Indian Journal of Ecology (2023) 50(5) (SI): 1735-1741
DOI: https://doi.org/10.55362/IJE/2023/4128

Manuscript Number: 4128
NAAS Rating: 5.79

Impact of Climate Change and Biological Factors on Agriculture in Western Himalaya- People's Perception

Ravindra Kumar, Zoya Shah, Neha Thapliyal[1], K. Chandra Sekar[1], Himanshu Kandpal and Dhani Arya[*]

Department of Botany, Soban Singh Jeena University Campus, Almora-263 601, India
[1]Centre for Biodiversity Conservation and Management, G.B. Pant National Institute of Himalayan Environment Kosi-Katarmal, Almora-263 643 India
E-mail: dhaniarya@gmail.com

***Abstract*:** Climate change is one of the most important environmental challenges that affect all the natural ecosystems of the forest and agriculture. This article provides a brief overview of the impacts of climate change and other biological factors on agriculture in the western Himalayan region based on the perception of local inhabitants and researchers. In this study, questionnaire survey was conducted in which 10% of total population was interviewed from 7 villages of Almora district, Uttarakhand, west to their Himalaya. According to responses, significantly higher proportion of respondents (42.85%) perceive rise in temperature as major sign of climate change and consider deforestation (35.70%) as major cause of this change. Respondents of the area experienced significantly higher effects of climate change from 10 to 20 years (67.14%). There has been a significant decrease in the productivity of the main 10 crops such as *Triticum aestivum*, *Echinochloa frumentacea*, *Oryza sativa*, *Zea mays*, *Glycine max*, etc. The comparative study of crops was done between 1989 and 2019, where average production of *Triticum aestivum* (5027.84 kg/ha) and *Echinochloa frumentacea* (4244.02 kg/ha) continuously decreased during the period of ten years. The major future consequences of climate changes are increasing in agricultural loss and water loss/ scarcity. To mitigate the impact of climate change and other biological factors are awareness and reforestation and sustainable utilization of resources, forest management and flexible government policy.

***Keywords*:** Climate change, Biological factors, People's perception, Kumaun Himalaya

The Indian Himalayan region is home to about 51 million people, practicing hill agriculture in fragile and diverse ecosystems, including species-rich forests. The region has a considerable hydropower potential and feeds numerous perennial rivers which depend upon the sustainable existence of glaciers (GoI 2010, DST 2012). Agriculture forms the main livelihood source for 70% of the Himalayan region, and was significant contributor to the household food security of the local communities (Tiwari and Joshi 2015, Hussain et al 2016). However, the current discourses on agriculture in the Himalaya have recurrently highlighted the on-going agrarian distress in the region manifested by deteriorating land productivity (Ojha et al 2017), declining yield in the last decades (Negi et al 2012), exacerbating food insecurity (Gautum and Andersen 2016) and deepening poverty (Gentle and Maraseni 2012). Farmers, in recent times, have been a victim of unprecedented climate-induced social, economic and environmental transitions in the region (Barua et al 2014, Macchi et al 2014). Climate change impacts are set to profoundly change global ecological and social systems, bringing about fundamental changes to human behavior (Evans 2019). Nonetheless, studies have demonstrated evidence that communities who are more in touch with their surroundings are able to accurately detect environmental changes, such as seasonal temperature and weather fluctuations (Poudel and Duex 2017, Uprety et al 2017). In addition, high dependence on monsoons, unavailability of irrigation facilities and small landholdings intensify the sensitivity of Himalayan farmers (Kuniyal 2003, Rasul 2014). The climate-related shift in production capacity has led to changes in crop yield, reduced crop diversity and increased pest-invasion in the region (Negi et al 2012, Kaul and Tornton 2014). In the previous years, agriculture sector in India has been hard hit by extreme natural calamities such as droughts, floods, heat waves and cyclones (Goswami et al 2006) causing fall in the productivity of food grains, aggravating the food vulnerability of marginal and small farmers, leading to food insecurity and poverty (Birthal et al 2014). Although the weather conditions affect the crop productivity to a considerable extent, soil fertility, varieties of seeds, pests and diseases are some of the other factors that are dependent on climatic variations (Khan et al 2009). Moreover, that too clusters of monkeys and pigs living in areas closer to agricultural fields and that the monkeys and pigs populations were increasing (Sahoo and Mohnot 2014). The objective of the study are: The objective of the study were to assesses the impact of climate change and biological factors on agriculture crops of the study area, reduction in

crop production and to predict the future impacts of climate change.

