Review Article

Climate Change effects and Mitigation Measures in Uttarakhand Himalayas Region

Abstract: One of the biggest environmental issues affecting the world's natural ecosystems is climate change. Based on the literature that is currently accessible, this article offers a succinct summary of how the Uttarakhand Himalayan Mountains' agriculture, water, and 15.61% forest are affected by climate change. Numerous research have been conducted on a variety of Himalayan ecosystem-related topics, but only a small number of local studies have been published that address factors connected to climate change. This is mainly because there is a dearth of organized and targeted data on the subject. Thus, the qualitative analysis shows that in order to meet the demands of research on many elements of climate change impacts, mitigation, and adaptation, it is imperative to strengthen the climate data gathering network.Over the last four decades, this region has been found in soil water content reduce, total precipitation and run-off, land-used change due to urbanization that are challenges for both community and government to mitigate and adaptation.

Keywords:Adaptation, Climate change, Mitigation, Resilience, Vulnerability.

Introduction: The Uttarakhand Himalayasare facing significant impact from climate change. Some of the key effect includes melting glaciers, changing precipitation patterns, increased frequency of extreme weather events like floods and landslides, and shifts in biodiversity. These changes have implications for the local communities, ecosystem, and water resources in the region. Efforts are being made to study and address these impacts through adaptation and mitigation strategies. Mountain ecosystems are critical to the sustainability of the environment, the growth of the local economy, and the security of human livelihoods on a worldwide scale. Still, mountains are among the planet's most delicate ecosystems. They are also recognized as being water and biodiversity repositories, as well as suppliers of ecosystem products and services that downstream communities depend on a regional and global scale (Rautela & Karki, 2015). Because the mountain ecosystems erect obstacles to the unhindered passage of winds, they aid in stabilizing atmospheric circulation. These have been crucial in keeping the summer monsoon in check and protecting the Indian subcontinent from the westerlies in the winter (Kale et al., 2004).

UNDER PEER REVIEW

The Himalayan region is warming more quickly than other mountain regions, and the gradual replacement of traditional wood and stone masonry with reinforced cement structures is hastening the impact of heat islands in the mountain region, which is what led to the glacier burst in Uttarakhand. In the Himalayas, there are over 8,000 glacial lakes, 200 of which are considered hazardous. The glacier at Joshimath caused extensive damage in the upper regions of the ecologically delicate Himalayas and resulted in a major flood in the Dhauli Ganga River. (Bandyopadhyay, 2021).

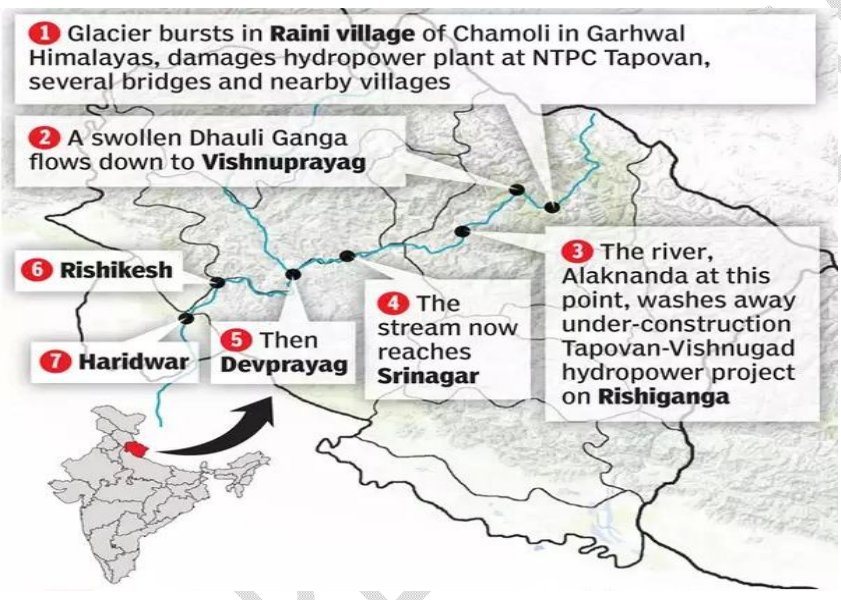

Fig. 1. Trail of Destruction

(Source: The Times of India)

