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CAUSES, IMPACTS & MITIGATION MEASURES FOR FLASH FLOODS IN INDIAN HIMALAYAN REGION.

Pooja Yadav[1], Shishir Kumar [2]

[1]FACULTY OF ARCHITECTURE AND PLANNING LUCKNOW
e-mail- poojayadav3276@gmail.com
[2]FACULTY OF ARCHITECTURE AND PLANNING LUCKNOW

ABSTRACT

The Himalayas is the crown of India but Because of its inherent characteristics and climatic conditions, the young Indian Himalayan region is vulnerable to a variety of natural disasters. Risks include varying degrees of earthquake severity, floods or flash floods, and glacial lake eruptions. The Uttarakhand flash flood of 2013 caused by a glacial lake outburst is considered the worst disaster of the decade. Flash flood 2021 Chamoli (Uttarakhand) caused by an avalanche, Amarnath flash flood July 2022 caused by a cloud burst, Leh flash flood 2010 caused by a cloud burst are some recent examples of flash floods in the Indian Himalayan region which shows that flash floods are getting frequent in hilly regions. The best use and exploitation of land and water resources are provided through flood risk management, which is essential for a nation's economy and sustainable development. In India, measures have been developed to lessen the negative consequences of flooding in plains by emphasizing flood risk management. However, due to the difficult terrain, restricted accessibility, and low degree of monitoring, flood risk management in hilly areas is still in its early stages. The last several decadal floods have demonstrated that only building safeguards alone could not provide sufficient safety from such catastrophes. There is a need for a such framework that can efficiently manage these calamities. The research aims to analyze the various causes that trigger flash floods in hilly regions, the consequences of such events, and their level of impact. The study discusses various guidelines, policies, and strategies for risk reduction to analyze the gap & challenges that are crucial in effective flood management.

Keywords: GLOF, Flash Floods, mitigation measures, Himalayan Regions, IHR, Risk Reduction, Uttarakhand, Kedarnath,

1.INTRODUCTION

India is a rapidly urbanizing country. Natural disasters and climate change are the two complicated challenges that have a long-term impact on environmental, economic, and social well-being. India is highly vulnerable to floods. Out of the total geographical area of 329 million hectares (MHA), more than 40 MHA is flood-prone*(AYOG, 2021)(NDMA, n.d.).*According to 'WHO' Floods are the most frequent type of natural disaster and occur when an overflow of water submerges land that is usually dry. Floods can cause widespread devastation, resulting in loss of life and damages to personal property and critical public health infrastructure(Rathod Krina, R., Dixit, 2022). Certain types of disasters occur in certain parts of the country. Also, there are various types of floods, but hilly regions are more prone to flash floods due to their fragile geology and different climatic conditions. Few water-related calamities occur during the monsoon season (nearly every year) in various locations throughout this mountain. The Uttarakhand flash flood of 2013 caused by a glacial lake outburst is considered the worst disaster of the decade. Flash flood 2021 Chamoli (Uttarakhand) caused by an avalanche, Amarnath flash flood July 2022 caused by a cloud burst, Leh flash flood 2010 caused by a cloud burst are some recent examples of flash floods in the Indian Himalayan region which shows that flash floods are getting frequent in hilly regions. These events result in havoc and heavy loss. We cannot avoid disasters. So, we can only try to reduce the impact of disasters. Even though we have made significant advances in flood forecasting and early warning systems, flash floods are still a challenge because they occur due to intense short bursts of rainfall, and measuring the intensity and duration of high intense rainfall is extremely difficult*(Vishwanath & Tomaszewski, 2018)*. The paper focuses on the major causes and impacts of flash floods in the Uttarakhand region which lies in the western Himalaya of the Indian Himalayan region and the mitigation measures taken by national & state governments.

1.1 Types of flood

'WHO' categorizes floods into 3 common types - River floods, flash floods & coastal floods.

- **Flash floods-** Flash floods are caused by rapid and excessive precipitation, which quickly raises water levels, and rivers, streams, channels or roads can be overridden.
- **River floods –** Flooding is caused by constant rainfall or the melting of snow that causes a river to exceed its capacity.
- **Coastal floods –**Coastal flooding occurs as a result of storm surges associated with tropical cyclones and tsunamis.

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1.2 What are Flash floods?

Due to their combination of extreme speed and destructive power, flash floods are the most dangerous type of flood. When heavy rains exceed the soil's ability to absorb water, flash floods happen. Mountains and steep hills accelerate runoff, which raises rivers quickly. Rocks and loamy, flat soils prevent moisture from penetrating the soil. Rapid flash flooding can also result from flooded soil. They can happen minutes after the problematic rains, which reduces the window of opportunity for public protection and warning.*(The National Severe Storms Lab, 2018).*

A flash flood is a short and sudden local flood with great volume. It has a limited duration which follows within a few (usually less than six) hours of heavy or excessive rainfall, rapid snowmelt caused by sudden increases in temperature or rain on snow, or after a sudden release of water from a dam or levee failure, or the break-up of an ice jam *(World Meteorological Organization, 2012).*

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1.3 Study area

There are 13 Indian States/Union Territories that make up the 2500 km long Indian Himalayan Region, including Jammu and Kashmir, Ladakh, Uttarakhand, Himachal Pradesh, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Assam, and West Bengal. With a population of close to 50 million, this region stands out for its diverse demographics and adaptable economic, environmental, social, and political systems. (AYOG, 2022).

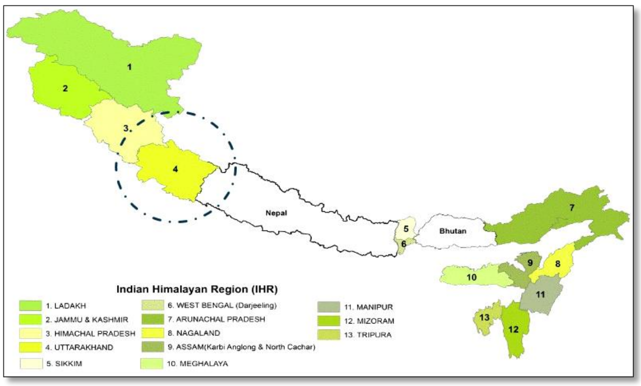

Figure 1 Indian Himalayan region (Mapsofindia.com)

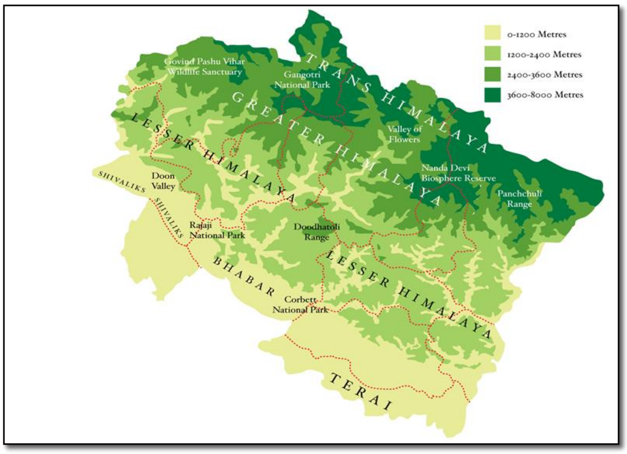

Figure 2 Morphological Classification of Himalaya (uttarakhand.org)

