IJARETY

International Journal of Advanced Research in Education and TechnologY (IJARETY)

Volume 11, Issue 3, May-June 2024

Impact Factor: 7.394

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

INNO SPACE
SJIF Scientific Journal Impact Factor

doi crossref

निस्केयर
NISCAIR

| ISSN: 2394-2975 | www.ijarety.in| | Impact Factor: 7.394| A Bi-Monthly, Double-Blind Peer Reviewed & Referred Journal |

|| Volume 11, Issue 3, May-June 2024 ||

DOI:10.15680/IJARETY.2024.1103030

Analyzing the Vulnerability of the Kumaon Region to Natural Disasters and Climate Change

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ABSTRACT: The Kumaon region, situated in the northern part of India, is characterized by its unique geographical and climatic conditions. This paper aims to comprehensively analyze the vulnerability of the Kumaon region to natural disasters and climate change. The study incorporates a multi-disciplinary approach, including geospatial analysis, climate modeling, and socio-economic assessments to evaluate the region's susceptibility to environmental challenges. The findings suggest that Kumaon faces a significant risk of natural disasters and climate change impacts, necessitating proactive mitigation and adaptation measures.

KEYWORDS: Kumaon, vulnerability, natural disasters, climate change, geospatial analysis, climate modeling, socio-economic assessment, adaptation, resilience.

I. INTRODUCTION

The Kumaon region, located in the northern Indian state of Uttarakhand, is known for its stunning landscapes, diverse ecosystems, and rich cultural heritage. It is home to several significant hill stations and has been a popular tourist destination. However, the region is highly susceptible to a range of natural disasters and is experiencing the adverse effects of climate change, raising concerns about its sustainability and resilience.

The Kumaon region is highly active from a tectonic perspective, experiencing substantial tectonic activity. This area is characterized by steep slopes, varying altitudes, and a notably variable climate, rendering it exceptionally susceptible to various hazards. Even minor ecological disturbances within the mountain ecosystem can trigger disasters. In recent years, the region has witnessed numerous geological hazards, including landslides, debris flows, flash floods, earthquakes, avalanches, glacial lake outbursts, and extensive rainfall, resulting in significant disasters with loss of life and property on an annual basis. These disasters often coincide with the pilgrimage and tourism season, leading to higher casualties. As human movement in the region increases, so does the risk of landslides and natural disasters. One noteworthy event involved a cloud burst, leading to torrential rains that breached the Chorabari glacial lake, resulting in flooding at the Kedarnath temple and its surrounding areas. This left people stranded for several days at other important pilgrimage sites such as Badrinath, Hemkund Sahib, Gangotri, and Yamunotri.

Glaciers are highly sensitive to climate variations, reacting swiftly to changes in temperature and precipitation. They advance during cooler periods and shrink in warmer conditions. However, the extent of glacier change can take time due to local topographical adjustments, known as the time-lag effect. Glaciers expand as they advance, shifting their terminus to lower altitudes. Conversely, they retreat in warmer summers with reduced snowfall, causing them to shrink and their terminus to ascend to higher altitudes. Climate change can lead to glaciers reaching new equilibrium sizes and shapes (Greene, 2005). Over the past century, climate change has influenced glaciers worldwide, resulting in a mix of shrinking and advancing behaviors (UNEP, 2007; O‘Reilly, 2015).

The last glacial age occurred approximately 70,000 years ago, peaked about 20,000 years ago, and ended around 10,000 years ago. During this time, about 32 percent of the Earth's land area was covered in ice, a figure that has now been revised to 10 percent due to ongoing warming. In addition to the cyclical glacial and interglacial ages, short periods of localized cooling and warming also occur, affecting glacier structures. Since the Little Ice Age (LIA), most glaciers worldwide have been retreating due to various factors, including rising temperatures. In the Himalayas, the monsoon plays a significant role, with most accumulation and ablation occurring during the summer (Ageta and Fujita, 1996; Fujita and Ageta, 2000). Cold glaciers in high altitudes and polar regions can receive accumulation in any season (Chinn, 1985).

Global warming-induced climate change has triggered various events and processes, such as the unnatural melting of glaciers and changing weather patterns. The melting of Himalayan glaciers has two adverse impacts on the environment: the loss of freshwater reserves and rising sea levels (Kaser et al., 2006). Consequently, this has led to

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storms, droughts, flash floods, cloudbursts, changes in vegetation, and more. To address these impacts effectively, a comprehensive approach is needed, including long-term observations and analyses to better understand the interactions between the various components of mountain ecosystems and their climate (Bolch et al., 2019).

