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# Impacts of changes in climate on mountain water resources of Himachal Pradesh

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**सार** – इस शोध पत्र में हिमाचल प्रदेश के जल संसाधनों जैसे - जल संतुलन में कमी/अधिकता, हिमपात की प्रवृतियाँ एवं प्रमुख नदियों के सतही जल बहाव पर जलवायु परिवर्तन के प्रभाव का परीक्षण हेतु अध्ययन किया गया है। जल संतुलन में अधिकता के विश्लेषण से स्पष्ट रूप से पता चला है कि पिछले तीन दशकों के दौरान सभी कृषि जलवायविक क्षेत्रों में कमी की प्रवृति देखी गई है। जल संतुलन के आधिक्य की अधिकतम उपलब्धता की अवधि जुलाई से हटकर अगस्त में आ गई है और इसमें 35.7 प्रतिशत की कमी दर्ज की गई है। निचले पर्वतीय क्षेत्रों में खरीफ ऋतु में जल बहुलता और रबी की ऋतु में पानी की कमी पाई गई है, जबकि मध्य पर्वतीय क्षेत्रों में पिछले तीन दशकों में पानी की कमी खरीफ ऋतु में और जल की बहुलता रबी की ऋतु में पायी गयी है। मैन-कैंडल प्रवृति परीक्षण विश्लेषण सितम्बर से दिसम्बर तक मासिक औसत हिमपात में कमी को दर्शाता है। यह प्रवृति विश्लेषण आगे यह दर्शाती है कि जनवरी और फरवरी के दौरान हिमपात की प्रवृति में वृद्धि हो रही है जिसके कारण सर्द ऋतु के दौरान होने वाले हिमपात में विलंब हो रहा है। सितम्बर से दिसम्बर और मार्च से मई के दौरान होने वाले हिमपात में गिरावट की प्रवृति प्रेक्षित की गई है जिससे सर्दी की अवधि छोटी हो रही है। दिसम्बर और मई के दौरान हिमपात की प्रवृति में विशेष रूप से कमी पाई गई है। प्रवृति परीक्षण से पता चला है कि मनाली में व्यास नदी और कुल्लू जिले के औट में पार्वती नदी के सतही जल प्रवाह में सभी महीनों में काफी कमी आई है। सर्दी के महीनों के दौरान किन्नौर जिले के सोंगतोंग में सतलुज नदी के जल प्रवाह में भी काफी कमी पाई गई है। भाखड़ा बाँध में सतलुज नदी के वार्षिक जल अन्तर्वाह प्रवृति में भी कमी पाई गई है। अत: इस अध्ययन से यह स्पष्ट हो जाता है कि हिमाचल प्रदेश के पर्वतों में पिछले तीन दशकों के दौरान जलवायविक परिस्थितियों में हुए बदलाव के कारण जल संसाधन प्रभावित हुए हैं।

**ABSTRACT.** The study examined the impacts of climate change on water resources, *viz*., surplus / deficit water balance, snowfall trends and surface water flow of major rivers of Himachal Pradesh. The analysis on surplus water balance clearly showed decreasing trends in all the agro-climatic zones during past three decades. Maximum availability of surplus water balance period showed a shift during July to August and registered a decrease of 35.7 percent. The low hill regions exhibited water surplus during kharif season and water deficit during rabi season, while, mid hill regions exhibited water deficit during kharif season and water surplus during rabi season during past three decades. The Mann-Kendall trend test of snowfall indicated a decrease in monthly average snowfall from September to December. The trend analysis further showed increasing trends of snowfall during January and February indicating delay in snowfall during winters. The decreasing trends of snowfall were observed during September to December and March to May indicating shrinking winter period. The significant decreasing trend of snowfall was observed during December and May. The trend test revealed significant decrease of surface water flow of river Beas at Manali and Parvati at Aut in Kullu district during all the months. The water flow of river Sutlej at Songtong in Kinnaur district also showed significant decreasing trends during winter months. Similarly, the annual water inflow of the Sutlej River at Bhakhra Dam showed decreasing trend also. Thus, the studies clearly indicated that water resources have been impacted due to changes in climatic conditions in mountains of Himachal Pradesh during past three decades.