MATERIAL AND METHODS

The study area, Almora district, Uttarakhand is located at 79° 44' 35" E longitudes and 29° 32' 55" N latitudes. Appropriate semi structural questionnaire formats were developed for gathering the perceptions of people regarding the impacts of biotic and abiotic factors on crop production. A total of 7 villages of Hawalbagh block namely Syuna, Jyoli, Katarmal, Kaneli, Chalar, Udiyari, and Pakhura were selected for the questionnaire-based surveys. An average of 10% of questionnaires was filled up with the help of out of total families (households) present in each village. The information was collected after a long session of discussions with the expected families such as what was the impact of abiotic factors (temperature, droughts, precipitation, etc.) and how they influence your local biodiversity, water resources, and crop productivity. Moreover, the impact of biotic factors (diseases, pest pathogens, monkeys, boars and pigs) on crop productivity was also investigated through questionnaires during the field investigation. After the collection of complete information, their suggestions, recommendations, and future strategies were also gathered regarding the mitigations and adaptation to fight against these challenges, and then the data was compiled and documented.

Data analysis: The survey data collected were analyzed using one-way analysis of variance to assess the distribution of sample means from observations at a 95% confidence level. The IBM SPSS 25 version was employed for Descriptive statistical analysis of various qualitative and quantitative parameters.

RESULTS AND DISCUSSION

Response on climate change: The respondents of the study area understand the concept of climate change and how this change has impacted their lives. According to their response, a significantly higher proportion of respondents (42.85%) perceive a rise in temperature as a major sign of climate change, followed by erratic rainfall and low snowfall (24.89%), longer drought spells (19.57%), shifting in monsoon pattern as well as fluctuating weather conditions (12.69%) (Table 1). Similarly people's perception-based findings were also reported in the Himalayan region (Baul et al .2013). Local communities in the Himalayan region are seen to have widespread indigenous knowledge about climate change impacts and they have been successfully coping with these changes (Byg and Salick 2009, Chaudhary et al 2011). And have reported various indicators of climate change like drying up of water springs, early flowering and budburst in some species, seasonal change in rainfall, shifting and adaptation of natural vegetation, pest disease attack, early crop maturity, loss of livestock population, and water scarcity (Negi et al 2017). In general farmer's thoughts and experiences are congruence with scientific studies (IPCC 2007). The study area indicates that long-term changes in surface air temperature over India during the twentieth century also broadly agree with earlier assessments (Rai et al 2012, Vinnarasi et al 2017, Kothawale et al 2016, Kulkarni et al 2017, Srivastava et al 2019).

Response on the main cause of climate change: The respondents of the study area state that the main causes of climate change are deforestation (35.70%) followed by forest fires (27.15%), urbanization and industrialization (25.72%), (Table 2). However, no significant variation was exhibited among the main causes of climate change as reported by respondents. The related scientific report indicates that climate change is caused by natural phenomena and anthropogenic activities (Montzka 2011, Stem 2014). The respondents of the area experienced significantly higher effects of climate change from 10 to 20 years (67.14%), followed by about 20 to 30 years (16.71%) and from 10 years (14.28%), while 1.87% respondents did not give any response (Table 1c). Similarly, previous people perception study indicates that increase in annual temperature and reduction in annual rainfall, with greater unpredictability in comparison to 30 years ago (Baul et al 2013). The previous scientific study indicates that the Kosi River basin also examined the rainfall status for the past 34 years (1981-2015) and decreasing trend was observed (Shrestha, 2019). Similarly, the HKH experienced a significant decline in snowfall (Ren et al 2015, You et al 2015) and glacial area (Kulkarni and Karyakarte 2014, Wester et al 2019) in the last 4-5 decades. Most of the Western Himalayan (WH) stations recorded a significant warming trend from 1975 onwards (Dimari and Das 2012, Negi et al 2018). Significant rise in surface temperature was observed throughout the HKH region during the past six decades (Kulkarni et al 2013, Rajbhandari et al 2016).