Objective

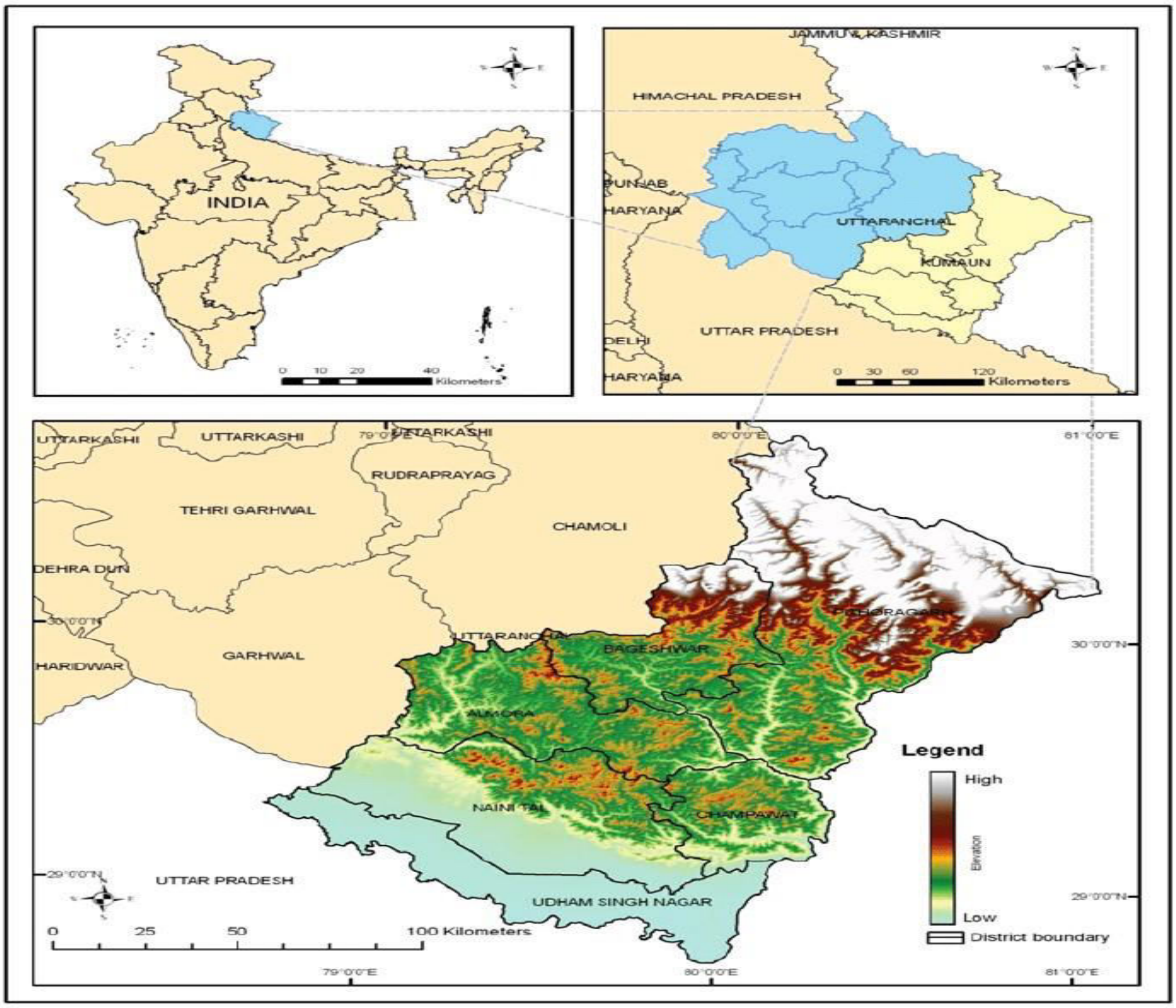
- Conduct a detailed analysis of the Kumaon region's vulnerability to natural catastrophes and climate change.
- Use a multidisciplinary approach, combining geospatial analysis, climate modeling, including socioeconomic assessments.
- Assess susceptibility to environmental challenges.
- Focus on the high risk of natural disasters and climate change impacts.
- Suggest proactive mitigation and adaptation strategies.

II. METHODOLOGY

Review of different research article . Geo spatial data from sources such as satellite imagery, aerial photography, and digital elevation models (DEM) will be obtained. This data may include land cover, land use, topographical features, and geological information.

