ASSESSMENT OF LAND SURFACE TEMPERATURE AND ITS IMPACT ON VEGETATION CHANGE IN UTTARAKHAND DURING THE YEAR 2000-2023 USING GEOSPATIAL TECHNIQUES

CHAPTER 1

INTRODUCTION

1.1 Normalised Difference Vegetation Index (NDVI)

Today, NDVI is used in a variety of application ranging from monitoring crops to vegetative health; precision agriculture; land use and land cover mapping and ecosystem heath.

The landscape composition is changing naturally or due to anthropogenic activities. Changes in land cover (LC) due to the expansion of anthropogenic activities driven by an increase in the size of populations, as well as its manifestations and effects have affected regional climate. By LC changes we mean here human alterations of the terrestrial surface for food and other necessities. Natural, and/or anthropogenic drivers have always induced gradual or rapid changes in terrestrial ecosystems at a range of spatial temporal scales Changes in land cover (LC) brought about by various human activities and natural processes significantly impact both global and regional weather and climate patterns. The main connections between land cover and climate include the exchange of greenhouse gases (such as water vapor, carbon dioxide, methane, and nitrous oxide) and sensible heat between the land surface and the atmosphere. Additionally, these changes affect the radiation balance (both solar and long-wave) of the land surface and the land surface's roughness, which influences its ability to absorb momentum from the atmosphere (Loveland et al., 2003).

Normalized Difference Vegetation Index (NDVI) as a Remote Sensing Technique for Assessing Vegetation Quantity and Health of the Surface Area NDVI is widely used for monitoring of vegetation growth, health and stress and damage detection especially in the field of agriculture, forestry and ecology. It is possible to map and classify different vegetation types and detect changes in vegetation cover over the years using NDVI values.

In other words, this method used the near-IR radiation, which all living plants reflect, and subtracted only the radiation reflected in the kHz from cell walls. This detects live green vegetation and measures how objects reflect and absorb light. To establish the condition of a plant it is necessary to compare the absorption and reflection values of red and near-infrared light. This is where NDVI comes in.

1.2 How is NDVI calculated

Plants reflect near-infrared (NIR) light well but not visible light. A healthy plant contains a lot of chlorophyll and absorbs more light in the red range of the spectrum and reflects more in the NIR. And so, NDVI employs this botanical feature to distinguish healthy green vegetation from non-green vegetation or stressed vegetation Plants have a great combination of reflectance, they reflect a lot of near-infrared (NIR) and absorb a lot of red.setVisible light.

This is computed by finding the difference of red and NIR band and then dividing this value by the sum of red and NIR band which is further calculated for each pixel of an image. It ranges from -1 to 1 while values near -1 is little to no vegetation, 0 is either bare soil or water and closer to 1 is more and healthier vegetation.

Mathematically, the red-light signal and the near-infrared light have the capacity to differentiate healthy plants from sick plants and also to differentiate plants from non-plants.

The formula below for the evaluation of NDVI:

$$NDVI \quad = \frac{(\mathbf{NIR-Red})}{(\boldsymbol{NIR+Red})}$$

Now, the values range from -1 to +1. A higher or more positive value indicates greater plant vigour and general health.

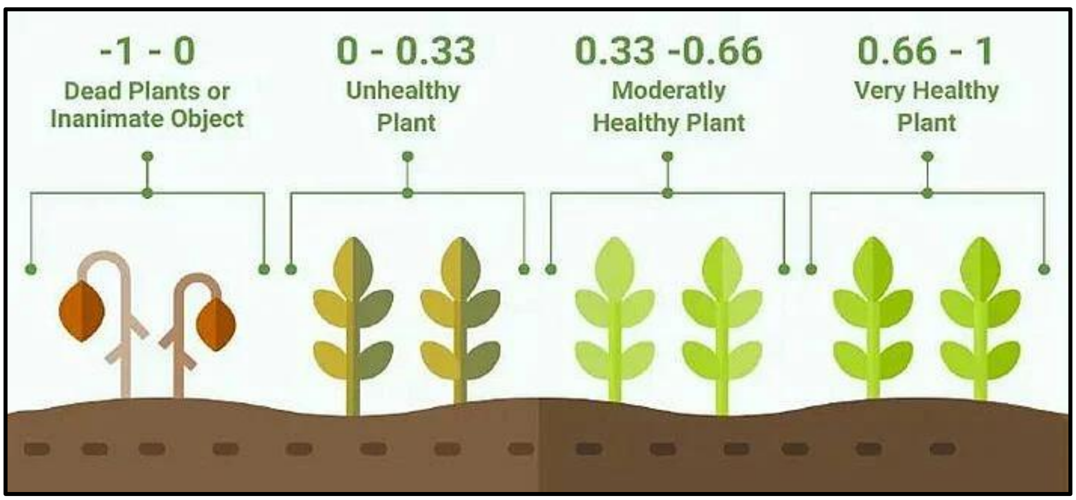

Figure:1.1- Sketch picture shows indiactor of NDVI and general growth

In general, vegetation with healthy amounts of chlorophyll and cell structures absorbs a lot of the visible light and reflects most of the NIR light. Conversely, unhealthy vegetation reflects additional visible light and hardly any NIR light. NDVI is used to distinguish between vegetation and non-vegetation or unhealthy vegetation by specific reflectance pattern of healthy plants, so it can be used to monitor vegetation growth, its health and also to detect stressed, damaged areas in plant cover.

1.3 Importance of NDVI

The Normalized Difference Vegetation Index (NDVI) is a vital tool utilized in remote sensing and environmental science, offering a quantitative assessment of vegetation health and density across large geographical areas. Derived from the spectral reflectance of the Earth's surface, particularly in the visible and near-infrared (NIR) wavelengths, NDVI serves as a proxy for various vegetation attributes, including leaf area, chlorophyll content, and photosynthetic activity. This makes it invaluable for monitoring ecosystem dynamics, changes in land cover, and agricultural productivity.

NDVI's foundation lies in the unique spectral signatures of healthy vegetation. Chlorophyll, the pigment responsible for photosynthesis, absorbs most visible light in the blue and red wavelengths for energy conversion. However, it reflects a significant portion of near-infrared (NIR) light, as it is not efficiently absorbed for photosynthesis. In contrast, non-vegetated surfaces such as soil, rocks, and water exhibit similar reflectance across the visible and NIR spectra.

1.4 Applications of NDVI

Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing technique with a variety of applications in agriculture, forestry, and environmental monitoring. Some specific examples of how NDVI is used in these fields include

1.4.1 NDVI in Agriculture

NDVI is frequently applied to vegetation monitoring, counting crops. This can aid the farmer to identify parts of the field which are under stress or have nutrient deficiencies, and this information can be used to fine tune irrigation and fertilization. It is also used to monitor the growth, development, and health of crops over time, as well as to estimate crop yields.

Precision agriculture: technology that allows farmers to optimise their management decisions of farms and fields using data, is where NDVI come in.

NDVI values can be used to identify variations in crop growth and health, and to target specific management practices, such as fertilization and irrigation, to areas of the field that need it most. This can lead to more efficient use of resources and can improve crop yields and quality.

1.4.2. NDVI in Forestry

We use NDVI to evaluate the density and health of forests, as well as to measure changes in forest cover through time and contrast various forest types. It can also be used to find stressed or damaged areas of the forest, likely from pests, diseases, or other causes. It can also be used to calculate forest biomass and carbon sequestration potential. It detects changes in vegetation cover, like canopy cover, leaf area index, and biomass and helps in monitoring the health of forests at large areas using NDVI.

Using NDVI values can identify whether an area is recovering well from management practices, and if an area is not recovering well. Combining NDVI with complementary sources of data (like

LiDAR) can help to refine this understanding of forest structure and biomass properties. NDVI data can now be collected remotely and more often, at lower costs, and much faster thanks to the expansion of UAV use cases.

1.4.3. NDVI for Environmental Monitoring

NDVI can be used to monitor the health and productivity of vegetation in natural ecosystems, such as grasslands, savannas, and wetlands. It can be used to detect changes in vegetation cover due to human activities or natural events, such as deforestation, land use change, and drought. NDVI can also be used to monitor the recovery of vegetation after disturbances, such as fires or floods.

NDVI can be used to detect changes in vegetation cover, such as changes in canopy cover, leaf area index, and biomass. NDVI can also be used to detect changes in ecosystem structure, such as changes in the density of vegetation, and to identify areas of ecosystem regeneration.

NDVI can also be used to monitor the effects of environmental management practices, such as restoration, conservation, or reforestation, on ecosystem health. NDVI values can be used to identify areas that are recovering well from management practices, and to detect areas that are not recovering as well. (https://www.cropin.com/)

1.5 Land Surface Temperature (LST)

LST refers to the temperature of the Earth's surface as measured from a distance, typically using satellite-based sensors. It represents the temperature emitted by the surface and is influenced by factors such as solar radiation, surface material properties, and atmospheric conditions.

1.5.1 Measurement: LST is primarily measured using thermal infrared (TIR) sensors onboard satellites. Instruments like the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) are commonly used. These sensors detect thermal radiation emitted by the surface and convert it into temperature readings using established radiative transfer models.

Calculating Land Surface Temperature (LST) typically involves several steps, from obtaining satellite data to applying algorithms that convert thermal infrared (TIR) data into temperature values.

Here’s a detailed on how to calculate LST:

1.5.2. Data Acquisition / Satellite Data Sources: Obtain thermal infrared data from satellites such as:

1.5.2.a MODIS: (Moderate Resolution Imaging Spectroradiometer) on NASA’s Terra and Aqua satellites.

1.5.2.b Landsat series: particularly Landsat 8, which has the Thermal Infrared Sensor (TIRS).

1.5.2.c Sentinel-3: with the Sea and Land Surface Temperature Radiometer (SLSTR).

1.5.3. Pre-processing

1.5.3.a Radiometric Correction: Convert raw digital numbers (DN) from satellite images to radiance values using calibration coefficients provided in the metadata.

Example for Landsat 8:

Convert DN to top-of-atmosphere (TOA) radiance:

$$L\lambda = ML \times Qcal + AL$$

where:

- $L\lambda$ is the TOA radiance.
- ML is the radiance multiplicative scaling factor.
- AL is the radiance additive scaling factor.
- $Qcal$ is the quantized and calibrated standard product pixel values (DN).

1.5.3.b Atmospheric Correction: Adjust for atmospheric effects (optional but recommended for higher accuracy).

1.5.4. Brightness Temperature Calculation

Convert the TOA radiance to brightness temperature (TB) using the inverse of the Planck function.

Example for Landsat 8:

where:

$$\mathbf{TB = K_2 / \ln (K_1 / L\lambda) + 1}$$

- TB is the brightness temperature in Kelvin.
- K_1 and K_2 are the thermal conversion constants specific to the sensor.
- $L\lambda$ is the TOA radiance.

1.5.5. Land Surface Emissivity (LSE)

Emissivity Estimation: Calculate or estimate the land surface emissivity (LSE) based on land cover type. Emissivity values vary depending on surface material and vegetation cover.

1.5.5.1 NDVI Threshold Method:

Calculate NDVI from red and NIR bands:

$$NDVI = \frac{(\mathbf{NIR-Red})}{(NIR+Red)}$$

Use NDVI to estimate LSE (εε):

$$\varepsilon = \begin{cases} 0.99 & \text{for water} \\ 0.97 - 0.98 & \text{for vegetation} \\ 0.93 - 0.96 & \text{for bare soil} \end{cases}$$

Alternatively, a more detailed formula considering NDVI values can be used.

1.5.6. Calculate Land Surface Temperature (LST)

Apply the following formula to convert brightness temperature to LST considering emissivity:

$$LST = \frac{T_B}{1 + \left(\frac{\lambda T_B}{\rho}\right) \ln(\varepsilon)}$$

where:

- LST is the land surface temperature in Kelvin.
- TB is the brightness temperature in Kelvin.
- λ is the wavelength of emitted radiance (e.g., 10.895 µm for Landsat 8 band 10).
- ρ is the Planck's constant divided by the Boltzmann constant (14380 µm K).
- ε is the surface emissivity.

1.5.7 Example Calculation for Landsat 8

1.5.7.a Convert DN to Radiance:

$$L\lambda = 0.0003342 \times Q_{cal} + 0.1$$

1.5.7.b Convert Radiance to Brightness Temperature:

$$T_B = \frac{1321.08}{\ln\left(\frac{774.89}{L_\lambda} + 1\right)}$$

1.5.7.c Estimate Emissivity using NDVI:

Calculate NDVI from NIR and Red bands.

Estimate emissivity **ε**ε**.**

1.5.7.d Convert Brightness Temperature to LST

$$LST = \frac{T_B}{1 + \left(\frac{\lambda T_B}{\rho}\right) \ln(\varepsilon)}$$

1.5.8 Tools and Software

Several tools and software packages can automate these steps:

1.5.8.a Google Earth Engine: Cloud-based platform that allows for complex geospatial processing.

1.5.8.b QGIS with Semi-Automatic Classification Plugin: Free and open-source software for remote sensing analysis.

1.5.8.c ERDAS IMAGINE and ENVI: Commercial software packages with advanced remote sensing capabilities.

1.5.9 Importance of LST

1.5.9.1 Climate Monitoring and Modelling:

1.5.9.1a Climate Change Indicators: LST data are crucial for monitoring global and regional temperature trends, contributing to the understanding of climate change. Variations in LST can indicate changes in surface energy balance, albedo, and heat fluxes.

1.5.9.1b Climate Models: LST is an essential input for climate models that simulate atmospheric and surface interactions. Accurate LST data help improve model predictions of future climate scenarios and their potential impacts.

1.5.9.2 Agriculture and Crop Management:

1.5.9.2a Soil Moisture and Irrigation: LST provides insights into soil moisture conditions and evapotranspiration rates, aiding in efficient irrigation planning and water resource management.

1.5.9.2b Crop Health Monitoring: Abnormal LST patterns can indicate crop stress due to factors such as drought, disease, or nutrient deficiency. Farmers and agronomists use this information to make timely interventions to mitigate crop loss.

1.5.9.3 Urban Heat Island Effect

1.5.9.3a Heat Islands: Urban areas often exhibit higher LST compared to rural surroundings due to human activities and infrastructure, leading to the Urban Heat Island (UHI) effect. Monitoring LST helps in understanding and mitigating UHI impacts on urban climates, energy consumption, and public health.

1.5.9.3b Urban Planning: LST data support urban planning initiatives aimed at reducing heat accumulation through green spaces, reflective materials, and improved urban design.

1.5.9.4 Hydrology and Water Resources:

1.5.9.4a Water Bodies: LST measurements over water bodies provide information on surface water temperature, which is crucial for studying aquatic ecosystems, fisheries, and hydrological cycles.

1.5.9.4b Snow and Ice: LST data help monitor the melting and freezing processes of snow and ice, contributing to water resource management and flood prediction in mountainous regions.

1.5.9.5 Environmental and Ecological Studies:

1.5.9.5a Habitat Monitoring: LST is used to monitor habitats and ecosystems, especially in arid and semi-arid regions where temperature extremes affect vegetation and wildlife.

1.5.9.5b Fire Detection: Elevated LST can indicate the presence of wildfires, enabling early detection and management of forest fires. Satellite-based LST measurements are integral to fire monitoring systems.

1.5.9.6 Surface Energy Balance and Land-Atmosphere Interactions:

1.5.9.6a Energy Balance: LST is a key component in calculating the surface energy balance, which involves the exchange of energy between the Earth's surface and the atmosphere. Understanding this balance is vital for studying weather patterns and energy fluxes.

1.5.9.6b Land-Atmosphere Feedbacks: Changes in LST influence atmospheric processes, including cloud formation, precipitation patterns, and atmospheric circulation. LST data help in studying these feedback mechanisms.

1.5.9.6c Remote Sensing Technologies: Advances in remote sensing technologies and data processing algorithms continue to improve the accuracy and spatial resolution of LST measurements. Emerging satellite missions and sensors will enhance the capability to monitor LST at finer scales and in real-time.

1.5.9.6.d Integration with Other Data: Combining LST data with other environmental variables, such as vegetation indices (e.g., NDVI), soil moisture, and precipitation, provides a comprehensive understanding of land surface processes and their interactions.

1.5.9.6e Climate Adaptation and Mitigation: LST information supports climate adaptation strategies, such as developing heat-resistant crop varieties, designing climate-resilient infrastructure, and implementing sustainable water management practices.

1.5.9.7. Relationship Between NDVI and LST

The relationship between the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) is critical in understanding ecological and climatic interactions. NDVI, which measures vegetation health and density, inversely correlates with LST due to the cooling effect of transpiration in vegetated areas. High NDVI values indicate lush vegetation, leading to increased transpiration, which cools the surface and results in lower LST. Conversely, low NDVI values signify sparse or unhealthy vegetation, resulting in reduced transpiration and higher LST. This relationship highlights the role of vegetation in moderating surface temperatures, which is crucial for urban planning and agricultural practices. Furthermore, studying NDVI and LST together can help monitor drought conditions, assess ecosystem health, and model climate change impacts. Thus, the NDVI-LST relationship is essential for environmental management and understanding the feedback mechanisms between vegetation and surface temperatures.

1.5.9.7.1 Inverse Correlation in Vegetated Areas:

1.5.9.7.1a Vegetative Cooling Effect: areas with dense vegetation, high NDVI values typically correlate with lower LST. This inverse relationship is due to the cooling effect of transpiration and high albedo of healthy vegetation. Transpiration releases moisture, which cools the surface, while the high reflectance of NIR radiation by chlorophyll reduces heat absorption.

- **Example:** In forested regions, dense canopies with high NDVI values often exhibit lower LST due to the shading and cooling effects of trees.

1.5.9.7.2: Direct Correlation in Non-Vegetated Areas

1.5.9.7.2a Bare Soil and Urban Areas: In regions with sparse vegetation or non-vegetated surfaces (e.g., deserts, urban areas), low NDVI values often correspond to higher LST. Bare soils and urban materials tend to absorb more solar radiation, leading to increased surface temperatures.

- **Example** In urban areas, low NDVI values due to concrete and asphalt surfaces are associated with higher LST, contributing to the urban heat island effect.

1.5.9.7.3 Seasonal and Temporal Variation

1.5.9.7.3a Seasonal Changes: The relationship between NDVI and LST can vary seasonally. For instance, during the growing season, NDVI increases as vegetation becomes lusher, often leading to a decrease in LST. Conversely, during the dry season, vegetation stress or senescence leads to lower NDVI and higher LST.

1.5.9.7.3b Temporal Dynamics: Short-term changes in NDVI and LST can indicate environmental stressors such as droughts. A rapid decrease in NDVI coupled with an increase in LST can signal the onset of drought conditions affecting vegetation health.

1.5.9.8 Spatial Variability:

1.5.9.8a Land Use and Land Cover Types: The NDVI-LST relationship can vary significantly across different land use and land cover types. Agricultural areas, forests, grasslands, and urban regions each exhibit distinct NDVI-LST dynamics based on their specific surface properties and land management practices.

- **Example:** In agricultural areas, irrigation can maintain high NDVI and low LST, while nearby fallow or harvested fields might show lower NDVI and higher LST.

1.5.9.9 Impact of Soil Moisture

1.5.9.9a Soil Moisture Influence: Soil moisture content can influence the NDVI-LST relationship. Moist soils, often associated with high NDVI due to healthy vegetation, tend to have lower LST due to higher evaporation rates. Conversely, dry soils can elevate LST and reduce NDVI.

1.5.9.10 Applications and Implications

1.5.9.10a Drought Monitoring: Combined NDVI and LST data can effectively monitor drought conditions. A decrease in NDVI and an increase in LST often indicate vegetation stress and water scarcity.

1.5.9.10b Urban Heat Island Studies: The relationship between NDVI and LST is crucial for understanding and mitigating the urban heat island effect. Increasing urban green spaces (higher NDVI) can help reduce LST and mitigate heat islands.

1.5.9.10c Agricultural Management: Monitoring NDVI and LST together aids in assessing crop health, planning irrigation, and detecting heat stress in agricultural fields.

1.5.9.10d Climate Change Research: The NDVI-LST relationship provides insights into how vegetation and surface temperatures respond to climatic variations, informing climate adaptation and mitigation strategies.

1.6 Research Objectives

- To Study the Annual, inter-annual and sessional variation of vegetation growth from 2000 to 2023.
- To Study the land Surface temperature change of Uttarakhand from year 2000 to 2023.
- Relationship between vegetation changes (NDVI) and Land Surface Temperature (LST) since last two decades.

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CHAPTER 2

REVIEW OF LITERATURE

The Himalayan region of Uttarakhand, India, is characterized by its diverse ecosystems, complex topography, and significant climatic variations. Research on NDVI (Normalized Difference Vegetation Index), LST (Land Surface Temperature), and precipitation has been crucial for understanding vegetation health, climate dynamics, and environmental changes in this sensitive area. This literature review provides a year-wise analysis of the research developments in these parameters, highlighting significant contributions from global and Indian researchers, specifically focusing on Uttarakhand.

1970s-1980s: Foundations of Remote Sensing

Rouse et al. (1974) introduced the NDVI, providing a ground-breaking method to assess vegetation health using satellite imagery. NDVI calculates the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs), normalized by the sum of these two bands. This simple yet effective index has become a cornerstone in remote sensing for vegetation monitoring.

1980s

The development of thermal infrared sensors on satellites facilitated the measurement of LST, offering insights into surface temperature variations critical for understanding energy balance and thermal dynamics of the Earth's surface. Initial applications of LST helped in various studies including urban heat islands, surface energy budgets, and climate change effects.

1990s: Early Applications in the Himalayas

Negi and Singh (1992) utilized NDVI to monitor forest cover changes in Uttarakhand, highlighting the impact of deforestation and land-use changes. This study marked one of the early applications of remote sensing in the Indian Himalayas, demonstrating the potential of satellite data in environmental monitoring in remote and rugged terrains.

2000-2010: Advancing Remote Sensing Techniques

Singh and Mal (2005) analysed long-term precipitation data and its impact on vegetation cover using NDVI. They emphasized the sensitivity of Himalayan vegetation to monsoonal rainfall patterns, highlighting the importance of understanding precipitation variability for managing water resources and agricultural productivity.

Joshi et al (2006) conducted comprehensive studies on the relationship between NDVI and forest health in the Kumaon region. They utilized multi-temporal satellite data to monitor seasonal and interannual changes in vegetation cover, providing critical information for forest management and conservation efforts.

Tiwari et al (2008) explored the relationship between LST and vegetation cover, finding that deforested areas exhibited higher temperatures, which adversely affected local climate and vegetation health. Their work demonstrated the utility of LST in identifying areas experiencing thermal stress due to land-cover changes.

2011-2015: Integrating Climate Data and Remote Sensing

Pandey et al (2011) investigated spatial and temporal variations of LST in the Uttarakhand Himalayas, correlating these variations with changes in land cover and elevation. Their findings underscored the importance of LST in understanding regional climate dynamics and its implications for vegetation and human activities.

Singh et al (2012). monitored seasonal and interannual vegetation cover variations using NDVI. They found that NDVI could effectively capture the phenological cycles of different vegetation types, reflecting the seasonal dynamics and health of vegetation in the region.

Bhatt and Goel (2013) analyzed urban heat island effects in Dehradun using LST data. Their research highlighted the significant impact of urbanization on local temperature regimes and provided insights for urban planning and climate adaptation strategies.

Pandey et al (2014). studied the impact of climate change on vegetation phenology using NDVI. They observed that shifts in NDVI patterns correlated with changes in temperature and precipitation, indicating the sensitivity of Himalayan vegetation to climate variability.

2016-2020: Technological Advancements and Detailed Analyses

Sharma et al. (2016) utilized satellite-based precipitation data to study its effects on vegetation phenology in Uttarakhand. They found strong correlations between precipitation anomalies and NDVI variations, emphasizing the critical role of precipitation in sustaining the region's diverse ecosystems.

Kumar et al. (2017) combined NDVI, LST, and precipitation data to assess the impacts of climate change on forest ecosystems. Their study revealed significant shifts in vegetation patterns and thermal regimes, linked to changes in precipitation and temperature, thus providing a comprehensive understanding of climate impacts on forests.

Bharti and Joshi (2018) examined the impact of extreme precipitation events on vegetation using NDVI. They found that such events could lead to significant vegetation stress, affecting the overall health and productivity of the region's forests and agricultural lands.

