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Vulnerability of Indian Agriculture to Climate Change: A Study of the Himalayan Region State

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Abstract**—**Climate variability and changes are the emerging challenges for Indian agriculture with the growing population to ensure national food security. A study was conducted to assess the Climatic Change effects in medium to low altitude areas of the Himalayan region causing changes in land use and cereal crop productivity with the various climatic parameters. The rainfall and temperature changes from 1951 to 2013 were studied at four locations of varying altitudes, namely Hardwar, Rudra Prayag, Uttar Kashi and Tehri Garwal. It was observed that there is noticeable increment in temperature on all the four locations. It was surprisingly observed that the mean rainfall intensity of 30 minutes duration has increased at the rate of 0.1 mm/hours since 2000. The study shows that the combined effect of increasing temperature, rainfall, runoff and urbanization at the mid-Himalayan region is causing an increase in various climatic disasters and changes in agriculture patterns. A noticeable change in cropping patterns, crop productivity and land use change was observed. Appropriate adaptation and mitigation strategies are necessary to ensure that sustainable and climate-resilient agriculture. Appropriate information is necessary for farmers, as well as planners and decision makers for developing, disseminating and adopting climate-smart technologies.

Keywords—Climate variability, agriculture, land use, mitigation strategies.

I. Introduction

SIGNIFICANT changes are taking place in the Earth's atmosphere due to increased pollution, deforestation, land use changes and population growth worldwide. Increased climatic changes are making a great impact on world food security. The projected increase in temperature from 1.1 °C and 6.4 °C by the end of the 21st century [1] and the wide variation in spatial and temporal rainfall patterns are having severe negative effects on crops, and soil and water resources throughout the world. These changes are more evident at hilly areas where changes in altitudes shelter variable biodiversity, and there are limited agriculture lands and shallow soils.

India is a large country with a 60.4% of agricultural land area out of total available land area of 2973,190 hectares. Due to diversified climatic conditions and high dependency on monsoon rainfalls, the cropping pattern of the region is highly variable and depends on irrigation water availability, and the socioeconomic condition and physiographic features of the area. The climatic conditions are more variable in the Himalayan region where land use patterns are changing more sharply due to increased urbanization and industrial growth. There is increased concentration of carbon dioxide (CO_2) and other trace gases over last century in the atmosphere which resulted in global warming [2]. This warming is much higher than the global average over last 100 years [3]-[5].

The Indian subcontinent depends on monsoon rainfall. The change in the total amount of precipitation is highly variable with the altitudes and both increasing and decreasing trends in different parts of the region [6]. Climate change induced hazards such as floods, landslides, and droughts are imposing significant stresses on the livelihoods of the Himalayan population and downstream populations. According to the IPCC's Fourth Assessment Report, significant stresses have been imposed on the inhabitance and agriculture due to floods, landslides and drought [4], [7]. Climatic changes are more evident in the densely populated lowland regions which are dependent on rainfall mountain water sources for their domestic, agricultural, and industrial needs [8], [9]. Groundwater conditions responsible for slope failures are related to rainfall through infiltration, soil characteristics, antecedent moisture content, and rainfall history [10], [11]. The physical and anthropogenic processes are more active on slopes and due to urbanization activities, soils at the slopes is destabilized.

The total population of Uttrakhand is 10.8 million (predicted) and increasing with the rate of 1.78% with a population density of 159 per km^2. The population growth at lower altitudes (Haridwar) is quite higher at 2.4%. With the increasing population, the food requirement in the area is also increasing at a higher rate.

The study of land use change, and changes in various climatic components in Himalayan regions at different altitudes provides the changes in agriculture patterns of the area and paves the way to develop a mitigation strategy for food security problems in the region.

II. Materials and Methods

A. Study Area

Uttrakhand state is centrally located in the Himalayan region between 28° 43' – 31° 27' N latitudes and 77° 34' – 81° 02' E longitudes. It is in the northern part of India and shares international boundaries with China and Nepal.

