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Natural disasters are a symptom of climate change: A case study of Kedarnath in Uttarakhand

Sramana Banerjee[1], Shashi Singh[2, *]
Apeejay School of Architecture and Planning, Greater Noida,Uttar Pradesh, India
* *corresponding author at*: Email id - sramanabanerjee14@gmail.com

Abstract
Unsustainable development practises lead to climate change, which in turn causes unexpected natural disasters. The Himalayas are particularly vulnerable to the effects of climate change. Anthropogenic activities, such as population increase and widespread deforestation, have contributed to dramatic shifts in climate in recent decades. Glaciers and snow have melted over the Himalayan states as temperatures have climbed. The frequency and severity of floods in the area have been exacerbated by the region's fragile topography and the constant fluctuation of meteorological conditions. This research seeks to get better understanding of such catastrophes by examining the 2015 landslide and cloud burst in Kedarnath, Uttarakhand, which led to a flash flood in the Mandakini river. Damage was extensive, with thousands of lives lost along with animals. Natural catastrophes have altered the landscape in ways that go well beyond the monetary and human costs. According to research, global warming altered regional weather patterns and eroded the Chokarbari glacier, all of which contributed to the June 2013 Kedarnath calamity. This study examines the tragedy's origins, its immediate effects, and the disaster management strategies necessary to stop such disasters from happening again and repair Kedarnath's reputation as a tourist attraction.

Keywords: Catastrophes;Kedarnath;Climate change;Global warming;flood;Cloud burst

Methodology

The work has been broken into many sections for study purposes. The study's methodology is as follows:

- A thorough research of the literature was conducted to gather data and gain a thorough knowledge of the type of past studies done on related subjects to comprehend the fragile nature of the Himalaya which is the world's youngest mountain range.
- The study will be based on literature review and analysis of published research papers and articles.

Introduction

Climate change anxiety has gone worldwide. Climate change will cause long-lasting alterations to our weather patterns. Due to population growth and urbanisation, humans cut down vast swaths of flora in order to make way for roads, parking lots, and skyscrapers. Noise, air, water, and soil pollution, as well as sanitation and transportation challenges, are only some of the environmental problems that result. The percentage of land covered by trees fell from 84.9% in 1970 to 75.4% in 2000. Changes in the mean rainfall pattern, their variability, the intensity, and the frequency of severe rainfall events are all on the rise as a direct result of climate change. Devastating floods and landslides hit the Indian state of Uttarakhand on June 16-17, 2013, due to a cloudburst in the region. Building dams, tunnels, and highways often necessitates blasting hills, which has a negative impact on the surrounding ecosystem, according to environmentalists. The resulting loss of forest cover reduces the capacity of plants to store water. Uttarakhand sits on the Himalayan foothills' southern slope. Glaciers and towering Himalayan

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peaks dominate the northern half of the state. The abundance of Hindu temples and the resulting influx of Hindu visitors have earned the state the nickname Dev Bhoomi. Garhwal and Kumaon are the two main cultural and linguistic groups of Uttarakhand. The Garhwal area is home to the majority of India's most revered holy sites. Himachal Pradesh and Uttarakhand, both in the Himalayas' highest reaches, are mostly made up of forested and mountainous terrain. During the scorching summer months on the Indian subcontinent, these locations are not only major pilgrimage centres but also popular tourist destinations. The holy city of Kedarnath is the furthest away from civilization of the four chota Char dhams. According to environmentalists, the state's massive destruction may be traced back to careless building in a fragile ecosystem. The disaster rocked Kedarnath on June 16th, 2013. The whole state was impacted by the severe rain and subsequent flooding. Bageshwar, Chamoli, Pithoragarh, Rudraprayag, and Uttarkashi were the hardest struck out of the State's thirteen districts, however all of them were damaged. More than 340 millimetres (mm) of rain fell in the Indian state of Uttarakhand on June 17th, 2013. This is more than three times the average daily monsoon rainfall of 65.9 mm. This resulted in historic flooding and destruction in Uttarakhand. Uttarakhand saw severe rainfall from June 14th to June 17th, 2013, which, when coupled with the melting snow (due to high temperature during summer season), exacerbated flooding in the region (Kedarnath and adjoining areas). The Mandakini valley in the Rudraprayag district took the brunt of the natural calamity. The Kedarnath Shrine and the surrounding communities of Rambara, Agastyamuni, Tilwara, and Guptkashi were flooded by torrential rainfall and the possible collapse of the Chorabari Lake. Due to debris from flash floods, landslides, and damaged highways, over a hundred thousand people were stranded in different parts of the state.