**Key words** – Climate change, Water resources, Snowfall, Water balance.

## 1. Introduction

India, with 2.4 percent of the world's total area and 16 percent of world's total population accounts for only 4 percent of the total available water (Anonymous, 2010a). As a part of Himalayan ecosystem having unique geography of the mountains, Himachal Pradesh produces wide spectrum of climates and is home to a wide range of

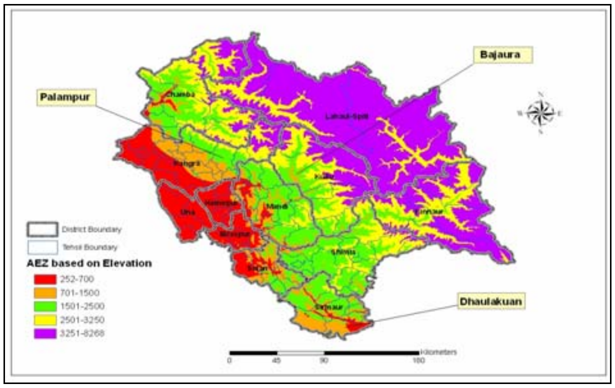



**Fig. 1(a).** Study sites, *viz*., Kangra, Kullu and Sirmour representing different agro climatic conditions

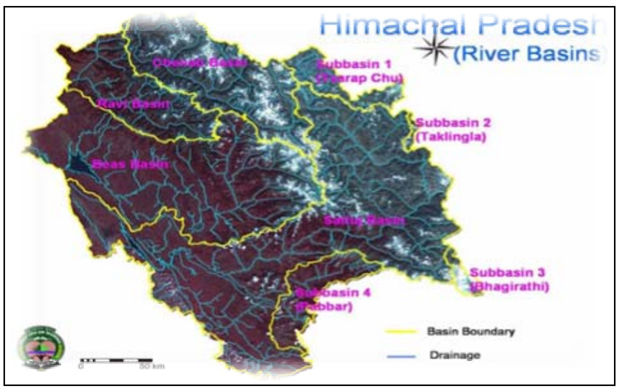



**Fig. 1(b).** Major River Basins and Drainage lines (rivers) of Himachal Pradesh

natural fresh water resources. Water storage in Himachal Pradesh is estimated at around 14000 million $m^3$ comprised of 387 $km^3$ ice reserves within 4160 $km^2$ area (Anonymous, 2010b). In general, the area above 4000 m amsl (above mean sea level) is mostly covered with snow and ice throughout the year (Bhagat *et al*., 2004). The glaciers and glacial lakes are the source of water for many North Indian rivers during critical summer months. Snow and glacier melt runoff contributes substantially to the annual flows of major Himalayan rivers and its estimation is required for the planning, development and management of the water resources of Himachal Pradesh Agriculture and related sectors, food security and energy security are crucially dependent on the timely availability of adequate amount of water and a favorable climate. Agriculture, horticulture and animal husbandry are the mainstay of 60-70 percent of the population in the hills despite very small area under irrigation (Partap and Partap, 2002). However, the signals of climate change have clearly indicated towards increasing temperature, reducing rainfall and snowfall and shrinking winter season (Bhagat *et al*., 2007a). The agricultural and fruit crops in Himachal Pradesh are mainly dependent upon the snow fed gravity flow channels (kuhls) and fresh snowfall. The occurrence of heavy fresh snowfall event during 2004-05 had shown its beneficial impacts on various crops (Bhagat *et al*., 2007b). The small changes in temperature result in both increase and decrease of water resources up to 30 percent or more (Anonymous, 2010c). Since, climate change does not occur uniformly throughout the globe, it is expected to impact each region differently (Bae *et al*., 2007). The changing availability of freshwater resources is likely to be one of the most important consequences of projected 21st century climate change for both human and natural systems (Kingston and Taylor, 2010). Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of stream flows and demands (particularly agricultural), requiring a review of hydrologic design and management practices. Hence, climatological analysis in the present study that produces the trends of water resources, surface water flow and surplus water balance in relation to climate change was done to contribute towards the decision making and development of sustainable and effective management strategies of water resources in the state.

