VIDYASAGAR UNIVERSITY

MUGBERIA GANGADHAR MAHAVIDYALAYA

DEPARTMENT OF GEOGRAPHY

A PROJECT REPORT
ON
LAND SUBSIDENCE AND STRUCTURAL COLLAPSE OF JOSHIMATH, UTTARAKHAND

SUBMITTED BY- SUSMITA JANA
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Mugberia Gangadhar Mahavidyalaya

Bhupatinagar :: Purba Medinipur

West Bengal :: India

Email: mugberia_college@rediffmail.com

NCTE Recognized & NAAC Accredited with CGPA 2.71 Institution

http://www.mugberiagangadharmahavidyalaya.org

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This is to certify that Mr./ Miss. **SUSMITA JANA**

Roll **1126129** *Number* **200070** *a PG / UG student of*

SEM **VI**, *Department of* **Geography** *has*

successfully completed a dissertation / project entitled

LAND SUBSIDENCE AND STRUCTURAL COLLAPSE OF JOSHIMATH, UTTARAKHAND

for the paper **CC 14** *in the year* **2023**

Date : **07/08/2023**

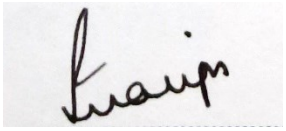
Signature of HOD

Signature of Principal

Principal
Mugberia Gangadhar Mahavidyalaya

BONAFIDE CERTIFICATE

This is to certify that the project work entitled, ‘‘Land subsidence and structural collapse of Joshimath, Uttarakhand” is a bonafide record of the project work under taken and completed by **SUSMITA JANA** Under my guidance and supervision during the academic session 2022-2023, submitted to Department of Geography, Mugberia Gangadhar Mahavidyalaya, for Partial fulfilment of the requirement for the degree of B.Sc in Geography.



Place: Mugberia
Date: 07/08/2023

Signature of supervision
Irani Banerjee Chatterjee

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To construct the project report successfully there is needed a lot of help from different fields. I would like to express deepest gratitude to all those who have guided and associated me for completing this report

On

Land Subsidence and Structural Collapse of Joshimath, Uttarakhand

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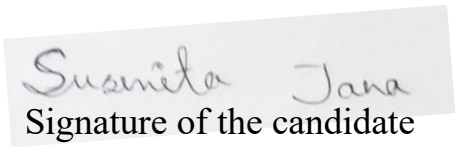

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Introduction

Land subsidence refers to the gradual or sudden sinking of the Earth's surface due to various natural and human-induced factors. Land subsidence can be triggered by both natural and human activities. Natural causes include earthquakes, glacial isostatic adjustment (the slow uplift or subsidence of the Earth's crust after glaciations), soil compaction, erosion, sinkhole formation, and the addition of water to fine soils, which can lead to settlement. Human activities, such as resource extraction (e.g., mining, fracking), groundwater pumping, drilling for oil and gas, and the removal or shifting of underground elements, can also cause subsidence[1].

1. **Human Activities and Infrastructure:** Human activities like resource extraction, especially when done on a large scale, can lead to the subsidence of the land. When water, oil, gas, or other resources are extracted from the ground, the removal of these materials can create voids or empty spaces underground, causing the surface to sink or collapse[2]. Similarly, heavy infrastructure loads, such as buildings, bridges, and roads, can exceed the carrying capacity of the underlying soil, leading to subsidence.

2. **Natural Causes:** Apart from human activities, subsidence can also occur naturally. Earthquakes can cause the sudden sinking or shifting of the Earth's surface, and weathering processes over time can compact soil, leading to gradual subsidence. Glacial isostatic adjustment, a process that occurs after glaciers receed, can also result in land subsidence or uplift in certain regions.

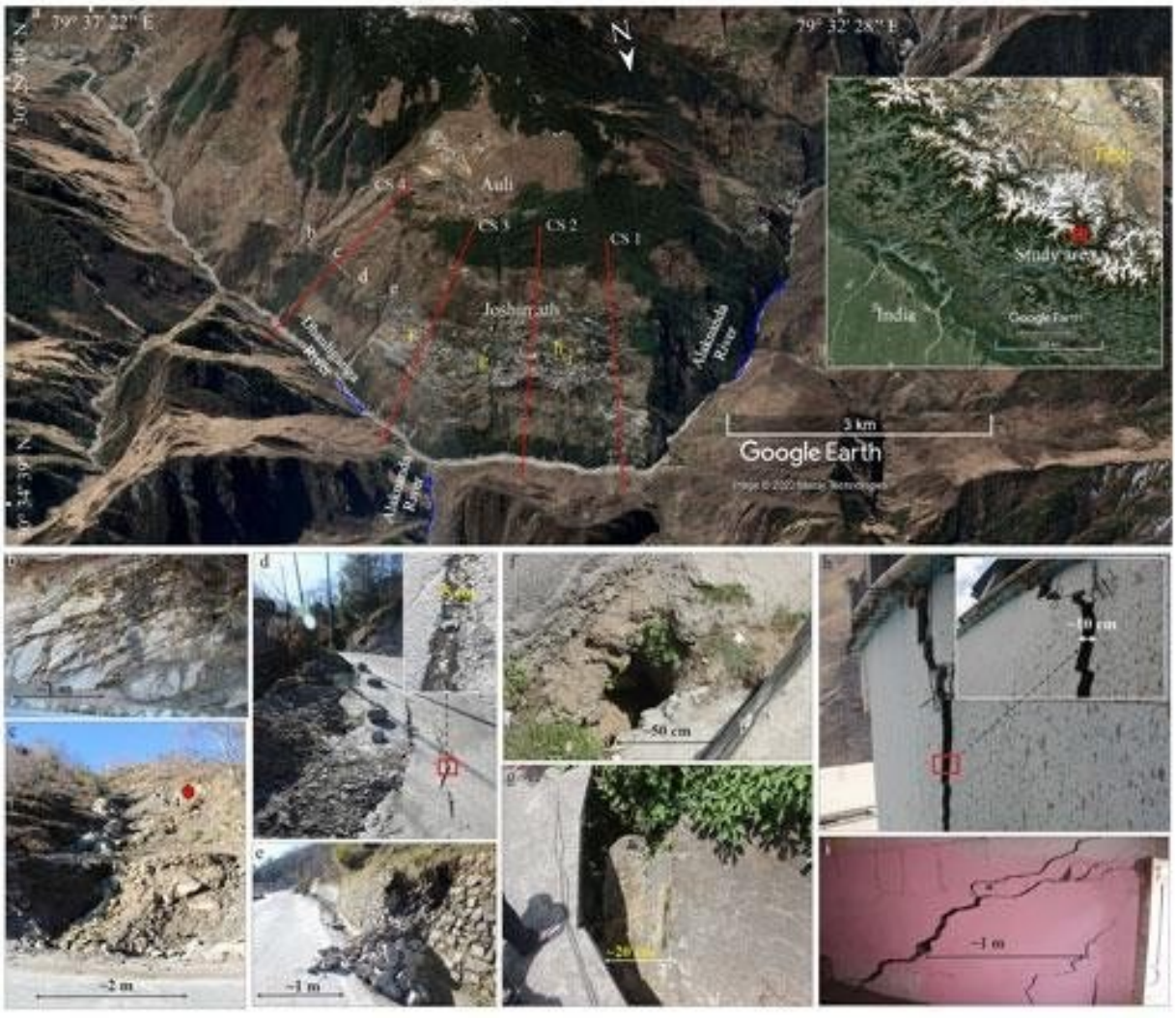
Overall, land subsidence is a significant geological phenomenon that can have serious consequences for the environment, infrastructure, and human populations in affected areas. Monitoring and understanding the causes of subsidence are crucial for managing its impacts and mitigating risks.

