

The Project

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PREFACE

The availability of water for residence, agricultural, and other uses is a major concern since water shortage has a significant influence on people's livelihoods. Although water scarcity caused by low rainfall is a common and inevitable phenomenon, climatic change caused by global warming, greenhouse gas emissions, changes in the ecosystem and water bodies, rapid urbanization, rapid population growth, and other factors have exacerbated the variation in rainfall, resulting in changes in its amount and duration. Assam, a water-rich state, is seeing a decline in water resources as a result of climate change and high population growth. A thorough investigation into meteorological drought conditions could aid in the proper planning and management of drought mitigation and adaptation methods in Assam.

Assam is located at the center of the northeast India which extends from 24° N to 28° N and 89° E to 96° E covering a total area of 78,438 km². The climate of Assam is sub-tropical with humid summers and dry winters. Assam receives a normal annual rainfall of 2201 mm. Although it is a flood prone state due to high rainfall and high discharges of the rivers and its numerous tributaries in the monsoon season, but in the dry season of the year it also experiences insufficient water availability for water consumption by people, agricultural activities, etc. Total cultivation area of the state is 2.83 million hectares and the irrigation infrastructure of the state as on present time is not well sufficient to serve the purpose. Also, according to 2011 census, the population of the state is 31.17 million and it is increasing although recent census has not been made till now still it is assumed to be increased by a considerable number. With the increase in population, the vulnerability to drought also increases. Presently, it has 33 districts. This study presented an insight to the drought characteristics in various districts of Assam.

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Director

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ABSTRACT

Assam is generally a flood prone state but the distress caused due to occurrence of drought cannot be neglected. Past studies stated that due to declination of southwest monsoon in the region in recent times and over-exploitation of water resources by the people results in reduction in availability of water to meet the demands of the people. Even Assam is not an arid region like the western states of India still it is affected by drought in the recent years. So, a study is carried out to observe and characterize the drought condition of Assam with the help of drought measuring indices like Standardized Precipitation Index (SPI) obtained by the meteorological parameters of the region. Here, in the study, a district wise (33 districts) analysis for characterization of drought in the state is performed to observe and understand the past drought condition of Assam from 1951 to 2020 with the observed data of Indian Meteorological Department (IMD) with a focus on predicting the future possibility and condition of drought from 2026 to 2055 through the projected data generated by global climatic models i.e. Coupled Model Inter comparison Project (CMIP 6) models under 6th assessment report of Intergovernmental Panel on Climate Change (IPCC). Four future scenarios of IPCC 6th Assessment Report are considered for assessment of drought. The study finally resulted in the conclusion that although Assam mostly experienced moderate drought condition in the past and also will be experiencing the same in the future but there will be drought of higher duration and severity in the near future likewise as it was occurred in the recent past as resulted by the study. Moreover, some districts experience a greater number of droughts in a year at certain stage of the time period while the other districts experience the same at different stages of the period. Also, number of droughts per year is higher in case of worst future scenario of IPCC. Along with the characterizing the drought, its vulnerability due to physical and socio-economic parameters is assessed to demarcate the regions of the state which are more or less vulnerable to drought. The drought parameters so obtained from characterization along with some additional socio-economic parameters from the concerned department were used to analyze the vulnerability of drought in the state. Physical parameters such as average annual precipitation, precipitation trend, and average inter arrival time of drought have indirect relationships with the vulnerability of drought while the rest of the physical parameters have direct relationship. Likewise, socio economic drought parameters such as annual replenishable GW and literacy rate have indirect relationship with the vulnerability of the drought, while the rest of the indicators have direct relationships. Based on the Iyengar and Sudharshan's approach, these physical and socio-economic parameters were weighted. In

case of physical indicators, highest importance/weights were obtained for extreme drought percentage followed by critical precipitation and average inter arrival time of drought. These three indicators would contribute 44 percent of the weightage in developing the physical drought vulnerability map of Assam. In the case of socio-economic indicators, groundwater level has the highest importance of 16 percent while gross irrigation area in Assam has the lowest importance of just 9 percent. After weighting the drought vulnerability indicators, physical and socio-economic drought vulnerability maps were generated and then, these two maps were overlaid to result in overall drought vulnerability index of Assam. According to the physical drought indicators, districts of Assam namely, Dhemaji, Dibrugarh, Charaideo, Sivasagar, Jorhat, Lakhimpur, Majuli, Golaghat, Biswanath, Nagaon, Hojai, Karbi Anglong, Dima Hasao, Cachar, Hailakandi, Karimganj, and Sonitpur were found vulnerable to meteorological drought. While districts, viz., Nagaon, Morigaon, Karbi Anglong, Dhubri, Barpeta, Goalpara, and Darrang were found vulnerable to drought from socio-economic perspective. Despite the limitation of this study in adopting only the meteorological approach for drought determination, it will help the beneficiaries and the policy makers to formulate their policies with reference to the analysis of drought made in the study.

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1.1 General

Water is an essential element of our life. It is used by people in their day-to-day life for drinking, household purposes, etc. Also, water is the main element required for growing crops in the agricultural fields. Resources of water are mainly the groundwater, rivers, lakes used by the people for their livelihood. The availability of water for our domestic use, agricultural purposes, etc. is of high concern as the scarcity of water causes great impact on livelihood of the people. Scarcity of water in groundwater resources by over extraction of water by people to fulfill the domestic water demand. In Dhaka city where water demand is increasing at average rate of 4% since 1990 while groundwater table depletes more than 70 m down in city due to extensive withdrawal of water (Arfanuzzaman and Rahman, 2017). The groundwater depletion to very lower level makes it difficult and costlier to extract groundwater. Over exploration of groundwater for irrigation purposes caused depletion of groundwater to a greater extent in the consecutive years from 1995 (Shahid and Hazarika, 2010). Also, the groundwater depletion results in reduction of water in yielding of the crops in the agricultural fields hereby causing a decline in the production of maize, wheat in the winter season (Bhattarai et al., 2021). The reason for the water shortage is the condition of low rainfall occurring specially in winters. In Assam, the annual, pre-monsoon season and monsoon seasons exhibited increasing trends of rainfall while the post monsoon and winter seasons shows decrease in rainfall trends (Gogoi and Rao, 2022).

Due to the low rainfall, the flow of the rivers and streams also are seen to be reduced, carrying very low discharges causing the disturbances in the water resources of its basin. Although the scarcity of water due to low rainfall is a normal and natural phenomenon but in the recent years, the climatic change due to global warming, emissions of greenhouse gases, changes in the ecosystem and water bodies, rapid urbanization, rapid increase in population etc. are worsening the variation in the rainfall hereby causing changes in its amount and duration. In Assam which is rich in water resources is facing declining of water resources due to the climate change, rapid population and also the water is getting polluted due to the environmental pollution which deteriorates the quality of water (Sharma, 2003). The variation of rainfall causes considerable changes in the stream flows and groundwater availability. Rainfall with high peaks causes flash floods and water logging while rainfall with

lower value causes in the reduction in groundwater availability and river flows.

The phenomenon of prevailing dryness in a region for a long period of time due to low rainfall and subsequent run off is termed as drought. Drought hampers the domestic consumption of water with depletion of groundwater and water resources in lakes and rivers. It also largely affects the agricultural activities as the crops are deprived of meeting the required water demand for growing of crops. Along with it, drought affects flow of the rivers, streams. Drought is mainly classified into three types (Subramanya, 2018):

- a) *Meteorological drought*: It is defined by rainfall receives less than the normal value. A region is said to be affected by meteorological drought if it receives rainfall less than 75% of the normal value. Also, if it receives rainfall between 75 -50 % then it is affected by moderate drought while receiving below 50 % rainfall indicates severe drought.
- b) *Hydrological drought*: It is defined when the flow of the rivers, groundwater availability decreases below the normal value. It has four components such as magnitude, duration, severity and frequency of occurrence. In the study of hydrological drought many techniques are used to estimate surface and groundwater deficit. Low-flow duration curve, low-flow frequency analysis and stream flow modelling are used to study the surface water deficit.
- c) *Agricultural drought*: It is defined by the decrease in the soil moisture due to low rainfall hampering the growth of crops. Also, it depends on crop sown and soil on which the crop is sown. Remote sensing techniques through imagery are used to monitor the agricultural drought.

1.2 Characterization of Drought

Droughts are generally moderate, severe and extreme in accordance with the intensity of drought indices. They are calculated from the meteorological parameters such as rainfall, evapotranspiration, etc. Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Aridity Index (AI), Palmer Drought Severity Index (PDSI) are some of the drought indices. SPEI considers the precipitation (rainfall) and evapotranspiration into account for calculation of its intensity while SPI considers only the rainfall. Aridity Index is the ratio of difference of potential evapotranspiration and actual

evapotranspiration to the actual evapotranspiration of a region. PDSI also uses temperature and rainfall to determine its intensity. Out of these indices, SPI is used in the study as it is more reliable and best suited drought indices, as it uses only the precipitation data in defining the drought.

Recent extreme weather occurrences, such as droughts and floods brought on by irregular rainfall, have resulted in losses in agricultural production. Due to this, mitigation and adaptation measures have been called for. These actions can be implemented with a thorough characterization of the natural phenomenon of hazards. Numerous studies have shown that changes in climate variables, such as an increase in the frequency of heavy rainstorms, a decrease in the number of rainy days, and the occurrence of dry spells during the rainy season, are the foreseeable characteristics of changing rainfall patterns. An investigation in the Brahmaputra and Barak basins revealed that both annual and monsoon rainfall has reduced since the year 2001, which is associated with an increase in the number of deficit years. (Deka et al., 2013; Rathore et al., 2013). Contrary to other natural hazards, droughts develop over a long period of time and often cover a wide area, making it challenging to predict when they will start with what extent of severity. It is a natural phenomenon caused by persistent shortage of rainfall causing hydrological, agricultural, and socio-economic impacts. Since the majority of Indian agriculture is rainfed, the roughly four-month monsoon season, from June to September, has a significant impact on the country's agricultural industry. This makes the monsoon's behaviour extremely important for the nation's agricultural production.

The occurrence of drought conditions is frequently sparked by an increase in the frequency of dry spells, which has detrimental effects on the economy and society. Longer dry spells may impair the availability of surface and groundwater resources, whereas shorter dry spells frequently have an impact on agricultural operations. About 50 million people in India experience drought every year, and 16% of the country's total land area is drought-prone (Arumugam and Anbazhagan, 2017). Drought has traditionally been a frequent occurrence in dry and semi-arid areas. This is no longer the case because many areas with considerable rainfall frequently experience severe water shortages. For instance, Cherrapunji in Meghalaya, which receives over 11,000 mm of rain annually and is the second rainiest places on earth, currently experiences water shortages (Ray et al., 2015) for approximately nine months of the year (NDMA, 2010). Other instances of drought occurrences in high rainfall

regions of North East India are Guwahati city of Assam (Jhalaria et al., 2007), North Lakhimpur district of Assam (Shrivastava et al., 2008), Tura town of Meghalaya (Ray et al. 2013), East Sikkim district (Kusre and Lalringliana, 2014), whole northeastern region of India (Parida and Oinam, 2015), and Nagaland (Nongbri et al., 2016). Thus, drought can occur at any place, irrespective of the climate, and is an issue related to water resource management (NDMA, 2010).

Assam is situated in one of the areas with most rainfall, where floods occur virtually every year, although it has also recently experienced drought conditions. Twice since 2010, Assam has experienced drought-like conditions that have affected a significant number of districts. Assam's 14 districts had drought-like conditions in 2014, while 20 additional districts did the same in 2019 (ASAPCC, 2022). According to a report from the Assam State Disaster Management Authority published in 2022, the number of drought weeks will increase by 75% from the baseline period of 1971–2000 to the future period of 2021–50, having an impact on Assamese people's livelihood due to reduction in production in agriculture and allied sectors. It has also been reported that increase in frequency of dry spells has produced extensive damage to paddy cultivation in the North Brahmaputra Plain zone (Neog et al., 2018). In a report (ASAPCC, 2013), published by Assam State Disaster Management Authority, due to drought-like conditions that occurred continuously for two years in 2005 and 2006, several Assam districts were severely impacted. It has an impact on more than 1.95 crore people whose livelihood depends on agriculture and allied sectors. A loss of over 100 crores of rupees was also reported as a result of crop failure and other incidentals.

Therefore, drought becomes crucial to measure and quantify the extent of the drought so that timely, effective measures can be made. Drought indices are one method for quantifying drought and can give decision-makers quantitative data on the characteristics of drought (Dogan et al., 2012). Understanding a drought's features, such as its duration, severity, inter-arrival time, and frequency, is essential for coping with the misery it might cause. With these characteristics known, drought mitigation planning would be quite simple (Pandey and Ramasastri, 2001). In the present study, it is attempted to characterize drought occurrences at each district of Assam using the drought indicator- SPI.

1.2 Drought Vulnerability

With the characterization of drought, its vulnerability to drought also holds significance. The

parameters such as number of droughts, drought duration, rainfall scenario, potential evapotranspiration, etc. can be used to depict the vulnerability of physical drought of a region. A region is more vulnerable to drought where the number of droughts and its duration is comparatively higher than the other regions. In Assam, the southern and north-eastern portion of the state received the maximum average annual rainfall comparatively than the central portion of the state for the time period from 1981 to 2017. Any slight variations in the rainfall trend could certainly be vulnerable in the state of Assam (Gogoi and Rao, 2022). However, the region with the most favorable rainfall condition is less vulnerable to drought.

Besides vulnerability of drought due to physical parameters, the socio-economic parameters such as water demand for domestic consumption and irrigation, area of irrigation, water availability, population density, health, income, education of the people etc. leads to socio-economic vulnerability of drought. As drought results in low availability of water for domestic and agricultural purposes, so the region with higher demand for domestic water consumption and irrigation are more vulnerable to drought. While the region with abundance of water availability is less vulnerable to drought. Well-developed infrastructure of a region and proper education of the people hereby can help to reduce the scarcity of water thus makes the region less vulnerable to drought.

In the recent years, the decline in southwest monsoon is seen in the North Eastern Region as compared to 1980s and 1990s resulting in probability of drought being 54 % whereas the Western region which is generally an arid region has only 27 % probability of occurrence of drought. This cause an impact on the agricultural sector where it is observed that rice production during the drought years 2005-6 and 2009 shows a negative production of drought. (Parida and Oinam, 2015). The annual reports published by Central Ground Water Board shows variation in groundwater level over the years and the District Plans published by Irrigation Department of Assam depicts the increase of water demand for domestic and irrigation purposes with increase in area of irrigation.