## 2. Data and methodology

### 2.1. *Study area*

The state of Himachal Pradesh is a mountainous region in the Indian Himalayas covering an area of 55673 sq km where mountains and hills occupy most of the land. It extends from the Shivalik hills in the South to the Great Himalayan range including a slice of Trans-Himalayas in the North. Geographically, the state of Himachal Pradesh is situated between 30°22'44" to 79°04'20" E longitude. There are four major river basins in Himachal Pradesh and source of four major rivers flowing in north India [Fig. 1(a)]. Annual mean temperature of the state remains between 10.4 °C to 22.7 °C, with temperature decrease from southwest to northeast part of the state. Average rainfall of the state is 1122 mm. Maximum amount of rainfall occurs during monsoon period, *i.e*., June to September. The economy of the study area is comprised of agriculture and more than 70 per cent population is practicing agriculture and share of agriculture and animal husbandry in the net state domestic product (NSDP) of Himachal has been reduced from 34.9% in 1980-81 to 19.6% in 2005-06 (Anonymous, 2009). Agricultural activities are often affected by rainfall and snowfall pattern.

### 2.2. *Study sites*

Three study sites located in three different districts, *viz*., Kangra, Kullu and Sirmour representing different agro-climatic conditions [Fig. 1(b)] were selected for studying the water balance (surplus/deficit) using the method of Thornthwaite *et al*. (1957). The Palampur site (1290 m amsl) represents mid-hill humid zone, Bajaura (1220 m amsl) represents mid-hill sub-humid zone and Dhaulakuan (468 m amsl) represents sub-montane and low-hills sub-tropical zone of Himachal Pradesh. The decadal and recent five years surplus water balance was worked out for each month to relate to the climate change at three sites, *i.e*., Palampur, Bajaura and Dhaula Kuan each representing different agro-climatic zones.

2.3. Trend Analysis

The snowfall data was collected from twenty one different sites located in Sutlej basin for the period of 1986-2004. Sutlej comprises the largest river system in the state (30.7% of the total water resources of state) with a total catchment area of 20,398 km$^2$ and ice reserves of 94 km$^3$. The Beas River comprises 76 km$^3$ of ice reserves and a catchment area of 13,663 km$^2$ making 24.5 per cent of state's total water resources (Anonymous, 2010d). The discharge data was recorded from 1966 to 2006, for river Beas at Manali gauge site, Parvati at Parvati site near Aut, Sutlej at Songtong located at Kinnaur and at Bhakhra Dam for discharge flow of rivers. The data on snowfall and river discharge flow was collected from Bhakhra Beas Management Board (BBMB), Chandigarh. In the present study, the trend analysis of snowfall and surface water flow of major rivers was done using non-parametric Mann-Kendall trend test [Mann (1945); Kendall (1975)]. This is a statistical method used for studying the spatial variation and temporal trends of hydro-climatic series. The Mann-Kendall trend test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

Mann-Kendall is a statistical method used to test trend significance over time series data. The $n$ time series values ($X_1$, $X_2$, $X_3$, …, $X_n$) are replaced by their relative ranks ($R_1$, $R_2$, $R_3$,…, $R_n$) (starting at 1 for the lowest up to $n$).