Land subsidence measurement:

The tool for identifying and mapping any land-surface movement is interferometric synthetic aperture radar (InSAR). The utilization of repeat-pass radar pictures from Earth-orbiting satellites by InSAR allows for incredibly detailed monitoring of subsidence and uplift. Assessments of the InSAR data can be made to better our understanding of the subsidence mechanisms after subsidencehas been recognized and mapped. The subsidence brought on by the use of our water and land resources can be reduced by scientific understanding and careful management of natural resources (United States Geological Survey, 2019)[3]. A landslip is a type of mass wasting that occurs when a large amount of rock, soil, or debris moves down a slope due to the force of gravity[4]. Landslides are further classified into five types based on their movement, including collapses, tilts, slips, spreads, and flows. These types are categorized into bedrock, debris, and earth depending on the type of geological material involved. Debris flows are also called mudflows or mudslides, while rock falls are common forms of landslides. This information is from the United States Geological Survey. TheHimalayas, the world's tallest mountain range, are located in India. They were created when the Indian and Eurasian plates collided. As the Indian plate moves northward towards China, it continuously stresses the rocks, making them weak, friable, and vulnerable to earthquakes and landslides. Natural disasters are said to be caused by the Indian crust's sluggish motion, which accumulates tension at a rate of roughly 5 cm each year. Some landslides cause unmatched and singular calamities. Together with avalanches and landslides are most occurring disasters in this region and considered among primary hydrogeological hazards that have a substantial impact on large areas of India. These mountain ranges, representing for around 15% of the continent, comprisethe Himalayas, the, the Western Ghats, the Nilgiris, the Eastern Ghats, Northeastern hill ranges and the Vindhyans. Only the Himalayas can claim to have experienced landslides of every kind—large and small, swift and slow, old and recent. Landslide issues of an astounding variety are a serious problem in the Northeastern region. Landslides continue to be a major issue in several states of India, including Sikkim, Mizoram, Tripura, Meghalaya, Assam, Nagaland, and Arunachal Pradesh, as well as the Darjeeling region in West Bengal. To address the issue of landslides, measures need to be taken for reducing their impact and effectively dealing with them. This involves identifying hazard zones, stabilizing and managing unstable slopes, and implementing monitoring and early warning systems in specific areas. (Uttarakhand State Disaster Management Authority, n.d.)[5] 1 Yaspal Sundrial et al. (2023) studied the sinking land in two towns in Uttarakhand, India, due to

various factors like seismic stress, domestic discharge, building load, and rainfall[6]. Jurgen Mey et al. (2023) focused on landslides that obstruct the National Highway (NH-7) between Rishikesh and Joshimath in Uttarakhand, India, by mapping the areas where landslides occur and identifying the environmental factors that influence their occurrence[7]. Abdullah Tabish Ahmed et al. (2017) provided an overview of the types of disasters that affect India and the geographical locations that are prone to them, along with an analysis of India's paradigm change in disaster management[8]. The structural collapse that occurred in Joshimath, Uttarakhand on January 2023 stressed on the need forurban planning to minimize environmental shocks and risks in the face of economic and demographic growth.

Satellite photographs captured by the Cartosat-2S satellite and issued by the National Remote Sensing Centre (NRSC) of the Indian Space Research Organisation (ISRO) have revealed that Joshimath may soon face complete submersion due to land subsidence[9].



The present report focuses on Joshimath's land subsidence crisis and how the disaster affects life in the small town of Joshimath.

The present report has been divided into three parts:

Part I: The Study Area

This part deals with the location of the study area. Data regarding the physical and demographic details of the area (Joshimath) area are also mentioned here. This chapter puts the study area of Joshimath into the focus of study. Without this chapter, the background study of the area and the impact of the collapse would have been incomplete.

Part II: The Problem

This part of the report focuses on the problem of structural collapse of Joshimath on January 2023 and gives a detailed study on the reasons of the collapse.

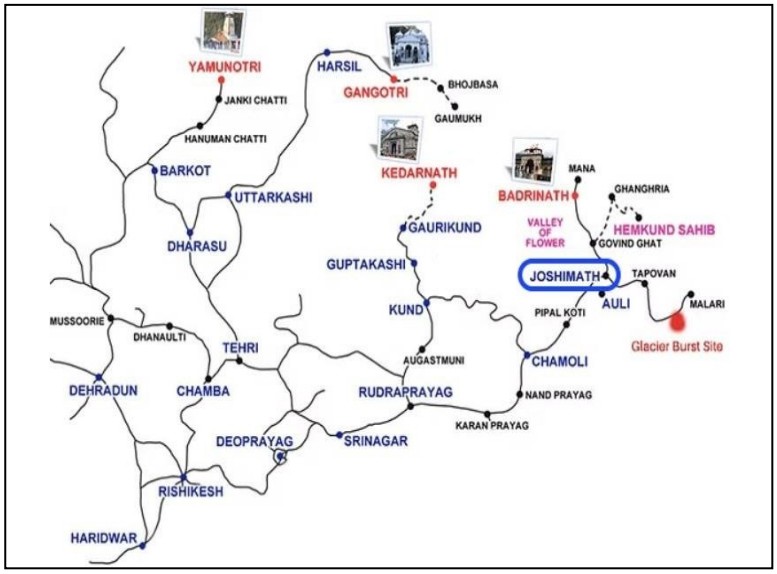
Part III: The Management

This part deals with the management decisions taken up by the government and other stakeholders to deal with the problem.

In the final section of this part, future recommendations are suggested that can overcome such problems of land subsidence and structural collapse in near future.

PART I: THE STUDY AREA

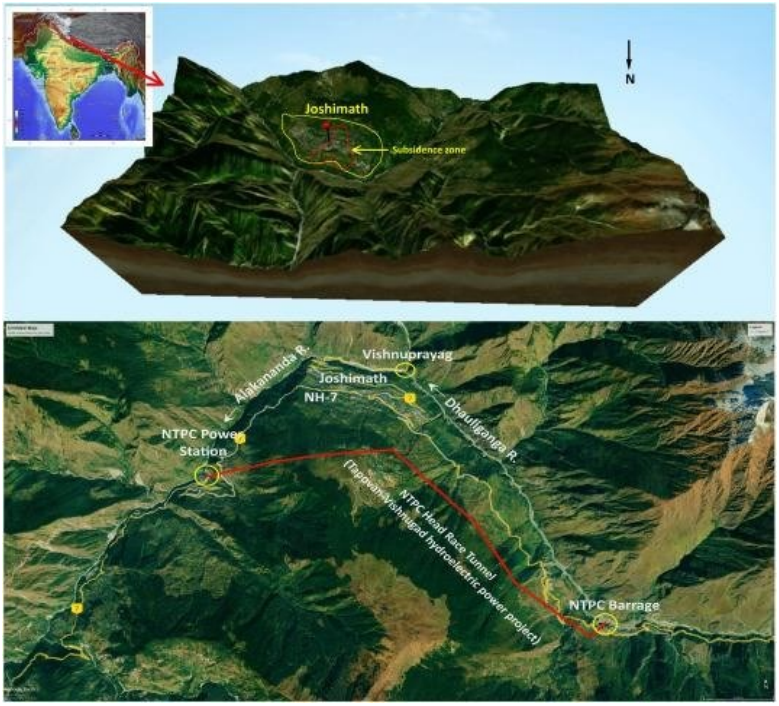
The study area in the report is Joshimath, a small CD block of Chamoli district in Uttarakhand which is known for being the winter abode of lord Badrinath, a resting place for tourists visiting the Valley of Flowers and located at a close vicinity to Auli, one of the India's top ski destination[10], anda staging ground for troops headed to the India-China de-facto border. Joshimath is more than just a quiet scenic town in the foothills of the Himalayas. The area is important in both as a tourist destination, a religious pilgrimage and a political as well as strategic point.