People's responses to the impact of climate change on agriculture: According to the responses of the people in the study area, the impact of climate change has been seen in agriculture is mostly witnessed to low crop productivity (37.98%) and early maturation (22.04%) (Table 2a).The main impact of climate change was observed in agriculture production attributed to lack of rain, the presence of insects, pests, and unwanted invasion. Similar findings were also reported on the basis of people perception's (Suberi et al 2018, Dalal et al 2018). Intergovernmental Panel on Climate

Change (IPCC)'s report shows that the crop yield in many countries of Asia has declined, partly due to the rising temperature and extreme weather events and rainfall variability (Cruz et al 2007). The changes in climatic events such as temperature and rainfall significantly affect the yield of crops (Mahi 2021). The previous study indicates that, historically, low precipitation events have been attributed to many of the largest falls in crop productivity (Kumar et al 2004, Shivakumar et al 2005); agriculture is considered the most endangered activity, adversely affected by climate changes (Ali et al 2019). Furthermore, climate change-induced diseases and pests have also negatively impacted crop yields (Bhatta et al 2015), thus contributing to a reduced agricultural output (Paudel et al 2016).

Impact of other biological factors on agriculture: Apart from climatic parameters, some factors affect crop productivity as per respondents included mainly animal attacks, most importantly monkeys (45.72%), wild boars (30%), rodents (14.28%), and birds (10%) (Table 2b). The respondents agreed that they observed the effect of biotic factors most significantly, (65.72%) respondents feel it from 15 years, then (18.56%) from 10 years, (11.43%) from 5 years and (4.29%) respondents from 20 years. Similar findings were also reported by earlier workers crop damaged by rodents (Parshad 1999, Sridhara and Tripathi 2005), and wild boars damaged crops (Rao et al 2002, Dalal et al 2018). In other studies, outside of the region, people also reported an increase in the incidences of crop damage by wild animals, including monkeys, boar, deer, bears, and rodents due to an increase in their population. Animals that engage in these activities are often labeled 'crop raiders' and their actions as 'crop raiding' (Humle & Hill 2016). Crop raiding is commonly used to mean the action of, or results of, wild animals damaging standing crops by feeding on or trampling them (Hill 2017).

Reduction in agricultural production: According to the perception of the people, there was a significant decrease in the productivity of the main 10 crops due to climate change and other responsible factors like monkeys, boars, rodents, and birds. A comparative study of crops was done between 1989 and 2019, the production of *Triticum aestivum* was 5027.84 kg/ha, now reduced to 2009.14 kg/ha between 2010 and 2019. There has been a reduction of up to 3018.7 kg/ha in *Triticum aestivum* production. *Echinochloa frumentacea*

Table 1. People's response regarding to climate change and causes of climate change

Response	Rising temperature	Erratic rain & low snowfall	Long drought spells	Shifting monsoon period
Understanding of climate change				
Proportion (%)	42.85±0.69[a]	24.89±0.52[b]	19.57±0.27[c]	12.69±0.21[d]
		F= 4.57 p= 0.04*		
Main causes of the climate change				
Response	Deforestation	Forest Fire	Urbanization & industrialization	Motor vehicles and others
Proportion (%)	35.70±0.39	27.15±0.35	25.72±0.36	11.43±0.11
		F= 2.65 p= 0.06		
Villagers response to climate change from				
Response	10 – 20 years	20 – 30 years	< 10 years	No climate change
Proportion (%	67.14±1.25[a]	16.71±1.01[b]	14.28±0.79	1.87±0.02
		F= 21.80 p< 0.001***		

Table 2. Responses of people to the impact of climate change and other responsible factors on agriculture