It is predicted that permafrost thawing and glacier retreat will increase the quantity and extent of glacier lakes while decreasing the stability of mountain slopes (high confidence). In areas where there are no records of past events, landslides, floods, and cascading disasters will also occur (high confidence), according to the government panel on climate change's special report on oceans and cryosphere (SROCC) (IPCC, 2019). The timing of hailstorms in Uttarakhand's high altitude regions is also changing, occurring as late as May instead of March. This causes more damage to a variety of fruit crops during the flowering and early fruit stages. In the Himalayan region, the majority of glaciers are receding. As a result, the annual glacier melt will not be able to supplement the water supply in the area. It is difficult to pinpoint exactly how retreating

glaciers may affect each location's water supply due to variations in temperature, precipitation timing, volume, and type, as well as glacial behavior and dynamics (Thadani et al., 2015).

HIMALAYAN AGRICULTURE AND CLIMATE CHANGE:

The productivity of agriculture and the stability of rural communities' livelihoods are being threatened by erratic, unpredictable, and unanticipated changes in the climate. The food supply chain can be disrupted, food access can be lowered, and food quality can be impacted by climate variability and change. As a result, there is a growing emphasis on the vulnerability of farmers and, by extension, the agriculture production systems, which is reflected in the region's human development indicators.

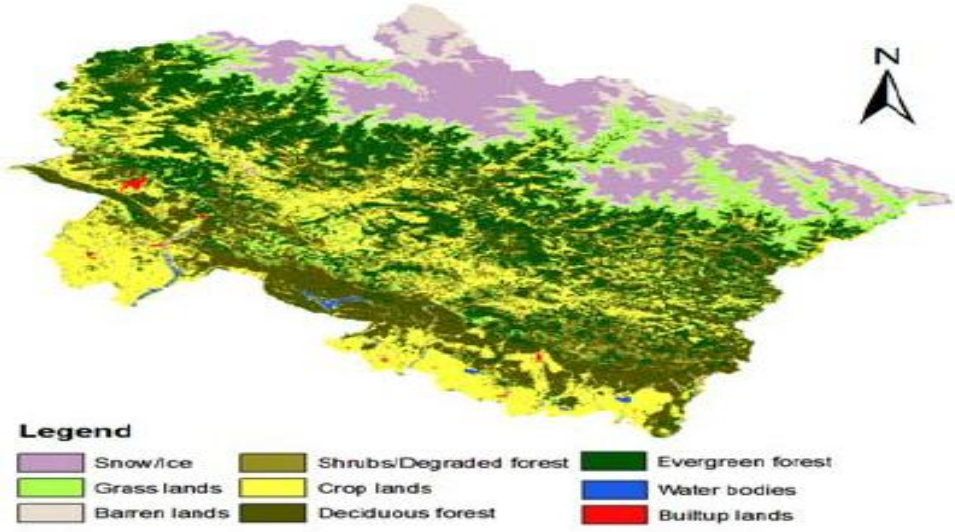

Fig. 2. Land use/land cover map of Uttarakhand

(Source: UAPCC, 2014)

The goal of the current study is to evaluate farmers' susceptibility to improve location-specific adaptation and mitigation techniques. The study was carried out in Uttarakhand, an Indian state in the North Himalayas, namely in the Uttarakhand state.Drought impacts due to Climate Change causes warmer temperature enhance evaporation, which reduces surface water and dries out soils and vegetation and also altering the timing of water availability.The majority of farmers in the area are only somewhat vulnerable to climate change, according to research on the susceptibility of farmers in Uttarakhand's Himalayan region. The level of awareness among farmers in hilly

