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LAND SUBSIDENCE RISK ASSESMENT AND DISASTER MANAGEMENT STRATEGIES, JOSHIMATH, UTTARAKHAND

Chapter 1: Introduction: -

Located in the beautiful Indian state of Uttarakhand, Chamoli District is well-known for its breathtaking scenery, abundant wildlife, and lively cultural legacy. Joshimath is a prominent town that is a gateway to multiple pilgrimage sites and provides stunning views of the Himalayas, making it one of the region's noteworthy locations.
The region faces significant difficulties to infrastructure, human settlements, and environmental stability due to the persistent threat of landslides and land subsidence, even in the middle of its breathtaking natural beauty. These phenomena affect local communities' lives and means of subsistence and go beyond simple geological occurrences. They also have significant socioeconomic ramifications.

Objective of the Research: -

1. To find out the causes of the land subsidence in Joshimath area.
2. A detail assessment of risks due to the land subsidence over the study area.
3. Prepare a land subsidence disaster management strategy for the study area.

1.1 Landslide: -

One of the most common and harmful natural disasters on Earth, landslides can result in a great deal of property damage, human casualties, and environmental destruction. These geological phenomena are caused by the force of gravity, which is typically triggered by several factors like rainfall, earthquakes, volcanic activity, human activity, or changes in groundwater levels. They occur when masses of rock, soil, or debris flow down a slope.

Fig 1.1 Landslides

1.2 Causes of Landslides: -

The major causes of the landslide are as follows: -

1.2.1 Natural Causes: -

Heavy Rainfall: - Intense and prolonged rainfall can saturate soil and weaken slope stability, leading to increased landslide activity, especially in areas with steep topography.

Earthquakes: - Seismic activity can induce landslides by shaking loose soil and rock material, destabilizing slopes and triggering mass movements.

Volcanic Activity: - Volcanic eruptions can generate pyroclastic flows, lahars, and debris avalanches, which contribute to landslide occurrences in volcanic regions.

Freeze-Thaw Cycles: - Alternating freezing and thawing of water within soil and rock crevices can weaken material and facilitate slope failure, particularly in cold climates.

Erosion: - Natural erosion processes, such as river incision, coastal erosion, and glacial retreat, can undermine slope stability and trigger landslides along vulnerable terrain.

1.2.2 Anthropogenic causes: -

Deforestation: - Clearing of vegetation for agriculture, logging, or urban development reduces soil cohesion and increases surface runoff, elevating the risk of landslides.

Construction Activities: - Excavation, blasting, and improper construction practices can disturb natural slope stability, leading to localized landslides and slope failures.

Mining Operations: - Extraction of minerals and resources alters landscape morphology, disrupts natural drainage patterns, and weakens slope integrity, predisposing areas to landslide hazards.

Land Use Changes: - Conversion of natural landscapes into urbanized areas or agricultural fields alters surface hydrology and increases susceptibility to landslide events.

Poor Infrastructure Management: - Improperly designed or maintained infrastructure, such as roads, embankments, and retaining walls, can exacerbate landslide risks by impeding natural drainage and destabilizing slopes.

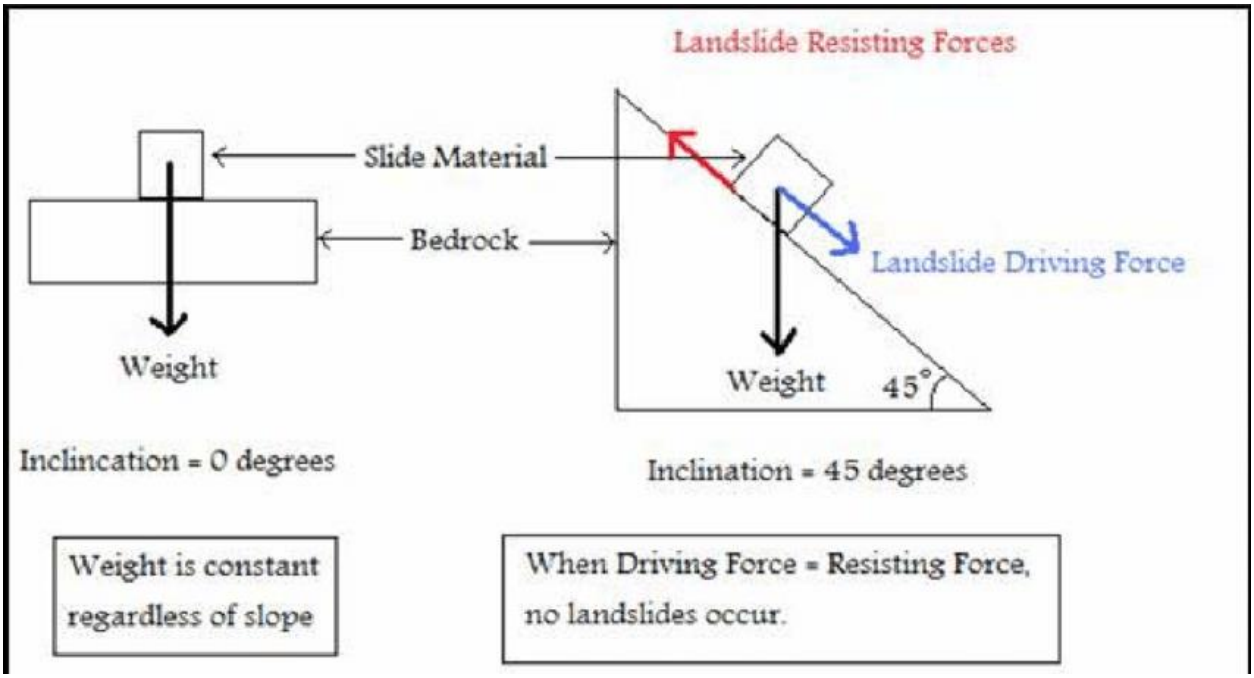


Fig 1.2 Causes Of Landslides

1.3 Consequences on Livelihoods and Economic Activities: -

Loss of Lives: - Landslides can result in fatalities, as individuals may be buried or crushed by collapsing debris. Rapid onset and unpredictability of landslides can make evacuation and rescue efforts challenging, increasing the risk to human life.

Injuries and Trauma: - Survivors of landslides may sustain injuries ranging from minor cuts and bruises to severe trauma and fractures. Medical resources may be strained in affected areas, exacerbating the challenges of providing timely medical care and assistance**.**

Displacement of Communities: - Landslides can render homes and settlements uninhabitable, forcing residents to evacuate to safer locations. Displacement may be temporary or permanent, disrupting livelihoods, social networks, and community cohesion**.**

Infrastructure Damage: - Roads, bridges, buildings, and utilities infrastructure are vulnerable to damage or destruction during landslide events. Disrupted transportation networks hinder access to essential services such as healthcare, education, and emergency response**.**

Environmental Degradation: - Landslides can result in the loss of vegetation, soil erosion, and alteration of natural drainage patterns. Sediment runoff into water bodies can degrade water quality, disrupt aquatic ecosystems, and increase the risk of flooding downstream**.**

Economic Losses: -The direct and indirect costs of landslides include property damage, loss of agricultural productivity, disruption of economic activities, and expenditures on emergency response and recovery efforts. Businesses may suffer financial losses due to supply chain disruptions and reduced consumer demand.

Impact on Livelihoods: - Agricultural lands, forests, and grazing pastures affected by landslides may experience reduced productivity or complete loss, jeopardizing the livelihoods of farmers, foresters, and pastoral communities. Loss of income sources can lead to food insecurity and poverty among affected populations.

Risk of Secondary Hazards: - Landslides and subsidence can trigger secondary hazards such as flooding, debris flows, and dam failures, exacerbating the impact on communities downstream.

Social and Psychological Effects: The trauma and stress associated with experiencing landslides and subsidence can have long-lasting effects on the mental health and well-being of affected individuals and communities.

Challenges for Reconstruction and Recovery: Rebuilding and recovering from landslides and subsidence can be challenging and costly, requiring significant resources, time, and expertise to restore infrastructure and livelihoods in affected areas.

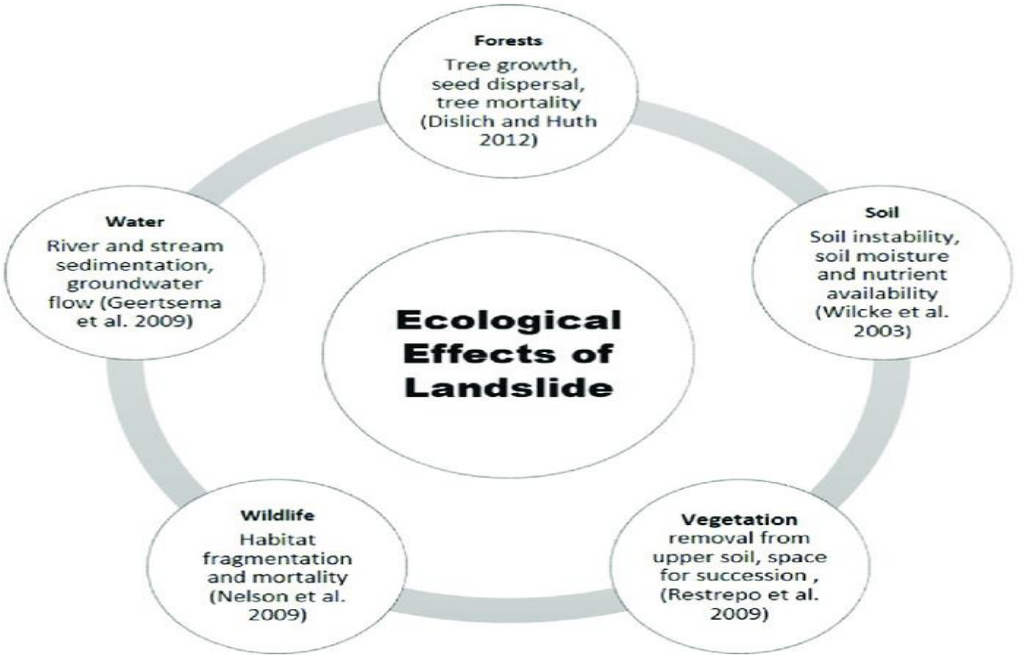


Fig 1.3 Ecological Effects of Landslides

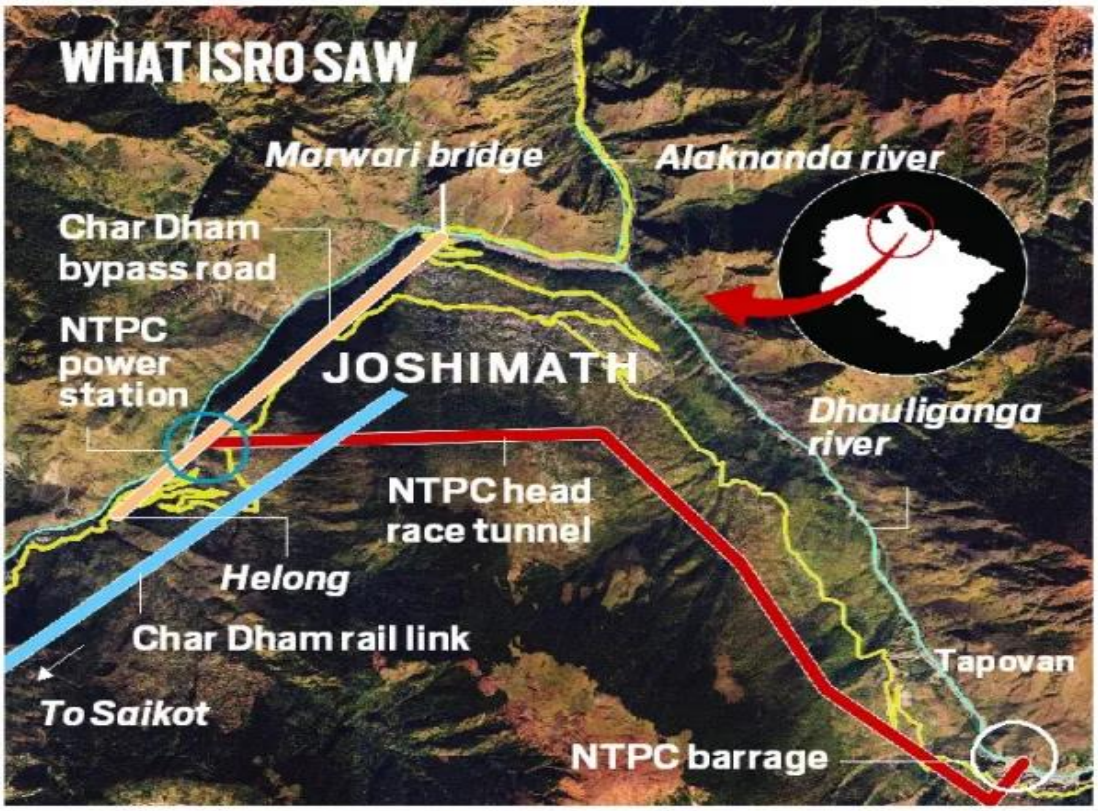


Fig 1.4 Joshimath study Area

1.3 Types of Landslides: -

Landslides manifest in various forms, each with its distinct characteristics, triggers, and impacts. Understanding these different types of landslides is essential for accurate hazard mapping, vulnerability assessment, and mitigation planning. Common types of landslides observed in Chamoli District include:

<table>
<tr><th colspan="2" rowspan="3">TYPE OF MOVEMENT</th><th colspan="3">TYPE OF MATERIAL</th></tr>
<tr><th rowspan="2">BEDROCK</th><th colspan="2">ENGINEERING SOILS</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="2">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">TOPPLES</td><td>Rock topples</td><td>Debris topple</td><td>Earth topples</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td colspan="2">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2" rowspan="2">FLOWS</td><td>Rock flow
(deep creep)</td><td>Debris flow</td><td>Earth flow
(soil creep)</td></tr>
<tr><td colspan="3">(soil creep)</td></tr>
<tr><td colspan="2">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

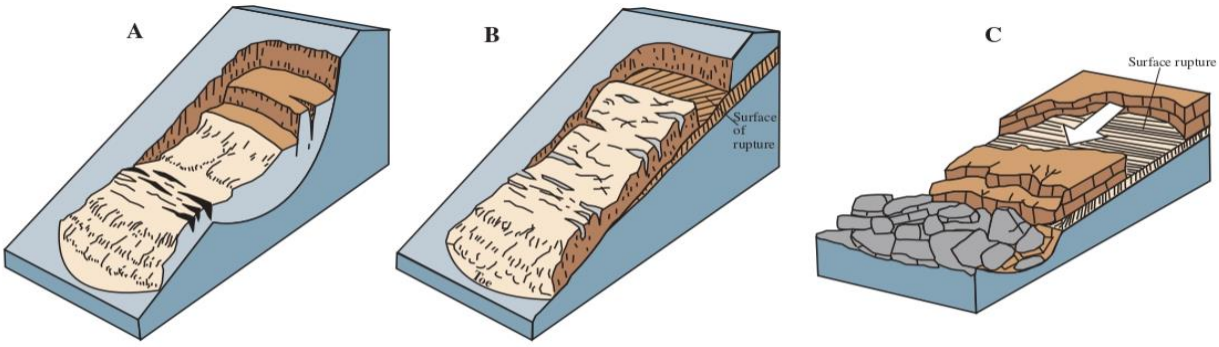
Rockfalls: -Occur when individual rock fragments detach and fall freely down a slope due to weathering, erosion, or seismic activity. Rockfalls are typically characterized by rapid movement and pose significant hazards to infrastructure and human settlements located downslope.