Rawat et al. (2019) used an integrated approach combining NDVI, LST, and precipitation data to study the impact of climate variability on agricultural productivity. Their research provided valuable insights for developing strategies to mitigate the adverse effects of climate change on agriculture in the region.

Patil et al. (2020) utilized high-resolution satellite data to analyse vegetation dynamics in response to climate variability. Their research emphasized the need for advanced monitoring and conservation strategies to manage the natural resources of Uttarakhand effectively.

2021-Present: Modern Techniques and Comprehensive Studies

Mehta et al. (2021) employed machine learning techniques to model vegetation health and climate impacts using combined NDVI, LST, and precipitation data. Their predictive models offered new tools for environmental management, enhancing the ability to forecast and mitigate climate impacts.

Pandey et al. (2022) continued their research on climate change impacts, focusing on integrating high-resolution satellite data with ground-based observations. Their work aimed at improving the accuracy of climate impact assessments and developing robust conservation strategies.

Sharma et al. (2023) explored the effects of a severe drought on vegetation health by combining NDVI, LST, and precipitation data. Their study highlighted the compounded impact of reduced precipitation and increased temperatures on vegetation stress, emphasizing the need for integrated climate monitoring systems.

Early Developments and Key Contributions

Early 1990s
Initial applications of NDVI in the Himalayas focused on broad-scale vegetation monitoring. These studies established baseline data for forest cover and land-use changes, providing critical insights into the region's ecological dynamics.

Mid 1990s to Early 2000s
Researchers began exploring the relationships between NDVI and climatic variables such as temperature and precipitation. These studies laid the groundwork for understanding how vegetation responds to climate variability and extreme weather events.

Mid-2000s: Integrating Advanced Technologies

2005-2006

The integration of NDVI with other remote sensing data, such as LST and precipitation, allowed for more comprehensive studies of vegetation health. Researchers utilized multi-temporal satellite data to monitor changes over time, providing a more detailed understanding of the region's ecological dynamics.

2007-2008

Studies focused on the effects of land-cover changes, such as deforestation and urbanization, on local climate and vegetation health. These studies highlighted the importance of preserving forest cover to maintain ecological balance and mitigate climate impacts.

2010-2015: Advances in Climate and Vegetation Studies

2010-2012

The focus shifted towards understanding the impacts of climate change on vegetation phenology. Researchers used NDVI to monitor seasonal changes and identify trends in vegetation growth and productivity in response to climatic variability.

2013-2015

Studies began to integrate climate models with remote sensing data to predict future vegetation patterns under different climate scenarios. This approach provided valuable insights for developing adaptation and mitigation strategies to address the impacts of climate change.

2016-2020: Detailed Analysis and Technological Integration

2016-2018

Researchers utilized high-resolution satellite data to analyze the spatial and temporal variability of LST, NDVI, and precipitation. These studies provided detailed insights into the interactions between climate variables and vegetation health, highlighting the importance of multi-parameter analysis for comprehensive climate impact assessments.

2019-2020

The integration of machine learning techniques with remote sensing data enabled researchers to develop predictive models for vegetation health and climate impacts. These models offered new tools for environmental management, enhancing the ability to forecast and mitigate climate impacts.

Recent Developments and Future Directions

2021-Present

Recent studies have focused on improving the accuracy of climate impact assessments by integrating high-resolution satellite data with ground-based observations. Researchers continue to explore the interactions between NDVI, LST, and precipitation to develop robust conservation strategies for the Uttarakhand Himalayas.

Future Directions

Future research should focus on enhancing the resolution and accuracy of remote sensing data, integrating advanced analytical techniques, and developing comprehensive models to predict and mitigate the impacts of climate change on vegetation and ecosystems. Collaboration between global and Indian researchers will be crucial for addressing the complex environmental challenges in the region.

Indian Contributions and Regional Focus

Negi and Singh (1992). Their early work utilizing NDVI for forest cover monitoring laid the foundation for subsequent research in the region. They highlighted the potential of satellite data in environmental monitoring, providing a basis for future studies on vegetation dynamics and land-use changes.

Joshi et al. (2006). Their comprehensive studies on NDVI and forest health in the Kumaon region provided critical information for forest management and conservation efforts. They emphasized the importance of continuous monitoring for sustainable resource management.

Pandey et al. (2014). Their research on the impact of climate change on vegetation phenology using NDVI highlighted the sensitivity of Himalayan vegetation to climate variability. Their findings provided valuable insights for developing strategies to mitigate the adverse effects of climate change on vegetation.

Sharma et al. (2018). extended the research on climate variability impacts by combining NDVI, LST, and precipitation data. Their integrated approach offered a more detailed understanding of how these variables interact to influence vegetation health and productivity in Uttarakhand. Their findings have been crucial in informing local conservation and management strategies.

CHAPTER 3

STUDY AREA

3.1. LOCATION OF STUDY AREA

Across 53,484 square kilometres, 93% of Uttarakhand is hilly territory, and 65% is covered in forests. The state is located on the southern slopes of the Himalayan range (Negi, 2009). The region's height, which varies from 200 meters in the Gangetic plains to over 7800 meters in the Himalayas, influences the region's different weather and vegetation. A total of 1546 mm of rainfall on average every year, most of which falls between June and September during the monsoon. The precipitation distribution is highly variable because of the sharp elevation gradient extending from south to north **(Singh & Mal, 2014).** This gradient also determines patterns of vegetation.

At elevations between 3000 and 4800 meters, alpine shrubs and meadows flourish; vegetation is absent above 4800 meters. Beneath the canopy of trees, the temperate Western Himalayan There is Subalpine Conifer Forest. The Temperate Western Himalayan Broadleaf woods, which stretch from 2600 to 1500 meters, replace these woods as they descend from 3000 to 2600 meters. At elevations lower than 1500 meters, the Himalayan Subtropical Pine Forests are predominant (Singh & Singh, 1987). Terai-Duar Savannas and Upper Gangetic Plain Moist Forests, much of which has been cleared for cultivation, are features of lowland regions (**Tiwari & Joshi, 2012a**).

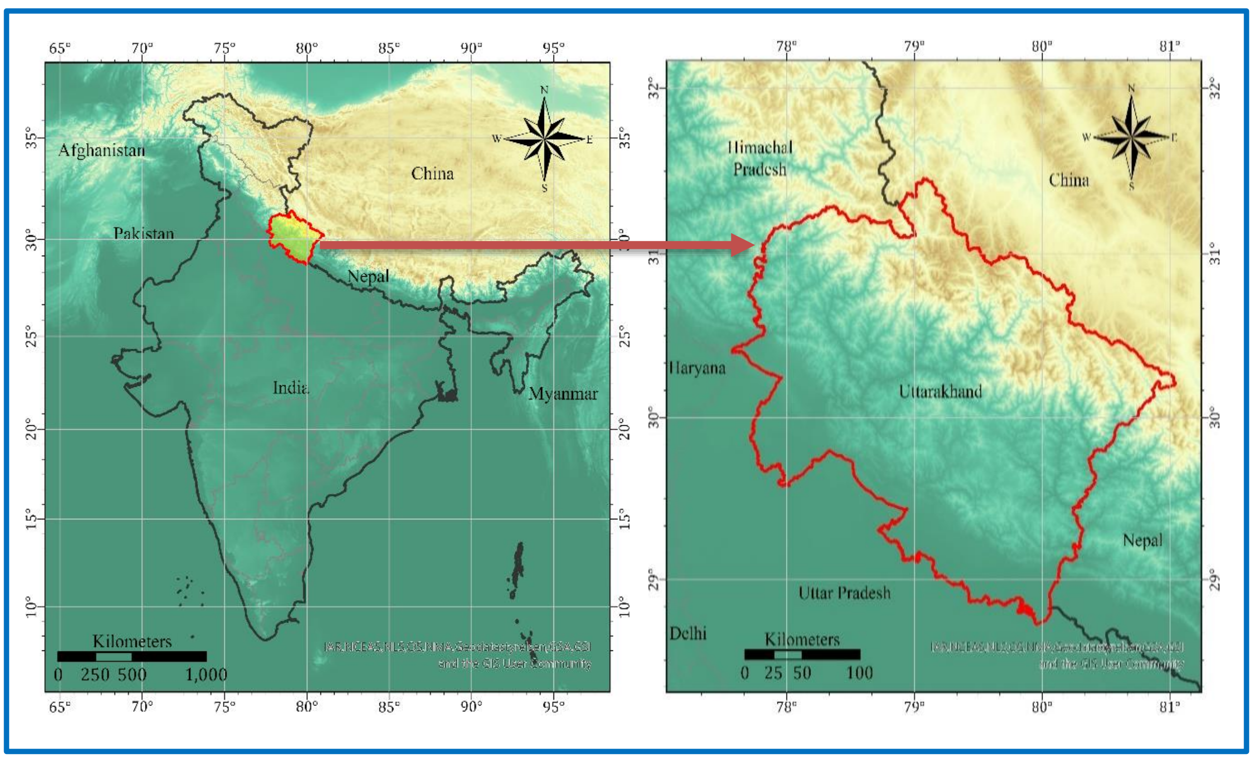

Figure:3.1 Study Area: Western Himalay, Uttarakhand, India

Uttarakhand has created six national parks, six animal sanctuaries, and two conservation reserves, all of which are overseen by state and federal governments, in order to preserve its vast biodiversity. Attracting both local and foreign tourists, the state plays a major role in India's tourism industry. Still, recent decades have seen a substantial increase in urbanization. The population of the state grew by 15.83% between 2001 and 2011, within the same time span, with the urban population increasing from 25.67% to 30.23% (India, 2011). Numerous factors, including the development of rural growth centres, the extension of urban areas already in place, the intensification of agriculture, better transportation, the growth of the tourism industry, improved market accessibility, and insufficient land use regulations, are responsible for this growth (Tiwari & Joshi, 2012b). Based on recent statistics, the natural forest area of Uttarakhand has lost 5.85% due to urban growth between 1981 and 2011 (Tiwari & Joshi, 2012c).

3.2. GEOGRAPHICAL BACKGROUND OF STUDY AREA

Due to its unique terrain, Uttarakhand is typically separated into two regions: the eastern Kumaon and the western Garhwal. The Sanskrit phrase meaning North Country is where the word Uttarakhand originates. With a total size of 53,484 km², 93% of Uttarakhand is made up of mountains, while 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 Yamuna and the Ganga at Gangotri, two of the most significant rivers in Hinduism, have their sources in this area. At yamonotri These two, together with Badrinath and Kedarnath, make up the Chota Char Dham, a Hindu pilgrimage site. The state is home to the Bengal tiger at Jim Corbett National Park, India's oldest national park. The Valley of Flowers, a Unesco World Heritage Site in the upper reaches of the Bhyundar Ganga near Joshimath in the Gharwal district, is well-known for the diversity and uniqueness of its flowers and flora. Sir Joseph Dalton Hooker, Director of the Royal Botanic Gardens, Kew, who was visiting the region, was one of those who brought it up. As a result, Lord Dalhousie enacted the Indian Forest Charter in 1855, effectively overturning the prior laissez-faire policy. The Indian Forest Act of 1878 gave Indian forestry a firm scientific foundation.

Dietrich Brandis established the Imperial Forest School in Dehradun as a direct result of this in 1878. It was renamed the 'Imperial Forest Research Institute' in 1906 and is currently known as the Forest Research Institute of India. The model "Forest Circles" surrounding Dehradun, utilized for teaching, demonstration, and scientific observations, had a long-term good impact on the woods.

3.3 FLORA AND FONA

Uttarakhand has a diversity of flora and fauna. It has a recorded forest area of 34,666 km^2 (13,385 sq mi), which constitutes 65% of the total area of the state. Uttarakhand is home to rare species of plants and animals, many of which are protected by sanctuaries and reserves. National parks in Uttarakhand include the Jim Corbett National Park (the oldest national park of India) in Nainital and Pauri Garhwal District, and Valley of Flowers National Park & Nanda Devi National Park in Chamoli District, which together are a UNESCO World Heritage Site. A number of plant species in the valley are internationally threatened, including several that have not been recorded from elsewhere in Uttarakhand. Rajaji National Park in Haridwar, Dehradun and Pauri Garhwal District and Govind Pashu Vihar National Park & Gangotri National Park in Uttarkashi District are some other protected areas in the state.

Leopards are found in areas that are abundant in hills but may also venture into the lowland jungles. Smaller felines include the jungle cat, fishing cat, and leopard cat. Other mammals include four kinds of deer (barking, sambar, hog and chital), sloth, Brown and Himalayan black bears, Indian grey mongooses, otters, yellow-throated martens, bharal, Indian pangolins, and langur and rhesus monkeys.

In the summer, elephants can be seen in herds of several hundred. Marsh crocodiles (*Crocodylus palustris*), gharials (*Gavialis gangeticus*) and other reptiles are also found in the region. Local crocodiles were saved from extinction by captive breeding programs and subsequently re-released into the Ramganga river. Several freshwater terrapins and turtles like the Indian sawback turtle (*Kachuga tecta*), brahminy river turtle (*Hardella thurjii*), and Ganges softshell turtle (*Trionyx gangeticus*) are found in the rivers. Butterflies and birds of the region include red helen (*Papilio helenus*), the great eggfly (*Hypolimnos bolina*), common tiger (*Danaus genutia*), pale wanderer (*Pareronia avatar*), jungle babbler, tawny-bellied babbler, great slaty woodpecker, red-breasted parakeet, orange-breasted green pigeon and chestnut-winged cuckoo.

In 2011, a rare migratory bird, the bean goose, was also seen in the Jim Corbett National Park. A critically endangered bird, last seen in 1876 is the Himalayan quail endemic to the western Himalayas of the state.

Evergreen oaks, rhododendrons, and conifers predominate in the hills. Prunus cerasoides (pahiyya), *sal* (*Shorea robusta*), silk cotton tree (*Bombax ciliata*), *Dalbergia sissoo*, *Mallotus philippensis*, *Acacia catechu*, *Bauhinia racemosa*, and *Bauhinia variegata* (camel's foot tree) are some other trees of the region. *Albizia chinensis*, the sweet sticky flowers of which are favoured by sloth bears, are also part of the region's flora.

A decade long study by Prof. Chandra Prakash Kala concluded that the Valley of Flowers is endowed with 520 species of higher plants (*angiosperms*, *gymnosperms* and *pteridophytes*), of these 498 are flowering plants. The park has many species of medicinal plants including *Dactylorhiza hatagirea*, *Picrorhiza kurroa*, *Aconitum violaceum*, *Polygonatum multiflorum*, *Fritillaria roylei*, and *Podophyllum hexandrum*.

In the summer season of 2016, a large portion of forests in Uttarakhand caught fires and rubbled to ashes during Uttarakhand forest fires incident, which resulted in the damage of forest resources worth billions of rupees and death of 7 people with hundreds of wild animals died during fires. During the 2021 Uttarakhand forest fires, there was widespread damage to the forested areas in Tehri district. A number of native plants are deemed to be of medicinal value.

The government-run Herbal Research and Development Institute carries out research and helps conserve medicinal herbs that are found in abundance in the region. Local traditional healers still use herbs, in accordance with classical Ayurvedic texts, for diseases that are usually cured by modern medicine.

3.4 DEMOGRAPHY

3.4.1 Population Density: The native people of Uttarakhand are generally called Uttarakhandi and sometimes specifically either Garhwali or Kumaoni depending on their place of origin in either the Garhwal or Kumaon region.

According to the 2011 Census of India, Uttarakhand has a population of 10,086,292 comprising 5,137,773 males and 4,948,519 females, with 69.77% of the population living in rural areas.
The state is the 20th most populous state of the country having 0.83% of the population on 1.63% of the land. The population density of the state is 189 people per square kilometre having a 2001–2011 decadal growth rate of 18.81%. The gender ratio is 963 females per 1000 males. The crude birth rate in the state is 18.6 with the total fertility rate being 2.3. The state has an infant mortality rate of 43, a maternal mortality rate of 188 and a crude death rate of 6.6.

Table:3.1 District wise population distribution in the Uttarakhand Himalaya (Source: Census of India, 2011 & 2001)

District	**Population**					
	2011	%	2001	%	Change	%
Haridwar	18,90,422	18.7	14,47,187	17.1	4,43,235	30.6
Dehradun	16,96,694	16.8	12,82,143	15.1	4,14,551	32.3
Udham Singh Nagar	16,48,902	16.3	12,35,614	14.6	4,13,288	33.4
Nainital	9,54,605	9.5	7,62,909	9	1,91,696	25.1
Pauri	6,87,271	6.8	6,97,078	8.2	-9,807	-1.4
Almora	6,22,506	6.2	6,30,567	7.4	-8061	-1.3
Tehri	6,18,931	6.1	6,04,747	7.1	14,184	2.3
Pithoragarh	4,83,439	4.8	4,62,289	5.4	21,150	4.6
Chamoli	3,91,605	3.9	3,70,359	4.4	21,246	5.7
Uttarkashi	3,30,086	3.3	2,95,013	3.5	35,073	11.9
Bageshwar	2,59,898	2.6	2,49,462	2.9	10,436	4.2
Champawat	2,59,648	2.6	2,24,542	2.6	35,106	15.6
Rudraprayag	2,42,285	2.4	2,27,439	2.7	14,846	6.5
Total	1,00,86,292	100	84,89,349	100	15,96,943	11.8

Table:3.2 Gender Distribution and Density of Population (Source: Census of India, 2011 & 2001)

District	General Distribution			Density		
	2011	**2001**	**Change (%)**	**2011**	**2001**	**Change (%)**
Haridwar	880	868	1.4	801	612	30.9
Dehradun	902	893	1	541	414	30.7
Udham Singh Nagar	920	902	2	649	424	53.1
Nainital	934	906	3.1	225	198	13.6
Pauri	1103	1104	-0.1	129	129	0
Almora	1139	1147	-0.7	198	205	-3.4
Tehri	1077	1051	2.5	170	148	14.9
Pithoragarh	1020	1031	-1.1	68	65	4.6
Chamoli	1019	1017	0.2	49	48	2.1
Uttarkashi	958	941	1.8	41	37	10.8
Bageshwar	1090	1110	-1.8	116	108	7.4
Champawat	980	1024	-4.3	147	126	16.7
Rudraprayag	1114	1117	-0.3	122	120	1.7
Total	963	962	0.1	189	159	18.9

3.5 Physiography

Physiographic zones of Uttarakhand: Uttarakhand can be divided into several physiographic zones, all running parallel to each other from northwest to southeast. The northern zone, popularly known as the Himadri, contains segments of the Zaskar and the Great Himalaya ranges, Adjacent to and south of the Great Himalay is a zone containing the Lesser Himalayas, known popularly as the Himachal.To the south of the Himachal is a stretch of the Siwalik Range. The southern edge of the Siwalik Range merges with a narrow bed of gravel and alluvium known as the Bhabar, which interfaces to the southeast with the marshy terrain known as the Tarai. The combined Siwalik-BhabarTarai area ranges in elevation from 1,000 to 10,000 feet (300 to 3,000 metres). South of the Siwaliks are found flat-floored depressions, known locally as duns, such as the Dehra Dun. These are

- **The Greater Himalaya**
- **The Lesser Himalaya**
- **Siwaliks and Doon**
- **Bhabhar and Tarai zones**

- **1. Terai and Bhabar Zone (200-500 meters)**
  The southernmost part of Uttarakhand includes the Terai and Bhabar zones, characterized by flat terrain and fertile soils. This area supports dense forests and intensive agriculture due to its subtropical climate. The Terai is known for its marshy lands, while the Bhabar is a narrow strip of porous land at the Himalayan foothills. This zone is crucial for crops such as rice, wheat, and sugarcane (Valdiya, 1980).

- **2. Shivalik Hills (500-1,500 meters)**
  Above the Terai lies the Shivalik range, with lower hills and a subtropical to temperate climate. This zone supports mixed forests of sal, pine, and broad-leaved species. The Shivaliks face significant soil erosion and landslides due to loose sedimentary rocks. Terrace farming is common, growing crops like maize, millet, and vegetables (Rawat & Chaturvedi, 1984).

- **3. Middle Himalayas (1,500-3,000 meters)**
  The Middle Himalayas, or Lesser Himalayas, have a temperate climate with distinct seasonal variations. This zone features dense forests of oak, deodar, and rhododendron. Agriculture is significant, with crops such as wheat, barley, and fruits. The region supports horticulture and livestock rearing (Singh et al., 1994).

- **4. Greater Himalayas (3,000-5,000 meters)**
  The Greater Himalayas, characterized by an alpine to sub-alpine climate, experience cold temperatures and heavy snowfall. Vegetation is sparse, consisting mainly of alpine meadows and hardy shrubs. This zone is essential for glacial studies and water resources, as it houses major glaciers. Limited agriculture and pastoralism are practiced due to harsh conditions (Sharma et al., 2010).

- **5. Trans-Himalayas (Above 5,000 meters)**
  The highest altitude zone, the Trans-Himalayas, has extremely harsh climatic conditions, with very low temperatures and minimal vegetation. It includes snow-capped peaks and glaciers. Human habitation is almost non-existent, and the area is primarily significant for mountaineering and high-altitude research (Valdiya, 1980).

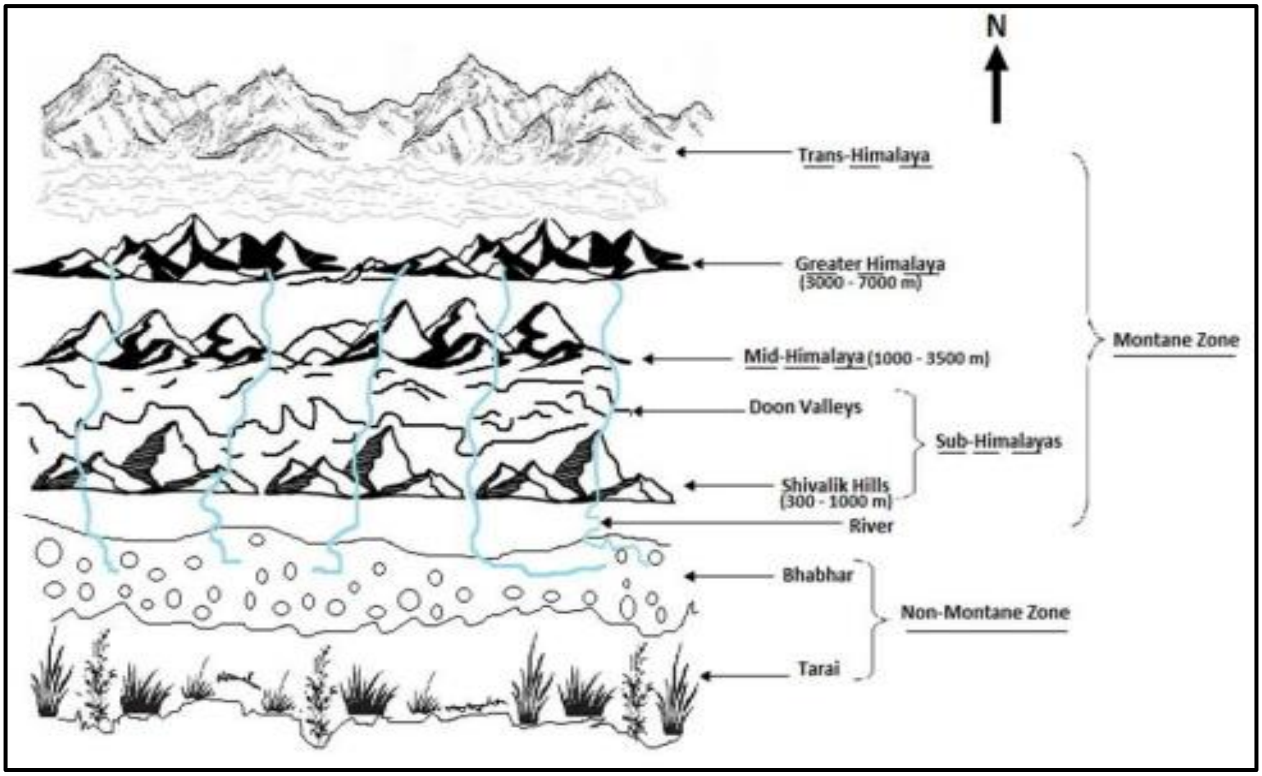

Figure:3.2 Diagrammatic representation of different physiographic zones in Uttarakhand (not to scale).
Source: Mamgain et al

3.5.1 Slope

Uttarakhand, located in the Western Himalayas, is characterized by its rugged and varied topography, with slopes playing a crucial role in shaping its ecological and environmental dynamics. The slopes of Uttarakhand range from steep gradients in the higher altitudes to gentler inclines in the lower regions. This diversity in slope impacts both natural processes and human activities significantly.