Fig1 Location map showing districts of Uttarakhand

The Himalayan region experiences climatic change as a result of global warming.

Climate change may get the most attention, but it's not the only thing threatening the Himalayas. The Himalayas' precipitation and the melting reaction of glaciers and snow cover are significantly impacted by global warming. As global temperatures rise, the melting glaciers in the Himalayas will cause recurring, catastrophic floods. Arun Shrestha, one of the primary authors of the paper, claims that the high mountains will heat up far more. He then says Even if the world manages to keep global warming below 1.5 degrees Celsius (2.7 degrees Fahrenheit) by the turn of the century, which would be nothing short of a miracle. The ICIMOD climate scientist contributes a chapter to the report. The effects of climate change on these mountains are expected to worsen during the next several decades. Many aspects of river flows, groundwater recharge, natural hazards, biodiversity, ecosystem composition, structure, and function, and people's ability to make a living are all at risk (Nijssen et al. 2001; Parmesan 2006; Bates et al. 2008; Ma et al. 2009). “Average Asian land temperatures are expected to rise by 3°C by the 2050s and 5°C by the 2080s, according to the IPCC, with the Tibetan Plateau seeing a far bigger increase (Rupa et al.2006; IPCC 2007a). The Greater Himalayan people and ecosystems may be severely

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impacted by the current focus on temperature increases of 2-3 °C in concerns of catastrophic climate change (Anderson & Bowe 2008; Hansen et al. 2008; Solomon et al. 2009). By the year 2080, the IPCC projects that annual precipitation on the Tibetan Plateau would have increased by ten to thirty percent. However, this effect might be mitigated by increasing evapotranspiration rates (IPCC 2007a). The negative impacts of climate change are exacerbated by several additional environmental and social factors, many of which are well-known to be severe. According to a number of studies, the Himalayas have warmed by more than double the world average of 0.74 °C in the last century. The present proportion of yearly precipitation is higher than historical norms in some locations. Shorter winters and early snowmelt have implications for river regimes and natural hazards. Climate change, which has increased the frequency and intensity of severe weather events, is likely the most important driver. Increased global warming is generally acknowledged as a source of extreme fluctuations, especially when combined with stronger monsoon circulations. Deforestation and shifts in weather patterns are two of the many consequences of human population growth in recent times. The ordinary lives of people have been impacted by both climate change and large environmental disasters.

Rainfall data of Uttarakhand State

The study Observed Rainfall Variability and Changes Over Uttarakhand State by IMD Pune presents the findings of an analysis based on 30 years' worth of data (1989-2018) on the state's average spatial rainfall pattern, average spatial pattern of different rainfall events, trends, variability, and extreme rainfall events during the monsoon months and annually. In order to determine the seasonal distribution of rainfall (March-May), the whole year was divided into three parts: the monsoon (June-September), the post-monsoon (October-February), and the pre-monsoon (March-May).

2.The following table displays the average monthly, seasonal, and yearly rainfall (in millimetres) and coefficient of variation (in percent) for the state of California between the years 1989 and 2018. This shows that the monsoon season accounts for around 82% of the yearly rainfall, followed by 10% during the post-monsoon season and 8% during the pre-monsoon season.

	June	July	August	September	JJAS	Annual
Mean	162.1	382.0	360.2	189.7	1093.8	1385.5
C V	57.5	23.6	28.5	56.3	21.2	18.5

Table 1 Mean rainfall (mm) and coefficient of variation of the states for the monsoon months South West monsoon seasonal & annual.

