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ABSTRACT

Global climate change is expected to cause serious impact on many aspects of the natural environment including the water resources. As described by the IPCC (IPCC, 2007), the magnitude as well as frequency of extreme events is likely to change due to climate change. Under the influence of climate change, the magnitude and temporal distribution of water availability at reservoir sites is likely to be impacted. Currently, reservoirs are managed, designed and operated on the assumption of stationarity of hydro-meteorological variables. This assumption is hardly justified in view of the recent climate change. Therefore, the need of the hour is to manage reservoirs while taking into account the impacts of climate change.

The objective of the present research is to conduct a comprehensive assessment of climate change impacts in Satluj river basin in India. The Satluj River originates from Mansarowar lake in Tibet at an elevation of about 4572 m, and is a major tributary of the River Indus. The entire Satluj basin lies between latitudes 30° and 33° N and longitudes 76° and 83° E. The Satluj River enters the Indian state of Himachal Pradesh at Shipkila at an altitude of 6,608 meters, and flows in the south-westerly direction through Kinnaur, Shimla, Kullu, Solan, Mandi and Bilaspur districts. The total length of the river is 1,448 km. The Satluj leaves Himachal Pradesh to enter the plains of Punjab at Bhakra, where the India's highest gravity dam has been constructed. The catchment area of the Satluj to Bhakra dam is about 56,876 km² of which 36,900 km² lies in Tibet and 19,975 km² in India.

A well acknowledged method of evaluating climate change impacts is through the analysis of hydro-meteorological data. Analysis of trends in several hydroclimatic variables was, therefore, carried out in the present research. The results clearly revealed a greater number of increasing trends in most of the variables investigated than could be expected to occur by chance. A clear warming pattern was observed in the basin with the majority of the stations (six of eight) exhibiting increasing trends in annual average maximum temperatures (TMX). None of the stations exhibited a statistically significant decreasing trend in annual TMX. The trends in annual average minimum temperatures (TMN) were, however, mixed with a bias towards increasing trends. The increased warming in the basin could have implications for water availability in the basin as the contribution of snow and glacier melt to annual runoff at Bhakra reservoir is about 60%.

The El- Niño southern oscillation (ENSO) driven by sea-surface temperature changes in the tropical Pacific Ocean can have major effects on weather conditions around the world. The ENSO has shown greater variability in recent decades, indicating that it may strengthen under climate change. The present research investigated the linkages of both warm and cool phases of ENSO with the monsoonal precipitation in the Satluj River basin. The results indicated a negative association between the warm phase and monsoonal precipitation at the majority of stations in the basin. During the cool phase of ENSO, a positive association between the monsoonal precipitation was observed in the majority of stations. It was concluded from the analysis of linkages of ENSO with monsoonal precipitation in the basin that the warm phase of ENSO is associated with weak Indian monsoon.

To evaluate the potential impact of climatic changes on the streamflow generation at Bhakra - a major dam in the basin - a SWAT based hydrological model for the basin was developed. The changes in seasonal and annual streamflows at Bhakra in response to PRECIS generated outputs of climate variables for two future time slices of interest; midcentury (2021-2050) and endcentury (2071-2098) were estimated under A1B, A2 and B2 emission scenarios. The values of streamflow during the baseline period near the vicinity of the Bhakra dam ranged from 1892 to 2160 cumec compared to 1623 to 1891 cumec for the base period. Lower rates of streamflow could occur in some sub-watersheds located in the northern and southeastern parts of the watershed for both midcentury and endcentury periods. Results indicate a substantial increase in average streamflows at Bhakra under all the three scenarios. The increase observed in streamflows in the non-monsoon seasons may be attributed to larger glacier melt contribution caused by projected higher temperatures for both the future periods considered. Since more than half of the annual streamflow volume at Bhakra is contributed by glacier melt (Singh and Jain, 2002), increased streamflows at the reservoir site points towards enhanced melting in the upper parts of the basin. With increased streamflow volume at Bhakra, the vulnerability of the basin to high magnitude flooding events is likely to increase under future scenarios of climate change in the basin.

Major achievements of the present research include development and application of: (1) a framework for the identification of trends in hydro-meteorological variables; (2) methodology for the detection of linkages between large scale climate indices and climate variables, and (3) SWAT model for evaluating the hydrological response of the basin to projected changes in climate variables at future time scales of interest. Adaptations to adverse impacts of climate change are critical for the sustainable development of the study basin. Information related to streamflow projections should be incorporated into planning activities by the policy makers. The results presented herein could provide valuable aid to policy makers in formulating adaptation and mitigation strategies to counteract the adverse impacts of climate change in Satluj river basin.