Impact of climate change on agriculture					
Response	Low crop productivity	Early maturation	Reducing shape and size	Invasion of alien plant species	Diseases, pest and pathogen
Proportion (%)	37.98±0.99[a]	22.04±0.87[b]	14.64±0.55[c]	13.29±0.36[c]	12.05±0.44[c]
				F= 3.77	p< 0.01**

Other responsible factors which affect the crop productivity of people				
Response	Monkeys	Wild boars	Rodents	Birds
Proportion (%)	45.72±2.23[a]	30.10±2.03[b]	14.28±0.85[c]	10.23±0.26[d]
			F= 7.93	p< 0.001***

Table 3. Showing the average reduction in crop production (Kg/ha)

Major crops	Average crop production (Kg/ha)			Average reduction in crop production (Kg/ha)
	1989- 1999	2000 -2009	2010-2019	1989-2019
Wheat (*Triticum aestivum*)	5027.84	3225.47	2009.14	3018.7
Rice (*Oryza sativa*)	3991.88	3244.92	1505.86	2468.88
Maize (*Zea mays*)	2098.83	1472.47	777.84	1320.99
Maduwa (*Eleusine coracana*)	4014.30	2407.78	1759.49	2254.81
Madira (*Echinochloa frumentacea*)	4244.02	2260.28	1259.70	2984.32
Kala bhatt (*Glycine soja*)	3020.69	1616.48	1010.55	2010.14
Soya bean (*Glycine max*)	3759.17	2020.60	1403.21	2355.96
Gahat (*Macrotyloma uniflorum*)	1500.38	1003.07	302.96	1197.47
Urad (*Vigna mungo*)	1159.54	711.57	477.97	1145.26
Masoor (*Lens esculenta*)	1282.62	912.38	507.76	774.86

was gradually decreased and the production between 2010 and 2019 was only 4244.02 kg/ha. Thus, a decrease of up to 2984.32 kg/ ha was observed in the production of *Echinochloa frumentacea*. Earlier scientific studies indicate that, in recent decades, the area under traditional crops has drastically declined (>60%), and many of the crops are at the verge of extinction, such as *Glycine spp., Hibiscus sab-dariffa*, *Panicum miliaceum*, *Perilla fruitescens*, *Setaria italica*, *Vigna spp*. (Maikhuri et al. 2001; Negi and Joshi 2002). Currently, climate change has a negative influence on food security as various predictions indicate a significant decrease in the productivity of different crops (Thompson et al., 2010). Many studies already found that climate change can reduce the yield of wheat by 3.5 to 12.9% (Gammans et al 2017), of maize by 34.6 to 35.4% (Li et al 2014), and of paddy by 10 to 15% (Nelson et al 2009, Li et al 2018). The IPCC (2007) concurred that higher temperature is also the reason for reduction in cereals (e.g., rice and wheat) production especially in South Asian countries. Comprehensive review around the globe is pointing to clear evidence of a decline in the yields of important cereal crops under climate change conditions (Mall et al 2006, Lobel, and Gourdji 2012, Timsina and Humphreys 2006).

Future impacts of climate and suggestions of villagers to reduce these impacts: According to the people's responses, climate change will have more negative effects in the future. Most of these effects will result in loss of agriculture, followed by water scarcity, more drought, and migration of people, epidemics, and problems of inflation. While people suggested reduction strategies for impact of climate change and people provided some suggestions to reducing the impact of factors effecting crop productivity. The impacts of climate change are one of the greatest challenges the country is facing today and would continue to be so in the near future (Chhogyel and Kumar 2018). Many climate models have predicted a decrease in precipitation with an increase of dry periods (Maloney et al 2014, Chadwick et al 2016, Duffy et al 2015). The IPCC report projects that in the coming decade's climate changes will increase in all regions. For 1.5°C of global warming, there will be increased heat waves, longer warm seasons, and shorter cold seasons. At 2°C of global warming, heat extremes would more often reach critical tolerance thresholds for agriculture and health (IPCC 2021). In order to reduce the vulnerability impressions, people gave their important suggestions, the main ones being aware, afforestation, and conservation of water sources less use of oil gas and chemical fertilizers. Besides, the mixed cropping pattern is the best option for reducing the impact of climate change. This pattern has been started for few times by villagers.