So, for the state of Assam where the agricultural activities are principle means of living for many people and the recent deficit rainfall scenario prevailing in the state with the increase of water demand due to increase in population, a study on the characterization of drought and also its vulnerability to drought is required to understand drought scenario of Assam. This

may help the policy makers to take necessary steps for mitigation of drought.

1.3 Objectives of the study

To carry out a comprehensive analysis of drought in Assam and its districts, the following objective is framed.

1. To characterize historical drought occurrences for all the districts of Assam.
2. To project future drought occurrences at district level using projected precipitation.
3. To generate drought vulnerability map of Assam at district level.

CHAPTER II LITERATURE REVIEW

To characterize the drought for Assam both for the past and future scenarios, SPI which is reliable and commonly used indices is used. SPI has no many factors or parameters to determine its intensity as it requires only the precipitation of the respective regions. Paulo and Pereira (2006) carried out the drought characterization of a region named as Alentijo to the south of Portugal. Three drought indices such as theory of run, Palmer Drought Severity Index (PDSI) and Standard Precipitation Index (SPI) are used in the study. Out of these indices, SPI was found to be more suited as SPI requires only the precipitation data to measure its intensity. The other two indices are seen to have limitations as they are comparatively difficult and requires more data along with the precipitation.

Also, the time scale of SPI also has a significant impact on the assessment of the drought in a region. Mishra et. al (2007) carried out a drought assessment of the Kansabati river basin in India using SPI. Drought interarrival time, joint probability distribution function of drought, are estimated to investigate the drought assessment of the basin. They have concluded that the higher SPI series i.e. SPI of longer timescale are having longer drought interarrival time. Also, with higher SPI series, its peak value decreases while increasing the severity and duration. Persistence of continuing in the same state is high for SPI of longer timescale. Asrari and Masoudi (2014) have analysed the spatial pattern of drought using SPI of 30 stations in Far province in southern Iran for the time period of 1972-2006. Three hazard criteria i.e. maximum severity of drought in the period, trend of drought and maximum number of sequential arid years are used for the study and vulnerability map is generated. It was found that 74 % of the region experienced moderate drought and are widespread while 26 % of the region are observed in northern and eastern parts of the region.

The trend and the return period of the occurrence of the drought is significantly causing the wet and dry conditions of the region. Bhunia et al., (2019) in their paper carried out the analysis of drought phenomenon in pre-monsoon, monsoon and post monsoon season for three drought-prone districts of West Bengal namely Purulia, Bankura and Midnapore. Standard Precipitation Index (SPI) is used to characterize the drought. The seasonal Mann–Kendall trend test for different SPI series (seasonal) is used to detect the trend of drought events and also Gumbel's Return period is employed to determine the probable recurrence interval of several drought types. It was

found that moderate drought has a return period of just 6-12 years along with the increase in dry events and decrease in wet and normal event worsen the situation of scarcity of water.

As CMIP 6 has many models for the simulation of climatic condition of the globe but only some models yield good result and also some specific models are suited for the definite regional climate. So, a few models which are suited for the India and its surrounding regions climatic simulations are chosen with reference to the research studies done with the CMIP 6 models in the Indian subcontinent. Kumar and Sarthi (2021) studied the performance of BCC-CSM2-MR, BCC-ESM1, MPI-ESM1-2-HR and MPI-ESM1-2-LR from CMIP6 in evaluation of wind, humidity and rainfall on seasonal and monthly scales for the period of Indian summer monsoon season (June-July-August-September) for the historical time period (i.e. from 1979 to 2014). The simulated results of rainfall obtained by all the four models follow the observed rainfall variability on the interannual scale in July-August-September with BCC-CSM2-MR model showing the best representation of the observations. Iqbal *et. al.*, (2021) evaluated the performance of 35 GCMs from CMIP6 with the APHRODITE rainfall in the Mainland South-East Asia (MSEA) for the period of 1975–2014 based on four spatial indices including GK lambda, Mapcurves, Cramer's V and TheilU, and then the overall ranking of GCMs was derived using Compromised programming (CP). They have found that models MRI-ESM2-0, EC-Earth3 and EC-Earth3-Veg are best suitable in replicating APHRODITE rainfall climatology of MSEA. Rajbansi and Das (2021) evaluate the suitable GCMs from CMIP6 to be used for predicting the Indian summer monsoon precipitation. Out of 10 GCMs studied, EC-Earth3, IPSL-CM6A-LR, and MIROC6 models well simulated the Indian summer monsoon precipitation variability (both spatial and temporal scale) from 1901-2014. These three models are then used for predicting future projections (2071-2100) of drought for the shared socioeconomic pathways (SSP) scenarios. Anil and Raj (2022) examined 21 GCMs from CMIP6 for simulation of historical monthly precipitation over the period of 1951 to 2014 in the Krishna River Basin. They used two methods namely symmetrical uncertainty method (SU) and multi-criteria decision method (MCDM) for executing in the selection of suitable GCMs. BCC-CSM2-MR, IPSL-CM6A-LR, MIROC6, INM-CM5-0 and MPI-ESM1-2-HR models were found to be suitable for the Krishna River Basin. Konda and Vissa (2022) studied 30 GCMs models from CMIP6 in order to examine the simulations of surplus/deficit of Indian summer monsoon rainfall and its associated air sea interaction on intra seasonal and interannual timescales. BPM; AWI-ESM-1-1-LR, BCC-CSM2-MR, BCC-ESM1, CNRM-CM6-1, CNRM-ESM2-1, GFDL-CM4, INM-CM5-0, MIROC-ES2L, MIROC6,

TaiESM1 models were found to be best as they well simulated the seasonal mean precipitation with Taylor skillscore > 0.75 and normalized root mean square error < 0.7 .

Drought parameters being obtained by analyzing the rainfall and drought measuring indices and the parameters of the social and economic conditions and perception shows the vulnerability of drought in the region. Weighted assigned technique with fuzzy logic can be used to estimate the vulnerability of drought. Kabir and Hasin (2011) have carried out a comparative study between Analytic Hierarchy Process (AHP) and Fuzzy-Analytic Hierarchy Process (FAHP) for multi criteria inventory classification model. Out of the two weighted technique process, FAHP was proved be a convenient approach for the decision makers to carryout their opinions for the purpose. It was capable of capturing the vagueness of human thinking and providing the solution to research problem in a structured and simple manner. Saha et.al. (2021) carried out a drought vulnerability study for the state of Odissa. Fuzzy AHP (Analytic Hierarchy Process) is used in determining the physical and socio-economic vulnerability of drought in the state. For the physical drought, 12 physical parameters are considered and also 12 socio-economic parameters are considered for socio-economic drought. Both physical and socio-economic vulnerability maps are prepared from the respective parameters which are later on overlaid to obtain the overall vulnerability map with five drought vulnerability classes as very high, high, moderate, low and very low. The results so obtained showed that 33.94 % of the state experiences very high vulnerability. Also, the approach is validated using the statistical metrics such as receiver operating characteristics curves, accuracy, root-mean-square-error and mean-absolute-error which implied that the approach is effective for determining the vulnerability of drought of a region. Another widely used method is Iyengar and Sudarshan (1982) which is based on variance comparison. It combined the weights and uncertainties associated with multiple measures. The application of weights in this manner should ensure that significant changes in any of the indicators do not overwhelm the input from the remaining indicators, skewing the overall ranking of the countries. Tapas et al. (2022) used this method to develop multivariate integrated drought monitoring index for Warangal region of Telangana. Sahana et al. (2021) used this method in combination with other weighting techniques for drought vulnerability and risk assessment in India.

3.1 Study area

Geographically, Assam is located at the center of the Northeast. It extends from 24° N to 28° N and 89° E to 96° E covering a total area of 78,438 km². Two main rivers Brahmaputra and Barak flows through it and it is surrounded by hills and mountains. The climate of Assam is sub-tropical with humid summers and dry winters. Assam receives a normal annual rainfall of 2201 mm. Although it is a flood prone state due to high rainfall and high discharges of the rivers and its numerous tributaries in the monsoon season, but in the dry season of the year it also experiences insufficient water availability for water consumption by people, agricultural activities, etc. in some parts of the state. Total cultivation area of the state is 2.83 million hectares and the irrigation infrastructure of the state as on present time is not well sufficient to serve the purpose. Also, according to 2011 census, the population of the state is 31.17 million and it is increasing although recent census has not been made till now still it is assumed to be increased by a considerable number. With the increase in population, the vulnerability to drought also increases. Presently, it has 33 districts as shown in Fig. 3.1.

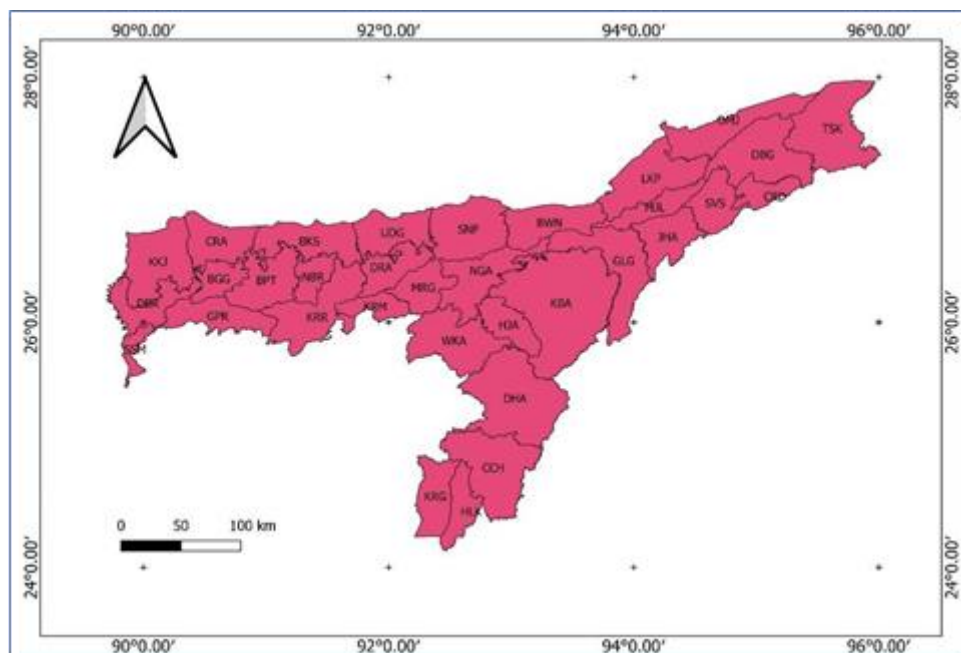


Fig. 3.1 Study area: Assam and its districts

3.2 Acquisition of data

3.2.1 Historical Data

Indian Meteorological Department (IMD) is a government agency which deals with

the meteorological dataset and forecasting of meteorological calamities like cyclones, heavy rainfall etc. Also, it provides necessary warnings of the calamities and changes of the meteorology of the India on regular time basis. Precipitation mostly rainfall in India and temperature are observed daily by the department on hourly, daily, monthly basis. Rainfall and temperature for a region for a certain time period can be obtained from them. Data for rainfall and temperature is available in the gridded form of dataset for being used by researchers to carry out their research activities. Rainfall and temperature data for Assam was obtained from the IMD website (Pai et al., 2014). The time period of the data considered in the study is from 1951 to 2020.

3.2.2 Projected data

Rainfall and temperature data for the future years or projected time period can be obtained by the global climate models also known as General Circulation models developed by various countries in relation to the sixth assessment report of Intergovernmental Panel on Climate Change (IPCC). The IPCC is an international body or organization mainly focusing on the climate change issues and dealing with the analysis of climate change. There are five future scenarios under the 6th assessment report of IPCC in terms of socio-economic pathway (SSP) such as SSP 1, SSP 2, SSP 3, SSP 4 and SSP 5, classified based on forcing levels. SSP 1 depicts the most favorable scenario with sustainable development using green energy while the SSP 5 depicts the worst scenario with extreme fossil fuel emissions.

Under the sixth assessment report of IPCC, climatic models are developed to study the future scenario with the parameters such as precipitation, temperature, humidity etc. They are known as Coupled Model Intercomparison Project (CMIP 6) models which are generally used for climatic study in the recent time. CMIP 6 models generate climatic parameters for both historical i.e. past scenarios (1951-2014) and future scenarios (2015-2100) on a global grid system. The future scenarios considered by the models are SSP126, SSP245, SSP 370 and SSP 585. The grid system has a spatial resolution of 0.25°.

In this study, five models of CMIP 6 models namely BCC-CSM2-MR, MIROC6, EC-Earth3, MPI-ESM1-2-HR and MIROC-ES2L are selected for the study. They are selected out of all the CMIP 6 models as they are found to be most suitable for the simulation of climate of Indian sub-continent. The datasets are in the form of netcdf file. The parameter such as rainfall and temperature (maximum and minimum) were extracted from the global

gridded dataset file for the future and past scenarios. The baseline time period was considered from 1985 to 2014 while the time period of future scenario was considered from 2026 to 2055. Precipitation (rainfall) and temperature (both maximum and minimum) were also extracted for all the grids in accordance with the geographical area of Assam.

3.2.3 Processing of acquired data

The historical and projected data so obtained for the specific time period under all scenarios were then processed in order to obtain the district wise precipitation (rainfall) and temperature data. In case of the projected data, the average rainfall and temperature of the five CMIP 6 models for the respective region and time period was calculated and represented as Ensemble model. The reason behind this was to capture the average variation of the five models. From the Historical and projected temperature data, using Hargreaves equation, the district wise potential evapotranspiration (PET) is calculated for observed projected scenarios which would be used as a physical drought vulnerability parameter.

3.3 Methodology

A flowchart showing the overall methodology of this study is given in Fig. 3.2. The data from different sources are processed through various software such as Microsoft excel, python, and ArcGIS to obtain monthly time series of precipitation and temperature for each 33 districts in Assam. Then, the rainfall series was used to calculate SPI and then analyzed to obtain historical and drought characteristics. Some drought characteristics and rainfall characteristics will turn themselves as physical drought vulnerability parameters. Socio-economic parameters would be acquired from various departments of the Government of Assam and they along with the physical parameters will go for pairwise comparison to compute weights. After computing weights, separate vulnerability maps will be generated and then overlay them to get the final drought vulnerability map of the Assam at district scale.