Debris Flows: - Also known as mudflows or lahars, debris flows are fast-moving mixtures of water, soil, rock, and organic material. Triggered by heavy rainfall, snowmelt, or volcanic activity, debris flows can mobilize large volumes of material downslope, causing extensive damage to property and infrastructure.

Rockslides: - Involve the sudden detachment and rapid downslope movement of large blocks of rock along pre-existing fractures or bedding planes. Rockslides often occur in mountainous terrain with steep slopes and are influenced by factors such as geological structure, weathering, and seismic activity.

Landslips: - Characterized by slow, gradual movement of soil and debris along a cohesive surface, landslips often occur in clay-rich soils or weak rock formations. Landslips can result from prolonged rainfall, groundwater saturation, or human activities such as excavation or construction**.**

Earthflows: - Formed by the slow, viscous movement of saturated soil and weathered rock downslope, earthflows exhibit a characteristic "tongue-shaped" morphology. Commonly triggered by prolonged rainfall or snowmelt, earthflows can pose significant hazards to infrastructure and natural ecosystems**.**



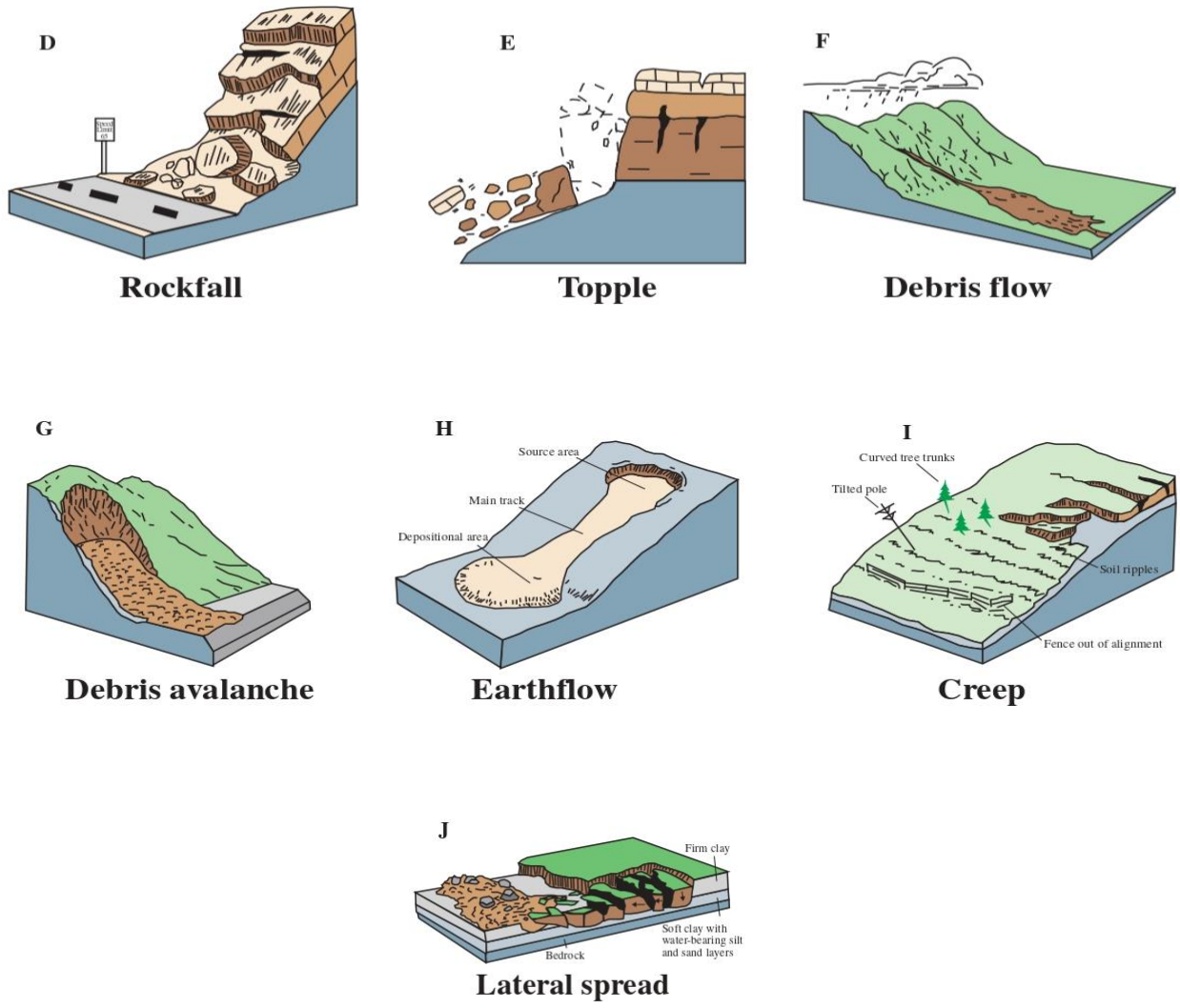


Fig 1.5 Types of Landslides

1.4 Database: -

1.4.1Primary Sources:

Primary data sources involve the collection of original data through field observations, surveys, interviews, and measurements. In the case of landslide studies, primary data collection methods may include: -

Field Surveys: - Conducting detailed field surveys to identify landslide-prone areas, assess slope stability, and document landslide characteristics such as size, movement, and frequency.

Remote Sensing: - Utilizing satellite imagery, aerial photographs, and LiDAR (Light Detection and Ranging) data to map landslide scars, detect changes in land cover, and monitor slope movements over time.

Geological Investigations: - Conducting geological surveys and mapping to understand the underlying geology, structural controls, and lithological characteristics of landslide-prone areas.

Community Engagement: - Engaging with local communities, stakeholders, and experts to gather information on past landslide events, community perceptions, and coping strategies.

1.4.2 Secondary Sources: -

Secondary data sources encompass existing literature, reports, databases, and archival records that provide valuable information on landslides and related phenomena. In Chamoli District, secondary data sources may include: -

Historical Records: - Reviewing historical accounts, newspaper articles, and government records to compile a chronological record of landslide events, their impacts, and response efforts.

Scientific Literature: - Reviewing published studies, research papers, and academic journals to gain insights into landslide processes, triggering mechanisms, and mitigation strategies in similar geological and environmental settings.

Government Reports: - Accessing reports from government agencies, research institutions, and non-governmental organizations (NGOs) that document landslide occurrences, hazard assessments, and risk management initiatives in the study area.

Digital Databases: - Accessing online databases, repositories, and GIS platforms that host spatial data, maps, and information relevant to landslide research and analysis.

1.5 Research Methodology:

This section outlines the approach and techniques used to collect, analyze, and interpret landslide data in Chamoli District. In landslide studies, a combination of analytical, descriptive, and statistical techniques is often employed to characterize landslide hazards, assess vulnerability, and develop mitigation strategies: -

Questionnaires: - Questionnaires consist of a set of structured questions administered to respondents either in person, via mail, email, or online. They can be used for both quantitative and qualitative data collection.

Interviews: - Interviews involve direct interaction between the researcher and the respondent. They can be structured, semi-structured, or unstructured, depending on the level of flexibility needed to explore responses in-depth.

Observation: - Observation involves systematically watching and recording behaviors, events, or interactions in the field. It can be participant observation, where the researcher is actively involved in the setting, or non-participant observation, where the researcher remains an observer.

Surveys: - Surveys involve collecting data from a sample of individuals within a population using standardized questionnaires. Surveys can be conducted face-to-face, over the phone, via mail, or online.

Focus Groups: - Focus groups involve bringing together a small group of participants to discuss specific topics in depth. A moderator guides the discussion to elicit opinions, attitudes, and perceptions from participants.

Ethnography: - Ethnography involves immersing the researcher in the natural environment of the participants to observe and understand their behavior, culture, and social interactions.

Case Studies: - Case studies involve an in-depth examination of a single individual, group, organization, or event. Researchers collect data through various methods such as interviews, observation, and document analysis.

Experimental Research: - Experimental research involves manipulating one or more variables in a controlled setting to observe the effects on other variables. Field experiments can be conducted in natural settings to increase the ecological validity of the findings.

Action Research: - Action research involves collaboration between researchers and practitioners to address real-world problems or improve practices. It often involves cycles of planning, action, observation, and reflection.

Literature Review: -

He mentioned landslides in Chamoli district, Uttarakhand have profound impacts on the livelihoods and economic activities of local communities. How these events result in the loss of lives, damage to property, disruption of agricultural practices, and decline in tourism revenue. This paper focuses on explaining the impacts of landslides on the socio-economic fabric of the region which is significantly affected, with vulnerable populations experiencing heightened levels of poverty and food insecurity and also effective mitigation strategies entail the implementation of slope stabilization measures, adoption of resilient agricultural practices, promotion of alternative livelihood options, and community-based disaster preparedness programs to reduce the impact of landslides on the people activities. **Divya Singh, Deepesh Goyal, et al (2023)**

He explains how the landslides in Chamoli District, Uttarakhand, are predominantly triggered by factors such as heavy rainfall, seismic activity, and steep terrain. These events have severe consequences, including loss of life, destruction of infrastructure, and displacement of communities. This paper gives a detailed study of the causes and consequences of landslides and its impact on livelihoods is significant, particularly for those reliant on agriculture and tourism, which are disrupted by damaged roads and loss of land. Economically, landslides result in substantial costs for reconstruction and rehabilitation efforts. Also, this paper explains about the mitigation strategies which include early warning systems, slope stabilization measures, afforestation, and land-use planning to reduce vulnerability and hazard exposure(**Chadha, 2023).**

He mentioned landslide hazards in Chamoli District, Uttarakhand, stem from geological factors, anthropogenic activities, and climatic conditions. This paper gives a detailed overview of the landslide hazards which pose severe consequences, including disruption of transportation networks, loss of agricultural land, and damage to infrastructure. The livelihoods of local communities, predominantly reliant on agriculture and tourism, are jeopardized by landslides, leading to economic downturns and increased poverty levels. Also, this paper explains the strategies to mitigate these risks, strategies such as slope stabilization techniques, land-use planning regulations, community-based disaster management initiatives, and investment in early warning systems are essential. **D.P. Kanungo, Shaifaly Sharma, (2013).**

This paper gives a detailed description about the Chamoli District, Uttarakhand, which faces recurrent landslide hazards due to its rugged terrain and monsoonal climate. These hazards have devastating consequences, including loss of human lives, damage to infrastructure, and disruption of economic activities. The livelihoods of local communities, primarily dependent on agriculture and tourism, are severely impacted by such events. Also, this paper provides solutions or mitigation measures encompass a multi-faceted approach, including land-use planning regulations, construction of retaining structures, reforestation initiatives, and the establishment of early warning systems. **Pratik Chaturvedi, Varun Dutt, et al. (2014**).

Most of the Greater Himalayan cities recurrently face multiple natural hazards or disasters such as earthquake, landslide, sinking, glacier busts and flash flood. So, Joshimath is no exception because it is situated on tectonically very active young fold Himalayan Mountain chain. Previously, many incidents like landslides, subsidence or sinking and flash flood occurred in and around Joshimath city and multiple major and minor cracks also exposed on roads, walls and floors of houses. From 11 January 2023, major portion of Joshimath city is continuously started to sink and major and minor cracks have been developed on roads, floors, ceilings and walls of houses. Around 1000 people have been evacuated from the unsafe area and risky buildings. Here, Schmidt hammer rebound test for rock strength, deep learning technique (landslide susceptibility) and geo-hydrological techniques have been applied. This geospatial with field-based study investigated the reasons behind the recent big disaster and this research finding will definitely assist to policy makers for sustainable planning and management. **Biswajit Bera, Soumik Saha, Sumana Bhattacharjee, (2023).**

STUDY AREA

A state in northern India, UTTARAKHAND, literally "Northern Land," is often referred to as Uttaranchal (English), which was the official name until 2007. Because of the state's many Hindu temples and pilgrimage sites, it is frequently referred to as the "Devbhumi," which means "Land of the Gods." The Ramadan, Terai, and Bhabar regions of Uttarakhand are well-known for their natural surroundings. Its borders run north-west via the Tibet Autonomous Region of China, east through the Sudurpashchim Province of Nepal, south-west through the Indian states of Uttar Pradesh and west through Himachal Pradesh. Garhwal and Kumaon, the state's two divisions, each contain thirteen districts in total. The largest and rail-heading city of Uttarakhand is Dehradun. It serves as the state's winter capital. Located in the Chamoli district, Bhararisain serves as Uttarakhand's summer capital. The state's High Court is situated at Nainital. The state's indigenous population is commonly referred to as Uttarakhandi, or more precisely 1QA depending on where they are from. With 10,086,292 people, Uttarakhand is the 20th most populous state in India, according to the 2011 Census of India.

Uttarakhand is located between latitudes 28° 44' & 31° 28' N and longitudes 77° 35' & 81° 01' E. It was separated from UP on November 9, 2000.With a total size of 53,566 km^ (20,682 sq mi), 86% of Uttarakhand is made up of mountains, and the remaining 65% is covered in forests. High Himalayan peaks and glaciers encircle the majority of the state's northern region. A growing number of Indian roads, trains, and other physical infrastructure projects in the first half of the nineteenth century raised worries about uncontrolled logging, especially in the Himalaya.

The Ganges at Gangotri and the Yamuna at Yamunotri, two of the most significant rivers in Hinduism, have their source in the glaciers of Uttarakhand. Numerous lakes, streams, and glacial melts provide them with food. These two are part of the Chota Char Dham, a sacred Hindu pilgrimage, together with Badrinath and Kedarnath. The oldest national park on the Indian subcontinent, Jim Corbett National Park, is located in the state and is home to the Bengal tiger. Renowned for the diversity and uncommonness of its flora, the Nanda Devi and Valley of Flowers National Parks are situated in the upper reaches of Bhyundar Ganga, close to Joshimath in the Garhwal region, and are recognised as UNESCO World Heritage Sites. During his visit to the area, Sir Joseph Dalton Hooker, the Director of the Royal Botanic Gardens in Kew, brought up this issue. Lord Dalhousie reversed the prior laissez-faire attitude by issuing the Indian Forest Charter in 1855 as a result.