Historical climate data from meteorological stations and global climate models will be collected to establish a baseline for temperature, precipitation, and weather patterns.

Study area: The Kumaun division of Uttarakhand, as depicted in given Figure, encompasses a land area of 21,034 square kilometers. It is situated between latitudes 28°44′ N to 30°49′ N and longitudes 78°45′ E to 81°05′ E, with elevations ranging from 200 meters to 6000 meters above mean sea level.



Location map of Kumaun Region

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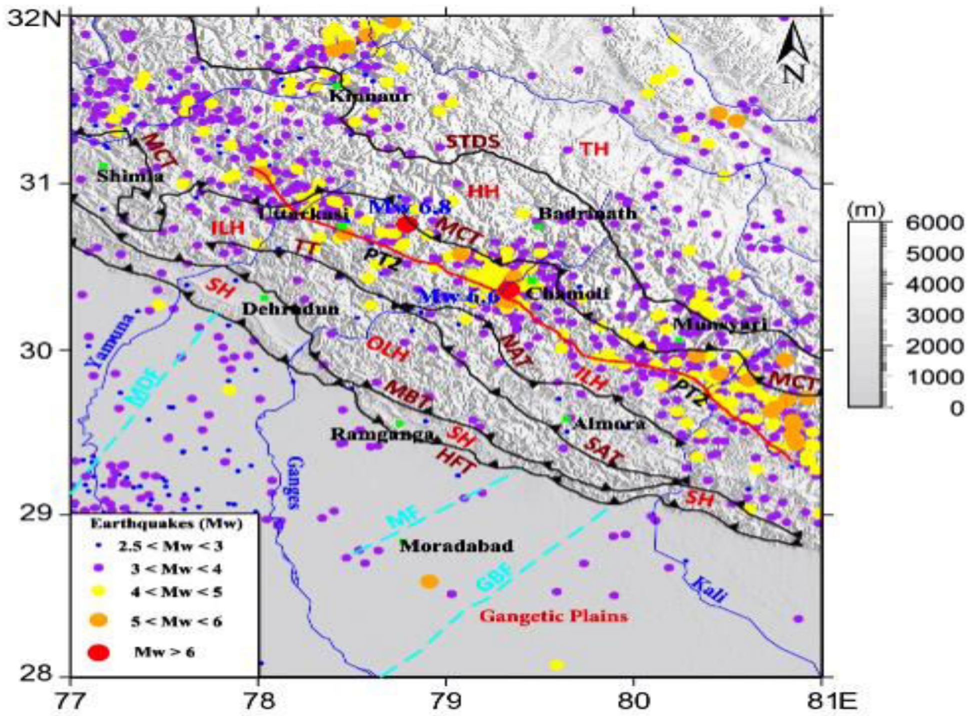
Land Use Analysis: Land use changes over time will be analyzed to identify shifts in patterns that might contribute to vulnerability. For instance, the expansion of urban areas into hilly terrains may increase landslide risk.

Forest Cover Assessment: Forest cover is crucial for erosion control and regulating water flow. The extent and health of forested areas will be assessed, and deforestation trends will be examined in relation to vulnerability to natural disasters.

Topographical Analysis: Topographical features such as slope, aspect, and elevation will be examined to identify areas prone to landslides and flooding. Steeper slopes, for example, may be more susceptible to landslides.

Vulnerability Mapping: By integrating the data collected and analyzed, vulnerability maps will be generated. These maps will highlight high-risk zones for various natural disasters, providing a spatial understanding of the region's vulnerability.

From: Crustal velocity and interseismic strain-rate on possible zones for large earthquakes in the Garhwal–Kumaun Himalaya



Morphotectonic map of the study area with seismicity. Major plate boundary faults namely Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), South Tibetan Detachment System (STDS) are marked along with the Mahendragarh–Dehradun Fault (MDF), Moradabad fault (MF), Great Boundary Fault (GBF) and the physiographic transition (PT2). The major morphotectonic zones namely Sub-Himalaya (SH), Outer Lesser Himalaya (OLH), Inner Lesser Himalaya (ILH), Higher Himalaya (HH) and the Tethyan Himalaya (TH) are marked. Colored dots indicate the seismicity of the region with size increasing with magnitude (data from ISC catalog). The basemap is the 3 arc-second elevation from SRTM Digital Elevation Model in greyscale and the map was created by Generic Mapping Tool (GMT) open source software version 5.4.5 (https://www.generic-mapping-tools.org/).