The test statistic $S$ is

$$S = \sum_{i=1}^{n-1} [ \sum_{j=i+1}^{n} \operatorname{sgn}(Rj - Ri)]$$

where ,

$\operatorname{sgn}(x) = 1$ for $x > 0$

$\operatorname{sgn}(x) = 0$ for $x = 0$

$\operatorname{sgn}(x) = -1$ for $x < 0$

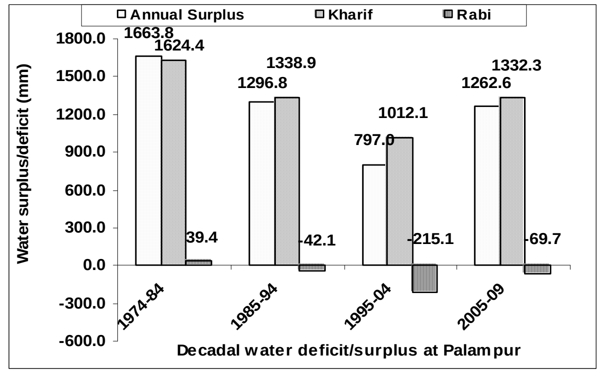



**Fig. 2.** Decadal water balance at Palampur (District Kangra) for the period 1974-84, 1985-94, 1995-04 and 2005-09

If the null hypothesis $H_0$ is true, then $S$ is approximately normally distributed with:

$\mu = 0$

$\sigma = n (n - 1) (2n + 5) / 18$

The $z$-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables).

$z = | S | / \sigma^{0.5}$

A positive value of S indicates that there is an increasing trend and vice versa. A significance level $\alpha$ is also utilized for testing either an upward or downward monotone trend (a two-tailed test). If Zc appears greater than $Z\alpha/2$ where $\alpha$ depicts the significance level, then the trend is considered as significant. In this analysis, the null hypothesis was tested at 95% confidence level.

## 3. Results and discussion

3.1. *Water balance studies in different agro-climatic zones of Himachal Pradesh*

3.1.1. *Palampur in district Kangra*

The water balance of agro-climatic region Palampur for past three decades (1974-84, 1985-94 and 1995-2004) showed a water surplus/balance of 1663.8, 1296.8 and 797.0 mm annually (Fig. 2). However, during the recent five years (2005-2009), the water surplus/balance of 1262.6 mm annually was observed which was higher by 58.4% from 1995-2004. The monthly analysis of decadal water deficit/surplus revealed that maximum surplus water was observed during the month of July for the decade 1974-84, which shifted to month of August during next two decades, *i.e*., 1985-94 and 1995-04. The water surplus showed a reduction of 4.1 mm during recent five