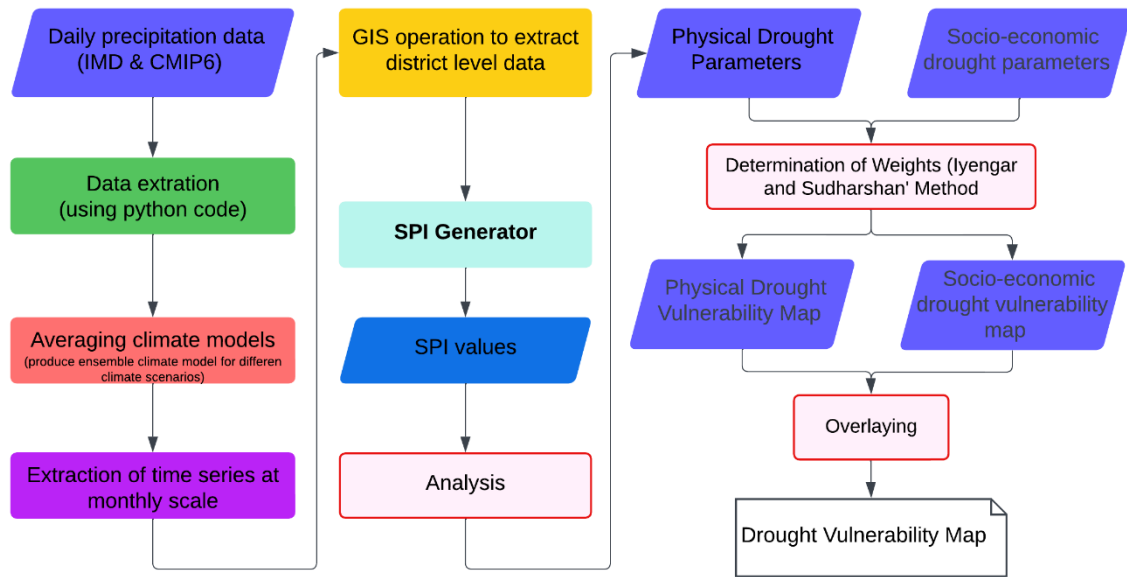


Fig. 3.2 Flowchart of the methodology adopted for the study

3.3.1 Calculation of SPI

The district wise observed data for rainfall so acquired from IMD are then used to obtain the SPI of different timescale of all the districts for the time period from 1951 to 2020. Similarly, projected rainfall data of all districts are used for obtaining the district wise SPI of all the models including the Ensemble model of CMIP 6 models for all the scenarios. Five different time scale of SPI are considered in the study which are as SPI01, SPI03, SPI06, SPI12 and SPI24 at 1-, 3-, 6-, 12-, and 24- months, respectively.

SPI was employed in the current study as an indicator for identifying drought. This index simply needed data on precipitation and had a sliding time scale. Rainfall is the main indicator of drought and the foundation of the majority of drought monitoring systems, even if it may not encompass the whole range of drought characteristics. The SPI has wide range of acceptability among various researchers on drought. The SPI is regarded as one of the top indicators for determining the severity of a drought (Keyantash and Dracup, 2002; Dogan et al., 2012). SPI was suggested by Morid et al., (2006) for use in drought monitoring in Tehran, Iran because it did a good job of spotting the start of a drought. The SPI may serve as a useful indicator for describing various aspects of agricultural drought because of its adaptability in adopting sliding time scales (White and Walcott, 2009). If rainfall deficit persists for a longer period, especially during growing season of crops, agricultural drought may arise (Faiz et al., 2021) due to shortage of soil moisture in the crop root zone. A shorter time

period, such as 3–, or 6– months, would be sufficient to describe a drought that affects agriculture, whereas a longer time scale, such as 12–, 24–, or longer months, would be significant from the perspective of water resources in reservoirs and groundwater. A 1-month time period for a drought analysis would frequently produce inaccurate conclusions in areas with considerable rainfall variability. Since the majority of crops grown in Assam have a growing period of 3–5 months, a timescale of 3– months is employed in this study to reflect the effects of drought on agriculture.

The SPI, a drought indicator, was developed by McKee et al., (1993) and extensively described by Edwards and McKee (1997). In SPI, Gamma probability distribution function is used. The Gamma distribution used in calculation of SPI is as follow:

$$G(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad \text{Eq. (3.1)}$$

Where, α and β are the shape and scale parameters, respectively. To determine these parameters, maximum likelihood solutions are used (Thom 1966) as follow:

$$\alpha = \frac{1}{4A} \left[1 + \sqrt{\frac{4A}{3}} \right] \quad \text{Eq. (3.2)}$$

$$\beta = \frac{\bar{x}}{\alpha} \quad \text{Eq. (3.3)}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad \text{Eq. (3.4)}$$

Where, n is the number of rainfall observation and \bar{x} is the mean rainfall. When $x = 0$, the Gamma function is undefined, thus for rainfall = 0, the cumulative probability is:

$$H(x) = q + (1 - q).G(x) \quad \text{Eq. (3.5)}$$

Where, q is the probability of zero events. If m is the number of zeros in the series of rainfall, then q becomes m/n (Thom 1966). Further in SPI calculation, the cumulative probability, $H(x)$ is normalized to become SPI value as follow:

$$SPI = - \left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ for } 0 < H(x) \leq 0.5 \quad \text{Eq. (3.6)}$$

$$SPI = + \left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \text{ for } 0.5 < H(x) \leq 1 \quad \text{Eq. (3.7)}$$

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \text{ for } 0 < H(x) \leq 0.5 \quad \text{Eq. (3.8)}$$

$$t = \sqrt{\ln\left(\frac{1}{[1-H(x)]^2}\right)} \text{ for } 0.5 < H(x) \leq 1 \quad \text{Eq. (3.9)}$$

$$c_0 = 2515517; c_1 = 0.802853; c_2 = 0.010328; d_1 = 1.432788; d_2 = 0.189269; \text{ and } d_3 = 0.001308 \quad \dots \text{Eq. (3.10)}$$

Due to the fact that SPI values are normalized, they equally represent both wet and dry conditions. Table 1 shows how Mckee (1993) classified drought situations based on SPI values. In this study, a drought event begins when SPI reaches -1.0 or lower and ends when the SPI becomes positive. In this study, SPIgenerator program developed by National Drought Mitigation Centre has been employed. This program can calculate SPI at multiple time scale along with drought duration for multiple drought severity level.

Table 3.1 Classification of drought based on SPI range

Drought category	Range of SPI
Moderate drought	-1.00 to -1.49
Severe drought	-1.5 to -1.99
Extreme drought	-2.00 and less

With the calculated values of SPI, number of drought months and duration of drought in months of respective districts are obtained. Along with it, the percentage of drought months for each district is also obtained. With these drought parameters, characterization of drought occurrence for historical and future were analyzed.

3.3.2 Drought Vulnerability

In this study, drought vulnerability will be determined from both physical and socio-economic drought indicators. Physical drought indicators include annual precipitation, precipitation trend, critical precipitation, temperature trend, extreme drought frequency, inter arrival time of drought, maximum drought duration, and potential evapotranspiration. Socio-economic drought indicators include ground water level, annual replenishable groundwater, net groundwater availability, net irrigation, population, literacy rate, total water demand, cropping index, and multidimensional poverty index. Two types of functional relationship are possible: increase in the value of the indicator increases or decreases the vulnerability. For example, if we take rainfall, it is clear that higher the value of this indicator, less will be

the vulnerability of that district and we can say there is decreasing functional relationship with vulnerability.

For the socio-economic vulnerability of drought, the socio-economic parameters would be obtained from the various concerned departments of the Government of Assam. Some of the parameters are measured and collected by them and published in their annual reports or plan reports for each district. Some of them are directly related to drought vulnerability while the others are indirectly related. Water availability is the availability of ground water and surface water. With the increase in water availability, affect caused by drought is less for that district. It is measured in Million Cubic Meter (MCM). It is obtained from the District Irrigation Plan prepared by the Irrigation department of Assam. Water demand is the total of the domestic water demand, crop water demand, livestock water demand, industrial water demand and power generation water demand. Higher is the demand for water more is its vulnerability to drought. It is measured in Million Cubic Meter (MCM). It is obtained from the District Irrigation Plan. In the plan both present (2016) and projected (2020/21) water demand is presented. Gross irrigated area is the total area under all crops irrigated once or more than once in a year. With the increase in the irrigated area, the drought vulnerability also increases as there will be more water demand for irrigation. It is measured in Hectares (ha). It is obtained from the District Irrigation Plan. Cropping Intensity is the ratio of the gross cropped area to the net sown area. More is the cropping intensity more is the drought vulnerability as the scarcity of water will cause more losses in the amount of crop cultivated. It is measured in percentage (%). It is obtained from the District Irrigation Plan. Districts with the higher population are more vulnerable to drought. It is obtained from the District Irrigation Plan. In the plan population of both the years 2016 and 2020/21 are mentioned. The income of the people in the districts can be assessed by the Multidimensional Poverty Index (MPI) mentioned in the National Multidimensional Poverty Index report published by the NITI Aayog. A well-income society having sufficient infrastructure will also leads to less vulnerability to drought.

For each indicator, the data were then arranged in the form of a rectangular matrix with rows representing districts and columns representing indicators. Let there be M districts and let us say we collected K indicators. For M number of districts and K number of indicators, X_{ij} , will be the value of the indicator j corresponding to district i and the matrix table will have M rows and K columns ($i=1, 2, 3, \dots, M$ and $j=1, 2, 3, \dots, K$).

The selected indicators had different scales and units. In order to obtain standardized values of indicators without any units, first they were normalized so that they all lied between 0 and 1. The methodology used in UNDP's Human Development Index (HDI) (UNDP, 2006) was followed to normalize the indicators. Normalization was done based on the functional relationship. If the indicators had increasing functional relationship with the vulnerability then normalization was done as:

$$X_{ij} = \frac{X_{ij} - \text{Min}\{X_{ij}\}}{\text{Max}\{X_{ij}\} - \text{Min}\{X_{ij}\}} \quad \text{Eq. (3.11)}$$

where, X_{ij} is the normalized value of indicator.

And if the indicators had decreasing functional relationship with the vulnerability then normalization was done as:

$$X_{ij} = \frac{\text{Max}\{X_{ij}\} - X_{ij}}{\text{Max}\{X_{ij}\} - \text{Min}\{X_{ij}\}} \quad \text{Eq. (3.12)}$$

It was clear that all these scores lied between 0 and 1. The value 1 corresponded to the district with maximum vulnerability arising out of a given indicator and 0 corresponded to the district with minimum vulnerability from an indicator. Then, these normalized indicators were assigned weights based on Iyengar and Sudharshan (1982) approach. Physical and socio-economic indicators were assigned weights separately and then overlaid at the final stage. This method uses variance for weight assignment and is statistically sound and well suited for development of composite index of vulnerability assessment. In Iyengar and Sudarshan's (1982) method, the weight, w_j , is determined by:

$$w_j = \frac{c}{\sqrt{V_j}} \quad \text{Eq. (3.13)}$$

where, $V_j = \text{Var}(x_i)$ over all the districts for j^{th} indicator and c is a normalizing constant that can be obtained as:

$$c = \left[\sum_{j=1}^K \frac{1}{\sqrt{V_j}} \right]^{-1} \quad \text{Eq. (3.14)}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and thereby distort the inter-district comparisons (Iyengar and Sudarshan, 1982). The drought vulnerability index (DVI) of the i^{th} district is assumed to be a linear sum of weighted X_{ij} as given below:

$$DVI = \sum_{j=1}^K w_j X_{ij} \quad \text{Eq. (3.15)}$$

where, w_j ($0 < w_j < 1$ and $\sum_{j=1}^K w_j = 1$) are the weights calculated using Eq. 3.13. The DVI so computed lied between 0 and 1, with 1 indicating maximum and 0 indicating minimum vulnerability.

4.1 Historical droughts in Assam

The occurrence of the droughts during 70 years from 1951 to 2020 was analyzed at different timescales. SPIs showed that there would be occasional drought as well as flooding conditions. When positive (wet condition) and negative (dry condition) were compared, positive SPIs slightly dominated the negative SPIs. This suggests that, despite droughts, there is potential to reduce the impacts of droughts by using excess water during wet conditions. In this report, only four districts (one from upper Brahmaputra region: Jorhat, two from central Brahmaputra region: Golaghat and Kamrup Metro and one from lower Brahmaputra region: Goalpara) were selected to present the drought conditions in the state. The monthly SPI series in these four districts are shown in Fig. 4.1.

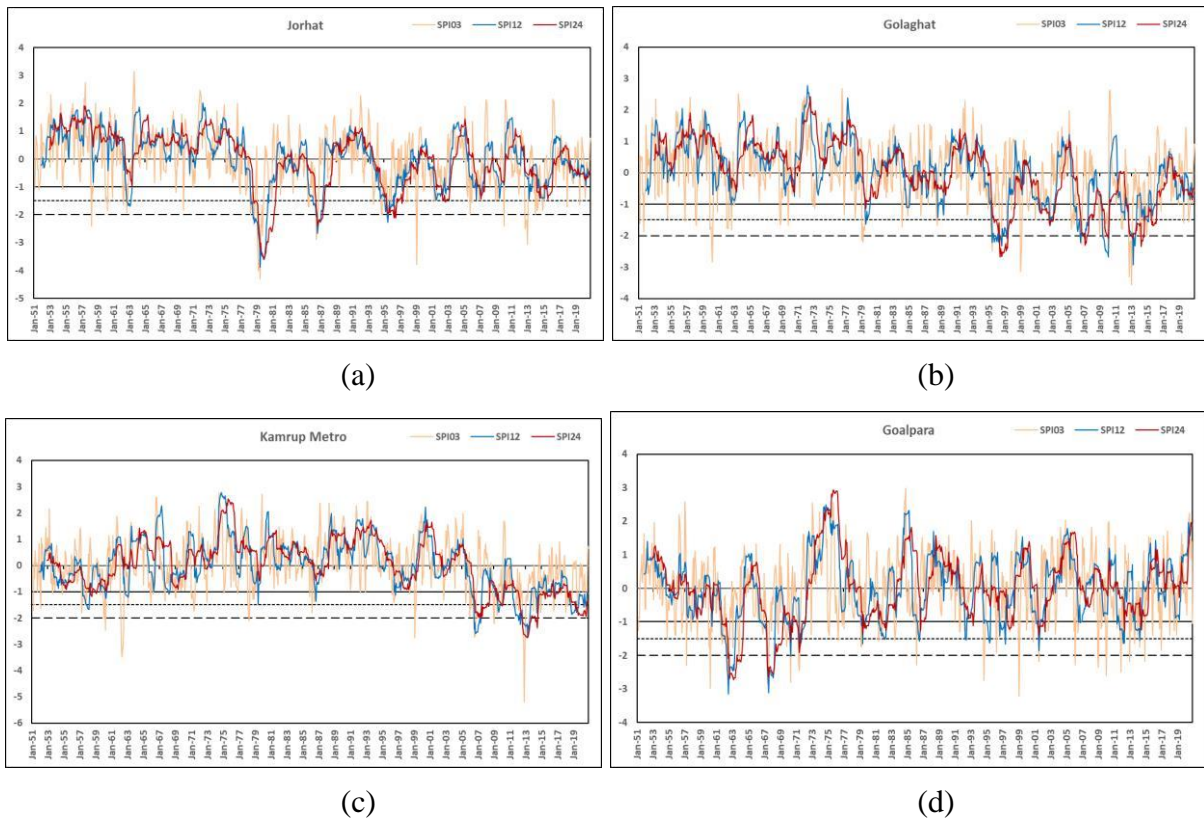


Fig. 4.1 SPI03, SPI12, and SPI24 of (a) Jorhat (b) Golaghat (c) Kamrup Metro (d) Goalpara

The districts showed a decreasing trend of SPI towards the end of the time period of 1951-2020, indicating higher severity. Although the districts experience SPI below -2 in early and mid of the time period, the SPI seems to have reduced considerably and showing a

dryness tend towards the end of the time period. SPI of shorter timescale shows a shorter duration of droughts and less severity with higher peaks while the longer timescale of SPI shows reduced peaks with higher duration and severity of drought. Total number of droughts in the four districts for different timescale of SPI are shown in Fig. 4.2, while no. of droughts occurred in a year are shown in Fig. 4.3. The results showed that moderate drought occurs mostly in comparison to the severe and extreme droughts in the districts. Golaghat experienced lesser number of moderate droughts comparatively while Goalpara experienced higher number of moderate droughts. Also, the number of droughts in a year of the time period of 1951-2020, was high towards the end of the time period in the districts of Kamrup Metro and Golaghat. While Jorhat experienced a greater number of droughts in a year in the middle of the considered time period and Goalpara experienced highest in the early years of the time period. Peaks of SPI of shorter timescale were lower than the peaks of larger time scale of SPIs. The percentage of drought occurrences in the four districts is shown in Fig. 4.4. In SPI of shorter timescale, the percentage of occurrence of drought was high for Goalpara while Golaghat had shown the highest percentage of occurrence of drought in the SPI of longer timescale.