The Kumaon and Garhwal Himalayas form the Indian state of Uttarakhand. These regions encompass various environmental zones, each with specific agricultural and ecological potentials and constraints. The narrow belt of the Outer Himalayas emerges from the northern parts of the Ganges Plains, known as the Terai region. Up to an altitude of around 1000 meters, this area is cloaked in tropical sub-humid Sal forests (Shorea robusta). These forests are primarily confined to steep slopes and are predominantly protected as state-managed Reserved Forests.

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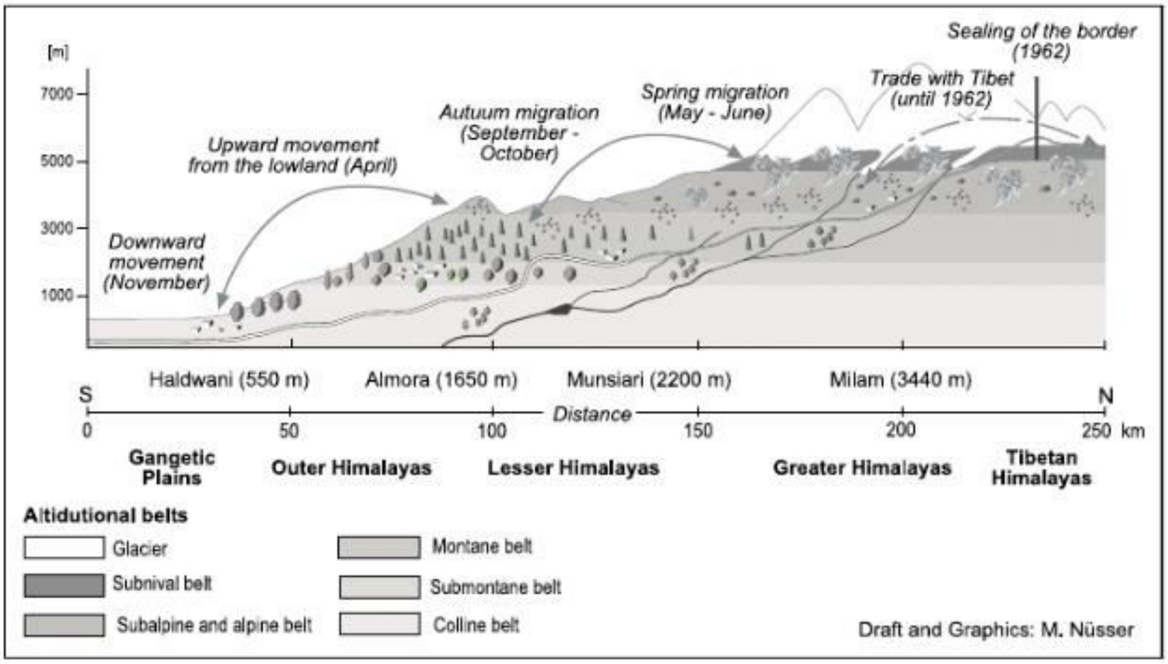

Vertical Zonation and Traditional Mobility Patterns in Kumaon, Northern India

Progressing northward, one encounters the range of the Lesser Himalayas, also referred to as Himanchal. This mountainous belt, spanning 70 to 100 kilometers in width with elevations between 1500 to 3000 meters, is primarily characterized by Pinus roxburghii forests. These coniferous forests have been a source for turpentine extraction since the early 20th century (Agrawal 2005). In the vicinity of settlements, nearly all available land is terraced and utilized for double cropping, featuring crops like rice, wheat, millet, and various legumes.

The Greater Himalayas zone in Uttarakhand is approximately 30-50 kilometers wide. The landscape is dominated by glaciated mountain peaks, with several exceeding 6000 meters and some reaching 7000 meters in height. The narrow transversal valleys are blanketed with montane forests and alpine grasslands. These forests boast a wide variety of tree species, including evergreen oak forests composed of Quercus semecarpifolia, Qu. dilatata, and Qu. leucotrichophora. These areas alternate with regions dominated by conifers like Abies spectabilis and Cupressus torulosa, as well as deciduous trees such as Alnus nepalensis, Aesculus indica, or various species of maples (Acer spp.).

Moving towards the northernmost part of the transect, we encounter the Tibetan Himalayas. Situated in the rain shadow of the main mountain range, this region receives relatively low summer precipitation. However, during the winter months, it is blanketed with thick, wet snow. Due to the landforms shaped by glacial erosion, the valley bottoms are relatively wide and shallow. These areas are covered in alpine meadows and dwarf shrubs and are predominantly used as pastures.