The slope of a terrain influences soil erosion, vegetation distribution, and water runoff patterns. Steeper slopes, which are prevalent in the higher Himalayan ranges of Uttarakhand, are more prone to soil erosion and landslides, especially during heavy rainfall events (Valdiya, 1980). These areas also exhibit distinct vegetation patterns, with altitude and slope gradient affecting the types of flora that can thrive. For instance, alpine and sub-alpine vegetation is commonly found on steep slopes, while gentler slopes support mixed forests and agricultural activities.

Hydrological processes are also closely linked to slope gradients. Steep slopes facilitate rapid runoff, reducing water infiltration into the soil, which can lead to flash floods downstream. Conversely, gentler slopes in the lower foothills allow for greater water infiltration, supporting diverse agricultural practices (Singh et al., 1994).

The interaction between slope and human activities is evident in the terraced farming systems of Uttarakhand, which are adapted to the hilly terrain. These terraces help in reducing soil erosion and managing water resources efficiently.

Understanding the slope dynamics of Uttarakhand is essential for sustainable land use planning and disaster management. Integrating slope analysis with other geospatial data can help in mitigating the adverse effects of natural hazards and optimizing land use strategies (Sharma et al., 2010).

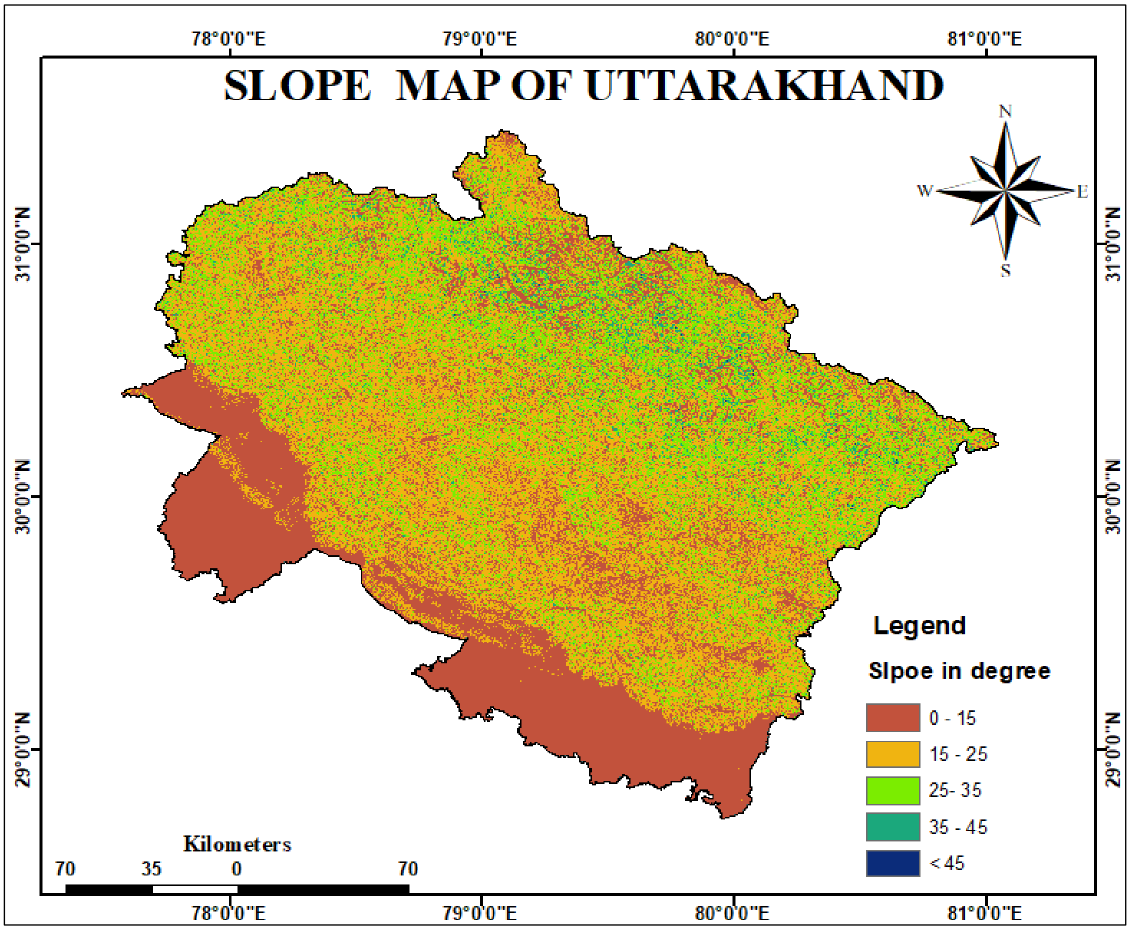

Figure:3.3 Slope map of Uttarakhand

3.5.2 Altitudinal zone

Uttarakhand, located in the Western Himalayas, features a diverse range of altitudinal zones, each with distinct climatic, ecological, and socio-economic characteristics. These zones range from the low-lying plains to the high-altitude regions, exceeding 7,000 meters. The classification of these zones is critical for understanding the region's environmental dynamics and guiding sustainable development practices.

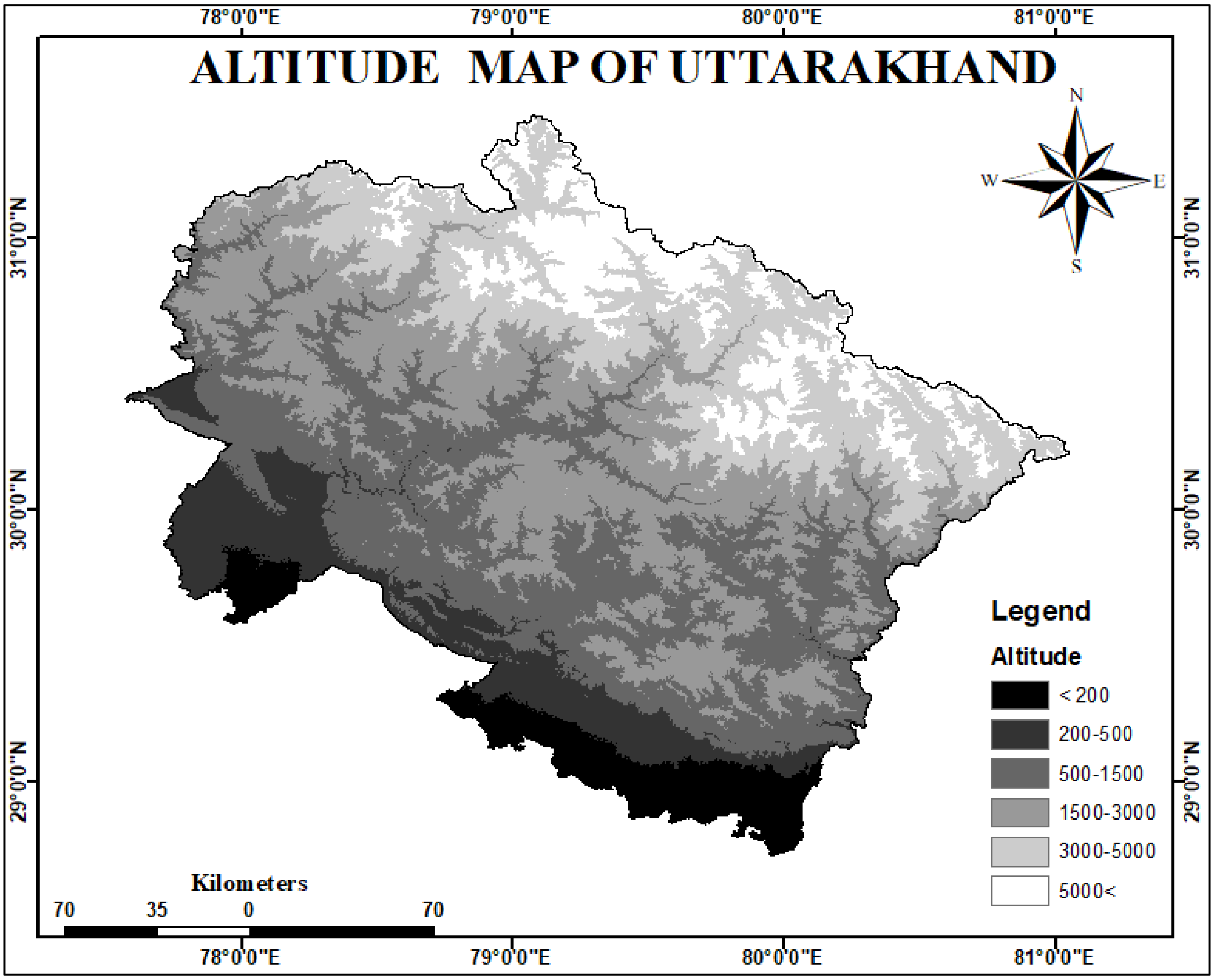

Figure:3.4 Altitudinal zones

3.5.3 Slope Aspect

The slope aspect, or the direction in which a slope faces, significantly influences the microclimate, vegetation, and soil properties of a region. In Uttarakhand, a state characterized by its rugged terrain in the Western Himalayas, slope aspect plays a crucial role in shaping ecological and environmental patterns.

Slope aspect affects solar radiation exposure, which in turn influences temperature, moisture levels, and vegetation growth. South-facing slopes in the Northern Hemisphere, such as those in Uttarakhand, receive more direct sunlight throughout the year compared to north-facing slopes. This results in warmer and drier conditions on south-facing slopes, which favour the growth of drought-resistant vegetation like pine forests. In contrast, north-facing slopes are cooler and retain more moisture, supporting dense, broad-leaved forests and a higher biodiversity (Singh & Singh, 1992).

The differences in solar radiation also impact soil development and erosion rates. South-facing slopes, being drier, often have thinner soils and higher erosion rates due to less vegetation cover.

North-facing slopes, with their cooler and moister conditions, tend to have thicker soils and lower erosion rates. This variation influences land use practices; for example, agriculture and settlement patterns in Uttarakhand are often adapted to the specific conditions created by slope aspect (Negi, 2002).

Furthermore, slope aspect influences snow accumulation and melting patterns in higher altitudes. North-facing slopes tend to retain snow cover longer than south-facing slopes, affecting water availability in downstream areas during the melting season. This has significant implications for water resource management in the region (Pant & Tewari, 1985).

Understanding the impact of slope aspect is essential for sustainable land management, conservation efforts, and mitigating natural hazards in Uttarakhand. It helps in planning agricultural activities, forestry practices, and infrastructural development in accordance with the natural environmental gradients.

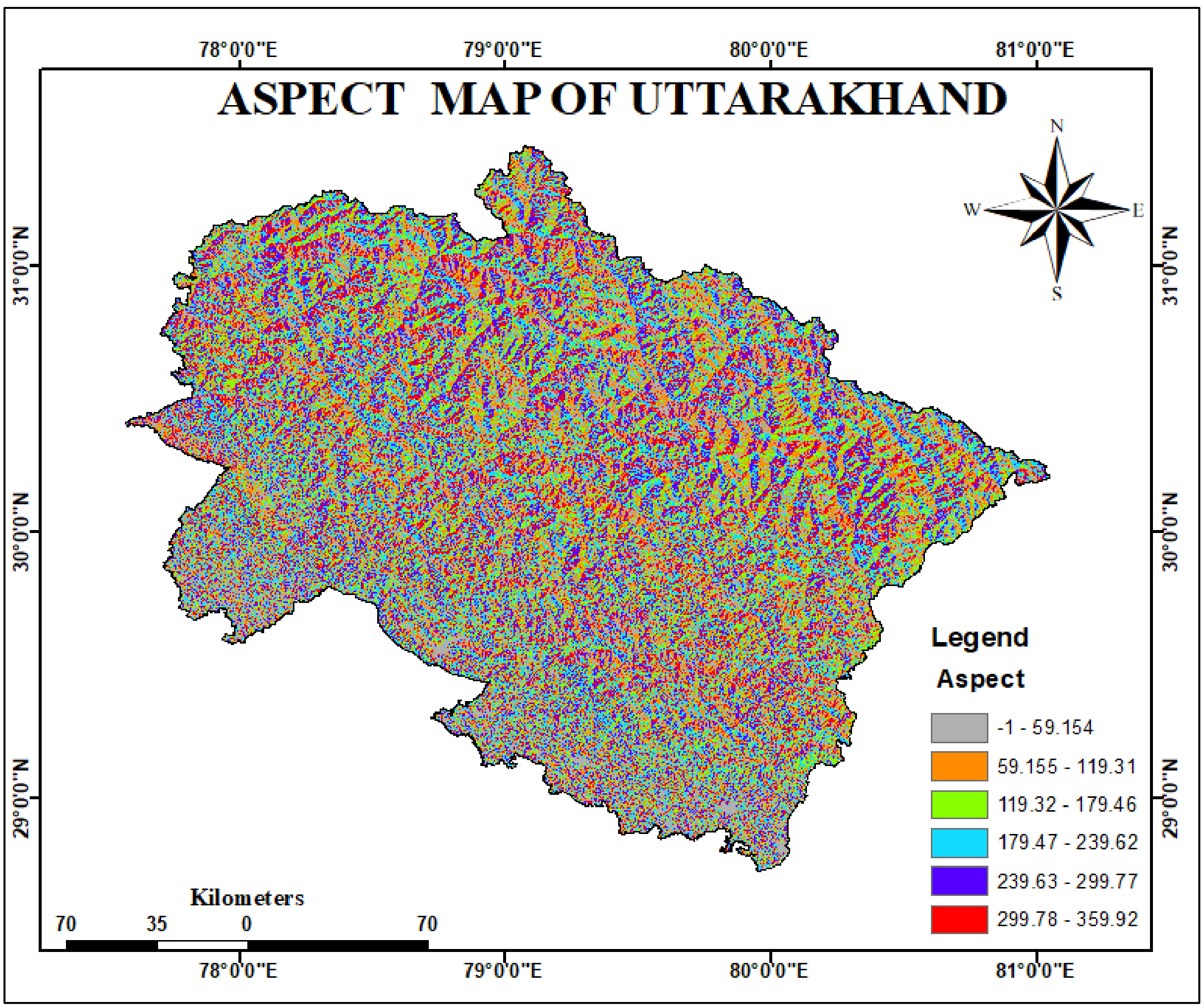

Figure:3.5 Aspect map of Uttarakhand

3.5.4 Drainage Pattern

The drainage pattern of Uttarakhand is predominantly dendritic, characterized by tree-like branching of rivers and their tributaries. This pattern is shaped by the underlying geology and the steep slopes of the region. The rivers carve out deep valleys and gorges as they descend, with notable features such as river terraces and alluvial fans forming in the lower reaches (Valdiya, 1980).

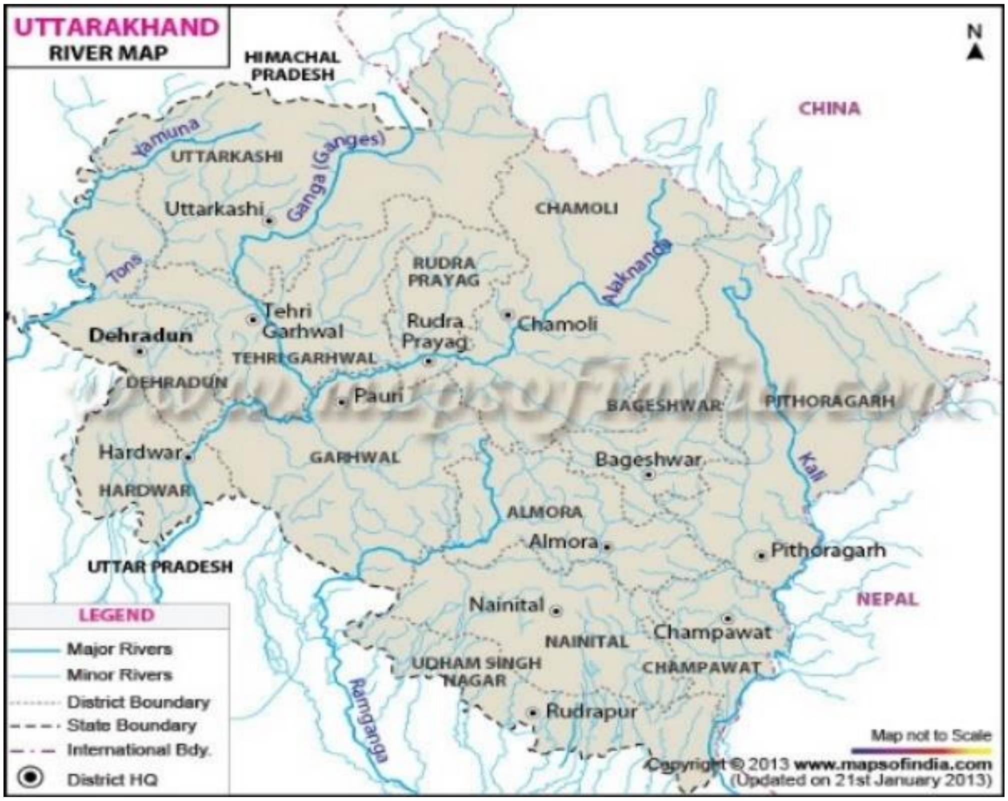

Figure:3.6 River Map of Uttarakhand (Source: www.mapsofindia.com)

The water quality of Uttarakhand's rivers is generally good, particularly in the higher portions. Water quality degrades downstream of several big communities and in the lower regions of the Himalayan foothills as a result of untreated sewage and industrial effluent discharge. However, the state's ambitious aim to develop 450 hydropower projects jeopardizes the sustainability of river ecosystems as well as the lives and livelihoods of those who live in the valleys.

Uttarakhand, located in Northern India, contains some of the most important and major rivers of India. The Ganga and the Yamuna have their sources in this state and comprise the most famous and major rivers of the country as a whole. They are supplied with water on a perennial basis by numerous lakes, glaciers and countless streams in the area

1. Yamuna: Originating from the Yamunotri Glacier at a height of 6,387 metres on the south western slopes of Banderpooch peaks in the uppermost region of the Lower Himalayas in Uttarakhand, The source of Yamuna lies in the Yamunotri Glacier at a height 6,387 metres, on the south western slopes of Banderpooch peaks, which lie in the Mussoorie range of Lower Himalayas, in the Uttarkashi district,Uttarakhand, north of Haridwar. Yamunotri temple, a shrine dedicated to the goddess, Yamuna is one of the holiest shrines in Hinduism, and part of the Chota Char Dham Yatra circuit. Also standing close to the temple, on its 13 km trek route, that follows the right bank of the river, lies the Markendeya Tirtha, where the sage Markandeya wrote the Markandeya Purana.

2. Bhagirathi: [Jadhganga, Assi Ganga, Jalkur, and Bhilangana]. A 100-kilometer network of dams and barrages prevents the R. Bhagirathi from flowing freely. R. Bhilangana has two medium-sized dams, while the lower reach is buried by the Tehri dam.Proposed dams and barrages endanger the Jadh Ganga and Assi Ganga rivers.

3. Alaknanda: The is a Himalayan river in the state of Uttarakhand, India and one of the two headstreamsof the Ganges, the major river of Northern India and the holy river of Hinduism. In hydrology, the Alaknanda is considered the source streamof the Ganges on account of its greater length and discharge; however, in Hindu mythology and culture, the other headstream, theBhagirathi, is considered the source stream. Several rivers in the Garhwal region merge with the Alaknanda at Panch Prayag or 'holy confluence of rivers'. These are: 1. Vishnuprayag, where the Alaknanda is met by the Dhauliganga River 2. Nandaprayag, where it is met by the Nandakini River 3. Karnaprayag, where it is met by the Pindar River 4. Rudraprayag, where it is met by the Mandakini River 5. Devprayag, where it meets the Bhagirathi River and officially becomes the Ganges the headwaters of the Bhagirathi are formed at Gaumukh (elevation 3,892 metres (12,769 ft)), at the foot of the Gangotri glacier and Khatling glaciers in the Garhwal Himalaya. It is then joined by its tributaries; these are, in order from the source: • Kedar Ganga at Gangotri (elevation 3,049 m (10,003 ft)), • Jadh Ganga at Bhaironghati (elevation 2,650 m (8,690 ft)), • Kakora Gad and Jalandhari Gad near Harsil (elevation 2,745 m (9,006 ft)) • Siyan Gad near Jhala (elevation 2,575 m (8,448 ft)), • Asi Ganganear Uttarkashi (elevation 1,158 m (3,799 ft)), • Bhilangna River near Old Tehri (elevation 755 m (2,477 ft)). The Bhilangna itself rises at the foot of the Khatling Glacier approximately 50 km (31 mi) south of Gurumukhi.

4. Ganga: The Ganges is the most sacred river to Hindus. It is also a lifeline to millions of Indians who live along its course and depend on it for their daily needs. It is worshipped as the goddess Ganga in Hinduism. It has also been important historically, with many former provincial or imperial capitals located on its banks. The Ganges begins at the confluence of the Bhagirathi and Alaknanda rivers at Devprayag. The Bhagirathi is considered to be the true source in Hindu culture and mythology, although the Alaknanda is longer the headwaters of the Alakananda are formed by snowmelt from such peaks as Nanda Devi, Trisul, and Kamet. The Bhagirathi rises at the foot of Gangotri Glacier, at Gaumukh, at an elevation of 3,892 m (12,769 ft)

5. Tons: The Tons is the largest tributary of the Yamuna and flows through Garhwalregion in Uttarakhand, touching Himachal Pradesh. The Tons thrust is named after this river. Tons valley lies in Jaunsar Bawar region, as it emerges from the Himalayas has Dehradun on its eastern bank. The cantonment town of Chakrata is situated between, the Tons and Yamuna rivers. Along with Ganges, it has now become a major destination for water-based adventure sports like white-water rafting in Uttarakhand.You can stay at Jaunsar Bawar region on the banks of the Tons river and enjoy the grade 4 rafting. Typical season for rafting in Tons is till July.

6. Ramganga: Gagas; Kosi The River Ramganga is a robust river that flows above the Kalagarh dam and exits Uttarakhand at 3 km u/s. The Gagas and Kosi rivers are drying up owing to low base flows and intensive exploitation.

7. Kaliganga: [Dhauliganga, Goriganga, Ramganga (E), Saryu, and Ladhiya]. If all of the projected HEPs on the R. Dhauliganga (E) and Goriganga are completed, they will dry up almost completely. The Saryu's water quality is already under jeopardy.

3.6 Climate

Uttarakhand, located in the Western Himalayas, experiences a diverse range of climatic conditions due to its varied topography, which ranges from low-lying plains to high-altitude regions exceeding 7,000 meters. The state's climate is influenced by factors such as altitude, latitude, and the presence of significant geographical features like the Himalayan mountain range.
Climatic Zones
The climate of Uttarakhand can be categorized into several distinct zones:

1. Subtropical Zone (200-1,500 meters):

Found in the southern Terai and Bhabar regions.
Characterized by hot summers with temperatures reaching up to 40°C and mild winters.
Receives significant rainfall during the monsoon season (June to September), contributing to the region's agricultural productivity (Singh & Singh, 1992).

2. Temperate Zone (1,500-3,000 meters):

Covers the Middle Himalayas or Lesser Himalayas.
Exhibits moderate temperatures with cooler summers and cold winters.
Receives substantial monsoon rainfall and occasional snowfall in winter. This zone supports diverse forests, including oak and rhododendron (Negi, 1991).

3. Alpine Zone (3,000-4,500 meters):

Located in the Greater Himalayas.

Characterized by cool summers and extremely cold winters with heavy snowfall.
Vegetation is sparse, consisting mainly of alpine meadows and hardy shrubs. This zone is crucial for glacial studies and water resources (Mani, 1981).

