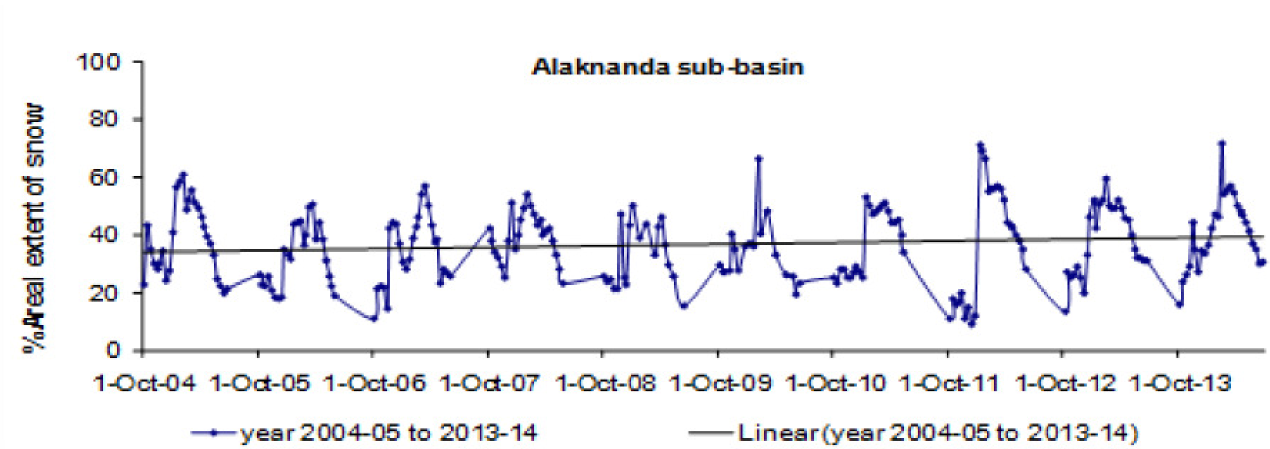

Fig. 9: Consistent trend of SCA in Alaknanda basin 2004-14 using AWiFS (SAC, 2016)

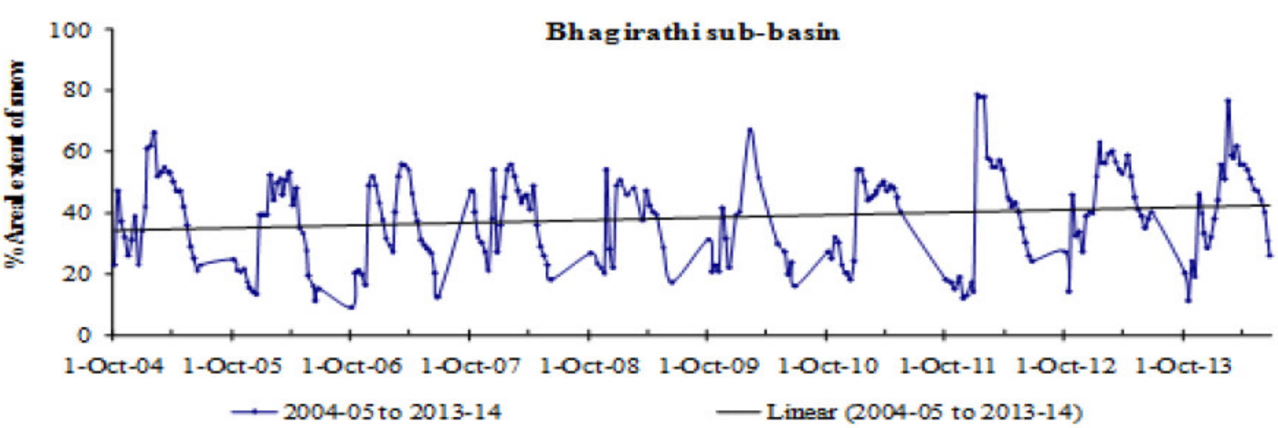

Fig.10: Increasing trend of SCA in Bhagirathi basin 2004-14 using AWiFS (SAC, 2016)

