CLIMATE CHANGE HOTSPOTS IN THE EASTERN INDIAN HIMALAYAN REGION

Working Paper Prepared by

[1]Assam University, Silchar

[2]Indian Council of Forestry Research and Education, Dehradun

[3]District Disaster Management Authority, Cachar

Working Group

Niranjan Roy[1], Rajiv Pandey[2], Rajib Gupta[3], Rakesh Kumar[2], Arun Jyoti Nath[1]

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1. Background

Mountains are one of the most fragile ecosystems with high biodiversity and provision of several ecosystem services such as water for drinking and irrigation, climate regulation, carbon sequestration, aesthetic and cultural values contributing to human wellbeing. The Hindu Kush Himalaya (HKH), a mountainous region, is a critical geo-ecological asset and origin of ten major river systems, providing water for drinking, irrigation and power for over 1.3 billion people (nearly 20% of the world's population) in Asia. The HKH region fed the rivers and streams of the region, including the Indus, Ganges and Brahmaputra river systems of India supporting collectively about 50% of the country's total utilisable surface water resources.

The Himalaya is delineated by different climatic sub-zones due to diverse geographical variability of the differential topographical distribution of the region. Several activities including agriculture expansion and intensification, deforestation, degradation, habitat fragmentation, overexploitation of resources, invasive species, and climate change have threatened the Himalayas. Climate change is the most precarious and likely to impact forest and other ecosystems affecting food production, and significantly risks the poorest, women, children and the elderly in the HKH. Moreover, a rise in the number of climate-induced extreme weather events like floods, droughts, heatwaves and natural hazards like wildfires, landslides are expected to increase, leading to risk to all sorts of infrastructure, including hydropower.

The climate of the HKH is characterised by tropical and subtropical climatic conditions with significant temperature and precipitation changes since the twentieth century and a more noticeable warming trend. During the first half of the twentieth century, warming in Himalaya was at 0.16 °C per decade and doubled (0.32°C per decade) during the second half of the century. The long-term trends in precipitation in the HKH region are inconsistent due to the influence of local thermodynamic and orographic processes on large scale ocean-atmospheric processes. Trends of annual precipitation in the Indian Himalayan region is inconsistent during the period 1871–2008. Pronounced warming has been observed in the HKH with an increase in annual mean surface-air-temperature at a rate of about 0.1 °C per decade during 1901–2014 and about 0.2 °C per decade during 1951–2014, resulting in projected warming in the range of 2.6–4.6 °C by the end of the twenty-first century. The increase in temperature and changes in precipitation over the HKH region is a major concern for the snow cover and glaciers leading to a major threat to the regional water resources directly affecting agriculture food production. The Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) was published in 2007 and it observed "Warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level"; and "most of the observed increase in temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations".

Due to this unique geographical location, EIH represents numerous forest types falling within one of the biodiversity hotspots of the world, the Indo-Burma biodiversity hotspot. Long-term monitoring of weather and climate in the region is essential to account for improved representation in climate modelling for precise projections besides improved estimation of the profound hydrological and agricultural impacts in the region. The lack of information on the climatic variation in IHR at large spatial and local level poses challenges for the precise evaluation of the climatic impacts leading to restricting the planning process. Trend analysis of climatic parameters facilitates the assessment of the climate of a region with estimates of variations in climate and critical for water demand and supply for various purposes and better planning in a region. Therefore, the present evaluation attempts to account for the spatial and temporal trend of annual average temperature and total precipitation in the EIH region based on the data for 1990–2019. The objective of the report was to identify the climate change hotspot in the EIH.

2. The identification of climate change hotspot

The EIH region extends from 21° 56' 26.296" to 29°27'41.59" North latitude and 87° 59' 14.024" to 97° 24' 43.345" East longitude (Fig. 1) and covers an area of 2,73,326 km^2 and accounts for about 8.3% of the total geographical area of India. The EIH region extends in nine Indian states namely Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Sikkim, and the hilly regions of West Bengal. The region is primarily mountainous with a roughly two-thirds area with less than 10% as a plateau and around 30% as plains. The land elevation varies from almost sea level to over 7,000 metres above MSL. While Assam and Tripura have more than two-third of their area occupied by the alluvial plains, the region of Arunachal Pradesh, Mizoram, Nagaland and Meghalaya and Sikkim are mostly mountainous without any plains. The region is divided into three broad climate groups viz., tropical, warm temperate mesothermal and snow microthermal as per the Köppen climate classification. The Himalayas in the north, the Meghalaya plateau in the south and the hills of Nagaland, Mizoram and Manipur in the east influence its climate. The climate of the region is a predominantly sub-tropical humid climate, with hot and humid summers, severe monsoons, and mild winters and governed by different mountains and hills as well as the southwest and northeast monsoons. While regions of Manipur, Tripura, and Mizoram located in the south have a tropical wet and dry climate, most of Assam, Nagaland, northern parts of Meghalaya and Manipur and parts of Arunachal Pradesh bear warm temperature mesothermal climate. The average climate of valley regions differs from the mountain region. The mountainous states of Arunachal Pradesh and Sikkim have a montane climate with cold, snowy winters and mild summers.

The temperature of the regions is influenced by the varying altitude from south to north and proximity to the sea in western areas. The mean summer temperatures vary between 30 to 33°C in the plains with a mean summer temperature of around 20°C in hills. Winter, summer and rainy season, are three seasons in the region. The region is among the rainiest on the Earth where most of the area receives more than 1000 mm of annual rainfall. About 90% of the annual rainfall of the region is contributed by the southwest monsoon to the region with most during April to late October with June and July being the rainiest months.