4. Nival Zone (Above 4,500 meters):

Encompasses the high-altitude peaks and glaciers.
Features harsh climatic conditions with very low temperatures year-round and heavy snowfall.
Vegetation is minimal, and the area is largely covered by ice and snow (Valdiya, 1980).

5. Seasonal Variation

Uttarakhand experiences significant seasonal variations:

- **Summer (April to June):** Warm and pleasant in the hills, hot in the plains.
- **Monsoon (July to September):** Dominated by heavy rainfall, particularly in the southern regions. The monsoon is critical for agriculture but also brings risks of landslides and floods.
- **Autumn (October to November):** Clear skies and mild temperatures, a favorable season for tourism.
- **Winter (December to March):** Cold, with snowfall in higher altitudes and frost in the lower regions.

6. Climate Change Impact

Climate change has started to alter the climatic patterns of Uttarakhand. Studies have indicated changes in precipitation patterns, with increasing instances of intense rainfall and prolonged dry spells. Glacial retreat is another significant impact, with glaciers in the region receding, affecting water availability downstream (Negi, 2009). These changes pose challenges to agriculture, water resources, and overall sustainability in the region.

7. Socio-Economic Implications

The diverse climate of Uttarakhand influences its socio-economic activities, including agriculture, tourism, and hydroelectric power generation. The variability in climatic conditions necessitates adaptive strategies for sustainable development and disaster risk reduction (Ghosh et al., 2015).

3.6.1 Rainfall

Rainfall patterns in Uttarakhand are influenced by its unique geographical features, including its diverse topography and proximity to the Indian monsoon. The state receives precipitation from both the southwest monsoon, which brings heavy rains during the summer months, and from western disturbances, which cause rainfall in the winter and spring seasons.

The distribution of rainfall across Uttarakhand varies significantly due to its varied terrain. The southern regions, including the Terai and Bhabar areas, receive higher rainfall amounts compared to the northern mountainous regions. This is attributed to orographic effects, where moist air masses from the Bay of Bengal ascend the southern slopes of the Himalayas, leading to orographic rainfall. The northern regions, sheltered by the Greater Himalayas, experience lower precipitation levels.

Dr. P. S. Negi, in his research on the environmental factors influencing the Himalayan region, highlights the importance of orographic effects in shaping rainfall patterns in Uttarakhand. He emphasizes that the orographic lifting of moist air masses along the southern slopes of the Himalayas results in enhanced rainfall in these areas (Negi, 1991).

Furthermore, climate change is likely to impact rainfall patterns in Uttarakhand, with projections indicating changes in precipitation intensity and distribution. Dr. H. S. Negi, in his study on climate change impacts on the Himalayan glaciers, suggests that alterations in precipitation patterns could have significant implications for water resources and ecosystems in the region (Negi, 2009).

Understanding rainfall patterns in Uttarakhand is crucial for water resource management, agriculture, and disaster preparedness. Scientists continue to study these patterns to assess the impacts of climate change and to develop adaptation strategies for the region.

3.6.2 Temperature

The temperature in Uttarakhand is influenced by its diverse topography, altitude variations, and seasonal monsoonal patterns. The state experiences a wide range of temperatures, from subtropical conditions in the lower regions to alpine climates in the higher Himalayas.

The plains and foothills of Uttarakhand, such as the Terai and Bhabar regions, exhibit subtropical temperatures with hot summers and relatively mild winters. Conversely, the higher altitudes in the Himalayas, including the Greater and Lesser Himalayan ranges, experience cooler temperatures year-round, with significant variations depending on altitude and aspect.

Dr. A. Mani, in his comprehensive study on the climate of the Himalayas, highlights the significant temperature variations observed in Uttarakhand due to its altitude range. He emphasizes that the state's higher elevations experience cooler temperatures, with alpine conditions prevailing in the upper reaches (Mani, 1981).

The seasonal variations in temperature are pronounced in Uttarakhand. During the summer months, temperatures can soar in the plains and foothills, while the mountainous regions remain relatively cooler. In contrast, winters bring cold temperatures across the state, with snowfall occurring in the higher altitudes.

Climate change is also expected to impact temperatures in Uttarakhand, with projections indicating rising temperatures and altered temperature patterns. Dr. H. S. Negi, in his research on climate change impacts on the Himalayas, suggests that rising temperatures could lead to changes in snow and glacier dynamics, affecting water resources and ecosystems (Negi, 2009).

Understanding temperature dynamics in Uttarakhand is crucial for assessing climate change impacts, managing natural resources, and adapting to changing environmental conditions.

3.7 Geomorphology

Uttarakhand's geomorphology is shaped by its dynamic geological processes, diverse topography, and tectonic activity. The state encompasses a wide range of landforms, including rugged mountains, deep valleys, and alluvial plains, reflecting its complex geological history and ongoing landscape evolution.

The Himalayan mountain range dominates Uttarakhand's landscape, comprising both the Lesser Himalayas and the Greater Himalayas. These mountains are characterized by steep slopes, deep gorges, and glaciated peaks, sculpted by tectonic uplift, erosion, and glacial activity over millions of years.

Dr. K. S. Valdiya, in his extensive research on the geology of the Himalayas, provides insights into the formation of Uttarakhand's mountainous terrain. He highlights the role of tectonic forces in shaping the region's geomorphology, including the uplift of the Himalayas and the development of fault systems and thrust belts (Valdiya, 1980).

In addition to its mountainous areas, Uttarakhand features several distinct geomorphic regions. The Terai and Bhabar plains in the southern foothills are characterized by alluvial deposits and a network of rivers and streams. These plains are prone to floods and erosion, shaping the region's agricultural practices and human settlements.

The Middle Himalayas exhibit a rugged terrain with deep valleys and steep slopes, supporting dense forests and diverse flora and fauna. The region's geomorphology is influenced by fluvial erosion, mass wasting, and weathering processes, contributing to its ecological diversity.

The state's geomorphology plays a crucial role in shaping its socio-economic activities, including agriculture, tourism, and infrastructure development. Understanding the geological processes and landforms of Uttarakhand is essential for natural hazard mitigation, sustainable land use planning, and environmental conservation.

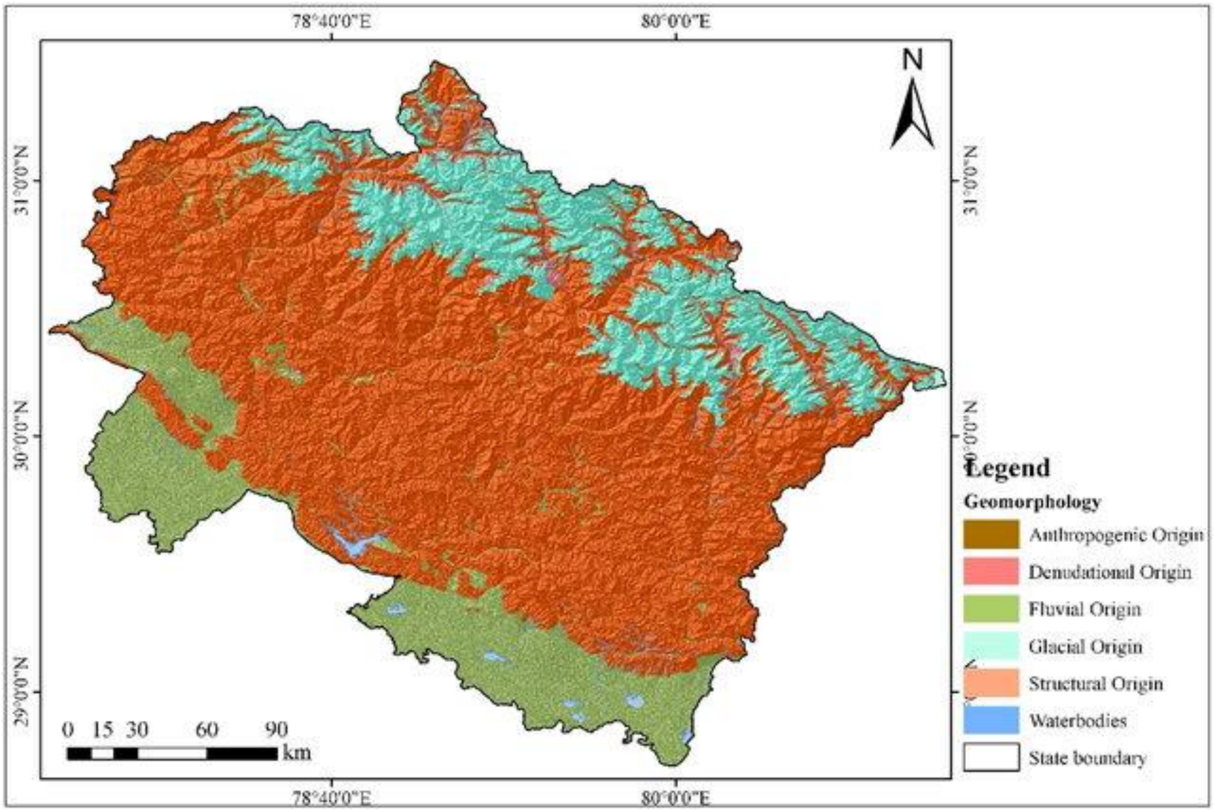

Figure:3.7 (Major geomorphological classes in the Uttarakhand Himalaya.) **Source:** H. Khali Et Al.

3.7.1 Geological Structure

Uttarakhand's geological structure is primarily influenced by the collision of the Indian and Eurasian tectonic plates, resulting in the uplift of the Himalayan mountain range and the formation of diverse geological features. The state's geological structure comprises several major units, including sedimentary rocks, metamorphic rocks, and igneous intrusions.

Dr. K. S. Valdiya, a renowned geologist, extensively studied the geological structure of the Himalayas, including Uttarakhand. In his research, he elucidates the complex geological processes that have shaped the region, highlighting the role of tectonic forces, erosion, and sedimentation in the formation of Uttarakhand's geological structure (Valdiya, 1980).

The Himalayan region of Uttarakhand primarily consists of folded sedimentary rocks, formed by the compression and folding of ancient marine sediments. These rocks, including shale, sandstone, and limestone, bear witness to the geological history of the region and contain valuable information about past environmental conditions.

Metamorphic rocks, such as gneiss and schist, are also prevalent in Uttarakhand, particularly in the Higher Himalayas. These rocks have undergone intense heat and pressure, resulting in their characteristic banded appearance and mineral composition.

Additionally, igneous intrusions, including granite and diorite, are found in some parts of Uttarakhand, indicating past volcanic activity and magmatic processes.

Understanding the geological structure of Uttarakhand is essential for various applications, including mineral exploration, groundwater management, and natural hazard assessment.

3.7.2 Lithology

The lithology of Uttarakhand, encompassing a diverse array of rock types and formations, reflects its complex geological history and tectonic evolution. The state's lithological composition comprises a combination of sedimentary, metamorphic, and igneous rocks, each contributing to its unique geological landscape.

Dr. K. S. Valdiya, a prominent geologist, has conducted extensive research on the lithology of the Himalayas, including Uttarakhand. His studies provide valuable insights into the composition and distribution of rock formations in the region, shedding light on their geological significance and origin (Valdiya, 1980).

Sedimentary rocks, formed by the deposition and lithification of sedimentary particles, constitute a significant portion of Uttarakhand's lithological makeup. These rocks include shale, sandstone, limestone, and conglomerates, indicating past marine, fluvial, and terrestrial environments. They are predominantly found in the foothill plains and valleys of the state.

Metamorphic rocks, resulting from the alteration of pre-existing rocks due to heat and pressure, are widespread in Uttarakhand, particularly in the Higher Himalayas. These rocks, such as gneiss, schist, and marble, exhibit distinct banding and mineralogical changes, providing insights into the regional tectonic processes and geological history.

Igneous rocks, formed from the solidification of molten magma, are also present in Uttarakhand, primarily as intrusive bodies and volcanic formations. Granite, diorite, and basalt are among the common igneous rocks found in the region, reflecting past magmatic activity and volcanic eruptions.

The diverse lithology of Uttarakhand influences various aspects of the region, including soil composition, landscape morphology, and natural resource distribution. Understanding the lithological characteristics of Uttarakhand is essential for geological mapping, mineral exploration, and land-use planning.

3.7.8 Structure

Uttarakhand's geological structure is characterized by its intricate tectonic framework, comprising a mosaic of faults, folds, and thrusts resulting from the collision between the Indian and Eurasian plates. This collision initiated the uplift of the Himalayas, shaping the region's geological architecture over millions of years.

Dr. K. S. Valdiya, an eminent geologist, has extensively studied the structure of the Himalayas, including Uttarakhand. His research elucidates the complex tectonic processes and structural elements that have contributed to the formation of the region's geological structure (Valdiya, 1980).

One prominent structural feature of Uttarakhand is its system of thrust faults, where older rock units have been thrust over younger units due to compressional forces. These thrust faults, such as the Main Central Thrust and the Main Boundary Thrust, are indicative of the Himalayan tectonic regime and play a significant role in shaping the region's topography.

Folded structures are also prevalent in Uttarakhand, particularly in the Lesser Himalayas. These folds, including anticlines and synclines, are a result of the compressional forces exerted during tectonic convergence. They contribute to the rugged terrain and steep slopes characteristic of the Himalayan landscape.

Furthermore, the region's geological structure exhibits a complex arrangement of rock formations, including sedimentary, metamorphic, and igneous rocks. These diverse lithological units, combined with the tectonic structures, contribute to the geological diversity and mineral wealth of Uttarakhand.

Understanding the structure of Uttarakhand is essential for various applications, including seismic hazard assessment, mineral exploration, and groundwater management. It provides valuable insights into the region's geological history and evolution, shaping scientific understanding and resource management strategies.

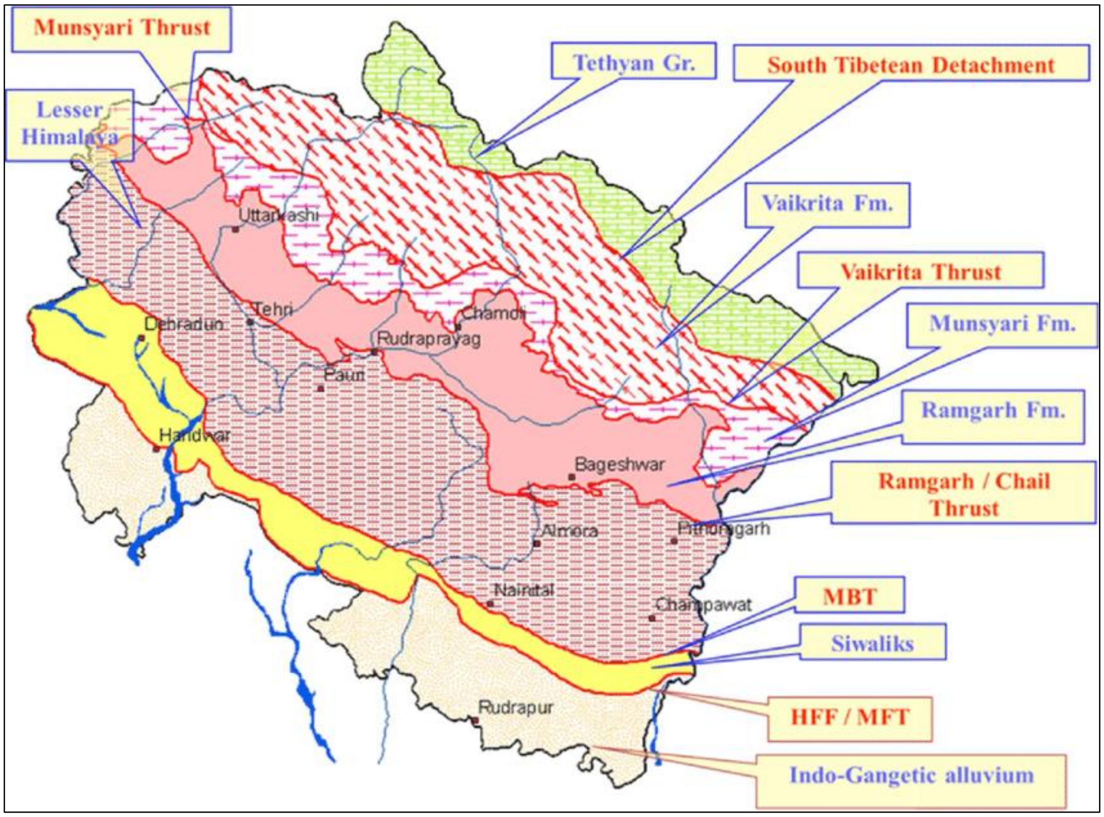

Figure:3.8 Map depicting Geology of the area with litho-physiographic region, Source (S. Khanduri IJESKA (2020) 2 (2) 48-63)

Geologically, in the Himalayan mountains-Uttarakhand Himalayan system provides unique research space for the study to ensure the continental lithosphere response in favour of its destructive Collison history (Dewey and Burke 1973; LeForte 1975). In context of mass movement, the effective role of geological sequence (formation, litho units) cannot be ignored from the literatures (Middlemess 1885; Holland 1908; Auden 1935; Heim and Gansser 1939; Misra and Sharma 1967; Jain 1971; Rupke 1974; Valdiya 1979, 1980; Srivastava and Mitra 1994; Searle et al. 2003; Richards et al. 2005). It is observed that the Himalayan geology has been studied for over a century by many geologists. In sequence to that (Heim and Gansser 1939) first introduced the major Himalayan physiographic sequence as The Sub-Himalayan Seq. (SHS), the Lesser Himalayan Seq. (LHS), the Central Himalayan Crystalline (HCS), and the Tethyan Himalayan Seq. that aged from Cenozoic (quaternary) to Archean and dipping to its north with the alternating dipping thrust-fault systems as Himalayan Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), and later recognized South Tibet Detachment fault (STDF). Each tectonic unit is not only representing its physiography (average elevation) but also separated by the boundaries of intra-crustal fault zones (thrusts and wrench faults). Stratigraphic association is shown in Figure 3.9. Here the map dimension intends to introduce Himalayan geology as a whole with the diverse regional geological setup (Uttarakhand Himalaya) alongside regional structures to elucidate the relationship between landslides and geology. Based on the section review it is observed that the regional setup ranges from the late Proterozoic-recent quaternary age. UH, stretched from south to north elaborates: the late tertiary to a recent quaternary group of rocks. Heterogenic lithology comprised of thickly bedded sandstone, siltstone and mudstone, weakly cemented conglomerate beds, and permeable quaternary deposits on moderate to steep slopes are primarily responsible for the landslide in the lower part region. It has been observed that the intensity usually occurs high along the active tectonic zones, specifically between the MBT–MCT in its south and north. The Proterozoic (mid)– Cambrian (early) age Lesser Himalaya (LH) rocks are bounded between these fault systems. Due to the intense structural presence (folding and faulting) along such rugged-hilly terrain, it becomes highly fractured, highly weathered (Pachauri 2010), sheared, and less consolidated. furthermore, compared to other Himalayan sequences,

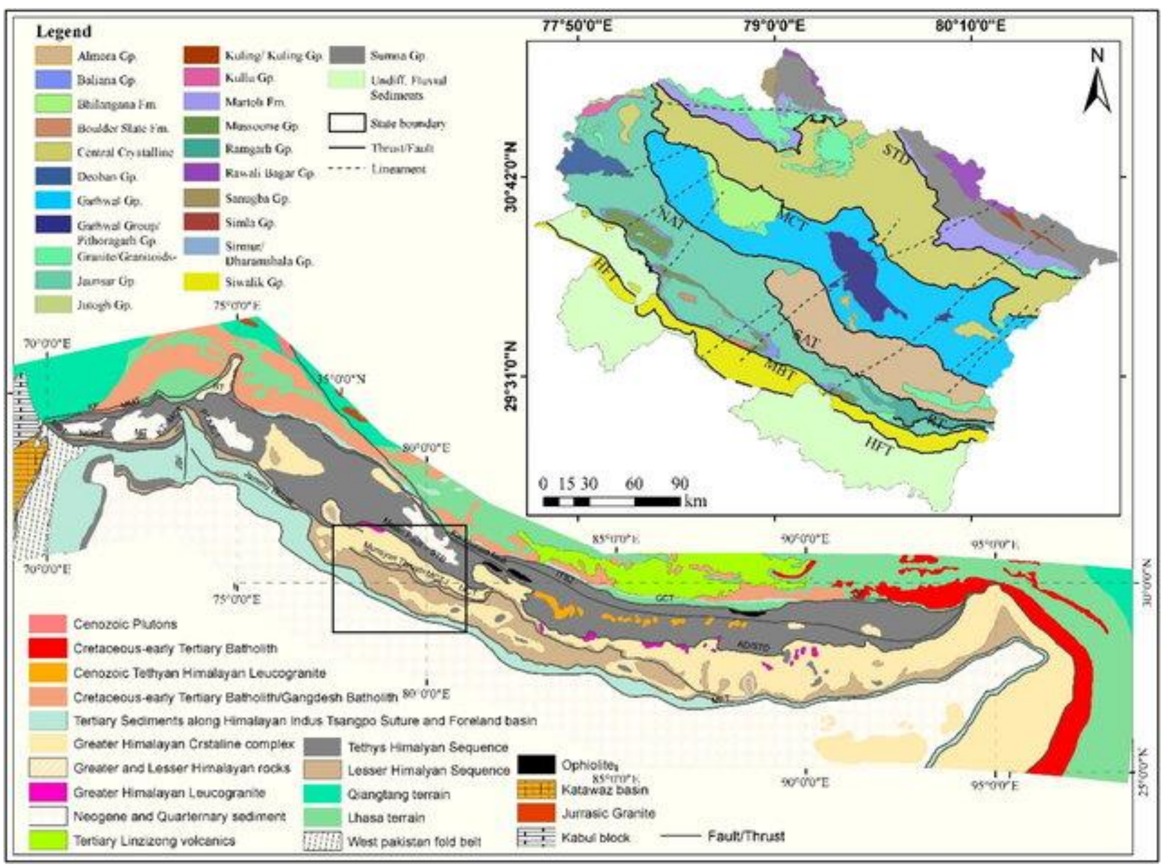

Figure:3.9 Geological map view of Uttarakhand Himalayan and Himalayan geological stretch (modified after Yin 2005and GSI 2021) Source: H. Khali Et Al.