Geology: -

The Uttarakhand Himalayas is divided into following regions:

1. Trans Himalayas
2. Higher Himalayas
3. Lower Himalayas
4. Shivalik Himalayas
5. Bhabar and Tarai.

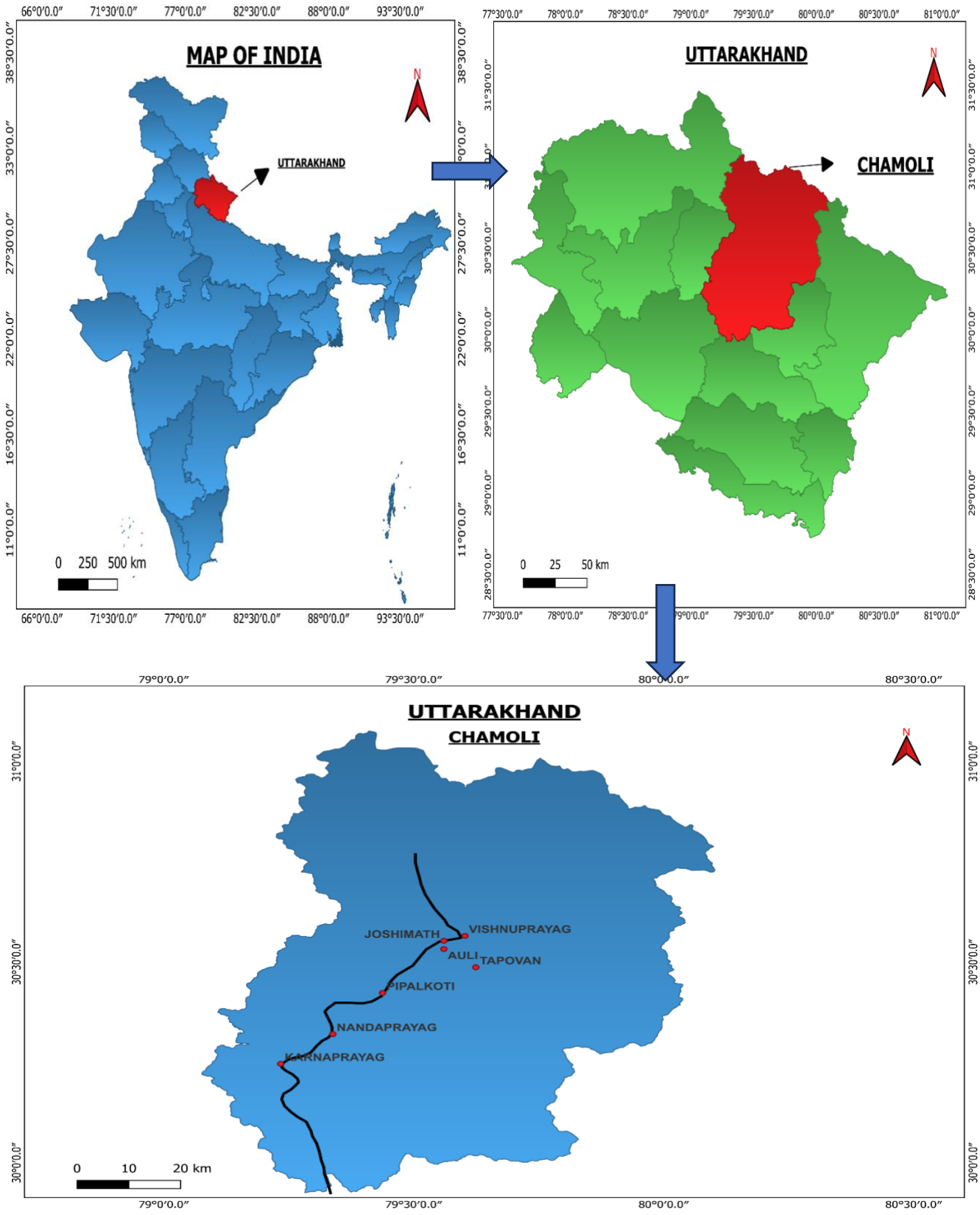


Fig 1.6 Study Area

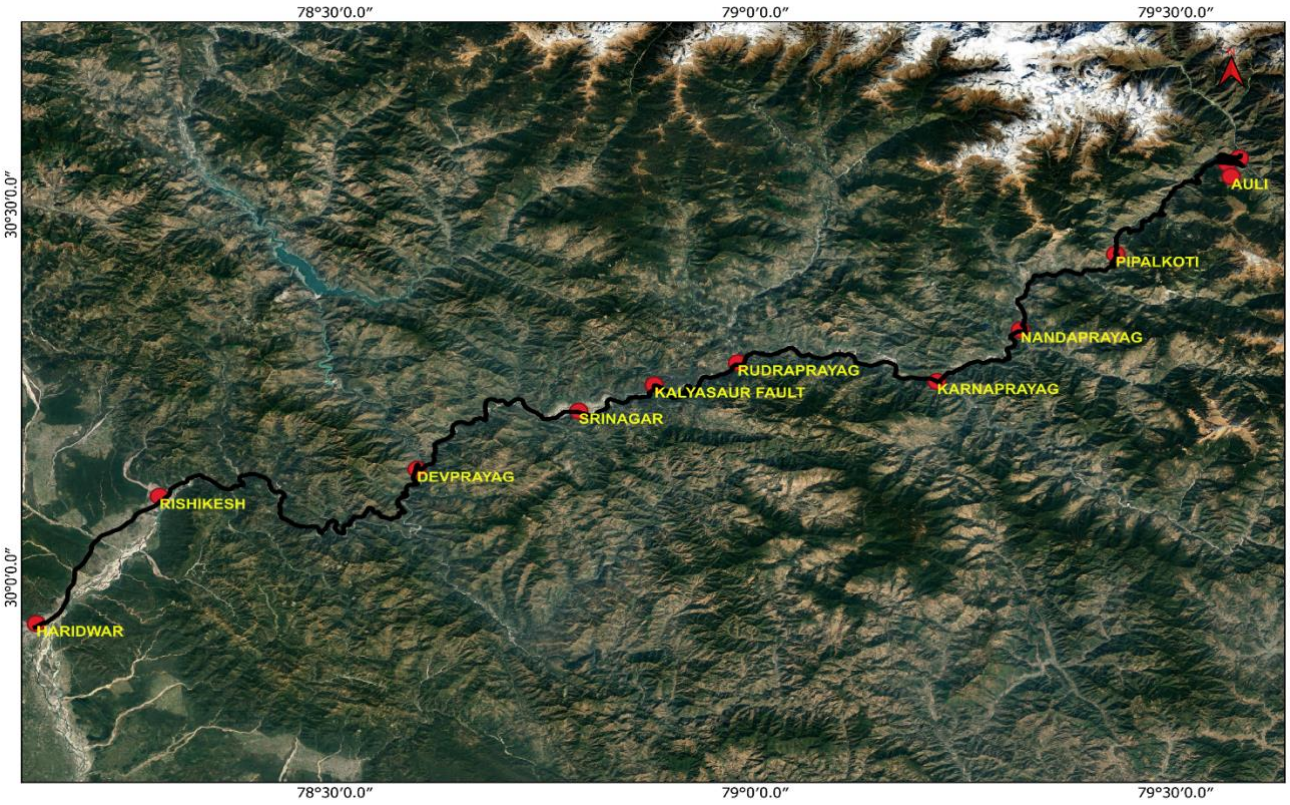


Fig 1.7 Transect survey

The Indian and Eurasian tectonic plates collided to form the Himalayan orogenic belt. The Himalayan Mountain range was raised as a result of this collision, and the orogenic belt was created. Due to the tremendous pressure and distortion this collision produced, the rocks in the area underwent metamorphosis and the Himalayas' distinctive geologic features were formed.

The ongoing collision and movement of these plates continue to shape the geology of the region through ongoing tectonic activity, earthquakes, and the formation of new mountains.

"The Martoli Group, a collection of metamorphic rocks found in the study region, originated more than 540 million years ago during the Neoproterozoic epoch. Rocks that have experienced metamorphism include phyllite, quartzite, and slate, which together comprise the Martoli Group. The Texture, mineral composition, and visual changes in rocks are also caused by metamorphism. The Central Crystalline Groups, which include gneiss, kyanite schist, quartzite, calc-silicate, etc., make up the majority of the study region."[1]

The rocks in the study area have also been subjected to weathering and alteration over time. This can cause the rocks to become more fragile and less stable.

[1] https://link.springer.com/article/10.1007/s10668-023-04263-0 (Divya Singh, Deepesh Goyal et al)

Climate: -

Srinagar experiences a temperate climate with warm summers and cold winters. It receives a heavy snowfall in the winter, making it a popular destination for winter sports. Summertime temperatures range from 15°C to 25°C during the day. They are gentle and pleasant. The temperature drops to between 5°C and 10°C at night.
The months of January through March are chilly, snowy, and below freezing. Because of the frequent snowfall, particularly from December to February, it is a well-liked location for fans of winter sports.

The climate of Rishikesh is subtropical, with warm summers, chilly winters, and a short monsoon season. During the day, summer temperatures range from 25°C to 35°C, and they are hot and muggy. The nights are warm but not as hot, with temperatures between 15°C and 25°C. Daytime highs during the winter months often range from 10°C to 20°C (50°F to 68°F), making them chilly and pleasant. Temperatures can dip to between 5°C and 10°C (41°F and 50°F) during night.
From July to September, Rishikesh enjoys a monsoon season that is marked by a lot of rain. Rainfall revitalises the surrounding vegetation and replenishes the Ganges River, which makes it a perfect time of year for those who enjoy white-water rafting.

Vegetation: -

Starting from Joshimath, the landscape is dominated by coniferous forests, rhododendrons, and meadows. The higher elevations around Joshimath are covered with alpine forests dominated by coniferous trees such as pine, deodar (cedar), and fir. These forests provide habitat to various species of birds and animals adapted to the cold mountain environment.

In addition to forests, Joshimath is also home to lush meadows adorned with a variety of wildflowers during the spring and summer months. These meadows attract trekkers and nature enthusiasts seeking to explore the region's natural beauty. As you descend towards Rishikesh, the vegetation gradually shifts due to changes in altitude and climate. The lower elevations around Rishikesh are characterized by subtropical forests consisting of deciduous trees such as Sal, teak, and oak. These forests are home to a diverse range of wildlife, including monkeys, deer, and birds. The presence of the Ganges River further enhances biodiversity, supporting a variety of plant species along its banks.

Fig 1.8 Rhodendron flower

Topography: -

Joshimath is a hill located in Uttarakhand's Chamoli district. It is approximately 1,875 metres (6,152 feet) above sea level. Situated in the Garhwal Himalayas, it provides access to many trekking routes, some of which lead to well-known pilgrimage destinations such as Hem Kund Sahib and Badrinath. Rugged hilly terrain, thick woods, and a multitude of streams and rivers that emerge from the nearby glaciers and snow-capped peaks define the landscape surrounding Joshimath.
At an altitude of roughly 340 metres (1,115 feet) to 372 metres (1,220 feet) above sea level, Rishikesh is situated in the Himalayan foothills. It is situated where the Ganges and Chandrabhaga rivers converge. Rishikesh has a more diverse topography, having both plains and hills regions. The town is well-known for its gorgeous location next to the banks of the holy Ganges River and amid hills covered with forests. Famous for being a hub for yoga and meditation, Rishikesh attracts tourists from all over the world with its calm and spiritually uplifting atmosphere.

Fig 1.9 While Surveying

Population: -

A Tehsil called Srinagar is situated in Uttarakhand's Garhwal district. It is one of the districts of Garhwal's nine tehsils. Srinagar Tehsil has 12828 houses with a population of 53689, of which 27185 are male and 26504 are female, according to the Census of India 2011. There are 5896 children in the population between the ages of 0 and 6, or 10.98% of the total population. Srinagar Tehsil's sex ratio is approximately 975, whereas Uttarakhand state's average is 963. In Srinagar Tehsil, the literacy rate is 78.87%; 83.51% of men and 74.12% of women are literate. There are 378 people living in Srinagar per square kilometre, covering an area of 141.86 sq. km. Of the entire population, 62.53% reside in urban areas and 37.47% in rural areas.

A Tehsil called Joshimath is situated in Uttarakhand's Chamoli district. It is one of the districts of Chamoli's six tehsils.

Joshimath Tehsil has 12358 houses with a population of 48202, of which 27828 are male and 20374 are female, according to the Census India 2011 data. There are 5543 children in the world between the ages of 0 and 6, or 11.5% of the total population.
Joshimath Tehsil's sex ratio is approximately 732, whereas Uttarakhand state's average is 963. Joshimath Tehsil has a 77.09% literacy rate, with 84.15% of men and 67.45% of female's literate. Joshimath has a population density of 10 people per square kilometre and a total size of 4676.63 sq. km
In the Uttarakhand district of Dehradun resides the Tehsil of Rishikesh. It is one of the districts of Dehradun's six tehsils.
Rishikesh Tehsil has 54517 houses with a population of 260343, of which 123560 are female and 136783 are male, according to the Census of India 2011. There are 31230 children in the population between the ages of 0 and 6, or 12% of the total.
The sex ratio in Rishikesh Tehsil is approximately 903, whereas the state average for Uttarakhand is 963. In Rishikesh Tehsil, the literacy rate is 75.04%; 80.41% of men and 69.1% of women are literate. With 520 people per square kilometre, Rishikesh has a total size of 500.73 sq. km. 52.99% of people live in urban areas and 47.01% live in rural areas overall.

Economy: -

Joshimath is a tiny town in Uttarakhand's Chamoli district. It is mostly recognised for its religious significance because it provides access to a number of Hindu pilgrimage sites, including Hem Kund Sahib and Badrinath.
Joshimath's economy is heavily reliant on tourism, particularly travel for pilgrimages. Thousands of pilgrims visit Joshimath and neighbouring religious sites during the pilgrimage season, which usually takes place in the summer, boosting the local economy.
In addition to tourism, agriculture plays a major role in Joshimath's economy. However, agriculture is restricted to subsistence farming because of the region's rugged climate and steep topography
Rishikesh Known as the global hub for yoga and spirituality, is located next to the Ganges River in the foothills of the Himalayas. Travellers looking for adventure sports, yoga retreats, and spiritual experiences from both domestic and foreign countries are drawn to it.
Tourism has a major role in Rishikesh's economy. Numerous lodging options, yoga studios, ashrams, and adventure sports including trekking, bungee jumping, and white-water rafting are available in the town.
A robust handicraft sector is also present in Rishikesh, manufacturing goods including traditional Indian crafts, yoga accessories, and meditation materials. Many times, these goods are offered for sale to local visitors.

Settlement: -

In the Joshimath region, we found that the settlements are scattered and nuclear. Majorly the means of livelihood is for self-living and agriculture is practiced in the hill slopes. However, as we descended in the valley towards Rishikesh, we found comparatively larger settlements and a mix of residential and tourist complexes.

Fig 1.10: While Surveying

Infrastructure: -

Joshimath is a vital hub for pilgrims starting on the Char Dham yatra across Uttarakhand. It is mostly accessible by road and has a variety of lodgings, including inexpensive guesthouses and temporary shelters during high pilgrimage seasons. Medical facilities are available, although they may be less modern than in urban areas. Mobile phone coverage is available, but it may be patchy due to the terrain.

Rishikesh, a popular spiritual and adventure tourism destination, is well-connected by road and rail. Its many lodgings options suit to all budgets, including luxury resorts and riverfront campsites. With multiple hospitals, clinics, and pharmacies, it provides extensive healthcare services to both locals and visitors alike. The city has strong mobile phone coverage and abundant internet access, which improves the entire guest experience.

CHAPTER 2

CAUSES AND CONSEQUENCES OF LAND SUBSIDENCE

LAND SUBSIDENCE RISK ASSESMENT

INTRODUCTION: -

Land subsidence, or the progressive sinking or settling of the Earth's surface, poses serious dangers to human communities and infrastructure, especially in areas prone to geological instability. The Chamoli district in Uttarakhand, India, is one such place where ground sinking has become a major concern due to a variety of geological, environmental, and anthropogenic influences.

A thorough survey was done to gain a full understanding of the scope and nature of land subsidence concerns in the Chamoli district. The survey aims to analyses local inhabitants' awareness, perceptions, and experiences with land subsidence, as well as their mitigation and adaptation plans.

A sample size of 162 people was chosen using systematic random sampling to ensure representation from various demographic groups and geographical regions within the district. Respondents included residents, landowners, community leaders, and other stakeholders who were directly affected by or participating in land use and development activities.

This study aims to provide significant insights into the current views and realities of land subsidence in the Chamoli region, allowing policymakers, urban planners, and local populations to make more informed decisions. This study aims to contribute to sustainable land management practices and resilience-building efforts in sensitive places such as Chamoli by clarifying the underlying causes of land subsidence and suggesting suitable mitigating solutions.

The study used a structured questionnaire to gather relevant information on participants' demographics, understanding of land subsidence issues, experiences with subsidence-related phenomena such soil erosion and landslides, and perceptions of associated dangers. The questionnaire also attempted to uncover factors that influence land use decisions and the implementation of risk mitigation strategies.

Face-to-face interviews were used to collect data, which allowed for an in-depth study of participants' viewpoints and experiences. Before administering the survey, all participants supplied informed consent and promises of anonymity and confidentiality to encourage open and honest responses.