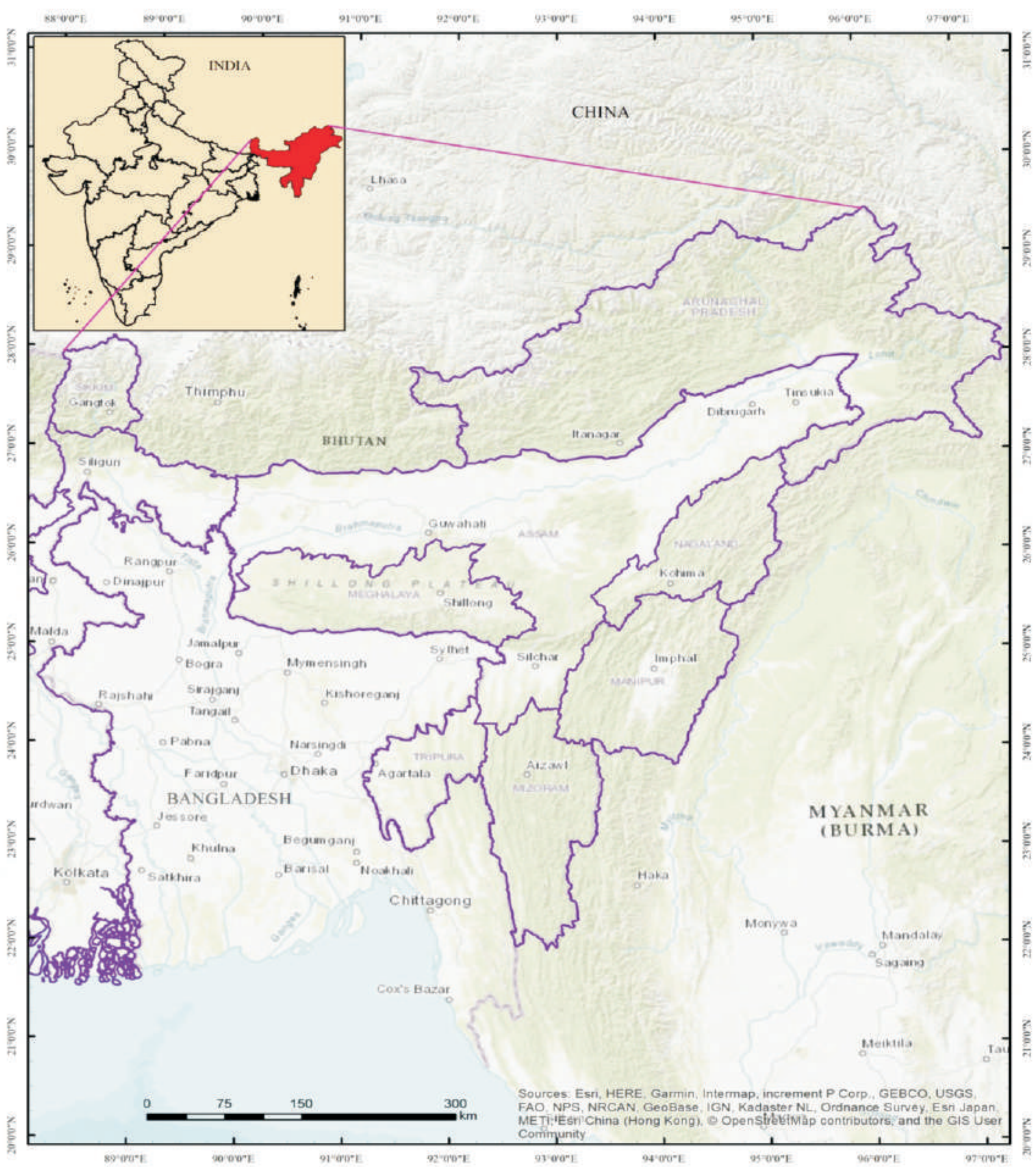

Figure 1. Map of the EIH Region along with the Indian states

Regions with simultaneously warming and decreasing precipitation trend are termed as the hotspot of climate change. The hot spot map is generated based on the severity of changes in climatic parameters i.e. MAT and TAP. The maps of observed change severity of MAP and TAP are integrated through the weighted overlay method where equal weights are assigned to each layer. The integrated change severity map is termed as the hot spot of climate change. It highlights the region where simultaneous warming along with decrease in precipitation is observed.

3. Spatio-temporal trend of annual mean temperature

Trend analysis - Parametric approach

The regional profile of the trend of MAT based on OLS regression method show gradually increasing linearity with time (Fig. 2). A high correlation is observed for the state of Arunachal Pradesh (0.62), Nagaland (0.57) and Assam (0.56); however, moderate correlation is noted for Manipur (0.48) and Meghalaya (0.41). The region of Tripura (0.29), Mizoram (0.30), Sikkim (0.31) and hill districts of West Bengal indicate a relatively low correlation. Other than Sikkim, Tripura and Meghalaya, the rest of the states have shown a statistically significant ($p < 0.05$) increasing trend in annual mean temperature with time (Fig 2).

Trend analysis – Non-parametric approach

The Mann-Kendall test show a monotonically increasing trend for annual mean temperature in the EIH region (Fig 3). The annual average temperature is found to be gradually increasing from the western side to the eastern side of the EIH region. The regions comprising Sikkim, Hill districts of West Bengal, Tripura and Mizoram demonstrate a small area with highly statistically significant ($p<0.05$) increasing trend in annual mean temperature. However, the region of Meghalaya, Assam, Mizoram, Manipur, Nagaland and Arunachal Pradesh show consistently increasing annual mean temperature with a very high level of statistical significance ($p<0.05$) (Fig 3).