The region has a temperate climate, while at the plain areas, the climate is tropical and forms a transitional zone between humid eastern dry to sub humid western Himalaya. The temperature in the area rages between 0 °C to 43 °C. The average annual rainfall of the state is 1,547 mm and the altitude variation ranges from 200 m to more than 8,000 m above mean sea level.

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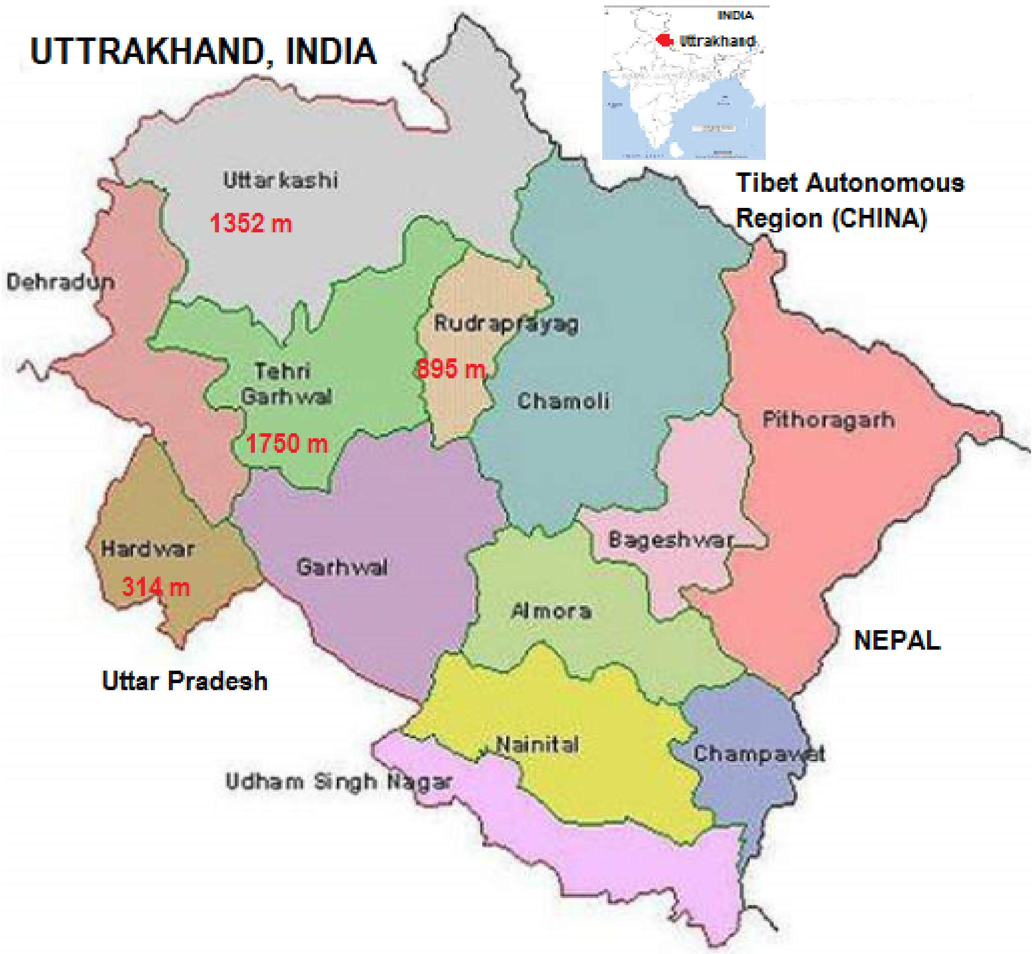

Fig. 1 District Map of Uttarakhand showing elevation of selected districts

TABLE I
SELECTED DISTRICTS UNDER STUDY AND THEIR PHYSICAL DETAILS [6]

Zone	Selected Districts	Elevation, m	latitude	longitude
Mid-Himalayas	Tehri Garwal	1,750	30.3012	78.5661° E
Mid-Himalayas	Uttar Kashi	1,352	30.9287°N	78.4752° E
Sub-Himalayas	Rudra Prayag	895	30.2844	79.0645° E
Sub-Himalayas	Haridwar	314	29.9457	78.1642° E

