Article

Increased Human Interventions under Climate Change is Intensifying Extreme Events in Uttarakhand Himalaya

Surajit Banerjee, Research Scholar, Department of Geography and Resource Management, Mizoram University, Aizawl – 796004, Bharat

Introduction

The Uttarakhand Himalaya, lying in the central part of the Himalayas, is one of the most ecologically sensitive regions, experiencing rapid warming. The situation is worsening by increased anthropogenic interventions and the unsustainable race of profit maximization through development. Consequently, the region is witnessing an increase in the frequency of extreme weather events such as cloudbursts, flash floods, Glacial Lake Outburst Floods (GLOF), and intensifying frequent landslides. Despite their different origins, these two issues are interconnected and have compounded effects on the geomorphology, structural stability, ecosystems, human lives, and livelihoods of local communities. This convergence makes the region even more fragile to the adverse impacts of climate change.

Uttarakhand is witnessing a rapid increase in the frequency and magnitude of flash floods like the Kedarnath disaster (2013), glacial lake outburst floods like Chamoli (2021), the Rishi Ganga cloudburst (2024), and numerous landslides. The most recent addition is the Dharali flash flood on 5th August 2025, claiming 145 lives and the livelihoods of thousands. Primarily these incidents were considered as the result of cloudbursts and warming-induced failure of moraine dams of glacial lakes. The intensity of warming is as high as an increase of 2°C in mean temperature in a few places of highlands within the last 40 years (Kumar et al., 2024). Glacial retreat is especially severe in human-impacted regions such as Gangotri (34 meters per year) and Pindar (16 meters per year) (Kumar & Khanduri, 2024). These changes are disrupting regional hydrology and significantly increasing the risk of Glacial Lake Outburst Floods (GLOFs). Additionally, the intensifying monsoon, with increased precipitation during summer, contributes more to ablation than snow accumulation, thus accelerating glacier melt. Altered rainfall patterns and early peak flows in rivers are shifting the flood season earlier and making it more unpredictable. In this situation monitoring extreme events are important and understanding their anthropogenic link become necessary. Therefore, this article try assess the link between this two.

Study Area

The Uttarakhand Himalaya lies between 28°43' N and 31°27' N and 77°34' E and 81°02' E, covering a 53,485 sq. km. area, of which 86% is mountainous (Sati, 2020). The mighty Greater Himalaya stands in the northern part of the study area, followed by the Lesser and Siwalik Himalayas in the southward area. The highest summits, including Nanda Devi (7816 meters), Kamet (7756 meters), Trishul (7120 meters), Dunagiri (7066 meters), etc., are covered by a dense layer of ice. Major glaciers like Gangotri, Yamunotri, Pindari, Milam, and Bandar Punch glaciers produce important rivers like the Ganga, Yamuna, Koshi, Ramganga, Alaknanda, Pindar, Gomti, and Tons, respectively, in this part of the Central Himalayas (Fig. 1). The diverse physiography ranges from bright snow-clad peaks to precipitous mountains, picturesque valleys, small hills, doons, river valleys, and plain lands. There are four different climatic zones as per Kappen's climate classification: tundra, humid continental with a severe winter, tropical upland with a short warm summer, and subtropical monsoon from north to south, respectively. The mean annual precipitation ranges from 97 to 177 cm (Banerjee et al., 2024). The maximum temperature of the area varies from 0°C in the north to 30°C in the south in May and from -4°C in the north to 24°C in the south in January, while the minimum temperature of the area lies between 0°C in the north and 24°C in the south in May and -8°C in the north and 8°C in the south in January. However, nowadays, a warming trend and high variation in temperature are taking place, triggering a significant amount of snow melting at higher altitudes.