II. CLIMATE MODELING

The Kumaun division of Uttarakhand, as depicted in given Figure, encompasses a land area of 21,034 square kilometers. It is situated between latitudes 28°44′ N to 30°49′ N and longitudes 78°45′ E to 81°05′ E, with elevations ranging from 200 meters to 6000 meters above mean sea level (amsl).

The annual average temperature hovers at approximately 13°C in this region. June stands out as the hottest month, with an average temperature of 18.3°C, while January takes the title for the coldest month, with an average temperature of 6.4°C. Rainfall averages around 1500 mm per year, with November being the driest month, receiving only 50 mm of rainfall, and July claiming the title of the wettest month, with a substantial 500 mm of rainfall. Monthly average relative humidity fluctuates, ranging from 46 percent in April to 93 percent in September. The yearly average relative humidity settles at 65.9 percent, typically in August. The composition and distribution of species in this region exhibit significant variations along gradients of altitude, temperature, and rainfall.

Climate modeling plays a pivotal role in understanding how climate change may affect the Kumaon region. In this phase, the following steps will be followed:

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Model Selection: Advanced climate models like the Regional Climate Model (RCM) and the Community Earth System Model (CESM) will be employed. These models can simulate future climate scenarios based on various greenhouse gas emissions scenarios.
Future Projections: The selected climate models will be run to project future temperature changes, altered precipitation patterns, and an increase in extreme weather events. Projections may be made for different timeframes (e.g., 20, 50, 100 years) to assess both short-term and long-term impacts.

Interpreting Model Output: The results from the climate models will provide insights into how climate change is likely to affect the Kumaon region. This includes information on temperature increases, shifts in monsoon patterns, and increased risk of extreme events like heatwaves and heavy rainfall.
The combination of these provides a comprehensive understanding of the vulnerability of the Kumaon region to natural disasters and climate change, allowing for more informed policy recommendations and adaptation strategies.

III. VULNERABILITY TO NATURAL DISASTERS

1 Landslides:

The Kumaon region is particularly vulnerable to landslides due to its unique geological and environmental conditions. The methodology for assessing this vulnerability and proposing mitigation measures includes the following steps:
Geological Composition: Kumaon's rugged terrain is characterized by steep slopes and diverse geological formations. Some areas may consist of loose, unconsolidated materials, making them more prone to landslides. Geospatial analysis will involve mapping the geological composition of the region to identify potential landslide-prone zones.
Land Use and Human Activities: Increased human activities, such as construction, deforestation, and agriculture, can destabilize slopes and contribute to landslide risks. Geospatial analysis will examine land use changes over time to determine the extent to which human activities may have increased vulnerability.
Vulnerability Mapping: The geospatial analysis will result in vulnerability maps that highlight areas with a high risk of landslides. These maps will serve as a visual representation of landslide-prone zones, allowing policymakers and communities to prioritize these areas for mitigation efforts.
Mitigation Measures: Based on the vulnerability mapping, recommendations for risk reduction and mitigation will be proposed. These measures may include slope stabilization, afforestation efforts, land use planning, and early warning systems to alert residents in landslide-prone areas.

2 Flooding:

The Kumaon region experiences both flash floods and riverine floods, primarily during the monsoon season. The methodology for assessing flood vulnerability and suggesting risk reduction measures includes the following steps:
Precipitation Patterns: Climate models will project changes in precipitation patterns, with a focus on extreme precipitation events that could lead to flooding. These models will provide insights into the expected increase in heavy rainfall during the monsoon.
River Systems and Drainage: The region's river systems and drainage patterns will be analyzed to identify vulnerable areas that are prone to flooding. This will include assessing riverbank erosion and the capacity of local rivers to handle increased water flow.
Flood Vulnerability Mapping: Geospatial analysis will also be employed to create vulnerability maps for flooding. These maps will highlight areas at risk of inundation, allowing for the prioritization of flood control efforts.
Mitigation Measures: Recommendations for flood risk reduction will be based on the vulnerability maps and climate projections. These measures may include the construction of flood control infrastructure, such as embankments and reservoirs, and the development of early warning systems to alert communities of impending floods.