Location of Joshimath

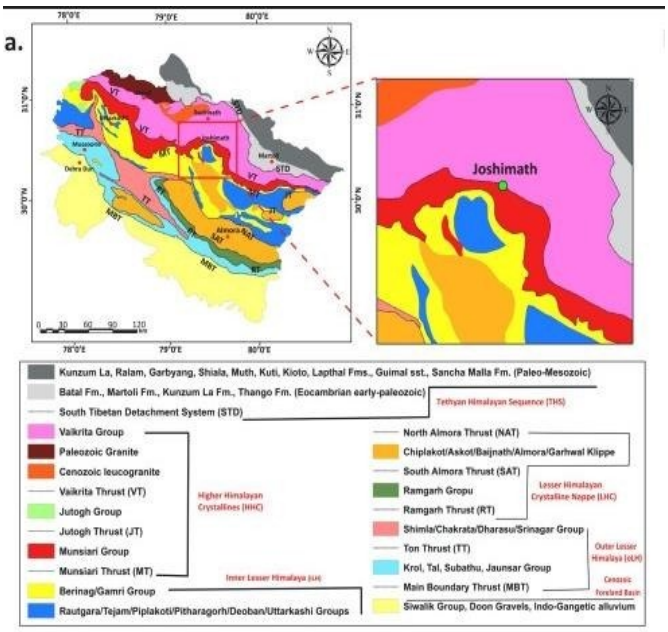
Located at 30.5561° N, 79.5617° E, Joshimath is one of the six tehsils (blocks) in Uttarakhand's Chamoli district, spread over an area of 2458 square kilometers. It is located at over 6,000 feet (1,890 metres) in the Garhwal Himalayas mountain ranges. As per the 2011 Census, it had a population of 16,709[11] up from 13,202 in the 2001 Census, a decadal rise of around 27 percent[12]. In 2023, its population is estimated to be approximately 22,900[13].The town is a gateway to pilgrimage sites such as the Badrinath Temple and Hemkund Sahib, is the starting point for several mountain-climbing expeditions9. Besides located at such a picturesque landform, Joshimath is strategically located near the India-China border and hence serves as a majorbase camp for the Indian army and the road structure passing through the Joshimath is of great strategic importance.

The town (fall in high-risk seismic Zone-V) is traversed by running streams with a high gradient from Vishnuprayag, a confluence of the Dhauliganga and the Alaknanda rivers[14]. It is home to one of the four cardinal maths or monasteries established by Adi Shankara - Sringeri in Karnataka, Dwarka in Gujarat, Puri in Odisha and Joshimath near Badrinath in Uttarakhand.



Geological setting of the study area

The Alaknanda River catchment is underlain by both sedimentary and highly metamorphosed gneissic rocks (Gansser, 1964)[15]. Lithologically, the Alaknanda River traverses through the Tethyan Sedimentary Sequence (TSS), Higher Himalayan Crystalline (HHC) and the Lesser Himalayan Metasedimentaries (LHM) (Robert et al, 2020)[16]. The Alaknanda River catchment is underlain by both sedimentary and highly metamorphosed gneissic rocks (Gansser, 1964; Valdiya, 1980). In its upper course, the Alaknanda river flows through the Central Crystalline zone, which is composed of migmatized and granitized Archaean metasediments. After passing through the Central Crystalline, the river traverses through limestones, marbles and quarzitic sequences of the Tejam and Berinag Formations, limestone and dolomite-bearing Uttarkashi Formation and the outcrops of phyllite and micaceous graywackes of the Chandpur Formation before its confluence with the river Bhagirathi (Singh et al. 1998)[17].



Socioeconomic Data of the Study Area: Joshimath

1. CD data

Joshimath is a Nagar Palika Parishad city in district of Chamoli, Uttarakhand. As per census 2011 town code of Joshimath is 800291.

Joshimath Town/City Data ---Census 2011

Description	Data
Town Name	Joshimath
CD Block Name	Joshimath
Teshil Name	Joshimath
Reference Year	2009
Sub District HQ Name	Joshimath
Sub District HQ Distance	0 Km
District HQ Name	Gopeshwar
District HQ Distance	67 Km
Nearest City of 1 Lakh Population	Dehradun
Nearest City of 1 Lakh Population Distance	286 Km
Nearest City of 5 Lakh Population	Dehradun
Nearest City of 5 Lakh Population Distance	286 Km

The Joshimath city is divided into 9 wards for which elections are held every 5 years. The Joshimath Nagar Palika Parishad has population of 16,709 of which 9,988 are males while 6,721 are females as per report released by Census India 2011.

Population of Children with age of 0-6 is 2103 which is 12.59 % of total population of Joshimath (NPP). In Joshimath Nagar Palika Parishad, Female Sex Ratio is of 673 against state average of 963. Moreover Child Sex Ratio in Joshimath is around 866 compared to Uttarakhand state average of 890. Literacy rate of Joshimath city is 91.28 % higher than state average of 78.82 %. In Joshimath, Male literacy is around 95.23 % while female literacy rate is 85.19 %. Total number of house hold in Joshimath is 3898.

Census Data of Joshimath District Chamoli, State Uttarakhand- India --Census 2011

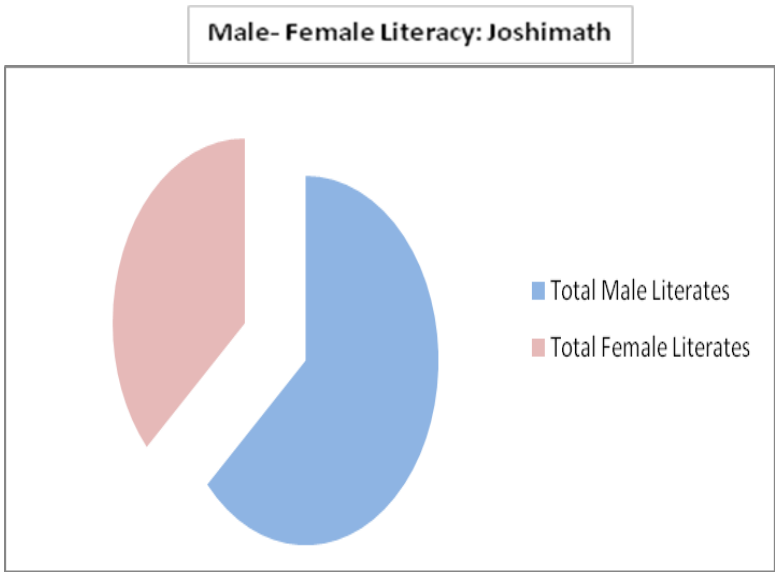
Population	Area (Ha)	Density (P/Ha)	Sex Ratio	Literacy
16709	11.49	1454	673	91.28%

Population of Joshimath , District Chamoli in state Uttarakhand, India

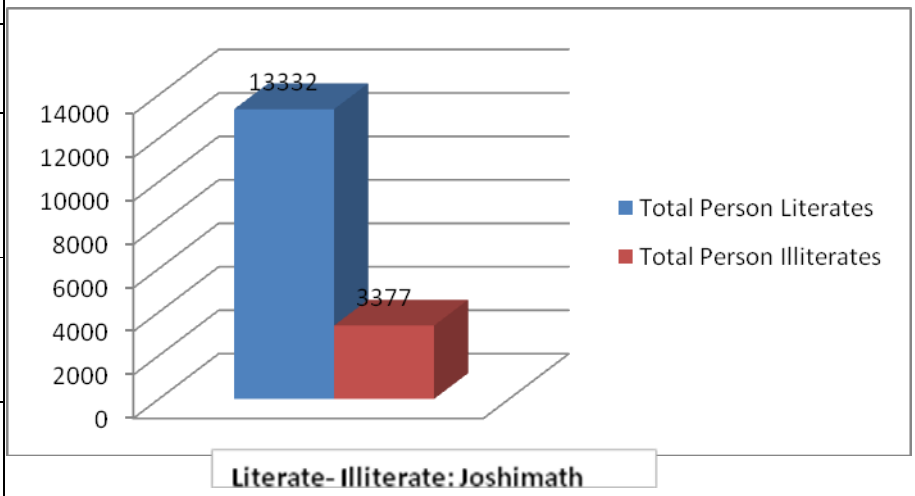
Total Population	Male Population	Female Population
16709	9988	6721