regions regarding climate events was deemed moderate. In order to prepare the farming community for the negative effects of climate change, we must launch multimodal campaigns to increase awareness among them, change their mindset, inform them of the risks and uncertainties associated with climate change, and provide them with alternative, location-specific adaptation strategies (Raghuvanshi & Ansari, 2020).Uttrakhand's total population is 10.8 million (estimated), growing at a pace of 1.78% per year, or 159 people per km. At 2.4%, the population growth at lower altitudes (Haridwar) is significantly higher. The area's need for food is growing at a faster rate in tandem with the growing population (Isaac & Isaac, 2017).Even though it makes up a very minor portion of the global economy, it has always been a significant factor in estimations of the total economic effects of climate change. It was customary to predict in the 1990s that the early phases of climate change would help world agriculture in a positive way (Mendelsohn & Nordhaus, 1999).The effects of climate change on US agriculture ultimately depend on how extreme weather events and climate variability change. There could be serious repercussions if droughts, floods, and storm damage become more frequent and intense. These occurrences result in surface and groundwater erosion, waterlogging, and the leaching of chemicals, pesticides, fertilizers, and animal waste(Reilly, J. et al,.2001). Longer growth seasons were predicted for northern regions due to warmer weather, while carbon fertilization was predicted to help plants everywhere. In the Himalayan region, net temperature increases are predicted to fall between 1.7 and 2.2 degree Celsius, while precipitation increases of 60 to 206 mm are predicted for the 2030s. There has been an annual rainfall rise of 5 to 13 percent since the 1970s (UAPCC 2012). Soil is one of the most valuable natural resources, and both soil and climate have a significant impact on a region’s biodiversity.Agro-ecosystem productivity is also highly influenced by the quality of the soil. Uttarakhand has a wide range of soil types, including the black soils of the temperate zone, the freshly laid down alluvium of the dun valley, the deep, fertile, and alluvial soils of the Tarai tract, the thin, fragile soil of the Shivalik hills, and the parched, naked soil of the inner dry valleys.

UNDER PEER REVIEW

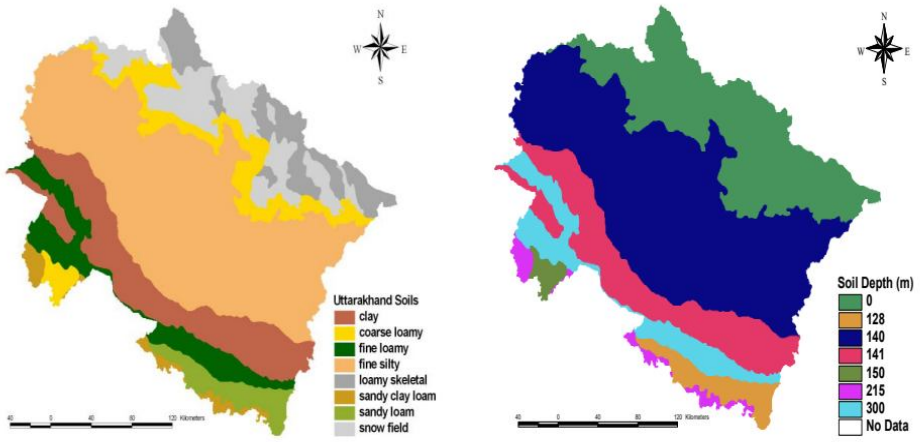

Fig. 3 .Uttarakhand soils and soil depth mapping by NBSS&LUP

(Source: UAPCC, 2014)

Because of the appropriate soil depth, a considerable amount of humus, moisture, and mineral nutrients, the soils in valley bottoms are more fruitful than those on ridge tops. This natural resource is gradually running out because of the increased soil erosion brought on by the region's growing deforestation and degradation. There are numerous classifications for the different kinds of soils in Uttarakhand.The soils of Uttarakhand are classified into eight categories by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur, based on soil texture. These categories include sandy loam, sandy clay loam, fine loam, fine silt, clay, coarse loam, loamy skeleton, and snow field (UAPCC 2014).Pollinator populations will be impacted by changes in floral diversity brought about by changes in land use and land cover, as well as the disappearance of native cultivars. Changes in pest occurrence, movement, and viability are also caused by climate change. A pest or disease may extend its regular range into a new area due to a change in the climate, causing losses and disrupting native plant populations(Rosenzweig et al., 2001).

SOCIO-ECONOMIC IMPACT OF CLIMATE CHANGE:

The Uttarakhand Himalayas, a region known for its diverse landscapes and fragile ecosystems, is facing the significant challenges posed by climate change. The local communities in this region, whose livelihoods are primarily dependent on agriculture and natural resources, are particularly vulnerable to the impacts of a changing climate. (Jha et al., 2021) The social and ecological

