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Climate Change Impact and Traditional Adaptation Practices in Northeast India: A Review

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Abstract

The review explores the intricate traditional knowledge (TK) nurtured by the diverse indigenous communities of Northeast (NE) India, emphasizing on their adaptive strategies amidst the region's evolving climate patterns. NE India faces a multitude of climate change-induced risks, including earthquakes, landslides, flash floods, and thunderstorms/lightning, highlighting the critical role of indigenous knowledge in mitigating these challenges. Through generations of experience, indigenous cultures have amassed a treasure trove of traditional ecological knowledge, particularly pertinent in NE India's context. Given the region's vulnerability to climate change impacts, these indigenous practices are indispensable. The review provides an in-depth analysis of these aspects, shedding light on recent climate change impacts, prevalent issues, and the indigenous adaptation strategies in NE India. Recognizing the significance of indigenous knowledge in climate change adaptation, the review stresses the importance of integrating it with scientific knowledge to enhance adaptation effectiveness. It extensively covers various aspects of traditional farming systems, watershed governance, the preservation of biodiversity, and traditional medical practices in NE India. However, the region faces challenges from growing development, the industrial revolution, and devastation, emphasizing an urgent need to document, evaluate, and preserve indigenous cultures' traditional ecological knowledge (TEK).

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Introduction

Climate change has emerged as a major concern in the modern world as per strong scientific and socioeconomic study findings. It is now recognized as one of the foremost global concerns, given its potential impacts on various aspects, including

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agriculture and security, water supply, biodiversity in forests and other natural ecosystems, and the overall well-being of humans and urban development.[1] According to the most recent IPCC (2021) assessment, climate change and its associated hazards are expected to have a negative impact on many sectors.[2] Changes in average temperature, seasonal shifts, and other climatic effects have been observed.[3] Indigenous cultures are thought to be more vulnerable to climate change consequences due to their social and natural environments.[4]

Many adaptation methods have been implemented across societies, and migration is one of the most popular modes of adaptation which is induced by reduced crop yields resulting in restricted livelihood options.[5] As per the initial assessment report from the IPCC, it is projected that by the year 2050, approximately 150 million individuals could be compelled to migrate from their residences due to climate-related disasters, which encompass floods, droughts, and storms.[6] In a warmer environment, the hydrological cycle is expected to accelerate, leading to alterations in rainfall patterns. Warmer air can hold greater moisture and hasten the drainage of surface moisture. Increased atmospheric moisture content tends to intensify rainfall and snowfall events, increasing the likelihood of flooding (Fig. 1). Nonetheless, when there is no moisture available for evaporation in the soil, incident solar radiation can raise temperatures, potentially leading to longer and more severe droughts thus impacting the ground-water levels and moisture in the soil, groundwater replenishment, and the occurrence of both flood and drought events in different regions.[7]

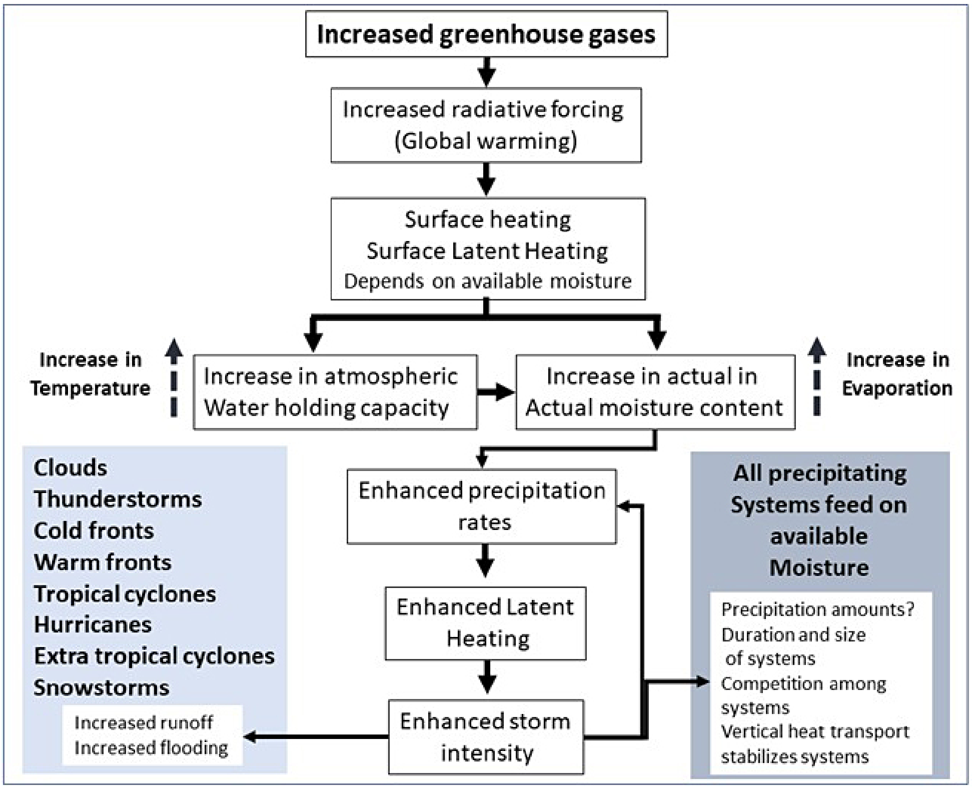

Fig. 1: Conceptual structure of the influence of climate change and greenhouse gases on the hydrologic cycle and events linked to several climate extremes.