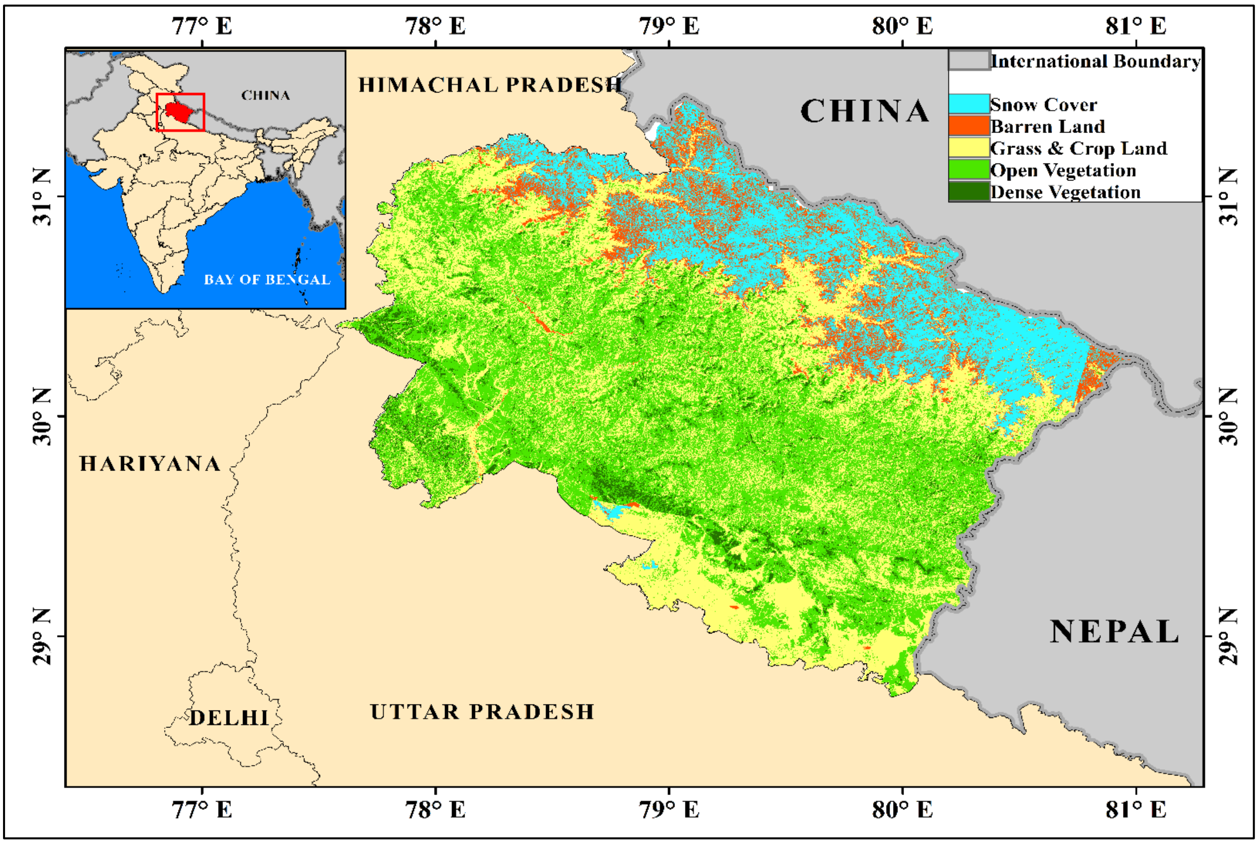

Fig. 1. Location of the study area.

Methodology

Climatic data were collected from the terra-climate monthly weather data, and landslide data were extracted from NAS global landslide inventories. Landslide data was extracted from landslide archives of NASA, and data on highways were extracted from Open Street maps. Temperature and precipitation trend was calculated in Google Earth Engine platform by comparing 1980 and 2024 values. Landslide hotspot and susceptibility layer were downloaded from Geological Survey of India.

Result

The analysis reveals that temperature changes in Uttarakhand display a marked altitudinal variation. In higher elevations, warming is more rapid compared to the lower elevations (Fig. 2a). Particularly, the cryosphere has experienced the highest mean temperature increase (1.5°C) between 1980 and 2020. Overall, the entire state has experienced an average warming, yet the rate of temperature rise is much slower in the lowlands. Specifically, in high-altitude zones, the rising temperatures coupled with reduced snowfall are accelerating glacier melt, thereby altering the seasonal flow regimes of Himalayan rivers. Precipitation trends further accentuate this vulnerability. In higher altitudes, total annual rainfall deficit is negligible to moderate (up to 50 mm in 40 years); however, middle altitudes and lowlands experience a massive decrease in total annual precipitation (up to 400 mm between 1980 and 2020). Rainfall has been stagnant in river valleys in the middle altitudes and central parts of the state, particularly within river valleys (Fig. 2b). However, despite the rain deficit, in most of the areas, extreme rain within a short period of time is being observed, accelerating the irregularity of rain. Consequently, after a dry spell, when massive cloudburst rain occurs, the already fragile geomorphology of the region triggers slope instability. The shift from snowfall to rainfall at higher elevations and rain deficit in lower areas amplify soil saturation and reduce snowpack accumulation, thereby exacerbating both flood hazards and long-term water insecurity in the dry season.