TABLE II
DIFFERENT SOIL TYPES DISTRIBUTION IN UTTARAKHAND

Sl. No.	Soil zones	Altitude (m)	Climatic Zones	Types of soil
I	Shiwalik and Doon areas	300-900	Moist	Dry Jalod soil
II	Lower Himalayas	900-1,800	Dry-Temperate	Grey forests soil
III	Upper Himalayas	1,800-3,000	Moist Temperate	Grey deciduous soil
IV	Alpine areas	3,000 & above	Moist Temperate	Himani soil

Fig. 1 shows the map of various districts and the project area under Uttrakhand state, India. The state has the total geographic area of 53483 km^2 out of which about 19% is under permanent snow cover, glaciers and steep slopes [12].

Table I shows the location of four districts at various elevations and latitude of the Himalayan region. Table II shows the different soil types distribution with varying climatic zones in Uttarakhand, India.

Landsat data of 30 m resolution was acquired for the Uttrakhand area and analyzed for land use changes. Rainfall data from 1951 to 2010 was acquired from the India water portal and analyzed to interpret the results. Extreme value Gumbel probability method was followed to estimate the rainfall intensity for different recurrence intervals. The runoff was estimated by the curve number method. Twelve year crop production and crop yield data [15] were used to establish the relationship with climate change.

III. RESULTS AND DISCUSSION

A. Land Use Changes

Remote Sensing images of land use at the Uttrakhand area that there is 7% decrease in vegetative cover from 2002 to 2010 and the settlement has been increased to 8% (Figs. 2-5).