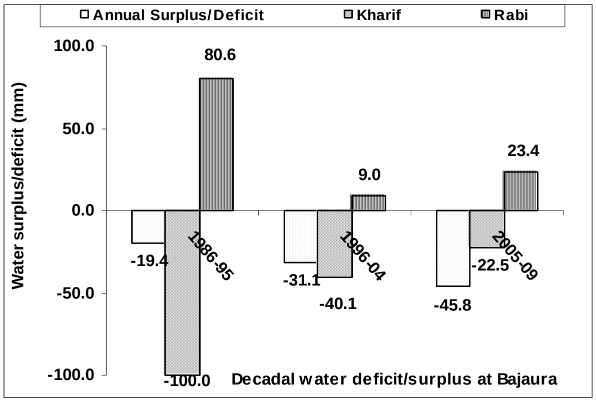



**Fig. 3.** Decadal water balance at Bajaura (District Kullu) for the period the 1986-95, 1996-04 and 2005-09

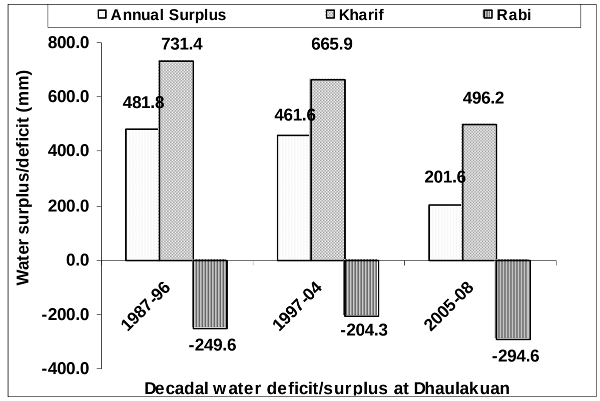



**Fig. 4.** Decadal water balance at Dhaulakuan (District Sirmaur) for period 1987-96, 1997-04 and 2005-08

decrease in water surplus balance during 1985-94 and 1995-04 as compared to 1974-84. Similar trends of decreasing water surplus also reported by Prasad and Rana (2010). The rabi season accumulated 39.4 mm water surplus during 1974-84 however water deficit of 42.1, 215.1 and 69.7 mm was obtained during rest of the two decades and recent five years, respectively.

3.1.2. *Bajaura in district Kullu*

The water balance studies of Bajaura for the two decades, *i.e.*, 1986-95 and 1996-2005 showed a water deficit of 19.4 and 31.1 mm, respectively (Fig. 3). However, during recent five years (2005-09) annual water deficit was found increased by 45.8 mm. The monthly decadal water surplus of Bajaura revealed that maximum surplus water was observed during the month of March (71.9 mm for the decade 1986-95) which was 20.1 mm during recent five years, *i.e.*, 2005-09. The monthly decadal analysis of water deficit/surplus during the month of March for the decade 1986-95 shifted to month of September during 2005-09. On seasonal scale, the kharif season experienced 100.0, 40.1 and 22.5 mm of water deficit whereas, rabi season experienced 80.6, 9.0 and 23.4 mm of water surplus during past two decades and recent five years, respectively.