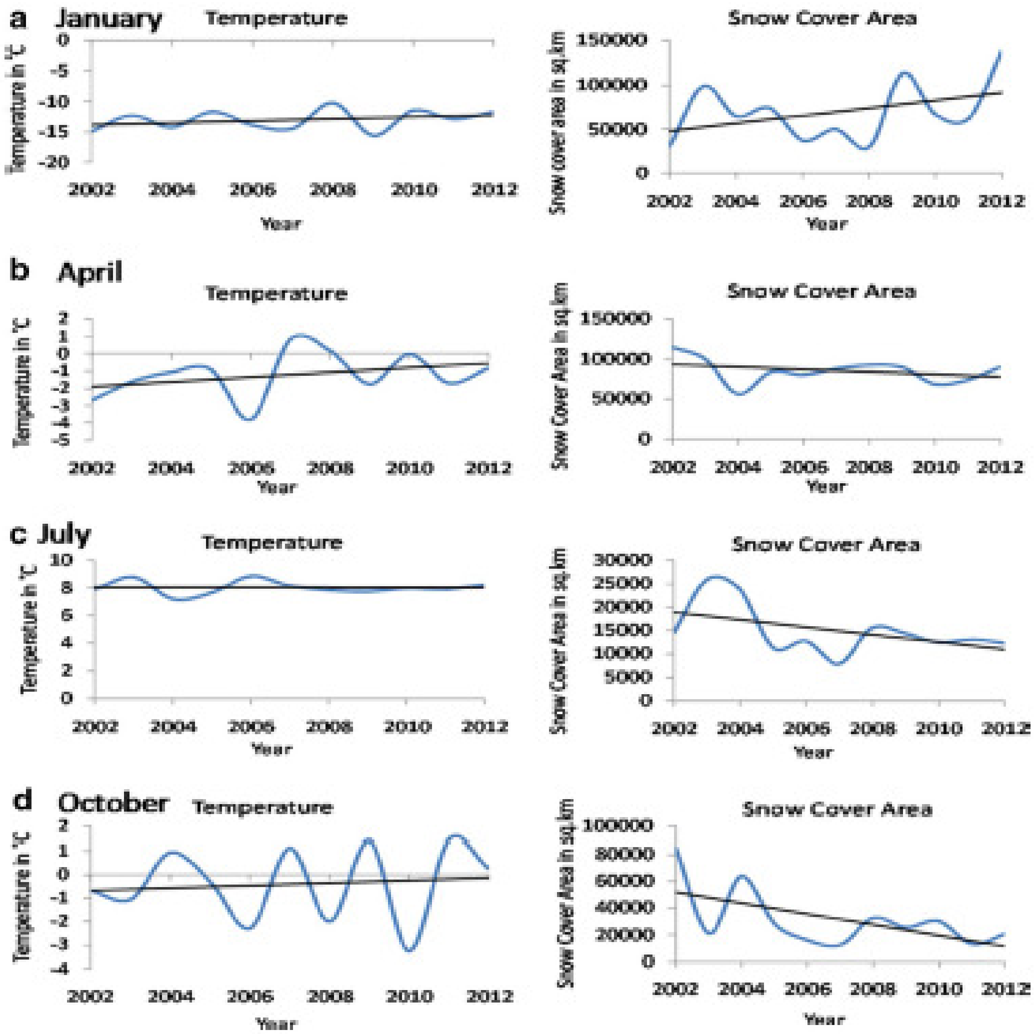

Fig.11: Trend of temp. & SCA in Brahmaputra basin (Barman and Bhattacharjya, 2015)

River flows

The flows in the rivers in Himalayan region are an integrated effect of precipitation, temperature, and snow and glacier melt. Though the abstractions of river flows for different utilizations affect their availability in the downstream regions, the quantity of abstractions keeps on decreasing with elevation because of lesser population and other developmental activities. Further, these abstractions may be of constant nature at annual time step and may not be quantitatively significant in comparison to river flows. Therefore in most of the cases, the trends of observed flows have been estimated at selected sites rather than trends of computed virgin flows which is a tedious exercise because of non-availability of temporal utilization statistics. Trends of seasonal flows in Tawi river in Jammu region (Kumar et al., 2013) are presented in Fig. 12.