CAUSES OF LANDSUBSIDENCE AT JOSHIMATH

These are the major causes for land subsidence in the Joshimath study area are as follows: -

- **High Physical Weathering:** -
  The term "physical weathering" describes how mechanical processes like frost action, abrasion, and pressure release break down rock into smaller pieces.
  Because of the effects of gravity and erosion, physical weathering can be especially noticeable in areas like Joshimath, which are known for their harsh terrain and steep hills.

  Repeated freezing and thawing cycles, as well as the actions of water, ice, and wind, can fracture rock masses over time, causing land surfaces to gradually sink and contributing to land subsidence.

- **Diurnal Temperature Contrast**: -
  The substantial variations in temperature between day and night are referred to as diurnal temperature contrast.
  Thermal stress is primarily induced on granite surfaces by diurnal temperature oscillations in high-altitude places such as Joshimath, where temperature differences can be significant.
  Temperature-related rapid expansion and contraction of rock can encourage the formation of fissures and cracks, speeding up physical weathering processes and increasing the risk of land subsidence in the affected area.

- **Deglacial Processes**: -
  Melting glaciers and the subsequent dispersal of glacial meltwater, silt, and debris are known as deglacial processes.
  Climate change-related deglaciation has accelerated across the Himalayan region, including the vicinity of Joshimath, resulting in faster rates of glacier retreat and ice loss.
  In downstream places like Joshimath, the release of meltwater and debris from retreating glaciers can change hydrological regimes, destabilize slopes, and cause soil erosion and land subsidence.

- **Climate Crisis**: -
  For vulnerable areas like Joshimath, the climate crisis—which is typified by rising temperatures, changed precipitation patterns, and an increase in the frequency of extreme weather events—poses serious problems.
  Land subsidence hazards can be increased by increased rainfall intensity, extended droughts, and unpredictable weather patterns, which can worsen landslides, soil erosion, and other geomorphic processes.
  Subsidence is further exacerbated by the warming climate, which speeds up processes like permafrost thawing, which can destabilize slopes and compromise the stability of land surfaces.

- **Disintegrated Bedrock Structure**: -
  The stability and resilience of landscapes are significantly influenced by the underlying bedrock structure.
  The integrity of land surfaces may be jeopardized in regions with cracked or disintegrating bedrock, such as those impacted by tectonic activity or geological faults, increasing the risk of erosion, landslides, and subsidence.
  In areas like Joshimath, geological processes including faulting, folding, and uplift can erode bedrock structures over time, making land subsidence easier to start.

- **Weakening of Hillslopes**: -
  Because of the interaction of geological, hydrological, and climatic processes, hillslopes are naturally dynamic geomorphic landforms.
  The strength and stability of hillslopes can be weakened by elements such soil erosion, plant loss, and human disturbances, which increases their susceptibility to mass wasting events and progressive land subsidence.
  In hilly areas like Joshimath, human activities like deforestation, increased agricultural production, and urbanization can hasten hillslope degradation and raise the risk of subsidence.

- **Changes in Land use and Land Cover**: -
  The stability and resilience of a landscape can be significantly impacted by changes in land use and cover, which are brought about by both environmental and human influences.
  In order to cause soil erosion, sedimentation, and land subsidence, factors such as deforestation, intensification of agriculture, urban sprawl, and infrastructure development can change the characteristics of the soil, interfere with natural drainage systems, and increase surface runoff.
  Rapid changes in land use brought on by population expansion, economic expansion, and tourism in Joshimath and surrounding areas can increase the susceptibility of these areas to subsidence, hence it is important to utilize conservation and cautious land management techniques to reduce the hazards.

Fig 2.1 Landslide

LOCAL PERSPECTIVE: -

Local individuals believe that heavy rainfall and frequent earthquake are the triggering factors that make the area vulnerable to many natural hazards. The possible cause of land subsidence in the area Joshimath is believed due to Deglacial process and weakening strength of hill scope also the Changes in land use and land cover of the area. Some individuals also claimed that the entire area is on fragile sand and stone it is also a major role of land subsidence in area**.**

Most of the cases, local people do not have any ideas about Himalayan **neotectonics and geology** which largely accelerate the magnitude of environmental risk. Government should improve the capacity buildings and disaster resilience among the people of Himalayan terrain.

CONSEQUENCE OF LAND SUBSIDENCE: -

The consequences of land subsidence can be far-reaching and impactful, affecting both the natural environment and human infrastructure. Here are some of the key consequences:

- **Damage to Infrastructure**: Land subsidence poses a significant risk to infrastructure such as buildings, roads, bridges, pipelines, and railways. As the land sinks, structures may experience uneven settling, leading to cracks, tilting, and even collapse. Subsidence can also damage underground utilities, including water and sewer pipes, leading to leaks and service disruptions.

- **Impact on Water Resources**: Land subsidence often results from the over-extraction of groundwater, which can deplete aquifers and compromise water availability. Subsidence-induced changes in land elevation can alter surface water flow patterns, affecting drainage systems and exacerbating flooding risks in low-lying areas.

- **Loss of Agricultural Productivity**: Subsidence can adversely affect agricultural land by altering soil characteristics, reducing fertility, and impairing irrigation systems. Sinking land levels may disrupt surface water management, leading to waterlogging, salinization, and crop damage.

- **Environmental Degradation**: Land subsidence can disrupt natural ecosystems and habitats, impacting biodiversity and wildlife populations. Subsidence-induced changes in topography may alter hydrological regimes, leading to habitat loss, wetland degradation, and shoreline erosion.

- **Economic Costs**: The economic costs of land subsidence can be substantial, encompassing repair and replacement of damaged infrastructure, loss of property value, increased insurance premiums, and lost productivity in affected areas. Businesses may incur losses due to service interruptions, transportation delays, and higher operating costs.

- **Public Health and Safety Risks**: Land subsidence can pose risks to public health and safety, particularly in densely populated urban areas. Structural damage to buildings may jeopardize occupant safety, while disruptions to water and sewer systems can compromise sanitation and hygiene. Increased flooding risks associated with subsidence can also pose threats to human health through waterborne diseases and contamination.

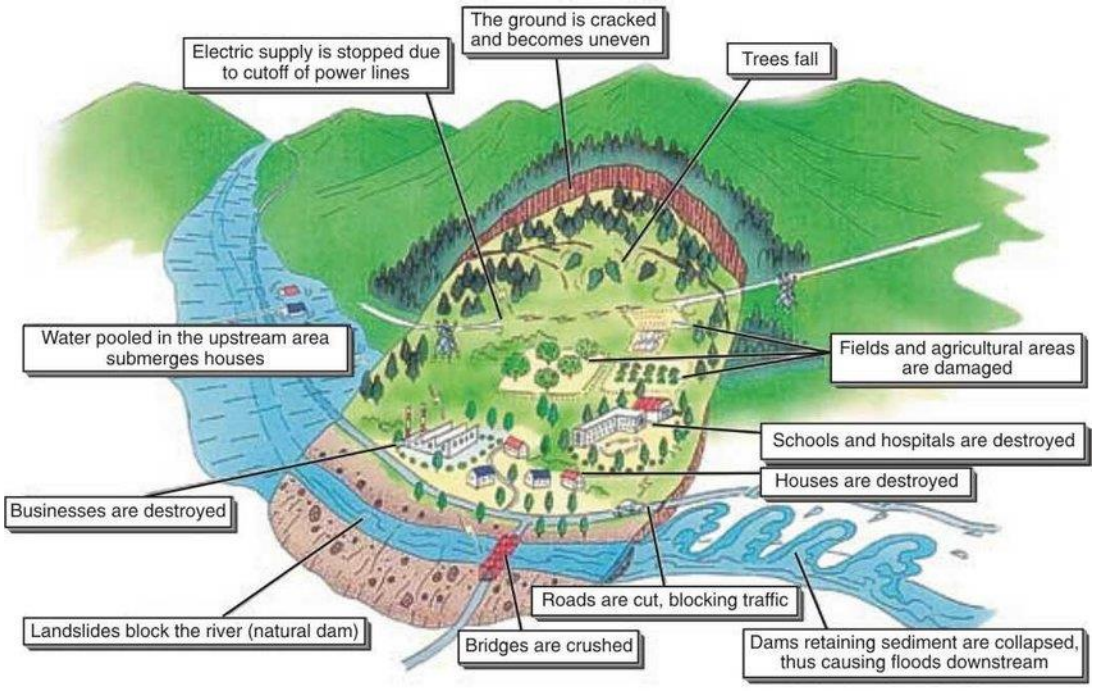


Fig 2.2 Potential Effects of Landslides

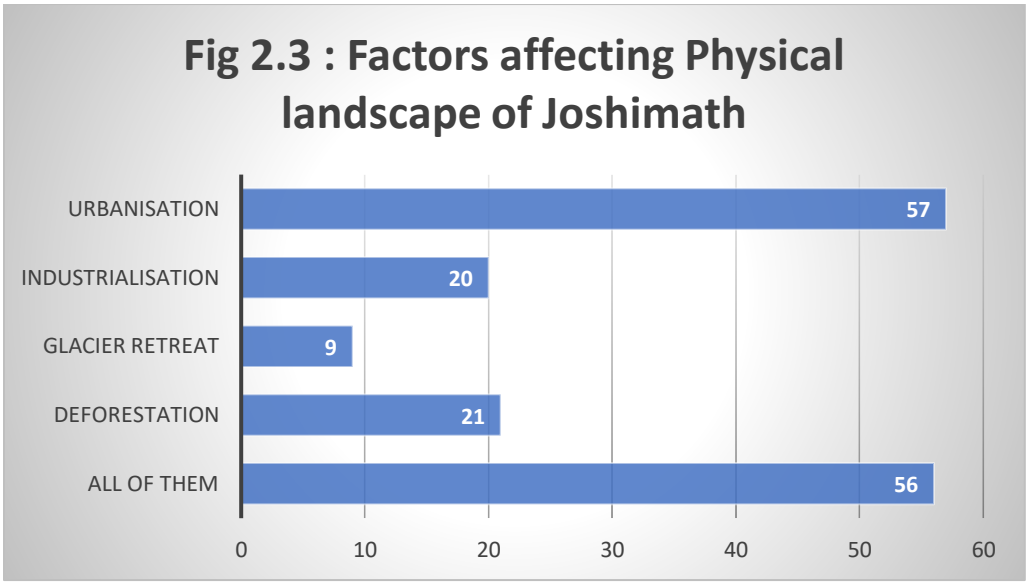
DATA ANALYSIS

The data has been analyzed and processed with the help of statistical techniques and google sheets has been used to present the data through diagrams such as pie and bars.

As per the objectives of the study and the questionnaire designed, the data is also analyzed accordingly.

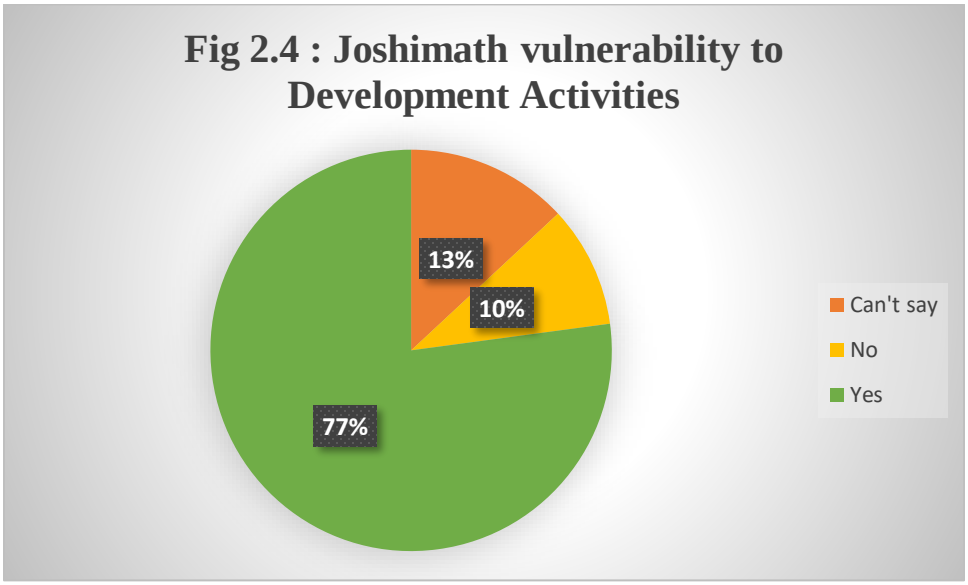
The study included a total of 162 participants, The participants were drawn from different villages in the same study area of Joshimath Uttarakhand, out of the 162 respondents 38.88% are female and 62.34% are males, the respondents are between the age group 20-60.

1. **Do you think the physical landscape of Joshimath has changed over the years?**



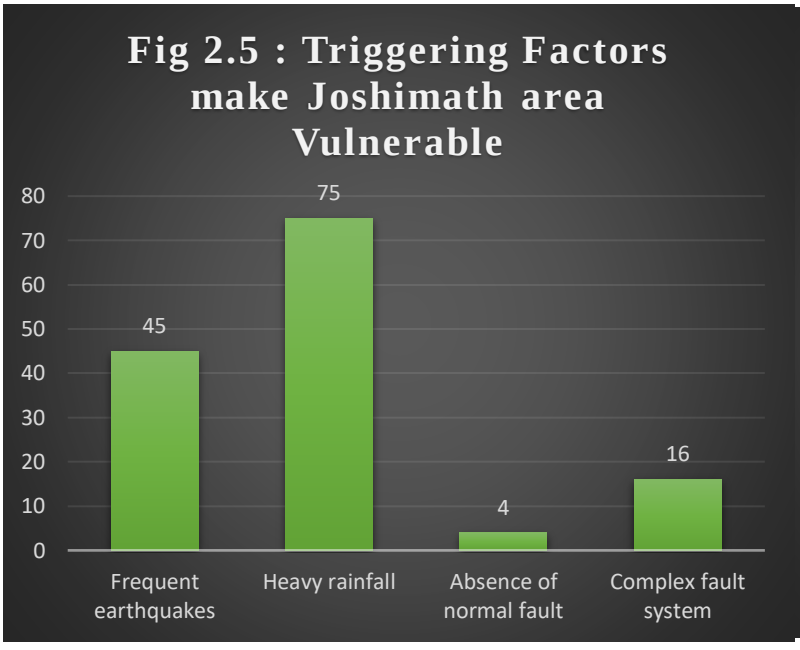
As per the findings, many of the respondents have responded that urbanization activities or heavy construction activities have changed the physical landscape of Joshimath in the current scenario as compared to 10-15 years ago. Due to urbanization other factors also gets influenced like the deforestation and industrialization activities etc.

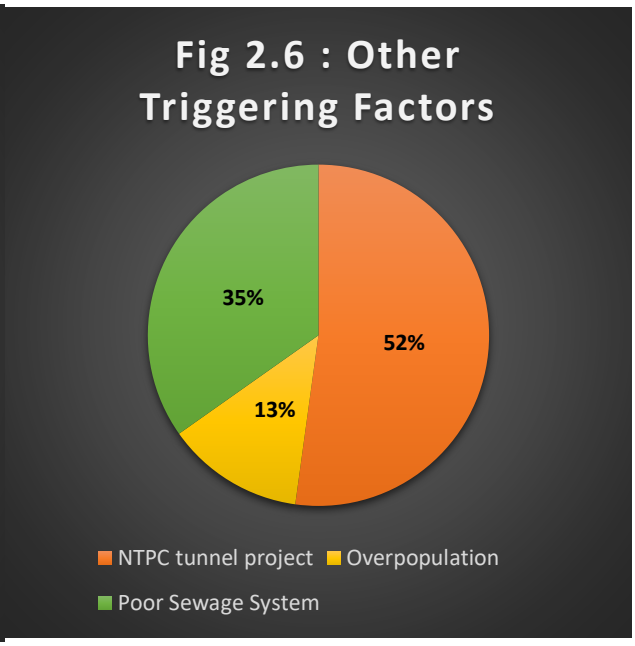
2. **Do you believe that being a landslide area, Joshimath town is highly vulnerable to any type of developmental activities?**



As per the findings, many respondents have agreed that after frequent occurrence of disasters like landslide, flash flood. That the Joshimath area has become vulnerable to the developmental activities and this is the reason of frequent occurrence of disasters.