India is recognized as one of the world's twelve megadiverse nations, for its exceptional species endemism and rarity. This is particularly evident in two key biodiversity hotspots, the Western Ghats and Eastern Himalayas. NE India, known as a part of the Eastern Himalaya hotspot, boasts vibrant biodiversity and is home to around 150 tribal groups, each contributing to the area's cultural and ethnic diversity. These varied communities in NE India have formed distinct beliefs, rituals, and traditions due to observations shaped by their encounters with their natural surroundings. This indigenous knowledge is continuously evolving and is used to build techniques to improve their lives. Natural resources are deteriorating due to various factors, including deforestation, the expansion of human and livestock populations, higher demand for fuelwood, reduced land ownership rights, shorter cycles of traditional shifting cultivation (known as *jhum*), the transformation of natural forests into horticultural crop plantations, mining activities, excessive grazing, and forest fires.[8] The mountainous topography of the region, coupled with practices like crop cultivation on slopes and excessive livestock grazing, makes the soil resources susceptible to erosion and degradation. There is a notable scarcity of documents and research on the climate change scenario in Northeast India despite its strategically significant location, which greatly influences the activities of nearly all the states in the region. As a result, this review aims to investigate the repercussions of climate change on ecosystems, human communities, wildlife, and plant life in the NE region. It emphasizes the potential challenges in conducting future vulnerability and risk management assessments in this region due to the limited existing research and knowledge.

Northeast India, often referred to as the "Land of the Seven Sisters," is situated within the geographical coordinates of approximately 20° N- 29° 30' N, and 89° 46' E - 97° 30' E.[9] It is made up of 8 states that cover a total area of 26.2 million hectares, constituting around 7.9% of the total geographical area,[10] linked to mainland India via the narrow Siliguri corridor that is around 22 km long known as the 'chicken's neck.' This corridor is surrounded by Nepal and Bangladesh. Additionally, the NE region shares international boundaries with four neighboring foreign countries, namely Bangladesh, Bhutan, China, and Myanmar, spanning a total of 5,182 km.[11] It has a unique geographical configuration where more than 99% of its overall boundary is shared with international borders. This region includes the states of Assam, Nagaland, Manipur, Mizoram, Meghalaya, Sikkim, Arunachal Pradesh and Tripura.[12] The two main river basins are the Brahmaputra and Barak[13] where over 225 indigenous tribes in the area depend significantly on the forest resources for their livelihood. The region's abundant forest ranges 80.9% in Arunachal Pradesh, 35% in Assam, with other states falling in between (e.g., 76% in Manipur and 88.6% in Mizoram), which play a crucial role in supporting industries such as timber exports, tourism, wildlife resorts, and hillside shifting cultivation.

The primary objectives of this study are to document the TK of indigenous communities in NE India, assess the effectiveness of their adaptation strategies in mitigating climate change impacts, evaluate the potential for integrating traditional knowledge with scientific methods to enhance climate resilience, and identify the challenges posed by development and industrialization to the preservation of TK. The novelty of this review lies in its detailed exploration of the diverse and rich traditional knowledge systems unique to NE India, a region often overlooked in mainstream climate change adaptation research. By focusing on the distinctive climatic and cultural context of NE India, this review explores the critical role of indigenous knowledge in enhancing adaptive capacity and resilience, providing valuable insights for adaptation strategies both locally and globally.

Methodology

This comprehensive review incorporates findings from 93 studies spanning from 1990 to 2023, aiming to provide an inclusive overview of relevant literature. To conduct our bibliographic search, we utilized keywords like "traditional ecological knowledge in NE India," "NE community," and "traditional ecological in natural resource management" across records from Google Scholar, Web of Science, Science Direct, Google and Scopus. Additionally, we gathered information from diverse sources such as books, articles, magazines, newspapers, and literature from NGO reports and data accessed through Nagaland University, Lumami, Central Library. Initial screening eliminated redundant data, following which we compiled details on indigenous knowledge, state-specific rules, and conventions, focusing on various aspects such as sacred creatures, fragrant, and medicinal plants compiled from data collected from the eight states of NE India (Fig 2). Secondary data sources include forest survey information and regional community insights, with the overall studies included in this paper spanning nearly two decades and bringing light on the interconnection of TK in NE India. The review also emphasizes the effects of climate change on numerous local communities in NE India. In response to these impacts, many communities have developed various adaptation strategies to cope with the harsh climatic variations. These adaptations include managing water scarcity, ensuring food security, and mitigating the impacts of extreme weather events.

Study Site

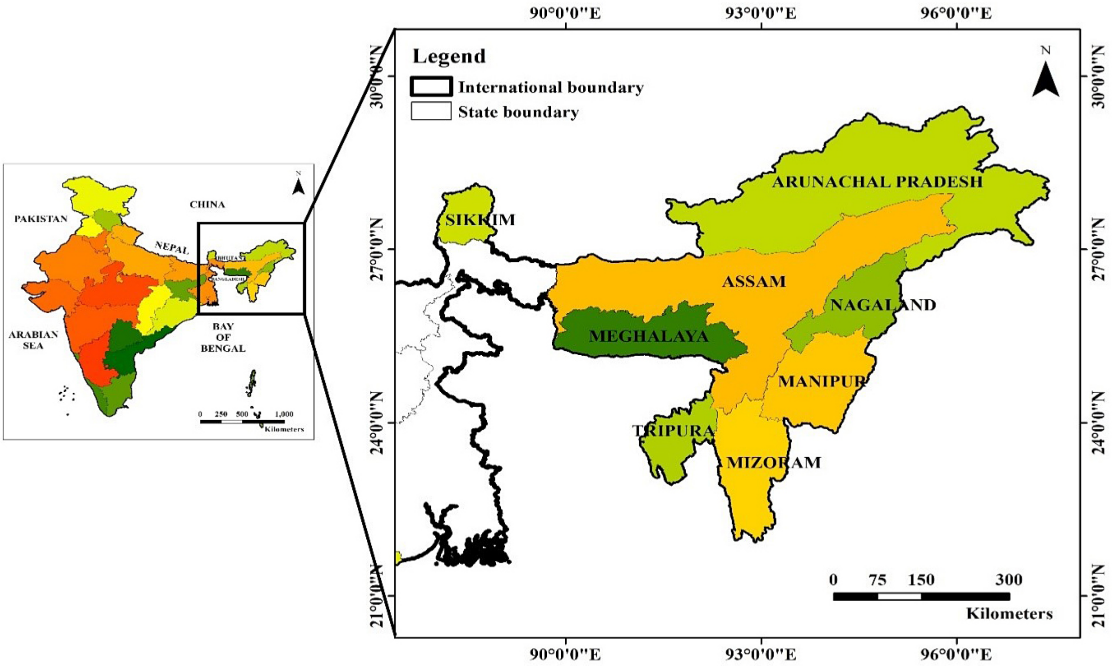

Fig. 2: Map illustrating the study area's location

Vulnerability, Environmental Security and Sustainability

Vulnerability and environmental security are fast developing as important research areas within the realms of global change and earth system science in an era distinguished by globalization and the ubiquitous influence of climate change.[14] This affects nations, regions, and even individual households differently, leading to varying levels of vulnerability. Consequently, effective adaptation strategies require customized approaches and methods that address diverse, vulnerable populations.[15] When discussing the reduction of catastrophic risks associated with climate change, it is vital to emphasize the significance of sustainability and environmental security. Disaster prevention and mitigation efforts rely heavily on the capacity of vulnerable populations to cope, as they often lack the resources and means to effectively respond to the impacts of hazards and disasters. In comparison to other regions of India, the NE region has a lower average degree of economic development and growth.[16]