About 10 percent of the Himalayas are covered with glaciers and an additional area of nearly 30 to 40 percent supports the snow cover. In total, there are about 9,575 glaciers (37,500 km²) in the Indian Himalayan Region (IHR), spread across 6 states and union territories i.e., Jammu-Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh *(NDMA, 2020)*

The study area (Uttarakhand) lies between latitudes 28°44' & 31°28' north and longitudes 77°35' and 81°01' east in the southern slope of the Himalayas just after the Himachal Pradesh. Uttarakhand state is known as "Dev Bhoomi" due to its spiritual and religious profile. Additionally, renowned for the diversity of its ecology & culture. The state's geographical area is 53483 sq. km., or 1.6% of the total geographic area of the nation. Of that, 46,035 sq. km. are hilly, with steep slopes and large areas covered in snow (AYOG, 2022). There are glaciers, numerous perennial rivers, rocky mountainous terrain, and dense forests among the varied topography. The area's elevation ranges widely, from 300 to 8,000 meters.

Grounded on the elaboration of the Himalayas, Uttarakhand represents a sampling of the range, including the Trans-Himalaya, Greater Himalaya or Himadri, Lesser Himalaya, Shivalik Ranges, foothills & Terai, and the Plains of Dehradun, Haridwar, and Udham Singh Nagar*(Board, n.d.)*. The state is composed of 2 regions namely Garhwal and Kumaun. The Garhwal region consists 7 districts-Uttarkashi, Chamoli, Pauri, Rudraprayag, Tehri, Dehradun & Haridwar. Kumaun region consists remaining 6 districts - Udham Singh Nagar, Nainital, Almora, Pithoragarh, Champawat & Bageshwar.

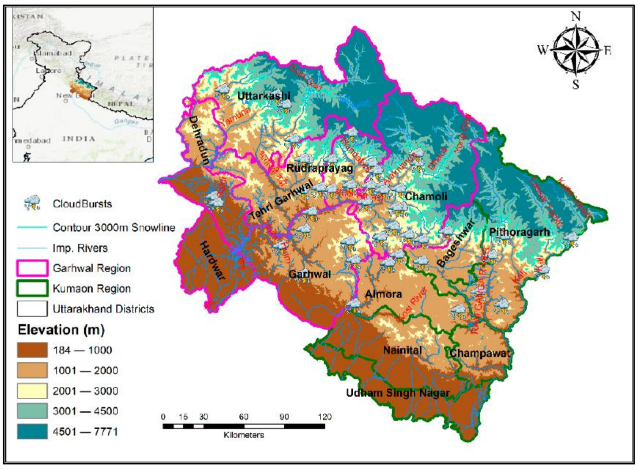

Figure 3 Map Showing Regions, Districts, and Location of Cloud Bursts (Uttarakhand) (Kansal & Singh, 2022)

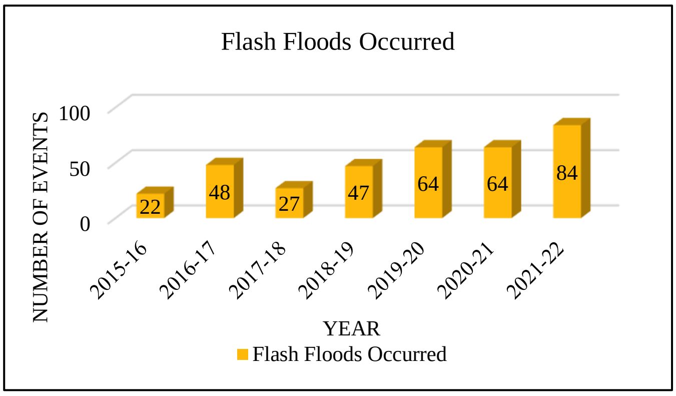

Figure 4 Number of Flash Floods Occurred During 2015-22 In Uttarakhand (USDMA)

The above data shows that flash floods are very frequent and increasing year by year in the Uttarakhand region and their impact is also increasing.

2.Methodology

Based on the 3 parameters i.e. Major causes, impacts, and measures taken for risk reduction study is divided into 4 parts. The first section discusses the region's risk profile for disasters and the various reasons why flash floods occur in hilly areas. 2nd part of the paper reviews the categorization of impacts on human beings and also on the environment. The 3rd part of the study summarizes the acts, policies, plans, programs, and strategies in the Uttarakhand Himalayan Region to reduce the risk of flash floods and in the last part, some case studies are reviewed to analyze the strategies and policies followed to risk reduction and mitigation in the Hindukush Himalayan Region.

2.1 Vulnerability profile of the region to disasters

Due to its fragile geological, tectonic activity changing topography, landscape, and ecological system,s it is one of the most disaster-prone states in India*(Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015)*. It has been facings many disasters like earthquakes, cloudbursts, landslides, avalanches, floods, etc. In recent past years.

2.1.1 Earthquake

The state falls in either Zone IV or V of the Earthquake Zonation Map of India. Pithoragarh, Bageshwar, Chamoli and Rudraprayag districts fall in Zone V {representing the damage risk > IX on MSK (Medvedev- sponheuer- Karnik) scale} while Udhamsingh Nagar, Nainital, Haridwar, and Dehradun districts fall fully in Zone IV(*SDMA Uttarakhand, 2020*). Almora, Champawat, Tehri, Uttarkashi, and Pauri, 5 districts partially fall in zone V and partially in zone IV (representing the damage risk VIII ON MSK scale)*(Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015)*. The state is highly vulnerable to earthquakes due to the use of traditional construction techniques and locally available materials. People are also unskilled and unaware of building codes, advanced techniques, new construction materials, and technology.

2.1.1 Landslide

Around 510 (290 in Rudraprayag & 220 in Chamoli district) landslide-prone zones were identified in the upper Alaknanda in 2016. These zones are created because of rapid road construction on steep slopes, excessive deforestation, and agricultural practices*(Talwar, 2022)*. Research by 'The Wadia Institute of Himalayan Geology summaries that 51% of Uttarakhand falls under 'high' & 'very high' landslide-susceptible zones (fig. 5). These zones are located in the vicinity of the higher Himalayas. Some mostly visited tourist places i.e. Uttarkashi, Badrinath & Munsyari are located within these high-risk zones (Azad, 2021).