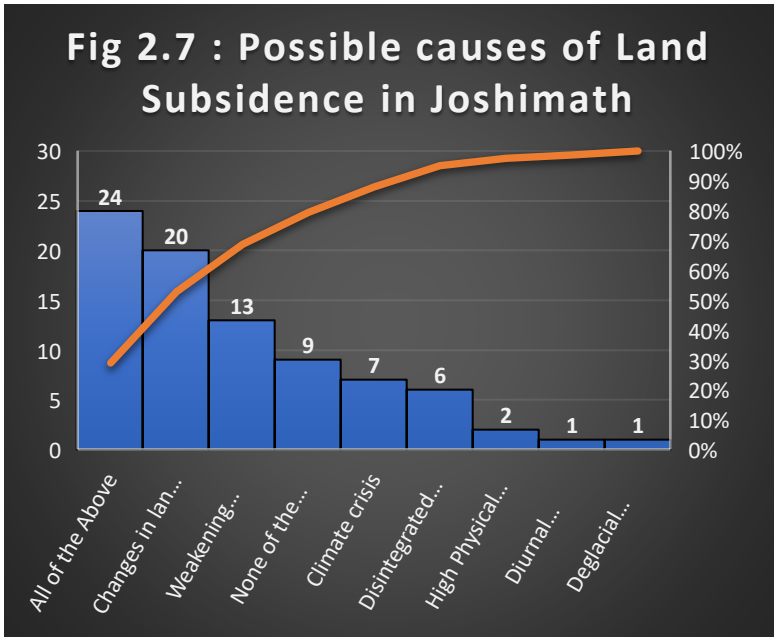
3. **What are the triggering factors that make the area vulnerable to many natural hazards?**

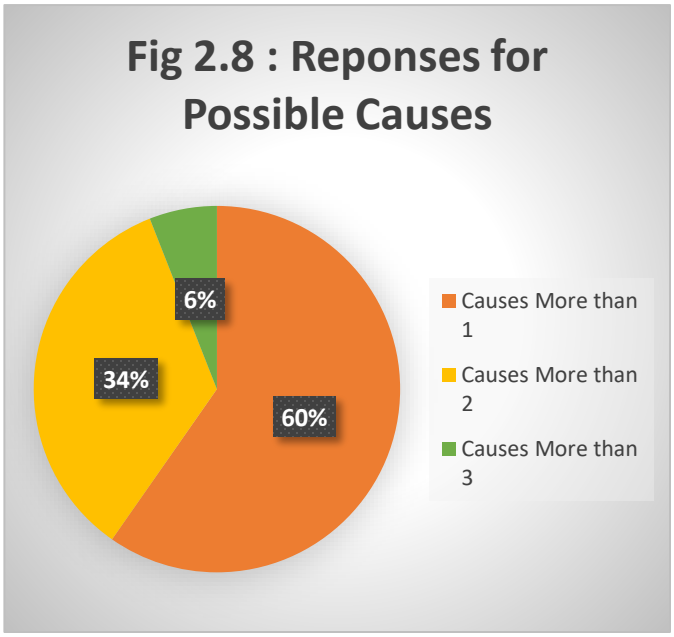




As per the Findings, many respondents have an opinion that the most trigger factors which makes the Joshimath area vulnerable to natural disasters are Heavy rainfall and also frequent earthquakes due to subduction of Indian plate on Eurasian plate. Also, some of the respondents have responded that other factors like Heavy construction activities like blasting, tunnel making project and also poor sewage system of Joshimath area makes it vulnerable to disasters.

4. **What could be the possible cause of land subsidence in your area?**





As per the findings, many respondents have given Reponses to explain the possible causes of land subsidence in the Joshimath study area. Mostly people have agreed to all the factors nonetheless have caused the land subsidence in the area. And many respondents have also responded about more than one causes may be responsible for the land subsidence in the Joshimath area.

Chapter 3

IMPACT AND RISK ASSESMENT OF LAND SUBSIDENCE

- **THINGS TO DO BEFORE OCCURANCE OF A DISASTER: -**

  - To determine whether locations are vulnerable to ground subsidence, do a thorough risk assessment. To map risky zones, use satellite photography, historical data, and geological surveys.
  - In order to manage development in high-risk locations, implement land use planning restrictions. Limit or forbid building on ground that is prone to sinking. Promote sustainable land management techniques to reduce compaction and soil degradation.
  - Infrastructure developments should have design requirements that are resistant to sinking. In order to lessen the consequences of subsidence on structures such as roads, bridges, buildings, and utilities, use suitable foundation designs, materials, and construction procedures.
  - Install monitoring equipment to keep tabs on ground movement and spot subsidence early on. Utilize tools like GPS, satellite images, ground-based sensors, INSAR (Interferometric Synthetic Aperture Radar), and satellite photography to track changes in subsurface conditions and land elevation over time.
  - Inform the general public, interested parties, and decision-makers on the dangers of land subsidence. Give advice on reaction plans, disaster preparedness, and preventive measures. Implement educational campaigns, workshops, and outreach initiatives to foster community resilience.
  - Create thorough disaster preparedness measures so that you can react to events of land sinking efficiently. Provide emergency shelters, evacuation routes, disaster response teams, and communication methods. To improve preparedness and test emergency protocols, regularly conduct drills and exercises.
  - To handle land subsidence concerns completely, encourage cooperation between government agencies, local authorities, community organizations, academia, and industry stakeholders.

- **THINGS TO DO DURING THE OCCURRENCE OF A DISASTER: -**

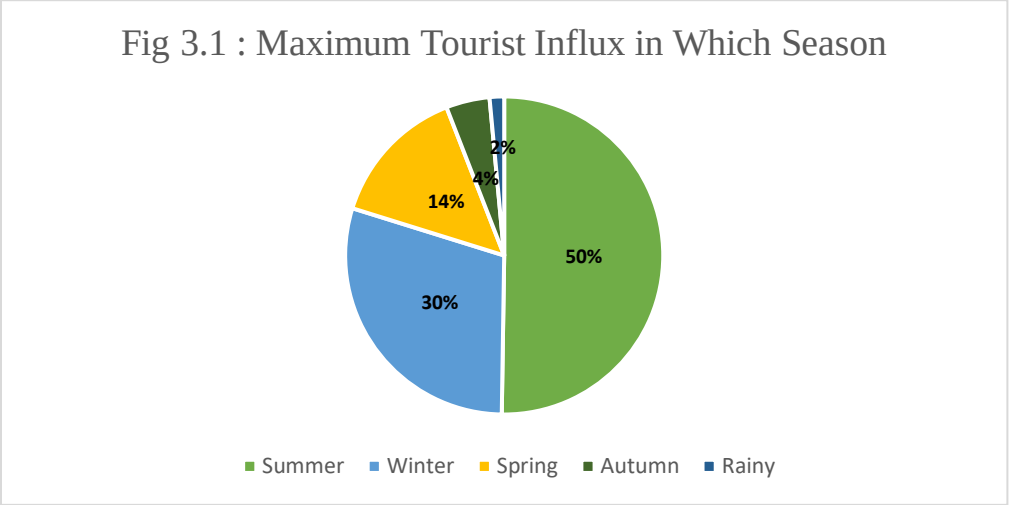
  - Remain vigilant and awake throughout a strong storm. People are frequently killed by landslides when they are asleep.
  - Use a battery-operated radio to tune in to local news channels for alerts on impending torrential rain.
  - Pay attention to any odd noises, such the sound of falling boulders or breaking trees, that could be signs of moving debris.

- Get out of the way of any debris flow or landslip as soon as you can. Mudflow risk is higher in areas close to stream channels especially during extended periods of heavy precipitation. Mudflows have a faster speed than human locomotion. When crossing a bridge, look upstream, and stay off the bridge if a mudflow is on its way.
- Steer clear of low-lying places and river valleys when there is a lot of water flowing through them or severe rainfall.
- If you are close to a stream or canal, pay attention to any abrupt changes in the water's flow and whether it turns muddy from clear. These alterations could indicate debris flow activity upstream, so be ready to respond swiftly.
- If there is a landslip and you are inside a building, seek shelter beneath some heavy furniture.

➢ THINGS TO DO IN POST- OCCURANCE OF A DISASTER: -

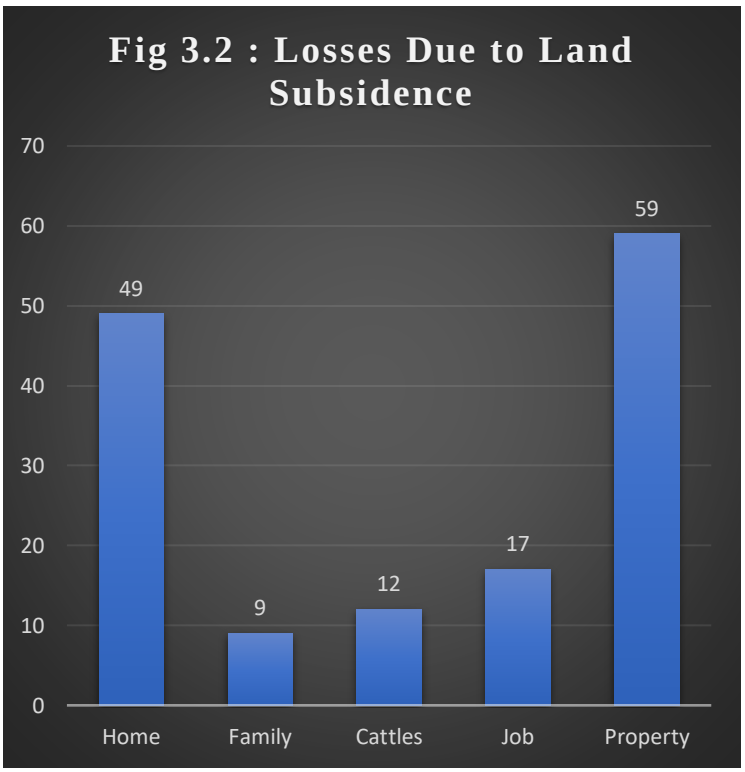
- Remain clear of the sliding area. The possibility of recurrences exists.
- To stay up to date on emergency information, tune in to your local radio or television stations.
- Keep an eye out for flooding, which could follow a debris flow or landslip. A landslip may be followed by a flood.
- Without going into the actual slide area, look for those who may be hurt or trapped close to the slide.
- Provide first aid if you are qualified to do so, or ask for rescue.
- Search for and notify the proper authorities of any damaged roads, railroads, or utility lines. By reporting probable risks, you can stop additional hazards and injuries from occurring by getting the utilities switched off as soon as feasible.
- Inspect the surrounding soil, chimney, and building foundation for damage. Damage to chimneys, surrounding land, or foundations may provide information about the area's safety.
- As soon as possible, recover the damaged area because erosion brought on by the absence of ground cover may soon create more landslides and flash flooding.
- Consult a geotechnical specialist for guidance on assessing landslide dangers or creating corrective measures to lower the likelihood of landslides.
- Look for the people living in the red zone which are more susceptible to risk after occurrence of any landslide.
- Inspect the surrounding damaged infrastructure like wealth and property, transport networks and environment and ecology need to be quickly assessed and recovery needs to be done.
- Provide the basic minimum needs of a individual like food, cloth, shelter needs to be fulfilled of those who are affected by the disaster and also government should provide compensation for the damaged to wealth and property of the people after the occurrence of any disaster.

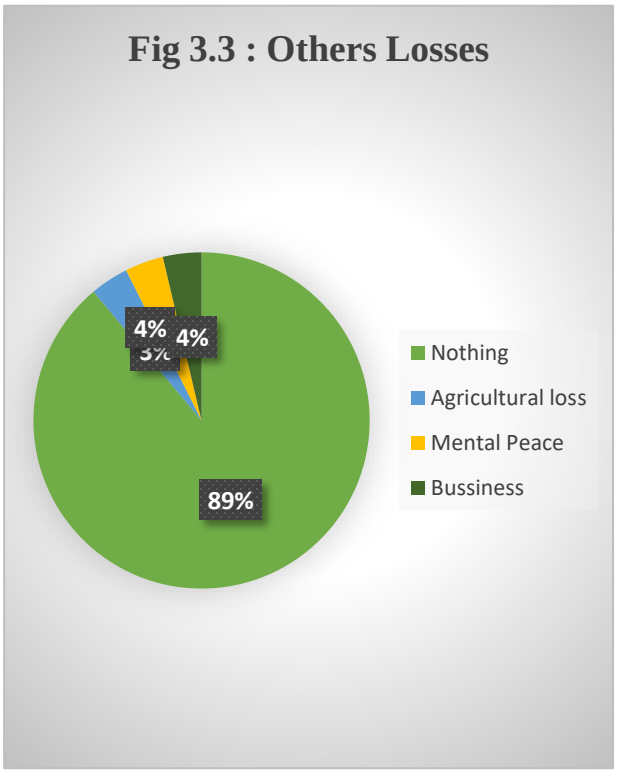
1. **In which season, is there an influx of maximum tourists?**



As per the findings, most of the respondents have responded that most of the influx of tourist are witnessed in summer season, because of calm weather and the paths for the Badrinath a famous spiritual place gets opened and many tourists comes to enjoy the scenic beauty and spiritual practices.