CONCLUSION

Agriculture and livestock are one of the main livelihood sources of the marginal living people of the Himalayan region who are straightway exposed to climate and therefore most affected by the climatic variability. The respondents interviewed in the study area agreed to recognize that rises in temperatures, precipitation patterns, longer drought spells, and shifting monsoon patterns have been feeling for the previous twenty to thirty years. Moreover, respondents also believed that for some years the number of main wild animals like monkeys and boars is also increasing, which is causing more damage to agricultural production. Due to both these reasons, crop production has reduced drastically in the last ten to fifteen years, and some people have stopped growing these crops. Due to this, the economic and social conditions

of the people have also been deteriorated, which is not a good sign for the future. Respondents of the study area have given their valuable suggestions regarding reducing the impact and vulnerability to climate change and other responsible factors which included community awareness, adaptive measures, reforestation, conservation of water resources, and less use of oil-gas and chemical fertilizers.

REFERENCES

Aggarwal PK 2008. Global climate change and Indian agriculture: impacts, adaptation and mitigation. *Indian Journal of Agricultural Sciences* **78**(10): 911-919.

Barua A, Katyaini S, Mili B and Gooch P 2014. Climate change and poverty: building resilience of rural mountain communities in South Sikkim, Eastern Himalaya, India. *Regional Environmental Change* **14**: 267-280.

Baul T, Ullah K, Tiwari KR and Mc Donald MA 2013. People's local knowledge of climate change in the middle-hills of Nepal. *Indian Journal of Traditional Knowledge* **12**(4): 585-595.

Bhatta LD, van Oort BEH, Stork NE and Baral H 2015. Ecosystem services and livelihoods in a changing climate: Understanding local adaptations in the upper Koshi, Nepal. *International Journal of Biodiversity Science, Ecosystem Services & Management*, **11**(2):145-155.

Birthal PS, Negi DS, Kumar S, Aggarwal S, Suresh A and Khan MT 2014. How sensitive is Indian agriculture to climate change? *Indian Journal of Agricultural Economics* **69**(4): 474-487.

Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, and Xavier PK 2006. Increasing trend of extreme rain events over India in a warming environment. *Science* **314**(5804):1442-1445.

Byg A and Salick J 2009. Local perspectives on a global phenomenon-Climate change in Eastern Tibetan villages. *Global Environmental Change* **19**(2): 156-166.

Chadwick R, Good P, Martin G and Rowell DP 2016. Large rainfall changes consistently projected over substantial areas of tropical land. *Nature Climate Change* **6**: 177-181.

Chaudhary P, Rai S, Wangdi S, Mao A, Rehman N, Chettri S and Bawa KS 2011. Consistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape. *Current Science* **101**(4): 504-513.

Chhogyel N and Kumar L 2018. Climate change and potential impacts on agriculture in Bhutan: A discussion of pertinent issues. *Agriculture & Food Security* **7:** 79.

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C and Huu Ninh N 2007. Asia. *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change.,* Eds. Cambridge University Press, Cambridge, UK, pp 469-506.

Dalal N, Joshi A, Soragi B, Chaudhary S, Sharma S, Naidu S and Kazmi Y 2018. People's perception to climate change in remote Himalayan mountains and rainfall variability in the Kailash Sacred Landscape-India. *Journal of Climatology and Weather Forecasting* **6**(2): 231.

Dimri AP and Dash SK 2012. Wintertime climatic trends in the Western Himalayas. *Climatic Change* **111**: 775-800.

DST 2012. *Dynamics of glaciers in the Indian Himalaya: science plan.* Himalayan Glaciology Technical Report No. 2. Science and Engineering Research Board (SERB), Department of Science and Technology.

Duffy PB, Brando P, Asner GP and Field CB 2015. Projections of future meteorological drought and wet periods in the Amazon. *Proceedings of National Academy and Sciences* **112**(43): 13172-13177.

Evans GW 2019. Projected behavioral impacts of global climate change. *Annual Review of Psychology* **70**: 449-474.