3 Earthquakes:

Kumaon is situated in a seismically active zone and is susceptible to earthquakes. The methodology for assessing earthquake vulnerability and proposing mitigation measures includes the following steps:
Seismic Hazard Assessment: Geospatial analysis will incorporate geological data to assess the seismic hazard in the region. This includes identifying fault lines and areas with higher seismic activity.
Building Vulnerability: The study will assess the vulnerability of existing buildings and infrastructure to earthquake-induced damage. This involves examining building codes and construction practices in the region.
Disaster Preparedness: The effectiveness of disaster preparedness plans and the readiness of local authorities and communities to respond to earthquakes will be evaluated. This includes assessing the availability of emergency resources and evacuation plans.

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Mitigation Measures: To mitigate earthquake risks, recommendations will be made to rigorously enforce building codes and encourage earthquake-resistant construction. Additionally, the study will suggest measures for enhancing disaster preparedness, including public education on earthquake safety and the development of earthquake response plans.

By employing these methodologies, the research will provide a comprehensive understanding of the region's vulnerability to natural disasters, leading to the formulation of practical and informed strategies to mitigate these risks and enhance the resilience of the Kumaon region.

4.Climate Change Impacts

Changing Temperature Patterns:

Climate change is leading to significant alterations in temperature patterns within the Kumaon region. The methodology for assessing this impact and proposing adaptation measures includes the following steps:

Temperature Projections: Climate models project a consistent increase in average temperatures over the coming decades. This rise in temperature can have profound effects on the region's ecosystems, agriculture, and human well-being.

Ecosystem Impact: Higher temperatures can disrupt local ecosystems, affecting flora and fauna. Species that are adapted to cooler conditions may be displaced, leading to biodiversity loss. This can have cascading effects on the entire ecosystem.

Agriculture: Rising temperatures can have detrimental effects on agriculture. Crop yields and quality may be impacted, potentially leading to food security issues. Adaptation strategies are vital, including crop diversification to choose heat-tolerant varieties and improved water resource management to cope with increased evapotranspiration.

Human Health: Increased temperatures can also have direct health implications, particularly during heat waves. Public health campaigns and infrastructure improvements, such as cooling centres, will be essential to protect the population.

5. Altered Precipitation Patterns:

Climate change is expected to bring about shifts in precipitation patterns, with the potential to affect water availability, agriculture, and drinking water supply. The methodology for assessing this impact and suggesting adaptation measures includes the following steps:

Precipitation Projections: Climate models will project changes in precipitation patterns, which may include alterations in the timing, intensity, and distribution of rainfall. These projections will provide insights into how precipitation will change over time.

Agriculture and Water Supply: The altered precipitation patterns can impact agriculture, as changes in rainfall can disrupt planting and harvesting seasons. Moreover, changes in water availability can affect drinking water supply, especially in regions dependent on rainfall-fed sources. Strategies to address these impacts include water conservation measures and the promotion of rainwater harvesting.

Flood and Drought Risk: Changes in precipitation patterns can lead to increased flood and drought risks. Communities and local authorities need to prepare for these extremes by developing resilient infrastructure, early warning systems, and drought management strategies.

6. Glacial Retreat:

The Himalayan glaciers within the Kumaon region are experiencing rapid retreat due to rising temperatures. This phenomenon can have far-reaching consequences for river systems, water supply, and the environment. The methodology for assessing this impact and proposing mitigation measures includes the following steps:

Glacial Monitoring: Scientific assessments and geospatial analysis will be conducted to monitor the rate of glacial retreat. This will involve field surveys, satellite imagery, and other remote sensing techniques.

Water Resource Management: The melting glaciers are a crucial source of freshwater for the region. As they retreat, it can lead to a decline in water availability for drinking, agriculture, and energy generation. Sustainable water resource management practices will be essential to address these challenges.

River Systems: The retreat of glaciers can alter river flow patterns, potentially increasing the risk of floods during glacial lake outburst events and reducing the flow during the dry season. Communities need to be prepared for these changes through infrastructure development and adaptation measures.

Ecosystem Impacts: Glacial retreat can also disrupt local ecosystems. Changes in the timing and volume of water flow can affect aquatic life, as well as the livelihoods of those dependent on these ecosystems.

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IV. CONCLUSION

The Kumaon region faces a complex web of vulnerabilities due to its geographical, climatic, and socio-economic characteristics. This paper underscores the urgent need for proactive measures to enhance resilience, including strengthening disaster preparedness, sustainable land use practices, and climate adaptation strategies. The findings of this research can inform policy decisions and encourage stakeholders to take action to safeguard the Kumaon region from the increasing threats of natural disasters and climate change.

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International Journal of Advanced Research in Education and Technology

ISSN: 2394-2975 Impact Factor: 7.394

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