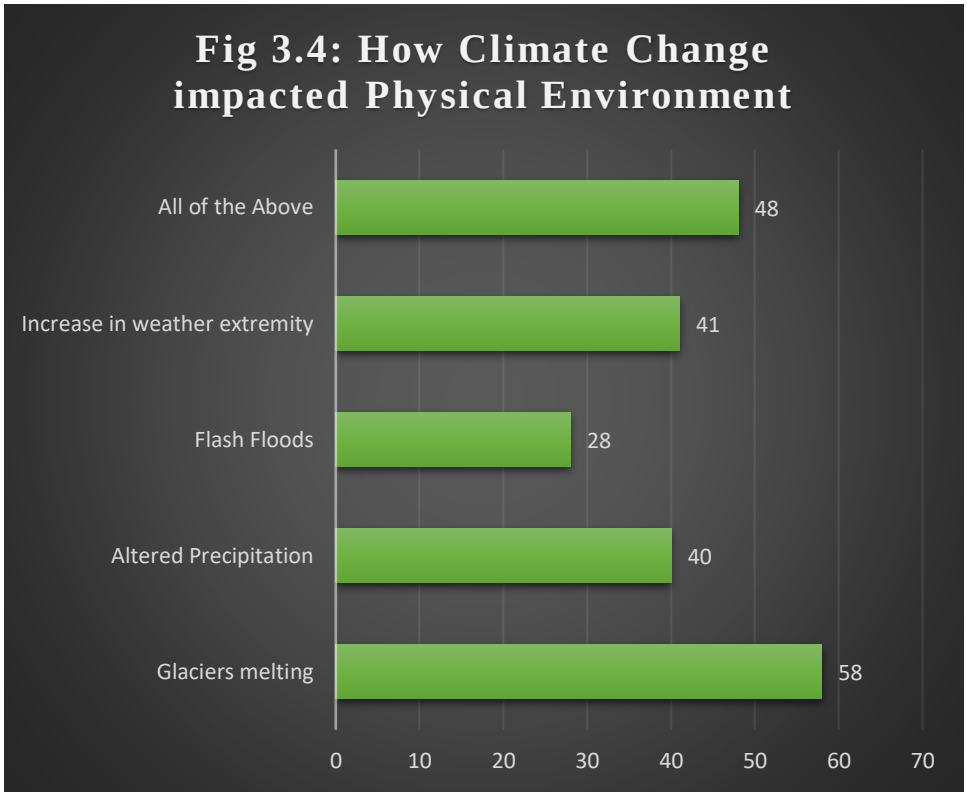
2. **What have you loss/damage during land subsidence in Joshimath?**





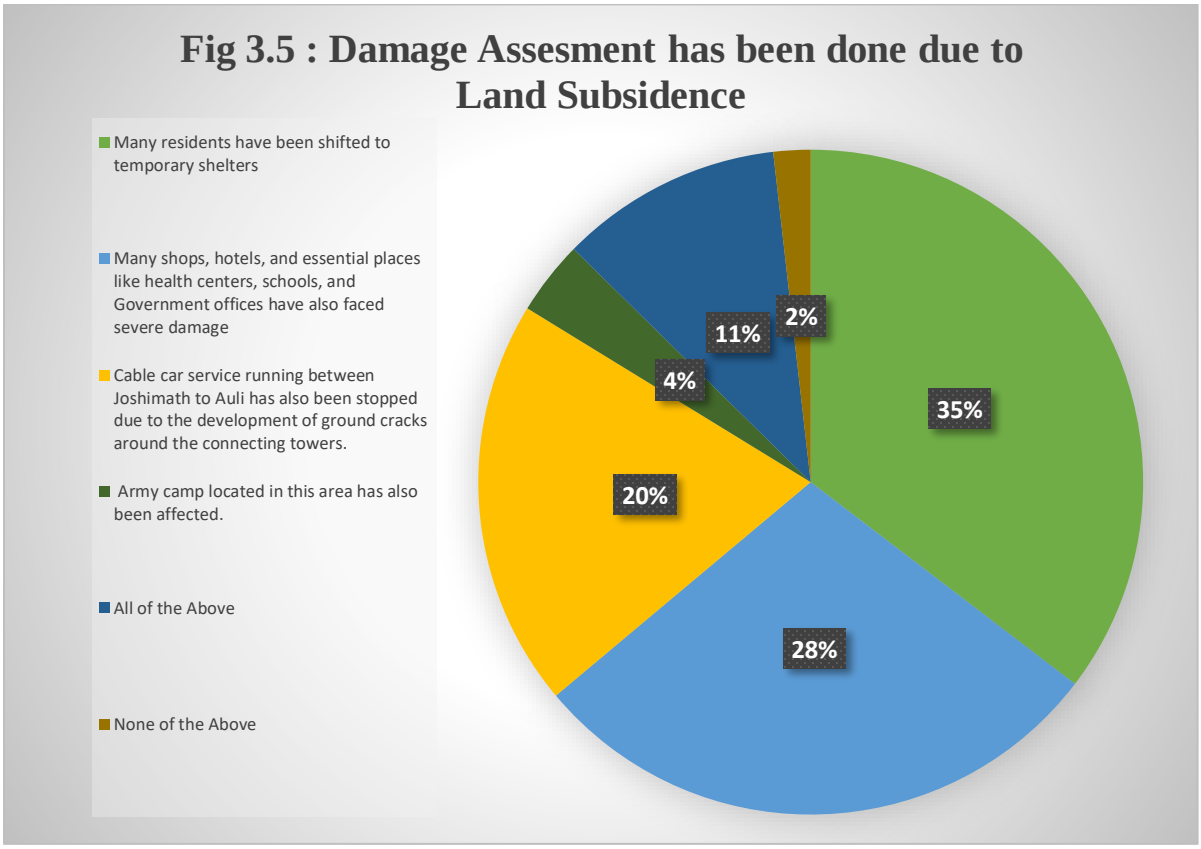
As per the findings, due to the Land subsidence event/ disaster have caused many damages to the property of the houses of the households living there mostly people living in the red zone area have been affected. And the remaining rest of the people have incurred losses in business, job, cattle's and family.

3. **How has the climate change impacted the physical environment?**



As per the findings, many respondents have responded that due to climate change the occurrence and intensity of snowfall has been decreased and said that the glaciers are melting which is a prominent factor for increase in the water level of the river which can lead to flood in the areas. Weather has also been altered nowadays the temperature only reaches till 5-10 degrees Celsius as compared to previous times where it used to reach below 0 degrees.

4. **Are you aware of what kind of damage assessment has been done so far due to subsidence of the ground in Joshimath?**



As per the findings, many of the respondents have responded that after the occurrence of land subsidence the primary initiative taken up by the government was to shift the residents affected to a temporary settlement and provide them compensation and basic provisional services like medical services, food/rations, water, shelter, clothes etc. Also, many Businesses incurred losses and damage in transport and communication network.

RISK ASSESMENT AFTER DISASTER

After the land subsidence has been happened in the region the main assessment of the area was as follows: -

- **Assessment of Damage**: Evaluate the extent of damage caused by the disaster, whether it's an earthquake, flood, landslide, or any other event. This includes infrastructure damage, loss of life, environmental impacts, and disruption to essential services.

- **Identification of Hazards**: Identify the potential hazards that may exist in the aftermath of the disaster. This could include unstable buildings or structures, compromised infrastructure such as roads and bridges, potential for further landslides or flooding, and environmental hazards like contaminated water sources.

- **Vulnerability Analysis**: Assess the vulnerability of the affected population and infrastructure to further risks. Factors such as population density, housing quality, availability of emergency services, and access to resources like food, water, and medical care are crucial considerations.

- **Risk Mapping**: Create maps that illustrate the spatial distribution of risks and vulnerabilities in the affected area. This can help prioritize response efforts and allocate resources effectively.

- **Early Warning Systems**: Implement or strengthen early warning systems to alert residents to potential hazards such as aftershocks, flash floods, or landslides. This may involve installing monitoring equipment, establishing communication channels, and conducting public awareness campaigns.

- **Emergency Preparedness and Response**: Ensure that emergency response mechanisms are in place and functioning effectively. This includes establishing evacuation plans, stockpiling emergency supplies, training emergency responders, and coordinating with local authorities, NGOs, and other stakeholders.

- **Long-Term Recovery and Rehabilitation**: Develop strategies for long-term recovery and rehabilitation, including rebuilding infrastructure, restoring livelihoods, addressing psychosocial needs, and fostering community-led initiatives for resilience-building.

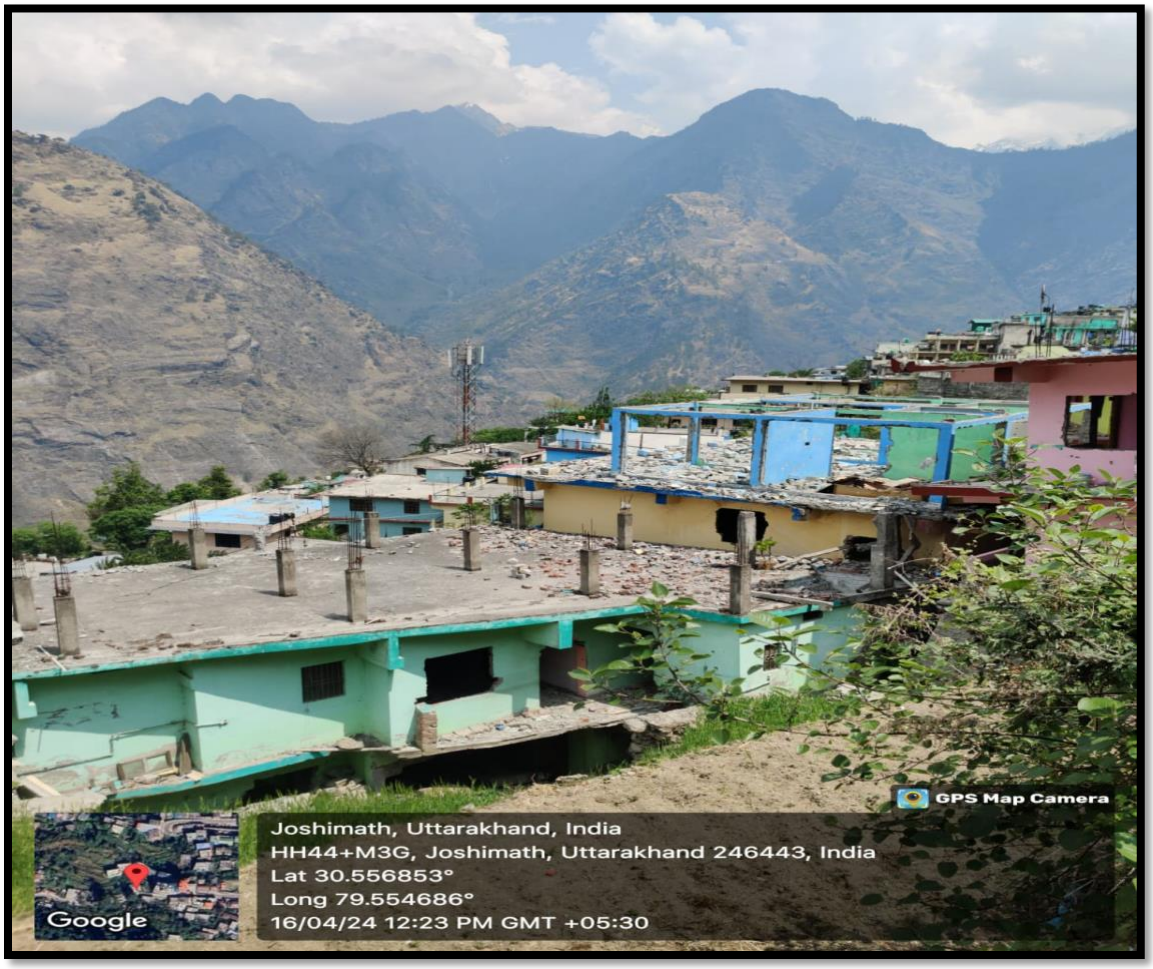


Fig 3.6 Red Zone Areas

CONCLUSION

As per the survey the tunnel construction being one of the main causes of land subsidence, after tunnel construction the development activities leading to deforestation, urbanization, industrialization become the main cause of landslide. For them the triggering factors are heavy rainfall, frequent earthquake, complex fault system, poor sewage.

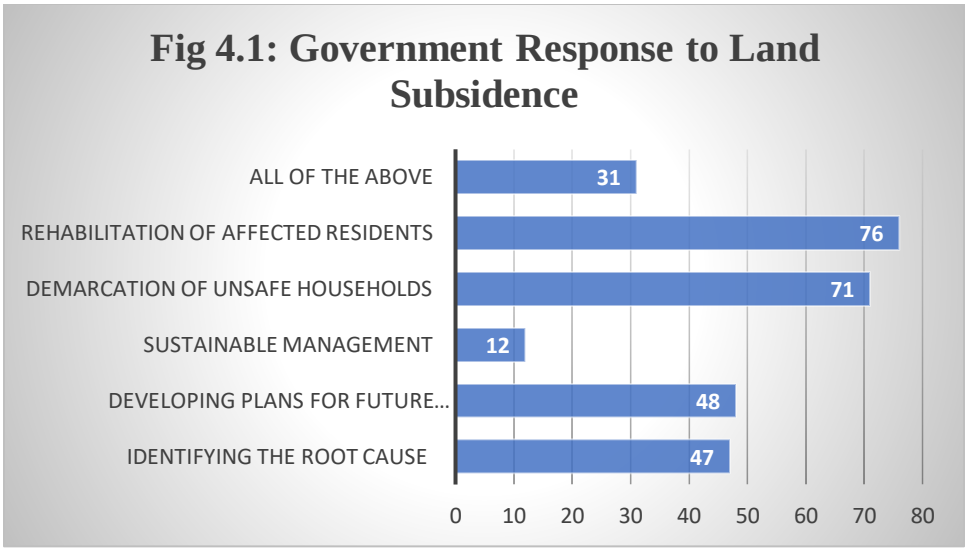
Risk assessment during the disaster includes, Immediate Threat Identification, Identifying the primary hazards and threats posed by the disaster, Evaluate the vulnerability of critical infrastructure, buildings, and populations to the identified hazards. Prioritize resource allocation based on the identified risks and vulnerabilities. Allocate personnel, equipment, and supplies to areas with the highest risk and greatest need. Coordinate with emergency response agencies, government authorities, and humanitarian organizations to ensure efficient resource deployment. Establish mechanisms for monitoring the situation in real-time to track the progression of the disaster and assess its impact. Utilize remote sensing technology, weather monitoring systems, and field assessments to gather data and maintain situational awareness.

The risk assessment after the disaster includes rehabilitation of people, people were staying in a primary school for a month later on were provided bunker houses to stay, assessment of humanitarian needs, people were provided the basic amenities food, shelter, electricity. they should also take care of health and must have provided the better required help to the vulnerable groups such as children, disabled and women. The demarcation of vulnerable houses has been done by the government, the houses are marked with red cross and residents are asked to leave the house and during survey we found that those houses were empty. The government is trying to find the root cause of the disaster continuous monitoring and surveys are performed in the area.

Chapter IV

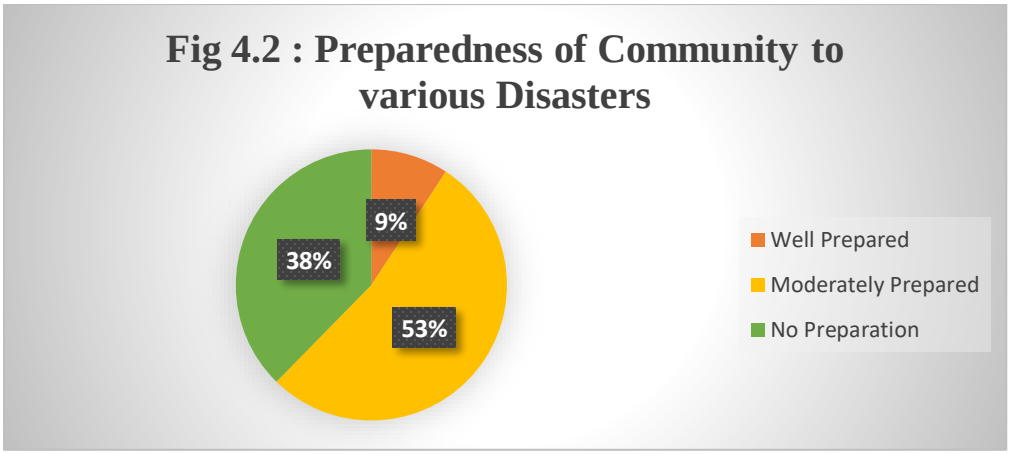
INITIATIVES TAKEN BY PEOPLE AND GOVERNMENT

1. **What is the government's response to land subsidence?**



As per the findings, most of the respondents responded that the primary initiative taken by the government is to rehabilitation of the affected residents and demarcation of damaged households and identifying its causes along with prevention of future mitigation.

2. **How you look on a capacity of your community toward various disasters?**



As per the findings, we can evaluate the preparedness of the community living there to combat various disasters can be seen that only 9% of the residents were well prepared and mostly the residents were moderately prepared as they have experienced the land

subsidence for the first time but the remaining 38% of the residents were not prepared which is a concern for the local community.