Gammans M, Mérel P and Ortiz-Bobea A 2017. Negative impacts of climate change on cereal yields: Statistical evidence from France. *Environmental Research Letters* **12**(5): 054007.

Gautam Y and Andersen P 2016. Rural livelihood diversifcation and household well-being: Insights from Humla, Nepal. *Journal of Rural Studies* **44**: 239-249.

Gentle P and Maraseni TN 2012. Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science & Policy* **21**: 24-34.

GOI 2010. *National Mission for sustaining the Himalayan eco-system under National Action Plan on climate change*. Draft Report. Department of Science and Technology, Government of India, pp 51.

Gurung SM 1989. Human perception of mountain hazards in the Kakani Kathmandu area: Experiences from the middle mountains of Nepal. *Mountain Research and Development* **9**(4): 353-364.

Hill CM 2000. A conflict of interest between people and baboons: Crop raiding in Uganda. *International Journal of Primatology* **21**: 299-315.

Hussain A, Rasul G, Mahapatra B and Tuladhar S 2016. Household food security in the face of climate change in the Hindu-Kush Himalayan region. *Food Security* **8**: 921-937.

IPCC 2007. *Intergovernmental panel on climate change; climate change. 2007*: The physical science basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge and New York, (Cambridge University Press, UK), pp 996.

IPCC 2021. *Climate change widespread, rapid and intensifying. Climate Change: The physical Science basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge and New York (Cambridge University Press, UK).

IRC 2002. Climate Change and the Indian Subcontinent: India Resource Center (IRC) Retrieved October 23, 2002 from http://www.rediffnews.com.

Kaul V and Thornton TF 2014. Resilience and adaptation to extremes in a changing Himalayan environment. *Regional Environmental Change* **14***:* 683-698.

Khan SA, Kumar S, Hussain MZ and Kalra N 2009. Climate change, climate variability and Indian agriculture: Impacts vulnerability and adaptation strategies. In: Singh, S. N. (eds) *Climate Change and Crops*, Environmental Science and Engineering. *Springer* Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-88246-6_2

Kothawale DR, Deshpande NR and Kolli RK 2016. Long term temperature trends at major, medium, small cities and hill stations in India during the period 1901-2013. *American Journal of Climate Change* **5**(3): 383-398.

Kothawale DR, Munot AA and Krishna Kumar K 2010. Surface air temperature variability over India during 1901-2007, and its association with ENSO. *Climate Research* **42**(2): 89-104.

Kothawale DR and Rupa Kumar K 2005. On the recent changes in surface temperature trends over India. *Geophysical Research Letters* **32**(18), https://doi. org/10.1029/2005GL023528.

Kulkarni A, Patwardhan S, Krishna Kumar K, Ashok K and Krishnan R 2013. Projected climate change in the Hindu Kush-Himalayan region by using the high-resolution regional climate model PRECIS. *Mountain Research and Development* **33**(2): 142-151.

Kulkarni A, Deshpande N, Kothawale DR, Sabade SS, Ramarao MVS, Sabin TP, Patwardhan S, Mujumdar M and Krishnan R 2017. Observed climate variability and change over India. In: Krishnan R, Sanjay J (eds) *Climate change over India: An interim report*. Published by Centre for Climate Change Research, IITM, pp 38. http://cccr.tropmet.res.in/home/reports.jsp

Kulkarni AV and Karyakarte Y 2014.Observed changes in Himalayan glaciers. *Current Science* **106**(2): 237-244.

Kumar Krishna K, Rupa Kumar K, Ashrit RG, Deshpande NR and Hansen JW 2004. Climate impacts on Indian agriculture. *International Journal of Climatology* **24**(11): 1375-1393.

Kuniyal JC 2003. Regional imbalances and sustainable crop farming in the Uttaranchal Himalaya, India. *Ecological Economics* **46**(3): 419-435.

Li X Takahashi T, Suzuki N and Kaiser HM 2014. Impact of climate change on maize production in Northeast and Southwest China and risk mitigation strategies. *APCBEE Procedia* **8**: 11-20.

Li M 2018. *Climate change to adversely Impact Grain Production in China by 2030*; IFPRI: Washington, DC, USA, Volume 2018.