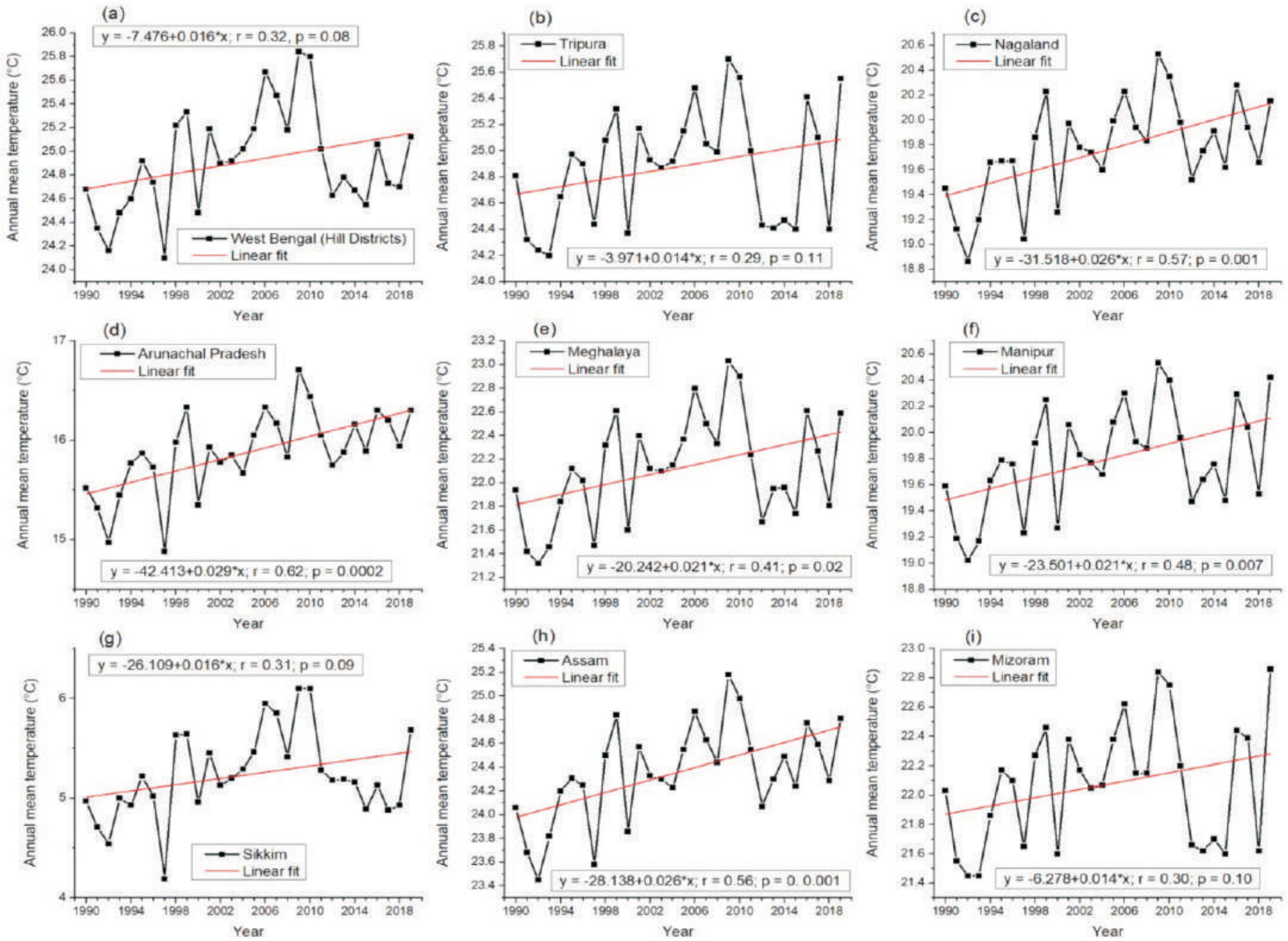

Figure **2**: Result of OLS regression trend of MAT with the linear fit line for different states of EIH region (a) West Bengal (Hill districts), (b) Tripura, (c) Nagaland, (d) Arunachal Pradesh, (e) Meghalaya, (f) Manipur, (g) Sikkim, (h) Assam and (i) Mizoram.