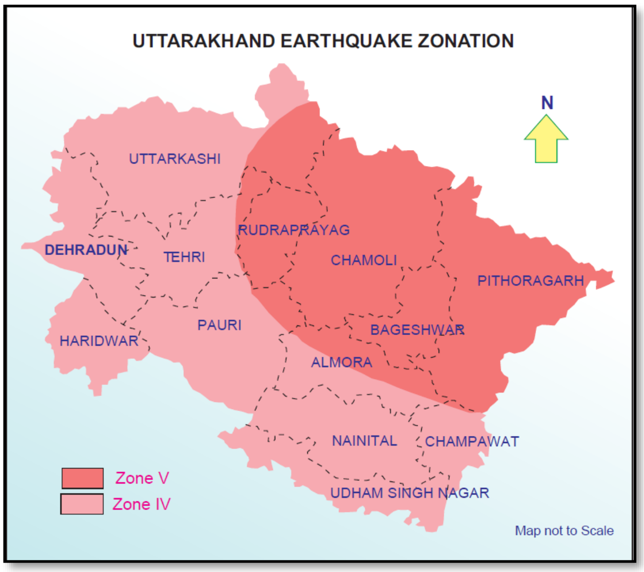

Figure 5 Uttarakhand Earthquake Zonation Map((Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015)

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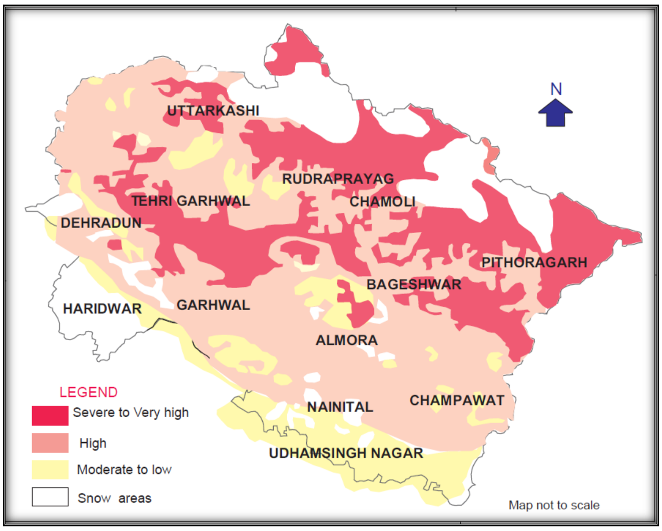

Figure 6 District Areas Vulnerable to Landslide (Uttarakhand) (Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015)

Some spectacular events of tragedies are reported as the Varnavat landslide, sher ka danda 1880 Uttarkashi District, the Malpa landslide in 1998 Pithoragarh District, and the Okhimath landslide in the Chamoli district. (SDMA, Natural Disaster landslide, 2022)

2.2 Causes of Flash Floods in Uttarakhand

Flash flooding is caused by several factors. The intensity and duration of the rain are the two important factors. Rainfall's intensity and duration are measured by the rate at which it falls. Additionally, topography, soil quality, and ground cover are significant factors. (NOAA, 2022)*(Gupta & Payra, 2022)*
The severity of flash floods has increased due to high elevations, extensive river networks, and the type of soil. Furthermore, it has been asserted that flood effects were made worse by state-wide hydroelectric power plants. This is because these projects involve clearing trees, blasting, tunnelling, and building in places where the layout hasn't been properly inspected. Currently, hydroelectric power plants are being investigated as a potential factor in the intensification of flood effects and hazards*(Vishwanath & Tomaszewski, 2018)*. It is clear from the power plant map that the majority of these plants are located in extremely risky areas. Flooding mostly results from heavy rainfall when natural watercourses are unable to transfer the additional water.
'Pandey & Vishwakarma 2019' categorizes major Causes of flash floods based on three factors – climactic factors, geological factors & anthropogenic factors.

Climatic Factor
- Cloud Burst
- GLOF- Glacial Lake Outburst Flood
- LLOFs – Land Slide Lake Outburst Flood
- The Failure of Artificial Dam
- Change in Solar Irradiance
- Change in Global Climate
- Change in Atmospheric Pressure In Local Or Regional
- Intense Rainfall
- Tidal Influences

Geological Factor
- Loose/Poor Strata
- Unfavourable Slope Angle
- Ground Cover
- Topography
- The Capacity of The Watercourse or Stream Network to Convey Runoff

Man-made Factor
- Development Activities
- Effect of Large Growing Population
- Unscientific Land Use Planning
- Deforestation
- Blasting for Construction of Roads
- Tourism
- Construction of Dams

Young, sensitive, steep gradients in the Himalayas are susceptible to climate change. These catastrophes in the mountain ecosystem are brought on by both natural and human-caused factors. Extreme rainfall brought on by the state's harsh climate and rapid flooding caused by the topography's complex vibrations is its two main natural disaster catalysts*(Kansal & Singh, 2022).*

2.2.1 Climactic factors

2.2.1.1 *Change in global climate*

As per 'The IPCC Report on climate change 2021' the Impact of climate change can be witnessed largely in every sector of the economy leading to huge social, environmental, and economic losses. Frequent and unexpected flooding is one of the worst tangible outcomes of climate change. In India, floods account for more than half of all climate-related disasters, resulting in $54.63 billion in losses between 1990 and 2017. One percent increase in floods can reduce economic growth by 2.7%(*AYOG, 2021*). The two major effects of climate change are -

- raising Sea level due to the melting of glaciers
- Variation in intensity of rainfall

Global warming causes the melting of glaciers, leading to the melting of permafrost on steep mountain slopes. This increases the likelihood of falling rocks and large rock slides that can encroach on the lake and cause GLOF (NDMA, 2020). The Dokriani Glacier in the Bhagirathi basin has been retreating at a rate of 15-20 meters per year since 1995, according to the Wadia Institute of Himalayan Geology, while the Chorabari Glacier in the Mandakini basin has been retreating at a rate of 9-11 meters per year between 2003 and 2017. (desk, 2022)

2.2.1.2 *Cloudburst*

Cloudburst is an extreme amount of precipitation, sometimes with hail and thunderstorms, which normally lasts for minutes but can also cause flash floods*(Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015)*. It is often defined as more than 100 mm/hour of rainfall within a limited geographical area of a few square kilometers. It is a natural phenomenon that the brutal upward motion of warm air with water vapor, blocks the path of continuing rainfall back into the clouds, making them unable to withstand these large amounts of new and old rainwater loads. The upward movement of warm air is directed at a specific area to dampen it. This causes a lot of rain to fall on the ground in a very short time, causing flash floods (ENVPK, 2021). Above a height of 1200 meters, the a forms of the Uttarakhand Himalaya are particularly vulnerable to landslides brought on by cloudbursts in the monsoon season. (SDMA, CLOUDBURST, n.d.). The table of historical events shows that most of the flash floods in Uttarakhand are the results of cloud bursts.

2.2.2 Glacial lake outburst floods (GLOFs)

'Central water commission' defines GLOFs as 'Glacial lakes are common in the high elevation of glaciers basin. In the Himalayas, where such lakes were frequently created by landslides, flash floods known as Glacial Lake Outburst Floods (GLOF) are common due to the eruption of glacial lakes. The b [illegible]se of short durations of, large volumes of water in relatively GLOFs has a tremendous potential to cause flooding in downstream areas, which could have disastrous effects. Global warming is the primary cause of glacial lake formation. The Himalayan region's catchment area contains 2028 glacial lakes and waterbodies with water propagation areas greater than 10 ha, which feed rivers that flow across India. 1525 water bodies and 503 glacial lakes are among these*(NDMA, 2020)*. There is a total of 60 glacial lakes and 508 water bodies in the Indian Himalayan region and 'Wadia Institute of Himalayan Geology' mapped based on satellite images from 2011 to 2013, a total of 1266 glacier lakes larger than 500 m2 in Uttarakhand. Out of the total, 809 are ice-dammed lakes with an area of 2.0 ± 0.1 km² and 329 (total area of 3.9 ± 0.2 km2) are categorized under moraine-dammed lakes. The maximum number of lakes i.e. 635 are distributed in the Alaknanda River basin with a maximum area (of 3.4 ± 0.2 km2) *(Bhambri et al., 2015).* These floods present serious geomorphological risks and have the potential to cause severe damage to any man-made structures that are in their path. Livelihoods are frequently disrupted for long durations by events *(Pandey & Vishwakarma, 2020).* As the climate continues to warm, it is anticipated that both the frequency of GLOFs and the risk from potential GLOFs will rise. In high mountains, the potential for flooding grows as new lakes form, existing ones expand, and sometimes even merge. (ICIMOD).