Lobel DB and Gourdji SM 2012. The influence of climate change on global crop productivity. *Plant Physiology* **160**(4): 1686-1697.

Macchi M, Gurung AM and Hoermann B 2014. Community perceptions and responses to climate variability and change in the Himalayas. *Climate and Development* **7**(5): 414-425.

Maikhuri RK, Rao KS and Semwal RL 2001. Changing scenario of Himalayan agro ecosystems: Loss of agro biodiversity, an indicator of environmental change in Central Himalaya, India. *Environmentalist* **21**: 23-39.

Malhi GS, Kaur M and Kaushik P 2021. Impact of climate change on agriculture and its mitigation strategies: a review. *Sustainability* **13**(3): 1318.

Mall RK, Singh R, Gupta A, Srinivasan G and Rathore LS 2006. Impact of climate change on Indian agriculture: A review. *Climatic Change* **78**: 445-478.

Maloney ED, Camargo SJ, Chang E, Colle B, Fu R, Geil KL, Hu Q, Jiang X, Johnson N, Karnauskas KB and Kinter J 2014. North American climate in CMIP5 experiments: Part III: assessment of twenty-first-century projections.*Journal of Climate* **27**(6): 2230-2270.

Montzka SA, Dlugokencky EJ and Butler JH 2011. Non-CO_2 greenhouse gases and climate change. *Nature* **476**: 43-50. .

Negi GCS and Joshi V 2002. Studies in the Western Himalayan micro-watersheds for global change impact assessment and sustainable development. In: Shrestha K L (ed) *Global Change and Himalayan Mountains.* Institute for Development and Innovation, Kathmandu, 153-165.

Negi HS, Kanda N, Shekhar MS and Ganju A 2018. Recent wintertime climatic variability over the North West Himalayan cryosphere. *Current Science* **114**(4): 760-770.

Negi GCS, Samal PK, Kuniyal JC, Kothyari BP, Sharma RK and Dhyani PP 2012. Impact of climate change on the Western Himalayan mountain ecosystems: An overview **53**(3): 345-356.

Nelson GC, Rosegrant MW, Koo J, Robertson RD, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, Magalhae M, Valmonte-Santos R, Ewing M and Lee DR 2009. Climate change: impact on agriculture and costs of adaptation. International Food Policy Research Institute: Washington, D. C., USA. http://dx.doi.org/10.2499/0896295354

Ojha HR, Shrestha KK, Subedi YR, Shah R, Nuberg I, Heyojoo B, Cedamon E, Rigg J, Tamang S, Paudel KP, Malla Y and McManusg P 2017. Agricultural land under utilisation in the hills of Nepal: Investigating socio-environmental pathways of change. *Journal of Rural Studies* **53:** 156-172.

Parsad VR 1999. Rodent control in India. *Integrated Pest Management Reviews* **4**: 97-126.

Paudel B, Gao J, Zhang Y, Wu X, Li S and Yan J 2016. Changes in cropland status and their driving factors in the Koshi river basin of the Central Himalayas, Nepal. *Sustainability* **8**(9): 933.

Poudel DD and Duex TW 2017. Vanishing springs in Nepalese mountains: Assessment of water sources, farmers' perceptions, and climate change adaptation. *Mountain Research and Development* **37**(1): 35-46.

Rai A, Joshi MK and Pandey AC 2012. Variations in diurnal temperature range over India: Under global warming scenario. *Journal of Geophysical Research Atomospheres* **117**, D02114. https://doi.org/10.1029/2011JD016697.

Rajbhandari R, Shrestha AB, Nepal S and Wahid S 2016. Projection of future climate over the Koshi river basin based on CMIP5 GCMs. *Atmospheric and Climate Sciences* **6**(2):190-204.

Rao KS, Maikhuri RK, Nautiyal S and Saxena KG 2002. Crop damage and livestock depredation by wildlife: A case study from Nanda Devi Bio-sphere Reserve. *Journal of Environmental Management* **66**(3): 317-327.