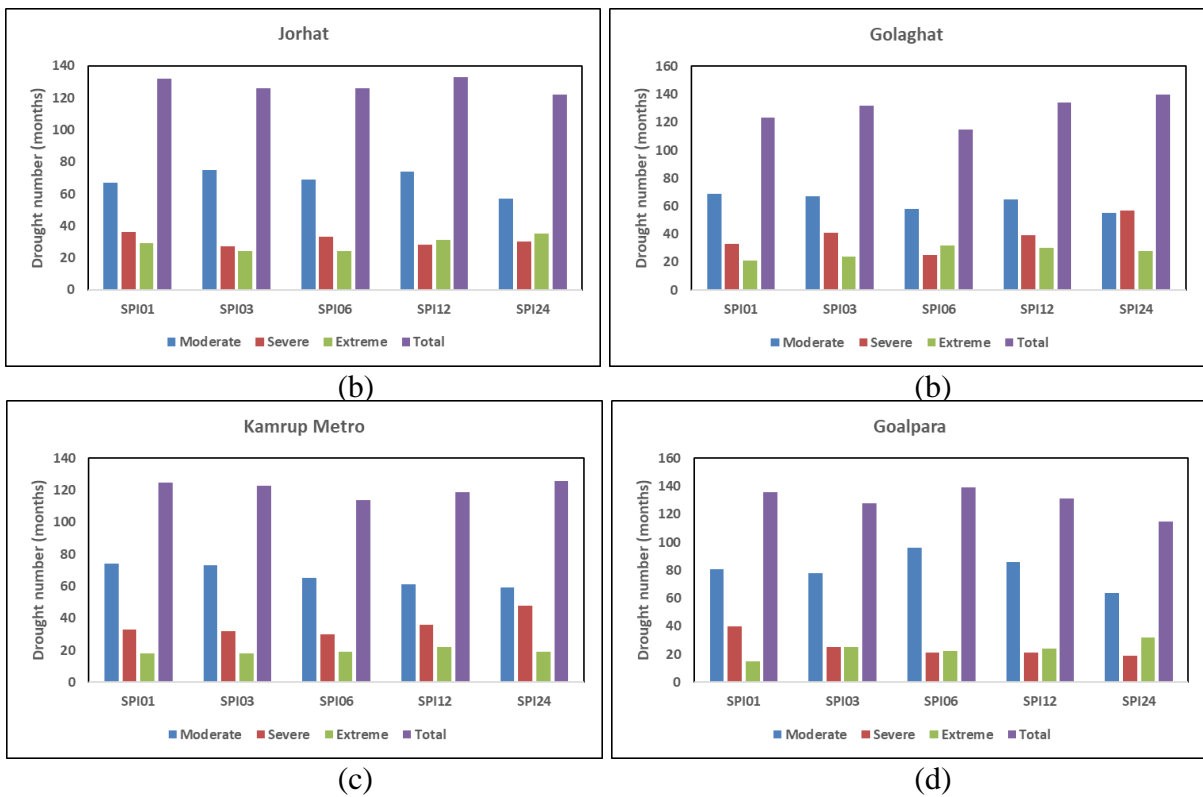


Fig. 4.2 Number of drought months of (a) Jorhat (b) Golaghat (c) Kamrup Metro (d) Goalpara

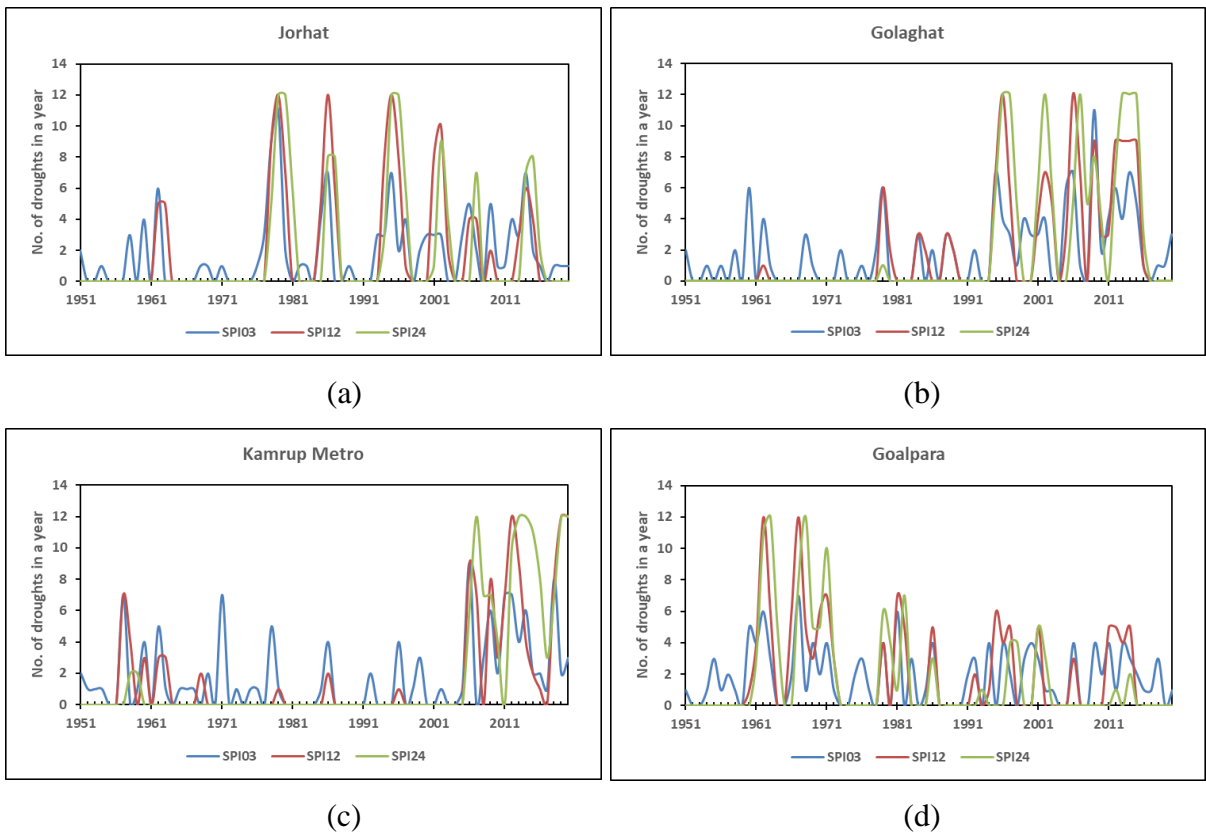


Fig. 4.3 Number of droughts in a year of (a) Jorhat (b) Golaghat (c) Kamrup Metro (d) Goalpara

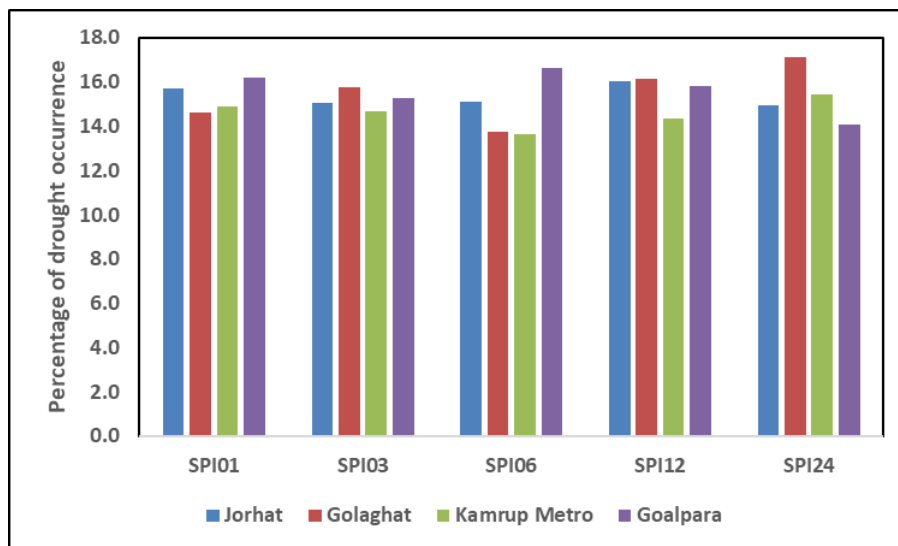


Fig. 4.4 Percentage of drought occurrence for the four districts

Drought duration is another characteristic of drought which could tell the severances of an ongoing drought. Average duration and maximum duration of drought for SPI03, SPI12, and SPI24 of all the districts of Assam were determined and shown in Fig. 4.5. The average duration of drought follows the same trend with the maximum duration of drought for

almost all the districts. With the increase in timescale of SPI, the drought duration was also increasing. Tamulpur had shown the highest average drought duration of 7 months while Sonitpur had shown the highest maximum drought duration of 41 months on the basis of SPI03. On the other hand, for SPI12, Dima Hasao had shown the highest average and maximum drought duration of 31 and 122 months respectively while Udalguri had shown the highest average and maximum drought duration of 90 and 158 months respectively on the basis of SPI 24.

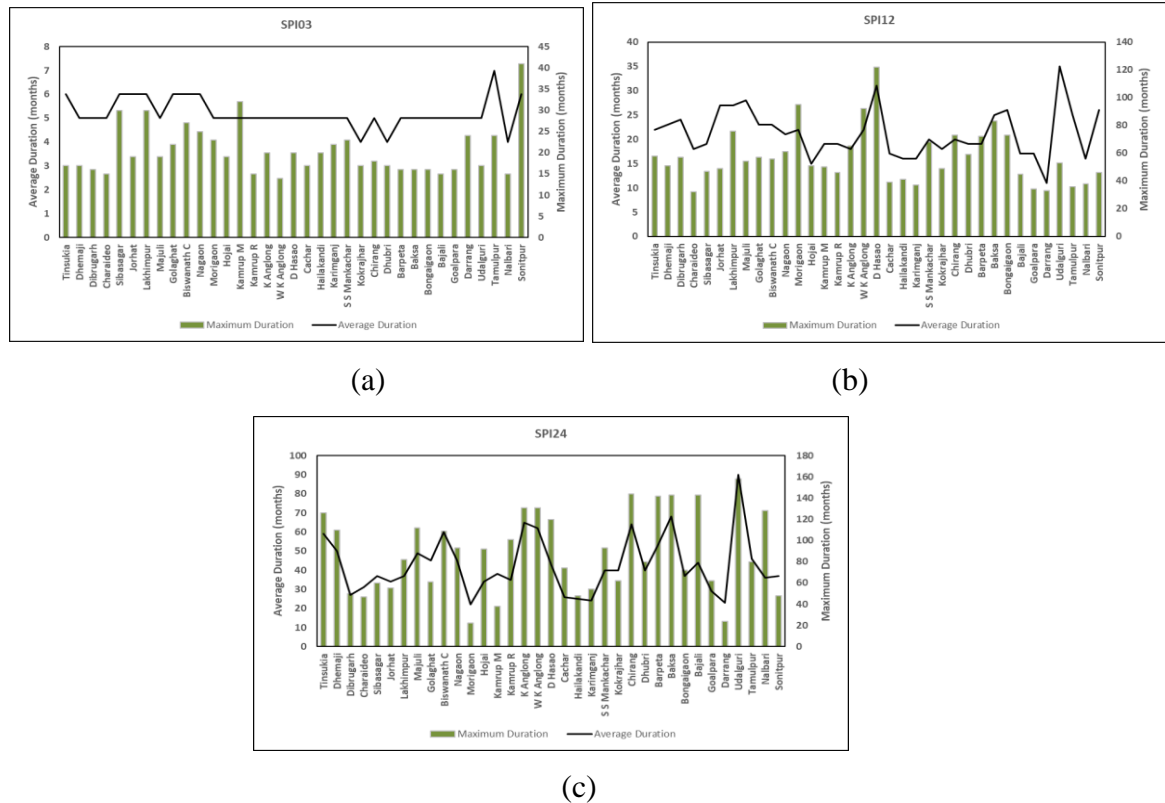


Fig. 4.5 Duration of drought based on SPI of (a) 3 month-timescale (b) 12 month-timescale (c) 24 month-timescale

4.2 Projected droughts in Assam

The occurrences of the droughts for 30 years from 2026 to 2055 were determined for different future scenarios of the ensemble model. In this report results of Kamrup Metro district is only shown. The district Kamrup Metro showed a decreasing trend of SPI towards the recent future i.e., after 8-14 years from the start of the projected time period for all the future scenarios. The district will experience a drought of higher duration and higher severity in the respective period of time of occurrence of the drought. SPI of shorter timescale showed a shorter duration of droughts and less severity with higher peaks while the longer timescale of SPI showed reduced peaks with higher duration and severity of drought.