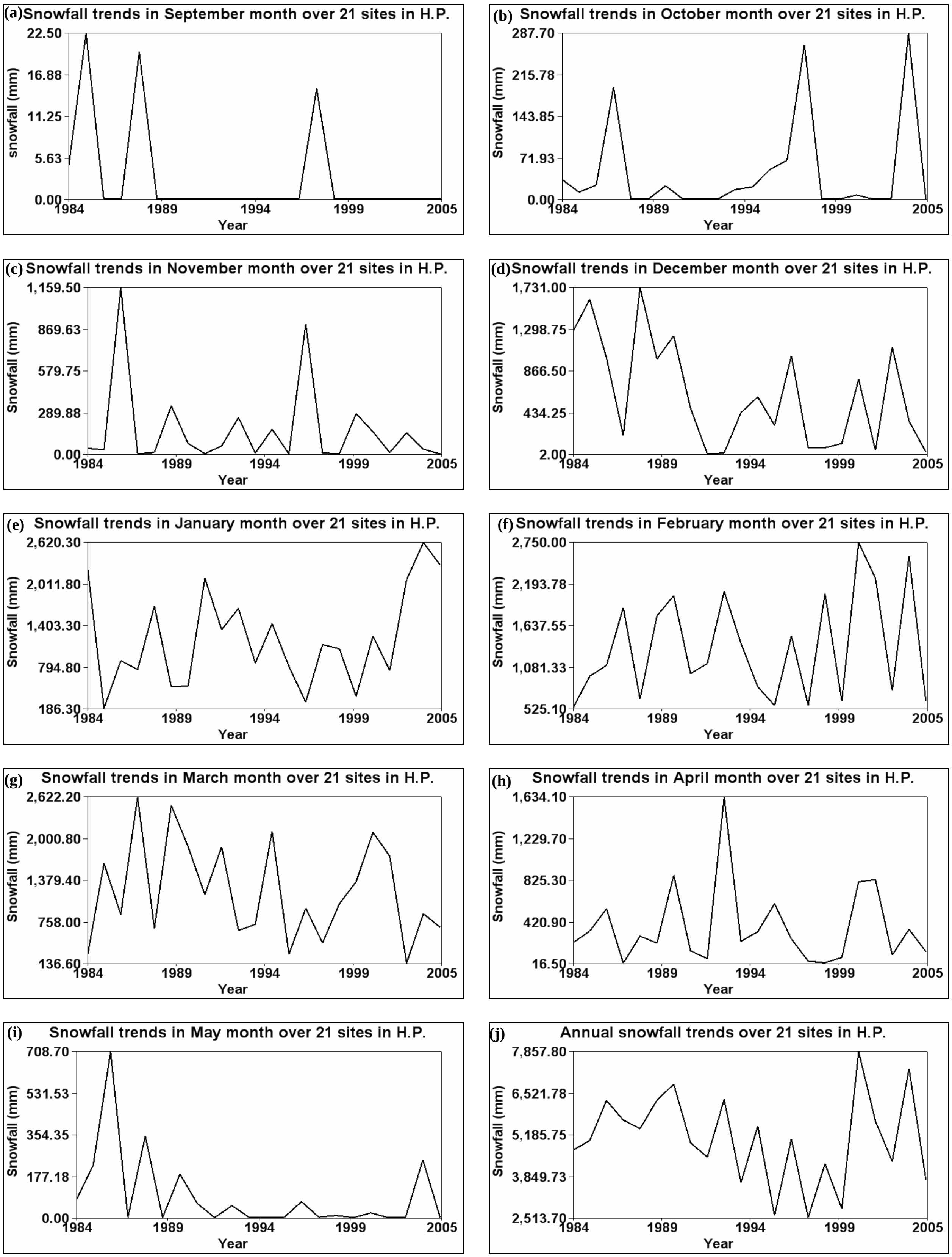
3.1.3. *Dhaulakuan in district Sirmour*

The water balance analysis indicated a reduction of 20.2 mm water surplus at Dhaulakuan from 481.8 in the years 1987-96 to 461.6 mm in the years 1997-04 (Fig. 4). However, during the years 2005-08 a water surplus of 201.6 mm was observed. The reduced water surplus was also largely affected due to deficit of 120.5 mm in the month of June during the period (2005-09). Also the water balance was observed to be shifted to July from month of August. On seasonal scale, the studies indicated that kharif season showed 731.4, 665.9 and 496.2 mm of water surplus in past two decades. However, rabi season experienced 249.6 and 204.3 and 294.6 mm of water deficit during the years 1987-96, 1997-04 and 2005-08 respectively.