Trends in Climate and Weather of NE India

According to widely accepted estimates, the average worldwide temperature is up by about 1°C since the beginning of civilization. At the present pace, global warming is expected to reach 1.5 °C in 2052, although the 'Nationally Determined Contributions' under the 2015 Paris Agreement are met.[17] Amid 1901 and 2018, India's mean temperature rose by 0.7 °C, and the biggest annual mean temperature increase (0.2 °C per decade) has been detected in several regions. According to the RCP8.5 scenario, the rise in average temperature over India by the end of the 21st century is expected between 2.4-4.4 °C. Chakraborty *et al.*[18] conducted research in the eastern Himalaya and revealed that Manipur, Sikkim, Mizoram. Arunachal Pradesh, Meghalaya, and Tripura recorded a rise in average annual temperature between 0.1-1.0 °C each decade, whereas Nagaland reported no change. The Cherrapunji-Mawsynram region in Meghalaya, India, is renowned as one of the wettest places on Earth, receiving an astonishing annual rainfall of over 12,000 mm.[19] The region has experienced a significant temperature range throughout the year, with summer temperatures ranging from 15-32 °C and winter temperatures from 0-26 °C. These temperature variations indicate that the area has a diverse climate. However, climate change has indeed had adverse effects on the region, potentially leading to shifts in temperature patterns, precipitation, and other climate-related factors that can impact its ecosystem and local communities.[20]

Singh *et al.*[21] have found diminishing trends in precipitation patterns during the last 50 years and an irregular pattern for the near future. Krishnan *et al.*[22] also reported rainfall increased by 6mm in the western Himalaya. While investigating the eastern Himalayan rainfall pattern, Saikia *et al.*[23] reported rainfall decreased by 1.0% (Sikkim), 1.3% (Manipur), 1.4% (Meghalaya). 4.2% (Tripura), 4.8% (Arunachal Pradesh), 7.7% (Mizoram), and 14.7% (Nagaland). The examination of Sikkim Himalaya rainfall trends shows an unpredictable pattern currently and predicts the same in the near future. Changes in rainfall patterns and precipitation have a detrimental impact on biodiversity elements, seed germination, seedling recruitment, pollination services, water scarcity, and other implications on the production of agriculture system. Recent research has indicated that human-induced factors, particularly related to alterations in land use and land cover (LULC), contribute to temperature shifts and can have far-reaching effects on the occurrence of heatwaves, cold spells, cloud formation, and rainfall patterns. Additionally, modifications in LULC have been associated with the release of atmospheric aerosols, which can directly and indirectly influence surface temperatures, consequently impacting rainfall patterns.[24]

Climate Change and NE India- Some Recent Facts and Events

Vulnerability assessment and risk management in the NE region of India in the face of climate change are indeed challenging due to the complexity of the issue and the limited research and data available.[25] The region's unique geographical features, such as its hilly terrain, extensive river systems, and proximity to the Bay of Bengal, make it particularly vulnerable to flash floods.[26,27] Rain water serves as the primary source of daily consumption in NE India, but recent years have witnessed shifts in rainfall patterns. Until August 2021, several states in the region experienced significant deficits in rainfall. Conversely, the Brahmaputra River has faced notable floods, leading to prolonged inundation periods lasting over ten days. An analysis by the India Meteorological Department (IMD) in 2018 revealed a declining trend in rainfall in Nagaland, Manipur, Arunachal Pradesh Mizoram and Tripura. These rainfall fluctuations affect various water systems, impacting both water availability and spring flow.[28] A recent incident documented that continuous rainfall led to flash floods and landslides in Mokokchung district (Nagaland). This unfortunate event resulted in injuries to at least two individuals and substantial property damage, amounting to several lakhs in losses.[29] Wokha district, which experiences the second-greatest monsoon rainfall in the state, has declined over the last 30 years. Additionally, according to the Nagaland State Disaster Management Authority (NSDMA) (https://nsdma.nagaland.gov.in/home), flash floods and waterlogging are anticipated in Nagaland's foothills and low-lying areas as a result of the recent heavy rainfall.[30] Droughts, characterized by insufficient rainfall, can lead to water scarcity, crop failures, and other issues. On the other hand, heavy rainfall, as witnessed in Assam, can result in devastating floods, landslides, and damage to infrastructure, affecting millions of people and causing loss of life and property.[31]

Rising global temperatures, driven by greenhouse gas emissions, contribute to the intensification and increased frequency of heat waves in many regions. These heatwaves can have profound health implications and affect agriculture and water resources.[32] Nagaland has witnessed a noticeable decrease in monsoon rainfall from 1989 to 2018, with the region consistently receiving less rainfall than the average annual total of 1,143 mm. This prolonged delay in the onset of the monsoon season in Nagaland has resulted in conditions resembling drought in the state. Consequently, production of rise initially projected to reach 551,000 metric tonnes (2020-2021), has experienced a significant decline, estimated at approximately 70%, with an expected yield of only 166,000 metric tonnes, as reported by Nagaland's Agriculture Production Commissioner, Y Kikheto Sema.[33] Official data reveals an estimated 525 hectares of horticultural crops and 68,662 hectares of *jhum* fields suffered damage due to inadequate rainfall, affecting approximately 915 villages.[34] Climate variability has significantly impacted plant physiology in various ways. Environmental extremes and fluctuations in climate have increased the likelihood of numerous stresses on plants. Climate change affects crop production through direct, indirect, and socio-economic impacts. Moreover, extreme climate events such as droughts, floods, high temperatures, and storms have escalated dramatically, as reported by the Food and Agriculture Organization (FAO).[35] Fig. 3 depicts the progression of climate change's impacts on agriculture.