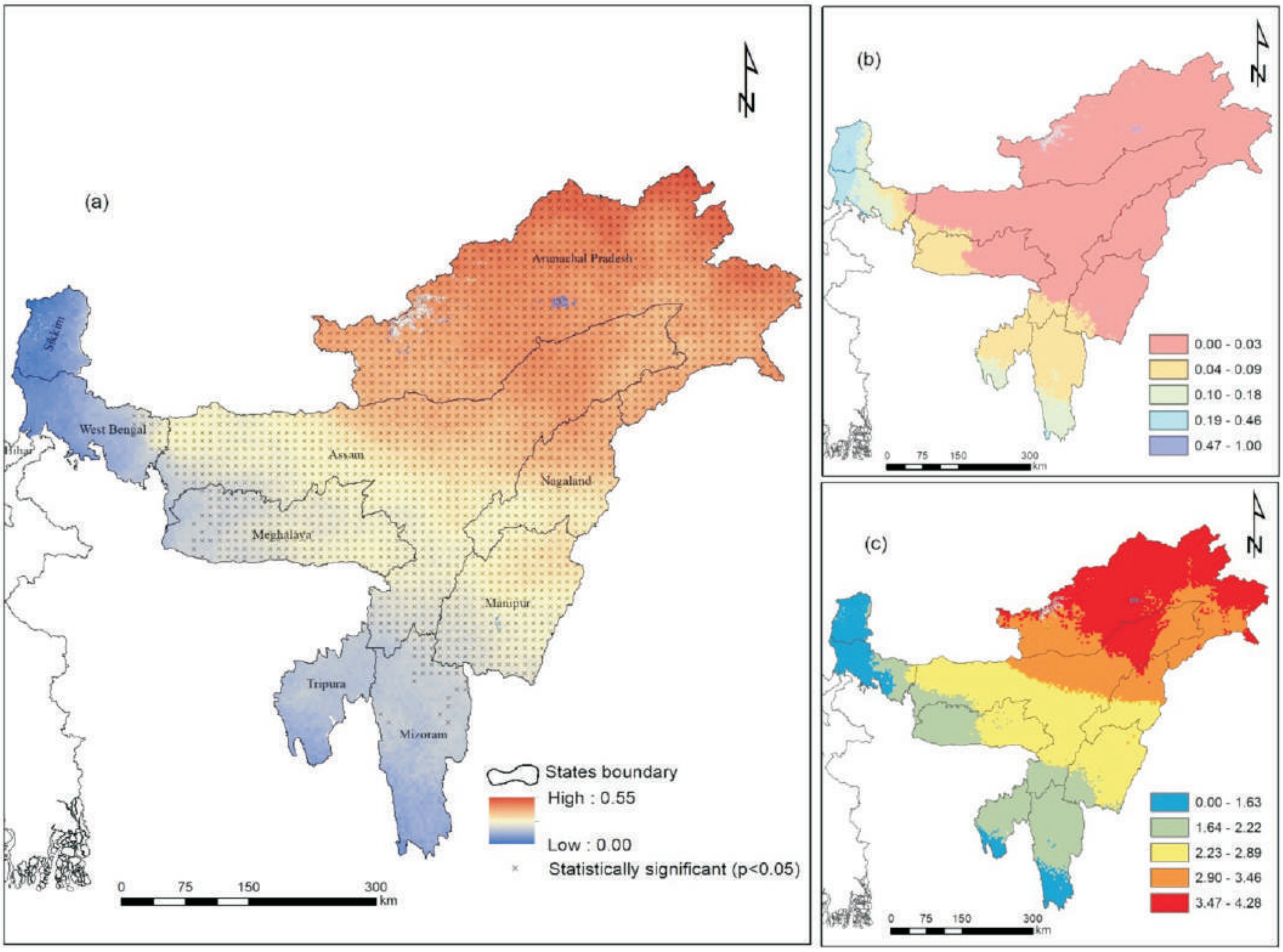

Figure **3**: The trend images of annual mean temperature showing (a) Mann-Kendall trend (b) p-value indicating the statistical significance of the MK test and (c) Z score of the MK test

The magnitude of the rate of change of annual mean temperature is estimated by the Theil-Sen slope (Fig. 4). The spatial distribution of the rate of change is categorized into five classes by the natural breaks (Jenks') method. The majority area of Sikkim, hill districts of West Bengal, Tripura and Mizoram show meager rate of increase varying from 0.017 to 0.037 °C annually and 0.27 °C per decade with a high ($p<0.05$) level of statistical significance. On the other hand, a high to very high rate of increase in MAT is observed among most of Arunachal Pradesh, valley region of Assam, the eastern part of Manipur, Nagaland and Meghalaya state of the EIH region. A moderate warming trend is observed in northern Manipur, Barak valley of Assam and the northeastern part of Meghalaya (Fig. 4).