3. **Is there any safe area in your community where shelter can be taking place during disaster hit?**

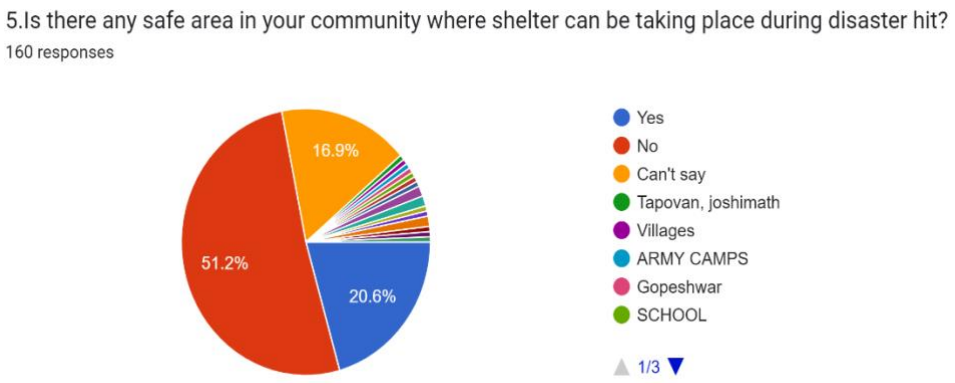
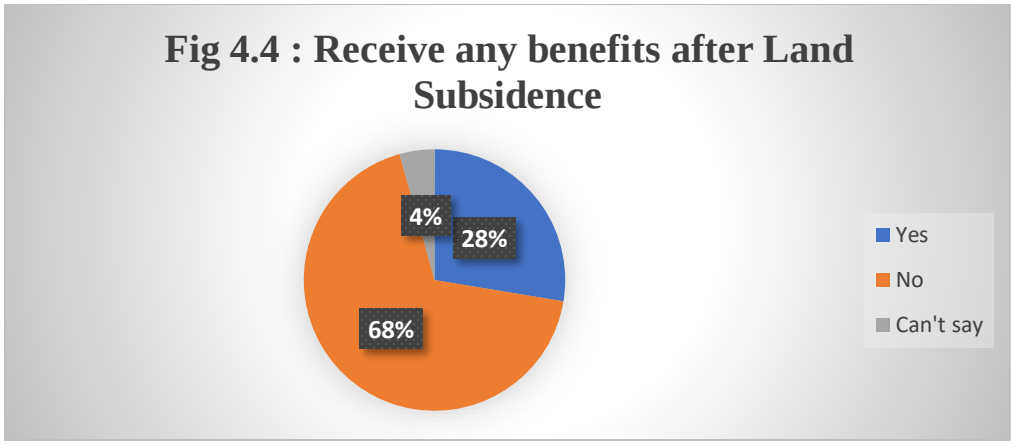


Fig 4.3: Safe areas During Disasters

As per the findings, many respondents almost 51% have responded that there is no safe place during an occurrence of a disaster only 20% have responded and mentioned about safe places like (school, army camps, Gopeshwar etc.).

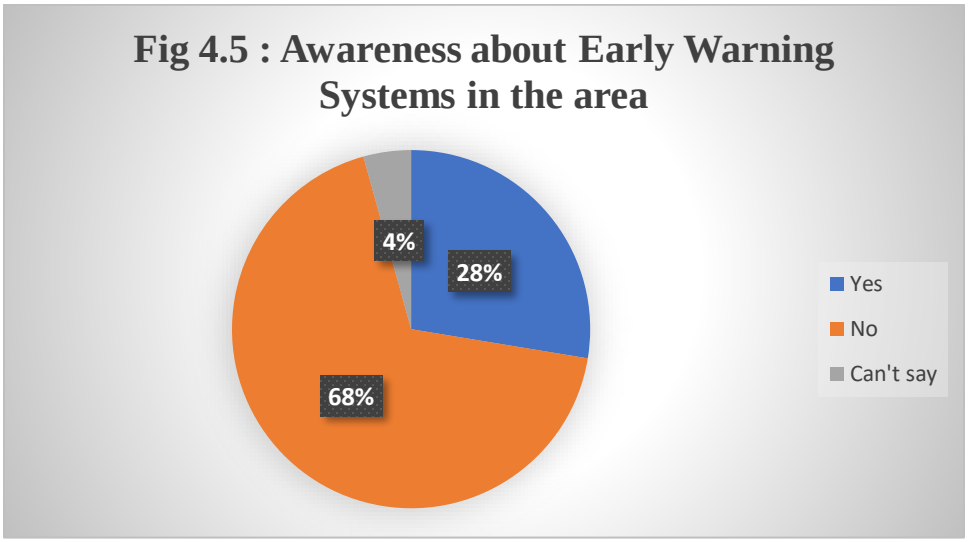
4. **Did you receive any benefits after the land subsidence disaster?**



As per the findings, most of the residents living there haven't received any benefits like compensation of the damaged wealth and property and incurred losses of lives, and many

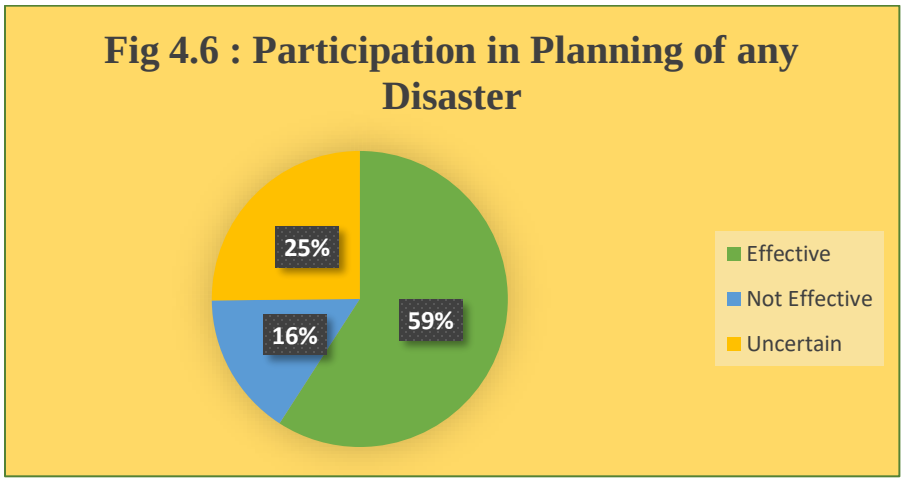
people have received the compensation on the basis of the floors of the houses and not on the size of the land holdings.

5. **Are you aware of any early warning disaster system in your area?**



As per the findings, about 68% of the people were not aware or they had an opinioned that there are no early warning systems installed by the government and very few have awareness about the early warning system and specified that it is installed in Tapovan area.

6. **Do you think a participation in planning of disaster management?**



As per the findings, most of the people believe that participation of the local people in the planning process is important because it is the local people who knows the ground problems of the area and can help in future prevention of any disaster.

CONCLUSION

From the detailed data analysis and study in the Joshimath area, one can make several important conclusions. First of all, the responses of all the respondents are united in their evidence of high physical development across Joshimath during the last ten years. The above development is expressed through urbanization and a high level of construction work, as well as through concerns regarding deforestation, industrialization, and danger of environmental changes. Physical development of the area as well as frequency of such environmental disasters as landslides and flash floods prove the great extent of vulnerability during development. The above is further intensified by rain, earthquakes, and active construction. As emphasized by the respondents, the causes of the phenomenon of land subsidence are diverse and can be as man-made as environmental and natural. Moreover, AP observation also showed the seasonality of tourism – mainly during summer, meaning that the area will need to manage infrastructure and risk. Moreover, the consequences of disasters for livelihoods are striking and include substantial property damage and economic impact. Additionally, the impact of climate change is implicated in altered weather conditions and glacier melting leading to the increase in floods. The government's comprehensive response to disasters, including relocation, compensation, and rehabilitation issues, highlights the prioritized response and the need for mitigation and adaptation measures to be taken into consideration comprehensively. In summary, human activities and natural processes and changes are intricately interrelated and give rise to the vulnerability of the Joshimath area. Hence, it is important to develop effective actions informed from these trustable results to ensure resilience and sustainable development amid shifting populations.

➢ Management Strategies: -

Disaster management is an integrated concept that seeks to reduce the effect of human lives, property and the environment of the vicissitudes of natural or human inhumane acts. Disaster management integrates different aspects, including preparedness, response, recovery and mitigation, to achieve optimal effectiveness in response to disasters. It is in the mitigation element that land subsidence falls under. Land subsidence results from different activities, geology and environmental variations. However, it is crucial to know that human activities account for most of the land subsidence cases. Land subsidence has consequences such as damaging infrastructure, destroying jobs and rendering the environment susceptible to natural disasters, including floods and landslides.

Controlling the sinking of land. Generally speaking, there are two types of policy approaches for supporting cities: adaptation and mitigation. On the other hand, a winning approach most likely incorporates both. Only subsidence caused by humans can be mitigated. Commonly used mitigating strategies include limiting the extraction of groundwater, creating artificial aquifers for recharging, or increasing (phreatic) water levels in regions with rich soils rich in organic matter to lessen the oxidation of organic matter. Lighter construction materials lessen the load on soft soils, which reduces consolidation and subsidence. However, there may be technical difficulties (such as using lighter materials in high-rise buildings), or adaptation strategies may be necessary for budgetary reasons (such as when mitigation costs are too high).

controlling the sinking of land. In general, there are two sorts of city-supportive policies: adaptation and mitigation. A successful strategy, on the other hand, will almost certainly include both. Only human-caused sinking can be mitigated. To reduce organic matter oxidation, common mitigation techniques include reducing groundwater extraction, building artificial aquifers for recharging, and boosting (phreatic) water levels in locations with rich soils. Lighter construction materials lower the load on soft soils, resulting in less consolidation and subsidence. However, technological challenges may arise (for example, adopting lighter materials in high-rise buildings), or adaptation measures may be required for fiscal reasons (for example, when mitigation costs are prohibitively expensive).

➢ Zonation: -

Geological surveys are critical for understanding the underlying geological formations, fault lines, and tectonic activity that cause land subsidence. Remote sensing tools, like as satellite photography, provide vital insights into land cover changes, ground deformation, and elevation variations, allowing for the identification of subsidence-prone locations.

GIS analysis integrates these facts to create zonation maps that categorise various places according to their susceptibility to land subsidence. High-risk zones are often defined as areas with active fault lines, steep slopes, or substantial urbanisation, all of which contribute to ground instability. Field surveys check remote sensing results and analyse local ground conditions, which improves the accuracy of zonation maps.

They help politicians, urban planners, and community stakeholders make sound decisions about land development, infrastructure construction, and disaster preparedness. In high-risk areas, measures may include imposing land-use restrictions to limit construction activity, strengthening essential infrastructure, and establishing early warning systems to mitigate the effects of land subsidence hazards.

Effective zonation of land subsidence areas necessitates coordination among multiple stakeholders, including local governments, research institutes, and citizens. By combining their knowledge and resources, these stakeholders can create complete zonation maps that accurately show the spatial distribution of land subsidence risk in Joshimath. Furthermore, continual monitoring and periodic updates to these zonation maps are required to react to changing environmental conditions and human activities, assuring the region's resilience and sustainability in the face of land subsidence risks.

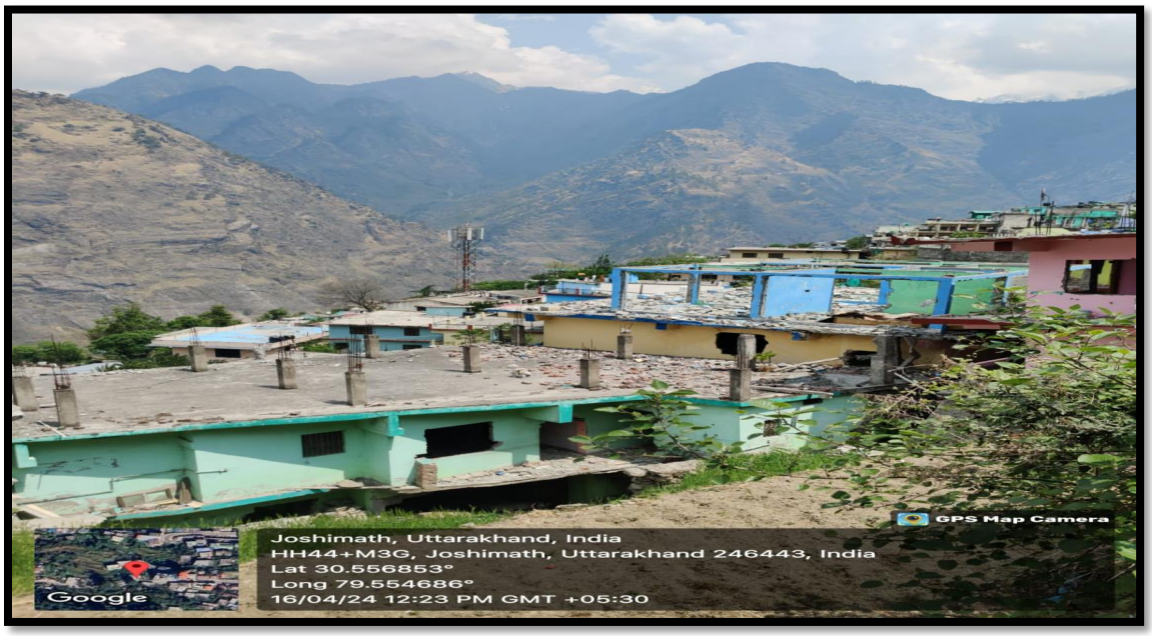


Fig 4.7: Red Zone Areas

➢ Drainage Correction: -

Joshimath's domestic water is expected to naturally flow downstream into the nine naalas that connect the villages and town to the rivers Dhauliganga and Alaknanda. However, as tourism grew and development became rampant, the natural flow of the water was impeded by houses and other structures, causing it to leak out of unexpected places. According to experts, a large portion of this water may have seeped into the ground, weakening the already loose particles in the subsurface. ***"The terrain is based on loose sediments so any kind of water that seeps into this has to be taken care of. The town has small drains, but there is no system to see where the water from these drains goes. They have been constructed in an unscientific manner***," says water policy expert Kavita Upadhyay who is currently a research associate in the Oslo Metropolitan University's Riverine Rights project.

Geologists also found that large amounts of water seeped from the river upstream, loosening the soil in Joshimath. Naala disappears underground and comes to the surface on a downslope, bringing muddy water before joining the Dhauliganga and Alaknanda rivers. Therefore, immediate action is required. Implementation of drainage measures is important to reduce land subsidence in the Joshimath area.

1. Conduct a thorough evaluation to identify places with drainage issues. This includes investigating soil permeability, topography, current drainage infrastructure, and land use patterns. Identify sites where poor drainage causes soil saturation and exacerbates land subsidence.
2. Natural Drainage Restoration: Restore and preserve natural drainage systems, such as rivers, streams, and wetlands. Enhancing these natural features helps to manage water flow, lowering the likelihood of soil saturation and instability. Erosion control and vegetation management can help to promote natural drainage processes.
3. Infrastructure Development: Construct or upgrade drainage infrastructure to effectively manage surface water runoff. This includes installing culverts, ditches, and stormwater drains to channel excess water away from vulnerable areas. Proper design and maintenance are essential to prevent blockages and ensure efficient water evacuation during heavy rainfall events
4. Land Use Planning: Implement land use planning strategies to minimize further exacerbation of drainage issues. Avoid construction in flood-prone areas and protect natural waterways from encroachment. Regulate urban development to reduce impervious surfaces and promote permeable land cover, which helps in groundwater recharge and reduces surface runoff.
5. Community Engagement: Engage local communities in drainage correction initiatives through education and participatory approaches. Raise awareness about the importance of proper drainage and involve residents in decision-making processes. Community

involvement fosters ownership and ensures the sustainability of drainage improvement efforts

6. Integrated Risk Management: Integrate drainage correction measures into broader disaster risk management plans. Coordinate with relevant stakeholders, including local authorities, disaster management agencies, and infrastructure developers, to develop comprehensive strategies that address multiple hazards, including flooding and land subsidence.