Rasul G 2014. Food, water and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environmental Science & Policy* **39**: 35-48.

Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y and Xu J 2019. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review *Plants* **8**(2): 34.

Ren Y, Parker D, Ren G and Dunn R 2016. Tempo-spatial characteristics of sub-daily temperature trends in mainland China. *Climate Dynamics* **46**: 2737-2748.

Rupa Kumar K, Krishna Kumar K and Pant GB 1994. Diurnal asymmetry of surface temperature trends over India. *Geophysical Research Letters* **21**(8): 677-680.

Sahoo SK and Mohnot SM 2004. A survey of crop damage by Rhesus monkeys and Hanuman langur in Himachal Pradesh, India. *Tigerpaper* **31**(4): 1-6.

Sen Roy S and Balling RC 2005. Analysis of trends in maximum and minimum temperature, diurnal temperature range, and cloud cover over India. *Geophysical Research Letters* **32**(12): L12702.

Shrestha S, Yao T and Adhikari TR 2019. Analysis of rainfall trends of two complex mountain river basins on the southern slopes of the Central Himalayas. *Atmospheric Research* **215**: 99-115.

Sivakumar MVK, Das HP and Brunini O 2005. Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. *Climatic Change* **70**: 31-72.

Sridhara S and Tripathi RS 2005. *Distribution of rodents in Indian agriculture*. Indian Council of Agricultural Research, Technical Bulletin No. 13. Central Arid Zone Research Institute, Jodhpur, India. Pp 136.

Srivastava AK, Kothawale DR and Rajeevan MN 2017. Variability and long-term changes in surface air temperatures over the Indian subcontinent. In: Rajeevan MN, Nayak S (eds) Observed climate variability and change over the Indian region. *Springer Geology* 17-35. https://doi.org/10.1007/978-981-10-2531-0_2

Srivastava AK, Rajeevan M and Kshirsagar SR 2009. Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region. *Atmospheric Science Letters* **10**(4): 249-254

Srivastava AK, Revadekar JV and Rajeevan M 2019. South Asia in state of the climate in 2018. *Bulletin of the American Meteorological Society* **100**(9): S236-S240.

Stern DI and Kaufmann RK 2014. Anthropogenic and natural causes of climate change. *Climatic Change* **122**: 257-269.

Suberi B, Tiwari KR, Gurung DB, Bajracharya RM and Sitaula BK 2018. People's perception of climate change impacts and their adaptation practices in Khotokha Valley, Wangdue, Bhutan. *Indian Journal of Traditional Knowledge* **17**(1): 97-105

Thompson HE, Berrang-Ford L and Ford JD 2010. Climate change and food security in Sub-Saharan Africa: A systematic literature review. *Sustainability* **2**(8): 2719-2733.

Timsina J and Humphreys E 2006. Application of CERES-rice and CERES-wheat in research, policy and climate change studies in Asia: A review, *International Journal of Agricultural Research* **1**(3): 202-225.

Tiwari PC and Joshi B 2015. Local and regional institutions and environmental governance in Hindu Kush Himalaya. *Environmental Science & Policy* **49:** 66-74.

Uprety Y, Shrestha UB, Rokaya MB, Shrestha S, Chaudhary RP, Thakali A, Cockfield G and Asselin H 2017. Perceptions of

climate change by highland communities in the Nepal Himalaya. *Climate & Development* **9**(7): 649-661.

Vinnarasi R, Dhanya CT, Chakravorty A and Agha Kouchak A. 2017. Unravelling diurnal asymmetry of surface temperature in different climate zones. *Scientific Reports* **7**: 3750-. https://doi.org/10.1038/s41598- 017-07627-5

Wester P, Mishra A, Mukherji A and Shrestha AB 2019. The Hindu Kush Himalaya assessment. Springer International Publishing, Springer Cham. 627. https://doi.org/10.1007/978-3-319-92288-1

You Q, Min J, Zhang W, Pepin N and Kang S 2015. Comparison of multiple datasets with gridded precipitation observations over the Tibetan Plateau. *Climate Dynamics* **45:** 791-806.

Received 08 June, 2023; Accepted 12 October, 2023