

Climate change vulnerability profiles for North East India

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Climate change vulnerability profiles are developed at the district level for agriculture, water and forest sectors for the North East region of India for the current and projected future climates. An index-based approach was used where a set of indicators that represent key sectors of vulnerability (agriculture, forest, water) is selected using the statistical technique principal component analysis. The impacts of climate change on key sectors as represented by the changes in the indicators were derived from impact assessment models. These impacted indicators were utilized for the calculation of the future vulnerability to climate change. Results indicate that majority of the districts in North East India are subject to climate induced vulnerability currently and in the near future. This is a first of its kind study that exhibits ranking of districts of North East India on the basis of the vulnerability index values. The objective of such ranking is to assist in: (i) identifying and prioritizing the most vulnerable sectors and districts; (ii) identifying adaptation interventions, and (iii) mainstreaming adaptation in development programmes.

Keywords: Agriculture, climate change, forest, vulnerability index, water.

Introduction

CLIMATE change is one of the biggest environmental threats facing the world, potentially impacting food production and security, sustained water supply, biodiversity of forests and other natural ecosystems, human health and settlements. Climate change modelling studies for India show that the Indian sub-continent is likely to experience a warming of over 3–5°C and significant changes (increases and decreases) in flood and drought frequency and intensity. National Communication Study¹ to UNFCCC and a special issue of *Current Science*² as well as several scientific papers published in recent years indicate signifi-

cant adverse impacts on food production, water resources, forest and biodiversity, and human health. World Bank's World Development Report³ points out that degraded ecosystems and natural resources in South Asia are more vulnerable to climate change. Further, the poorest people are the most vulnerable to adverse impacts of climate change because they often reside in high-exposure areas and also have low adaptive capacity to cope with climate risks³.

The North East region of India, consisting of eight states covering a geographic area of 26.2 mha and a population of 40 million, is characterized by large rural population (82%), low population density, large percentage of indigenous tribal communities (34–91%) and large area under forests (60%). The region has two main river basins (the Brahmaputra and Barak), a large dependence of the population on natural resources, and poor infrastructure development. The region is also characterized by diverse climate regimes which are highly dependent on the southwest monsoon (June–September). Over 60% of the crop area is under rainfed agriculture, and so is in areas highly vulnerable to climate variability and climate change¹.

The natural resources of the North East are also subjected to degradation and loss due to deforestation, unsustainable shifting cultivation practices, fragmentation and degradation which ultimately impact the biodiversity as well as forest biomass production. Increase in human and livestock population, increased extraction of fuel wood, lack of land ownership rights, shortening of jhum cycle, conversion of natural forests into plantations for horticultural crops, mining, overgrazing, and forest fire are the major causes of deforestation in North East India⁴. Due to the hilly terrain, cultivation of crops along the slopes and overgrazing by livestock, the soil resources of the region are subjected to erosion and loss. Many districts face severe water scarcity during the summer months⁵. In this article, an assessment of the overall implications of climate change and vulnerability in the North East for three major sectors, agriculture, water and forest, has been carried out to identify the vulnerable sectors and regions

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(districts) to climate variability and climate change. The objective is to understand the sector-wise vulnerabilities at the district level so that the targeted policies by development agencies can be designed to improve the most vulnerable sectors. In the case of the North East, district-wise vulnerability profiles are developed in all the eight states, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. This is a first of its kind study conducted in North East India whereby the local scale of vulnerability assessment is utilized. The coverage of all the 79 districts of all the 8 states is also unique to this study. In addition, the quantitative index development and ranking of vulnerability provide a scaled, comparable mechanism, which could be easily adapted for other states of India.

The main objectives of the study are to introduce a quantitative approach for assessing the vulnerability of the three key sectors of agriculture, water and forest. This is done by developing a vulnerability index (ranging from 0 to 5) for each of these sectors. Further, this index will be developed for the current climatic conditions and also for future projected climatic conditions.

Materials and methods

The present study uses the IPCC definition of vulnerability which is 'the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes'. There are three main components of vulnerability as defined by the IPCC: exposure, sensitivity and adaptive capacity. Exposure (E) in climate change literature is mainly a climatic phenomenon and according to IPCC can also include other socio-economic factors (e.g. globalization). Besides depending on the system under study, exposure can be a combination of both climate change and ecosystem factors. Sensitivity (S) is a characteristic of the system and represents 'dose-response relationship between exposure and impacts'. Adaptive capacity (AC) is a property of the system to adjust its characteristics or behaviour in order to expand its coping range under existing climate variability or future climate change⁶.

Vulnerability assessment

IPCC⁷ defines two streams of assessment of vulnerability, the contextual vulnerability assessment and the outcome vulnerability assessment. The contextual vulnerability assessment mainly assesses vulnerability in a constructional approach, obtaining a qualitative picture of vulnerability with the help of survey instruments and case-studies. The outcome vulnerability assessment utilizes a reductionist approach, using quantitative techniques such as modelling and dose-response functions⁸. The current method of vulnerability assessment, the index-based

approach, is an outcome-based vulnerability measurement⁹. The following approach was adopted for our vulnerability assessment.

Selection of region, scale and sectors: The North East region was selected. For the ease of decision-making, involvement of stakeholders, as well as for planning and implementation of developmental projects, a district-level vulnerability assessment was adopted in the present study for the North East region. We restricted our assessment to water, agriculture and forests sectors for this study.

Selection of climate change scenario: For predicting the future vulnerability of the North East region, the climate impact assessment results of near-term A1B scenario⁷ for the period 2021–2050 were used.

Development of sectoral vulnerability profiles: Vulnerability profiles were developed for current and future scenarios spatially using an index-based method.