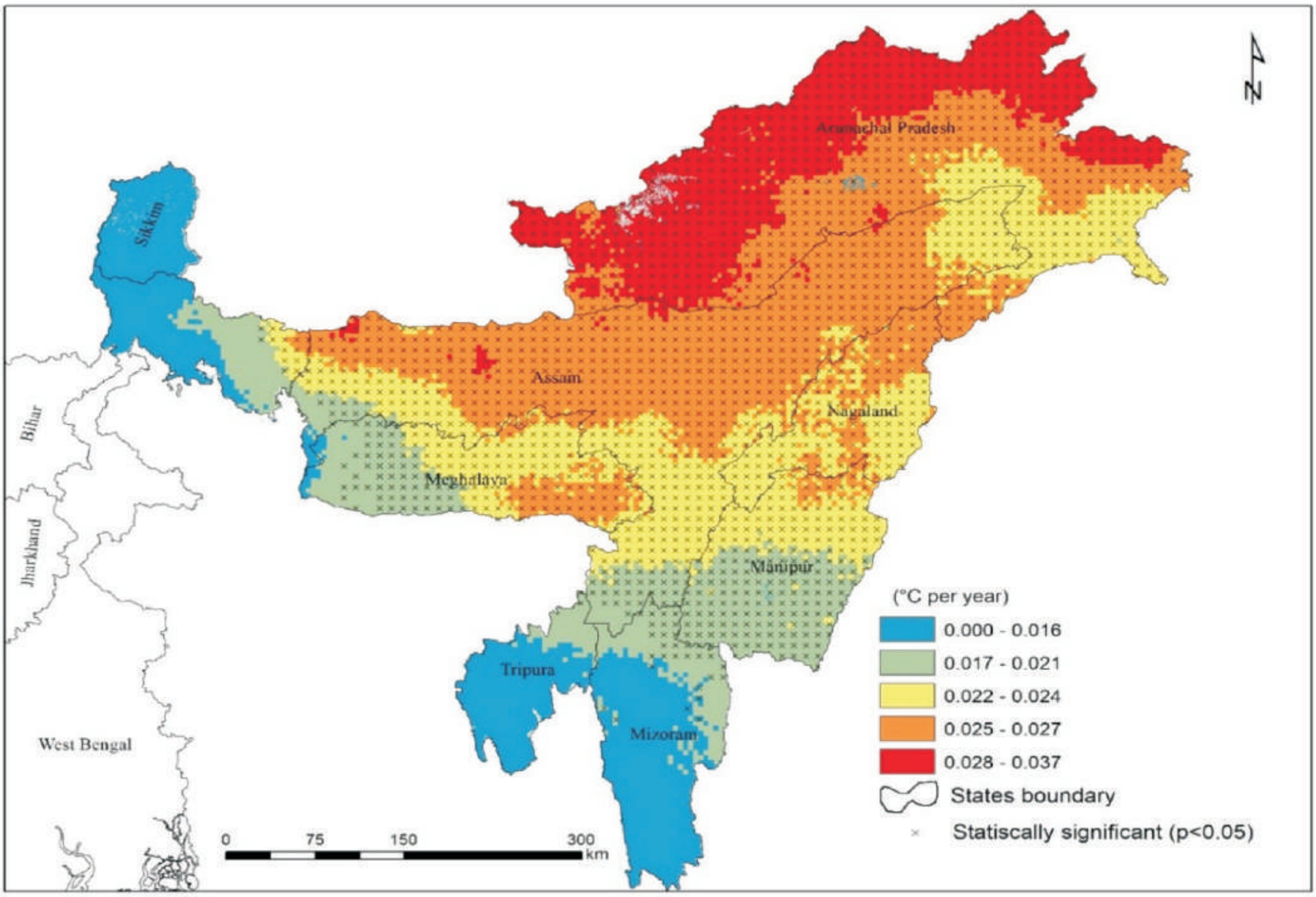

Figure **4**: The Theil -Sen slope for the annual mean temperature of the EIH region

Spatio-temporal trend of total annual precipitation

Trend analysis - Parametric approach

The TAP show a moderate to a low degree of decreasing trend with time across the states of the EIH region (Fig. 5). A moderate degree of negative (decreasing trend) correlation is observed for the State of Arunachal Pradesh (-0.51), Assam (-0.41) and Nagaland (-0.33). While a relatively low degree of decreasing trend is noted for Meghalaya (-0.26), hill districts of West Bengal (-0.22) and Manipur (-0.18) with a very low degree of decreasing trend in Sikkim (-0.05), Mizoram (-0.05) and Tripura (-0.09).

Only Assam and Arunachal Pradesh show a statistically significant ($p < 0.05$) decrease in total annual precipitation. For the remaining region of EIH, the trend is statistically non-significant ($p<0.05$).