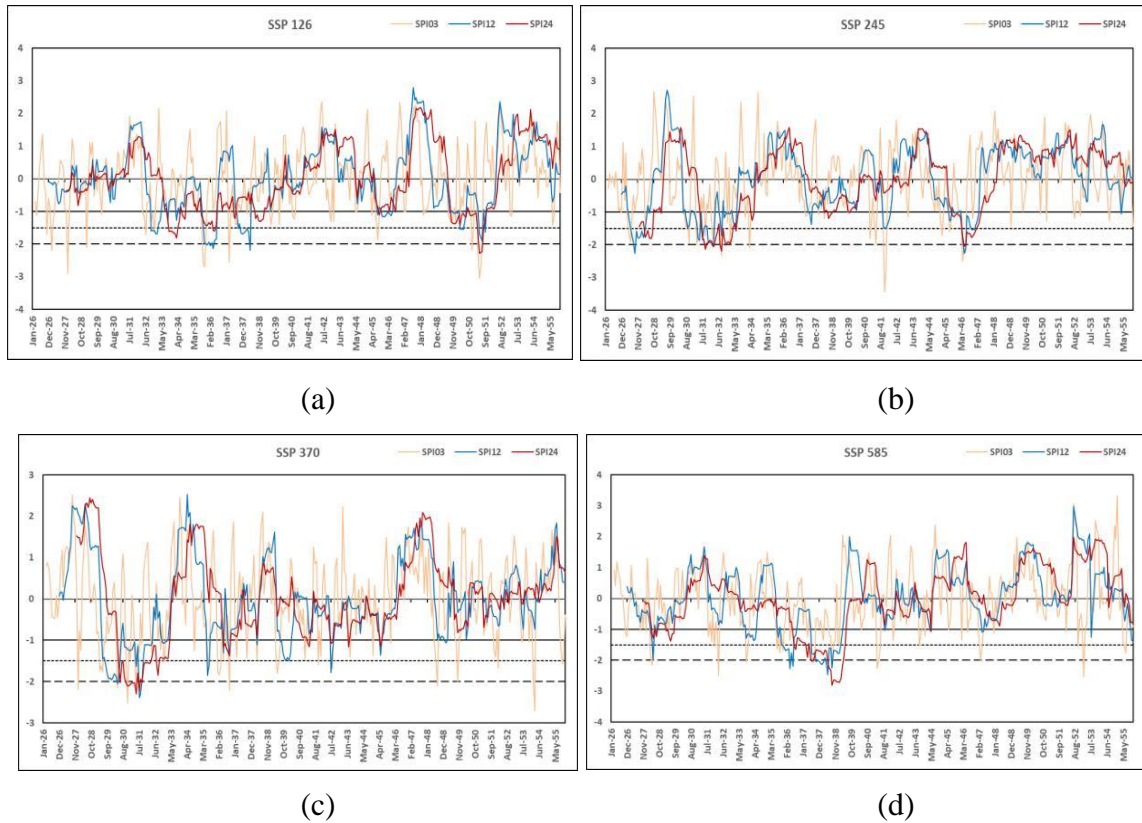


Fig. 4.6 SPI of 3-month, 12-month and 24-month timescale of Kamrup Metro for future scenario (a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

The number of droughts occurred in Kamrup Metro district for different SPI and different scenario is shown in Fig. 4.7. Also, the number of droughts in a year of the time period of 2026-2055, is shown in Fig. 4.8. In SSP 1-2.6, the number of droughts was higher towards the end of the time period while in SSP 5-8.5 it was higher in the middle of the time period. Peaks of SPI of shorter timescale were lower than the peaks of higher time scale of SPI.

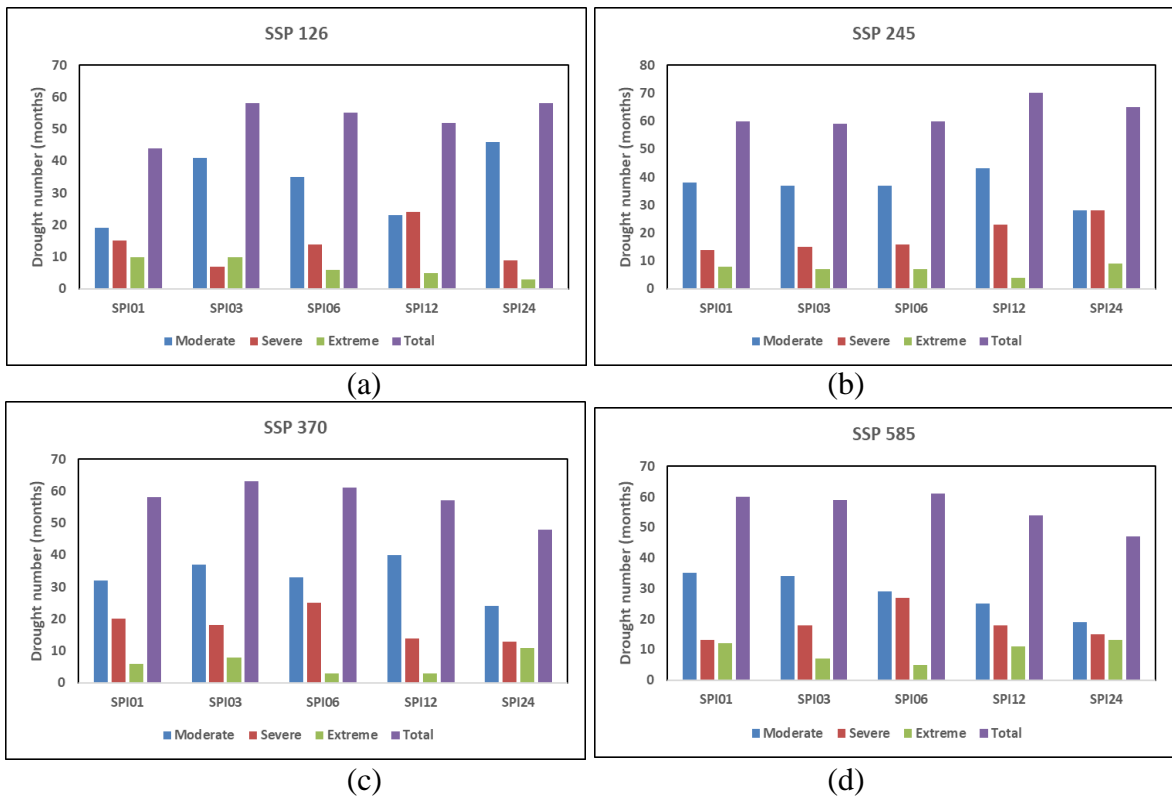


Fig. 4.7 Number of drought months of Kamrup Metro for future scenario (a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

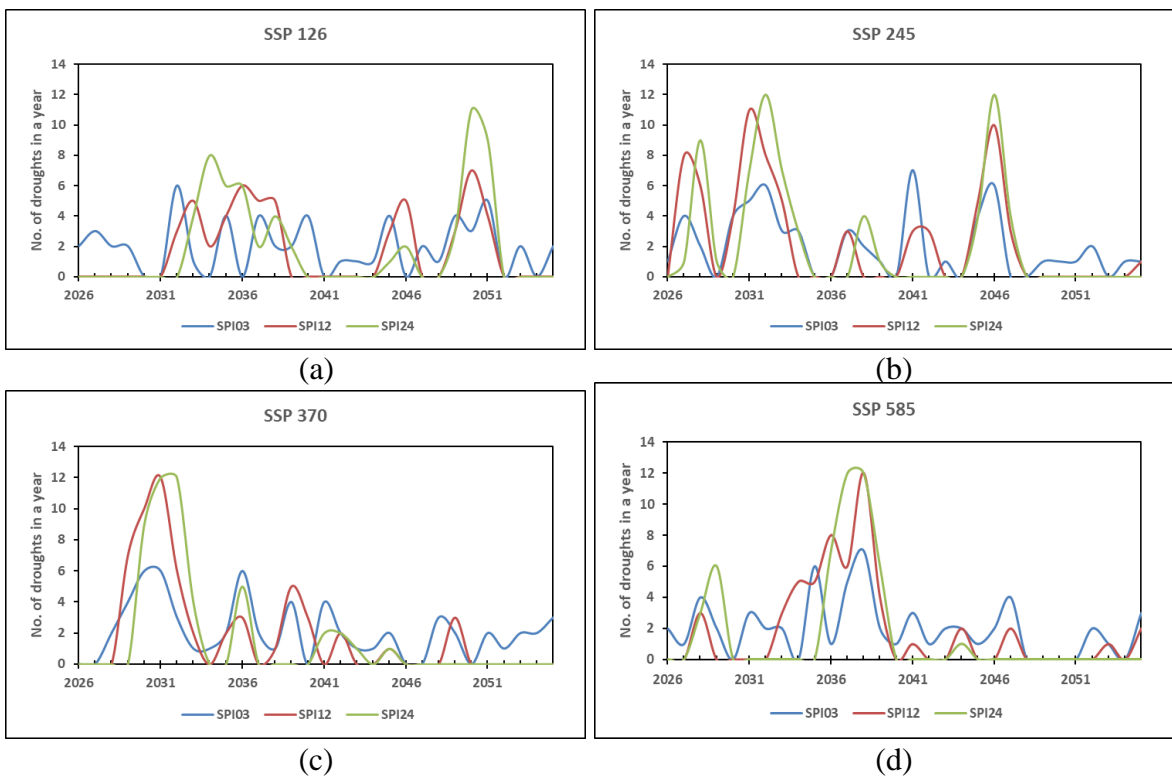


Fig. 4.8: Number of droughts in a year of Kamrup Metro for future scenario (a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

Percentage of drought occurrences in Kamrup Metro district is shown in Fig. 4.9. For the futurescenario of SSP 126, Golaghat had shown the highest percentage of drought in shorter timescale and Goalpara had shown the highest percentage of drought in longer timescale. For SSP 245 and SSP 370, Goalpara had shown the highest percentage of drought. For SSP 585, Jorhat had shown the highest percentage of drought in shorter timescale and Golaghat had shown the highest percentage in longer timescale.

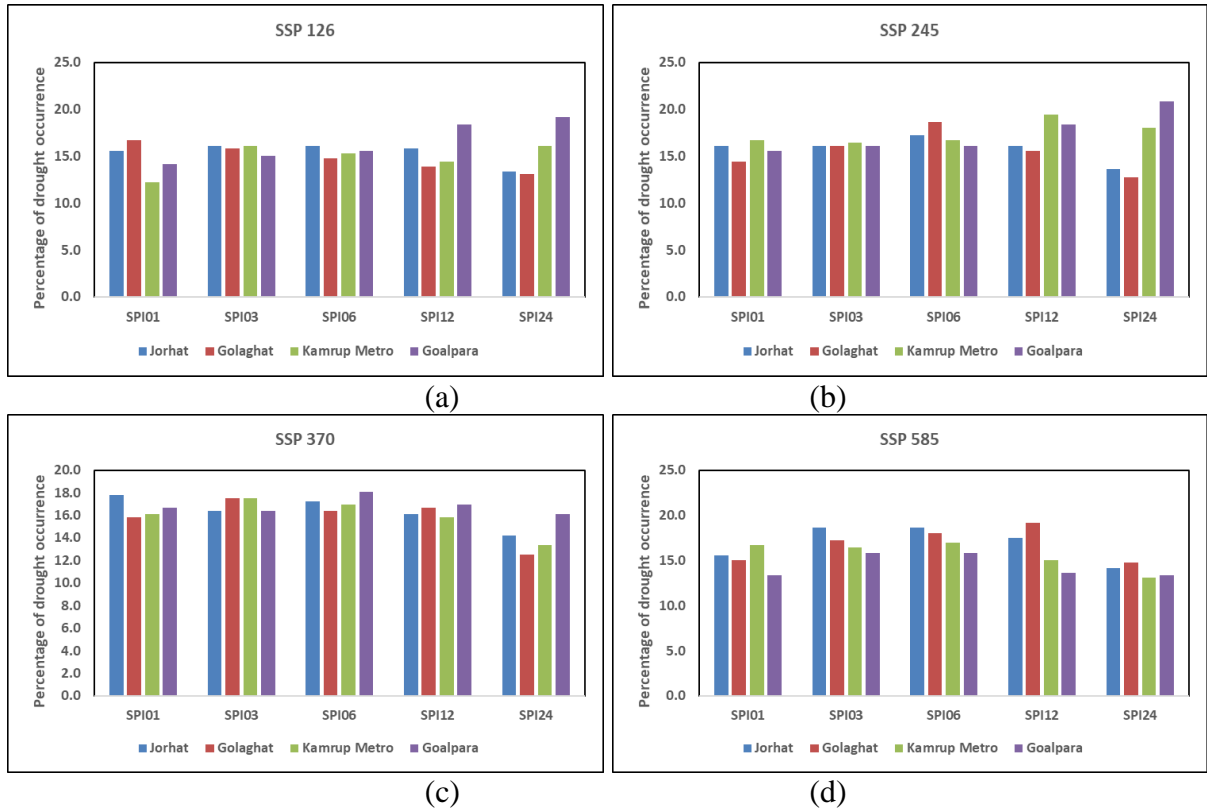


Fig. 4.9 Percentage of drought occurrence for the four districts for future scenario (a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

Average duration and maximum duration of droughts occurred in all the districts of Assam for SPI03, SPI12, and SPI24 are shown in Figs. 4.10–4.12, respectively. For, SPI03, the average duration of drought was about 4–5 months. In the SSP 585 scenario, the maximum drought duration of most of the districts were above 18 months with Dima Hasao had the highest maximum duration of drought of 27 months. While in the other future scenarios, maximum duration of the districts were less than 18 months. In SSP 126, Kokrajhar and Dhubri had the highest maximum drought duration of 17 months, in SSP 245, most of the districts had the highest maximum drought duration of 13 months and lastly in SSP 370, South Salmara Mankachar district had the highest maximum drought duration of 15 months.

For SPI12, the average duration of drought was in the range of 10–20 months in SSP 126 and SSP 585 scenarios while in the SSP 245 and SSP 370 scenarios, the average drought duration was in the range of 10–30 months. In the SSP 126 scenario, Biswanath Chariali had the highest maximum duration of drought of 50 months. In SSP 245, Hojai had the highest maximum drought duration of 39 months. In the SSP 370 and SSP 585 scenarios, nearly half of the districts had shown the maximum drought duration in the range of 46–47 months and 45–47 months, respectively.