Index-based approach towards assessing vulnerability

In this section, the general procedure for constructing a vulnerability index for any sector is described. For each of the components of vulnerability, formal indices can be constructed and combined. Methods of aggregating across sectors and scales have been developed in other contexts (e.g. the Human Development Index) and are beginning to be applied to climate change¹⁰. The vulnerability index for a specific sector is typically based on a number of indicators which determine the vulnerability of that sector to climate change. Construction of vulnerability index for each sector involves the following general methodology.

1. Identifying and defining the indicators: Indicators are selected according to assumptions, baseline considerations and limitations for each sector.
2. Quantification of indicators: Indicators are quantified based on secondary data sources, observations or measurements and stakeholder perceptions.
3. Normalization: For aggregation purposes, each indicator is normalized to render it as a dimensionless measure or number.

$$S_{i_{\text{normalized}}} = \frac{S_i - S_{i_{\text{min}}}}{S_{i_{\text{max}}} - S_{i_{\text{min}}}},$$

where S_i is the i th indicator value.

4. Principal component analysis (PCA): In this step, we identify the significant indicators and eliminate non-significant indicators from a set of inter-related indicators. It involves a mathematical procedure that transforms a number of possibly correlated indicators into a smaller number of uncorrelated variables called components. Each

component is a geometric combination of the indicators. In a PCA, a set of components are extracted using a criterion¹¹, whereby eigen value of each component that is extracted is greater than 1. Generally, indices are created out of an arithmetic or geometric combination of the indicators that are present in the extracted components. However, due to data availability issues and scarcity of secondary data about North East India, the selection of indicators using PCA was conducted only for the water vulnerability index. For agricultural vulnerability index and forest vulnerability index, the weighted average technique was used for vulnerability index calculation. Weights in the weighted average technique are assigned by expert consultation and the value of weights is generally between 0 and 1. The sum of all the weights in a weighted average is equal to 1.

5. Aggregation and categorization: Indicator sets for each sector are aggregated with appropriate weights to obtain the vulnerability index, VI.

$$VI = \frac{\sum_i^N K_i S_i}{K_i},$$

where K_i is the weight assigned for indicator S_i .

The weights are selected according to the index. The weights for the agricultural vulnerability index were decided to be equal across indicators on consultation with experts. Similar approach was adopted for the forest sector also by providing equal weights to all the indicators used in developing the forest vulnerability index. The weights for the water vulnerability index were calculated from the eigen values of the PCA.

VI is normalized further to get the final value on a scale of 0–5.

$$VI_{\text{normalized}} = 5 \left(\frac{VI - VI_{\text{min}}}{VI_{\text{max}} - VI_{\text{min}}} \right).$$

The normalized vulnerability indices are categorized across vulnerability classes (very low, low, moderate, high and very high). The assignment of vulnerability scales across the index values are as follows:

- Very low: $0 \leq VI_{\text{normalized}} < 1$,
- Low: $1 \leq VI_{\text{normalized}} < 2$,
- Moderate: $2 \leq VI_{\text{normalized}} < 3$,
- High: $3 \leq VI_{\text{normalized}} < 4$,
- Very high: $4 \leq VI_{\text{normalized}} < 5$.

The vulnerability assessment in this study is based on $VI_{\text{normalized}}$ values.

6. Plot the spatial pattern in vulnerability ($VI_{\text{normalized}}$ values) for each sector across districts using a GIS platform.

First the vulnerability to current climate variability was estimated. Vulnerability to projected climate change using the A1B scenario was also estimated to understand the behaviour of vulnerability in the future.

In the present analysis, the future climate vulnerability for the near-term (2020–2035) A1B scenario was assessed for the three vulnerability indices; agricultural, water and forest. Since the analysis time-frame is near-term and due to data scarcity for North East India, we have assumed that there would be not be much noticeable change in the indicators such as number of landholdings, net sown area, rural population density that compose the vulnerability indices. Comparative statistics of the indicators could be adopted for determining the future status of the indicators. Comparative statistics is generally a technique adopted from economics, where a forecast for the change in a composite item such as an index is done, holding all but one indicator constant. Thus the future changes in vulnerability indices could be attempted according to each indicator and by forecasting how the index will change according to a positive or negative change in the indicator. This is one of the areas of research for the future. Other areas of research for the future are as follows:

- The range of methods to construct indices of vulnerability can be further explored. For instance, rating approaches based on scores from 0 to 100 that do not involve the implied trade-offs between positive and negative normalized indicators can be adopted for developing future vulnerability index.
- Multiple future scenarios could be adopted to obtain a more robust view of the many factors, including climate change which may affect a region.

Sector-wise overview of the vulnerability assessment methodology

In this section, we outline the methodologies adopted based on the generic approach described earlier, used for assessing the vulnerabilities of districts in agriculture, water and forest sectors for North East India.

Agricultural vulnerability index

Assessment of current vulnerability: The assessment of vulnerability to current climate variability has been referred to as the ‘baseline’ or ‘current climate’ scenario. Secondary data available from various sources such as Census Reports and State Government published databases for the most recent available time point were used. The indicators for agricultural vulnerability were mostly selected by expert consultation. In the absence of knowledge on relative importance of different indicators, equal weights were assumed for all the indicators. The indicators were then aggregated using a weighted average technique, provided in the previous section. The following

indicators are used for calculating the vulnerability index in the agricultural sector.