Joshimath Town Census 2011 Data ---Census 2011

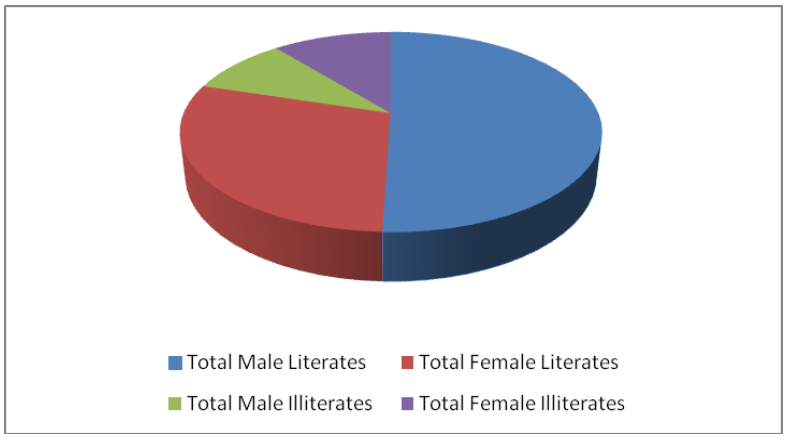
Description	Census 2011 Data
Town Name	Joshimath
Civic Type	NPP
Teshil Name	Joshimath
District Name	Chamoli



State Name	Uttarakhand
Total Population	16709
Total No of House Holds	3898
Total Male Population	9988
Total Female Population	6721
0-6 Age group Total Population	2103
0-6 Age group Male Population	1127
0-6 Age group Female Population	976
Total Person Literates	13332
Total Male Literates	8438
Total Female Literates	4894
Total Person Illiterates	3377
Total Male Illiterates	1550
Total Female	1827



Illiterates	
Scheduled Cast Persons	2343
Scheduled Cast Males	1284
Scheduled Cast Females	1059
Scheduled Tribe Persons	884
Scheduled Tribe Males	827
Scheduled Tribe Females	884



Literate- Illiterate: Joshimath

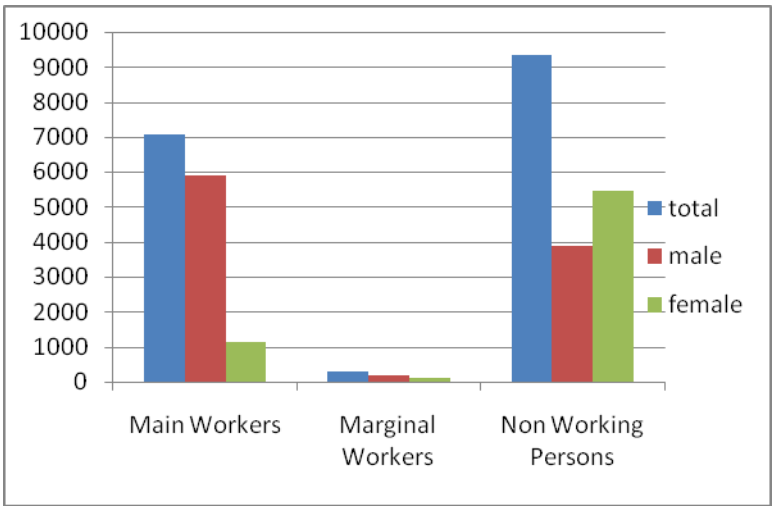
Workers profile of Joshimath

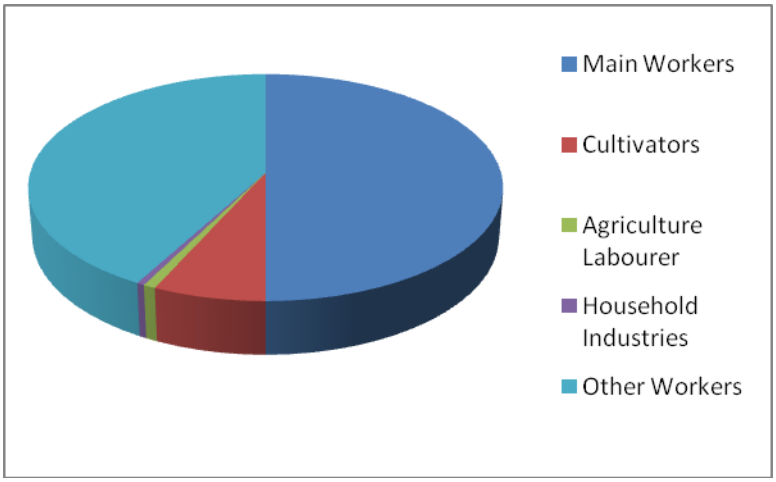
Total working population of Joshimath is 7368 which are either main or marginal workers. Total workers in the town/city are 7368 out of which 6102 are male and 1266 are female. Total main workers are 7068 out of which male main workers are 5915 and female main workers are 1153. Total marginal workers of Joshimath are 300.

Joshimath town Working Population ---

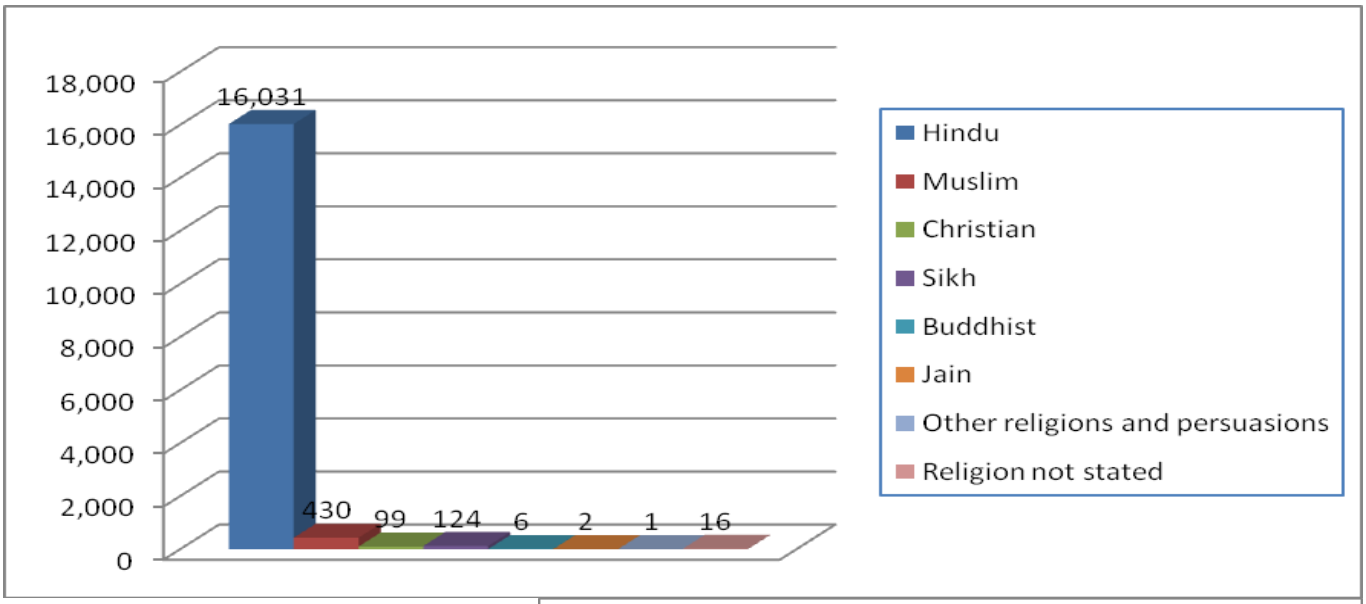
Census 2011

	Total	Male	Female
Total Workers	7368	6102	1266
Main Workers	7068	5915	1153
Cultivators	962	398	564
Agriculture Labourer	106	87	19
Household Industries	66	24	42
Other Workers	5934	5406	528
Marginal Workers	300	187	113
Non Working Persons	9341	3886	5455