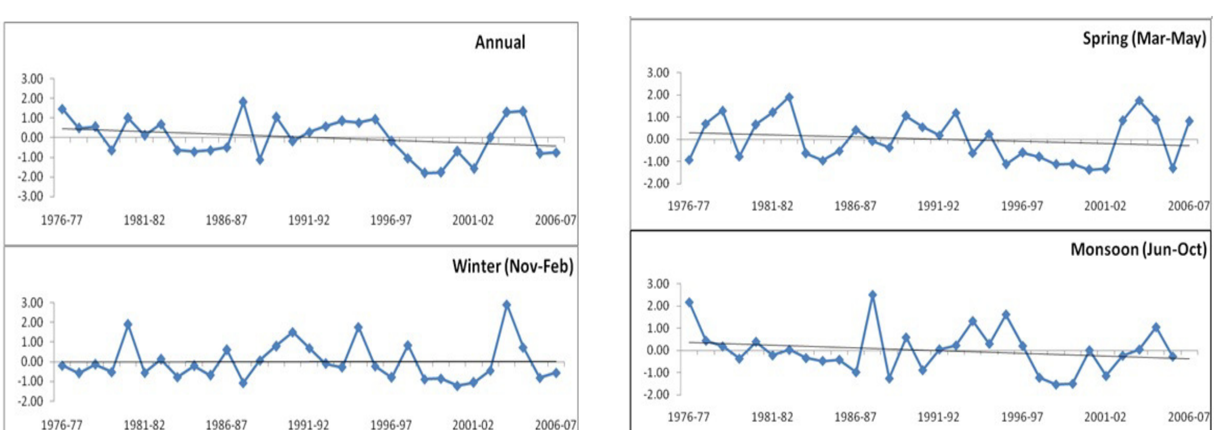

Fig. 12: Trends in seasonal/annual flow in Tawi river at Jammu (Source: Kumar et al., 2013)

Arora et al., 2013 estimated the trends annual flows in the Satluj basin. Figure – 13 shows that significant trends in river flows have been observed at Rampur and Suni sites as observed from the z-statistics plot.

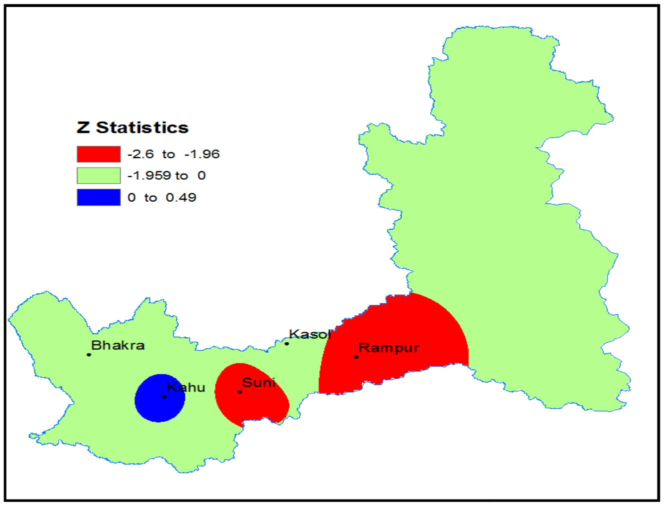

Fig. 13: Trends in annual flow in Satluj basin (Source: Arora et al., 2013)

Some flow trends in the Chenab basin (Arora et al., 2003) observe increasing flow trend in the upper part of Chenab basin (Fig. 14) which could be attributed to higher melting because of increased temperature.

NIH has established an observatory near the snout of the Gangotri glacier since the year 2000 with total catchment of about 556 km^2. Dataset at the observatory includes rainfall, temperature, humidity, wind speed and direction, sunshine hours, radiation, evaporation, discharge and suspended sediment. An AWS has been installed at Bhojwasa site. The flow observations for 16 years of record hints at a decreasing trend as shown in Fig. 15.

Sediment flows

Himalayas are the youngest mountain systems on Earth and they have high erosion and sedimentation rates. However, only a few observations of trends of sediments in river flows are reported. A few year record of sediment observations near Tehri dam shows decreasing trend in sediment observations (Figure – 16). The Tehri dam was commissioned in the year 2006 showing enormous recording of river sediments which have appreciably decreased since then which could be attributed to afforestation measures in the surrounding upstream region.