- Relative variability of rainfall – An indicator/proxy for exposure; it represents the variation of rainfall over a series of years. It is assumed that as relative variability increases, vulnerability increases.
- Percentage interannual variability of rainfall – An indicator/proxy for exposure; it represents the variation of rainfall over consecutive years. Vulnerability is directly proportional to this indicator.
- Area under rainfed/dryland crops – An indicator/proxy for sensitivity; it represents the area of crops that are rainfall-dependent. Vulnerability is directly proportional to this indicator.
- Rural population density – An indicator/proxy for exposure; it is the total population classified as rural in the census. Vulnerability is directly proportional to this indicator.
- Number of agricultural land holdings less than 2 ha – An indicator for exposure; it is defined as the number of agricultural land holdings belonging to marginal (< 1 ha) and small (1–1.99 ha) farmer categories. Vulnerability is directly proportional to this indicator.
- Net sown area – An indicator for total area sown in a district; it is also an indicator of exposure. Vulnerability is directly proportional to this indicator.
- Area under irrigated crops – An indicator for total area under irrigated crops in a district, it is also an indicator of adaptive capacity. Vulnerability is inversely proportional to this indicator.
- Area under high-yielding varieties – An indicator for total area under high-yielding varieties in a district; it is also an indicator of adaptive capacity. Vulnerability is inversely proportional to this indicator.
- Amount of fertilizers consumed – It includes fertilizers consumed [urea, phosphate (P_2O_5), potash (K_2O)] for kharif and rabi seasons in a district and is an indicator of adaptive capacity. Vulnerability is inversely proportional to this indicator.
- Amount of manure used – Total quantity of manure that has been applied to the area; it is an indicator of adaptive capacity. Vulnerability is inversely proportional to this indicator.
- Net annual groundwater availability – It is the available water resource after deducting the natural discharges; it is an indicator of exposure. Vulnerability is inversely proportional to this indicator.
- Mean rainfed crop yield – As rainfed paddy is the major food crop grown in the North East, this is the mean of annual crop yields of paddy from 1971 to 2007 and an indicator for adaptive capacity. Vulnerability is inversely proportional to this indicator.

In case of Sikkim, groundwater indicator has not been used due to the non-availability of district-wise data and

also because of the fact that the groundwater development is limited due to the presence of hard rocks and steep slopes. The deleterious effect of over fertilizing is not considered in this analysis.

The agricultural vulnerability profiles are stratified as: (i) very low, (ii) low, (iii) moderate, (iv) high and (v) very high. The stratification is according to the format provided in the general methodology section described earlier.

Assessment of future vulnerability: Future vulnerability refers to vulnerability under a 'climate change' scenario. In this case, the district-wise trend in mean rainfed crop yield was assessed for the future. This was done for the period 2021–2050 (A1B IPCC SRES storyline) using the INFOCROP¹² crop-yield model. The values used for all other indicators were those of the 'current climate' scenario, since projections for these indicators for the 'climate change' scenario were not available.

Water vulnerability index

Assessment of current vulnerability: Water vulnerability index is assessed at the district level for the North East region and in particular for the two river basins, namely Brahmaputra and Barak. District-wise vulnerability has been evaluated according to the procedure described in the general methodology section. The following four individual indicators are chosen for aggregating into water vulnerability index.

- Water availability: Amount of water available per unit area (mm). Higher availability (agriculture, domestic, industry) indicates lower vulnerability. Water availability is a proxy for adaptive capacity.
- Crop water demand (evapotranspiration): Amount of water used by standing crop during the crop-growing season per unit area (mm). Higher crop evapotranspiration implies higher yield (depending on crop type and variety) and lower vulnerability. This is an indicator of adaptive capacity.
- Drought indicator: This is based on the weekly soil moisture availability during June–September (monsoon months) used for the assessment of drought severity (by indicating relative dryness or wetness affecting water sensitive economies). Higher the drought indicator, higher the vulnerability. This is an indicator for exposure.
- Flood discharge: Flood discharge frequency is the number of extremely high stream discharge events and is calculated as the magnitude of flood peaks above 99th percentile. This is an indicator of exposure.

PCA approach is adopted for developing the water vulnerability index. After the components are extracted, the normalized values of the four indicators mentioned above

are multiplied with the weighing factor (i.e. elements of the first eigen vector) and then combined into a composite index, as mentioned in the general methodology section. The current values of the four indicators are derived using Soil and Water Assessment Tool (SWAT) developed by the Backlands Research Center of Texas A&M University¹² (SWAT is used on each of the river basins separately, using daily weather generated by the PRECIS RCM baseline scenario (1961–1990)). After the water vulnerability indices (current) were constructed, the districts of the North East states were ranked. Table 1 gives the eigen weights derived from PCA and assigned to weigh each of the four indicators of water vulnerability.

Assessment of future vulnerability: The SWAT model was run using PRECIS GHG climate scenarios for current and near term (2021–2050, IPCC SRES A1B) without changing the land use. From the SWAT outputs of this near-term scenario, future values/predictions of the four indicators were derived and aggregated using weights provided in Table 1, as discussed above.

Forest vulnerability index: For assessing vulnerability of forests of each district, four factors were taken into account. The first three are closely related to anthropogenic activity. For these, remotely-sensed data (on 1 : 250,000 scale) of the North East region were obtained, and these indicators were algorithmically derived for forest patches¹³ and later aggregated at the district level. The fourth factor is climate change impact projection, derived from the vegetation model, IBIS. The four factors are as follows.

- **Disturbance:** An indication of the human disturbance in forests of a particular district. More the disturbance, higher the forest vulnerability.
- **Fragmentation status:** An indication of how fragmented the forests of a district are. More the fragmentation status, higher the forest vulnerability.
- **Biological richness:** Indicates the species diversity of the forest and is a measure of the number of species of flora and fauna per unit area. It has been based on the ecosystem uniqueness, biological value, terrain complexity and disturbance regime. Higher the biological richness, lower the forest vulnerability.