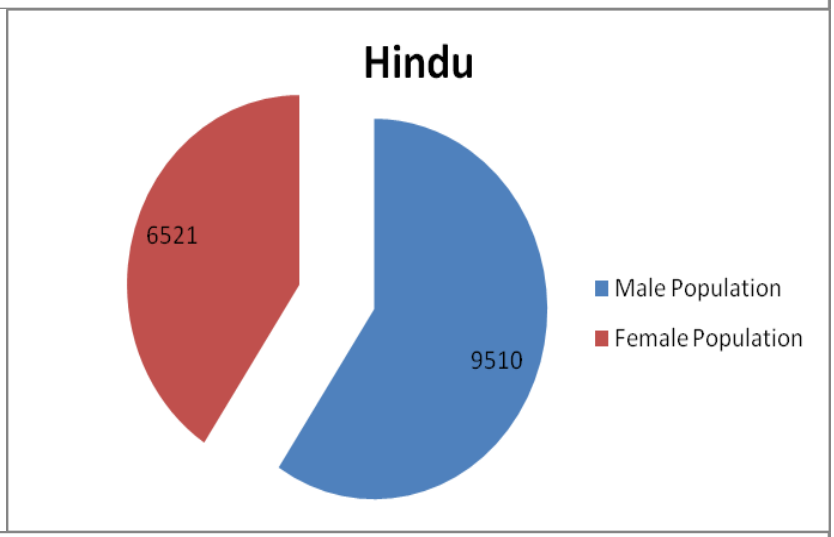


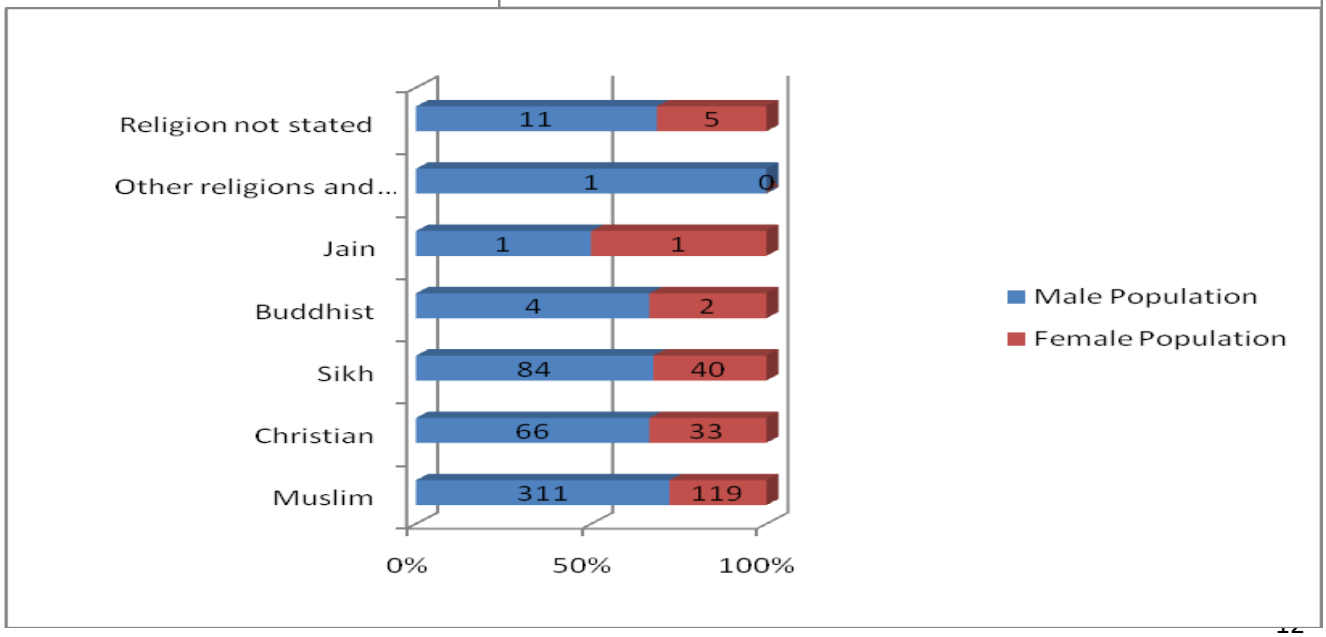


Religon wise census 2011 Data of Joshimath



Source: Religious Demography of Joshimath (MB) - Census 2011





PART II: THE PROBLEM

Background:

Cracks are seen on walls and buildings of Joshimath were first reported in 2021, as Chamoli district of Uttarakhand experienced frequent landslides and flooding. As per reports, the Uttarakhand government's expert panel in 2022 found that several pockets of Joshimath are "sinking" owing to man-made and natural factors.

Since early January 2023, Joshimath—a small town in the Chamoli district of Uttarakhand—has become a 'sinking town', with residential and commercial structures and road infrastructure developing cracks and many areas becoming unlivable or unusable. Joshimath has since been declared a "disaster-prone area"[18]As a result, the state government banned further construction in and around the town, and ordered the evacuation of more than 600 families from the danger zones.[4]Additionally, several structures were demolished for being "unsafe"[19].

. It was found that a gradual settling or sudden sinking of the earth's surface due to the removal or displacement of subsurface materials — has induced structural defects and damage in almost all wards of the city.

On 7th February 2021 at 1630 hours, a meeting of NCMC under the chairpersonship of Cabinet Secretary was held, wherein all the concerned agencies were directed to work in close coordination and to extend all requisite assistance to the Uttarakhand State administration. This meeting was also attended by Shri Sanjeeva Kumar, Member Secretary, NDMA; Lt. Gen. Syed Ata Hasnain, Member, NDMA and Shri Rajendra Singh, Member, NDMA.

On 17th and 22nd February 2021, meetings were held under the chairpersonship of Union Home Secretary, Government of India to review the progress of search and rescue operations as well as to decide the future course of action on the artificial lake formed in Chamoli district, Uttarakhand.



Land subsidence in Joshimath is not a new phenomenon. In 1976, a committee was then formed under the chairmanship of Garhwal Commissioner Mahesh Chandra Mishra to investigate the cause of cracks developing in some structures in town. The report submitted by the 18-member committee clearly stated that Joshimath was situated on an old landslide zone and could sink if development continued unabated; it recommended that construction be prohibited in Joshimath.