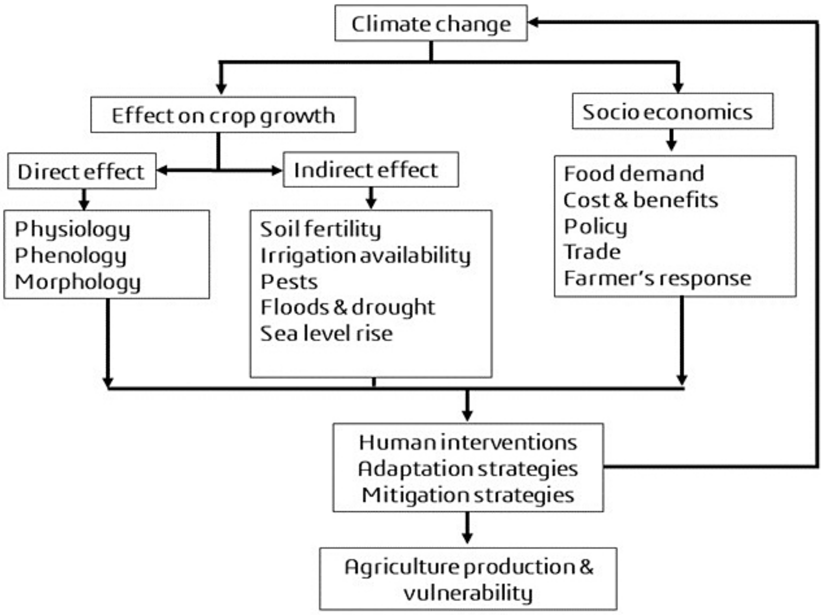

Fig. 3: Potential influence of climate change

In recent decades, the Sikkim Himalayan agroeco-systems have experienced a wide range of climate change, including unpredictable rainfall and snowfall patterns. North Sikkim, in particular, has seen an uptick in monsoon precipitation, which may be linked to increased flooding in the Teesta River.[36] Mizoram, influenced directly by the monsoon, experiences substantial rainfall from May to September, with an average annual precipitation of 245 cm.[37] Between 1951 and 2017, the region has observed a gradual temperature increase of 0.01 °C, primarily attributed to an annual rise of 0.03 °C in mean maximum temperatures.[38] In 2019, Mizoram experienced a devastating event in which three buildings, constructed as part of the Basic Service to Urban Poor (BSUP) scheme in Durtlang, collapsed owing to a landslide, claiming three and injuring eight. The incident was accompanied by intense and prolonged rainfall, leading to road blockages from debris falling from the affected area.[39]

Impact of Climate Change In NE India Perspective: an Overview

Climate change exerts a substantial indirect influence on agriculture, affecting various aspects such as the occurrence of droughts and floods, soil quality, and erosion rates. Additionally, it can disrupt insect populations, accelerate nutrient mineralization in the soil, and decrease nutrient utilization efficiency, all of which result in increased demand for irrigation water and plant nutrients. Extreme weather events like floods, droughts, heatwaves, cold spells, flash floods, cyclones, and hailstorms have a significant and often detrimental impact on crop production.[40]

Changes in the Temperature and Rainfall Patterns

The region's increasing aridity is a consequence of substantial shifts in rainfall patterns over the past century. The rise in temperature, coupled with a decrease in humidity and an increase in moisture, has led to unforeseen changes in rainfall patterns. Projections from the Union Ministry of Environment, Forests, and Climate Change suggest that temperatures in the area could rise by 1.8-2.1 °C by the end of 2030. During the same period, there may be an annual mean rainfall increase of 0.3-3% due to the impact of climate change.[41] According to data from the India Meteorological Department (IMD), the average maximum temperature in NE India soared to 33.75 °C, surpassing the previous record of 32.66 °C established in July 2009.[42] The Global and Planetary Change report also indicates that there could be a significant rise in an annual mean temperature, with a projected rise of 5.15-0.64 °C between 2011 and 2040. Additionally, it suggests that daily rainfall may increase by 0.09 mm per day, amounting to 33 mm annual increase. For Assam, models forecast a temperature increase of 1.7-2.0 °C, making it more vulnerable to climate change between 2021 and 2050. Arunachal Pradesh's state action plan on climate change had anticipated an annual rainfall decrease of 5–15% in the 2050s, but it is expected to increase by 25–35% in the 2080s.[24] Local residents engaged in agricultural activities have reported that climate change-related extreme events such as cloud bursts and heavy torrential rainfall have a detrimental effect on crop production over time. These events could result in the destruction and an overall decrease in crop yields. According to Manipur's climate action plan, the region is expected to see a temperature increase of 1.7 °C by the mid-2030s, along with a corresponding rise in rainfall of 15–19% during the same period. In the case of Nagaland, projections suggest that between 2020 and 2050, the region could experience temperature increase ranging from 1.6-1.8 °C. Additionally, there may be significant increases in rainfall, with estimates ranging from 15-20%, particularly in districts such as Wokha and Tuensang.[41]

Climate Change's Impact on Water Resources

Arunachal Pradesh has witnessed a decline in rainfall, leading to the drying up of up to 200 mountain springs in the region, which is attributed to a combination of human-induced geological, land use changes, and climate change, particularly in the alterations of rainfall patterns.[41] According to a study conducted by experts at the Central Agricultural University in Imphal in 2016, there were 18 years of mild drought and one year of moderate drought between 1975 and 2007 in the NE region. Manipur experienced a severe drought in 2009; during the early part of that year, 46% of the nation experienced moderate-to-severe drought conditions. These instances highlight the region's vulnerability to drought events and the need for effective water resource management and climate adaptation strategies in response to these challenges.[43]