Table 1. Eigen values used as weights for aggregating the water vulnerability index

Variable	Current	Future (A1B)
Water availability	0.5777	0.3405
Evapotranspiration	0.6303	0.5805
Drought	0.4597	0.448
Flood	0.2401	0.5885

- **Projected impact of climate change:** Projections on change in extents of vegetation type due to climate change (for a particular district) were used here. This indicator was derived using the vegetation type predicted by the IBIS dynamic global vegetation model within every forest grid in the North East, both for current and future climate. If these two were different, it was concluded that the future climate may not be optimal for the current vegetation for that grid. Hence, that forest grid was marked as being vulnerable to climate change. Then, the percentage of such vulnerable grids in each district was calculated. This was linearly scaled from 0 to 5, to give a climate change impact indicator for each district.

Assigning a suitable set of weights to these indicators is a major challenge. As we could not find any previous work discussing such weights with respect to forest vulnerability, we assigned equal weights to each of the indicators.

Assessment of current forest vulnerability: In this case, the present values for the disturbance index, fragmentation status index and biological richness index were derived¹³. The value given for the three indicators for each forest patch was converted to a scale of 0 to 5.0. They were later aggregated at the district level. All values of vulnerability in this study hence range from 0 (very low vulnerability) to 5.0 (very high vulnerability). The current impact of climate change was assumed to be minimal for the current climate scenario. Hence, a low value of 0 was given to this factor for all districts. These indicators were then aggregated, using equal weights to obtain the current forest vulnerability.

Assessment of future forest vulnerability: In this case, the values for the disturbance index, fragmentation status index and the biological richness index¹³ are assumed to be unchanged. However, the projected impact of climate change in the future was computed, as described above. This indicator varied from a low of 1.0 to a high of 4.2 for the future. The assumption is that vulnerabilities related to human activities will not change much in the future, but climate change will contribute an additional vulnerability. Aggregation of these four factors was done (again using equal weights) to generate the future forest vulnerability.

Results and discussion

Agricultural vulnerability index (AVI) profile

In the northeastern part of India, the pattern of agricultural growth has remained uneven across regions and crops. Food production in the North East, particularly in rainfed conditions, is highly subjective, based on climate

variability. Climate change will be an additional stress and will have direct consequences on food-production systems and indirect impacts on food security. An estimated 3.5 mha is under rainfed rice cultivation in this region, which accounts for about 30% of the total area under cultivation. Model simulations using INFOCROP¹⁴, a dynamic crop model, for rice in 64 districts of the North East showed that the yield will undergo change in most districts in the future under the A1B scenario, with an increase in yield projected for 21 districts and a decrease in yield for 43 districts (up to 10%); highest decrease in yield was observed for North Sikkim District of Sikkim. Most of the Districts in the North East face problems like fragmented and uneconomical land holdings, lack of proper irrigation facilities, lack of adequate infrastructure and modern agricultural technologies, poor transport and communication system, and lack of institutional credit. These problems are aggravated by the climate-induced extreme events (floods and droughts) leading to low agricultural produce and massive soil erosion in the region⁵. The district-wise ranking of AVI for both current climate and climate change scenario is presented in Figure 1.

Current climate scenario – AVI across districts: Tirap, West Siang, Nalbari, Changlang and Dibrugarh were the most vulnerable districts to current climate vulnerability. Kolasib, N.C. Hills, Cachar, Ukhrul and Morigaon are the districts with least vulnerability. Overall in the North East region, higher agricultural vulnerability is observed in the northern parts and vulnerability declines towards the south. Since agricultural vulnerability is a function of crop production and input, the high vulnerability of some districts may be attributed to the lower input levels (fertilizer, irrigation). In addition, the high relative variability and inter-annual variability of rainfall have created increased occurrence of droughts and floods in the recent times, leading to uncertainty in yield and increased agricultural vulnerability.

Climate change scenario – AVI across districts: Overall, in the future the AVI has decreased. This might be due to the increased rainfall and rice yields in the future scenario. The districts of Tirap, West Siang, Nalbari, Changlang and Dibrugarh remain very highly vulnerable. In the future scenario, the vulnerability of West Sikkim, North Sikkim, East Sikkim and Imphal East is projected to decrease from high to moderate levels. The districts of Bisnupur and South Tripura are projected to exhibit decreased vulnerability from moderate to low levels. The other districts do not show much variability from the current scenario.