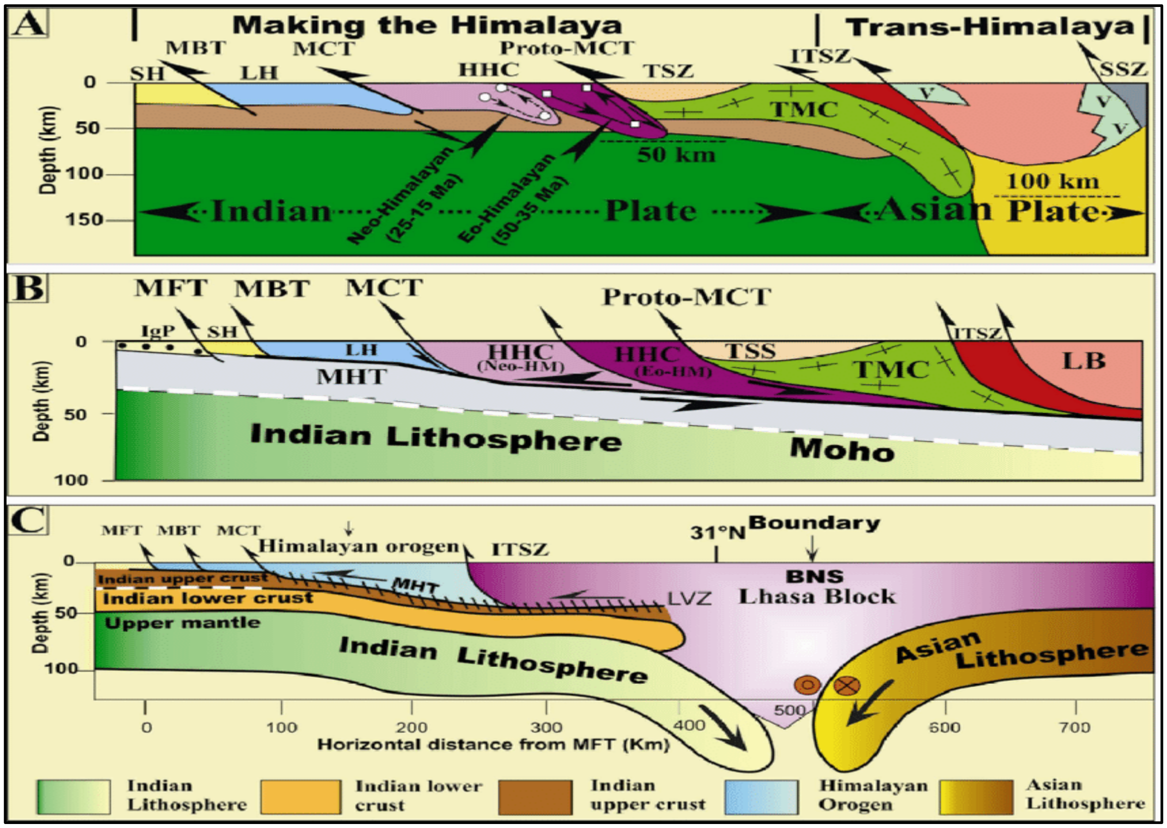

Figure:3.10 Simplified geological cross-sections across the Himalaya and Trans-(Source: A. Jain Et.al 2016)

In Figure3.11 Shown that Simplified geological cross-sections across the Himalaya and Trans-Himalaya showing their evolution through time. (A) Continental subduction in the NW-Himalaya. Shallower and younger continental subduction in the HHC produced peak Eocene (~48-45 Ma) Eo-Himalayan and pre-MCT metamorphism in upper amphibolite facies. Younger NeoHimalayan Miocene ~25 Ma metamorphism, anataxis and leucogranite generation between 25 and 15 Ma. Major discontinuities within HHC caused its differential exhumation. See Jain (2016) for details. Thrusting and imbrication along the MBT and MFT during late Miocene-Pleistocene. (B) Rotation of imbricated slices of the Himalayan Metamorphic Belt (HMB) to gently-dipping crustal wedges of the Tso Morari Crystallines (TMC), Higher Himalayan Crystallines (HHC) including its Higher Himalayan Discontinuities (HHD) by northward push from the subducting Indian continental lithosphere along the Main Himalayan Thrust (MHT) since post-15 Ma. Present-data magnetotelluric data from Garhwal and Ladakh-Karakoram constraint this configuration. The MHT approximately follows upper?lower continental crust boundary. The Indian Lithosphere shown by green-yellow shades, and Moho follows its upper contact. (C) Large-scale tectonics of the Himalayan orogen as a scrapped crustal wedge above the Main Himalayan Thrust (MHT). The Indus Tsangpo Suture Zone (ITSZ) delimits the Himalayan orogen. Simplified geophysical cross-section of the India-Asia convergence beneath the Himalaya and Tibet from the Himalayan-

Tibetan Continental Lithosphere During Mountain Building (Hi-CLIMB) profile, depicting "collision" between two plates in the Bangong-Nujiang Suture (BNS)

3.7.9 Seismic

Uttarakhand, situated in a seismically active region, experiences frequent seismic activity due to its location near the Himalayan orogenic belt. The state is prone to earthquakes resulting from the collision between the Indian and Eurasian tectonic plates, which has led to the uplift of the Himalayas and the formation of numerous faults and thrusts.

Dr. R. K. Chadha, a renowned seismologist, has conducted extensive research on seismic activity in the Himalayan region, including Uttarakhand. His studies emphasize the complex interplay of tectonic forces and fault systems that contribute to seismicity in the region (Chadha et al., 2007).

The seismic hazard in Uttarakhand is primarily associated with the presence of active faults, such as the Main Boundary Thrust and the Main Central Thrust, which accommodate the ongoing tectonic deformation. These faults can generate earthquakes of varying magnitudes, posing risks to infrastructure, human settlements, and natural landscapes.

Seismic monitoring and hazard assessment are essential for understanding and mitigating the risks associated with earthquakes in Uttarakhand. Dr. Chadha's research underscores the importance of continuous monitoring and seismic hazard mapping to enhance preparedness and resilience in the face of seismic events (Chadha et al., 2015).

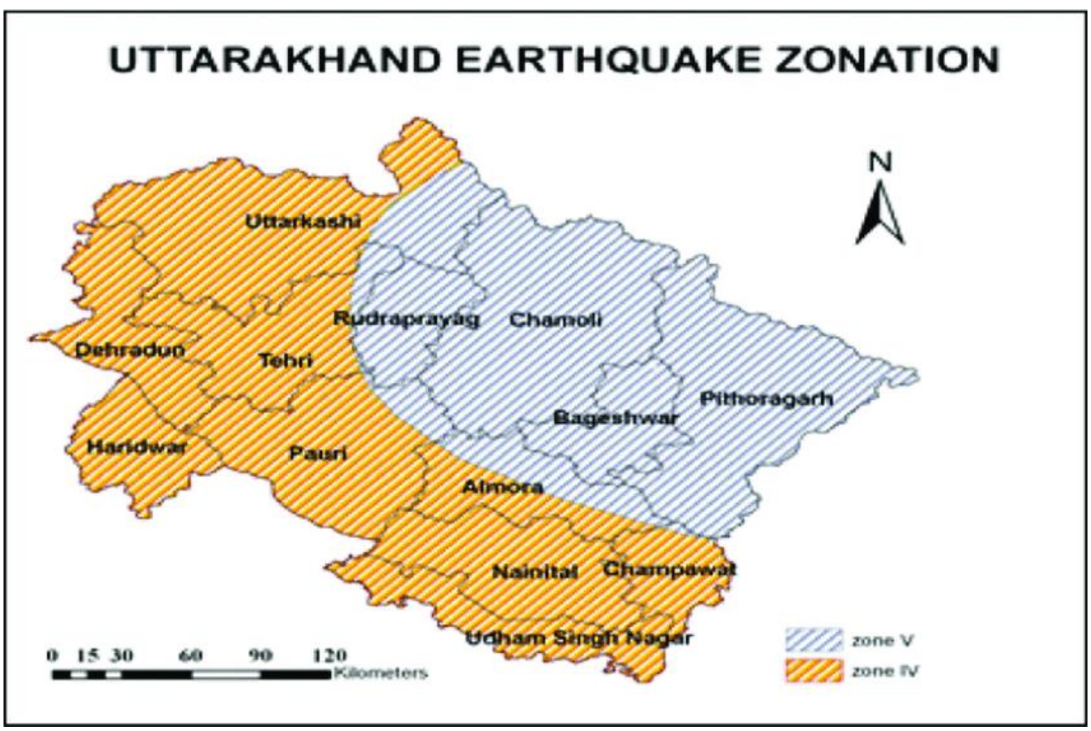

Figure:3.11 Uttarakhand earthquake zone. (Source: National Disaster Management Authority)

3.7.10 Uttarakhand's soil diversity reflects its varied topography, climatic conditions, and underlying geological formations. The state's soils are broadly categorized based on altitude and the parent material from which they are derived, influencing their characteristics and suitability for different land uses.

Dr. J. S. Singh, a prominent soil scientist, has extensively studied the soils of the Himalayan region, including Uttarakhand. His research highlights the significant role of topography and vegetation in soil formation and properties (Singh et al., 1992).

In the lower altitudes, particularly in the Terai and Bhabar regions, alluvial soils are predominant. These soils, deposited by rivers descending from the Himalayas, are rich in nutrients and highly fertile, making them ideal for intensive agriculture. They are primarily composed of sandy loam and clay loam textures, supporting crops like rice, wheat, and sugarcane.

Moving to the mid-altitudes, the soils are typically brown forest soils and podzols, formed under forest cover with moderate to high organic matter content. These soils are well-drained but can be prone to erosion, especially on steeper slopes. They support diverse forest types, including oak and pine forests, and are suitable for horticulture, growing fruits like apples and plums.

At higher altitudes, in the alpine and sub-alpine zones, the soils are generally shallow, acidic, and less fertile due to colder temperatures and reduced microbial activity. These soils, often referred to as mountain meadow soils, support alpine meadows and pastures, which are critical for traditional livestock grazing.

Understanding the soil properties of Uttarakhand is crucial for sustainable land management and agriculture. Dr. Singh's research underscores the need for soil conservation practices, especially in erosion-prone areas, to maintain soil health and productivity in the region (Singh et al., 1992).

3.8 General Land use

Uttarakhand's land use is influenced by its diverse topography, climate, and socio-economic activities. The state's land is primarily utilized for agriculture, forestry, urban development, and conservation, reflecting the intricate interplay between natural and human-induced factors.

Dr. M. Pant, an expert in regional planning, has conducted extensive research on land use dynamics in Uttarakhand. His studies highlight the complex relationship between land use patterns, ecological processes, and socio-economic factors shaping the region (Pant, 2013).

Agriculture is a significant land use in Uttarakhand, with terraced fields and subsistence farming practices prevalent in the mountainous regions. Crops such as rice, wheat, maize, and millets are cultivated in the fertile river valleys and terraced slopes, contributing to the local economy and food security.

Forestry plays a crucial role in Uttarakhand's land use, with dense forests covering a significant portion of the state's area. These forests provide valuable timber, fuelwood, and non-timber forest products, supporting livelihoods and biodiversity conservation efforts.

Urbanization and infrastructure development are altering land use patterns in Uttarakhand, particularly in the plains and foothills. Cities such as Dehradun, Haridwar, and Haldwani are experiencing rapid urban growth, leading to land conversion and environmental challenges.

Conservation initiatives, including protected areas and wildlife reserves, aim to preserve Uttarakhand's rich biodiversity and natural landscapes. These areas serve as habitats for endangered species and contribute to ecological balance and ecosystem services.

Understanding the dynamics of land use in Uttarakhand is essential for sustainable development and natural resource management. Dr. Pant's research underscores the need for integrated land use planning approaches that consider ecological, social, and economic dimensions to ensure the resilience and well-being of the region (Pant, 2013).

CHAPTER 4

DATASETS AND METHODOLOGY

Table 4.1 Data Set and Methodology

S. No	Name of Data Set	Year	Resolution/Scale	Reference	Purpose
1	MODIS Daily LST	2000-2023	1 Km	USGS	Land Surface Temperature change (Terra)
2	MODIS Monthly LST	2000-2023	1 Km	USGS	'MODIS/006/MOD11A2'
3	MODIS Monthly Vegetation	2000-2023	250m	NASA (www.reverb.echo.nasa.gov).	MOD13Q1 - MODIS/Terra Vegetation Indices 16-Day L3 Global

Here are detailed explanations for each dataset:

1. MODIS daily LST (2000-2023)

Resolution/Scale: 1 Km

Reference: USGS (United State Geological Survey)

Purpose: This dataset provides daily measurements of Land Surface Temperature (LST) captured by the MODIS sensor aboard NASA's Terra satellite. With a spatial resolution of 1 kilometre, it is instrumental in monitoring and analysing daily temperature fluctuations on the Earth's surface. This data helps in studying climate patterns, urban heat islands, and other temperature-related phenomena.

2. MODIS monthly LST (2000-2023)

Resolution/Scale: 1 Km

Reference: USGS

Purpose: This dataset offers monthly aggregated Land Surface Temperature (LST) data derived from MODIS sensor observations. Identified as 'MODIS/006/MOD11A2', it has a 1-kilometer resolution and spans from 2000 to 2023. It is used to observe long-term trends and monthly variations in surface temperature, aiding in climate change studies, agricultural monitoring, and environmental assessments.

3. MODIS monthly vegetation (2000-2023)

Resolution/Scale: 250m

Reference: NASA (www.reverb.echo.nasa.gov)

Purpose: This dataset contains the MOD13Q1 product, which provides 16-day composites of vegetation indices, specifically the Normalized Difference Vegetation Index (NDVI), at a 250-meter resolution. The data from the Terra satellite helps in monitoring vegetation health and density, understanding ecological dynamics, tracking phenological changes, and supporting land cover classification.

4.1 Google Earth Engine-Interface

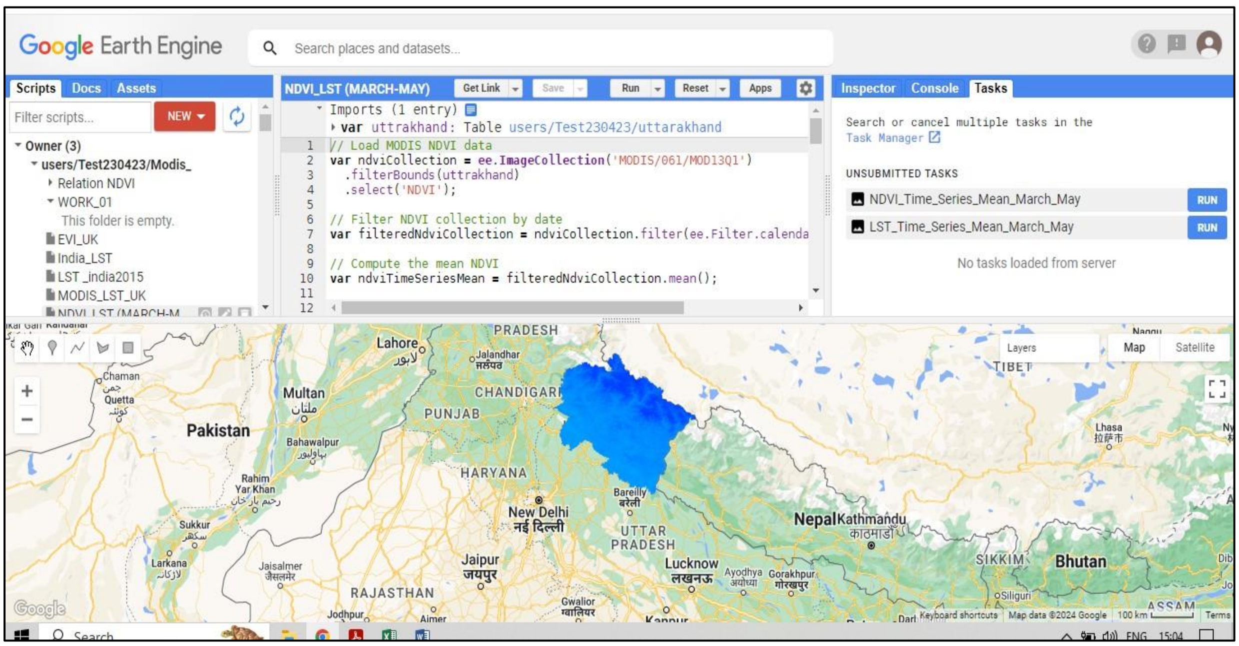

Figure: 4.1 Google earth engine interface

4.2 GEE Codes:

```
// Load MODIS NDVI data
var ndviCollection = ee.ImageCollection('MODIS/061/MOD13Q1')
.filterBounds(uttrakhand)
.select('NDVI');
// Filter NDVI collection by date
var filteredNdviCollection = ndviCollection.filter(ee.Filter.calendarRange(3, 5, 'month'));
// Compute the mean NDVI
var ndviTimeSeriesMean = filteredNdviCollection.mean();
// Clip the mean NDVI to your region of interest
var clippedNdvi = ndviTimeSeriesMean.clip(uttrakhand);
// Create chart for NDVI time series
var ndviChart = ui.Chart.image.series({
imageCollection: filteredNdviCollection,
region: uttrakhand,
reducer: ee.Reducer.mean(),
scale: 250,
}).setOptions({
title: 'NDVI Time Series (March - May)',
hAxis: {title: 'Date'},
vAxis: {title: 'NDVI'},
});

// Load MODIS LST data
var lstCollection = ee.ImageCollection('MODIS/006/MOD11A2')
.filterBounds(uttrakhand)
.select('LST_Day_1km'); // Select the daytime LST band
// Filter LST collection by date
var filteredLstCollection = lstCollection.filter(ee.Filter.calendarRange(3, 5, 'month'));
// Compute the mean LST
var lstTimeSeriesMean = filteredLstCollection.mean();
// Clip the mean LST to your region of interest
var clippedLst = lstTimeSeriesMean.clip(uttrakhand);
// Create chart for LST time series
var lstChart = ui.Chart.image.series({
imageCollection: filteredLstCollection,
region: uttrakhand,
reducer: ee.Reducer.mean(),
scale: 1000,
}).setOptions({
```

```
title: 'LST Time Series (March - May)',
hAxis: {title: 'Date'},
vAxis: {title: 'LST'},
});
// Display both charts
print(ui.Panel({
widgets: [
ndviChart,
lstChart
],
style: {width: '50%'}
}));
// Visualize the mean LST
Map.addLayer(clippedLst, {
min: 12000, // Adjust min value according to your data
max: 34000, // Adjust max value according to your data
palette: ['blue', 'cyan', 'green', 'yellow', 'red']
}, 'LST Time Series Mean (March - May)');
// Export the clipped NDVI image
Export.image.toDrive({
image: clippedNdvi,
description: 'NDVI_Time_Series_Mean_March_May',
scale: 250, // Adjust the scale as needed
region: uttrakhand, // Specify the region for export
maxPixels: 1e13 // Set maximum pixels as needed
});
// Export the clipped LST image
Export.image.toDrive({
image: clippedLst,
description: 'LST_Time_Series_Mean_March_May',
scale: 1000, // Adjust the scale as needed
region: uttrakhand, // Specify the region for export
maxPixels: 1e13 // Set maximum pixels as needed
});
```

4.2 METHODOLOGY

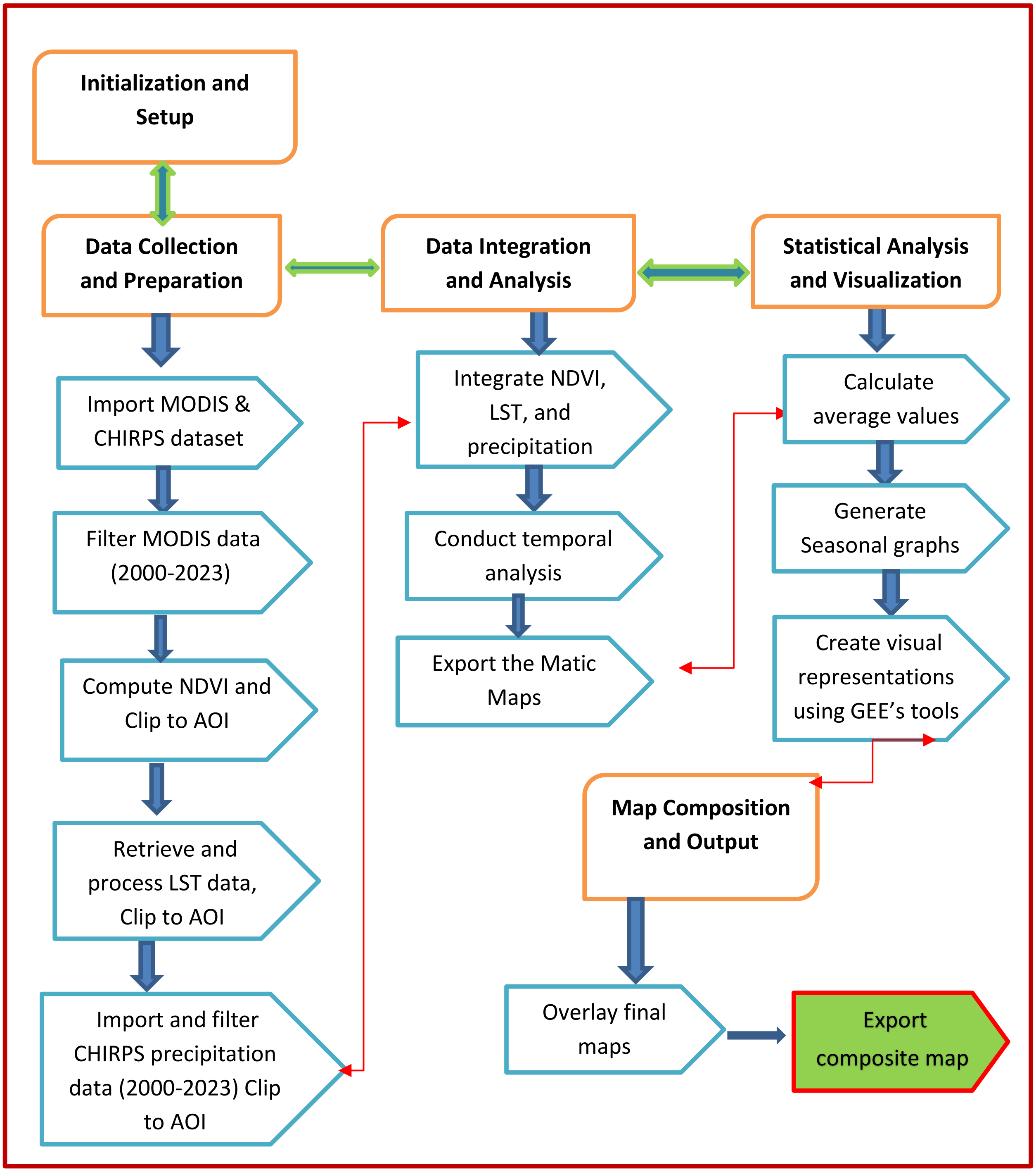

Figure:4.2 Methodology of Study Area

4.2.1 Initialization and Setup

Set up the necessary software environment, libraries, and tools required for data processing and analysis. This includes initializing the computational resources and ensuring access to necessary datasets.

4.2.1a Data Collection and Preparation

1. Import MODIS & TRMM dataset

Obtain the MODIS (Moderate Resolution Imaging Spectroradiometer) data for vegetation indices and Land Surface Temperature (LST), and the CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) data for precipitation.

2. Filter MODIS data (2000-2023)

Filter the MODIS dataset to include only data from the years 2000 to 2023, ensuring it covers the study period comprehensively.

3. Compute NDVI and Clip to AOI

Calculate the Normalized Difference Vegetation Index (NDVI) from the filtered MODIS data to assess vegetation health. Clip the NDVI data to the specified Area of Interest (AOI) for focused analysis.

4. Retrieve and process LST data, Clip to AOI

Retrieve the Land Surface Temperature (LST) data from MODIS, process it for accuracy and consistency, and clip it to the AOI to align with the NDVI data.

5. Import and filter TRMM precipitation data (2000-2023) Clip to AOI

Import the TRMM precipitation data, filter it for the period from 2000 to 2023, and clip it to the AOI to match the spatial extent of the other datasets.

4.2.1b Data Integration and Analysis

1. Integrate NDVI, LST, and precipitation

Combine the NDVI, LST, and precipitation data into a unified dataset, enabling comprehensive analysis of the relationships between vegetation, temperature, and precipitation.

2. Conduct temporal analysis

Perform temporal analysis on the integrated dataset to examine changes and trends over time, identifying patterns and correlations among the variables.

3. Export the Matic Maps

Generate and export thematic maps that visually represent the spatial distribution and temporal changes of NDVI, LST, and precipitation across the AOI.

4.2.1c Statistical Analysis and Visualization

1. Calculate average values

Calculate average values for NDVI, LST, and precipitation over specified time periods to facilitate statistical analysis and comparison.

2. Generate Seasonal graphs

Create graphs that depict seasonal variations and trends in NDVI, LST, and precipitation, helping to understand seasonal impacts on vegetation and surface temperature.

3. Create visual representation using GEE's tools

Utilize Google Earth Engine (GEE) tools to create detailed and interactive visual representations of the data, enabling deeper insights and more intuitive understanding of spatial and temporal patterns.

4.2.1d Map Composition and Output

1. Overlay final maps- Overlay the final thematic maps of NDVI, LST, and precipitation to create a comprehensive composite map that integrates all analysed variables.

2. Export composite map- Export the composite map, which combines the insights from all datasets, for presentation, reporting, or further analysis. This final output serves as a valuable resource for understanding the interrelationships between vegetation, surface temperature, and precipitation within the AOI.