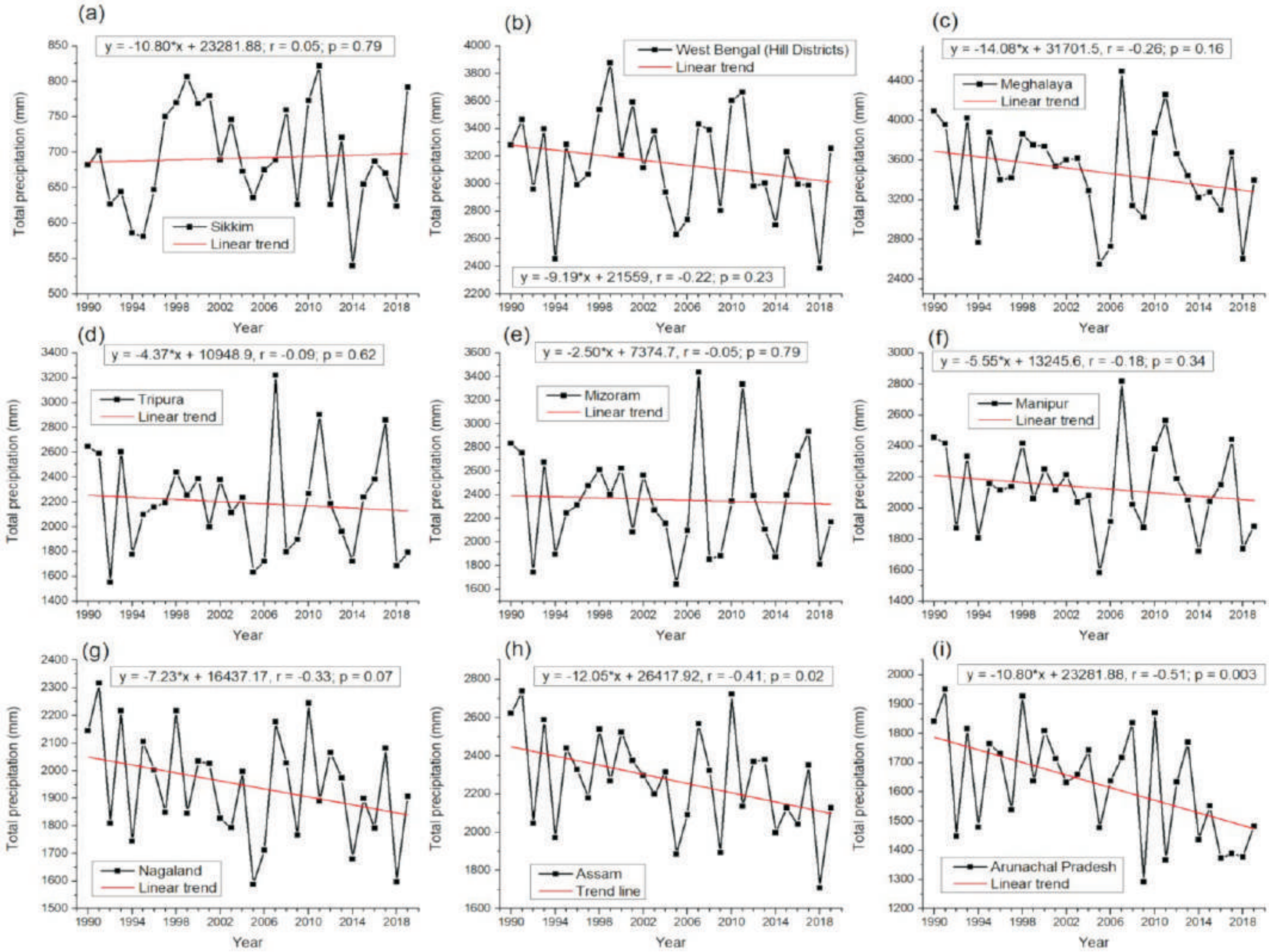

Figure **5:** The OLS trend of TAP for (a) Sikkim, (b) West Bengal (Hill districts), (c) Meghalaya, (d) Tripura, (e) Mizoram, (f) Manipur, (g) Nagaland, (h) Assam and (i) Arunachal Pradesh.

Trend analysis – Non-parametric approach

The Mann-Kendell trend test on TAP show a consistently decreasing trend of annual total precipitation in the majority of the EIH region (Figure 6). The regions with a consistently decreasing trend of annual precipitation with high ($p<0.05$) level of statistical significance are found to be located in mostly Arunachal Pradesh, Brahmaputra valley of Assam, the northern regions of Nagaland with few pockets of southern Meghalaya. Most of the remaining regions show a decreasing trend of annual precipitation with a relatively moderate ($p>0.05$ & <0.10) to low ($p>0.10$) level of statistical significance (Fig. 6).

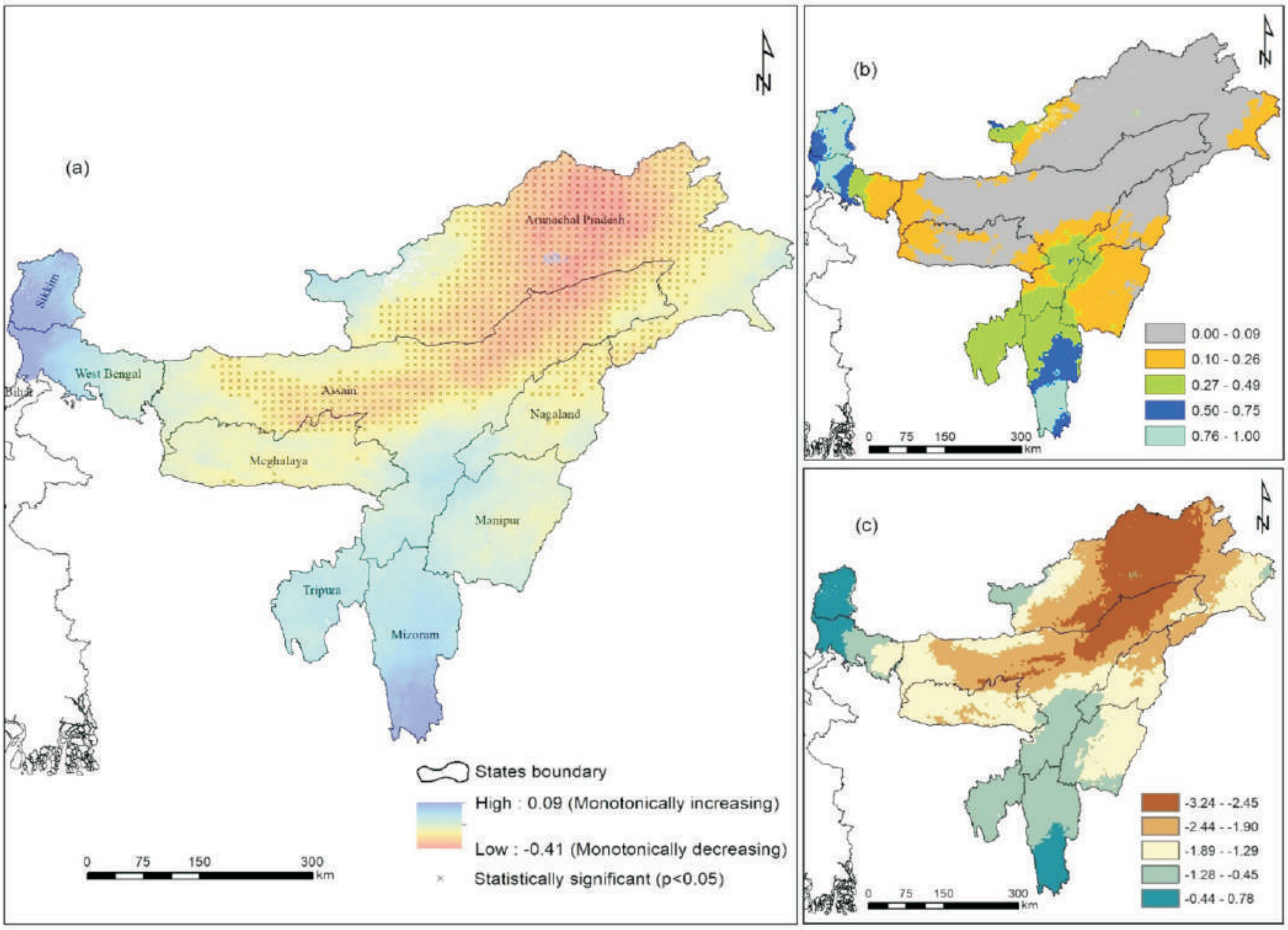

Figure 6: The MK trend images of TAP showing (a) Mann-Kendall trend (b) p-value indicating the statistical significance of the MK test and (c) Z score of the MK test