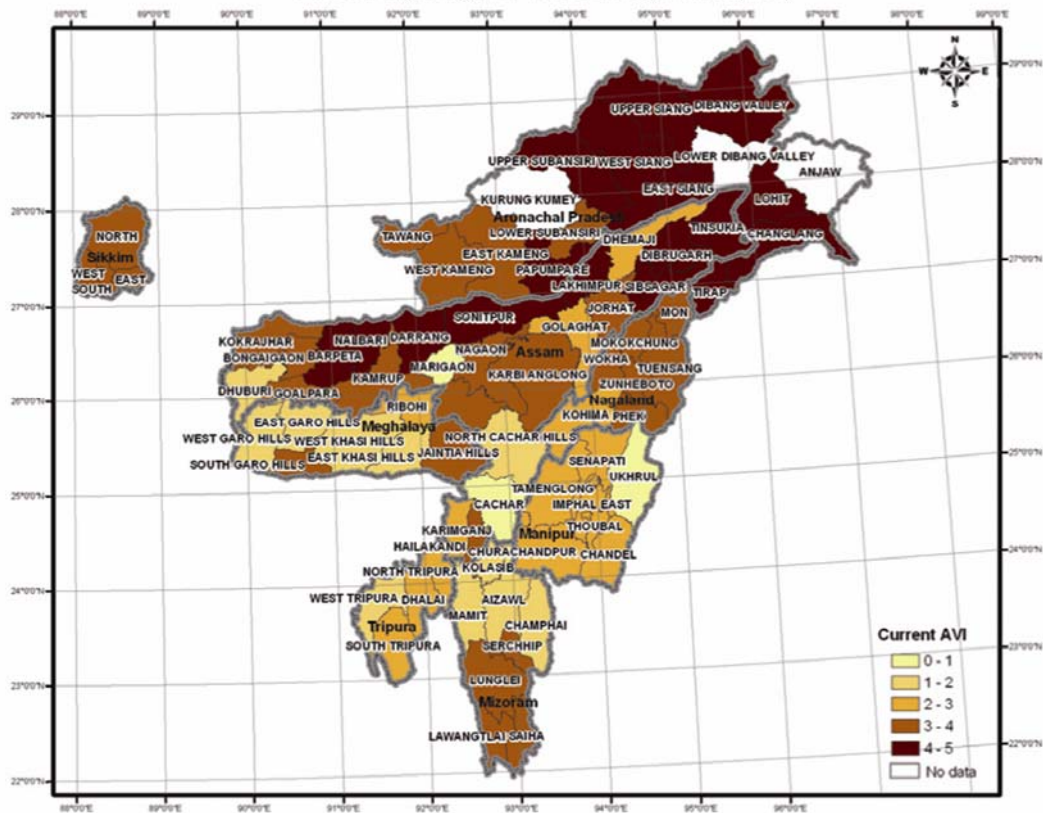
Water vulnerability profile (WVI)

The major river basins in North East India are that of the Brahmaputra and Barak, which cover bulk of the geo-

graphical area of the North East Indian States. During the southwest monsoon season, frequent floods are responsible for both human casualties and property damage as the powerful Brahmaputra river flows are constricted through the narrow Assam valley, fed by torrential rains and snow melt from the Himalayan ranges¹⁵. The impact of climate change on water resources of the two river basins was simulated using hydrological model SWAT. The results show both spatial and temporal variability. The trend in precipitation in the North East region exhibits considerable spatial variability with respect to the predictions for near term. The northern part of the North East shows a reduction in precipitation varying from 3% in the north-western portion to about 12% in the northeastern portion. In the remaining part of the North East, there is an increase in precipitation varying from 0% to as much as 25% in the central portion. Majority of the North East region, except for some parts of Mizoram, Tripura, Manipur and Assam, show an increase in the evapotranspiration during the near-term scenario. Even those parts of Arunachal Pradesh that showed a decrease in the precipitation exhibited an increase in evapotranspiration, all leading to increased water availability and thus lesser water vulnerability. This can only be explained by the higher temperatures that will enhance the evaporative force. However, the increase in evapotranspiration ranges from a small fraction to about 20%. The reduction in evapotranspiration in the southern portion is only marginal. The trend in the water yield in the North East region is similar to that in precipitation. The areas that have shown less increase in precipitation show correspondingly low water yield. The reduction in water yield for Arunachal Pradesh is up to about 20% and the increase in the water yield in Assam and Manipur areas is up to about 40%. Both intensity of floods and drought severity are likely to increase in many parts of the North East region. There is a general increase in flood magnitude of the Barak basin compared to Brahmaputra basin in future.

State-wise analysis shows that in Tripura, Mizoram, Manipur, parts of Meghalaya and Nagaland, the flood magnitude is likely to increase by about 25% in the future compared to the present. Arunachal Pradesh, Assam, Sikkim and parts of Meghalaya are likely to experience floods of lower magnitude (about 5–10% less) in future compared to the present. The numbers of drought weeks during monsoon months shows an increasing trend in Arunachal Pradesh, parts of Assam, Meghalaya, Mizoram, Tripura and Manipur, to the tune of about 25% increase in future. A few districts in Assam, Nagaland, Meghalaya and Mizoram show improvement in drought situation during the onset of monsoon. Many parts of the Brahmaputra basin show a tendency of extreme soil moisture stress during monsoon months, which is likely to lead to moderate to extreme drought condition. The district-wise ranking of WVI for both current climate and climate change scenario is presented in the Figure 2.

Current agricultural vulnerability index (AVI)



Future agricultural vulnerability index (AVI)