By following these detailed steps, the workflow ensures a thorough and systematic analysis of the relationships between NDVI and LST, considering the impact of precipitation, and provides clear visualizations and outputs to support decision-making and research.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 LANDUSE LAND COVER

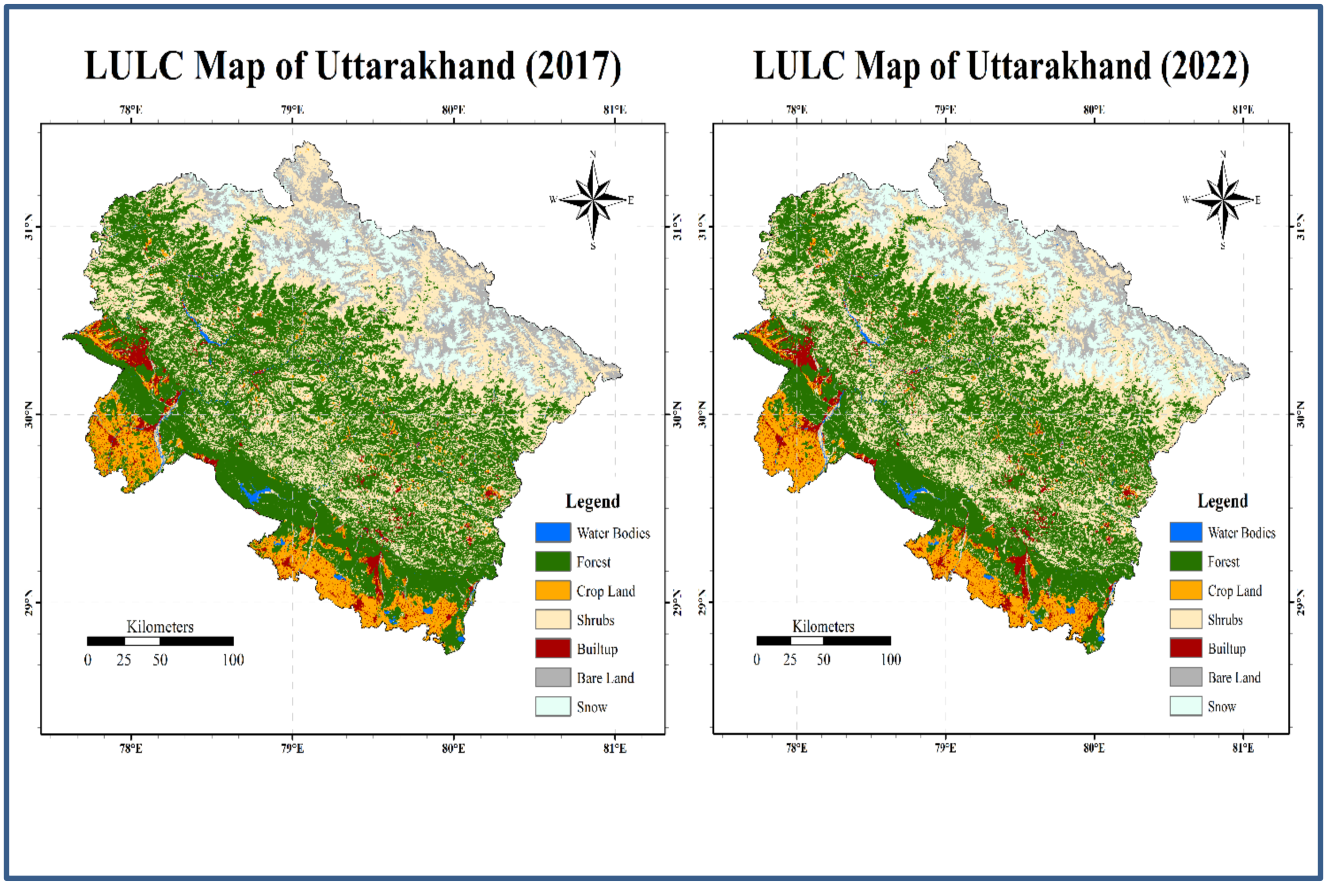

Figure:5.1 Study Area: land Use Land Cover Map 2017 and 2022, Uttarakhand, India

These LULC changes in Uttarakhand underscore the region's dynamic environmental landscape. The significant decrease in forest cover and increase in snow cover are particularly notable, with wide-ranging implications for biodiversity, climate regulation, and water resources. The observed changes call for integrated land management strategies that balance ecological preservation with the region's developmental needs. Enhanced monitoring using advanced remote sensing technologies and sustainable policy interventions are crucial to mitigating adverse impacts and promoting a balanced approach to land use in this ecologically sensitive area.

Table:5.1 Study Area: land Use Land Cover Classification 2017 and 2022, Uttarakhand, India

S.No	Class	2017		2022		Changes (2017-2022)
		Area (sq.km)	%	Area (sq.km)	%	%
1	Water Bodies	390.70	0.73	361.11	0.68	0.06
2	Forest	23679.36	44.33	22273.67	41.70	2.63
3	Crop Land	3493.42	6.54	3577.93	6.70	-0.16
4	Builtup	1523.19	2.85	1746.22	3.27	-0.42
5	Bare Land	4753.11	8.90	3763.56	7.05	1.85
6	Snow	3426.50	6.41	4909.53	9.19	-2.78
7	Shrubs	16151.23	30.24	16785.49	31.42	-1.19
8	**Total**	**53417.51**	**100.0**	**53417.51**	**100.0**	**0.00**

The Himalayan state of Uttarakhand, known for its rich biodiversity and diverse ecosystems, has experienced notable land use and land cover (LULC) changes from 2017 to 2022. This period has been characterized by both significant increases and decreases in various land cover classes, reflecting the complex interplay of natural processes and human activities in the region. The most substantial change observed is the decrease in forest cover, which shrank from 23,679.36 sq.km (44.33%) in 2017 to 22,273.67 sq.km (41.70%) in 2022. This 2.63% reduction highlights the extensive deforestation activities, likely driven by agricultural expansion, urbanization, and possibly illegal logging. Such a decline in forested areas poses serious threats to biodiversity, exacerbates carbon emissions, and undermines soil stability, leading to increased risks of erosion and landslides.

In contrast, snow-covered areas have seen a significant increase, rising from 3,426.50 sq.km (6.41%) to 4,909.53 sq.km (9.19%) over the same period. This 2.78% increase might be attributed to climatic variability, including shifts in precipitation patterns and temperature fluctuations, potentially reflecting broader climatic changes impacting the region. The increase in snow cover is crucial for water resources in Uttarakhand, which heavily rely on glacial and snowmelt for sustaining rivers and agriculture. However, it also necessitates further research to understand long-term trends and prepare for potential future water availability challenges.

Water bodies have slightly decreased from 390.70 sq.km (0.73%) to 361.11 sq.km (0.68%), a modest 0.05% reduction that could be indicative of changes in hydrological regimes or increased water extraction for agricultural and urban needs. Although relatively minor, this change can have localized impacts on aquatic ecosystems and water availability for various uses. Conversely, the area under built-up land has increased from 1,523.19 sq.km (2.85%) to 1,746.22 sq.km (3.27%), a 0.42% rise reflecting ongoing urbanization and infrastructure development.

This urban expansion can lead to the urban heat island effect, higher local temperatures, and further encroachment on natural habitats. The area classified as cropland has also grown, from 3,493.42 sq.km (6.54%) to 3,577.93 sq.km (6.70%), a 0.16% increase. This growth underscores the pressure to meet food security needs and the economic importance of agriculture in the region. However, it also emphasizes the need for sustainable agricultural practices to prevent further land degradation. On the other hand, bare land has decreased significantly from 4,753.11 sq.km (8.90%) to 3,763.56 sq.km (7.05%), a 1.85% reduction likely due to natural re-vegetation processes or active reforestation efforts.

Finally, the area covered by shrubs has increased from 16,151.23 sq.km (30.24%) to 16,785.49 sq.km (31.42%), a 1.18% rise. This increase in shrubland may indicate ecological succession processes where degraded forests or bare lands are gradually recovering. While this is a positive sign of land recovery, it also highlights the need for continuous monitoring to ensure these areas develop into mature forests.

5.2 NDVI SUMMER SEASON (MARCH-MAY) 2000-2023

Understanding the interaction between vegetation indices and land surface temperatures is crucial for assessing ecological and climatic changes. This study examines the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) from 2000 to 2023 across various seasons to elucidate trends and correlations. The NDVI serves as an indicator of vegetation health, while LST reflects the thermal state of the Earth's surface. This analysis aims to highlight the seasonal variations and long-term trends in these parameters to provide insights into the broader ecological and climatic dynamics.