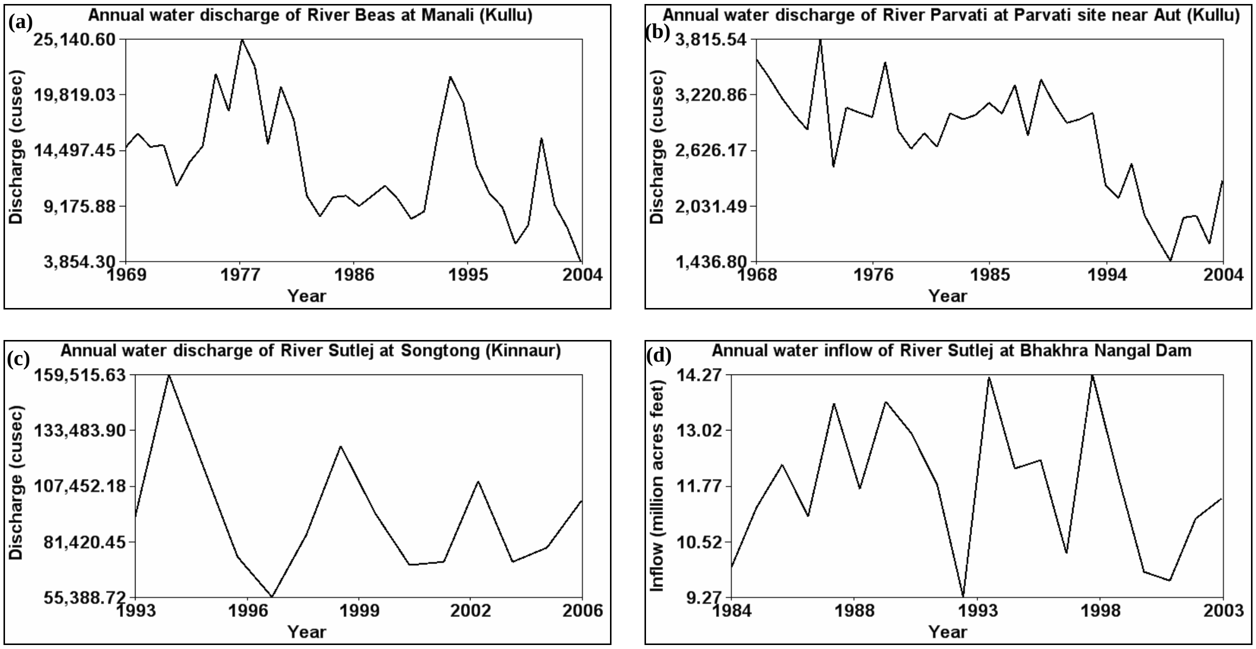
Similar studies from Punjab revealed an annual water deficit of 639-1236 mm and on the seasonal scale, water deficit to the tune of 16-758 mm and 528-722 mm was observed during kharif and rabi season, respectively (Kingra *et al*., 2004). The decadal analysis for lower plain regions of Himachal Pradesh revealed that water deficit during the month of April was 21.5 mm for the decadal period of 1987-96 which increased to 37.6 mm during recent three years, *i.e.*, 2005-08. Also, maximum availability of water surplus was observed during the month of August, 1987-96 which shifted to month of July during 2005-08. The water deficit starts soon after the withdrawal of monsoon, *i.e.*, from the month of October and increases with onset of the summer season. Accompanying increase in evapotranspiration, driven by rising temperature limits increase in ground recharge and runoff and small decrease in precipitation may produce large reductions in runoff due to the compound effects of reduced runoff and increased evapotranspiration (Mango *et al*., 2011). Thus, assured irrigation became important during the rabi season crops. Jain and Kumar (2012) found that on all India basis annual and monsoon rainfall decreased, and pre-monsoon, post monsoon and winter rainfall increased over the years, with maximum increase in the pre-monsoon season.

3.2. *Snowfall trends in Himachal Pradesh*

The snowfall trends in past two decades from 1984 to 2005 over different sites representing elevation ranging




**Figs. 5 (a-j).** Average monthly snowfall trends (Mann-Kendall test) from September to May in Himachal Pradesh




**Figs. 6 (a-d).** Annual river discharge and inflow trends (Mann-Kendall test) for major rivers of Himachal Pradesh

from 2000 to 4000 m amsl showed no significant decreasing trends at 21 observation sites with Mann-Kendall trend test [Fig.5 (j)]. The non-significant decreasing trends were observed for all the elevations, *i.e.*, 2030 to 2439 m amsl, 2598 to 2910 m amsl and 3130-4079 m amsl. The decadal data (1984-94 and 1995-2006) also showed non-significant decreasing trend. In the non parametric Mann-Kendall test analysis results indicated decreasing trends in monthly average snowfall during September to December [Figs. 5 (a-d)] and March to May [Figs. 5(g-i)]. Amongst different months, significant decreasing trends of snowfall was observed in December and May while no significant increasing snowfall trends were observed during January and February [Figs. 5(e-f)] indicating delay in arrival and early withdraw of snowfall occurrence in Himachal Pradesh. The studies on total precipitation and snowfall for all the months at Shimla also showed a decreasing tendency with an early withdrawal tendency by about 12 days per decade (Bhan and Singh, 2011). Such trends in snowfall occurrence increased the opportunity of growing more crops during March to October at higher elevations or temperate regions of Himachal Pradesh. Factually, snow acts as water storage over the winter, provides soil moisture recharge in the spring, and is of particular importance to agriculture productivity in mountainous regions. The heavy snowfall event during 2004-05 analyzed using satellite data also indicated higher productivity and area under different agricultural crops in Himachal Pradesh (Bhagat *et al*., 2007b).