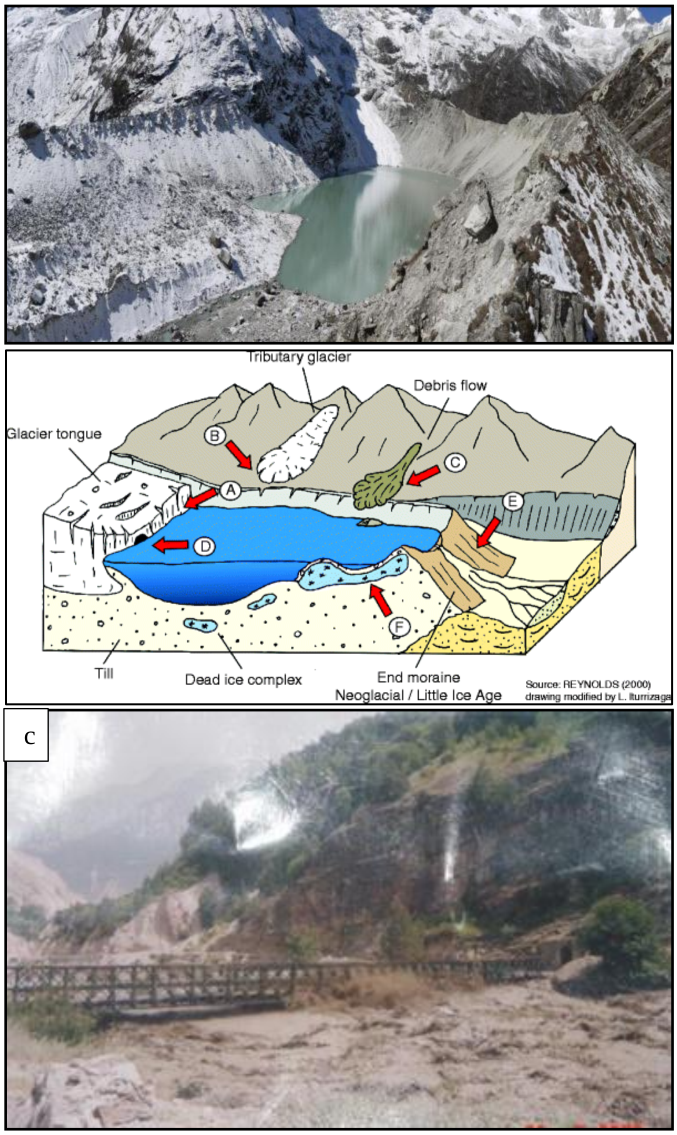

Figure 7 (a) Glacial Lake in Himalayan region (b) Mechanism of glacial lake Outburst flood (c) Landslides Lake outburst flood, Uttarakhand

Source (a)National Snow and ice data center (b) https://lms.chanakyamandal.org/current-event/glacial-lake-outburst-flood-glof/ (c) google.com

2.2.3 Landslide lake outburst floods

Due to the fragile geology landslides and avalanches occur very frequently with intense rainfall and result in flash floods*(Gupta & Payra, 2022)*. Lakes formed by landslides can rupture, resulting in landslide lake outburst floods (LLOFs).On 21 August 2021, in Harkot village, in Munsyari, Pithoragarh district a landslide lake outburst flood occurred. The size of the lake is mentioned to be 300 meters long and 10 meters high at an altitude of 7000 feet. The incident laid at risk of flash floods about 3000 people who live in downstream areas. (SANDRP, 2021). The disaster that occurred on 15 June 2013 in Kedarnath was caused by landslides induced due to intense rainfall in Sarasvati Valley and the Chaurabari glacial lake outburst.

2.2.4 Man-made factors

Day by day Increasing population and tourism in hilly regions are increasing the risk of floods. The other major reason for the formation of glacial lakes in the Himalayan region is burning the grass and trees in search of 'Keeda Jadi' (yellow-brown mummified caterpillar) which costs 15 lakhs per kilogram. People of Chamoli, Bageshwar, and Pithoragarh districts live in camps on hilltops and extract *Keeda Jadi* and harm natural resources (Sharma, 2017). The climate and mountain ecosystem are seriously threatened by a variety of anthropogenic activities, including the building of roads, structures, hydropower projects, extensive tourism, and forest encroachment*(Kansal & Singh, 2022).* The frequency and severity of landslides have increased, aggravating the flash flood situation in the state, and incidents of cloud bursts that have destroyed the state have become more frequent over time.

2.2.4.1 *Population growth*

Every year, 30 million tourists visit the state. Since 2000, when a separate state from Uttar Pradesh was formed, the number of tourists has jumped by 155%. The tourism industry makes up over 25% of Uttarakhand's GDP. From 84 lakhs in 2001 to 100.86 lakhs in 2011, the population rose. Population density increased from 159 people per square kilometer in 2001 to 189 people per square kilometer in 2016*(Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015).* Development efforts in the State have increased to accommodate the population growth and the expansion in tourism, as well as to provide amenities for visitors.

2.2.4.2 *Development activities*

Since 2000, it has experienced rapid growth with a variety of projects, including mining, roads, numerous hydropower projects, buildings, and tourism. Uttarakhand has at least 51 existing hydropower projects of various sizes, another 47 under construction, and 238 planned. Throughout their life cycle, from construction, deforestation, blasting, mining, obtaining materials from the riverbed for construction, muck disposal, debris dumping, damming, and altering hydrological cycle to allied activities like colonies, roads, infrastructure development, hydropower plants have a profound impact on geology and hydrology of the region (Thakkar, 2013). Agriculture and horticulture are facing the challenge of disinterest from local people and tourism being projected as a major source of livelihood in the hills. This has necessitated the construction and development of amenities & services for tourists. One kilometer of road construction requires the removal of 60,000 cubic meters of debris*(Satendra, A. K. Gupta, V. K. Naik, T. K. Saha Roy, A. K. Sharma, 2015).* Most of the roads in Uttarakhand were constructed without considering potential environmental effects or disaster concerns.