The Joshimath Situation Explained

In 1976, the Uttar Pradesh government set up an 18-member committee headed by M.C Mishra, the then Commissioner of Garhwal, to study the issue of land subsidence in Joshimath. The report had pointed out that "Joshimath is not situated on in situ rocks. It situates on weathered, landslide mass of big un-settled boulders in the loose matrix of fine micaceous sandy and clayey material. The rocks are crystalline consisting of schistose gneissic and quartzitic." Joshimath, the report said, also rested on an ancient landslide site of a substantial size. Several subsequent studies also reiterated some of these facts. In 2018, the Uttarakhand State Disaster Management Authority (USDMA) noted that the town's location was prone to landslides, and the area around Joshimath was covered with a thick layer of overburdened material.[20] It also said the town was situated on a fragile mountain slope that was

bounded by the Karmanasa and Dhaknala rivers on the west and the east,

and Dhauliganga and Alaknanda rivers on the south and the north. “Large boulders of gneisses and fragments of basics and schistose rocks are embedded in grey-coloured, silty-sandy matrix. This makes the town highly vulnerable to sinking,” Piyoosh Rautela, USDMA executive director, is quoted as saying[21]. The USDMA study found that the perennial streams, significant snow in the upper reaches, and highly weathered gneissic rocks with low cohesive characteristics made the area prone to landslides. These facts are further corroborated by research studies that find the Uttarakhand Himalayas highly susceptible to meteorological and geophysical hazards.

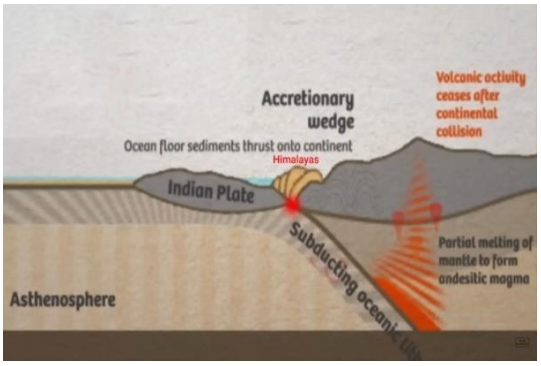
In February 2021, a glacial lake outburst in Chamoli caused a devastating flood that led to the deaths of 204 persons and 186 livestock. It damaged buildings, roads, bridges, and the hydro- projects at Raini and Tapovan. More importantly, it had an adverse impact on the landslide zone. This zone was further weakened when Joshimath recorded a heavy downpour of 190 mm on 17 October 2021. As highlighted by satellite data, its impact was that mountain streams expanded their channels and changed course, which aggravated the slope instability.

Studies have also established that eco-tectonic and geomorphic factors coupled with meteorological characteristics have rendered the Joshimath region highly vulnerable to subsidence. Notably, Chamoli district falls in Zone V (areas most susceptible to earthquakes) of the Seismic Zoning Map of India. Joshimath also sits on the Vaikrita Thrust, a tectonic fault line. The Main Central Thrust and the Pandukeshwar Thrust (the main geological fault lines) are also in close vicinity.[22]

Causes

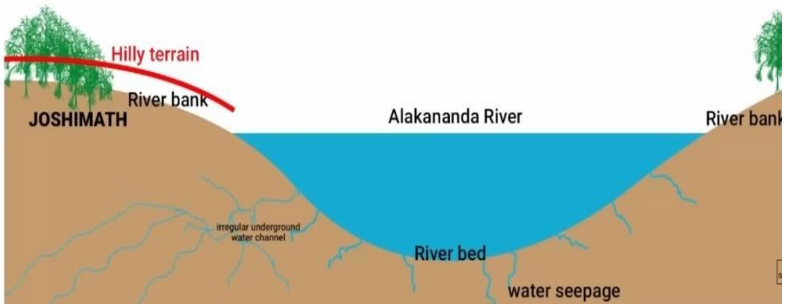
Joshimath’s land subsidence is caused by both natural and human interference. The natural causes are listed below, in this regard:

- Joshimath, as found by the geologists, are lying on ancient glacial debris (accretionary wedge) formed as a result of convergence of Indian Plate with the Eurasian plate. Located at the Middle Himalaya region, the town of Joshimath, is formed from loose debris which eventually compacted to form a landmass. Joshimath was always vulnerable to earthquakes as the region falls in the seismic zone V. The weak foundation of the city due



to its sitting atop a glacial moraine, which is distinct ridges or mounds of debris that are laid down by a glacier, the town's foundation has no solid rocks.

- Also, the debris of the Joshimath has angular sediments, which are worse than river deposited sediments. These sediments have voids, making them extremely unstable, geologically the soil beneath is full of cracks and crevices that cause huge water seepage in the area that gradually loosens the soil and cause subsidence.



<u>Anthropogenic Factors:</u>

- In the last several decades a boom in construction has made this region extremely vulnerable and susceptible to major land deformation. The rapid rise in construction activities in the area to the widening of the Char Dham Yatra road and the National Highway 7, which runs through the town taking tourists and cargo to the holy shrine of Badrinath every year, with having a record of taking 41lakh pilgrim in October 2022, has a very severe effect on the geology of the town.

The widening of the road was not just a big contributor, but also led to more and more hotels springing up in and around Joshimath. The roads in such geologically sensitive region should have been seven metres wide, but the government widened the roads to 12 metres[23], which led to more and more cleaning of the hills. This made the already ecologically sensitive region highly vulnerable to landslides as the top layer was cleaned for the road construction.

- The 2010 report of USDMA stated, "A tunnel boring machine (TBM) was employed for excavating the head race tunnel. On 24 December 2009, it punctured a water-bearing strata some 3 km inward the left bank of Alaknanda near Shelong village. The site was more than a kilometer below the surface, somewhere below Auli, according to the project authorities. The water discharge was reportedly between 700 and 800 litres per second. The aquifer discharge was about 60–70 million litres daily, enough to sustain 2-3 million people."

- Locals also blame NTPC Limited's 4×130 megawatt Tapovan Vishnugad hydel project for the situation -- a 12-kilometre tunnel has been carved into the hill[24].
- That is not all. In the last decade, the ridge that houses Joshimath has been traversed by running streams with a high gradient from Vishnuprayag, a confluence of the Dhauliganga and the Alaknanda rivers. The confluence has survived two big glacial and cloud outbursts that deposited heavy sediments causing major erosion in the region. "The outbursts brought debris worth 10,000 houses in one day, which made things worse for Joshimath," Dr. Kotlia adds. [25]

Joshimath is a classic case of all these factors working together to create a recipe for disaster. With increased tourism activities in Joshimath, due to its location, increased number of hotels, roads, and other human activities causing the area to severely burden that caused a gradual settling, or sinking of the surface of the area.

The impact of damage

SN	Parameters	Data
1	**Damages to projects**	Rishiganga Hydro Project (13.2MW) & NTPC Hydro Power project (520MW)
2	**Damage of Roads (Access routes) and bridges**	BRO Motor bridge on NH-7 at Raini washed away. 5 suspension bridges washed away.
3	**Number of affected villages**	13 villages (Paing, Murranda, Jugju, Juwagwad, Raini Chak Lata, Raini Chak Subhai, Bhangule, Gahar, Tapovan, Ringi, Subhai including Tok) due to damage of utililty supply lines [Electricity and water)
4	**Human Lives lost**	~204 died / missing (Bodies recovered: 80; Missing: 124)
5	**Animal & Livestock lost**	**Dead Animals** -03 (02 Goat, 01 Cow) **Missing Animals** – 186 (02 Cow, 04 Mule, 180 Goat)
6	**Damage to Buildings**	1 Temple & 1 pucca House at Raini Chak Lata
7	**Psycho-social impact**	Fear and panic amongst affected families. Trauma particularly for those families who lost their earning members. The affected families also lost their sources of regular income.
8	**Volume of Debris Dammed Lake**	0.219MCM of lake water **(Impending Risk)**

The Role of Remote Sensing

A preliminary study by the Indian Space Research Organisation's National Remote Sensing Centre found that land subsidence was "slow" between April and November 2022, with Joshimath sinking by 8.9 cm. However, between 27 December 2022 and 8 January 2023 (a 13-day period of "rapid subsidence"), the town sank by 5.4 cm. The report suggested that the entire town may face an existential threat due to land subsidence.[11] Some environmentalists have suggested that other human settlements in the region could also soon face a similar crisis.[12]

Satellite photographs captured by the Cartosat-2S satellite and issued by the National Remote Sensing Centre (NRSC) of the Indian Space Research Organisation (ISRO) have revealed that Dehradun Joshimath may soon face complete submersion due to land subsidence. The images, which show sinking regions of the town, have been made public by the Hyderabad-based NRSC, designating the entire town as a sensitive zone, including the Army's helipad and the Narasimha temple. As a result of ISRO's preliminary report, According to a report from the Indian news agency IANS on January 13th, the government of Uttarakhand is undertaking rescue operations in high-risk areas and evacuating residents to safer locations as quickly as possible.