### 3.3. *Trend of surface water flow in major rivers of Himachal Pradesh*

#### 3.3.1. *Discharge at Manali (Kullu)*

Trend analysis of Beas River discharge at Kullu was studied with 35 years of discharge data from 1969 to 2004 and the mean monthly discharge varied between 306.8 cubic meters per second (cusec) to 2356.0 cusec over the years. Mann-Kendall trend test was used for the determination of the trend and z-statistics revealed significant decreasing trends in all the month from January to December [Fig. 6 (a)]. The annual discharge of Beas River also observed a significant decreasing trend.

#### 3.3.2. *Discharge at Parvati (Kullu)*

The average water discharge during the period 1968-2004 (36 years) recorded for river Parvati at Parvati site near Aut region indicated significant decreasing trends in all the months. The maximum decrease in water discharge was observed during the month of July (7482.0 cusecs) followed by the August month (7006.0 cusecs). The analysis of the Mann Kendall test for the annual and monthly river discharge at river Parvati also exhibited significant decreasing trends [Fig. 6(b)]. Monsoon months of June, July and September witnessed decreasing rainfall, whereas August showed increasing trend on an all-India basis (Jain and Kumar, 2012).

3.3.3. *Discharge at River Sutlej (Kinnaur)*

Mean total monthly discharge of river Sutlej recorded at Songtong in district Kinnaur for the period of 1993 to 2006 indicated significant decreasing trends with Mann-Kendall test during all the months except June. The peak discharge of 20869.0 cusecs was observed during the July month followed by June 19472.0 (cusecs). The *z*-statistics indicated significant declining trends of water discharge from October to March [Fig. 6(c)]. However the summer months from April to September did not show significant decreasing trends. Similarly, the annual water discharge also not observed significant decreasing trends.

3.3.4. *Sutlej inflow in Bhakhra Dam*

The inflow of river Sutlej in Bhakhra is the final drainage outlet of the Sutlej basin. The inflow data for the period of 1984 to 2004 revealed a decreasing trend in annual inflow. Mann-Kendall test [Fig 6(d)] revealed no significant decrease in the annual discharge. Trend analysis of water inflow in Bhakhra dam recorded 12 times less rate of decrease than annual precipitation in the Sutlej basin (Rana *et al*., 2006). Although the different units (sub-basins or sub-divisions) had a non zero slope value, few values were statistically significant. Ranade *et al*. (2008) found no trend in the starting or ending date, duration and total rainfall of the hydrological wet season over different river basins of India. The studies indicated that future climate changes might have some impacts on the discharge regime of rivers, *e.g*., longer low-flow periods in summer months due to a decreased precipitation and increased evapo-transpiration (Wegehenkel and Kersebaum, 2009).

## 4. Conclusions

During past three decades, the surplus water balance studies showed decreasing trends in all the agro-climatic zones of H.P. At lower altitude, the surplus water balance showed lesser decreasing trends as compared to agro climate zone situated at higher attitude. Both Palampur and Dhaulakuan have exhibited water surplus during kharif season and water deficit during rabi season (except during 1974-84 at Palampur). On the contrary, Bajaura in Kullu district revealed reverse trends for seasonal water availability during the period under study. Also, shift of water surplus observed in low hill region from August to July during 2005-08. The snowfall trends for past two decades also showed decrease of snowfall in all the sites in Sutlej basin. The further studies on surface water flow of major rivers showed sharp decrease in all the months. Thus, the studies indicated that water resources in Himachal Pradesh were impacted due to changing climate conditions during past three to four decades.

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