Figure 7 Development activities- blasting for road construction (Rajput, 2020)

Figure 8 mining at river banks in Uttarakhand (Rajput, 2020)

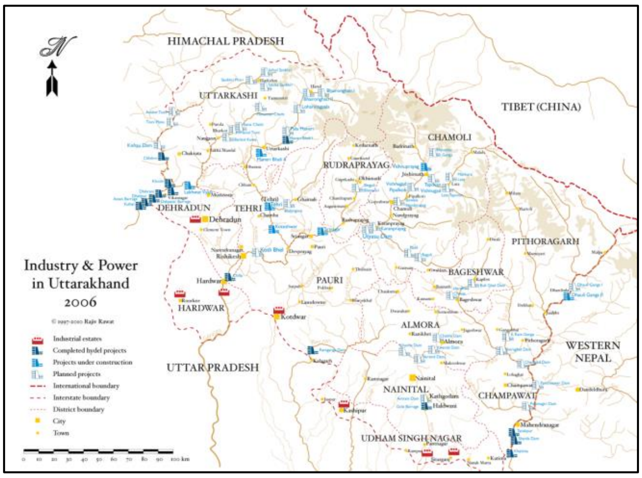

Figure 9 Hydro Power Projects in Uttarakhand(uttarakhand.org)

Blasting roads causes landslides and earthquakes. It is common practice in the Himalayan region to construct roads over the remains of previous landslides. The mountain is not dredged up, saving costs. As a result, capable engineers put pressure on the builders of the road to build a drainage system alongside the road. However, many lacks a drainage system that allows water to drain down. More landslides result from this (Chakravartty, 2012)

2.3 Impacts of flash floods

Every year, on average, floods affect 75 lakh hectares of land, cause 1600 fatalities, and cost Rs. 1805 crore in damage to crops, homes, and public utilities (NDMA, Floods, 2022). Devastating effects on the business, the environment, and people can result from flash flooding. Homes, workplaces, hospitals, vehicles, highways, bridges, and water tanks are all devastated during floods, particularly flash flooding. People end up in shelters, and as a result of floods, the ecosystem also suffers. Additionally, harmful chemicals and other pollutants wind up in the water, contaminating the water bodies that floods finally end up in. Flooding can also disturb the ecosystem's natural balance (OCHA, 2018). Boulders and trees can be rolled, buildings and bridges can be destroyed, and new channels can be scoured by flash floods. Water that is rising quickly can rise 30 feet or higher. Furthermore, rains that cause flash floods can also result in devastating mudslides (NOAA, 2022).

Flood impact is assessed according to the degree of inundation in the floodplain (max flood depth and duration); flow velocity;

and the rate of increase of flood water level. "Peterson" classified Damages as follows: direct and indirect damages, secondary damages, and intangible damage.

Direct damage is loss resulting from exposure of the property to flood water, including replacement and repair of private property and infrastructure, and the resulting loss of income crop damage. Indirect damages include lost business and services value, measures to health protection, traffic delay, etc. Secondary effects include a negative impact on people dependent on production caused by damaged goods or services. Intangible impacts include impacts on environmental quality, social welfare (including loss of life), and aesthetic value.

Figure 10 landslide occurred due to flash flood (Chicu Lokgariwar, 2013)

Figure 11 House washed away by the Uttarakhand floods (Chicu Lokgariwar, 2013)

Based on the type of damage impacts can be categorized into four types –

Physical impacts

- **risk of human life**
- human lesion (physical, emotional, and mental)
- Loss of life
- Relocation of people
- **Loss of livestock**
- Health risks
- tainted water
- infectious diseases
- lack of food resources
- exposure to the harsh climate (rain,cold) because of a lack of shelter

Economic impacts

- **Infrastructure losses**
- Transportation networks
- Communications networks
- Water supply and sewage systems
- Residential losses, Property, Furnishings
- **Government facilities** losses (including military)
- **Public facilities losses** (schools, Hospitals, etc.)
- **Employing businesses losses**
- Structural damages
- Inventory losses
- Sales losses
- **Displacement of business and farms**
- **Agricultural losses**
- Damages to lands,
- Land productivity, and facilities
- Crop losses
- Loss of recreation resources and facilities

Social impacts

- **Emotional and psychological**
- trauma associated with loss of personal property and
- memorabilia, homes, communities
- **Loss of community cohesion**
- **Disruption of educational programs**
- **Loss of security** related to job and income interruptions
- **Loss of recreation opportunities**

Environmental impacts

- Destruction of flora & fauna
- Damage to habitats, food chains species diversity and stability
- Damage to rare and endangered species
- Damage to natural recreational resources
- Damage to scenic resources
- Damage to archaeological and historical resources.

Flooding can seriously harm crops, fences, and livestock in important agricultural production areas. Transport issues brought on by flooded roads and damaged infrastructure exacerbate crop losses from rain damage, soggy soils, and late harvests. As food prices rise as a result of supply shortages, the effects of declining agricultural production frequently extend well beyond the areas of production. Those whose homes and businesses are directly impacted by flooding are not the only people who are impacted by damaged public infrastructure. The national economy is directly impacted by damage to highways, bridges, energy facilities, railroad tracks, and lodging facilities*(Government, 2018)*.

Because flash floods last only a few minutes and cause a lot of damage, it is very difficult to estimate the magnitude of the impact. To estimate human loss Uttarakhand government started the registration of tourists after the Kedarnath flood. There was a huge loss of human life in the 2013 flash flood. Recently one more disaster occurred in Uttarakhand which affected several hydel projects and human loss. On the morning of February 7, 2021, a broken glacial lake in the Rishi Ganga River caused extreme damage in Raini village, tapovan (Chamoli), Uttarakhand. About 170 people are missing. 72 people died. The 13.2mV Rishganga hydroelectric plant near Joshimath has completely washed away and the 520mV NTPC water project on the Dhauliganga River near Raini was partially damaged. Landslides demolished five bridges and damaged roads (Talwar, 2021). Also, in the Alaknanda River, it damaged the 444 MW Vishnugad Pipalkoti HEP of THDC India Limited which was under construction. The economic loss was Rs. 2000 crore. An upper catchment cloudburst in July 1970 raised the Alaknanda River in Uttarakhand by 15 meters. The entire river basin was impacted, stretching from Hanumanchatti near the pilgrimage town of Badrinath to Haridwar. A whole village was wiped out.

2.4 Mitigation measure

In recent years, events such as flash floods, torrential rains, glacial lakes, heavy rains, and landslides due to climate change are increasing in the Himalayan region. The hilly regions of Uttarakhand are mostly affected by the flash floods situation because of steep slopes and high drainage density. Thus, implementing flood reduction measures requires a holistic approach throughout the pre-flood, post-flood, and post-flood stages *(Kansal & Singh, 2022)*. There are various strategies used by central and state governments to deal with floods. Before planning a flash flood management program, it is essential to identify risks caused by flash floods. The risks are composed of three elements – hazard, exposure, and vulnerability*(World Meteorological Organization, 2012)*. Flood risk management may involve changing the probability of floods affecting a community and/or reducing the impact of flooding by reducing community vulnerability and exposure to flooding. It's important to strike a balance between the economic, social, and environmental aspects when thinking about risk-reduction strategies.