The region subsided around 5 cm within a span of a few days and the areal extent of subsidence has also increased. But it is confined to the central part of Joshimath town," the NRSC report said. It said a subsidence zone resembling a generic landslide shape was identified – tapered top and fanning out at base. The report noted that the crown of the subsidence was located near Joshimath- Auli road at a height of 2,180 metres.

After the state of Uttarakhand was created in 2000, tourism grew steadily, reaching 10 lakhs by 2012. From the point of view of municipality ward, about 19 lakhs of visitors, travelling towards Badrinath had arrived in Joshimath in the year of 2022. To accommodate this foot traffic, for more than 150 guesthouses and also many lodging places have built in the Joshimath over the years, covering an area of 2.5 square kilometres, which worsens traffic there.[26]

According to images released by the National Remote Sensing Centre of the Indian Space Research Organisation, Uttarakhand's Joshimath has witnessed a rapid subsidence of nearly 5.4 cm in the past 12 days. The report stated that a subsidence of nearly 9 cm was recorded between April-November 2022.

Joshimath, home to the monastery of Adi Sankaracharya and gateway to the Badrinath temple, is built on the deposits of an old landslide, which means the slopes can be destabilised even by slight triggers. The town is also in Zone V, denoting highest risk, in India's seismic zonation scheme.

Joshimath's geological setting, together with the unplanned and rampant construction in and around the town, has resulted in land subsidence. The signs of subsidence had first appeared in October 2021 but the situation became particularly alarming towards the end of 2022 and the beginning of 2023, when large parts of the town experienced sudden land-sinking and several houses developed major cracks as well.

A report on Joshimath published by the Uttarakhand State Disaster Management Authority (USDMA) in September 2022 said that floods in June 2013 and February 2021 heightened erosionin the area. Very heavy rains in October 2021 – 190 mm in 24 hours – also worsened the subsidence and vulnerability to landslides, it stated.

Part III: The Management

The Joshimath structural collapse and land subsidence has further raised the question of inevitability of sustainable plan for construction in future. The government and the management authorities have however taken up the following steps not only as crisis management of the situation, but also as disaster management plans.

Firstly, The Government has halted all construction activities in the region.

Second, An expert panel consisting of 8 people has made the recommendation that homes in the area that sustained the most damage be demolished, that areas that have become uninhabitable be identified, and that people be moved to safer areas as a matter of priority. The Government has already declared certain buildings as unfit for inhabitation. People are being relocated. Interim compensation has been provided to the affected families.

Third, controlled demolition of most vulnerable buildings is being undertaken.

Fourth, A group of specialists from the National Disaster Management Authority (NDMA), the National Institute of Disaster Management (NIDM), the Geological Survey of India (GSI), the Indian Institute of Technology Roorkee (IITR), the Wadia Institute of Himalayan Geology, the National Institute of Hydrology, and the Central Building Research Institute (CBRI) will investigate the situation and offer their recommendations.

Future Recommendations

First, There is need to balance development needs of the region with the protection of the environment. Development is necessary but not at the cost of local environment or population. Ensuring sustainability should be the top priority.

Second, The natural assets of the Himalayas, such as biodiversity, local ecology and environmental balance should be at the centre of any development plan for the area.

Third, Instead of focusing on massive dam construction, attention should be given to smaller projects that can help meet the energy needs of the community.

Fourth, Taking precautions to protect people's well-being ought to be the top priority right now. The State government ought to set up a communication channel that is both transparent andcontinuous

with the individuals who have been impacted.

Fifth, Mishra Committee Recommendations should be implemented for all development projects. No activity should be undertaken on unstable slopes unless structural stability can be ensured.

Mishra Committee Recommendations and Developmental Works

The Mishra Committee made several recommendations pertaining to Joshimath and the wider region based on its on-ground observations. It took stock of the heavy construction projects undertaken in this area after 1962 and the indiscriminate felling of trees to develop roads and buildings, which destroyed the natural forest cover in Joshimath. The committee advised that heavy construction work be restricted and that such activities be permitted only after a thorough examination of the soil's load-bearing capacity and the site's stability. It was also recommended thatrestrictions be placed on the excavation of slopes. Notably, the committee recommended avoiding blasting or digging to remove boulders for road repairs or other construction. Further, it suggested that stones and boulders should not be removed from the bottom of the hill in landslide-prone areas as doing so would take away to support and increase the possibility of landslides. It also suggested that if cracks developed, they should be sealed with lime, local soil, and sand. The committee pointed out that the felling of trees posed a danger to the town's sustainability and encouraged that trees and grass be planted widely to conserve soil and water resources. It said that cutting trees to supply the township with timber and firewood be strictly regulated, and the locals be provided with alternative sources of fuel. It also recommended avoiding any agricultural activity on the slopes.

The report noted that there was excessive water seepage in the area. Since any percolation of water would be disastrous, the committee recommended the closure of open drains and soaking pits, and the halting of construction of concrete sewage lines for sewerage flow. To prevent landslides, it recommended constructing a fixed draining system to avoid the seepage of open rainwater. Further, it suggested that roads should be metalled and be without scuppers that drain away the water from the road surface. It suggested that cement blocks should be placed in vulnerable spots on the riverbank to prevent erosion. It also recommended that hanging boulders on the foothills be provided with appropriate support and that erosion prevention and river training[h] measures be taken up.

Despite the Mishra Committee's recommendations, several infrastructure projects were undertaken in the region. The Tapovan-Vishnugad project, a 520-MW run-of-river hydropower project by the

National Thermal Power Corporation (NTPC), is being constructed on the Dhauliganga River in Chamoli district, and is expected to generate approximately 2,558 GWh of electricity annually. The project involves the excavation of a 12.1-km longhead race tunnel[i] and three adits.[j] These works require the use of a tunnel boring machine and possibly the use of the drill and blast method of tunnelling.[27]

Some experts have said the blasting activities for tunnelling caused cracks to appear across Joshimath,[28] and the state government said it would probe the project's role in land subsidence. However, in a letter to the state government, an official from the Ministry of Power stressed that the project did not have any adverse role in the current crisis and reiterated the Mishra Committee's conclusion of the town's vulnerability due to its location. Several on-ground studies have corroborated these assertions.

The Helang-Marwari bypass road under the All Weather Road initiative, starting 13 km before Joshimath, is another major construction project in the region. The road has two major objectives—cutting the distance to Badrinath Dham by about 30 km, and easing and expediting the movement of troops to the Indo-China border. Although the project faced some opposition from the Joshimath Bachao Sangharsh Samiti (Save Joshimath Movement), a citizens' initiative, which took the matter to the Supreme Court, the court authorised the construction in May 2022[29]. Notably, the group has repeatedly opposed major infrastructure projects in the region, warning of their consequences. In 2021-22, the group formed several internal committees comprising locals and independent scientists to assess the problems in the area and compile a report that offered several alternative solutions. This report was handed over to the government in 2022 but was rejected.