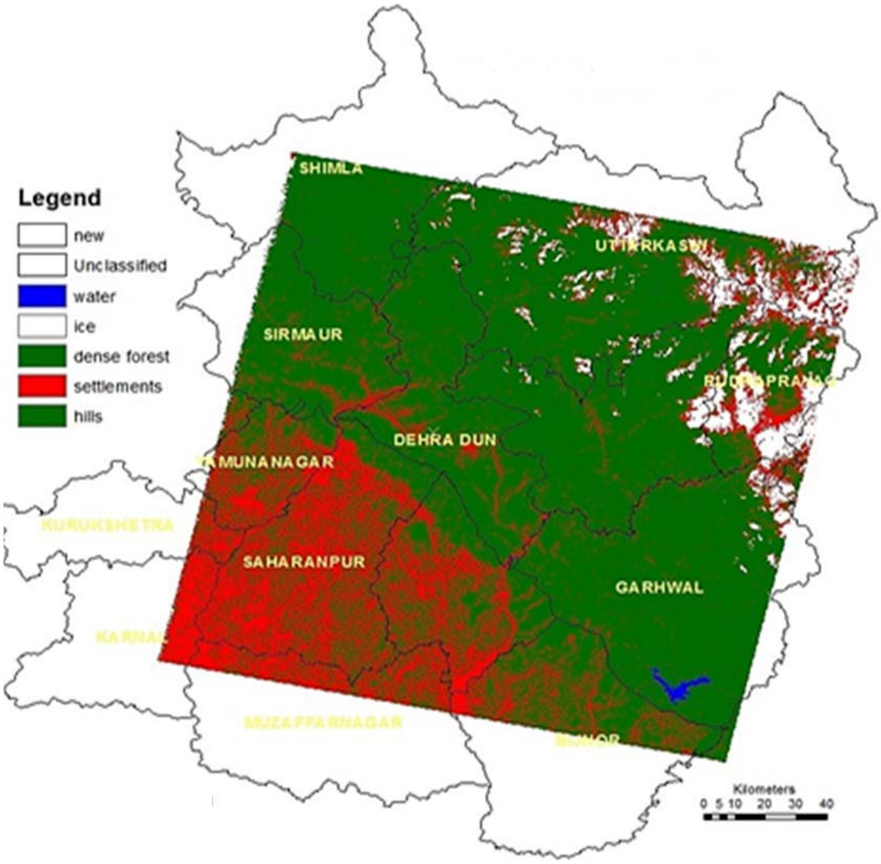

Fig. 2 Remote sensing image for Uttarakhand for 2002

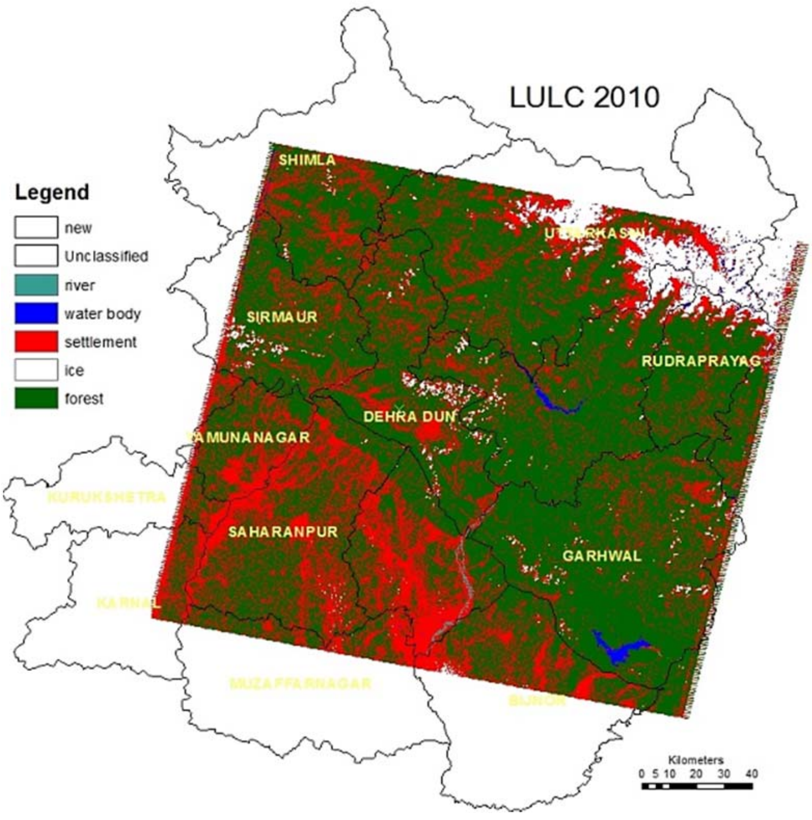

Fig. 3 Remote sensing images for Uttrakhand for 2010

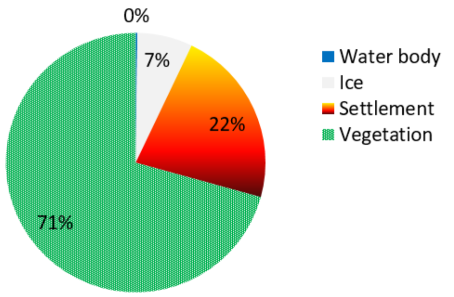

Fig. 4 Land use at Uttrakhand in 2002

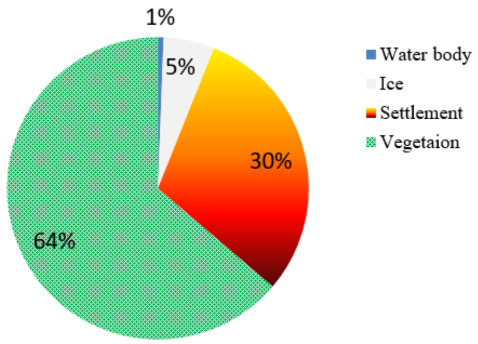

Fig. 5 Land use at Uttrakhand in 2010

There is a 5.7% decrease in net sown area from 2010 to 2014 in the Uttrakhand, which is probably due to increasing population and urbanization. This change has had an adverse effect on agriculture.