UNDER PEER REVIEW

systems in this Himalayan region are gradually being affected by climate change, as evidenced by the shifts in seasonal patterns and the increased frequency of extreme weather events. (Poudel, 2020) Climate change is expected to exacerbate the existing challenges faced by mountain people and their environments, with the greater Himalayan region as a whole being particularly sensitive to these changes. (Macchi et al., 2014) One of the key impacts of climate change in the Uttarakhand Himalayas is its effect on the region's agricultural practices. Agriculture in this region is highly dependent on natural resources, with communities mainly following subsistence agriculture. (Chauhan et al., 2020) The observed impacts of climate change include the shift of apple orchards towards higher altitudes, the loss of traditional water resources, reduced crop productivity, lower productivity of winter crops, and the loss of crops due to changed rainfall and precipitation patterns. (Chauhan et al., 2020) These impacts act on the fragile socio-economic conditions of the local communities, thereby exacerbating their vulnerability.As a result, as the environment changes, so do the economic circumstances of farmers. Direct or indirect effects of climate variables are felt by farmers in terms of their social and economic standing. Crop damage, low productivity, and high production costs brought on by climate change result in farmers losing revenue, poverty levels rising, and seasonal unemployment rates rising(Raghuvanshi et al., 2018).Due to changes in rainfall patterns and surface temperature; recently, high altitude observations of malaria mosquitoes have been made. Shifting weather patterns in the Himalayas have a significant impact on human health and general well-being. These patterns may accelerate the spread of infectious diseases. For instance, malaria, tick-borne illnesses, and other diseases associated with infection growth rates may spread more rapidly (Dhanai et al., 2014).

IMPACT OF CLIMATE CHANGE ON HIMALAYAN WATER RESOURCES:

Mountainous areas have demonstrated "above average warming" and are susceptible to climate change. The Intergovernmental Panel on Climate Change (IPCC) predicts that within the next few decades, the availability of water resources would be impacted by a range of effects, from decreased genetic diversity of animals to greater flooding caused by glacial melt in the Himalayas. Uttarakhand is a valuable freshwater reserve with over a dozen glaciers in the state and over fifteen significant perennial rivers fed by glaciers. The IPCC emphasizes once more

UNDER PEER REVIEW

how the worrying trend of glacial melts could cause many rivers to become seasonal rivers in the future, which would have an impact on the basin areas' economic potential.Considering that the Gangotri is the source of the Ganga River, the state's ecological balances and human livelihoods would be impacted by the increased glacial melt brought on by climate change. Globally, the last century has seen a thinning of glaciers and a decrease in ice cover, particularly in mountain glaciers. This is thought to be evidence of climate change (IPCC2001).Studies show that a large portion of these Himalayan Rivers get their water from snow and glacier runoff. The Satluj River at Bhakra Dam is predicted to get 60% of the annual snow and glaciers melt contribution (Singh and Jain, 2002), the Chenab River at Akhnoor receives 49% (Singh et al., 1997), and the Beas River at Pandoh receives 35% (Kumar et al., 2007). Concern has been raised about potential negative effects from changes in the availability of water resources in the upcoming decades due to a lack of water and population growth projections (Vaux et al., 2012). The current understanding regarding the impact of glacier shrinkage on the river flow variations is discussed in the IPCC (2007a) which stated that "as these glaciers retreat due to global warming, river flows are increased in the short term, but the contribution of glacier melt will gradually decrease over the next few decades" and "the enhanced melting of glaciers leads at first to increased river runoff and discharge peaks and an increased melt season" (IPCC, 2007b).As a result, it is not always possible to draw straight conclusions and comparisons from the well-researched glaciers at lower elevations to the Himalayan region's higher elevations, which have received less attention (Armstrong, 2010).According to scientific data, the majority of the glaciers in the Himalayan region are receding; raising worries that eventually annual glacier melt may not be able to sustain the region's water supply.In addition to the issue with water resources, glacier melt has an impact on animals and insects, includingHabitat disruption and loss the distribution and number of plants are changed by glacier melts, which affects herbivorous insects (Bhatt et al., 2020). Water flow variations have an effect on fish and otter habitats, as well as insects like mayflies and caddisflies (Negi et al., 2018).Changes in Food Webs and Nutrient Cyclesthe availability of food for aquatic insects (Sharma et al., 2018) and animals (Kumar et al., 2017) is affected by changes in stream flow and temperature regimes. The timing and amount of glacier melt variations affect how nutrients are delivered to habitats downstream (Gupta et al., 2016).Disruptions to Migratory Patterns and Behavior The migratory patterns of animals like the blue sheep (Mishra et al., 2018) and insects like butterflies are disrupted by changes in