Broadly flood protection measures can be categorized as structural and non-structural which are adopted by national, state, and district disaster management authorities. (AYOG, 2021)(Pandey & Vishwakarma, 2020)

Structural Measures

- Reservoirs
- Detention Basins/ Wet Lands
- Embankments
- Channelization of Rivers
- Channel Improvement
- Drainage Improvement
- Diversion of Flood Waters/ Interlinking of Rivers
- Watershed Management
- Anti-Erosion Works

Non- Structural Measures

- **Risk acceptance**
  - Emergency response system
  - Insurance
- **Risk reduction**
  - Prevention strategies
    - Delimitation of flood areas and securing flood plains
- Implementation of flood areas regulations
  - Application of financial measures
  - Mitigation Strategies
    - Reduction of discharge through natural retention
    - Emergency action based on monitoring, warning,
    - and response systems (MWRS)
    - Public information and education

Figure 12 mitigation measures

2.4.1 Structural Measures

The main thrust of the flood protection program undertaken in India so far has been on structural measures. The structural measures of flood management are aimed to keep the floods away from the people. 'Rajendra Chalisgaonkar'(Post Flood Disaster Mitigation Strategy in Uttarakhand) concluded that several defense structures are constructed after the 'Tsunami 2013' at many flood-prone areas (Kedarnath, Kalimath, Srinagar, Rudraprayag District, Hemkund Sahib & Assiganga). Some are working effectively but most of these are inefficient.

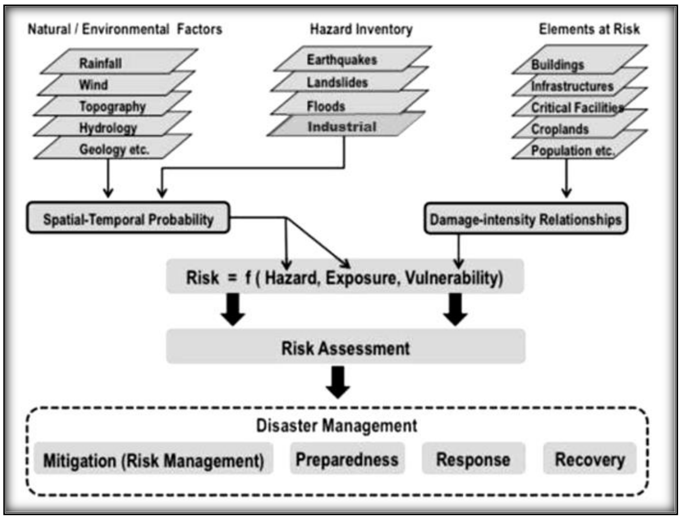

Figure 13 Disaster management cycle (National GLOF Guidelines 2020)

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2.4.1.1 *Reservoirs & Detention Basins/ Wet Lands*

Reservoirs can moderate the intensity and timing of incoming floods. Rivers store water during periods of high flow and release it after critical flood conditions to prepare for the next flood wave. Detention basins are typically formed using natural sinks/wetlands and lakes, building dams around them to increase capacity by providing suitable devices to regulate the release of stored water. This method is relatively inexpensive because the land under swamps and low depressions requires little levelling or cleanliness. Integration of such Detention basins/Wetlands with other structural measures in form of embankments, cross drainage works in form of sluices, etc. may be beneficial for efficiently managing floods.

2.4.1.2 *Embankments*

The river's embankment system confines it to its current path and prevents overflowing the banks. Earth that is readily available from nearby areas is typically used to build embankments. Embankments are designed and constructed to afford a degree of protection against floods of a certain frequency and intensity or against the maximum recorded flood depending upon the location protected and their economic justification (NDMA, 2008).

2.4.1.3 *Channel Improvement*

To increase the carrying capacity of a channel, either its area of flow or its velocity (or both) must be increased (NDMA, 2008). The method of improving the channel by improving the hydraulic conditions of the river channels by desilting, dredging, lining, etc., to enable the river to carry its discharges at lower levels or within its banks has been often advocated but adopted on a very limited extent because of its high cost and other associated problems (AYOG, January 2021).

2.4.1.4 *Watershed Management*

The watershed management measures include developing and conserving the vegetative and soil covers (Catchment Area Treatment) and also undertaking structural works like check-dams, detention basins, diversion channels, etc. By proper management of the watershed, silt carried and deposited in the lower reaches of rivers can be reduced, leading to the better-carrying capacity of the channel and thus serves as an effective flood control measure.

2.4.2 Non-Structural Measures

Various non-structural measures proposed for flood management include real-time flood prediction, zoning of flooded areas, the dam burst flood simulation, flood risk, and flood risk mapping. Such measures planning a flood management program to further regulate development activities and formulation of an emergency evacuation plan for a flood. These measures are also used to develop legislation for the minimization of human intervention in floodplains.

2.4.2.1 *Flood Forecasting*

The aim of a flash flood forecast technique is to offer well timed and and accurate information and data for the development of warnings to save lives (primarily) and property (Organization, 2016). Reliable forecasting and easily understandable warning information with sufficient lead time are of vital importance for evacuation. The work of flood forecasting and warning in India is entrusted to the Central Water Commission (CWC). Presently, around 1600 Hydro-meteorological sites are being operated by CWC across the country covering 20 river basins for gauge, discharge, sediment & water quality observations. Many of these stations are used as flood monitoring stations for formulating flood forecasts. The activity of flood forecasting comprises Level Forecasting and Inflow Forecasting.

A sufficient lead must be provided by the forecasting system. It's time for each community in the floodplain to react. The ability to reduce the number of fatalities increases with the lead time. For communities and users to act appropriately when warned, forecasts must be accurate enough to inspire confidence. If forecasts are wrong, credibility will suffer and no action will be taken in response. (Organization, 2016).

The various steps involved in the operation before the issue of forecasts and warnings are as follows:

- Observation and collection of hydrological and meteorological data.
- Transmission/Communication of data to the forecasting Centres.
- Analysis of data and formulation of forecasts.
- Dissemination of forecasts and warning to the Administrative and Engineering Authorities of the States.

In Uttarakhand, 176 weather instruments (107 AWS,28 ARG,16 ASG & 25 SFO) are installed and the data is shared with IMD (Indian meteorology department) to strengthen the early warning system & 3 Doppler Weather Radars established by IMD *(USDMA).*

2.4.2.2 *Early warning system*

The Early warning system (EWS) is an integral component of risk management for a natural disaster. It has been listed as one of the five priorities under the Hyogo Framework for Action (HFA) for building disaster-resilient nations and communities and is one of the seven global targets of its succeeding document, the Sendai Framework for Disaster Risk Reduction(SFDRR).