Source: Climate research and services India meteorological department ministry of earth sciences Pune

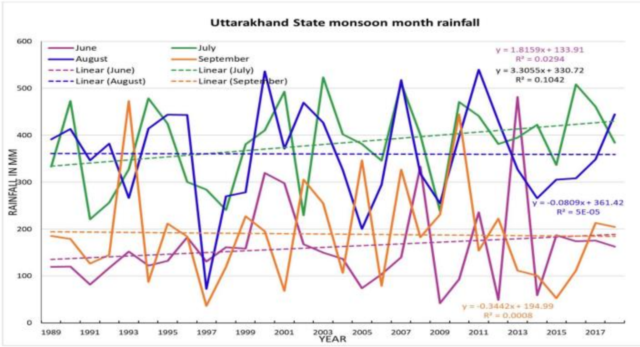

Table2:Time Series of rainfall in mm in the month of June, July, August & September & trends

Source: Climate research and services India meteorological department ministry of earth sciences Pune

It shows that increasingly large rainfall since June the late 1980 contributed the chances of a greater number of floods in this region.

Natural disasters and disasters without prior warning:

A natural disaster is when a dangerous threat materialises and endangers humanity. Natural processes are the cause of natural risks.

Natural catastrophes and risks are divided into several categories:

a. Atmospheric dangers (lightening, severe thunderstorm, droughts, tornadoes, tropical cyclone etc.)

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b. geological dangers (Volcanic eruptions, Tsunami, earthquake, landslides, subsidence, floods, impacts with space objects)
c. Additional natural hazard (wildfire, disease epidemics, insect infestations)
d. Catastrophic risk, (less frequent but have devastating consequences)
widespread plagues of disease, massive volcano explosions, etc.)
e. Rapid-onset hazards, such as volcanic eruptions, landslides, violent thunderstorms, wildfires, and lightning, which typically come on suddenly.
f. Drought, insect infestations, and disease epidemics are examples of slow-onset hazards that take years to emerge.

A proper division of labour and careful coordination between many actors at the regional, national, and local levels are essential for an efficient early warning system. There must be a single organisation designated to issue official warnings for each risk. Standard operating procedures (SOPs) that outline the key duties and obligations in an emergency situation should be in place. These SOPs should also be regularly tested and amended.

Over many years, early warning systems have been created in a number of Asia-Pacific nations. Cross-border risks and disasters are common throughout Asia and the Pacific. The nations of the Asia-Pacific have established regional cooperative mechanisms. However, there are holes in regional early warning systems for risks like landslides, flash floods, and glacial lake outburst floods.

For local mitigation and preparedness, downscaled projections are necessary. The warning system and the populations at danger should be properly connected, and it is necessary to update data on population changes, land use patterns, and other such changes on a regular basis.Maintaining appropriate signage and evacuation centres is necessary.

It is necessary to keep local populations and government authorities aware of risks.

Under order for an early warning system to be effective, it must be able to alert all those who are vulnerable to danger as soon as danger approaches in the following scenarios:

a) Rapid-onset disaster (such as a flash flood or a tsunami in a nearby area) only gives 15 to 2 hours from detection to impact.
b) Aditional risks (cyclone, seasonal flood) that can be identified days or weeks in advance, allowing people to evacuate or preserve their property and way of life. The warning agencies must disseminate information on time and accurately.

Snow and glaciers in the Himalayan region are melting as a result of rising temperatures:

Global warming's effects on glaciers must be examined since they cover a sizable amount of the planet's surface and provide a significant portion of the world's population with water. The Himalayan Glaciers regulate local climatic conditions as well as provide water to over 40% of the world's population. Snowfall and melting cause glacier formation on a periodic basis, depending on the season. A glacier's accumulation area is where the most snow falls, adding to the glacier's mass. The gradual freezing of snow creates snowfall, which in turn adds to the glacier's weight and sets in motion the glacier. The term ablation region is used to describe the lower parts of the glacier where melting and evaporation have occurred at a high rate.