IV. Climatic Changes

A. Variation in Temperature

Fig. 6 shows the decadal temperature variation trend for the period 1951-2014. It was observed that temperature has been increased at all the locations from 2010 to 2014, but the increase in temperature was quite high at lower elevations. According to Shrestha et al., in 1999, a temperature change of 0.06 ºC/yr was observed before 2000 [13].

B. Rainfall Variation

Frequent droughts and low crop production has been noticed at various districts in Uttrakhand due to uneven spatial and temporal variation of rainfall. A considerable increase in total rainfall has been recorded for all the monsoon months. Fig. 7 shows a decadal decrease in rainfall for Rudraprayag and Uttarkashi.

C. Rainfall Intensity

The decadal increase in rainfall intensity has been noticed from 2008, with the exception of 2009 when low intensity rainfall occurred (Fig. 8). The increase in intensity may create high runoff and have a direct impact on bare soil causing loss of productivity and loss of top productive soil.

Fig. 9 shows the rainfall intensity for 30 minutes and 60 minutes. Overall, an increase in rainfall intensity from 2008 has been noticed [14]. Alongside increases in the rainfall intensity, extreme weather events including heat waves, tropical cyclones, prolonged dry spells, intense rainfall, snow avalanches, thunderstorms, and severe dust storms have also been reported.

Drastic and sudden changes in critical variables including temperature and precipitation have adversely affected agriculture patterns in the area causing the adoption of plantation crops and a decrease in the cultivation of grain crops.

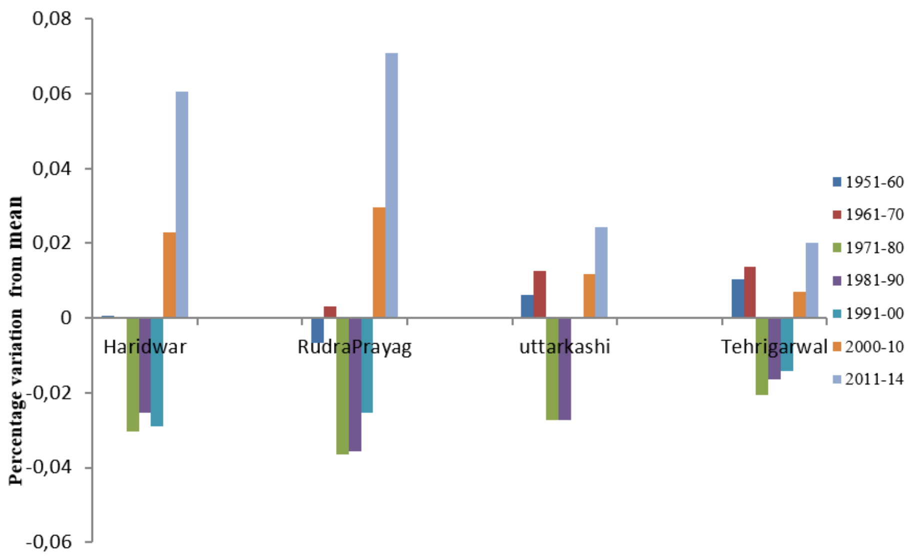

Fig. 6 Mean Decadal variation in temperature at different elevations for June from 1951 to 2014