UNDER PEER REVIEW

temperature and precipitation patterns (Bhattacharya et al., 2019). Changes in the timing and amount of glacier melt have an effect on the interactions between species, such as pollination and predator-prey relationships (Dhyani et al., 2017).A multifaceted strategy is needed to monitor or mitigate Uttarakhand increased runoff as a result of glacier melts. The following are some tactics:Watershed management Reforestation, soil conservation, and economical water usage are examples of sustainable watershed management techniques that can be used to lessen runoff (Kumar et al., 2020).Mitigation of glacier lake outburst floods (GLOFs) Building barriers, dams, or other structures may reduce the possibility of GLOFs (Shrestha et al., 2019).Water storage and harvesting Constructing water harvesting features, like reservoirs or ponds, can aid in storing extra water and reducing runoff (Gupta et al., 2019).Ecosystem-based adaptation it is possible to preserve water cycles and lessen runoff by maintaining and restoring natural ecosystems, such as wetlands and forests (Chaudhary et al., 2019).Infrastructure resistant to climate change Planning and building climate-resistant infrastructure, such as roads and bridges, can reduce damage caused by increased runoff (Mishra et al., 2020).

IMPACT OF CLIMATE CHANGE ON FOREST ECOSYSTEM:

Climate change, a global phenomenon driven by human-induced greenhouse gas emissions, has profound implications for the world's forest ecosystems. Forests play a vital role in mitigating climate change by absorbing and storing carbon dioxide, but they are also vulnerable to the adverse effects of a changing climate. (Anderegg et al., 2020) This research paper will explore the multifaceted impacts of climate change on forest ecosystems, highlighting the need for comprehensive, science-based policies and management strategies to ensure the long-term resilience and sustainability of these critical natural resources.The role of forests in carbon sequestration and climate change mitigation is well-established. However, recent studies have revealed that the climate mitigation potential of forests is increasingly at risk due to a range of physical and biotic factors influenced by climate change. (Anderegg et al., 2020) Drought, fire, insect infestations, and the spread of fungal pathogens are just a few of the climate-driven threats that can limit forest growth, health, and carbon storage capacity. (Anderegg et al., 2020) Initiatives to increase forest cover through afforestation and reforestation are actively being

UNDER PEER REVIEW

implemented at local, regional, and global scales, but their success will depend on understanding and addressing these climate-related challenges. (Ma et al., 2021)

Forests also influence climate change through their ability to act as sources of greenhouse gases when they are destroyed or degraded. By examining the physiological responses to a changing climate within forest ecosystems, we can better understand how species interactions may be influenced in the face of environmental perturbations (Atenkeng Tendong et al., 2019). Additionally, the valuation of ecosystem services provided by forests, as showcased in the Hambach forest case study, highlights the economic, social, and environmental significance of preserving forest ecosystems in the wake of climate change (Atenkeng Tendong et al., 2019). Through a comprehensive analysis of these factors, it becomes evident that addressing the impact of climate change on forest ecosystems is paramount for sustainable management and conservation practices. Climate change poses a significant threat to forest ecosystems, impacting various environmental conditions crucial for their survival. As anthropogenic warming alters temperature, precipitation patterns, and snow cover duration, forests in regions like Krasnodar are experiencing adverse effects. Studies indicate a moderately negative contribution of these climatic factors to the forecast dynamics of forestry (Yu.S. Kuznetsova et al., 2024). Furthermore, changing climatic conditions challenge forest trees to adapt to new environmental realities. With altered conditions such as temperature fluctuations and varying precipitation levels, trees face increased stress and reduced resilience (M. Fotelli, 2021). These changes not only affect individual tree species but also disrupt the delicate balance within forest ecosystems. As climate change continues to escalate, understanding and addressing these impacts are imperative to ensure the long-term health and sustainability of forest environments. the impact of climate change on forest ecosystems reveals a urgent need for conservation efforts to protect vital species and maintain ecological balance. The analysis of habitat suitability for key species such as Prunus armeniaca, Malus sieversii, and Prunus ledebouriana underscores the shifting ecological niches and significant reductions in resource utilization under current and future climate scenarios (Facheng Guo et al., 2024). These findings emphasize the critical importance of preserving these species to safeguard wild fruit forests and their ecosystem functions. Additionally, regional projections for Jalisco highlight the high vulnerability of the region to climate change, with projected temperature increases and precipitation variations that will lead to

UNDER PEER REVIEW

significant impacts across multiple sectors, including water resources, agriculture, biodiversity, and public health (Ramírez Sánchez Hermes Ulises et al., 2024). The expected consequences of climate change underscore the pressing need for comprehensive adaptation and mitigation strategies to mitigate the adverse effects on forest ecosystems and ensure their sustainability in the face of environmental challenges.