Climate Change's Impact on Glaciers and Glacial Lakes

Glaciers serve a vital role in preserving the hydrological cycle and ecological stability.[44] Rising temperatures and precipitation fluctuations across the Himalaya are the main worries for region's snow cover and glaciers, as it impacts freshwater accessibility. According to scientific evidence, the majority of glaciers in the Himalayan region have lost volume and mass with rising temperatures.[45] Studies reveal that glaciers in the Himalayan region continue to shrink, such as the Dokriani glacier (16.6m per year from 1962-1995),[46] Samudratapu glacier (18.45 m per year from 1963–2004),[47] Gangotri glacier (19.9m per year from 1965–2006),[48] and East Rathong glacier (15.1m per year from 1962–2011).[49] Another satellite-based assessment of 286 Himalayan mountain glaciers between 2000 and 2008 was conducted by Scherler *et al.,*[50] and according to their survey, 58% of glaciers are slowly advancing, while more than 42% are retreating. Also, according to a study conducted by Bahuguna *et al.*[51] it was found that 1752 glaciers (86.8%) had stable fronts, 248 (12.3%) had retreated, and 18 (0.9%) had snout advancement among the glaciers analyzed. Recent variability and climate change have had a profound impact on the glaciers of the Himalayan region. These glaciers are geologically young and relatively weak, making them highly vulnerable to even modest changes in climate conditions.[52] Many glaciers in the Sikkim Himalayas are retreating and thinning, creating new glacial lakes with an extension of old ones due to meltwater accumulation behind loosely consolidated end moraine dams.[53] According to recent research by the Sikkim State Council of Science and Technology in Gangtok and the Centre for Development of Advanced Computing (C-DAC) in Pune, various glacier lakes in the Sikkim Himalayan region have been observed to be increasing. Thus, this growth is a clear indication of the negative influence of change in climate on glacier lakes and the hazards they pose.[54]

Climate Change's Impact on Biodiversity

Between 2001 and 2020, the NE region as a whole saw a reduction in its forested land, amounting to a range of 5-14%. These statistics stress the alarming rate of deforestation and habitat loss, emphasizing the urgent need for conservation and sustainable forestry practices to protect the region's unique biodiversity and ecosystems.[55] During the same period, Nagaland has also witnessed a significant decline in its forest cover, with 17% reduction over the past two decades. This decline in forest cover represents the most rapid decline observed since 2001. Among the eight NE states, Assam, the largest among them, contributed to a 14.1% decrease in the forest cover during this timeframe. Following closely behind, Tripura experienced a 15% reduction in forest cover. These trends indicate the pressing issue of deforestation and habitat loss in multiple states within the NE region of India, highlighting the need for conservation and sustainable forestry practices to counteract these alarming declines in forested areas.[10] One pressing issue that has to be addressed is the paucity of information regarding the specific effects of climate change on the many plant and animal species that are native to the Northeast.

Climate Change's Impact on the Ecosystem

Inland Water

In the NE region of India, there are approximately 133,969 hectares of wetlands situated on floodplains and are distributed across the states of Assam, Manipur, Arunachal Pradesh, Meghalaya, and Tripura. It is predictable that over 100,000 fishermen rely on these wetlands for their livelihoods through capture fisheries. These wetland ecosystems play a vital role in supporting the region's ecological diversity and the livelihoods of the local fishing communities.[56] According to a study by Sarkar *et al.*[57] in the Brahmaputra River basin, climate change is expected to impact the interconnected wetlands in the floodplain substantially.

Forest

Based on the Forest Survey of India (FSI),[58] despite comprising only 7.98% of India's total land area, the NE region is responsible for one-fourth of the country's forest cover, encompassing 170,541 sq.km, and 65.05% of its total geographic expanse. The LULU mapping study was conducted by Ritse *et al.*[44] in Nagaland's Eastern Himalayan region, with a primary focus on the districts of Kohima and Dimapur, spanning three distinct periods: 1998, 2008, and 2018. The study utilized remotely sensed Landsat data with Landsat level 1 employing Geographic Information Systems (GIS) for LULC classification. Their findings revealed that rapid urbanization, uncontrolled construction activities, and poor land management practices have led to significant agricultural and forested land losses in both Kohima and Dimapur districts. These changes in LULC were influenced by secondary factors such as urban migration, expansion of fisheries ponds, and the marginalization of shifting farming practices.[59]

Impact on Agriculture and Food Security

Sustainable Development Goal 2 (SDG 2) underlines the importance of promoting sustainable agriculture to attain food security and eradicate hunger by 2030.[60] In the NE region of India, tea is one of the most lucrative crops, supporting the livelihoods of millions of people. The Tea Board of India has observed a consistent fall in tea production in recent years. For instance, Assam, a major tea-producing state in the NE area, yielded 5,12,000 tonnes of tea in 2007,[61] but it decreased to 4,87,000 tonnes in 2008, and production is expected to dip to 4,45,000 tonnes in 2009. The changing pattern of rainfall in NE India in recent years has been significant, impacting water scarcity, which can affect tea production. These variations in precipitation patterns can lead to moisture stress or excess moisture in tea gardens, ultimately impacting the quantity and quality of tea leaves produced.

Climate Change's Impact on Human Health

Japanese encephalitis, malaria, dengue, and lymphatic filariasis are prevalent diseases that have expanded to Assam, Mizoram, and Arunachal Pradesh due to increased flooding incidents.[62] Climate change leads to rising temperatures, ice melting, and the frequency of natural disasters such as cyclones, floods, and droughts, which can displace people from their homes. In general, insect pests, disease vectors, and pathogens tend to expand their range in warmer environments, which can also increase their survival rates.[63] From 2013 to 2017, Meghalaya, Mizoram, Tripura, and Arunachal Pradesh had the highest malaria-related deaths per 100,000 people among the states in India.[64] According to the Centre for Disease Control and Prevention (CDC), temperature can significantly affect human health, potentially leading to illness and death. During extreme heat events in the region, major cities' nighttime temperatures are often several degrees higher than those in surrounding areas, increasing the risk of heat-related fatalities. On the hottest days in NE India, there is often a high concentration of urban air pollutants, including ground-level ozone. Additionally, the combination of sea level rise and storm surges can significantly increase the risk of flooding, which can impact coastal populations' physical and mental health. For example, the states of Manipur, Tamenglong, Churachandpur, and Imphal East in NE India account for 70% of all malaria cases.[63]