Fig 4.8 Drainage System

➢ Relocation and Rehabilitation of the Residents: -

The relocation procedure includes locating acceptable resettlement sites, ideally on solid terrain, away from high-risk locations where additional sinking is likely to occur. To enable a smooth transition for the displaced population, these places are evaluated for things like accessibility, the availability of essential services, and chances for employment. In order to lessen the immediate effects of the disaster, efforts are being undertaken to offer temporary shelters and necessities to individuals who have been affected.

Rehabilitation is more than just moving somewhere else. They include efforts for community reconstruction, livelihood restoration, and psycho-social support. Counselling services are offered to assist people in overcoming the trauma of loss and relocation. The introduction of job possibilities and skill development programmes also helps the people rebuild their lives in the new community. Projects to improve community infrastructure are also carried out to help the displaced residents feel a feeling of solidarity and belonging.

Furthermore, the government is dedicated to making sure that the relocation and restoration projects are sustained over the long run. This entails putting policies in place to stop land subsidence in the future by using scientific methods including geological surveys, land-use planning, and the enforcement of building codes. In addition, continuous monitoring and assessment procedures are implemented to appraise the success of the relocation and rehabilitation initiatives and to handle any new issues or requirements of the impacted populations.

Fig 4.9 Request for Rehabilitation

- **COMMUNITY BASED DISASTER MANAGEMENT**

Case Study: -

In 2023, a devastating land subsidence struck Joshimath, causing widespread destruction and loss of life. Google's Crisis Response team, in collaboration with local authorities and humanitarian organizations, initiated a comprehensive disaster management effort to provide critical information and support to affected communities.

Google utilized its technology and platforms to raise awareness, facilitate communication, and coordinate response efforts: -

Crisis Map: -
Google launched a Crisis Map for Joshimath, a dynamic online platform that aggregated real-time information on the land subsidence impact, including affected areas, shelters, medical facilities, and road conditions. This map served as a centralized hub for both responders and affected individuals to access critical information and resources.

Person Finder: -
Google's Person Finder tool was deployed to help reunite families and loved ones separated during the disaster. Users could submit information about missing persons or search for information about individuals affected by the Joshimath, providing a valuable resource for families seeking to reconnect

Public Alerts:
Google collaborated with local authorities to disseminate public alerts and safety information through its platforms, including Google Search, Google Maps, and Google Now. This helped raise awareness among affected communities and provided guidance on evacuation procedures, emergency contacts, and other critical information.

Outcome and Impact: -
Google's crisis response efforts in Joshimath had a significant impact on the disaster management and recovery process: -
Information Accessibility: The Crisis Map and Person Finder tools provided vital information to responders and affected individuals, facilitating more efficient response and recovery efforts.
Reunification of Families: The Person Finder tool helped reunite thousands of families separated by the land subsidence, providing much-needed emotional support and relief to affected individuals.
Public Awareness: Google's public alerts and information dissemination efforts raised awareness among affected communities, empowering individuals to take proactive measures to protect themselves and their families during the crisis.

Conclusion: - Google's Crisis Response team demonstrated the power of technology and collaboration in enhancing community awareness and disaster management efforts during the land subsidence in Joshimath. By leveraging its platforms and expertise, Google played a crucial role in providing critical information and support to affected communities, ultimately contributing to the response and recovery process. This case study underscores the importance of leveraging technology and partnerships to build resilience and enhance disaster preparedness in vulnerable regions.

➢ ENGINEERING SOLUTIONS: -

Retaining walls: They should be engineered, designed to withstand the lateral earth pressures and surcharges expected, and drains should be included to prevent water pressures developingin the backfill.

Sewage: Whether treated or not, sewage must be taken away in pipes or contained in properly founded tanks so it doesn't soak into the ground.

Surface water: Properly drained from roofs and other hard surfaces shall be piped away to a suitable discharge point rather than being allowed to infiltrate into the ground.

Surface loads: They must be minimized. Fill embankments should not be built. Foundation loads should be taken down below the level at that a landslide is likely to occur and, preferably,to rock.

Vegetation clearance: On soil slopes, it shall be kept to a reasonable minimum. Trees and smaller vegetation, take large quantities of water out of the ground every day lowering the ground water table, eventually maintaining the stability of the slope.

Drainage: Flexible drainage pipes are must to ensure the removal of excess water from soil, whether its storm water or irrigated water.

Groundwater Management: - Land subsidence can be avoided by implementing groundwater management strategies to control groundwater extraction and avoid excessive aquifer depletion. This could entail putting in groundwater recharge systems, monitoring wells, and water-saving measures.

Soil Management Techniques: - using methods for stabilising soil, such as soil bioengineering, to strengthen soil slopes and stop erosion. This method uses vegetation and biodegradable materials. Furthermore, slopes that are vulnerable to subsidence can be stabilised with the use of geotechnical solutions including retaining walls, slope reinforcement, and soil nailing.

Slope Stabilisation: - grading, benching, and terracing are examples of slope stabilisation techniques that can be used to lessen slope steepness and increase stability. To stabilise unstable slopes and stop mass movement, retaining walls, soil anchors, and rock bolts may also be used.

Early Warning Systems: - putting in place early warning systems that use rainfall radar, stream gauges, and weather stations to collect data in real-time and send out timely alerts to communities who are at risk. These devices can assist locals in leaving for safety and reduce the number of people and things lost during a flash flood.

Fig 4.10 Engineering Solutions (Gabions Walls)

CONCLUSION

The Joshimath town, a centre piece of religious and tourist destination, is tectonically fragile landscape in the Northwestern Himalayas. Various anthropogenic activities like rapid urbanization, construction of hydropower projects and ingress of groundwater due to tunnelling are some of the major factors resulting in the land subsidence.

Additionally, since 1960s, the population of the Joshimath town has increased manifold. There is also an increase of about 20% in the built-up area in and around of the town within a span of about four years (2017–2020). Moreover, the Joshimath town lies on an ancient landslide and in the vicinity of major structural discontinuities, i.e., **Main Central Thrust (MCT) and Martoli Thrust**, which act as a catalyst and exaggerated the impacts of the subsidence.

The repercussions of this land subsidence have been significant. Over 3000 people have been affected, with at least 66 families forced to flee their homes. An unsettling 561 houses have reported structural cracks, rendering them unsafe.

The emerging threats induced by the land subsidence pose a challenging task for the government and engineering geologists for the future developmental activities. Further, there is a need to construct an integrated framework involving scientific communities, stakeholders, policy-makers, and local people to mitigate and minimize the losses due to such disasters.

As Joshimath grapples with the complex issue of land subsidence, proactive measures and scientific intervention are essential to mitigate further damage and ensure the safety of its residents. The situation serves as a reminder of the delicate balance between human development and the preservation of the natural environment.

RECOMMENDATIONS

Uttarakhand is very much prone to the land sliding equally in all its districts caused by its geographical location. There are many areas where the concerned authority must focus, theyare mentioned below:

Formation of taskforce at Villages: -

The possible village volunteer's taskforce members can be: -
Ex-service Men/NCC/NSS/Swimmers, Gram Rakhi/ Chowkidar, Anganwadi Workers /ANM, School Teachers, Youth Club Members/ Self Help group/Farmer group.

Institutionalising the process: -

The sustainability of Community Based approaches can be ensured by institutionalizing the process.
Contingency plan linked with Village/ GP Development plan, Emergency disaster management kit at village, recognizing and capacity building through trainings of the task force, involving the task force in other activities such as preparation of Social map, Resourcemap, Vulnerability/ Risk map, Safe/Opportunity map and development of Mitigation Strategy.
Mitigation Strategy mainly consists of:

- Accurate and timely warning system
- Food and Medicine kits at Safe shelters
- Trained personnel at all safe shelters
- Identification and registration of risk groups
- First evacuate the risk & vulnerable groups
- Provisions of basic need to the vulnerable groups

This all must be ensured by the collaboration between government and locals. Under 73rd and 74th constitutional amendments, the village panchayats and ULBs have the powers to initiate preparedness, mitigation, recovery and rehabilitation measures. They must receive anannual fund from government to make the mitigation plans at their level and local resources.

Indigenous Technological Knowledge for combating disasters: -

R&D groups must evaluate and seek solution of the concerned problem from the local techniques and ensure applicability over the temporal scale at particular place by sending adisaster management expert.

Uses of social media is Disaster Management: - As we are living in the social media world, we should use this technology as an opportunity tospread the awareness about dangers among the stakeholders and keep them updated at low cost and easy accessibility.

Social media offers varying capabilities and levels of interactivity. Media-Sharing Networks:Media-sharing networks provide users the ability to upload photos, videos, or slide presentations and share them in a public forum. Within emergency management, media- sharing networks allow community members to post geographically identified (i.e., geotagged) photos and videos captured on smartphones. This content can then be used to create crisis maps, which display social media content by location. Examples of media- sharing networks include Flickr, Instagram, Picasa, Pinterest, SlideShare, and YouTube.

Community Forums: Community forums are online discussion sites that give users the abilityto create content, comment on posts by other users, and upload and share files. Within emergency, they can also serve as a valuable source of information and resources following adisaster. Organizations interested in building and hosting a community forum can use tools and services.

Fig 1: Early Warning Systems

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APPENDIX

Land Subsidence in Joshimath Area

Field Survey Interview Schedule: Households Survey

A. Background of the Respondent

Name of the Respondent…… Age……..

Gender: ……. Marital Status: …… Educational qualification …….

What is your major source of income?.....

Name of the head of household.……...…… Relation with the head of household……

How long have you been living in Joshimath?.....

Contact no. & address……

B. Causes and Consequences of Land Subsidence

1. Do you think the physical landscape of Joshimath has changed over the years?

   i. Urbanization ii. Industrialization iii. Deforestation iv. Glacier retreat v. All of them

2. Do you think that the constant growth of habitation, deforestation, and construction practices increased the surge loads over unstable slopes?

   i. Yes ii. No iii. Can't say

3. Do you think that construction activities have disrupted natural drainage and settlement units have poor sewage systems, leading to flash floods?

   i. Yes ii. No iii. Can't say

4. In continuation (above), more seepage can be expected, which increases the potential of land subsidence?

   i. Yes ii. No iii. Can't say

5. Are you aware of any historical incidences of land subsidence beyond 2023?
   i. Yes ii. No iii. Can't say
6. Have you personally observed any signs of land subsidence in your area?
   i. Yes ii. No iii. Can't say
7. What is the status of river flow in your area?
   i. Increased ii. Decreased iii. Constant iv. No idea
8. Do you think your area has become more vulnerable after the landslide?
   i. Yes ii. No iii. Can't say
9. Do you believe that being a landslide area, Joshimath town is highly vulnerable to any type of developmental activities?
   i. Yes ii. No iii. Can't say
10. Do you know that the entire Joshimath landscape is unsuitable for developing townships?
   i. Yes ii. No iii. Can't say
11. What are the triggering factors that make the area vulnerable to many natural hazards?
   i. Frequent earthquakes ii. Heavy rainfall iii. Absence of normal fault
   iv. Complex fault system (fractured and jointed rock masses) v. Others (specify)
12. What could be the possible cause of land subsidence in your area?
   i. High physical weathering ii. Diurnal temperature contrast iii. Deglacial process
   iv. Climate crisis v. Disintegrated bedrock structure vi. Weakening strength of hill slope
   vii. Changes in land use and land cover viii. All of them ix. None of them
13. Do you know that the entire area is on fragile sand and stone?
   i. Yes ii. No iii. Can't say

C. *Impact of Land Subsidence*

1. Do you know that vibrations produced by blasting and heavy traffic have developed disequilibrium in the surroundings?
   i. Yes ii. No iii. Can't say
2. In which season, is there an influx of maximum tourists?
   i. Summer ii. Winter iii. Spring iv. Autumn v. Rainy

3. Do you agree that a significant number of tourists are increasing the risk exposure during Char Dham Yatra?

   i. Yes ii. No iii. Can't say

4. Do you agree to allow tourists in your area after Joshimath land subsidence?

   i. Yes ii. No iii. Can't say

5. What have you loss/damage during land subsidence in Joshimath?

   i. Home ii. Family iii. Cattles

   iv. Job v. Property vi. Others

6. How has the climate change impacted the physical environment?

   i. Glaciers melting ii. Altered precipitation iii. Flash floods

   iv. Increase in weather extremity v. All of them

7. Are you aware of what kind of damage assessment has been done so far due to subsidence of the ground in Joshimath?

   i. Many residents have been shifted to temporary shelters
   ii. Many shops, hotels, and essential places like health centers, schools, and Government offices have also faced severe damage
   iii. Cable car service running between Joshimath to Auli has also been stopped due to the development of ground cracks around the connecting towers.
   iv. Army camp located in this area has also been affected.
   v. All of the above
   vi. None of the above

8. Do you know that the local climate of Joshimath favors snowfall events, especially in the winter periods, and after the snow melts, it creates excessive water recharge in the ground, leading to saturated soil, followed by the underground subsidence.

   i. Yes ii. No iii. Can't say

9. How often do you feel the land subsidence is one of the major causes and concerns for threatening human life and biodiversity?

   i. Always ii. Occasionally iii. Never

10. Do you think that Rishi Ganga debris flood incident caused toe cutting of Joshimath hill and accelerated instability in upslope regions?

    i. Yes ii. No iii. Can't say

D. Initiatives taken by Peoples and Governments

1. What is the government's response to land subsidence?

   i. Identifying root cause ii. Developing plans for future mitigation iii. Sustainable management

   iv. Demarcation of unsafe households v. Rehabilitation of affected residents vi. All of them

2. Are you aware that it is advised not to remove boulders by digging or blasting the hillside for road repairs and other construction purposes?

   i. Yes ii. No iii. Can't say

3. Do you know that cutting trees for supplying townships with timber, firewood, and charcoal is strictly regulated?

   i. Yes ii. No iii. Can't say

4. How you look on a capacity of your community toward various disasters?

   i. well-prepared ii. Moderately prepared iii. No preparation

5. Is there any safe area in your community where shelter can be taking place during disaster hit?

   i. yes ii. No iii. Can't say

   If yes, where is that area……..

6. Has the community as you know, ever been involved in planning in any disaster management?

   i. Yes ii. No iii. Can't say

7. Do you think a participation in planning of disaster management

   i. Effective ii. Not effective iii. Uncertain

8. Do you think that the plantation of trees both in short term and long term brought some positive changes?

   i. Yes ii. No iii. Can't say

9. What could be the future direction to avoid such a disaster in a highly fragile landscape?

   i. Relocation of vulnerable residents
   ii. Improvement of water discharge system
   iii. Reduce excess pore-water pressure
   iv. Effective implementation of town planning policies and practices
   v. Installation of a disaster resilient system
   vi. Thorough investigation before initiating any developmental activities
   vii. Continuous monitoring of the area using advanced technologies (ground or satellite-based system)
   viii. All of the above

10. Did you receive any benefits after the land subsidence disaster?

    i. Yes ii. No iii. Can't say

11. Are you aware of any early warning disaster system in your area?

    i. Yes ii. No iii. Can't say

    If yes, then where…….

12. Are you aware of government initiatives to mitigate land subsidence in Joshimath area?

    i. Yes ii. No iii. Can't say

13. Have you got any support from

    i. local authority ii. State government iii. Union government iv. NGOs v. Military forces

14. If your property damaged during disaster, then

    i. Do you repair it ii. Leave it iii. Not repairable

15. Mitigation strategies taken by local authorities after the disaster

    ……

    ……..……

    ……..……

    …….

16. What could be the best possible solution to avoid such disasters in the future?

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……..……

……..……

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