CONCLUSION:

In conclusion, the impact of climate change on the Uttarakhand Himalayan region is significant, affecting agriculture, water resources, and forest ecosystems. The region is facing challenges such as melting glaciers, changing precipitation patterns, and increased frequency of extreme weather events, impacting local communities and biodiversity. Efforts to address climate change impacts through adaptation and mitigation strategies are crucial, as the region's vulnerability is evident in shifting agricultural practices, reduced crop productivity, and threats to forest ecosystems. Climate change also poses risks to water resources, with glacier melts affecting river flows and potentially leading to water scarcity in the future. Upholding the resilience and sustainability of forest ecosystems is essential, as they play a critical role in carbon sequestration and climate mitigation. Addressing climate-related challenges through science-based policies and conservation practices is essential to mitigate the adverse effects on forest environments and ensure long-term ecological balance and sustainability in the face of climate change. Strengthening climate data gathering networks and implementing location-specific adaptation strategies are essential steps in managing the impact of climate change on the Uttarakhand Himalayas.

UNDER PEER REVIEW

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UNDER PEER REVIEW

References

Rautela, P., & Karki, B. (2015). Impact of Climate Change on Life and Livelihood of Indigenous People of Higher Himalaya in Uttarakhand, India. American Journal of Environmental Protection, 3(4), 112–124. https://doi.org/10.12691/env-3-4-2

Kale, V. S., Gupta, A., & Singhvi, A. K. (2004, October 1). Late Pleistocene-Holocene Palaeohydrology of Monsoon Asia.Journal of Geological Society of India, 64: 403-417.https://www.geosocindia.com/index.php/jgsi/article/view/82841

Bandyopadhyay, K. (2021, February 7). Climate change behind Uttarakhand glacier burst, experts feel. The Times of India; Times Of India. https://timesofindia.indiatimes.com/india/climate-change-behind-uttarakhand-glacier-burst-experts-feel/articleshow/80736594.cms

IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Thadani, R., Singh, V., Chauhan, D. S., Dwivedi, V., & Pandey, A. (2015). Climate Change inUttarakhand. http://books.google.ie/books?id=od5MjwEACAAJ&dq=Climate+Change+in+Uttarakhand:+Current+State+of+Knowledge+and+Way+Forward&hl=&cd=1&source=gbs_api

Raghuvanshi, R., & Ansari, M. A. (2020). Farmers' Vulnerability to Climate Change: A Study in North Himalayan Region of Uttarakhand, India. https://acspublisher.com/journals/index.php/ijee/article/view/4282/3933

Isaac, R. K., & Isaac, M. (2017). Vulnerability of Indian Agriculture to Climate Change: A Study of the Himalayan Region State. World Academy of Science, Engineering and Technology, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, *11*(3), 236–242. https://doi.org/10.5281/zenodo.1129261

Mendelsohn, R., & Nordhaus, W. (1999). The Impact of Global Warming on Agriculture: A Ricardian Analysis: Reply. American Economic Review, 89(4), 1046–1048. https://doi.org/10.1257/aer.89.4.1046

Reilly, J. & Tubiello, Francesco & McCarl, B.A.. (2001). Climate change impacts on the united states. US National Assessment of the potential consequences of climate variability and change: Foundation. Chapter. 13. 379-403.