Climate Change and Urbanization Impact on Hydro-power Plants

Today, hydro-power is the world's most important renewable energy source, accounting for roughly 16% of total electricity usage. According to the Central Electricity Authority's (CEA) assessment, India has economically exploitable hydro-power potential totalling 1,48,700 MW of installed capacity.[65] Arunachal Pradesh alone, from NE India, has more than 50,000 MW of untapped hydro-power potential, but only 415 MW has been harnessed till date.[66] Hydro-power plants are among the most sensitive systems being impacted by climate change, and the rate of urbanization has disrupted the equilibrium of energy resource demand and supply.[67] Dams are frequently seen to cause flash floods in downstream areas, and because of the erratic rainfall and river run-off, the potential for dam-induced flash floods in the NE region will increase as a result of climate change.[68] The Doyang River in Nagaland is the largest and longest river, running through much of the Wokha district in NE India where the Doyang Hydroelectric Project (DHEP), a rockfill dam and hydroelectric project with a design capacity of 75 MW,[69] with more than 20 km^2 of was created to generate hydroelectric power. However, there are several land use practices such as shifting cultivation, timber plantation, deforestation, and rising population in the catchment area which have threatened floodplain habitats and have sparked renewed interest in preserving and managing floodplain vegetation near the Dam and in other sensitive regions.[70]

Climate Change Mitigation and Adaptation Strategies of Northeast Region

Forests can also help to mitigate climate change,[70] by improving the carbon density of existing forests at the stand and landscape sizes and lowering emissions caused by deforestation and degradation. According to the IPCC,[71] the forest sector's mitigation potential ranges from 8.2-13.5%. Carbon stock augmentation involves various methods such as forest restoration, vegetative restoration, planting, rehabilitation, and forest landscape restoration to increase the carbon stocks in degraded or deforested areas. These efforts aim to restore forests and enhance their capacity to sequester carbon from the atmosphere.

The state government also aggressively promotes horticulture and cash crop farming among the local populace. Additionally, under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), the central government has committed monies to establish rural employment prospects in the state. Housing developments funded by the Pradhan Mantri Awaas Yojana Gramin (PMAY-G) in various districts of Arunachal Pradesh have also received government support. Recently, the state has taken steps to address climate change by adopting a declaration centered on five key pillars: Environment, forests, and climate change; health and well-being for all; sustainable and adaptive living; livelihoods and opportunities; evidence-based and collaborative action to promote climate-resilient development.[72]

The Indian Council of Agricultural Research (ICAR) launched the National Innovations on Climate Resilient Agriculture (NICRA) initiative to improve the adaptability of Indian farming, encompassing crops, livestock, fisheries, and their resilience to climatic fluctuations. This large-scale project has three core goals: strategic research, showcasing technology applications, and enhancing capacity. NICRA's reach extends to over one lakh farming households nationwide and is actively implemented in 100 districts.[73] In 2011, this project was also extended to the Krishi Vigyan Kendra in the Ri Bhoi district of Meghalaya.[74] Since its inception, the NICRA project has actively promoted and supported the adoption of various technologies and improved agricultural practices to alleviate the effects of climate change, ultimately fostering farming as a sustainable enterprise, particularly in hilly regions.[75] Leveraging both traditional and genetically modified (GMO) crop varieties such as oilseed, sugarcane, rapeseed, and jatropha for biofuel production could be instrumental in alleviating the adverse impacts of carbon dioxide (CO_2) emissions from vehicles. A research study led by Soumya *et al.*[76] has identified three biomass samples: specifically, moj (*Albizia lucida*), bonbogori (*Ziziphus rugosa*) and areca nut husk (*Areca catechu*) as promising sources intended for biofuel production in the NE India. Consequently, energy-efficient agriculture will employ machinery powered by bioethanol and biodiesel rather than conventional fossil fuels,[77] and is evident that reduced rainfall, increased potential for weed growth, pest infestations, and diseases triggered by microorganisms and climate change all contribute to lower agricultural yields. To fulfil the rising worldwide demand for food crops, expanding cultivated acreage or increasing productivity on current farms is critical. Higher agricultural yields are required to satisfy the needs of increasing populations confined to water and land availability, and they can be achieved by implementing contemporary breeding techniques and biotechnology.[78]

Traditional knowledge

Learning from Tribal Communities to Mitigate Climate Change in NE India

Indigenous communities in NE India have cultivated a rich reservoir of traditional wisdom spanning decades and centuries. Traditional farmers adeptly adapt to climate variations by making informed choices regarding crop varieties and management techniques. This includes opting for locally adapted crop varieties resilient to drought, ensuring sufficient water resources, and cultivating plant species that enhance carbon sequestration. Furthermore, traditional farming systems and food production practices involve extensive crop planting, mixed cropping, agroforestry methods, flexible weeding, and gathering wild plants, among others. These communities possess remarkable skills in observing and interpreting environmental changes, drawing from their collective understanding of the land, skies, and oceans. Additionally, they have the capacity to anticipate future shifts in climate-related variables. These tried-and-true adaptation and mitigation measures, deeply rooted in traditional knowledge, bolster the resilience of social-ecological systems in an ecosystem that is susceptible to change and inhabited by indigenous groups. Indigenous people's traditional knowledge (TK) is essential for preserving biodiversity and maintaining environmental functions and has proven to be a vital source of information in recent years. Many indigenous peoples rely on TK for natural resource management, subsistence farming, preservation of water, and climate change adaptation.[79,80]

Water scarcity is a significant issue in the hilly areas of NE India, particularly during dry seasons when rainfall is limited. To address this challenge, various traditional methods of rainwater harvesting are employed. One common method is rooftop rainwater harvesting, where rainwater is collected from rooftops and stored in tanks. This harvested rainwater can be used for drinking, irrigation, agriculture, and other purposes. The collected rainwater can be made safe for consumption with basic filtration equipment.