Himalayan glaciers are the source of water for seven major Asian rivers: the Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze, and Huang He. Indian Himalayan glaciers are divided into three categories based on their proximity to the Ganga, Indus, and Brahmaputra river basins.

According to estimates, the Himalayas have a permanent ice cover covering around 17 percent of the mountain range. The region's most significant glaciers are Gangotri, Kedarnath, and Chita Shigri.

As a result of the upward rise in the snowline brought on by global warming, glaciers now receive more liquid precipitation than solid precipitation, changing their mass balance.

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Glaciers rapidly recede as a result of rising temperatures and more liquid precipitation, which may cause floods downstream.

Large glacial lakes are created as a result of glacier retreat, which further creates outburst floods. A hazardous flood is known as GLOF (Glacial Lake Outburst Flood).

Unsustainable development activity result in climate change causing disaster

Unsustainable expansion deprives future generations of opportunities. Construction of unsustainable projects sometimes occurs without enough forethought, which may result in the wasteful use of natural and synthetic materials. Unsustainable growth is the root cause of climate change. Global warming, ozone depletion, desertification, soil erosion, loss of forests, contamination of water sources, and extinction of plant and animal species are all indicators that human demand is exceeding environmental support capability. The planet's carrying capacity is being severely stressed by human activities like increasing population density, urbanisation, industrialisation, and other development projects, with dire results including a precipitous increase in the rate of deforestation. Natural disasters including earthquakes, floods, droughts, and landslides are more likely to occur as a result. Droughts, floods, and wind storms, all examples of severe weather, have become more often and more intense, while average temperatures have altered dramatically. The frequency of natural catastrophes has been linked to human activities, according to available evidence. Naturalism might be a response to the possibility that humans are the ultimate or primary cause of disasters. Natural calamities are exacerbated by unsustainable economic expansion.

Flood Fragile Landscape of Himalayan region

When it comes to folded mountain ranges, the Himalayas are among the youngest on Earth. That landscape is extremely delicate. As the tertiary age, in which it was formed, continues to rise and push northward and as its river valleys continue to deepen, the landscape becomes more unstable. Among the world's most dynamic and complex mountain ranges, the Himalaya is also home to a wide variety of animal and plant life. It's not just the wettest spot on the planet, but also a key biodiversity hotspot. The ecological fragility of the Himalayas is well-known, as is the region's geological unpredictability, tectonic and seismic activity, remoteness, lack of economic development, and widespread poverty. Every year, torrential downpours (also known as cloudbursts) cause massive damage and loss of life due to extreme meteorological conditions. The whole Himalayan region has been pummelling by massive rainfall on many occasions, leading to widespread devastation. According to the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment report, the frequency and severity of floods in the Himalayan region are predicted to rise as a result of increased monsoon precipitation and glacier retreat owing to global warming. Climates range from perpetually frozen summits to balmy lowlands in the Himalayas. The strong and intense monsoon rain causes slope collapse, mass movement, landslides, flash floods, and debris flows. Every time the monsoons come, the death toll and damage estimates grow substantially. Cloudbursts have caused flash floods in the Himalayan areas of Uttarakhand, Himachal Pradesh, and the Leh region of Jammu and Kashmir state in recent and current decades. Threats from the earthquakes ranged from the obvious to the hypothetical. When these disturbances cause massive amounts of water or rock to collapse on human communities and their resources, the nature of the risks increases. Cattle grazing and extensive deforestation would cause the normal flow of water to be disrupted and lead to the extinction of almost a quarter of the world's endemic species. The current rate of deforestation in the Indian Himalayan Forest might result in a loss of one-third of its cover by 2100. Because of this, the geography of the Himalayas is rapidly evolving. Human activities and global warming have profoundly altered the Himalayan terrain, causing ecological degradation and environmental instability.

Case study - Kedarnath, Uttarakhand:

The flash floods in Uttarakhand in 2013 were a huge natural catastrophe. Uttarakhand was hit by one of

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the biggest natural catastrophes in recent memory, with extensive damage and devastation and several deaths. Natural disasters are on the rise due to climate change, and this should serve as a wake-up call.