Uttarakhand State Action Plan for climate change, 2012

Uttarakhand State Action Plan for climate change, 2014

Rosenzweig, C., Iglesias, A., Yang, X., Epstein, P. R., & Chivian, E. (2001). No Title. *Global* Change & Human Health, 2(2), 90–104. https://doi.org/10.1023/a:1015086831467

Jha, S. K., Negi, A. K., Alatalo, J. M., & Negi, R. S. (2021). Socio-ecological vulnerability and resilience of mountain communities residing in capital-constrained environments. Mitigation and Adaptation Strategies for Global Change, 26(8). https://doi.org/10.1007/s11027-021-09974-1

Poudel, J. M. (2020). The rhythms of life in the Himalaya: seasonality and sociality among the Gurung people of the Nhāson Valley. International Journal of Anthropology and Ethnology, 4(1). https://doi.org/10.1186/s41257-020-00036-z

Macchi, M., Gurung, A. M., & Hoermann, B. (2014). Community perceptions and responses to climate variability and change in the Himalayas. Climate and Development, 7(5), 414–425. https://doi.org/10.1080/17565529.2014.966046

Chauhan, N., Shukla, R., & Joshi, P. (2020). Assessing inherent vulnerability of farming communities across different biogeographical zones in Himachal Pradesh, India. Environmental Development, 33, 100506. https://doi.org/10.1016/j.envdev.2020.100506

Raghuvanshi, R., Ansari, M., & Yadav, A. (2018). Measuring Socio-economic Profile of Farmers to Climate Change in Uttarakhand, India. International Journal of Current Microbiology and Applied Sciences, 7(07), 4035–4040. https://doi.org/10.20546/ijcmas.2018.707.469

Dhanai, R., Negi, R. S., Singh, S., & Parmar, M. K. (2014). The Effects of Climate Change on Natural Resources and Socio-economic Condition of Himalayan Communities of Uttarakhand, India. International Journal of Modern Communication Technologies & Research (IJMCTR*)*, 2(11).

IPCC. 2001b. Climate Change- The Scientific Basis, Summary for Policy Makers and Technical Sum- mary of the Working Group I Report. Intergovern- mental Panel on Climate Change, Cambridge University Press, Cambridge.

UNDER PEER REVIEW

Singh, P. and Jain, S.K. (2002): Snow and glacier melt in the Satluj River at Bakhra Dam in the Western Himalayan region, Hydrolog. Sci. J., 47, 93–106.

Kumar, V., Singh, P., and Singh, V. (2007) Snow and glacier melt contribution in the Beas River at Pandoh Dam, Himachal Pradesh, India Hydrolog. Sci. J., 52(2), 376–388.

Vaux, H.J., Balk, Jr., D., Cook, E.R., Gleick, P., Lau, W.K.-M., Levy, M., Malone, E.L. McDonald, R. , Shindell, D., Thompson, L.G., Wescoat Jr., J.L., and Williams, M.W.(2012) Himalayan Glaciers: Climate Change, Water Resources, and Water Security. National Academies Press.

IPCC, Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Do¨ ll, P., Kabat, P., Jime´nez, B., Miller, K. A., Oki, T., Sen, Z., and Shiklomanov, I. A. (2007a) Freshwater Resources and their Management, in: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., and Hanson,C. E., Cambridge University Press, Cambridge, UK, 173–210.

IPCC, Rosenzweig, C., Casassa, G., Karoly, D. J., Imeson, A., Liu, C., Menzel, A., Rawlins, S., Root, T. L., Seguin, B., Tryjanowski, P. (2007b) Assessment of Observed Changes 64 and Responses in Natural and Managed Systems, in: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., and Hanson, C. E., Cambridge University Press, Cambridge, UK, 79–131.

Armstrong, R. L. (2010) Recent Northern Hemisphere Snow Extent: a Comparison of data derived from visible and Microwave Satellite Sensors, Geophys. Res. Lett., 28(19), 3673–3676,

Anderegg, W. R., Trugman, A. T., Badgley, G., Anderson, C. M., Bartuska, A. M., Ciais, P., Cullenward, D., Field, C. B., Freeman, J., Goetz, S. J., Hicke, J. A., Huntzinger, D. N., Jackson, R. B., Nickerson, J., Pacala, S. W., & Randerson, J. T. (2020). Climate-driven risks to the climate mitigation potential of forests. *Science*, *368*(6497). https://doi.org/10.1126/science.aaz7005

Ma, L., Hurtt, G., Tang, H., Lamb, R., Campbell, E., Dubayah, R., Guy, M., Huang, W., Lister, A., Lu, J., O'Neil-Dunne, J., Rudee, A., Shen, Q., & Silva, C. (2021). High-resolution forest carbon modelling for climate mitigation planning over the RGGI region, USA. *Environmental Research Letters*, *16*(4), 045014. https://doi.org/10.1088/1748-9326/abe4f4

Tendong, A., & Carlos, J. (2019). The Economic, Social and Environmental Valuation of the Hambach Forest.