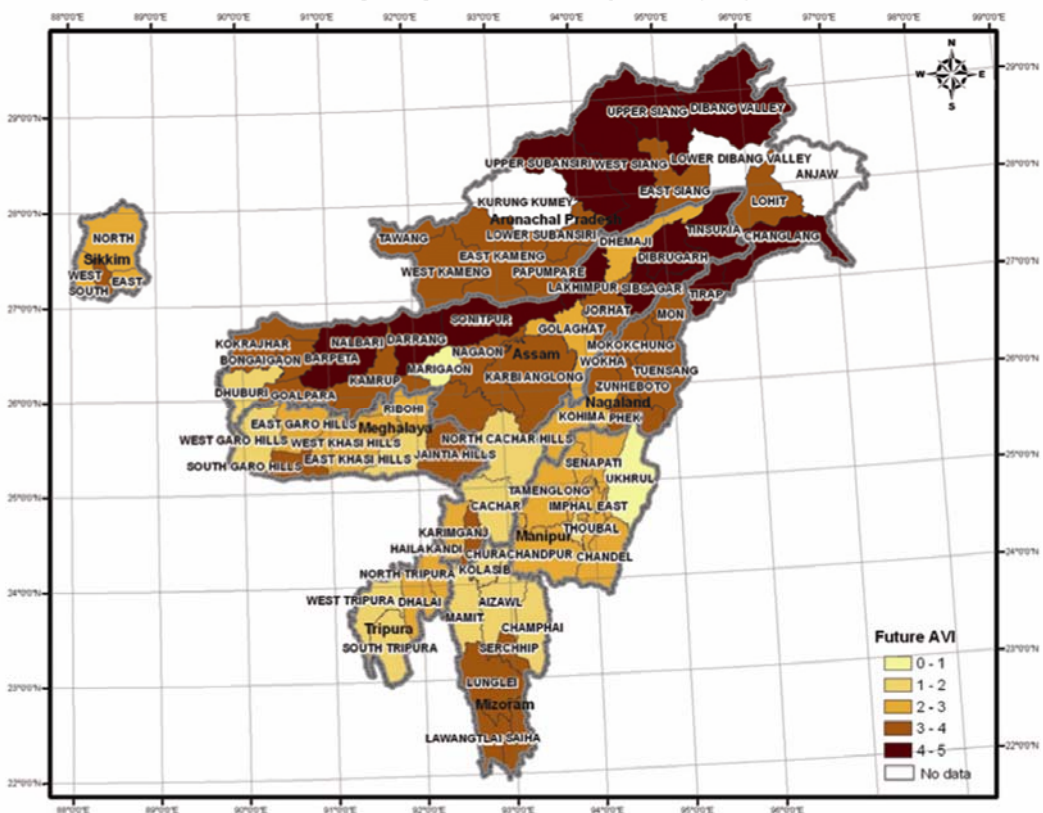


Figure 1. Distribution of current and future agricultural vulnerability over the districts of North East India.

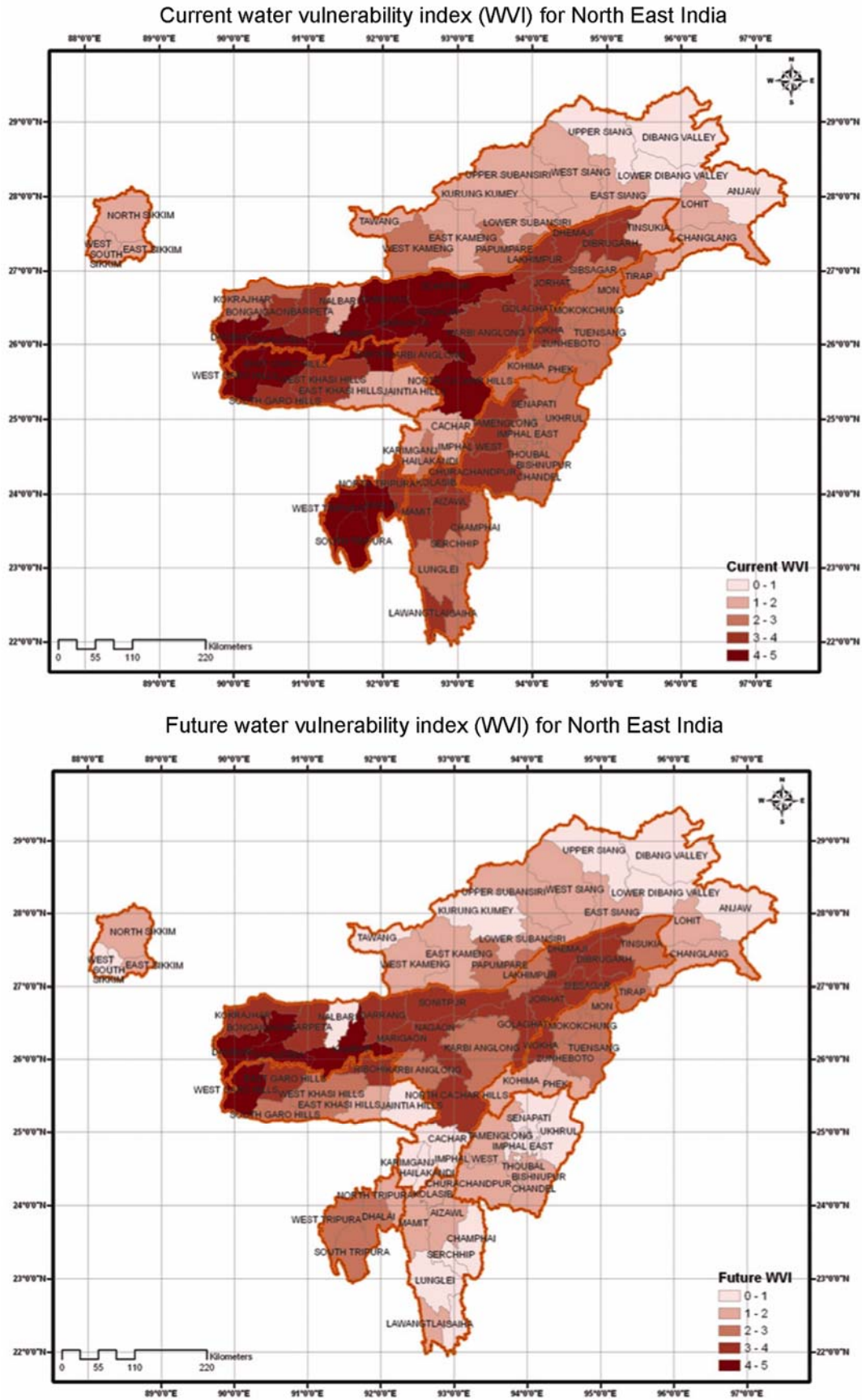


Figure 2. Distribution of current and future water vulnerability over the districts of North East India.