Increased tourist activity in Joshimath also led to the construction of many multistorey buildings. An August 2022 report by the USDMA noted many improperly planned structures without due regard to carrying capacity[30]. These have aggravated issues related to slope instability. Additionally, since Joshimath does not have a wastewater disposal system, increased on-surface anthropogenic activities have blocked natural water drainage systems, forcing water to find new drainage routes, thereby reducing the shear strength of the overburdened soil.

Aftermath

To be sure, the climate crisis appears to have played a part in the incident, just as it did in the February 2021 flash flood caused by glacier overflow in Raini that killed around 200 people, many of them at the Tapovan Vishnugad hydropower project site. Some residents of Joshimath claimed that they started noting cracks in their houses after this tragedy.

The state government on January 5 finally stopped construction work at Joshimath , including that of the Helang Bypass project and NTPC Tapovan Vishnugad Hydroelectric Project .

The NTPC project was scheduled to be commissioned in 2012-2013 but was delayed by a decade and even suffered financial losses due to a series of mishaps.

A few days ago, Uttarakhand Chief Minister Pushkar Singh Dhami visted Joshimath to take stock of the situation. He said the government is standing fully with the affected people of Joshimath, a town that has great religious, spiritual and cultural importance.

The government has already announced the evacuation of everyone living in the 'danger zone'. Rent of ₹4,000 per month will be given to the displaced families.

The NDMA office memorandum prohibiting interaction with the media or sharing of data on social media regarding Joshimath was issued , which was marked to the Director, Central Building Research Institute (CBRI), Roorkee; DG, Geological Survey of India (GSI), Kolkata; Director, NRSC-ISRO, Hyderabad; Chairman, Central Ground Water Board (CGWB), New Delhi; Surveyor General of India, SOI, Dehradun; Director, Indian Institute of Remote Sensing (IIRS), Dehradun; Director, National Geophysical Research Institute (NGRI), Hyderabad; Director, National Institute of Hydrology (NIH), Roorkee; Director, Wadia Institute of Himalayan Geology (WIHG), Dehradun;Director, IIT Roorkee; ED, National Institute of Disaster Management (NIDM), New Delhi; Secretary, Uttarakhand State Disaster Management Authority (USDMA), Dehradun.

Himalayan Developmental Strategy

While Joshimath residents and army troops are currently being relocated, authorities are also considering the creation of a 'new Joshimath' and assessing four locations near the town. Still, this crisis has raised the need to acknowledge the fragility of the larger Himalayan zone and consider alternative approaches to avoid similar catastrophes in other mountain towns.

The Garhwal Himalayas are home to over 51 million people, and such a large population cannot be relocated entirely despite the area's vulnerability. Importantly, the area also has certain advantages that can be harnessed for the greater good. For instance, it has considerable scope for hydroelectric projects. As a scenic natural area, the region is also a draw for mountain expeditions, rock climbing, trekking, and other tourist activities. It is also home to many religiously significant sites that attract numerous pilgrims. Such tourist activity provides a source of income to the locals, who may otherwise seek employment elsewhere. For instance, a 2018 survey of four towns preceding Joshimath on the Badrinath Temple route found that 57.5 percent of the households were engaged intourism services, with 37.5 percent exclusively dependent on tourism[31]. Additionally, this region contains many sensitive areas that border China and, as such, requires Indian military presence and infrastructure.

In light of this, it is a given that certain developmental activities will need to be undertaken. The crucial factor is the manner and volume of activities that can be permitted such that it minimises human-nature conflict. The Himalayas are the world's youngest mountain ranges, with unstable slopes that are prone to landslides and erosion. The region is among India's most earthquake-prone zones. Additionally, climate change has resulted in extreme and sudden rainfall. As such, the Himalayan region is very different from India's plains and so requires a different development model that considers this ecosystem.

Since the area is an important tourist destination, with high projected traveller numbers in the coming years, there will likely be a spurt in tourist-related developmental activity. These must adhere to the concept of carrying capacity (which the Uttarakhand government already recommends). Notably, the government has also urged the implementation of an effective pilgrim management system. This would mean curbing the number of tourists permitted to visit the regionor a particular site per day and each season. Uttarakhand, and indeed the other Indian states in the

Himalayas, can learn from Bhutan, which has imposed steep sustainable development fees in a bid to control the number of travellers. In addition, a hill-town levy, currently imposed in many hill stations to limit the inflow of vehicles, can be expanded to other towns. This will also provide some revenue for the upkeep of the town.

A different set of building standards and building regulations will need to be adopted for construction projects in the Himalayan region. These standards should mandate lightweight structures and a restriction on height. Building control regulations will have to be redrawn to conform to sustainability benchmarks in these fragile regions. In the 1960s, establishments (including government premises) were built with corrugated roofs to keep structures light and single-storied[32]. But in recent years, the tourism boom in Joshimath and the surrounding areas led tothe construction of many multistorey buildings on fragile slopes. Such constructions should be eschewed in favour of structures conducive to the ecosystem. Revised building regulations should also include earthquake-safe construction technologies and a mandated reduction of non-structural hazards in homes, schools, business centres, and offices. These new building codes will need to be strictly enforced to protect the built environment in the region. Importantly, there has been no reorganisation of the Town and Country Planning department since Uttarakhand's bifurcation from Uttar Pradesh. This should be done urgently, with sufficient staff to oversee the town planning.

While it is important to exploit the potential of hydroelectricity, it is equally crucial that not every potential site be pressed into service. The construction of very large dams should be completely ruled out because of high landslide vulnerability and large-scale human rehabilitation. The current goal of the hydroelectric projects in the region is to build about 70 projects and create 9,000 MW of power, but this needs to be reviewed urgently. Vulnerable areas in the river valleys need to be mapped, and villages on the riverbanks need to be rehabilitated in safer areas. Additionally, projects that are already underway may need to be redesigned to mimic the river flow.

The geological developments underway in Joshimath should be a case study for every town planner working in the hills. The factors at play in Joshimath are also found in other cities such as Nainital, Champawat, and Uttarkashi. All these cities are witnessing rampant construction, deforestation, population boom, and poor civic management. The only silver lining is that they are not on top of ancient glacial debris.

Nature has its own way of claiming its resources. Government, civil bodies, and citizens need to factor in these parameters when developing new cities.

Many more structures will become unstable, and numerous people will be displaced as the incidence of land subsidence[a] in Joshimath increase. This brief assesses existing literature on Joshimath, mainly related to the developmental works that were undertaken in the town and its vicinity, the tourism load on the town, and defence requirements at the international border. Given the Joshimathexperience, this brief highlights the need for a development model that considers the fragile Himalayan region, which includes several similar settlements (for instance, Nainital and Mussoorie)and especially given its significance to the Indian mainland: "The Himalayan ecosystem is vital to the ecological security of the Indian landmass through providing forest cover, feeding perennial rivers that are the source of drinking water, irrigation, and hydropower, conserving biodiversity, providing a rich base for high value agriculture, and spectacular landscapes for sustainable tourism"[33].

Conclusion

Given the national and local imperatives, there should be unanimity that development in the Himalayan region is necessary. The crucial factor is the volume and model of development that will be adopted. Developmental decisions on the region must be made after considering its entire ecosystem and the region's significance to the mainland.

The volume of development in the Himalayan region should be sustainable and not maximalist, and the model should respect the fragile ecosystem. However, while restrictions in tourism and infrastructure creation will adversely impact local employment, there is scope for greater investments in the environment sector—in biodiversity conservation, large-scale plantation and forestry, glacier and water body protection, and high-value organic farming.[34] The development of such activities will almost certainly generate enough jobs to replace those lost in the other sectors.

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