Location and geographical settings-

Kedarnath is located on the Central Himalaya's westernmost peak at 30°44′6.7″N, 79°04′1″E. It is in the Mandakini River valley, whose catchment area encompasses 67 square kilometres (up to Rambara) and is 23 percent glacierized. The U-shaped valley where the catchment area is located is between an elevation of 2,740 and 6,578 metres above sea level; the valley was formed by glaciers. Hanuman top (5,970 m), Kedarnath (6,940 m), Mahalaya peak (5,970 m), and Bhart Khunta (6,578) are some of the most well-known peaks in the area (5320 m).

The Chorabari Glacier, located at an altitude of 3,895 metres, is the source of the Mandakini River, which flows from Kedarnath's Companion Glacier to meet the Saraswati River near Rambara and Gaurikund. Both the Madhu Ganga and the Dudh Ganga join the Mandakini River close to Kedarnath. Vasuki Lake (4040 m asl) is the source of the Son Ganga, which flows into the Mandakini River at Sonprayag (1709 m asl) before joining the Alaknanda River at Rudraprayag.

Kedarnath is located on the plain formed by the meltwater of the Chorabari and Companion glaciers. Kedarnath is a small village located at the confluence of the Mandakini and Saraswati rivers, where the outwash aircraft makes a pit break. Each year, these streams lose ground due to bank erosion. As pilgrimage to the temple has increased, the Saraswati River has been diverted to flow now behind Kedarnath. The dwellings in Rambara and Gaurikund, located downriver, are under danger of landslides because the river is cutting through historic colluvial or fluvial deposits.

Disasters in Uttarakhand –

The following tables show the disasters which occurred in past in Uttarakhand due to floods, landslide, and cloudburst:

Table 1: Disasters in UK till 2009 (Flood and Landslide)

Year	Disaster	Impact
1978	Bhagirathi flash floods	Devastating impact on the region
1980	Gyansu Nala landslide	Claimed 24 lives and destroyed several houses
1991	Uttarkashi Earthquake	Caused the loss of 653 human lives, injuries to about 6000 people and the death of 1300 head of livestock in addition to damage to buildings, other structures and the infrastructure
1998	Malpa landslide	Devastating impact on the region
2001	Phata landslide	Devastating impact on the region
24 Sept. 2003	Landslide triggered by a cloud burst in Varunawat Hills, Uttarkashi	Engulfed three 4-story hotels and damaged several buildings, roads and other infrastructure. The estimated damages were to the tune of about 50 million dollars
8 August, 2009	Landslide disaster on Kuity village on Berinag– Munsiyari Road, Pithoragarh District	Wiped out two villages namely Jhakhla and Lah, claiming 43 lives.

Source: Demystifying a Himalayan tragedy: study of 2013 Uttarakhand disaster. *Journal of Indian Research*

Table 2: Disasters in UK till 2009 (Cloud burst and flood)

Year	Disaster	Impact
August 3rd & 4th	Cloudbursts occurred in Bhatwari and Dunda in Uttarkashi districts	The flood disaster caused bridges to collapse; homes, shops, village paths, electricity and water facilities were damaged, landline and mobile connectivity was also completely down and hundreds of hectares of agriculture land got destroyed. The 60 Kilometers of National highway from Uttarkashi to Gangotri was completely blocked. The bridge connecting Uttarkashi town and Bhatwari block at Gangotri village collapsed and almost 80 villages got totally cut-off. 1700 families were affected from Gangori to Uttarkashi. Around a population of 80000 is affected by this disaster. Government assessed a loss of Rs. 600 crores in the area where they have been able to receive damage information.
Sep 13th	Flood in Kedarnath	The upslope end of the Kedarnath temple was buried in debris. Many of the surrounding buildings had been entirely destroyed.
Sep 13th	Cloud bursts in Rudraprayag	A series of cloud bursts washed the road network (at each 50 m roughly) upto Kund (a small station at National Highway), and after that up to Okhimath.
Sep 16th	Cloud burst in Rudraprayag	Cloud burst lead to death of 73people