Central Water Commission (CWC) established 74 river gauging sites (28 Telemetry and 46 Manual) along the major rivers in Uttarakhand. The irrigation department is establishing a network of 59 Automatic Water Level Recorders (AWLR) in NHP (National hydrology project). Tehri Hydro Development Corporation Limited has installed 11 AWS (automatic weather stations) & 04 AWLR in the U/S of Tehri dam. Sirens with voice message dissemination facility installed along the course of Ganga between Koteshwar and Rishikesh at 08 places with the support of THDCIL *(USDMA)*

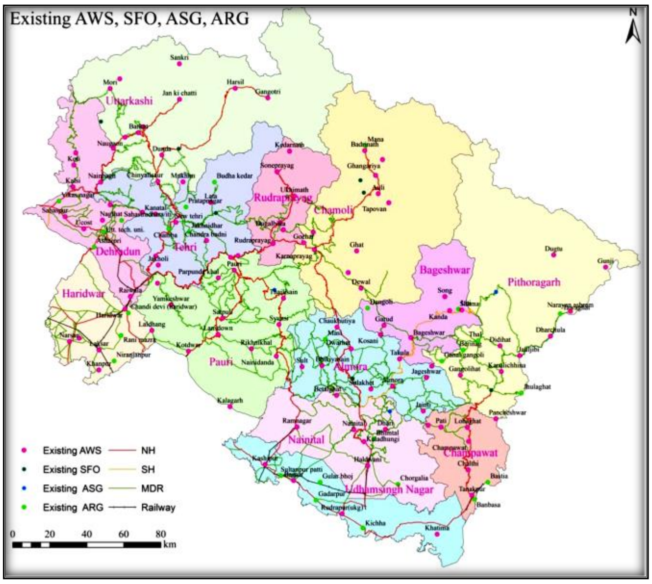

Figure 14 Locations of early warning systems in Uttarakhand (USDMA)

An early warning system employs a flood sensor coupled to a transmitter to detect increasing water levels in local water basins (rivers, lakes) or flood defense structures such as dams and embankments. When the water reaches a crucial level, a signal is wirelessly relayed to the receiver. The flood warning is subsequently communicated to concerned agencies and vulnerable people through mobile phones (Kansal & Singh, 2022).

2.4.2.3 *Flood Plain Zoning*

In order to minimize, if not completely avoid, flood damage, flood-plain zoning measures aim to demarcate zones or areas likely to be affected by floods of various magnitudes, frequencies, and probability levels and to specify the types of permissible developments in these zones. The union government also distributed a model draft bill for flood plain zoning legislation to all the states in 1975.

In December 2012, the Uttarakhand government passed the Flood Plain Zoning Bill and announced the limit of the flood plain area in two reaches, i.e.Haridwar (Chandi ghat to Lasker) and Uttarkashi (Gangotri to Badethi Chungi)*(AYOG, 2021)*

Flash flood hazard mapping is a component of floodplain management. It identifies flood zones and the areas that will affect a given return period*(Shrestha, 2008)*. Flood plain zoning restricts to use of the land or any human activity in the flood plains of a river. Land-use regulation controls new construction in regions of high flood risk and introduces necessary restrictions in regions of medium and low risk (Organization, 2016). Generally, the term "flood plain" includes water channels, flood channels, and nearby lowland areas susceptible to flooding by inundation. 'Pandey &Vishwakarma 2019' discussed flood plain zoning should be based on priorities -

a. First Priority

The important installation like defence installations, Industries, Public utilities like Hospitals, Electricity installations, Water supply, Telephone exchanges, Aerodromes, Railway stations, Commercial centres, etc. should be located in such a way that they are above the levels corresponding to 1 in 100-year flood or maximum observed flood levels. They should be above the levels corresponding to a 50-year rainfall and likely submergence due to drainage congestion.

b. Second Priority

Installation like Public institutions, Government offices, Universities, Public Libraries, and Residential areas could be located above 25-year flood zones with the stipulation that they are built on stilts or far higher levels.

c. Third priority

Parks, playgrounds, and parking places could be located in areas vulnerable to frequent floods.

2.5 Strategies to Reduce Vulnerability

The effectiveness of warning and response systems depends on the level of awareness at the local level. Because flash floods are local disasters, local collaborative and participatory efforts are essential to reduce risk. Through a participatory approach, local people have the opportunity to learn about risks and take full responsibility for risk reduction.

2.5.1 Participatory Planning

Effective planning for flash floods is not always possible because flash floods move too quickly and their impact is difficult to predict. This requires planning and coordination of activities. The ability to adequately respond to rapidly emerging phenomena depends on the knowledge and awareness of vulnerable residents, site users, and disaster management authorities. This requires a plan of simple counseling and educational activities that are systematic and carried out over the years.

Planning at the local level should be initiated by municipalities, but the planning process itself should be carried out with the participation of all stakeholders, People at risk, and those with the capacity to support risk reduction activities.

Cooperation, discussion, and contact between the groups at risk and professionals in drawing up plans bring many measurable advantages (Organization, 2016):

- They facilitate precise identification of areas at risk and reasons for this risk;
- They facilitate the finding of acceptable solutions that can be applied by various groups in preparedness, warning, response, and damage clearance;
- They increase the knowledge and awareness of residents in the sphere of evaluating the scale of the danger, the various methods of counteracting damage, and behavior during a flood; and
- They strengthen the credibility of the various groups taking part in the planning and encourage the acceptance of the proposed solutions by the local population.

Farmers, professional societies, industry, women, and volunteer groups need to be aware of flood management. Voluntary bodies can act as an interface between the government and the general public. Media such as television and newspapers play an important role in flood management.

2.5.2 Flood insurance

Flood insurance is one of the most important ways to share and spread the cost of risk for dealing with the impact of floods. This provides financial security against the potential risks of extreme events and allows governments to reduce the financial burden of managing flood recovery.

2.6 Guidelines/plans / Policies

To reduce the risk of natural disasters in the Indian Himalayan region various plans/policies are framed out by the government institutions such as Regulations for Land Use Zoning for Natural Hazard Prone Areas, Indian Standard Codes, Initiatives of the Ministry of Environment, Forest and Climate Change (MoEFCC), model building bye-laws, National water policy, etc. Some important initiatives taken especially for flash flood risk management in Uttarakhand are discussed below.

2.6.1 National Disaster Management Authority Guidelines Management of Glacial Lake Outburst Floods (GLOFs), 2020.

The Guidelines envision improving administrative response, bringing together the relevant scientific capabilities of the nation to eliminate the losses from glacial and landslide hazards. The main aim and objectives of these Guidelines are to develop a strategy that encourages the use of scientific information, maps, methodology, guidance for the early warning system, response management, and development and implementation of initiatives to reduce losses from glacial hazards. These Guidelines also describe the awareness, preparedness, capacity development, research and development, regulations and enforcements, and roles and responsibilities of the local, state, and national ministries/ departments along with the various scientific organizations and institutions to reduce the potential risks.

In the Guidelines, making a single law to regulate development activities is recommended. The multiplicity of rules/ regulations creates a situation of dilution of responsibilities. State and local governments are strictly advised to conduct EIAs and follow IS Code/latest building codes in GLOF and LLOF-prone areas and also the adoption of Model Building by-laws 2016.

As of now, there was not any specific agency to deal with flash floods (GLOF/LLOF), guidelines proposed the Ministry of Jal Shakti (MoJS) as Nodal Ministry and CWC as the Nodal agency for the glacial studies including GLOF and LLOF(NDMA, 2020). Suggested short-term, medium-term, and long-term plans like carrying out the mock drill for preparedness in vulnerable areas and incorporating flash floods safety education in books to create awareness among local communities, Revision of BIS CODES, Creation of a disaster management application, Creation of village task force & Volunteers and Wireless sensor network (WSN) based ground instrumentation and real-time monitoring of GLOF/LLOF. The establishment of A national level Centre for Glacial Research, Studies, and Management (CGRSM) by the Ministry of Jal Shakti under the umbrella of the National Institute of Hydrology (NIH) is a monitoring initiative.