The magnitude of the rate of change of annual precipitation is computed using the Theil-Sen slope estimator (Fig. 7). The higher (about 47.5 to 15.4 mm per year) rate of decrease in annual total precipitation with a very high ($p <0.05$) level of statistical significance is found mostly in southern Meghalaya, eastern regions of Assam valley and the central hilly and high mountain regions in north Arunachal Pradesh. The moderate rate of (about 15.43 to 3.86 mm per year) decreasing annual precipitation is noted in northern, eastern and western regions of Arunachal Pradesh and Brahmaputra valley of Assam and northern regions of Nagaland with high level of statistical significance. The remaining regions of the EIH had a relatively low decreasing/increasing rate of annual precipitation with a relatively low (p>0.05) level of statistical significance (Fig. 7).

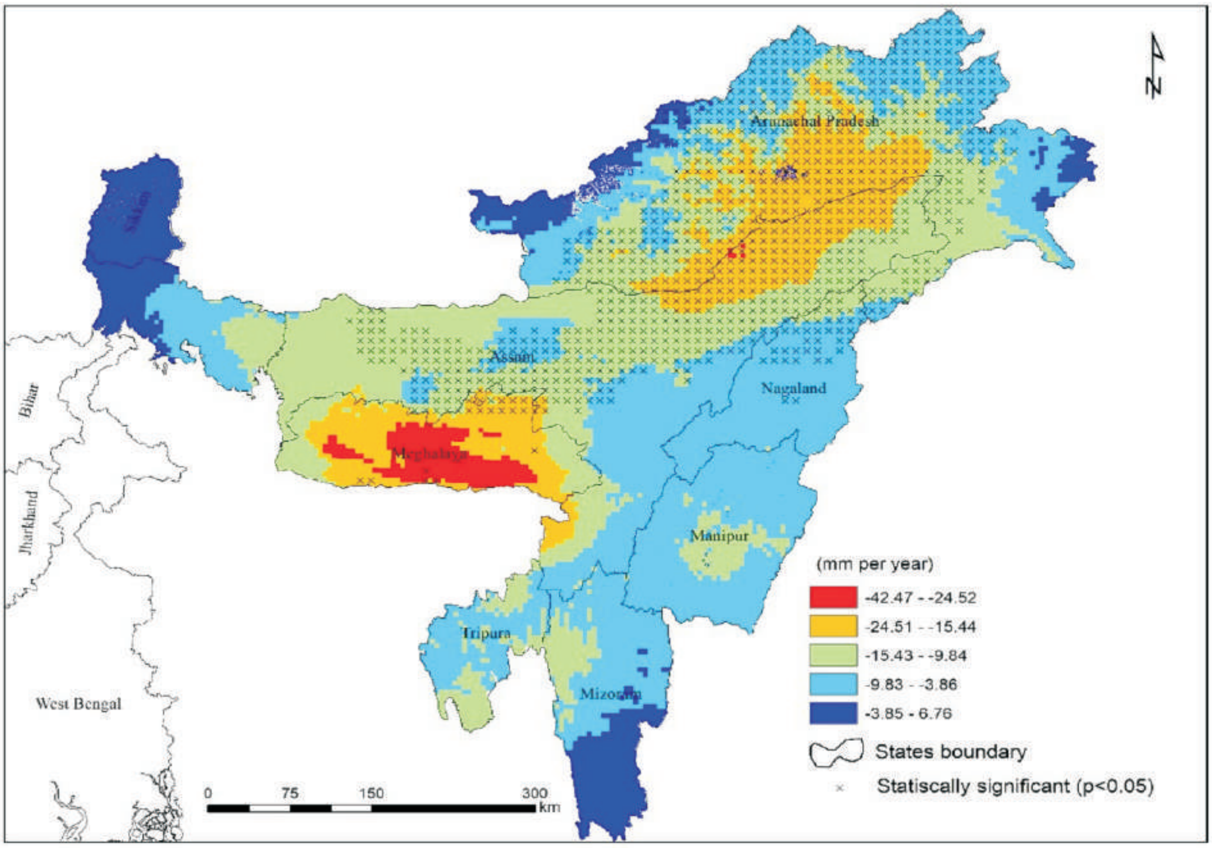

Figure **7**: The TS slope estimator for TAP of the EIH region

3.4 Hotspots of climate change

The distribution of the total area of the climate change hotspot is estimated and presented in Table 1. About 42% of the total geographical area of the EIH region is reeling under the threat of a high degree of climate change. On the other hand, one-third of the whole area is facing a moderate degree of simultaneous warming in average temperature and a decrease in annual precipitation (Table 1).

The hotspot map of climate change generated by integrating the TS trend of MAT and TAP is shown in Fig. 8. The hotspot of climate change is primarily observed in the Meghalaya, Assam, and Arunachal Pradesh region of the EIH. A very high degree of warming and a high degree of decrease in precipitation are observed simultaneously in southeastern Meghalaya and parts of southern hills and higher mountains of northern Arunachal Pradesh. Moreover, almost the whole Brahmaputra valley region and the majority of Arunachal Pradesh show a high degree of warming and a high increase in MAT and decrease in TAP.