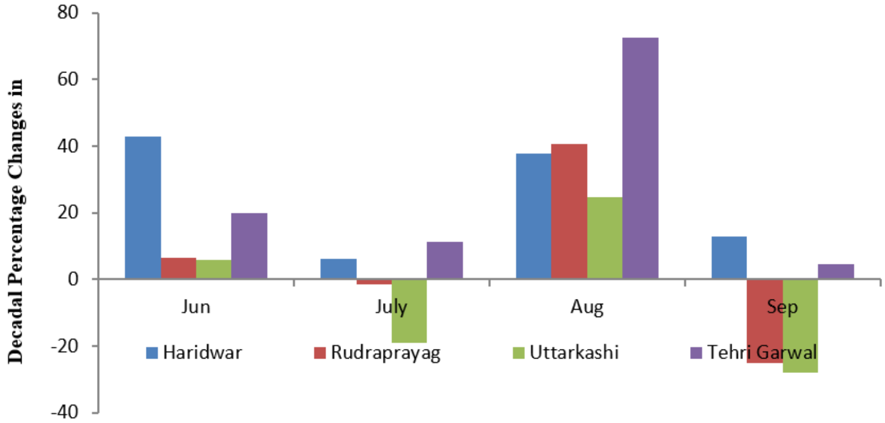

Fig. 7 Elevation-wise variation in rainfall for different months

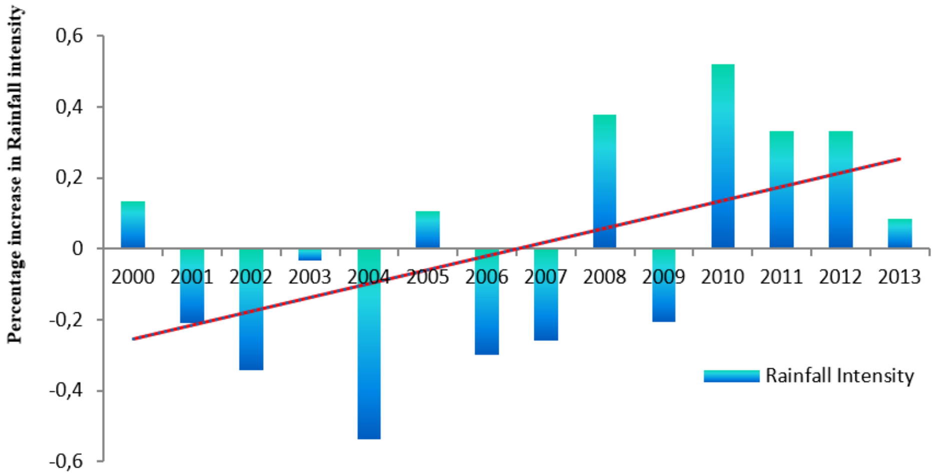

Fig. 8 Variation of rainfall intensity at an elevation >300 m to <1,500 m above mean sea level

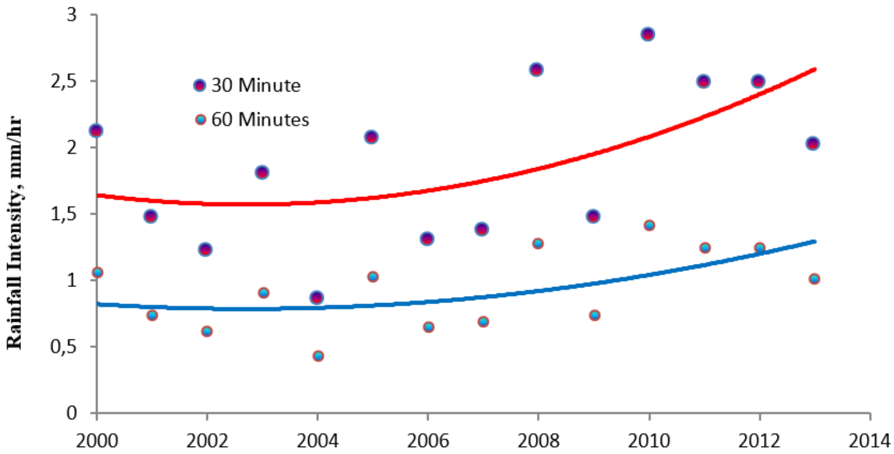

Fig. 9 Year-wise increase in rainfall intensity

D. Crop Yield Changes

It is evident from the Fig. 10 that the yield of wheat crops at all the selected locations has shown a minor increase. Although the years 2004 to 2009 have shown a sudden decrease in yield due to low rainfalls and no proper spatial distribution. The paddy crop has shown a decrease in yield (Fig. 11), probably due to insufficient rainfall at the time of transplanting and the high loss of top productive soils due to an increase in the amount and intensity of rainfalls. Haridwar, which is at a lower altitude, has shown no or minor decrease in paddy yields.