For SPI24, the average duration of drought was in the range of 20–40 months in almost all the future scenarios. In the SSP 126 scenario, West Karbi Anglong had shown the highest maximum duration of drought of 94 months. In SSP 245, Dhemaji had shown the highest maximum drought duration of 75 months. In the SSP 370 scenario, Tinsukia, Charaideo and Sivasagar districts had shown the maximum drought duration of 49 months. Lastly, in the SSP585 scenario, Tinsukia had shown the highest maximum drought duration of 82 months.

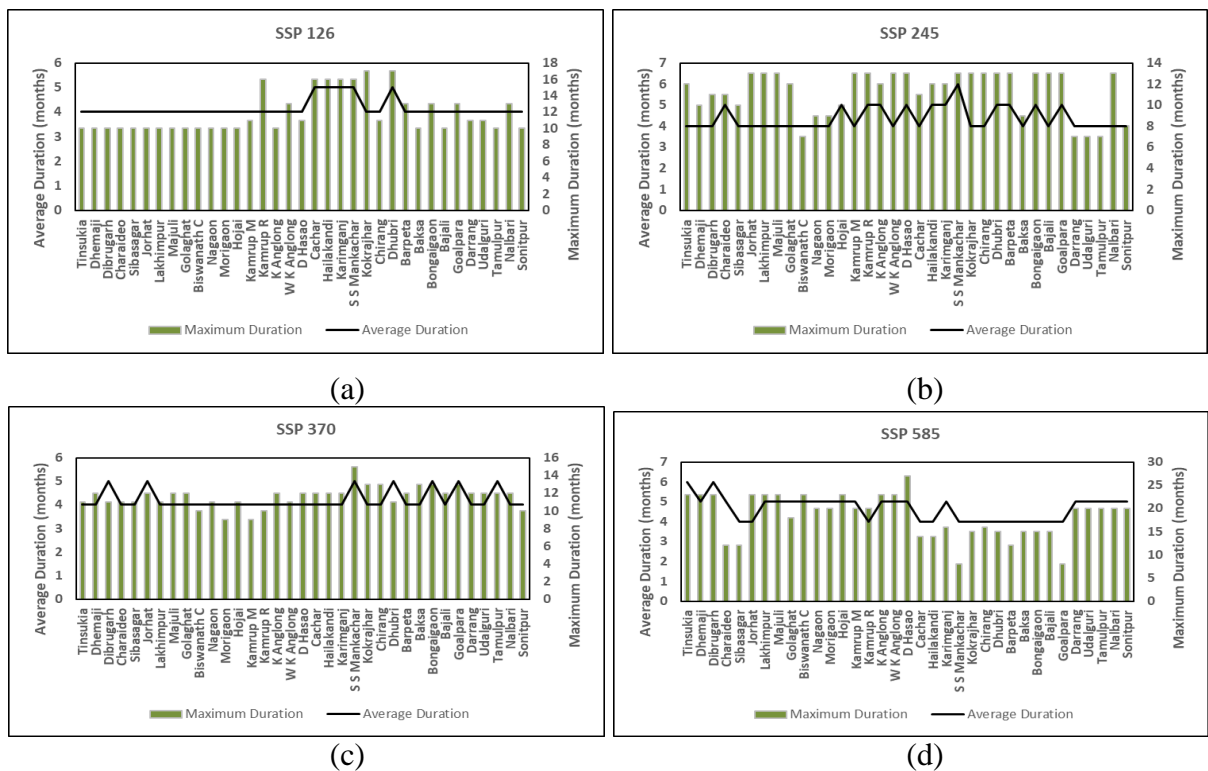


Fig. 4.10 Duration of drought based on SPI of 3 month-timescale for future scenario (a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

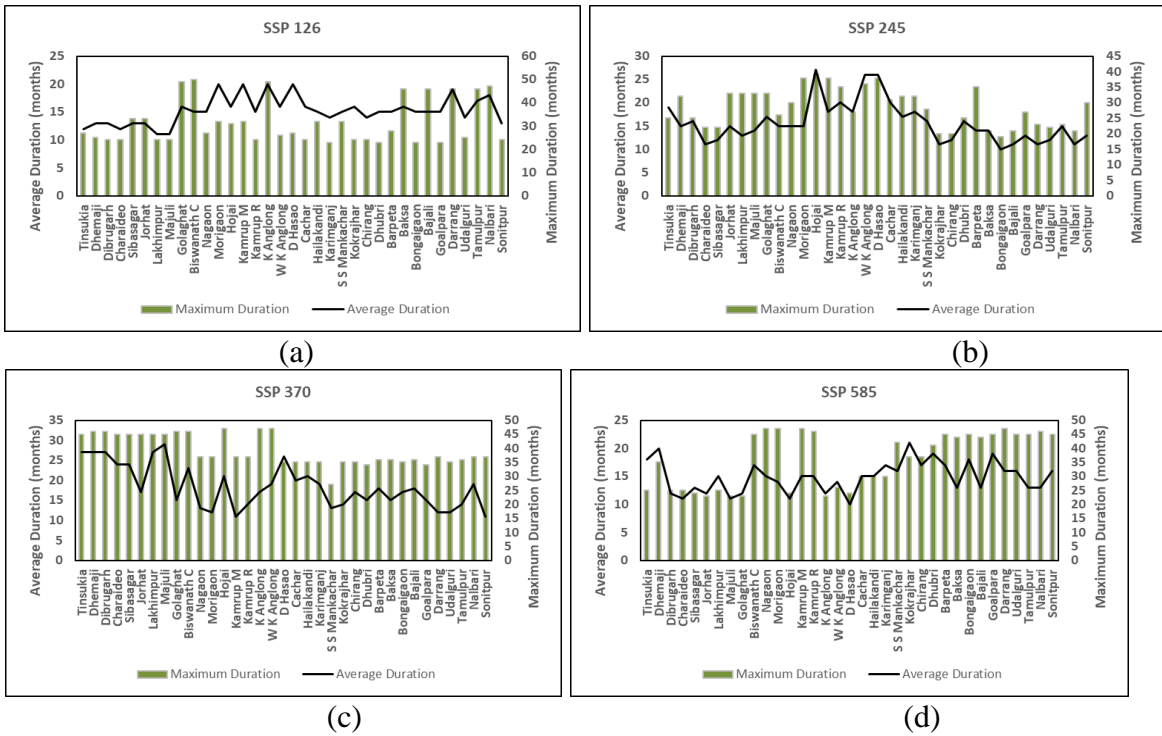


Fig. 4.11: Duration of drought based on SPI of 12 month-timescale for future scenario(a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

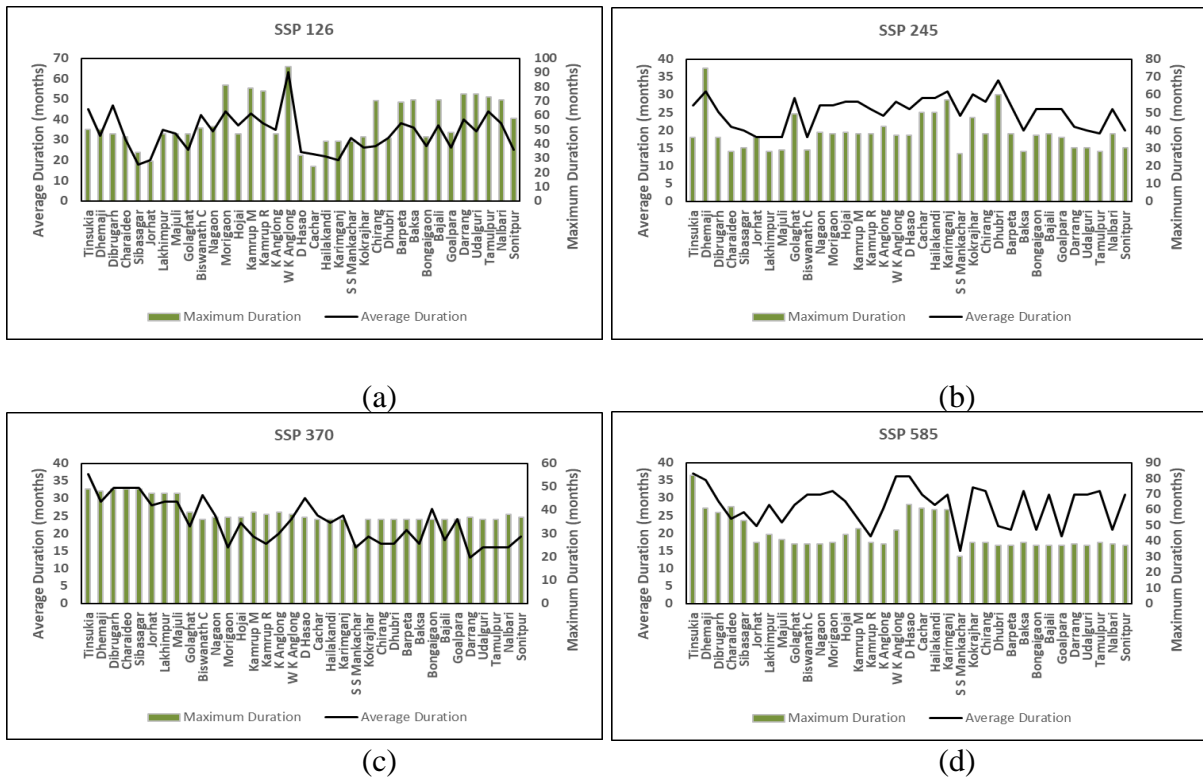


Fig. 4.12: Duration of drought based on SPI of 24 month-timescale for future scenario(a) SSP 1-2.6 (b) SSP 2-4.5 (c) SSP 3-7.0 (d) SSP 5-8.5

4.3 Drought Vulnerability Analysis

Physical and socio-economic parameters explained in Chapter 3 are required to define vulnerability of drought in the various districts of Assam. After collecting and analyzing the data, physical parameters were determined as shown in Fig. 4.13 (a-h).