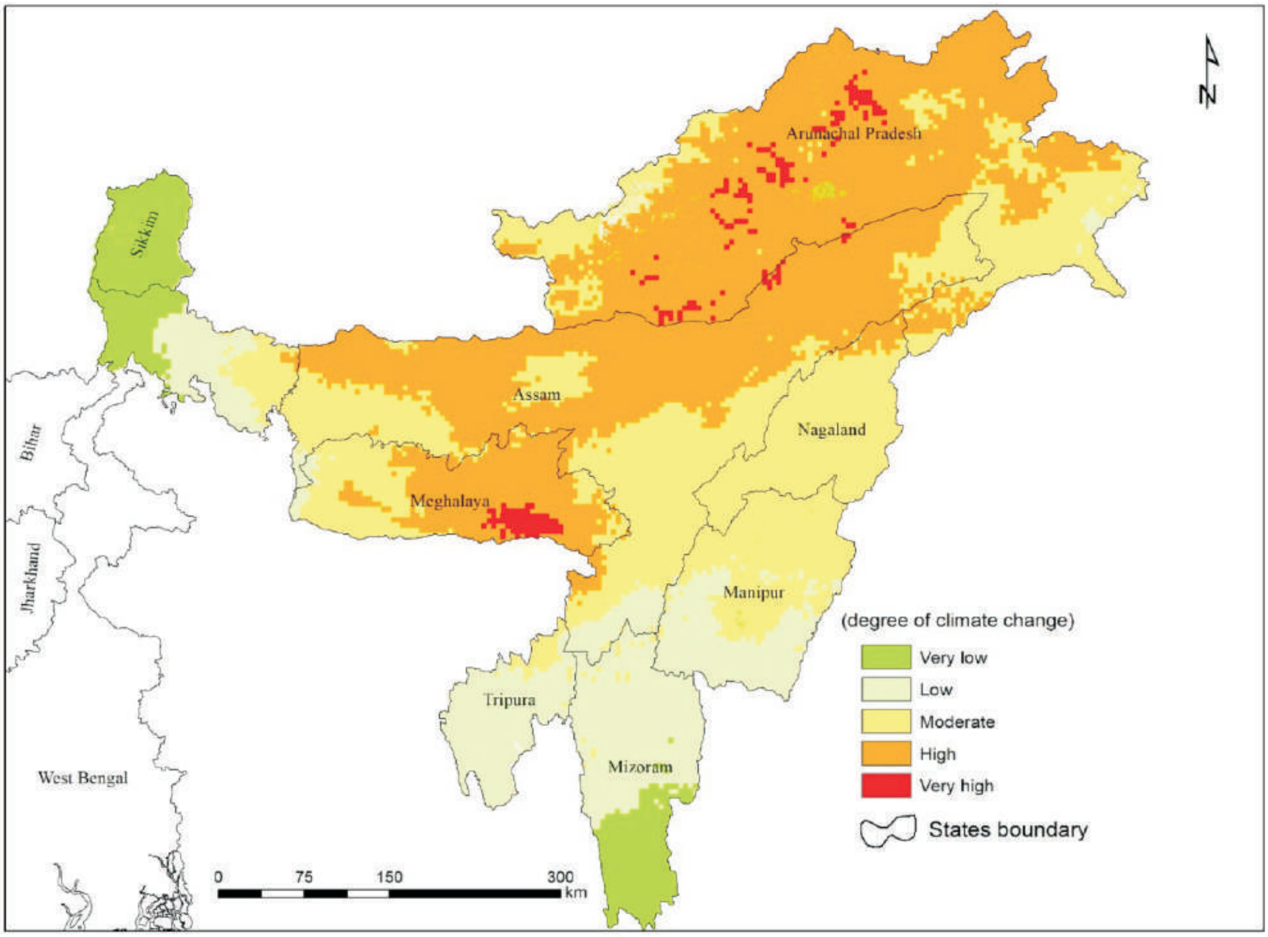

Figure 8. Hotspot of climate change in the EIH region

Table 1: Distribution of hot spot area of climate change

Severity of Climate Change	Area (sq. km)	% of Geographical area
Very Low	18424.4	6.8
Low	42223.2	15.5
Moderate	92974.8	34.1
High	115090.0	42.2
Very High	3940.1	1.4

4. Conclusion and recommendation

Assessment of the trend of temperature and precipitation is crucial to gauge changes in climate. Different mountains and hills and the southwest and northeast monsoons play an essential role in shaping the region's climate. The process datasets on monthly mean temperature and monthly total precipitation from 1990-2019 show gradually increasing trend for temperature with time from the western side to the eastern side of the EIH region. The precipitation show a moderate to a low degree of decreasing trend with time across the states of the EIH region specially in Arunachal Pradesh, Brahmaputra valley of Assam, the northern regions of Nagaland and few pockets of southern Meghalaya. The hotspots of climate change is located in the Meghalaya, Assam and Arunachal Pradesh region of the EIH. About 42% of the total geographical area of the EIH region is under the threat of climate change, specially southeastern Meghalaya and parts of southern hills and higher mountains of northern Arunachal Pradesh, whole Brahmaputra valley region and majority of Arunachal Pradesh.

The Glasgow Climate Pact –COP26 signed in 2021 by majority of the nations have seen major pledges from world leaders at the UN climate change summit in cutting methane emissions, tackling deforestation, phasing out coal and driving clean technology. Brazil, the European Union, India, Russia and the United States were among key players to announce fresh targets in a journey towards net zero emissions. India promised to net zero by 2070. The IPCC has said the world must hit to keep global average temperatures from soaring 1.5C above what they were in the pre-industrial era. Thus in the context of the global climate change mitigation strategies a tailored made plan may also be developed for the EIH regions to counter the impacts of changing climate.