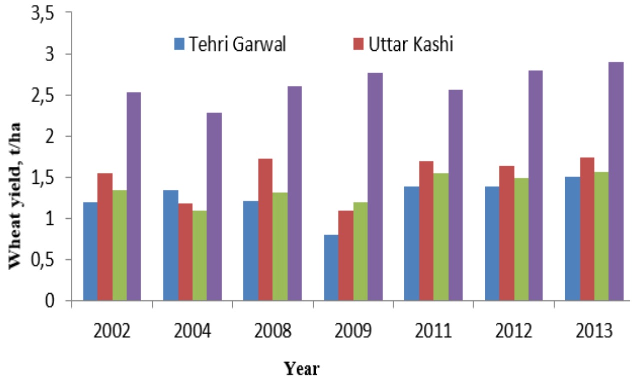

Fig. 10 Wheat yield at selected locations in Uttrakhand

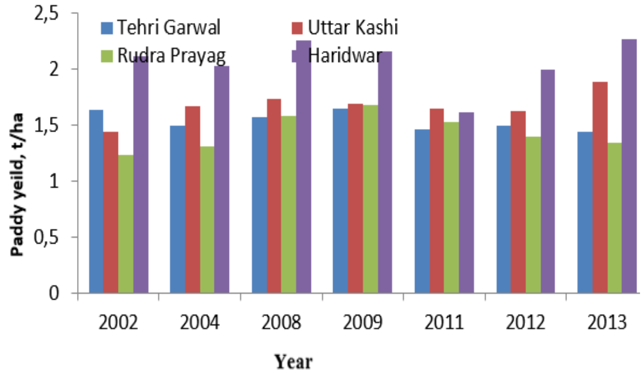

Fig. 11 Paddy yield at selected locations in Uttrakhand

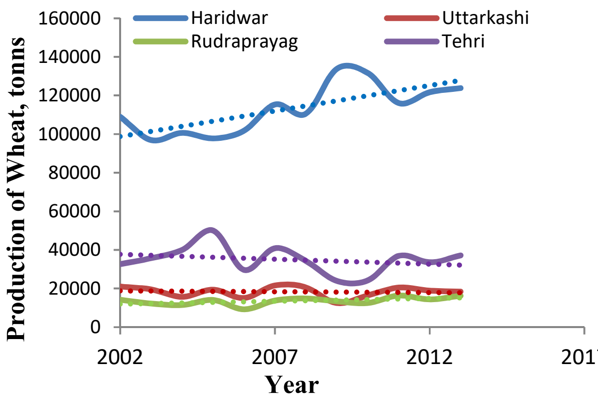

Fig. 12 Production of wheat at selected locations in Uttrakhand

Fig. 12 shows the production of wheat at selected locations. Production in plain areas has sufficiently increased, while a decrease in total production is seen at higher altitudes. The effect of climate change is more clearly visible in the past decade for the years 2006 to 2010.

The effect of climate change is more clearly visible at various altitudes. The increase in rainfall, spatial and temporal changes and high intensity are forcing farmers adopt other climate suitable agriculture crops, while the effect on yield of some of the crops of the region is visible and is adversely affecting agriculture in the area. An increase or decrease in the overall amount of rainfall, as well as shifts in the timing of the rainfall and a decadal increase in temperature, is making crop cultivation in the area more challenging and the adoption of new techniques and technology is becoming an urgent need in the region.

V. Conclusions

The results of the study show that there is a high variation in the climatic parameters and land use in the mid-Himalayan region at the altitude of 314 m to 1,784 m. Ice, snow cover and vegetative cover has been considerably reduced. The increased temperature, rainfall and rainfall intensity are having an adverse effect on soil productivity; although, not much reduction in grain yield is visible.

Since a large human population is dependent on the water and agriculture resources of the region, more concrete conservation, protection and watershed management measures are required to reduce the economic, physical and losses of life due to increased natural disasters.

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