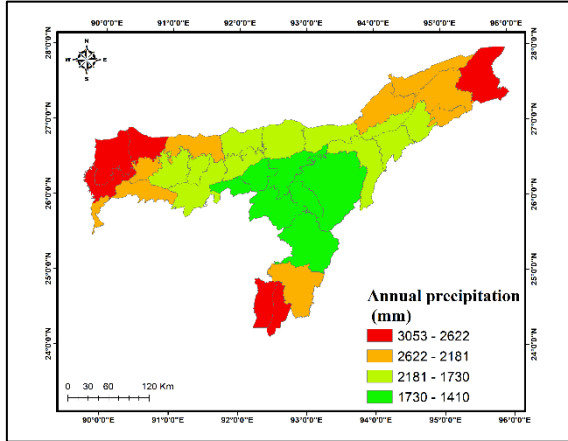


Fig. 4.13 (a) Average annual precipitation

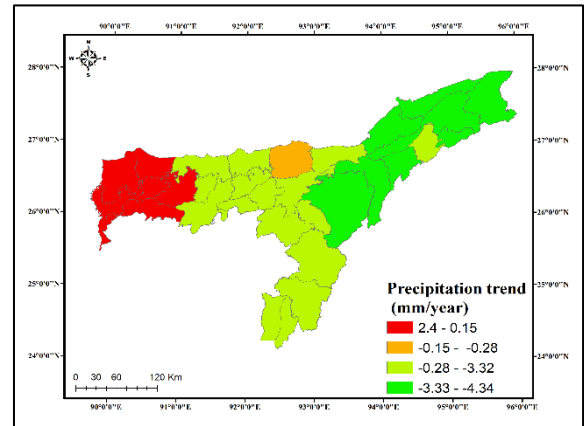


Fig. 4.13 (b) Precipitation trend

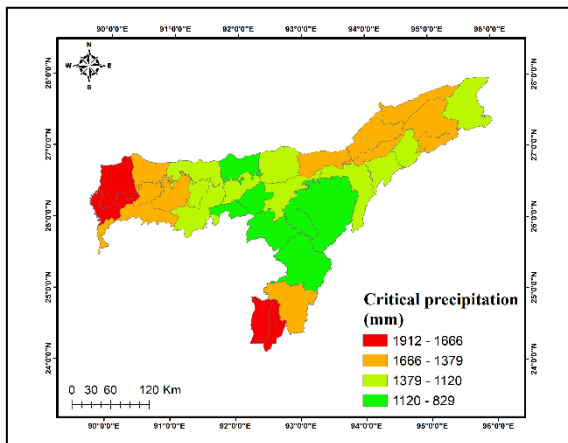


Fig. 4.13 (c) Critical precipitation

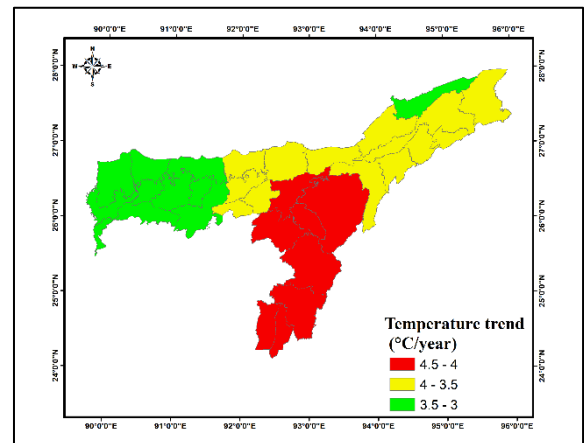


Fig. 4.13 (d) Temperature trend

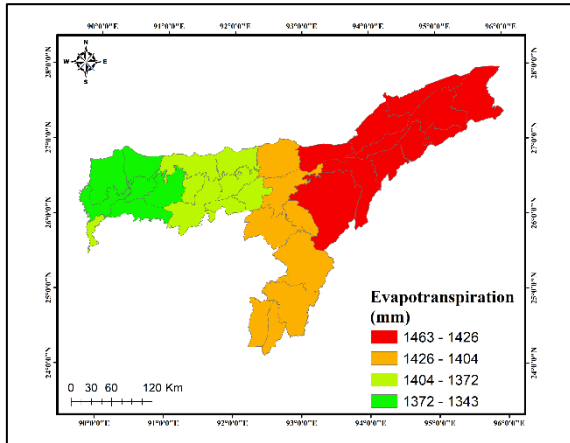


Fig. 4.13 (e) Evapotranspiration

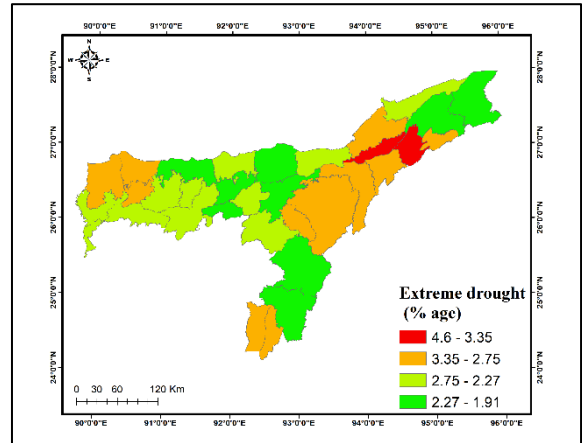


Fig. 4.13 (f) Extreme drought percentage

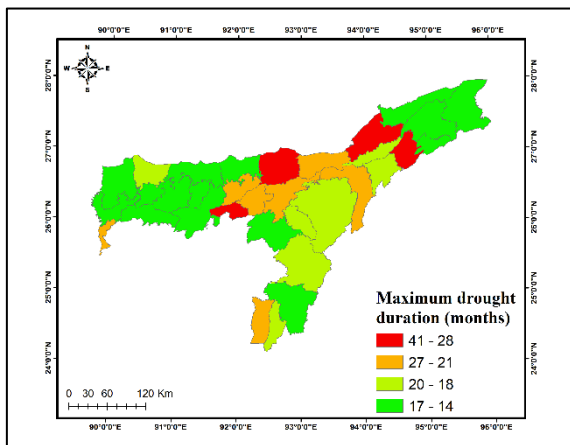


Fig. 4.13 (g) Maximum drought duration

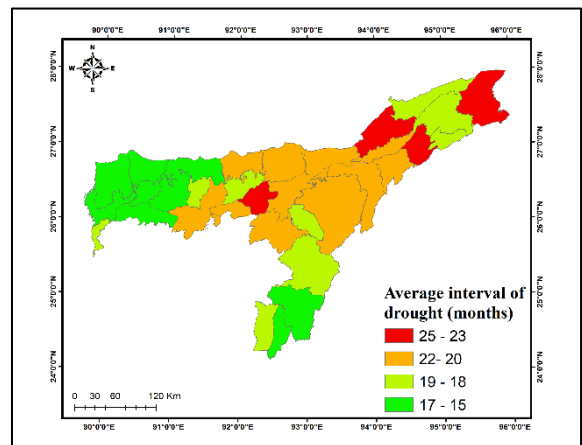


Fig. 4.13 (h) Average inter-arrival time of drought

The annual average precipitation in Assam ranged from about 1400 mm to 2050 mm, in which central region of Assam received lower rainfall. The analysis of precipitation trend in Assam has shown that most of the districts in Assam are on the decreasing trend of rainfall. However, the western region of Assam, comprising of seven districts (Fig. 4.13 (b)), are on the increasing trend of rainfall. The map of critical precipitation of Assam shown in Fig. 4.13 (c) is the map of indicating the rainfall required in each district to avoid occurrence of drought. Temperature in Assam were rising significantly in all the districts of Assam, indicating vulnerability to droughts. The trends of evapotranspiration [Fig. 4.13 (e)] also suggested that for most parts of Assam, particularly eastern region of Assam, are more vulnerable to drought. In this study, only the percentage of extreme drought occurrence was included for vulnerability analysis. In the entire 70 years of study, the extreme drought frequency in the state of Assam ranged from 1.91 % to 4.6 %. Maximum drought duration in

Assam was found to be ranged between 14 and 41 months, while average interval of time between any two drought events in Assam ranged between 15 and 25 months. Physical parameters such as average annual precipitation, precipitation trend, and average inter arrival time of drought have indirect relationships with the vulnerability of drought while the rest of the physical parameters have direct relationship. Likewise, socio economic drought parameters were prepared for drought vulnerability analysis in Assam, for which, thematic maps are shown in Fig. 4.14 (a–h). Socio-economic parameters such as annual replenishable GW and literacy rate have indirect relationship with the vulnerability of the drought, while the rest of the indicators have direct relationships. These relationships of the indicators with drought vulnerability are shown in Table 4.1.

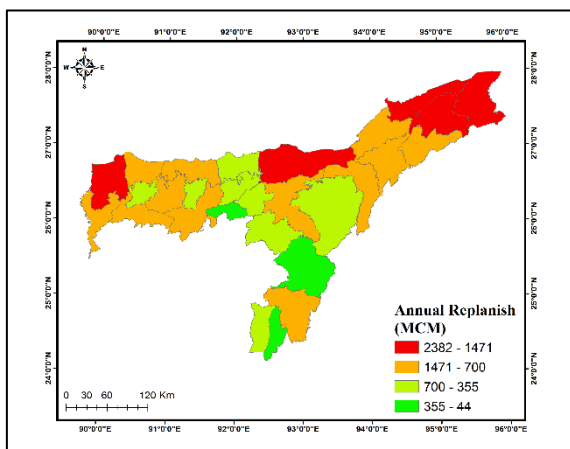


Fig. 4.14 (a) Annual Replenishable GW

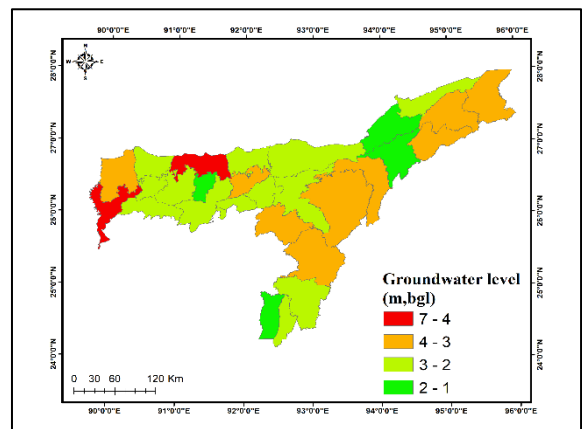


Fig. 4.14 (b) GW level

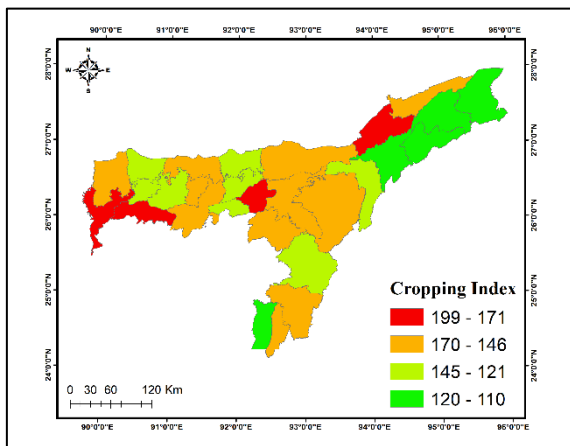


Fig. 4.14 (c) Cropping Intensity

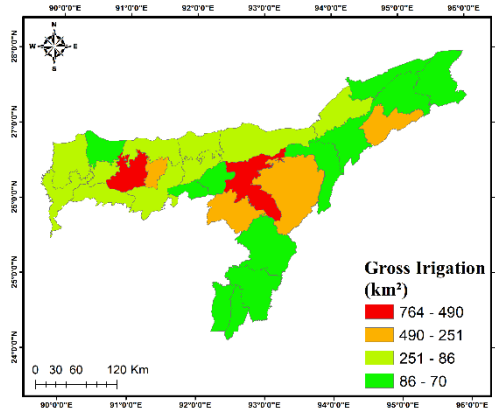


Fig. 4.14 (d) Gross Irrigation

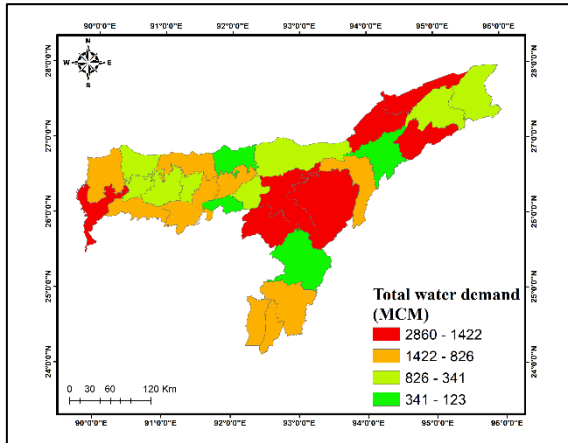


Fig. 4.14 (e) Total Water Demand

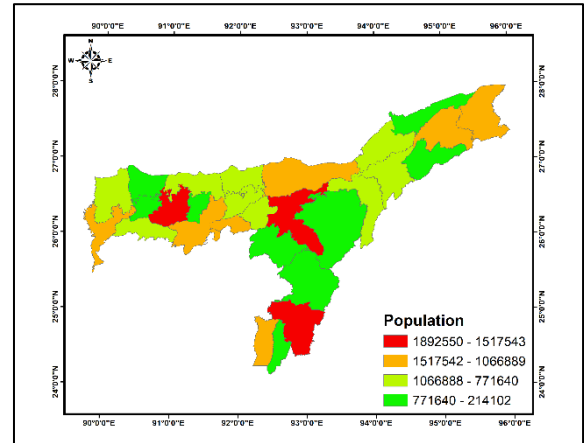


Fig. 4.14 (f) Population

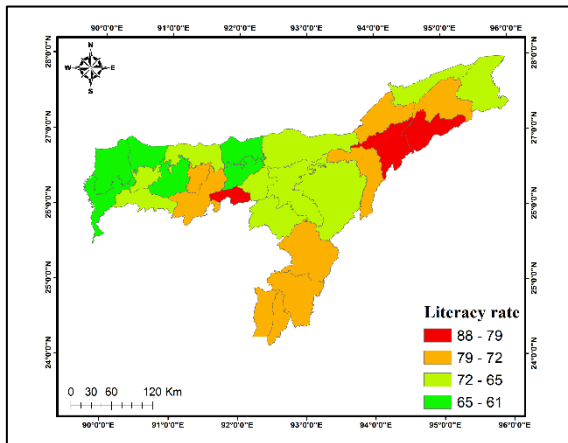


Fig. 4.14 (g) Literacy rate

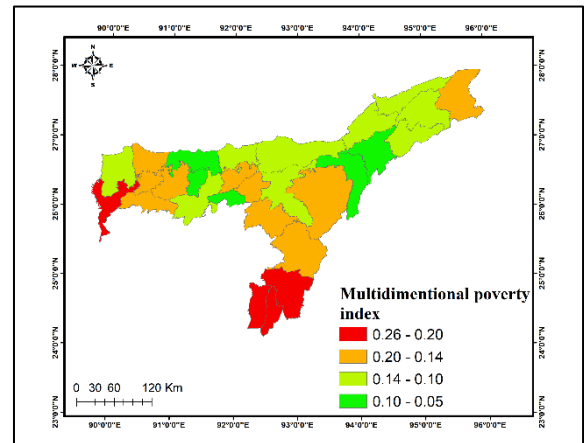


Fig. 4.14 (h) Multi-dimensional Poverty Index

Table 4.1 Functional relationships of the indicators with drought vulnerability

Component	Indicator	Relationship
Social	GW level	Direct
	Annual replenishable GW	Indirect
	Gross irrigation	Direct
	Population	Direct
	Literacy rate	Indirect
	Cropping index	Direct
	Multidimensional poverty index	Direct
	Total water demand	Direct
Physical	Annual precipitation	Indirect
	Precipitation trend	Indirect
	Critical precipitation	Direct
	Temperature trend	Direct
	Evapotranspiration	Direct
	Extreme drought percentage	Direct
	Average interval arrival time of drought	Indirect
	Maximum drought	Direct

Based on the Iyengar and Sudharshan's approach, these physical and socio-economic parameters were weighted as shown in Table 4.2 (physical indicators) and Table 4.3 (socio-economic indicators). In case of physical indicators, highest importance/weights were obtained for extreme drought percentage followed by critical precipitation and average inter arrival time of drought. These three indicators would contribute 44 percent of the weightage in developing the physical drought vulnerability map of Assam. In the case of socio-economic indicators, groundwater level has the highest importance of 16 percent while gross irrigation area in Assam has the lowest importance of just 9 percent.

Table 4.2: Weights of Physical indicators as determined by Iyengar and Sudarshan's method

Sl.no	Indicator	Wi (Physical)
1	Annual Precipitation	0.12
2	Annual Precipitation trend	0.11
3	Critical Precipitation	0.13
4	Temperature trend	0.12
5	Evapotranspiration	0.11
6	Extreme drought percentage	0.18
7	Average interval arrival time of drought	0.13
8	Maximum drought duration	0.10

Table 4.3 Weights of Socio – Economic indicators as determined by Iyengar and Sudarshan's method

Sl.no	Indicator	Wi (Social)
1	Groundwater level	0.16
2	Annual replenish	0.13
3	Gross irrigation	0.09
4	Population	0.14
5	Literacy rate	0.13
6	Cropping index	0.12
7	Multidimensional poverty index	0.13
8	Total water demand	0.10

After weighting the drought vulnerability indicators, physical and socio-economic drought vulnerability maps were generated as shown in Fig. 4.15 and 4.16, respectively. Then, these two maps were overlaid to result in overall drought vulnerability index of Assam (Fig. 4.17). The districts of Assam are categorized into two categories of low drought vulnerability and high drought vulnerability. Then these two maps were overlaid and overall drought vulnerability map of Assam as shown in Fig. 4.17 was generated. The final meteorological drought vulnerability maps of

Assam were prepared by giving equal importance to both physical and socio-economic indicators of droughts. The final drought vulnerability map of the Assam are categories into drought resistant districts and drought susceptible districts.