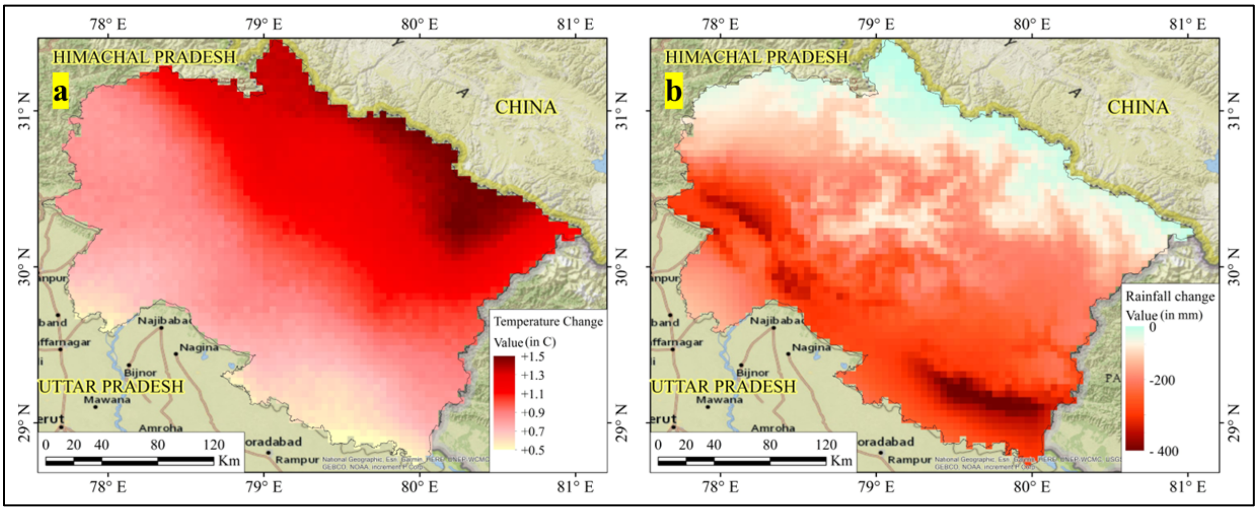

Fig.2. (a) Change in mean temperature between 1980 to 2020, (b) Change in total annual precipitation between 1980 and 2020.

Landslide susceptibility mapping highlights river valleys are experiencing the highest number of slope failures. Ironically, at the cost of environmental stability, infrastructure projects like the Char Dham highway have been constructed in such landslide-prone areas, accelerating the intensity and frequency of the hazard (Fig. 3). Despite high landslide susceptibility, during construction, many places recorded slope cutting at more than an 80° angle, exceeding geological safety concerns. Consequently, the interaction of climatic drivers with anthropogenic pressures has amplified the frequency and severity of landslide events. The combined outcome is an increasingly fragile mountain system where climate-induced changes and human interventions reinforce each other, raising serious concerns for sustainable development and disaster resilience in Uttarakhand.

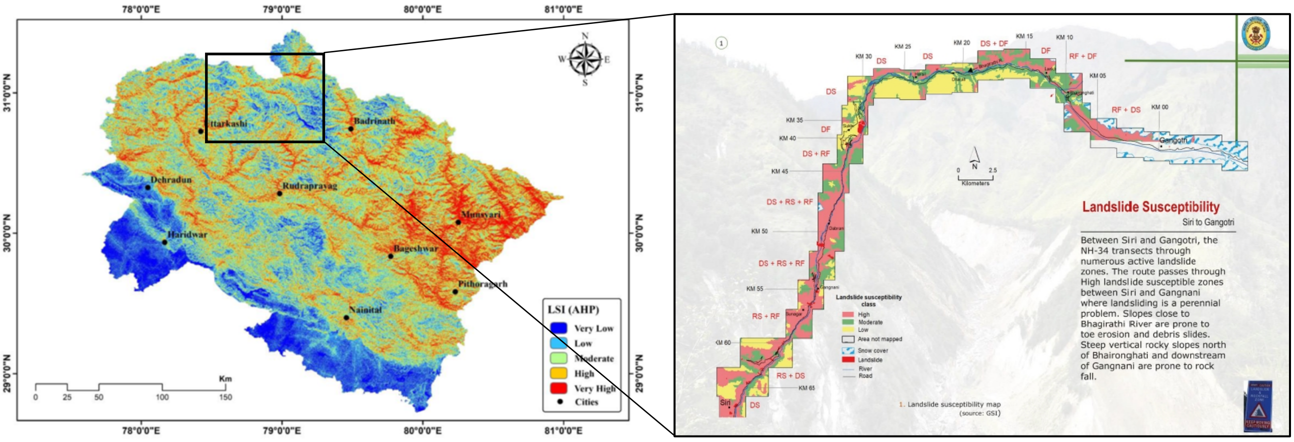

Fig. 3. (a) Landslide susceptibility map of Uttarakhand, (b) Landslide susceptibility in Char Dham highway route from Siri to Gangotri. (Source: Geological Survey of India).

Discussion and Conclusions

The findings reveal a complex interplay of climate change and human interventions in the Uttarakhand Himalaya. Rising temperatures at higher altitudes, declining snowfall, and glacier retreat are reshaping hydrological systems, while rain deficit yet occurrence of extreme events at middle altitudes heightens landslide risks. These climatic shifts, compounded by unregulated development transforming natural hazards into recurrent disasters. The convergence of warming and anthropogenic stress underscores the urgent need for integrated, scientific policies, environment friendly, and sustainable policy formation.

References

Banerjee, S., Sati, V. P., Almazroui, M., & Chakraborty, S. (2024). Spatio-Temporal assessment of areal fragmentation and volume of snow cover in the central himalaya. *Earth Systems and Environment*, *8*(4), 1639-1656.

Kumar, P., Patel, A., Rai, J., & Kumar, P. (2024). Environmental challenges and concurrent trend of weather extremes over Uttarakhand Himalaya. *Theoretical and Applied Climatology*, *155*(2), 1217-1246.

Kumar, S., & Khanduri, V. P. (2024). Impact of climate change on the Himalayan alpine tree line vegetation. *Heliyon*, *10*(23).

Sati, V. P. (2020). *Himalaya on the threshold of change*. Springer, Springer Nature, Switzerland.