In some regions, such as Meghalaya, bamboo pipes are utilized to transfer water from natural springs on hilltops to lower altitudes. Tribal farmers employ this technology in the Khasi and Jaintia hills of Meghalaya for drip irrigation of their crops. Rooftop rainwater collection is particularly popular in Shillong, the state capital of Meghalaya, which helps communities access a vital source of freshwater and mitigate the impacts of water scarcity.

Mizoram's state government takes proactive measures to address water scarcity in hilly areas by supporting the construction of water tanks designed to capture rainwater. Despite Mizoram's relatively high average rainfall of 250 cm, residents in hilly regions frequently encounter water scarcity issues because rainwater tends to drain quickly down steep mountain slopes. In addition to the construction of water tanks, both Mizoram and Nagaland employ an indigenous rainwater conservation system known as the 'Zabo' system. Under this method, rainwater is collected and stored in catchments along mountain slopes. The harvested rainwater serves various purposes, including agriculture and other domestic uses and local initiatives have a pivotal role in safeguarding a sustainable and accessible source of water for communities living in hilly terrain.[81]

Farmers in Tripura are taking steps to adapt to climate change by adopting organic farming practices involving organic manure, mainly cow dung. Farmers collect cow dung and combine it with other organic materials like grasses, fallen leaves, and small tree branches. This mixture is allowed to degrade and decompose, eventually turning into nutrient-rich organic compost. This organic compost is then used to enhance soil fertility by cultivating summer potato crops and other agricultural produce. Organic farming methods like this help improve soil health and crop productivity and contribute to sustainability by reducing reliance on chemical fertilizers and promoting environmentally friendly agricultural practices.[82,83]

In Assam, local communities have developed traditional techniques to mitigate the impacts of frequent floods. One of these methods is known as "kasa pithiya." This approach involves constructing man-made mounds to address the problem of waterlogging during floods. The mounds are typically shaped like a semicircle and are designed to resemble a turtle's shell as they rise above the floodwaters. By creating these elevated platforms, people can protect their homes, livestock, and essential belongings from being inundated by floodwaters.[84] Mishing families in Assam also employ innovative architectural techniques to adapt to the recurring floods in the region. They construct traditional houses known as "chang ghars" using locally available bamboo and other materials. These houses are designed to cope with floods. During flood events, when the water levels rise, Mishing families relocate to higher ground. The unique feature of the *chang ghar* is that it is built on stilts, allowing it to remain above the floodwaters. The raised platform keeps the living quarters dry and safe during the inundation caused by the floods. This architectural approach is a testament to the resilience and adaptability of the Mishing community, who have developed practical solutions to the challenges posed by the region's frequent floods, and reflects their deep understanding of the local environment and their ability to live in harmony with the natural forces that shape their lives.[85] The Mishing community's traditional weather forecasting and flood prediction methods have been passed down through generations. Their ability to read nature's indications and adapt to the region's natural problems demonstrates their tenacity and resourcefulness in dealing with Assam's frequent floods.[86] The use of ants' behaviour as a natural indicator for heavy rainfall and impending floods is an interesting example of traditional ecological knowledge and wisdom among local communities in NEIndia. Ants are known for their sensitivity to environmental changes, particularly moisture levels. When ants start moving to higher ground, it suggests that they are seeking refuge from rising water levels or excessive moisture, which can be associated with heavy rainfall.[87]

Farmers in Nagaland have shifted to coffee cultivation as a strategy to combat soil erosion and provide an alternative to traditional *jhum* farming, thus contributing to forest conservation. This transition has also opened up opportunities for farmers in NE states, which have been grappling with soil erosion exacerbated by climate change. Nagaland's Land Resources Department (LRD) initiated discussions with the coffee board in 2014 to adapt to climate change impacts and address soil erosion. Their objective is to promote the establishment of new coffee plantations and the restoration of existing ones. Coffee is cultivated on approximately 8,996.5 hectares, covering 0.8% of Nagaland's total land area. Despite the challenges posed by climate change, coffee farming in Nagaland serves as a means to enhance resilience against the adverse effects of shifting weather patterns.[88]

In Sikkim, the region experiences adverse effects of climate change, such as rising daytime temperatures and altered rainfall patterns, which can lead to fluctuations or even a decrease in total annual precipitation. These changes have a detrimental impact on both crop productivity and livestock rearing, including poultry. To mitigate these challenges, farmers in Sikkim have turned to environmentally friendly and practical solutions like vermicompost, farmyard manure, compost, crop residues, green manures, and oil cakes as organic nutrient sources.[89]

In Arunachal Pradesh, farmers use a method known as Indigenous Traditional Knowledge (TK) where grains are placed in bamboo baskets lined with 'ekam patta' leaves to cover the basket holes completely. 'Ekam patta' is chosen for its easy availability, durability, and large surface area compared to other leaves. After placing the grains, they are covered again with ekam patta, and the baskets are placed on stands to protect them from rodents, thereby extending the storage life of the grains.[90] The Apatani people in the Ziro Valley of Arunachal Pradesh have developed an irrigation system to support paddy-cum-fish cultivation. This system involves channelling water from streams in the surrounding hills through a complex network of primary, secondary, and tertiary channels to reach the fields. The Apatani tribe practices paddy-cum-fish cultivation by placing fingerlings into small pits dug in each terrace. During the monsoon season when the fields are flooded, the fingerlings swim in the paddy fields. This system relies on nutrient runoff from hill slopes and organic manure from houses and granaries above the fields. It serves as a prime example of sustainable wet rice cultivation, showcasing land and water conservation, nutrient recycling, and soil fertility maintenance.[91]

In Nongtraw, Meghalaya, the Khasi indigenous community highly values honey harvested in one of the world's wettest areas. When Khasi community members venture into the forest to collect honey, they follow a tradition of greeting the bees and "informing the bees" that they will only take what is necessary. This deep respect for local agrobiodiversity and ecological balance has proven beneficial to the Khasi people of Nongtraw in coping with food stress related to climate change.[92]

Table 1:Traditional methods to mitigate climate change by indigenous people of Manipur.[95,96]