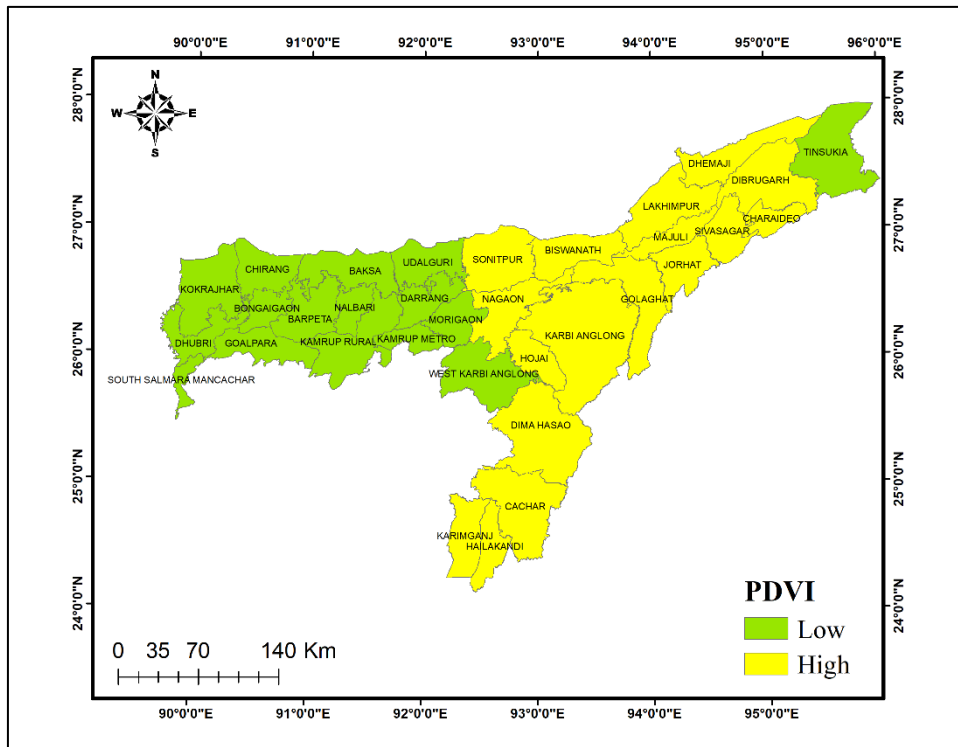


Fig. 4.15 Physical Drought Vulnerability Index of Assam

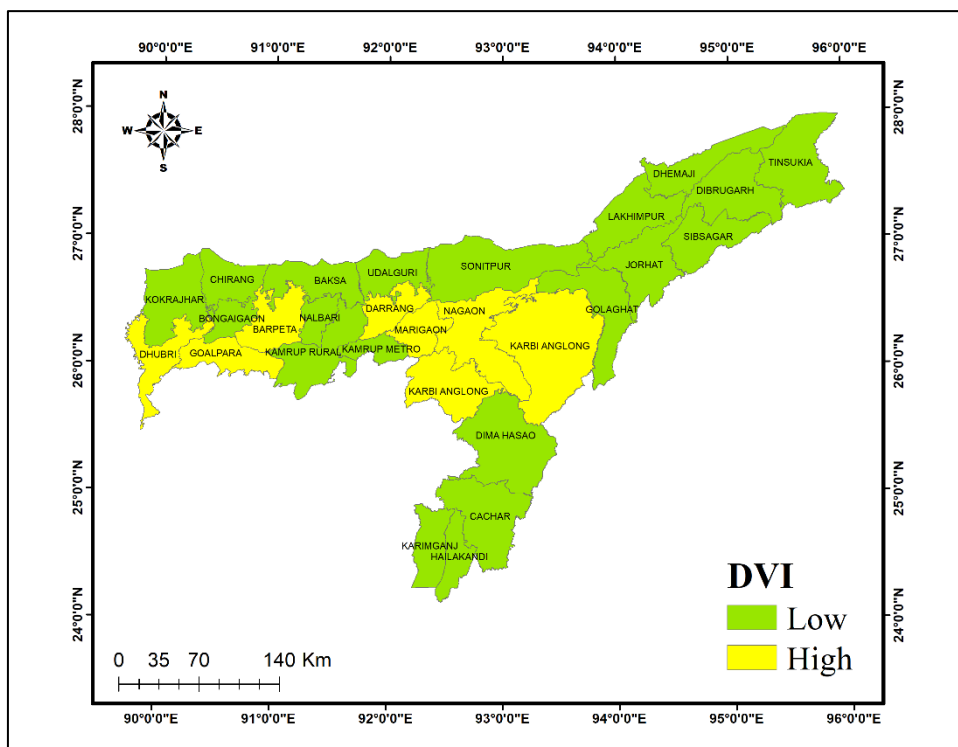


Fig. 4.16 Socio-Economic Drought Vulnerability Index of Assam

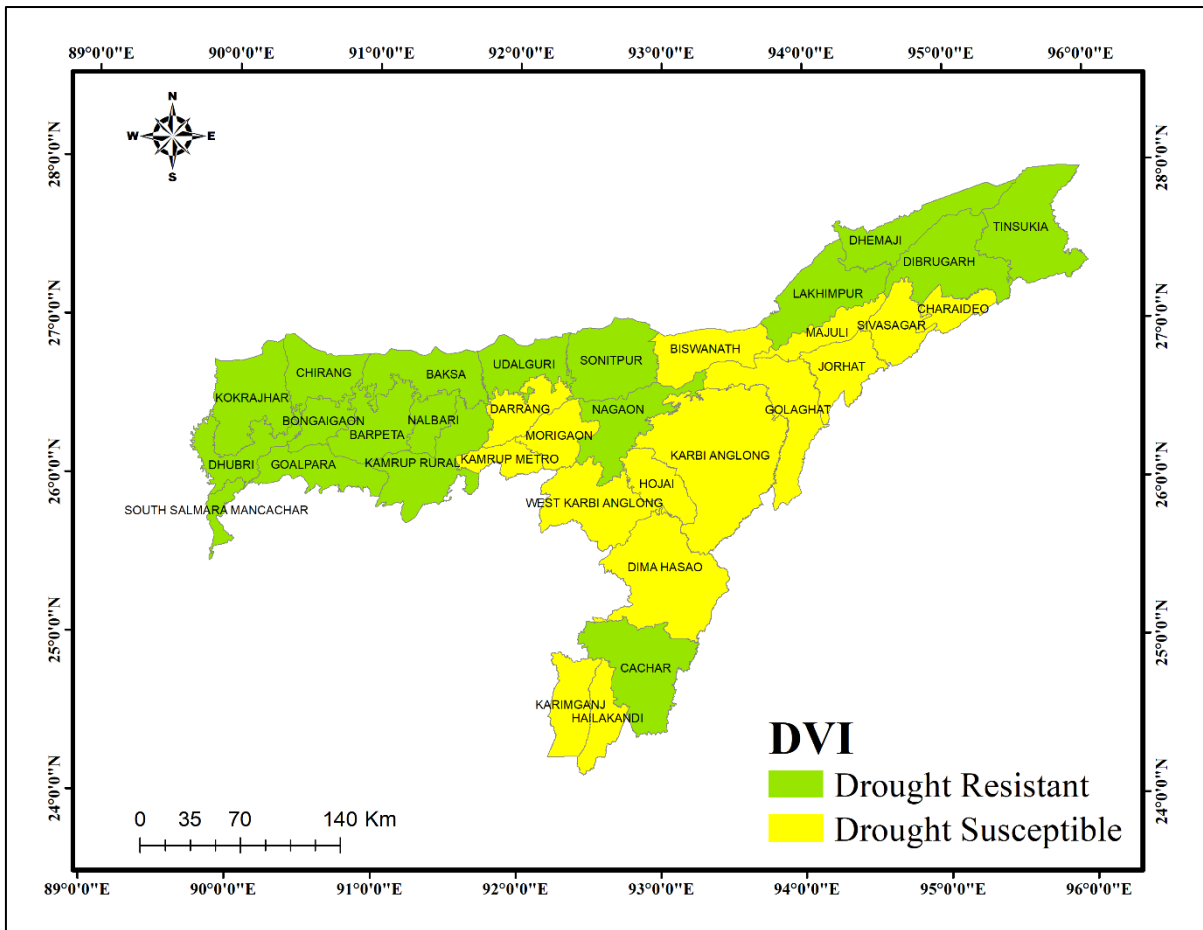


Fig. 4.17 Overall Drought Vulnerability Index of Assam

According to the physical drought indicators, districts of Assam namely, Dhemaji, Dibrugarh, Charaideo, Sivasagar, Jorhat, Lakhimpur, Majuli, Golaghat, Biswanath, Nagaon, Hojai, Karbi Anglong, Dima Hasao, Cachar, Hailakandi, Karimganj, and Sonitpur were found vulnerable to meteorological drought. While districts, viz., Nagaon, Morigaon, Karbi Anglong, Dhubri, Barpeta, Goalpara, and Darrang were found vulnerable to drought from socio-economic perspective. Newly formed districts which are part of these vulnerable districts were Hojai, West Karbi Anglong, and South Salmara Mankachar. After analyzing the statistics, it was found that nine districts, viz., Tinsukia, Kamrup Metro, Kamrup, Kokrajhar, Chirang, Baksa, Bongaigaon, Udalguri, and Nalbari were not susceptible to any of the physical as well as socio-economic drought vulnerability indicators. Out of the 33 districts in Assam, 21 districts as shown in Figs. 4.15 and 4.16 were found to be susceptible to drought from at least either of the two categories of indicators. Three districts namely Nagaon, Hojai, and Karbi Anglong were found vulnerable to both physical and socio-

economic drought indicators. The overall drought vulnerability map (as shown in Fig. 4.17) indicates that 15 districts out of 33 districts are vulnerable to drought. These districts were Charaideo, Sivasagar, Jorhat, Majuli, Golaghat, Biswanath, Morigaon, Hojai, Kamrup Metro, Karbi Anglong, West Karbi Anglong, Dima Hasao, Hailakandi, Karimganj, and Darrang. If we considered all the drought vulnerability maps (Physical, Socio-economic and Overall indicators), eight districts (Tinsukia, Kamrup, Kokhrajhar, Chirang, Baksa, Bongaigaon, Udalguri and Nalbari) are drought resistant districts. Whereas Hojai and Karbi Anglong were found most susceptible to drought in the state. Kamrup Metro which resides the most population in the state was found to be not susceptible to drought either physically or socio-economically alone, however, this district was found to be vulnerable to drought if both these indicators were considered altogether. In short, Assam's 15 districts are drought susceptible districts while 18 districts are drought resistant districts (Fig. 4.17). While classification of the overall drought vulnerability map in Assam, the value of drought vulnerability index above 0.5 were considered drought susceptible districts and vice versa. The minimum and maximum value of the drought vulnerability index are respectively 0.35 and 0.66. Therefore, 15 vulnerable states found in this study are in low to moderately vulnerable conditions. However, considering the climate change, in which the temperature trend is more likely to increase associated with shorter and intense rainfall found in other studies, these 15 districts may be taken up as priority districts for drought mitigation and adaptation strategies.

Limitations:

Drought indicated in this study are results of primarily lack in precipitation alone, in which, nearby waterbodies, groundwater level scenarios, water supply (irrigation & domestic) provision by either government, public and private were not considered. For example, Majuli which is an island in the mid of the Brahmaputra River was found to be vulnerable to drought. The meteorological/rainfall regime in this district was found to be affected by decrease precipitation well below its normal often times. Hence, this district was found vulnerable to drought, however, due to its vicinity with the waterbodies and low GW level, and with efficient management of GW resources, it can overcome the vulnerability condition of drought comfortably. These insights must be considered while implementing any drought intervention in the states. Another important limitation of the study is that the evapotranspiration process was ignored in determining the meteorological drought,

however it was considered during vulnerability assessment. Further, the socio-economic parameters utilized were acquired from open-sources, in which their reliability were to verified in the present study. Again, data such as gross irrigation and cropping index were utilized, however, it is difficult to verify the efficiency of such system being adopted at the ground level. The results of drought vulnerable districts are determined based on the assumption that all data are efficiently being adopted in the study. It was further acknowledged that, groundwater lift irrigation systems are limited in Assam. This resource can be utilized efficiently to cater soil moisture deficit by considering irrigation as an efficient strategy as adaptation to climate change.

The following initial conclusions can be drawn:

1. This study found that, more than 90% of the total annual rainfall occurs in JJAS & MAM, suggesting great dependency on these two seasons for growth of agriculture sectors.
2. This also led to suggestion that there is an urgent need to turn on the irrigation-based system from the traditional rainfed ecosystems.
3. The dominant positive SPI series also suggested that there is enough potential for development of irrigation system and recharge the groundwater resources.
4. Rainfall is projected to be decreased during 2026-2055 in majority of the districts in all four climate (SSPs) scenarios. In the SSP 370 scenario, all districts of Assam is projected to decrease in annual rainfall in the range of 2-5%.
5. The average percentage of drought occurrences is about 15% of the total time, which is almost very similar to the share of wet conditions. Between 1951 and 2020, on an average, 122 of the 838 months were fall under the drought condition.
6. Among all the districts, Biswanath was found to be affected most (143 months) while Karbi Anglong was the least affected one.
7. Further, in terms of severity, Sivasagar district was found to be affected by the greatest number of droughts of extreme nature.
8. The average duration of drought in Assam was found to be about 5.2 months, in which Sonitpur, Kamrup Metro, Lakhimpur, Sivasagar, and Bishwanath Chariiali districts were shown characteristics of larger drought duration.
9. Between 2026 and 2055, the average percentage of drought under SSP126, SSP245, SSP370, and SSP585 were projected as approximately 16%, 17%, 18%, and 17% respectively.
10. Roughly, about 15-20% of the total 30 years under investigation for all future climate scenarios will be under drought conditions.
11. Certain districts such as Tinsukia, Dibrugarh, Majuli, Nagaon, Morigaon, Hojai, Dima Hasao, Cachar, Hailakandi, and Karimganj would experience frequent drought under all climate scenarios.
12. Assam districts, including Dhemaji, Dibrugarh, Charaideo, Sivasagar, Jorhat, Lakhimpur, Majuli, Golaghat, Biswanath, Nagaon, Hojai, Karbi Anglong, Dima

Hasao, Cachar, Hailakandi, Karimganj, and Sonitpur, are vulnerable to meteorological drought based on physical indicators.

13. Thirteen districts, including Nagaon, Morigaon, Karbi Anglong, Dhubri, Barpeta, Goalpara, and Darrang, were identified as vulnerable to drought due to socioeconomic factors. Hojai, West Karbi Anglong, and South Salmara Mankachar are the newly constituted districts that make up these vulnerable districts.
14. Statistical analysis revealed that nine districts (Tinsukia, Kamrup Metro, Kamrup, Kokrajhar, Chirang, Baksa, Bongaigaon, Udalguri, and Nalbari) were not vulnerable to physical or socioeconomic drought indicators.
15. Out of 33 districts in Assam, 21 were identified as vulnerable to drought based on one or both categories of data. While three districts, Nagaon, Hojai, and Karbi Anglong, were identified as sensitive to both physical and socioeconomic drought indicators.
16. Of the 33 districts, 15 are at risk of drought, according to the overall drought vulnerability map. These districts were Dima Hasao, Hailakandi, Karimganj, Darrang, Karbi Anglong, West Karbi Anglong, Kamrup Metro, Jorhat, Majuli, Golaghat, Biswanath, Morigaon, Hojai, and Sivasagar.
17. These 15 districts might be chosen as priority districts for drought prevention and adaptation strategies in light of climate change, which is predicted to cause an increase in temperature trends linked to shorter and more intense rainfall identified in other studies.
18. It is concluded that districts with a greater number of droughts, and greater duration of drought spells needed to set up drought mitigation planning. The findings of this study will aid the efforts being made by the Assam Disaster Management Authority, Agriculture Department, Irrigation Department, and Water Resources Department in proper planning, action, and management of multiple entities with regard to the state's drought.

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