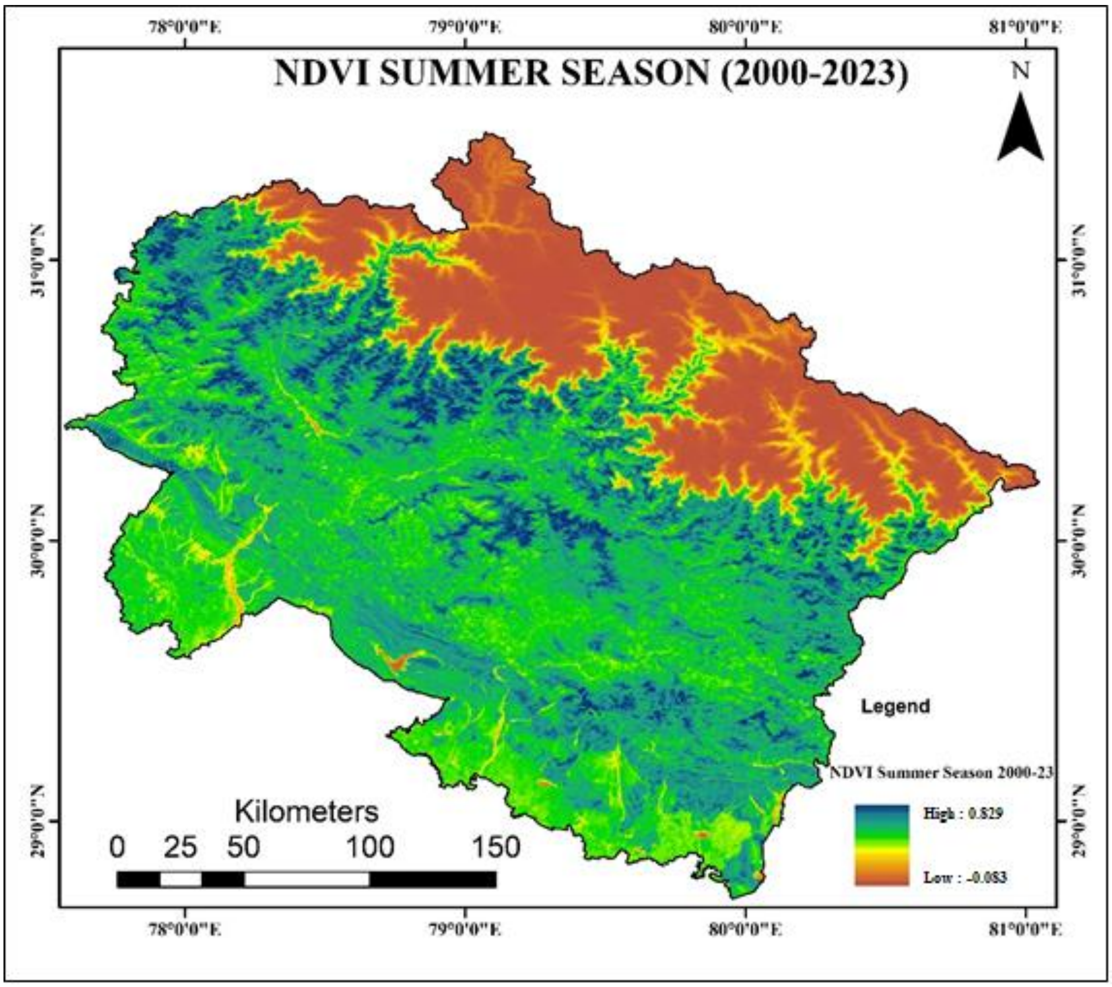

Figure: 5.2 NDVI Summer Season (March-May) 2000-2023

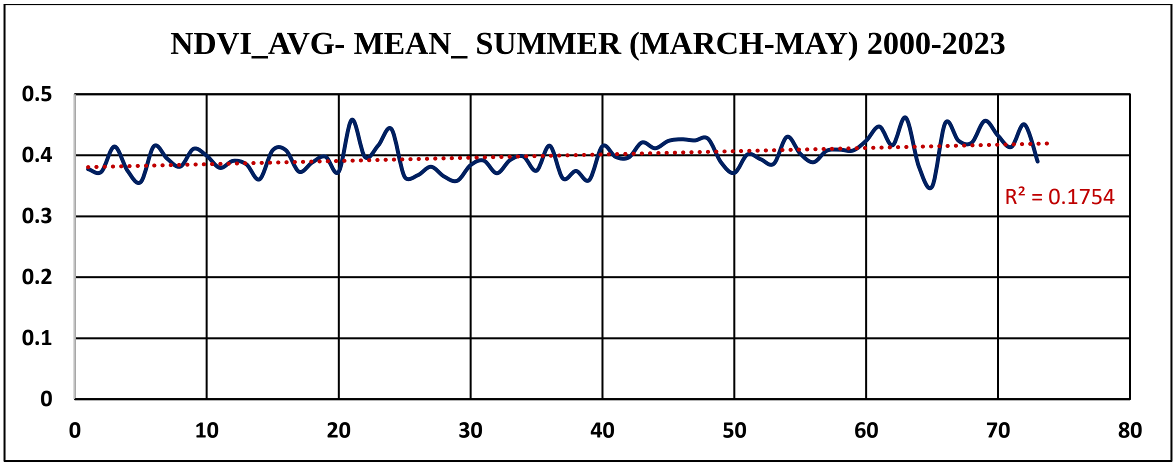

Chart: 5.2 NDVI Summer Season (March-May) 2000-2023

5.3 NDVI WINTER SEASON (NOVEMBER-FEBRUARY) 2000-2023

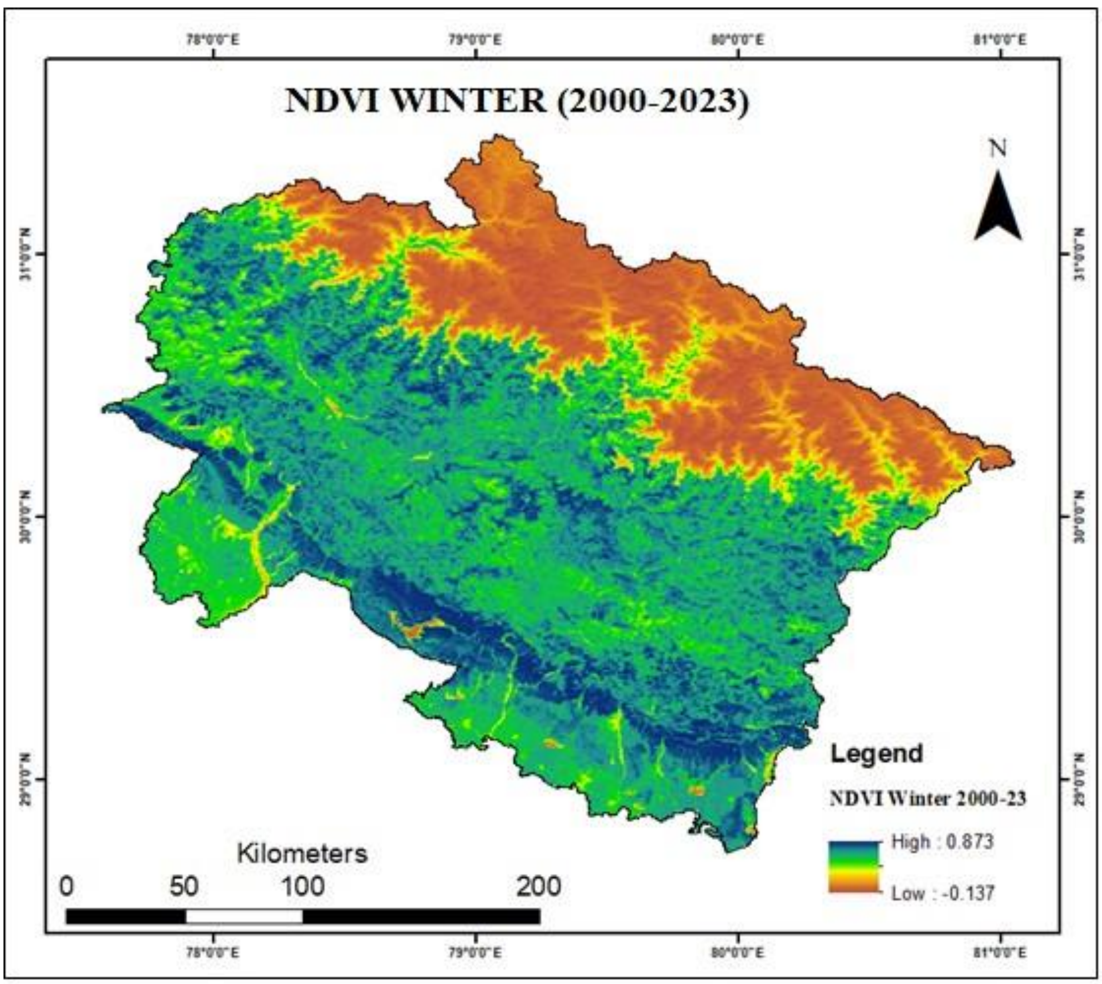

Figure: 5.3 NDVI Winter Season (November-February) 2000-2023

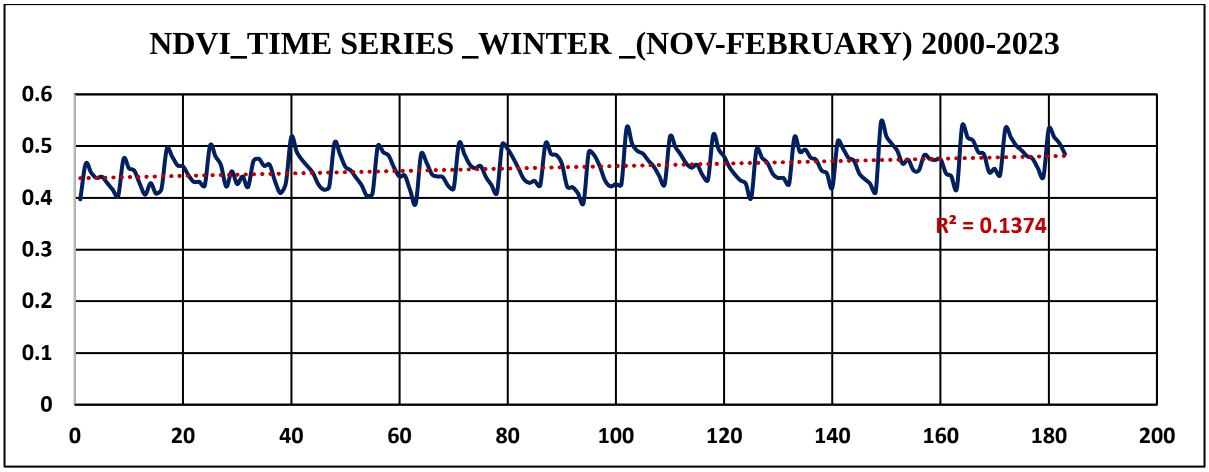

Chart: 5.3 NDVI Winter Season (November-February) 2000-2023

5.4 NDVI RAINY SEASON (JUNE-OCTOBER) 2000-2023

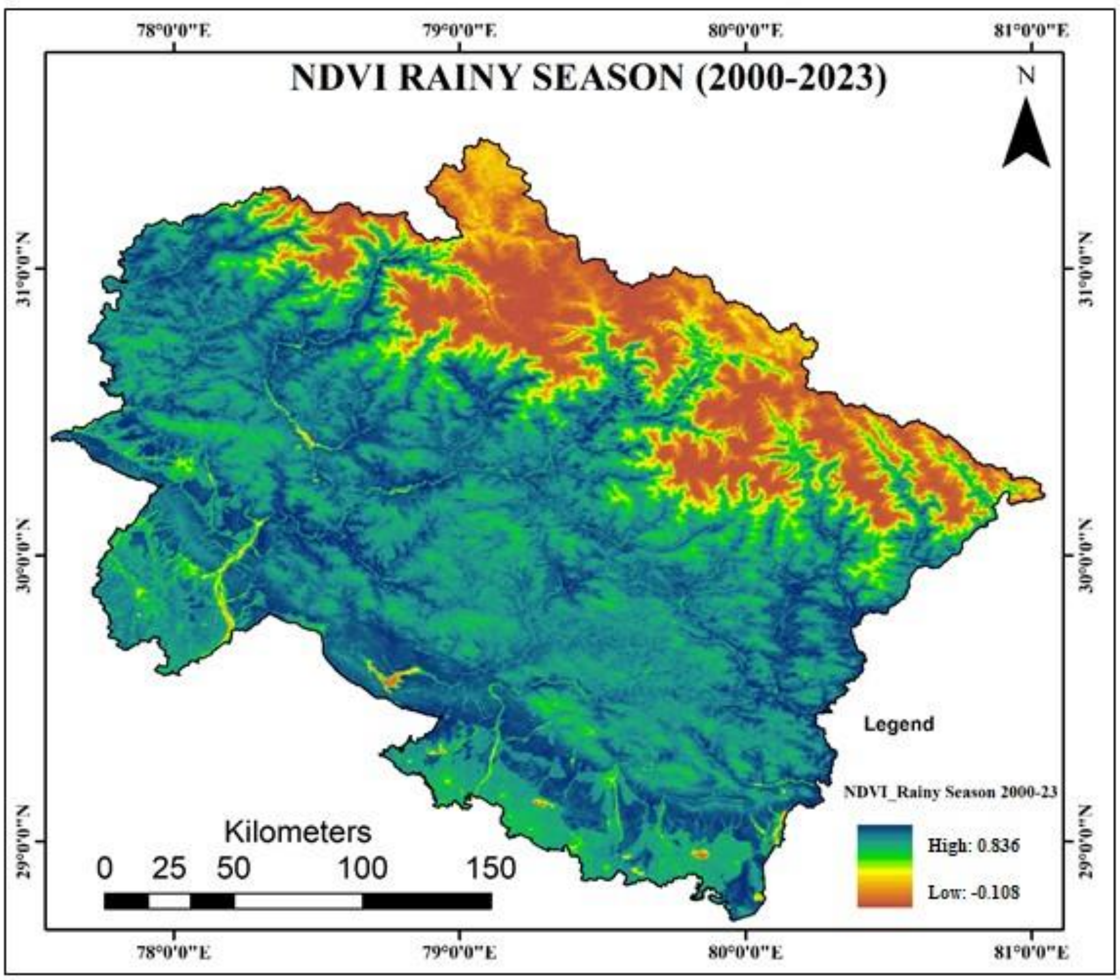

Figure: 5.4 NDVI Rainy Season (June-October) 2000-2023

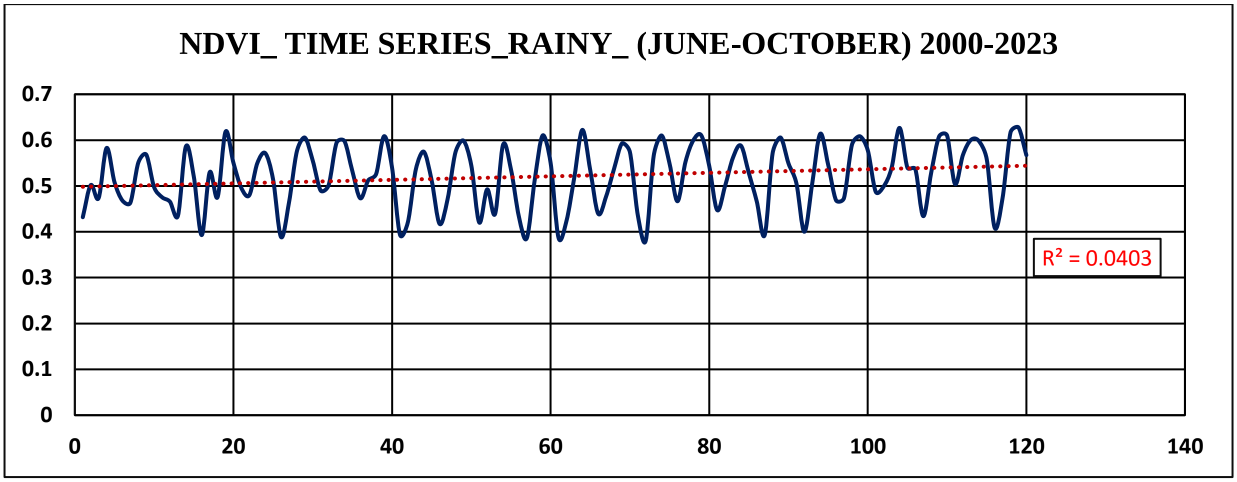

Chart: 5.4 NDVI Rainy Season (June-October) 2000-2023

5.5 NDVI AUTUMN SEASON (NOVEMBER) 2000-2023

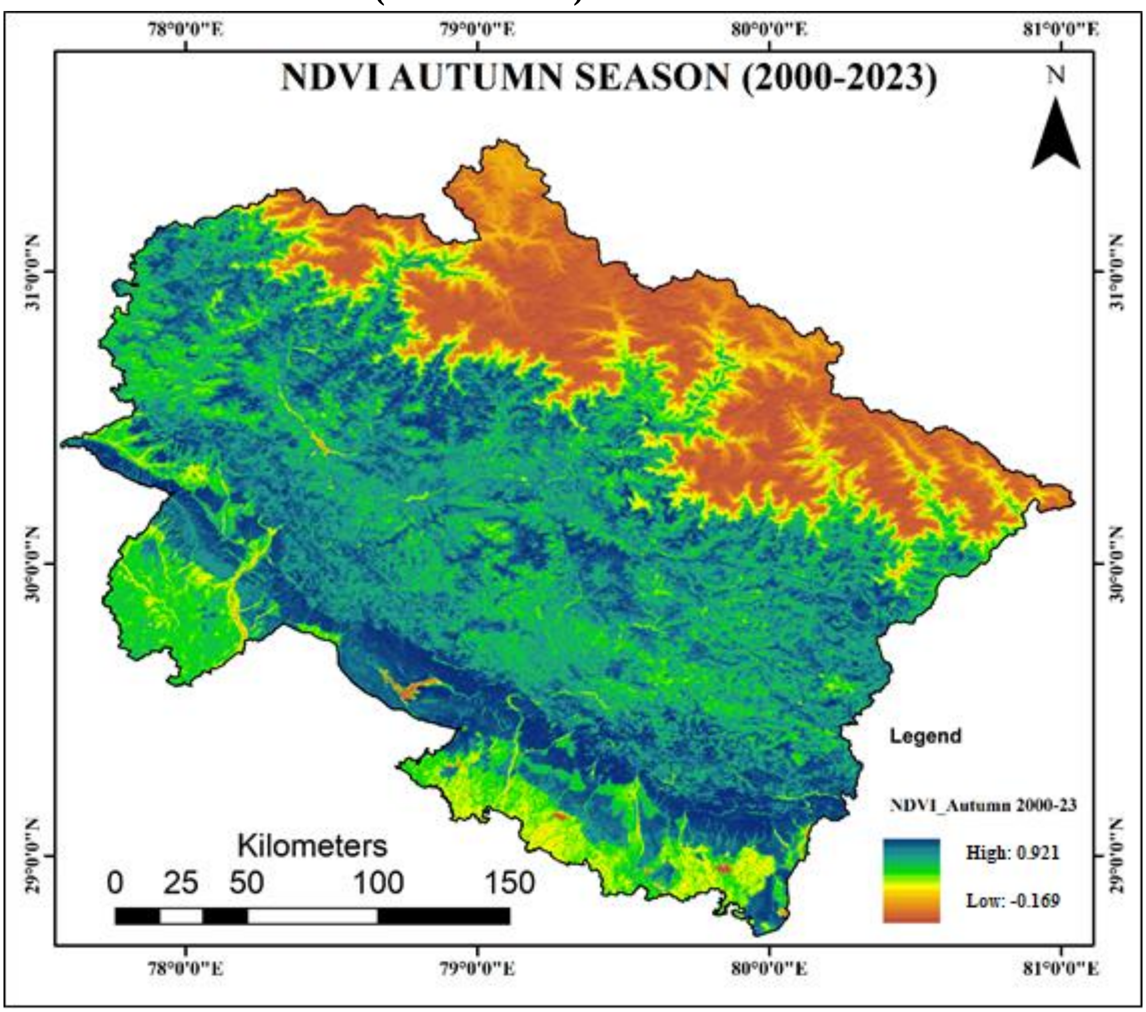

Figure:5.5 NDVI Autumn Season (November) 2000-2023

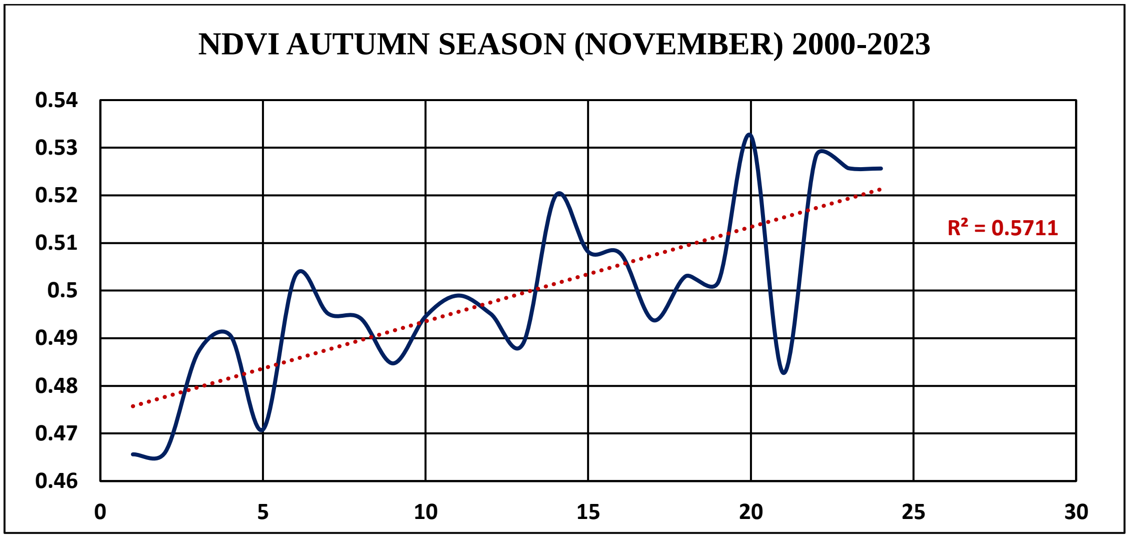

Chart: 5.5 NDVI Autumn Season (November) 2000-2023

5.6 NDVI SPRING SEASON (MARCH) 2000-2023

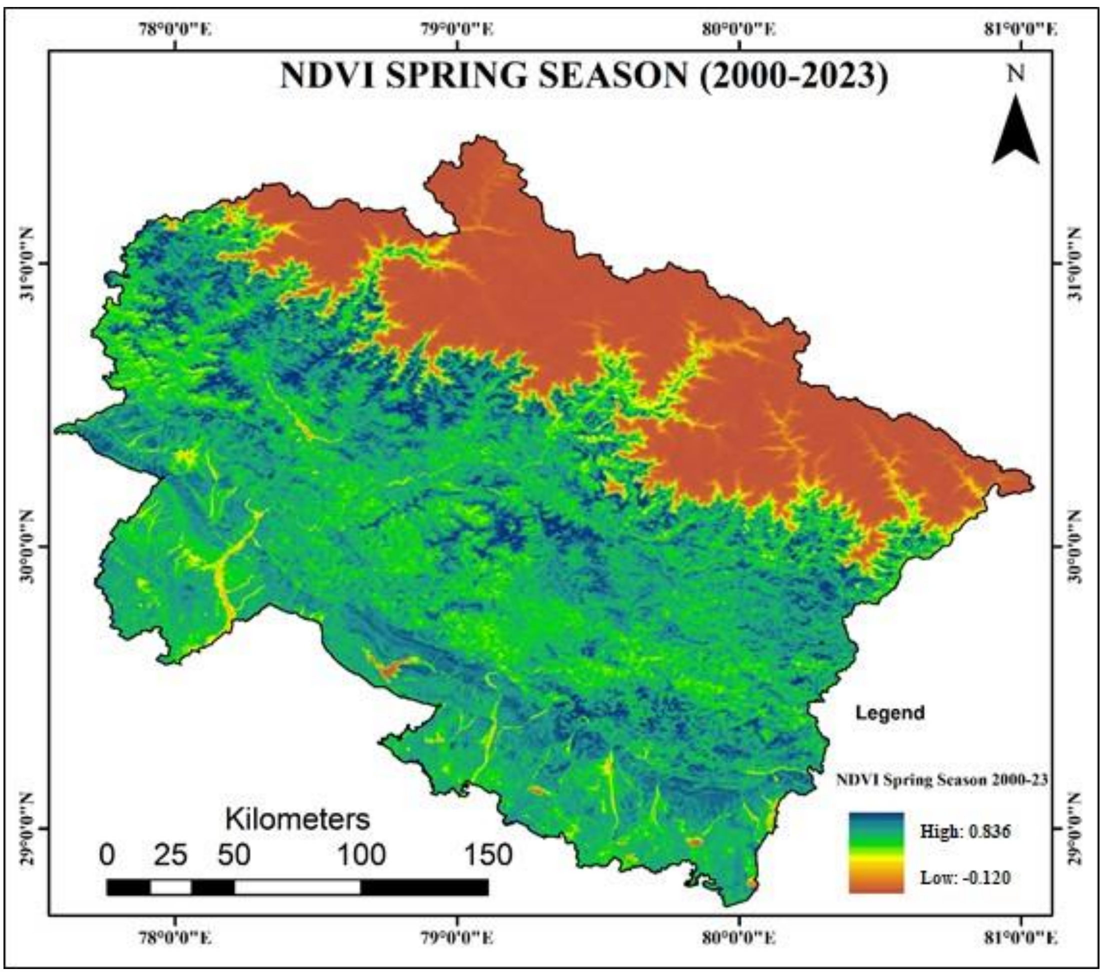

Figure: 5.6 NDVI Spring Season (March) 2000-2023

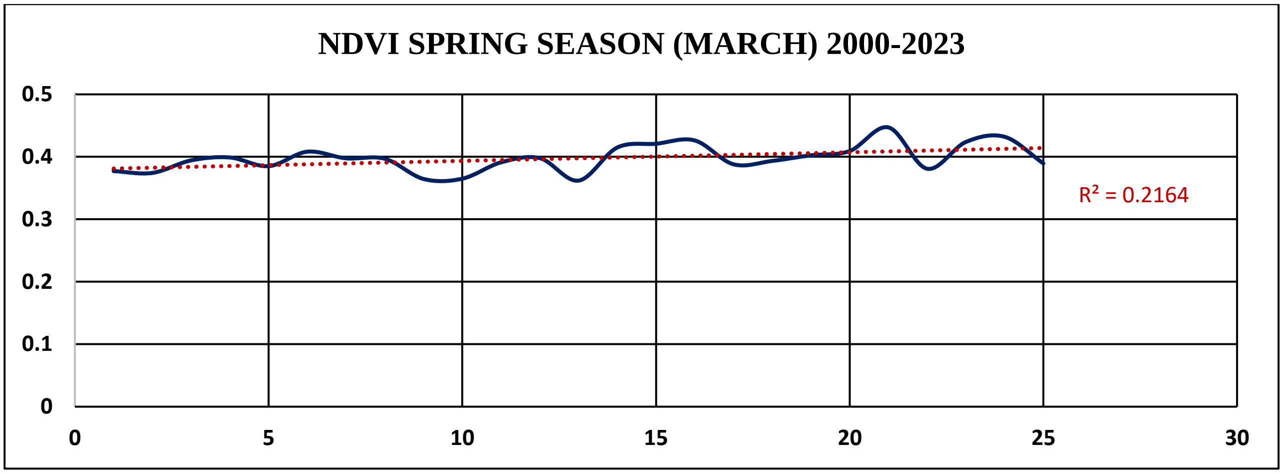

Chart: 5.6 NDVI Spring Season (March) 2000-2023

5.7 LST SUMMER SEASON (MARCH-MAY) 2000-2023

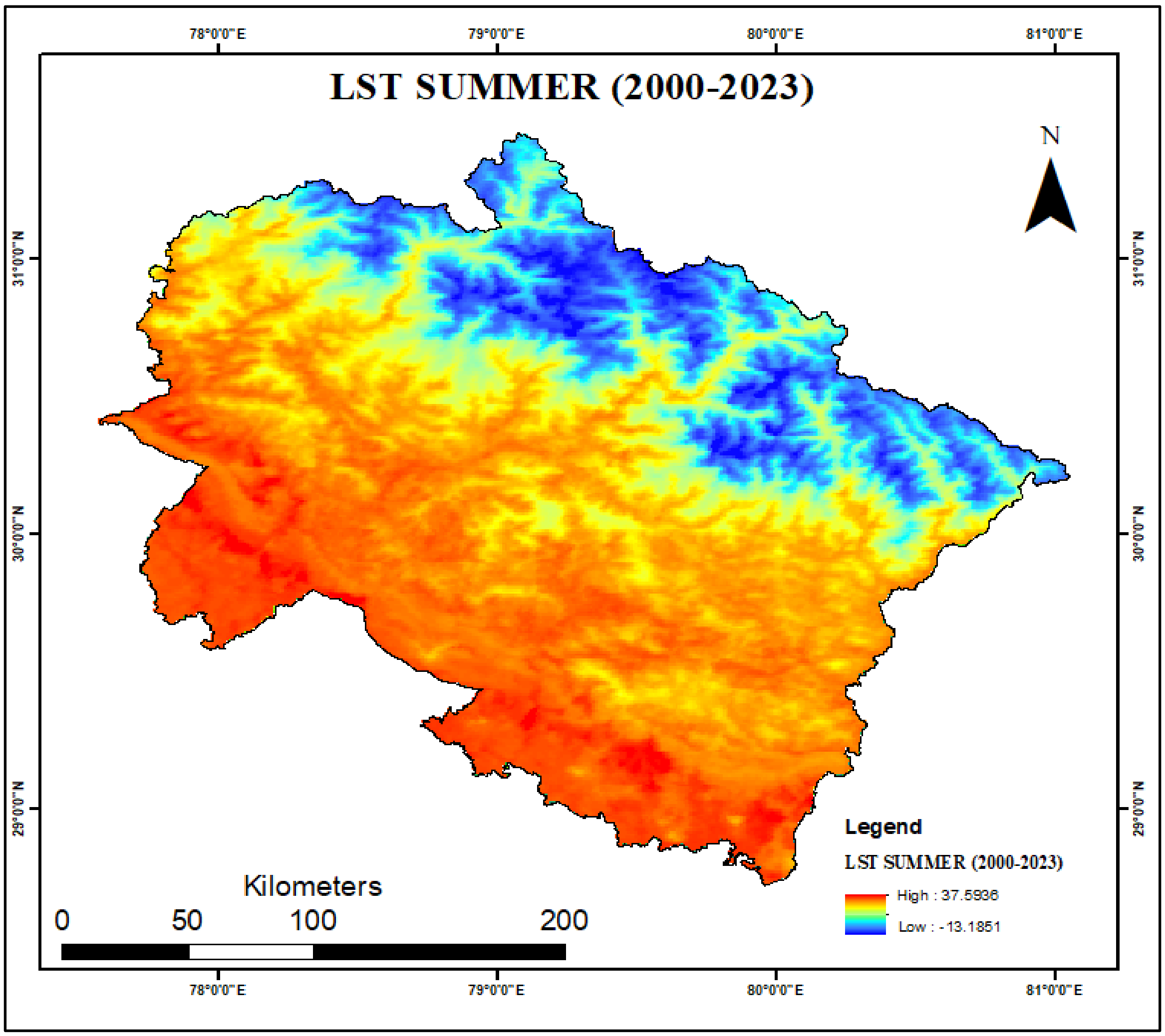

Figure: 5.7. LST Summer Season (2000-2023)

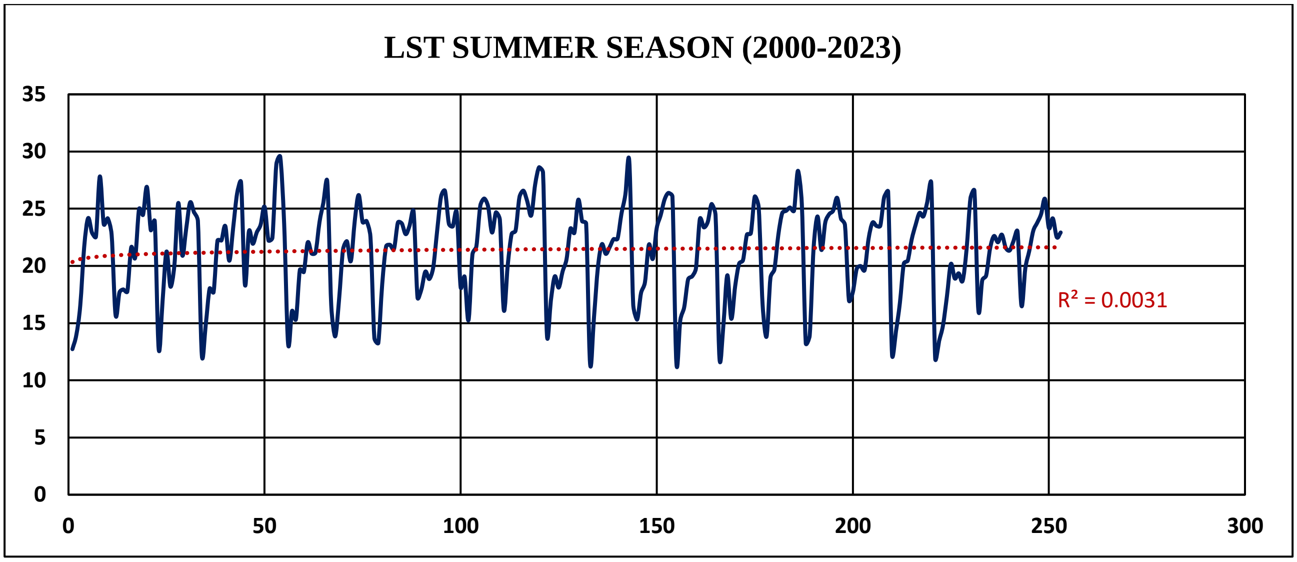

Chart: 5.7. LST Summer Season (2000-2023)

5.8 LST WINTER SEASON (NOVEMBER-FEBURARY) 2000-2023

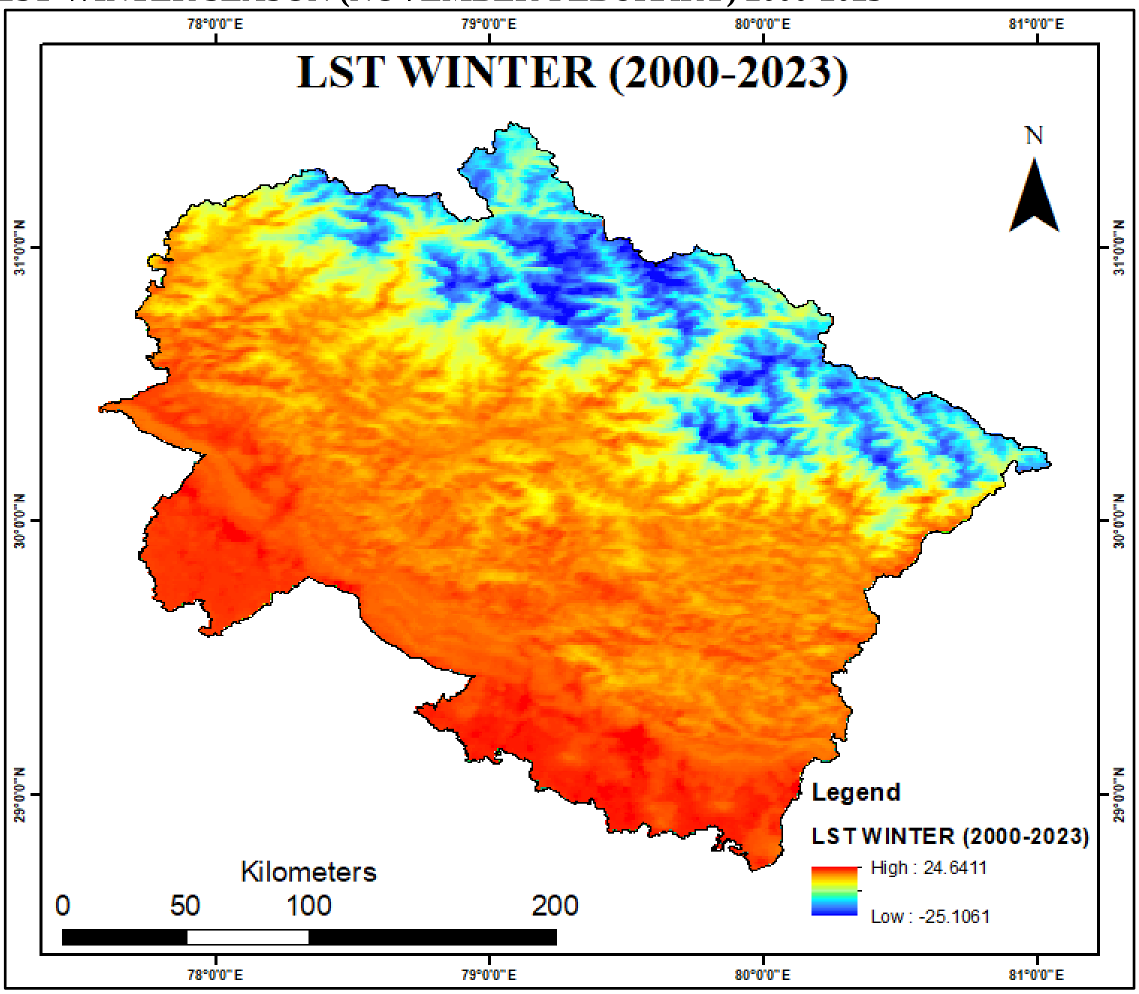

Figure: 5.8. LST Winter Season (2000-2023)

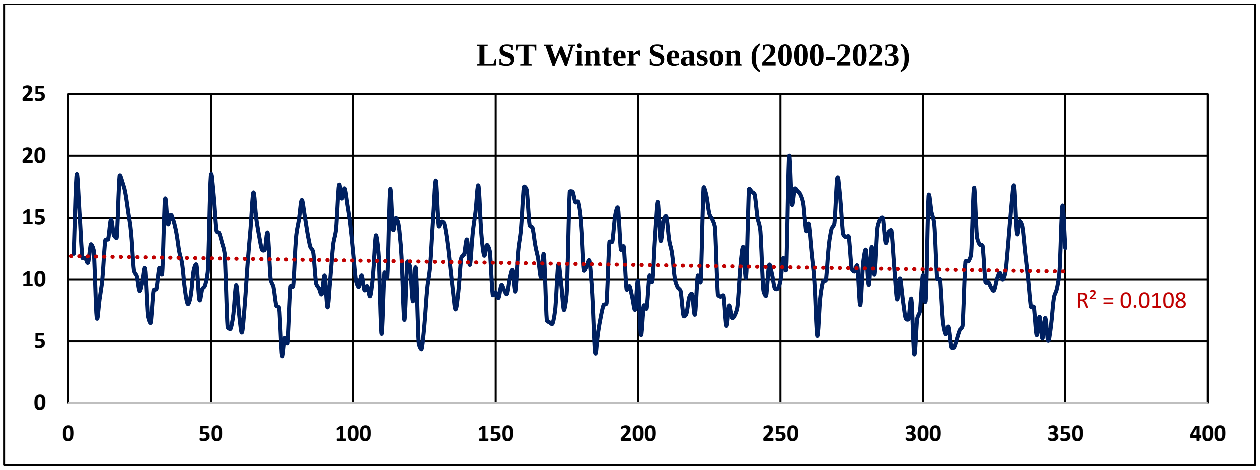

Chart: 5.8. LST Winter Season (2000-2023)