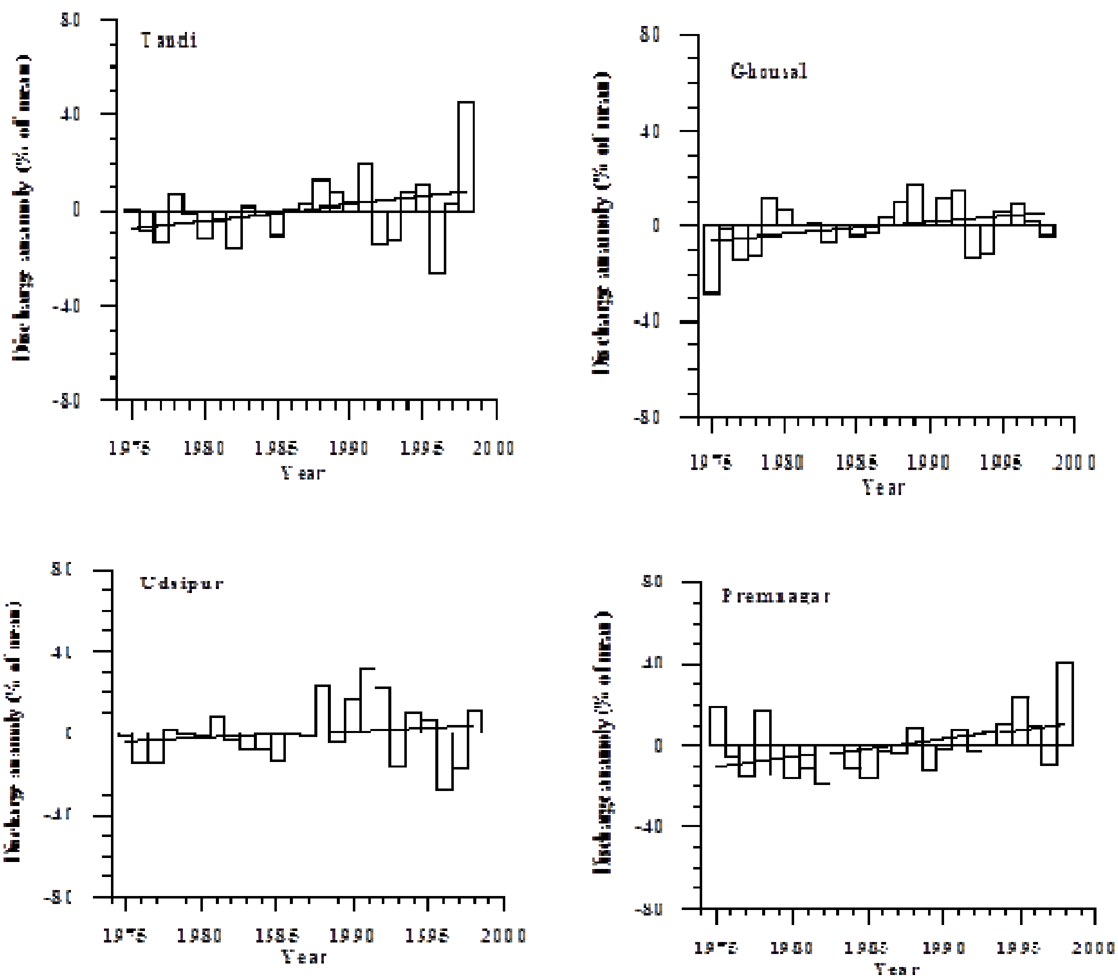

Fig. 14: Trends in annual flow at various stations in upper Chenab basin (Source: Arora et al., 2003)