Current climate scenario – WVI across districts: It can be observed that majority of the districts which rank as very highly vulnerable with respect to floods also ranked very highly vulnerable with respect to drought. This indicates that the increased intensity of rainfall in a short duration will lead to reduced soil moisture retention. West Khasi Hills, Kamrup, Marigaon, Papumpare, Tawang, Darrang, Zunheboto, Saiha and East Garo Hills, rank high (top 10 in the scale of 1–5) in WVI and Lower Dibang Valley, Dibang Valley, Anjaw, Tinsukia, Kurung Kumey, Lohit, Jaintia Hills, East Siang and Wokha, rank lowest in WVI (bottom 10).

Climate change scenario – WVI across districts: Goalpara, West Garo Hills, Dhuburi, Bongaigaon, Kamrup, Sonitpur, Barpeta, East Garo Hills, Ribohi and Nalbari rank high in WVI (top 10) and Dibang Valley, Lower Dibang Valley, Anjaw, Karimganj, Cachar, North Cachar Hills, Ukhrul and Tawang rank lowest in WVI (bottom 10).

Summary of the change in vulnerability status of districts of the North East from current to future is depicted in Figure 3. Thirty out of 78 districts in the North East region show no change in the status of their current vulnerability (refer the Figure 2 for district vulnerability status in the scale of very low to very high vulnerability), 23 districts are likely to be more vulnerable than their current vulnerability, and vulnerability may reduce for 25 districts.

Forest vulnerability profile (FVI)

The North East region has about 143,360 sq. km of forests; around 61% of land area is covered by forests¹⁶, which is one of the highest forest-cover fractions in the entire forest expanse of India. Much of the dense forests

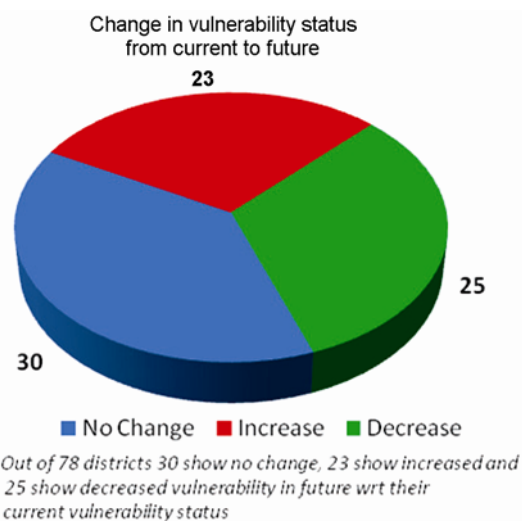


Figure 3. Change in water vulnerability status from current to future A1B scenario.

of Assam, Nagaland and Arunachal Pradesh are part of the Himalayan biodiversity hotspot, as defined by Conservation International¹⁷. Further, the percentage of population dependent on forests is quite high in the North East. But, the natural landscape in this region has been extensively modified in the recent past due to pressure on land, decreasing cycle of shifting (jhum) cultivation, exploitation of forests for timber and lack of a better scientific forest management strategy¹³. Hence, it is extremely important to study the vulnerability of the northeastern districts with respect to forestry. Modelling studies using IBIS¹⁸ projected the impacts of climate change on forests for the short to midterm (2021–2050). It was observed that the forests in the northern part of the North East are primarily impacted by climate change, leading to extreme vulnerability of the Himalayan biodiversity hotspot. Net primary productivity is projected to increase by 23% in this region, followed by increased biomass and soil carbon, leading to probable changes in vegetation type. The district-wise ranking of FVI is presented in the Figure 4.

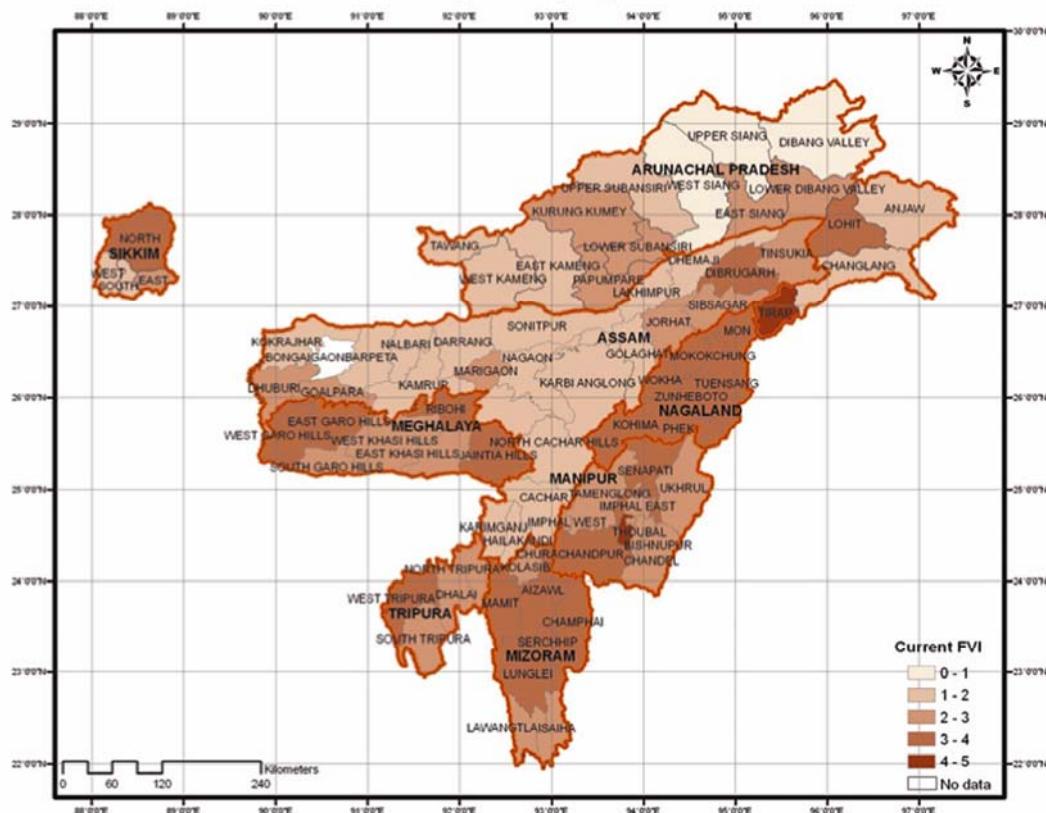
Current climate scenario – FVI across districts: Bishnupur and Tirap have very high vulnerability, while Tuensang, Lohit and West Garo hills have moderate to high vulnerability. Majority of the districts in the North East show moderately vulnerable forests. Figure 4 depicts the current and the future forest vulnerability, and it can be observed that districts in the southern parts of the North East are most vulnerable. This is due to the fact that these areas exhibit high levels of fragmentation and disturbance.