5.9 LST RAINY SEASON (JUNE- OCTOBER) 2000-2023

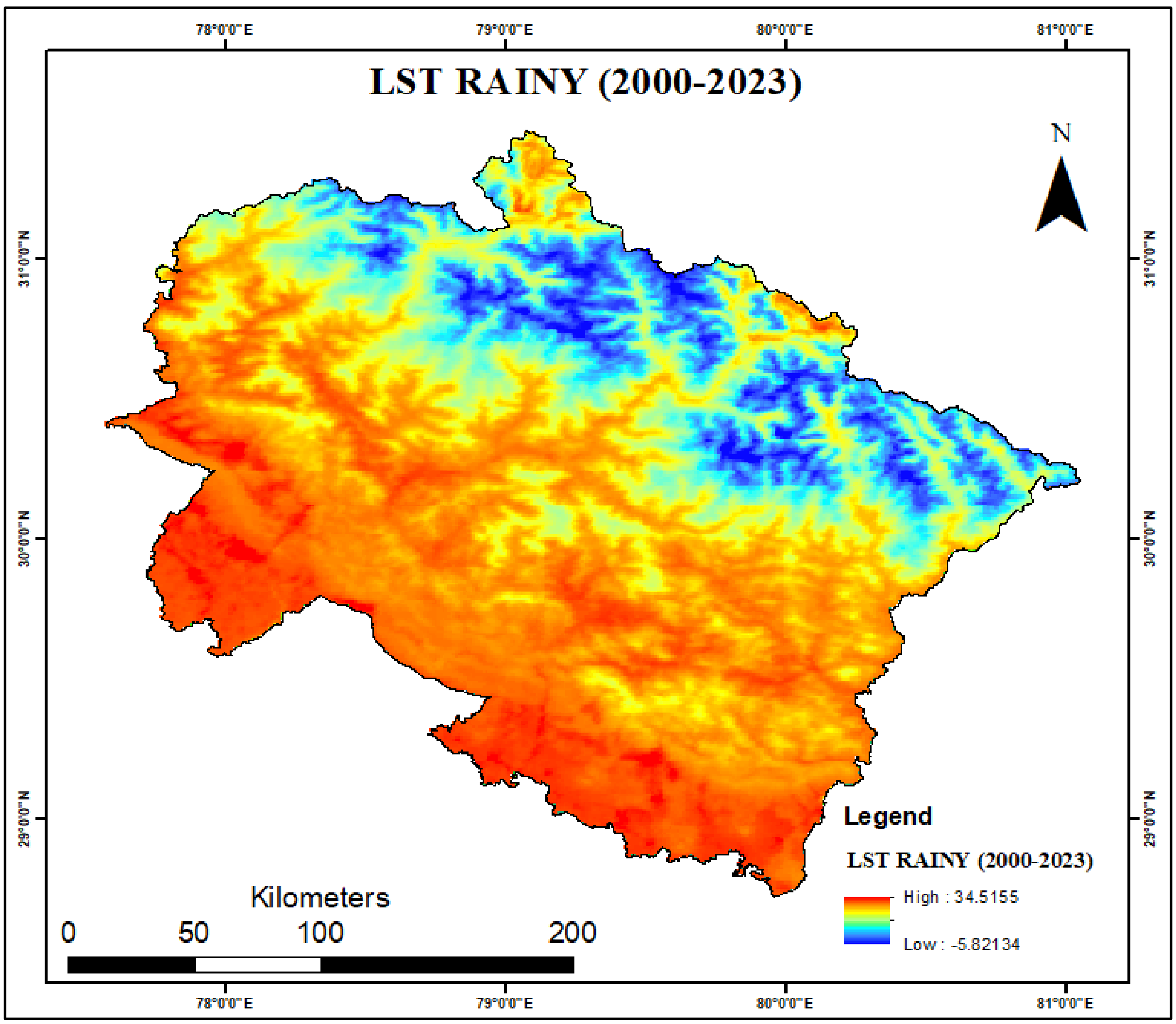

Figure: 5.9. LST Rainy Season (2000-2023)

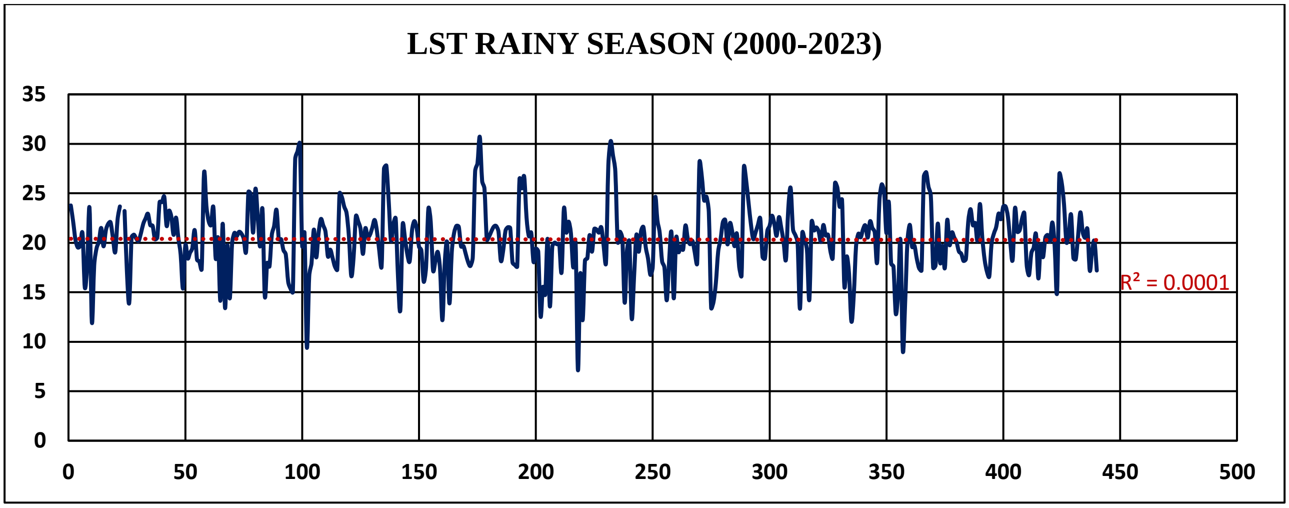

Chart: 5.9. LST Rainy Season (2000-2023)

5.10 LST AUTUMN SEASON (2000-2023)

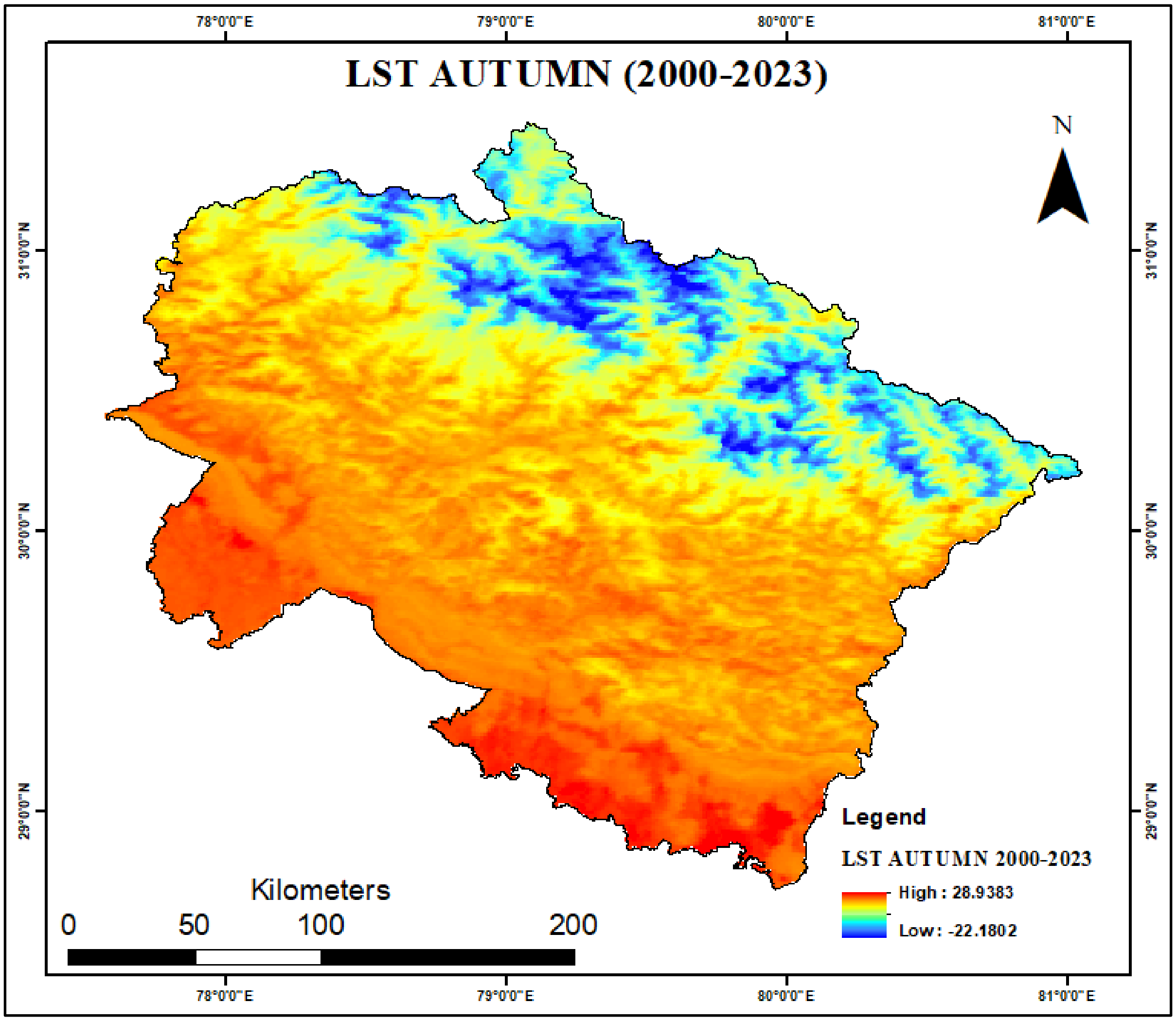

Figure: 5.10. LST Autumn Season (2000-2023)

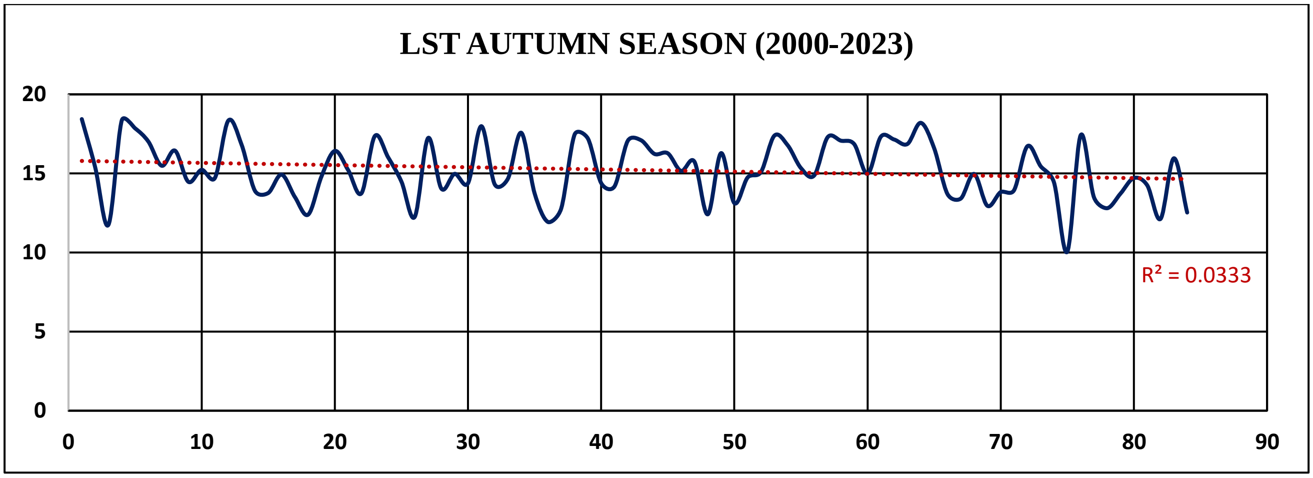

Chart: 5.10. LST Autumn Season (2000-2023)

5.11 LST SPRING SEASON (2000-2023)

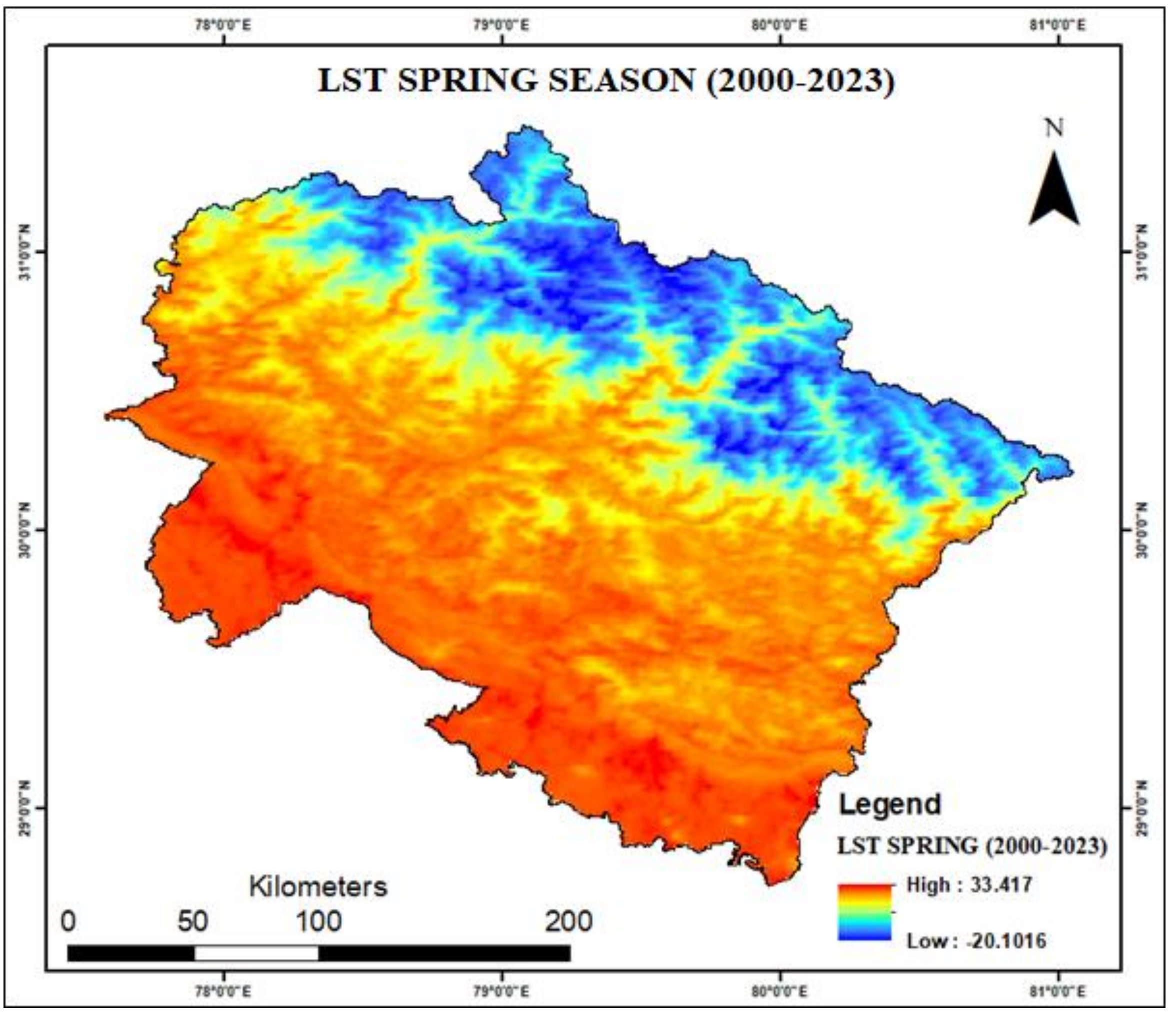

Figure: 5.11. LST Spring Season (2000-2023)

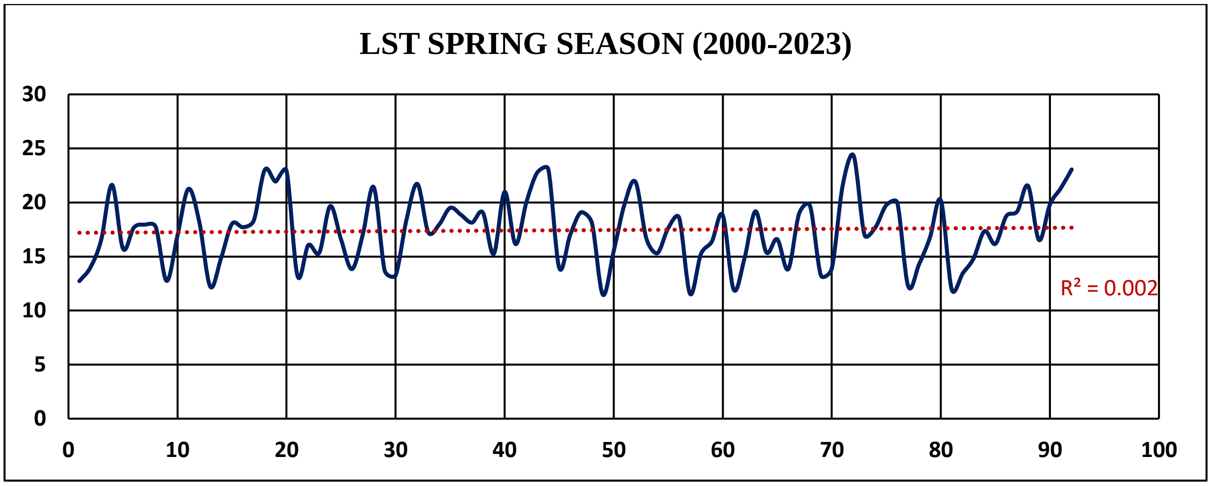

Chart: 5.11. LST Spring Season (2000-2023)

Summer (March to May)

During the summer months, NDVI values ranged from a high of 0.829 to a low of -0.083. The trend analysis indicated a weak positive correlation over time, with an R-square value of 0.175. This suggests a slight improvement or stability in vegetation health during the summer season over the study period. The observed variability in NDVI can be attributed to factors such as changes in precipitation patterns, agricultural practices, and land use changes.

Conversely, the LST values for the same period ranged from a high of 37.59°C to a low of -13.185°C. The trend line revealed an extremely weak correlation, with an R-square value of 0.0031, indicating negligible changes in temperature trends over the years. This minimal variation in LST suggests that summer temperatures have remained relatively stable, possibly due to the buffering effects of atmospheric dynamics and seasonal climate patterns.

Winter (November to February)

In winter, NDVI values ranged from 0.873 to -0.137, with a modest positive correlation indicated by an R-square value of 0.1374. This suggests a moderate improvement or stability in vegetation health during the colder months. Winter vegetation health could be influenced by reduced stress from lower temperatures and dormancy periods in certain plant species.

The LST during winter showed temperatures ranging from 24.64°C to -25.10°C, with a very weak correlation (R-square value of 0.0108). This reflects minimal temperature variations over the years, which might be due to the consistent climatic conditions that characterize winter periods, such as lower solar radiation and reduced evapotranspiration rates.

Rainy Season (June to October)

The rainy season presented NDVI values from 0.836 to -0.108, with a very weak positive correlation (R-square value of 0.0403). This weak correlation suggests slight improvements or stability in vegetation health despite fluctuations in rainfall. Rainfall during these months typically enhances vegetation growth, but variations in rainfall intensity and distribution can cause significant inter-annual variability in NDVI.

LST during the rainy season ranged from 34.5°C to -5.821°C, with a negligible correlation (R-square value of 0.0001). The almost non-existent trend in LST indicates stable temperature patterns, which might be influenced by the cooling effect of increased cloud cover and precipitation, leading to reduced solar heating of the land surface.

Autumn (November)

In autumn, NDVI values ranged from 0.921 to -0.169, with a moderate positive correlation (R-square value of 0.5711). This significant correlation indicates a substantial improvement or stability in vegetation health during this transitional month. Autumn often features favourable conditions for vegetation, such as moderate temperatures and residual soil moisture from preceding seasons, which contribute to higher NDVI values.

The LST during autumn ranged from 28.93°C to -22.180°C, with a very weak correlation (R-square value of 0.0333), suggesting minimal temperature changes. Autumn temperatures are generally moderated by decreasing solar radiation and the onset of cooler weather, which maintains relatively stable LST values.

Spring (March)

Spring NDVI values ranged from 0.836 to -0.120, with a weak positive correlation (R-square value of 0.2164). This indicates some improvement or consistency in vegetation health during the early growing season. Spring is typically characterized by the resurgence of vegetation following winter dormancy, driven by increasing temperatures and longer daylight hours, which promote photosynthetic activity and higher NDVI values.

LST during spring ranged from 33.41°C to -20.10°C, with a very weak correlation (R-square value of 0.002), reflecting negligible changes in temperature patterns. Spring temperatures often exhibit significant variability due to the transitional nature of the season, but the overall trend indicates stable thermal conditions over the long term.

CHAPTER 6

CONCLUSION

The provided analysis examines trends in the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and rainfall in Uttarakhand over the period from 2000 to 2023. This analysis is crucial for understanding the region's ecological health and the impacts of climate change and human activities.

NDVI Trends

NDVI, which indicates vegetation health and density, has shown consistent spatial patterns in Uttarakhand over the study period. Higher NDVI values are predominantly found in the lower altitudes and valleys, specifically in the southern, western, and central regions of the state. These areas benefit from favourable climatic conditions, such as adequate rainfall and milder temperatures, and effective land management practices, which support dense and healthy vegetation.

In contrast, the northern, north-eastern, and eastern regions of Uttarakhand exhibit lower NDVI values. These areas are characterized by harsh climatic conditions, rocky terrain, and higher altitudes, which limit vegetation growth. Despite these challenges, the NDVI values have remained relatively stable over the 23 years, indicating consistent vegetation health in most regions, with no significant degradation or improvement observed.

LST Trends

The LST maps, analysed across different seasons—summer, winter, rainy, autumn, and spring—reveal significant spatial and temporal variations in land surface temperatures across Uttarakhand. Higher LST values are typically found in the southern and central regions, corresponding to lower elevations and urbanized areas. The urban heat island effect is evident in these regions, where reduced vegetation cover and increased human activities contribute to higher temperatures.

In contrast, the northern areas, characterized by higher altitudes and dense vegetation, show lower LST values. This temperature gradient underscores the influence of topography and vegetation cover on land surface temperatures. Temporal trends indicate a general warming pattern over the 23 years, consistent with broader global warming trends. However, the R^2 values for the LST trends were low, suggesting that other factors, including microclimatic conditions and local human activities, play a significant role in influencing LST variations.

Implications and Recommendations

Understanding these trends in NDVI, LST, and rainfall is vital for sustainable land use planning, climate adaptation strategies, and ecological conservation in Uttarakhand. The stable NDVI values suggest that current land management practices are effective in maintaining vegetation health.

However, the general warming trend observed in LST highlights the need for strategies to mitigate the impacts of rising temperatures, particularly in urban areas where the heat island effect is pronounced.

Rainfall variability, with no significant trend, underscores the importance of adaptive water management practices to cope with unpredictable rainfall patterns. Integrating NDVI and LST data with other climatic variables and considering human impacts will provide deeper insights into the region's ecological dynamics.

Future Directions

To enhance our understanding of these trends, detailed temporal analyses and studies of specific climatic events, such as extreme weather events and their impacts, are recommended. Additionally, exploring the role of human activities, such as deforestation, urbanization, and agricultural practices, will further aid in developing effective strategies for sustainable natural resource management in Uttarakhand. The integration of remote sensing data with ground-based observations and climate models can provide comprehensive insights for policymakers and stakeholders involved in environmental conservation and climate resilience efforts.

Simultaneously, the inverse correlation between LST and NDVI points to a potential moderating effect of vegetation cover on local surface temperatures. The observed decline in LST is consistent with the cooling influence of dense vegetation, which can mitigate heat through shading and transpiration cooling processes. Moreover, the concurrent increase in LAI corroborates the notion of enhanced vegetation density and canopy development, further supporting the interpretation of improved ecosystem productivity and health.

These findings collectively suggest a complex interplay between climatic factors, vegetation dynamics, and surface temperature regulation within the Uttarakhand region over the studied period. Such insights are crucial for understanding ecosystem responses to environmental changes and can inform sustainable land management strategies aimed at preserving and enhancing ecosystem resilience in the face of ongoing global environmental shifts

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