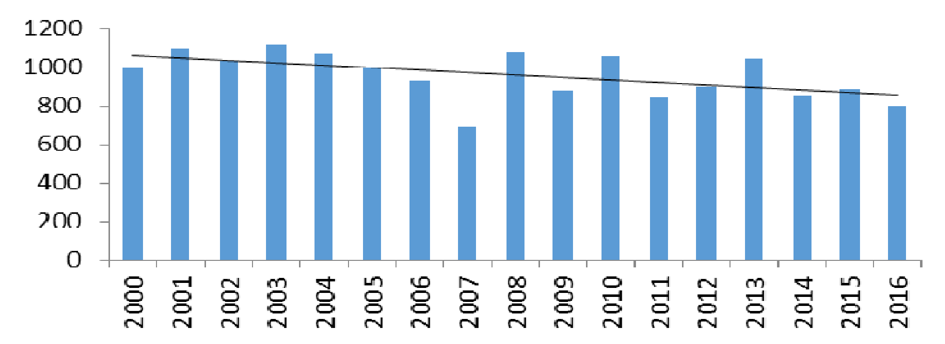

Fig. 15: Trends in seasonal flow (May – October) at Bhojwasa gauging site of NIH

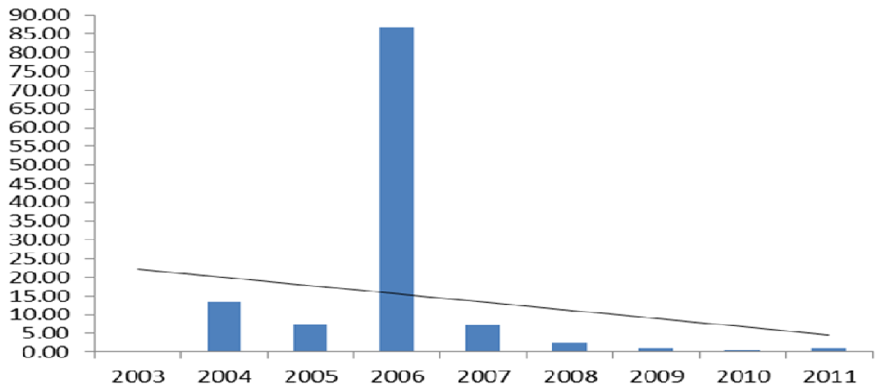

Fig. 16: Annual sediment load near Tehri

Occurrence of extreme (cloudburst) events

In the recent times, there is increased occurrence of cloudburst events in the Himalayan mountains. An analysis on the location of occurrence of these events and the population/villages that are vulnerable to these events is under progress under NMSHE-NIH project. Fig. 17 shows the geo-tagged extreme events in the Ganga basin from 2010 – 17 as reported in the newspapers.

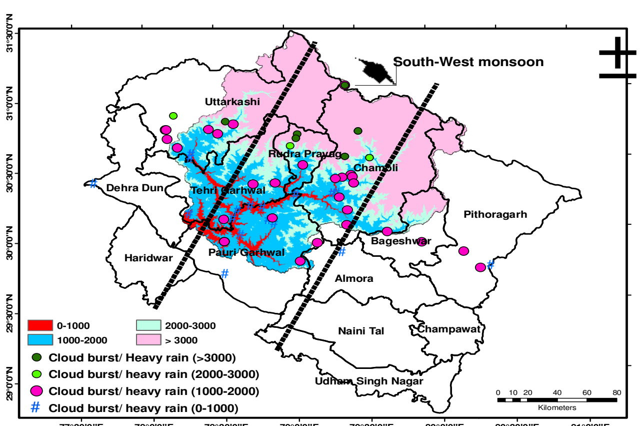

Fig.17: Geo-tagged extreme events during 2010-2017 (Source: Newspapers)

When the location of reported extreme events are superimposed over the village map, it is observed that most of the events follow a particular pattern similar to the monsoon front, and remain mainly concentrated in the elevation band between 500-2000 m. Further, analysis of the village population from the village map, prepared from 2011 census, shows that 78% of the population are living in the elevation band of 1000-2000 m spread over in 71% of the total villages habited in the Upper Ganga basin. Thus, the zones of occurrence of extreme events trigger large-scale losses to life and property.

IMPLICATIONS – ASSESSMENT OF POSSIBLE CAUSES

Based on the historical data, trends of a number of variables that affect the water resources availability in the Himalayan basins have been discussed. Of the different variables, some are related to the hydro-meteorology of the basins (can be termed as independent variables) such as precipitation, temperature, snow cover area, and cloudburst/extreme events, while the others (can be termed as dependent variables), not only depend on the independent variables but also on the conservation and management skills of the mankind.

In the previous section, the trends of variables have been established from a data length of certain duration. It is interesting to note that with the change in the data length, sometimes the nature of estimated trends almost reverses (as in the case of rainfall at the Srinagar station). Further, some trends are not consistent throughout the Himalayan arc but can vary from region-to-region or even within a region. However if we generalize, it is seen that temperature has been rising over a considerable part of the Himalayan arc though the anomalies are also observed. The possible cause of this increasing temperature seems to be more global than local. As has been predicted through various climate models, the increase in concentration of GHG in the atmosphere is responsible for the rising temperature over the whole Earth. The changes in the atmosphere also induces effect on other hydrological variables, particularly precipitation, evapo-transpiration, and atmospheric humidity.