Climate change scenario – FVI across districts: Bisnupur and Tirap are the most vulnerable in the A1B scenario. There is a shift of the districts from moderate to high FVI in the future scenario. The vulnerability of a districts like Mon and Nalbari changes from low to moderate in the future, possibly because of impacts of climate change on forests in these districts. Vulnerability for West Siang, Upper Siang, Dhemaji, Barpeta and Darrang increases marginally. In the district of Kokrajhar in Assam, the vulnerability of forests decreases in the future A1B scenario.

Conclusion

Climate variability and climate change could impact agriculture, water resources and forest sectors in the North East region. In the present study an attempt was made to assess the vulnerability of these sectors to climate variability and climate change. Vulnerability profiles were developed for these three sectors for the current climate scenario as well as for climate projected under A1B scenario for the 2030s. Vulnerability profiles were developed

Current forest vulnerability index (FVI) for North East India



Future forest vulnerability index (FVI) for North East India

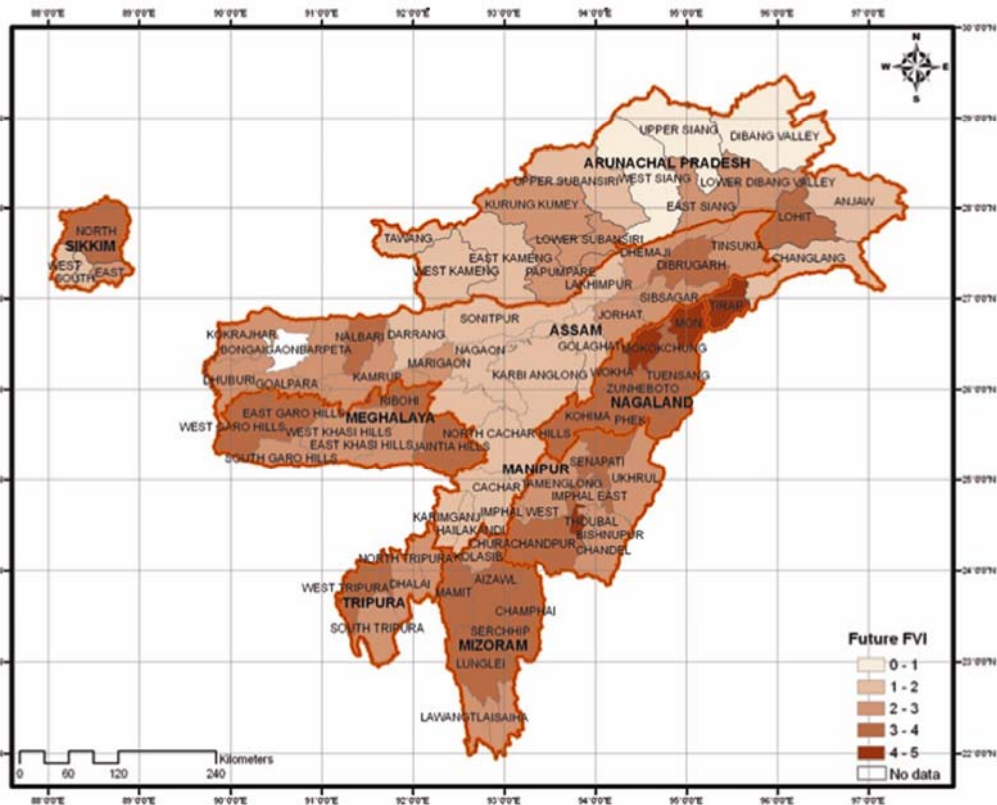


Figure 4. Distribution of current and future forest vulnerability over the districts of North East India.

using the index method. All the districts of the North East region were ranked according to the vulnerability index. The ranking of the districts based on the vulnerability index would assist planners, decision-makers and development agencies to identify the most vulnerable regions for adaptation interventions. This article has demonstrated the applicability and utility of the development of vulnerability profiles at the district level, which is a key administrative unit. Further, this study has also demonstrated the utility of developing vulnerability profiles under current climate and projected climate change (A1B) scenarios, which indicates the changes in vulnerability of the sector due to projected climate change impacts. Modelling of climate impact assessment as well as vulnerability index development was limited by the availability of biophysical as well as socio-economic data. The present study demonstrates the utility of an index-based approach for identifying the most vulnerable sectors and regions and to identify and prioritize adaptation interventions. There is a need for further research in using climate change and impact assessment data from multiple models as well as multiple approaches to vulnerability profile development.

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