Plants	Common name	Vernacular name	Description
Agave americana Linn. (Agavaceae)	Agave	*Kewa* (Manipuri) *Sisal* (Hindi)	This plant's flowering pattern is thought to foresee the course of storms/ winds in the year to come. Indigenous people rely on traditional knowledge to foresee weather trends and prepare for probable climatic events.
Ficus rumphii Blume. (Moraceae)	Golden Rumph's Fig	*Khongnang* (Manipuri) *Paras papal* (Hindi)	Crows (Corvus splendens) building nests on the limbs of this particular tree are believed to predict weather patterns. If crows make their nests on a tree's top branch, it is believed that floods would occur with less wind and wind-storms that year. If the nests are built on the tree's lower branches, it is predicted as a sign of strong winds with little rainfall.
Hibiscus cannabinus Linn. (Malvaceae)	Java jute	Sougri (Manipuri)	
Bambusa spp. (Poaceae)	Bamboo	*Waa* (Manipuri) *Bans* (Hindi)	If bamboo plants undergo a mass flowering event, it often leads to a significant increase in the population of rodents, particularly rats. These rodents can cause extensive damage to crops, leading to food shortages and potential famine. The phenomenon has been observed in various regions and serves as a traditional indicator of the potential for food scarcity bamboo flowering periods.

Mangifera indica Linn. (Anacardiaceae)	Mango	*Heinou* (Manipuri) *Aam* (Hindi)	The prediction based on mango trees is a traditional ecological observation that suggests potential weather patterns for the upcoming year. If mango trees produce an abundance of blossoms and inflorescences, it is traditionally believed to indicate that the upcoming year could experience greater wind, storms, and heavy rainfall but if mango leaves are observed to be dark green at the beginning of a season, it is traditionally believed to indicate that there will be abundant rainfall during that season.
Platycerium wallichii Hook. (Polypodiaceae)	Elkhorn ferns	*Saji-machi changkhrang* (Manipuri)	If the vegetative components of the elkhorn fern plant are dark green in color, it is traditionally thought to indicate a chance of rainfall in the current year but if the vegetative parts are bland in color, it is thought to indicate a lack of rain in the current year.

Bench terrace agriculture is indeed an effective technique for mitigating soil erosion in hilly and sloping areas like Chandel, Manipur, and other regions facing similar topographical challenges. This agricultural practice involves creating level or nearly level platforms or terraces on sloping terrain to help control soil erosion and conserve water.[93] In Manipur, indigenous communities primarily reside in rural areas and continue to uphold ancestral traditions centered around biodiversity conservation. These traditions encompass a rich heritage of botanical knowledge, which extends beyond the utilization of plants for sustenance, shelter, and clothing. They also include using plants for weather forecasting, predicting natural disasters, and warding off misfortune, particularly in traditional healing practices. The indigenous people have a deep reliance on their immediate environments and resources, especially plants and animals. They possess extensive knowledge of their local resources, and the majority of the population consists of rural farmers who maintain the ancient practices of biodiversity preservation passed down through generations and uphold their traditional beliefs, including botanical folklore.[94] In addition to utilizing various plants for purposes such as food, clothing, and shelter, the indigenous people of Manipur also possess knowledge about how these plants can be employed to predict the weather, prevent natural disasters, and mitigate the effects of bad luck. These botanical practices are practical and encompass cultural and spiritual aspects, serving as taboos or guidelines to avoid unfavorable events and maintain harmony with nature as shown in Table 1.

Future Research Directions

Climate change has indeed led to unpredictable and sometimes paradoxical shifts in rainfall patterns, causing areas accustomed to heavy rainfall to experience drought-like conditions while regions with typically less rainfall face flooding. The significant year-to-year variation in precipitation, coupled with the diverse topography across the states, presents formidable challenges for managing and formulating policies related to water resources. To address these challenges effectively, it is essential to develop a comprehensive climate change strategy that considers each region's unique conditions and vulnerabilities within the state. This strategy should be inclusive, involving local communities, experts, and policymakers to ensure that it addresses different areas' specific needs and concerns. Furthermore, constant monitoring and adaptive management will be required to address the dynamic character of climate change and its effects on water resources. A more in-depth investigation is needed to completely comprehend the causes of climate change and create novel adaptation and mitigation strategies. Many uncertainties persist in the literature, particularly regarding the enduring consequences of susceptibility to climate change, and comprehensive statistics concerning the state of affairs in the NE region of the country are lacking. The action plan for mitigating climate change should also give proper consideration to how the system's adaptation techniques and mitigation potential interact. There is an urgent need to inform supply chain management about the existing climate, the changes in topography that it has caused, and the many adaptation techniques that will be used to deal with the situation in light of the consequences of foreseeable changes in the climate. This can be done by launching awareness campaigns, developing training and capacity-building modules, creating learning resources, and creating support manuals for various risk scenarios. Current scientific understanding should allow such knowledge to be offered and used for technical solutions that fit within adaptation techniques rather than denying this potential content and the systems within which it has formed.

Conclusion and Recommendation

The current review provides information regarding climate change and its effects on several factors by combining scientific facts and perception-based investigations in the Northeast. Our existence must comprehend how climate change will affect humanity in the coming decades. The abnormal weather conditions both directly and indirectly impact the world's production and food quality. Therefore, one needs a strong and systematic action plan to combat the negative effects of a changing environment. The impact of climate change is becoming increasingly obvious with each passing year, and the region of NE seems to be particularly affected. Most of the literature anticipates increases in warmth and monsoon precipitation and declines in winter precipitation, resulting in future monsoon flooding. According to the study, the benefits of alternative policy options should be assessed to progress beyond mitigation and adaptation to climate change. The scientific evaluation of traditional resource uses is necessary, and indigenous knowledge should form the foundation of any conservation strategy that is backed by institutional backing and scientific understanding.

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Ethics Statement

The study does not involve an experiment on humans and animals.

Authors' Contribution

Tsenbeni N Lotha: Conceptualization, Investigation, Data curation, Writing- original draft. Vimha Ritse: Artwork, Formal analysis, investigation. Vevosa Nakro: Analysis & drafting. Ketiyala: Writing-review & editing. Imkongyanger: Analysis & drafting. Lemzila Rudithongru: Writing-review & editing. Nabajit Hazarika: Writing- review & editing, formal analysis. Latonglila Jamir: Conceptualization, Visualization, Formal analysis, Supervision, Writing- review & editing. Investigation.

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