Source: Demystifying a Himalayan tragedy: study of 2013 Uttarakhand disaster. Journal of Indian Research

Catastrophic disasters in Kedarnath:

Fig2 Kedarnath before flood Kedarnath after flood

Source: India Disaster Report 2013

On June 16, 2013, around 5:15 p.m., the region around the Saraswati River and the Dudh Ganga watershed were flooded, leading to an overabundance of water in all the channels. After this, erosion became quite active in all the other gulleys, leading to an excessive accumulation of

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water and silt in the main rivers. As a consequence, a great deal of water pounded the city, bringing a great deal of trash with it. We have never seen anything like the destruction that occurred when the massive torrent rushed towards Kedarnath town and washed away the upper part of the city (including the Sankaracharya Samadhi, Jalnigam Guest House, Bharat Seva Sangh Ashram, etc.). Our local weather sensors recorded 325 millimetres of rain falling on the foot of the Chorabari glacier on June 15 and 16". The town of Rambara was wiped out by rain on the evening of June 16th. The sudden downpours caused flash floods that washed away mountains, towns, people, animals, homes, vehicles, highways, and more. There was no way for anything to survive. Another flash flood hit the village of Kedarnath and caused major damage downstream on June 17, 2013, around 6:45 a.m., when the moraine blocking Chorabari Lake overflowed and collapsed (Figure 5a and b) (Gaurikund, Sonprayag, Phata, etc.). The settlement of Kedarnath wasn't the only one the floods destroyed. Everything was destroyed save the temple. Nearly 200 villages were swept away as it rushed downhill towards flat land, leaving the occupants with little to no time to escape. Up to 2,375 communities lost contact with the outside world. The study proves that the collapse of Chorabari Lake was caused by the torrential rains that fell in the area between June 15 and June 17, 2013. On June 4th, 2013, researchers found nearly seven feet of snow covering the top part of the lake. The heavy precipitation soon melted the glacier's right lateral basin, which subsequently flooded the Gandhi Sarovar Lake. The water in the lake was discharged via small channels at the lake's base, but there were no other places for the water to go. Within three days, the lake behind the moraine dam filled with millions of gallons of water, increasing the potential energy of the water and decreasing the shear strength of the dam. Eventually, the loose-moraine dam broke, unleashing catastrophic monsoon flooding over the Kedarnath valley.

Conclusion

The flooding in Uttarakhand was caused by people's insatiable desire for material goods and their habit of taking the natural world for granted. Reasons for the greatest natural catastrophe in the nation include environmental deterioration inflicted on the hills and strain on environmentally vulnerable slopes. Uttarakhand is particularly at risk during the monsoon season due to its geographical location, which makes the region susceptible to natural disasters such as heavy downpours, cyclones, earthquakes, and flooding. In 2013, the state was devastated by the early beginning of monsoon, which brought with it cloudbursts and landslides. In India, environmentally vulnerable regions are developing without being protected by any of the country's environmental legislation. More land slides are observed as a consequence of increased tourism, which has a negative impact on the environment. The Uttarakhand Himalayan disaster has wreaked havoc on the whole region, destroying homes, businesses, and religious sites—especially those in river valleys. Thousands of lives were lost, and many more are still missing, after this disaster. The floods in Uttarakhand exposed the country's lack of disaster preparation. Many bureaucrats and legislators have had their blinders removed by this case study, realising the environmental damage they've been causing. Uttarakhand became a natural catastrophe hotspot in 2013 due to an act of humankind. It's time for the government and the people of the community to step up and cooperate. Good policies in the context of climate change and mountain-related characteristics may frequently be attributed to good research based on reliable, relevant, valid information. It is crucial that we finish mapping the landslide risk zones. Creating and adhering to a set of landslide-specific rules and regulations is essential. The federal and state governments should fund the installation of effective and dependable early warning systems.

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