The precipitation trends in various river basins are not consistent. The Kashmir region shows a decrease in annual precipitation and the number of rainy days while the Chenab and Satluj basins show an increasing rainfall trend. Further, the Himalayan mountains in the Uttarakhand State show a mix of rising or falling precipitation trends over different recording stations. Precipitation in the Kashmir region is influenced by the alpine climate with most of the precipitation from western disturbances while the precipitation in the Chenab and Satluj basins may be influenced by both, the western disturbances and the summer monsoon. Uttarakhand experiences maximum influence from the monsoonal precipitation. Thus, in addition to the global changes, type of influencing climate and the topography of the region seems to have more pronounced effect on the precipitation in a region. The trends of snow cover area do not show any appreciable increasing or decreasing trend. From the trends of SCA in the Brahmaputra basin (Figure – 11), it is seen that snow cover area is showing increasing trend in January while reverse trends are observed in other three seasons which could be because of increasing temperature and consequent faster melting.

As mentioned earlier, river flows are the result of precipitation, temperature, snow and glacier cover area and the utilizations and conservation of water by the mankind. In Chenab basin, the results are consistent as the rainfall and temperatures are rising and so are the river flows. In J & K, Tawi river shows a declining trend. Though no trend is available for the precipitation in Jammu region, rainfall in Kashmir had been showing declining trend which could be responsible factor for flow decline in the region. However, annual flows are declining in Satluj basin at two gauging stations which could be attributed to increased glacial cover loss in the region due to increased temperature though the area of precipitation increase is negligibly small. From the observations at the snout of Gangotri glacier for last 16 years, the annual flows show declining trend. Since no field observations are available at/above the Gangotri glacier system, the causing factor for the decreased flow is still under investigation.

Challenges

The trends in the hydrological and hydro-meteorological variables in different river basins of the Himalayan arc suggest that there are going to be changes in the spatial and temporal availability of water in the Himalayan rivers. Some of these changes are the effect of global climate impacts for which we, as an individual or as a nation, can perform our part and rest depends on the way the rest of the World reacts.

One of the most immediate challenge for our country is to conserve water to the extent possible and develop measures to that effect. We need to understand the price of water and develop policies which inculcate the habits of efficient and optimum use of this resource with suitably designed disposal mechanisms. We can no longer afford to consider water as a free commodity which is available infinitely and renewed every year.

FUTURE DIRECTIONS - STRATEGIES FOR MORE DATA AND PLANS FOR COLLATION

It would be worthwhile if the trends of all possible hydrological and hydro-meteorological variables are assessed for concurrent years of observations to draw some meaningful inferences and cause-effect relationships. In this light, it would be worthwhile to include the data of other organizations, say SASE, or State organizations, in the analysis. Since the Himalayan basins are international basins and some of their data are in classified domain, DST can assist in the acquisition of the data. Some of the short-term and long-term measures suggested are as follows:

Short-term

- Available glacier map to be super-imposed on the habitat map of Ganga basin to identify most glacial hazard prone regions requiring immediate redressal.
- Short-term forecasting of hydrological and climatological data be displayed on the web portal which can be utilized for flash flood and water discharge forecasting.
- Identification and calibration of hydrological models for optimal operation of water resources projects and evaluation of performance of water systems with different flow series generated under varying climatic conditions.
- Study of Water-Energy-Climate Change relationship.

Long-term

- Continuous mapping of snow cover and assessment along with the pattern of maximum snow cover during winter.
- Strengthening of monitoring system:
  - Monitoring of climate and snow precipitation through AWS network
  - Monitoring of glacial lakes, their formation and potential for hazards
  - Monitoring snow/ice melt and suspended sediment load
  - Monitoring glacier recession, volumetric changes in mass volume and snowline fluctuations for better understanding of interactions of climate
- Risk and vulnerability assessment to understand the impact of climate change on glaciers and snow cover for water resources planning and management.
- Integration of all the information generated for Himalayan glaciers in various projects/studies under Geographical Information System (GIS) environment. This would eventually help in effective management and planning.

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D.Sc. for Dr. A.G. Bhole

Dr. Anand Govind Bhole born on 27th July, 1936 was declared eligible by Nagpur University for the award of D.Sc. (Doctor of Science) in the subject of Civil Engineering for his treatise (in three volumes) entitled "Simple and Low Cost Water Treatment Technologies for Rural Areas". The treatise is based on his patent and papers. Dr. A.G. Bhole retired as Professor and Head (Civil Engineering) from VNIT Nagpur in 1996 and then was Professor Emeritus for 3 years of L.I.T. (Nagpur) under AICTE fellowship. He did his Ph.D. from University College London under UNESCO fellowship in 1970. He completed his Ph.D. in 2.5 years.