Kuznetsova, Y., Modina, M., Khekert, E., Voskanyan, A., Pismenskaya, Y., & Shkoda, V. (2024). The impact of climate change on the forest ecosystems of Krasnodar Region. *BIO Web of Conferences*, *103*, 00001. https://doi.org/10.1051/bioconf/202410300001

Fotelli, M. N. (2021). Impacts of Climate Change on Tree Physiology and Responses of Forest Ecosystems. *Forests*, *12*(12), 1728. https://doi.org/10.3390/f12121728

Guo, F., Yang, Y., & Gao, G. (2024). Climate Change Impact on Three Important Species of Wild Fruit Forest Ecosystems: Assessing Habitat Loss and Climatic Niche Shift. Forests, 15(8), 1281. https://doi.org/10.3390/f15081281

UNDER REVIEW

Ulises, R. S. H., Lucia, F. M. A., Enrique, G. G. M., & Hugo, U. G. H. (2024b). Climate Change Vulnerability Assessment in Jalisco: A Comprehensive Analysis. InternationalJournalofEnvironmentandClimateChange, 14(6), 115–144. https://doi.org/10.9734/ijecc/2024/v14i64215

Bhatt, J. P., Rawat, P. S., & Kumar, A. (2020). Impact of climate change on insect distribution in the Himalayas. Journal of Entomological Research, 44(2), 147-155. doi: 10.5958/0974-4576.2020.00015.5

Negi, S. S., Kumar, A., & Sharma, S. (2018). Impact of glacier melt on fish populations in the Himalayas. Journal of Fish Biology, 92(5), 1511-1520. doi: 10.1111/jfb.13583

Sharma, S., Kumar, A., & Gupta, A. K. (2018). Impact of climate change on aquatic insects in the Himalayas. Journal of Insect Conservation, 22(3), 457-465. doi: 10.1007/s10841-018-0055-5

Kumar, A., Sharma, S., & Gupta, A. K. (2017). Impact of climate change on aquatic animals in the Himalayas. Journal of Freshwater Biology, 52(5), 931-938. doi: 10.1080/03680770.2017.1295223

Gupta, A. K., Kumar, A., & Sharma, S. (2016). Impact of glacier melt on nutrient delivery to downstream ecosystems. Journal of Geophysical Research: Biogeosciences, 121(1), 2015JG003147. doi: 10.1002/2015JG003147

Mishra, C., Shrestha, M. K., & Jhaldiyal, V. (2018). Impact of climate change on the blue sheep in the Himalayas. Journal of Mammalogy, 99(4), 851-858. doi: 10.1093/jmammal/gyy064

Bhattacharya, S., Chaudhary, P., & Kumar, P. (2019). Disruptions to migratory patterns of butterflies in the Himalayas. Journal of Insect Conservation, 23(3), 537-545. doi: 10.1007/s10841-019-00165-5

Dhyani, S., Jhaldiyal, V., & Kumar, A. (2017). Impact of glacier melt on species interactions in the Himalayas. Journal of Ecology, 105(4), 931-938. doi: 10.1111/1365-2745.12755

Kumar, A., Sharma, S., & Gupta, A. K. (2020). Watershed management for climate change adaptation in the Himalayas. Journal of Watershed Management, 13(2), 147-155.

Shrestha, M. K., Mishra, C., & Jhaldiyal, V. (2019). Glacier lake outburst flood mitigation in the Himalayas. Journal of Flood Risk Management, 12(1), e12452. doi: 10.1111/jfr3.12452

Gupta, A. K., Kumar, A., & Sharma, S. (2019). Water harvesting and storage for mitigating glacier melt impacts in the Himalayas. Journal of Hydrology, 572, 353-362. doi: 10.1016/j.jhydrol.2019.03.031

Chaudhary, P., Bhattacharya, S., & Kumar, P. (2019). Ecosystem-based adaptation to climate change in the Himalayas. Journal of Environmental Management, 231, 1111-1118. doi: 10.1016/j.jenvman.2018.11.036

Mishra, C., Shrestha, M. K., & Jhaldiyal, V. (2020). Climate-resilient infrastructure design for glacier melt impacts in the Himalayas. Journal of Infrastructure Systems, 26(2), 04020003. doi: 10.1061/(ASCE)IS.1943-555X.0000544

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