2.6.2 National disaster management plan 2019 v/s State disaster management plan 2020

The vision of the plan is to be disaster resilient. The plan is prepared to incorporate the Sendai framework's objectives – understanding the disaster, (Build Back Batter) in recovery, investing in Disaster Risk Reduction, promotion of capacity development, traditional mitigation measures deployment of advanced early warning systems with Inter-Agency Coordination, and climate change adoption.

The national disaster management plan 2019 includes a management framework for floods, landslides and avalanches, cloudbursts, and glacial lake outbursts floods separately. It also incorporated climate change in planning for disasters.

The state disaster management plan 2020 is in line with the NDMP. It adopted policies for floods, landslides, and avalanches. It includes preparedness, early warning, response, and recovery measures. Cloudbursts and glacial lakes are the main causes of flash floods in Uttarakhand. It is noted that SDMP 2020 has not included policies and management measures for these two major causes. Also, it does not discuss climate change risk management which plays an important role in the formation of glacial lakes.

2.6.3 Community Radio Policy

Community policy was formed by the Uttarakhand state disaster management authority after the Uttarakhand flash flood 2013. It plays a very important role in the disaster management cycle. 'Mandakini Ki Awaz' is the first radio station in Uttarakhand set up by local people in Rudraprayag. The People's Power Collective, which operates in the country's community radio sector, was a capacity builder and training partner for Mandakini Ki Awaz and helped fund and establish the radio station. His first official broadcast on 90.8 FM was in September 2014. This radio station covers approximately 350 villages (Srinivasan, 2021).

Pre-disaster Radio broadcast public awareness campaigns and develops networks with management authorities, organizations, and communities for quick response at the time of disaster. During disasters, it announces emergency evacuation, ways to safe places, and timely updates.

2.6.4 Rehabilitation policy

In 2011 State Rehabilitation Policy was framed and it is amended in 2017. Later in 2021 again it is amended. The main aim of the policy was to stop migration by rehabilitating people in their neighborhoods. Now the policy goal is to reduce the exposure of people to disasters. The objective of the policy is to rehabilitate people who are living in disaster-prone (vulnerable) areas. Seeing the consequences of the flash flood in 2013, the government declared 5 districts namely Rudraprayag, Chamoli, Pithoragarh, Uttarkashi, and Bageshwar as highly sensitive to disasters.

2.6.5 Installation of metrological instruments/sensors

The policy came in July 2022 for the installation of metrological instruments/sensors within 3 months for effective real-time data and early warnings of heavy rain & floods. Fig. 11 shows the locations of installed metrological instruments.

2.7 Case studies

For evaluation of 3 parameters i.e. major causes, level of impact, and Strategies adopted for future risk acceptance and mitigation in IHR 3 cases are chosen. First is flash floods in the Bhote Koshi river basin situated in Nepal, the second is

Kedarnath flood of 2013(Uttarakhand) and the third is a flash flood in the Niujuangou gully (china).

2.7.1 Analysis

The parameters taken for case studies are causes, damage, and measures taken to reduce future disaster risk.

Causes - The main cause of the flash flood in the Bhotekoshi river basin(Nepal) and Kedarnath flood 2013 (Uttarakhand) was the glacial lake outburst resulted due to heavy rainfall while the reason for the flash flood in the Niujuangou gully (china) was a severe earthquake in Wenchuan town.

Damage - In the 1st case (Bhote Koshi Nepal), public infrastructure, human life &livestock were highly affected. And after the risk mapping, it is observed that people and hydropower projects are extremely vulnerable to future flash floods.

In the second instance (the 2013 flood in Kedarnath, Uttarakhand), the tourism industry suffered a large loss and significant environmental damage due to which directly and indirectly people suffered a lot. The hydropower sector suffered a serious financial setback.

The 3rd case (The Niujuangou Gully, China) resulted in the greatest loss of human life and cattle as well as a significant loss of property.

Mitigation measures – structural and non-structural measures are common among the 3 cases. In the 1st case (Nepal) major focus was on risk mapping and preventing landslides by road alignments & slope stabilization. There are no specific guidelines for flash flood management. Integration of climate change with planning is the key measure for flash flood management.

China focuses on capacity building and community participation with an effective early warning system. Also, considering flash floods as a separate disaster china believes in the prevention of flash floods by effective water resource management.

In Uttarakhand (India) major emphasis is on the preparation of state and district disaster management plans & land use control. Monitoring glacial lakes, strengthening inter-agency coordination, and investing in risk reduction are some key initiatives. In the state and district disaster management plan climate change is not adopted till now as suggested by the national disaster management plan.

3.Conclusion

A flash flood is a natural disaster but the level of damage is increased due to anthropogenic reasons. In the study, it is analyzed that the main causes of flash floods in the Himalayan region are the geologic(landslide&earthquake) and climatic(cloudburst, glacial lake outbursts) conditions of the region but extreme human activities (such as rampant road construction, excess construction in flood plains, hydropower projects affecting the natural flow of water bodies, deforestation, tourism, etc) against nature act as a catalyst. Flash floods damage all existing infrastructure with loss of human life and livestock.

The impacts of flash floods are devastating because the occurrence of this type of flood is unexpected and very quick. It doesn't give time for preparing for safety. Because we can't prevent natural disasters, we can only minimize the potential of disasters by taking measures and effective planning. Therefore, for reducing the impact we have to reduce the vulnerability and exposure. The study suggests various effective measures for the mitigation of flash floods including plans, policies, structural measures, non-structural measures, land use planning, flood plain zoning, adoption of climate change in planning, etc. but there are various challenges in the implementation of suggested measures in the region. The challenges are topography & fragile geology, climatic conditions, lack of adequate data, poor data management & governance, and most important awareness.

4.Way Forward

- Flash floods are the result of other natural disasters like cloud bursts, landslides, earthquakes, and avalanches. Thus, for flash flood management, the management of these disasters should be in an effective manner.
- Policies and plans are there but due to a lack of inter-agency coordination, there are certain gaps. Therefore, the Integration of national, state, and district-level plans and policies should be taken into consideration.
- Effective enforcement and monitoring of building codes, land use regulations, and flood plain zoning.
- There is a need to develop policies specific to flash floods.
- community plays an important role in quick response and rescue and has local and indigenous knowledge, thus promoting a community-based management system.
- Develop an Effective framework for the response and recovery phase.
- Prepare Maps for vulnerable areas and identify vulnerable communities, prepare emergency plans, and evacuation plans, and empower communities to withstand flash floods. Flood risk assessment should be the initial step for the effective management.
- With Monitoring glacial lakes, it is necessary to consider activities that are causing glacier retreat. Control these activities to minimize the risk of glacial lake outburst floods.
- need to Efficiently use natural resources and promote planned development activities in hilly regions prone to disasters.

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