# CHAPTER 3

# Study Area and Data Used

## 3.1 Overview

The climate, topography, agroclimatic zone, geology, and other physical characteristics of the study area are thoroughly described in this chapter. Additionally, various datasets and programming tools used have been discussed and presented. Uttar Pradesh is the fifth-largest economy in India. It has a gross domestic product of $15.42 lakh crore (US$220 billion) and a GDP per person of $61,000 (US$860). Nearly 55% of workers depend on agriculture for their livelihood, whereas the sector contributes only 27.5% to the gross state domestic product. There is limited infrastructure for irrigation in Uttar Pradesh (India). Therefore, much of the farmed area depends on precipitation alone for sustenance. Nearly half of the Uttar Pradesh workforce is employed in agriculture, making climate change and its impact on water supplies an increasingly pressing issue.

The climate over Uttar Pradesh is spatially variable, with a predominantly humid subtropical climate and a hot semi-arid climate in parts of the state's western region. The states experience cyclones, floods, and droughts of varying severity on an annual basis. Repeated occurrence of climate extremes is causing significant property damage, the loss of life, and harm to agricultural output. Therefore, it must evaluate the characteristics of climatic extremes over the study region. This study analyses meteorological drought characteristics in Uttar Pradesh under observed and changing climate conditions. In addition, a comprehensive evaluation of dry and wet events characteristics in the study region was conducted over Uttar Pradesh. The significance of districts and their equitable distribution in Uttar Pradesh led to the creation of 18 divisional zones across the state. The 18 synoptic locations were selected spatially to represent the whole state. Therefore, these 18 synoptic locations have been chosen to better comprehend the spatial and temporal variability of meteorological variables (Temperature, Precipitation, and Potential Evapotranspiration) and meteorological drought in the observed as well as in changing climate scenarios.

## 3.2 Characterization of the Study Area

Uttar Pradesh is situated in the north-central part of India and spans an area of 243,286 $km^2$ (7.33% of the country's total area). Uttar Pradesh is the country's fourth largest state, with the highest population of 19.98 Crores according to the 2011 census. Nine other states landlock its international boundary with Nepal are Uttarakhand, Bihar, Jharkhand Chhattisgarh Madhya Pradesh, Rajasthan Haryana, and the national capital territory of Delhi. It covers the area between 23$^o$ 52'N to 31$^o$ 28' N latitude and 77$^o$ 51' E and 84$^o$38'E longitude. Uttar Pradesh is divided into 18 administrative divisions were chosen as synoptic locations are Agra, Allahabad (Prayagraj), Aligarh, Azamgarh, Bareilly, Basti, Chitrakoot, Faizabad (Ayodhya), Gonda, Gorakhpur, Jhansi, Kanpur, Lucknow, Meerut, Moradabad, Mirzapur, Saharanpur, and Varanasi portrayed in Figure 3.1. Uttar Pradesh's landscape is divided into three regions: the northern Siwalik foothills of the Himalayas, the Terai region, and the Gangetic plain, which occupies most of the central part and is characterized by highly fertile alluvial soils, flat terrain interspersed with ponds, lakes, and rivers, and a 2 m/km slope. The Vindhyan range and plateau in the southern part of Uttar Pradesh is characterized by the rock strata; varied topography of hills, plains, valleys, and plateaus; water scarcity. Nearly 31 rivers flow through Uttar Pradesh in which, the Ganges, Yamuna, Saraswati, Betwa, Sarayu, and Ghaghara being the large rivers of the study area. The Ganga is India's largest river basin, draining 8,61,452 $km^2$, nearly 26% of India's total geographical area. The Ganga is the transboundary river that flows through India and Bangladesh in Asia. The Gangetic basin flows through 11 Indian states, including Uttar Pradesh. The Himalayas border the basin on the north, the Aravalli on the west, the Vindhyan and Chhota Nagpur plateaus on the south, and the Brahmaputra Ridge on the east. The Gangetic Plains of Uttar Pradesh include the Upper-Gangetic Plains and a part of the Middle-Gangetic Plains.

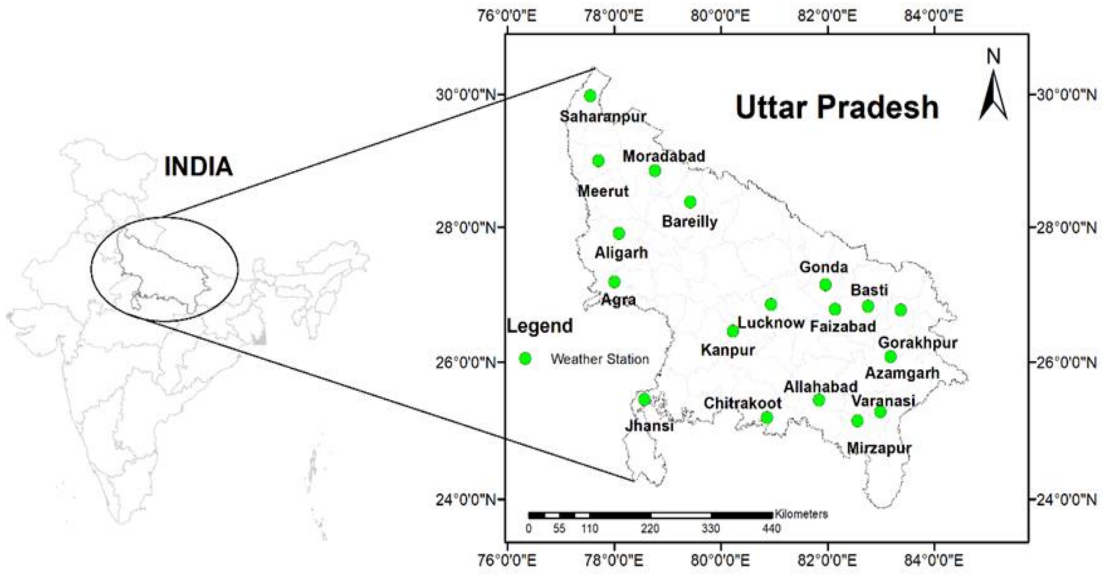


**Figure 3.1** Synoptic location of the study area (Uttar Pradesh state and its divisions) along with Meteorological stations.

### 3.2.1 Climate

The climate is primarily humid subtropical with dry winters (Cwa-type) in most of the U.P (Tropical Monsoon) and hot semi-arid (BSh-type) in parts of the western region. The climate varies across the state; however, the Indo-Gangetic Plain, which covers a large area, has a primarily uniform climate with minor regional variations. In India, Uttar Pradesh is a state of extremes, with temperatures ranging from 0°C to 50°C and cyclical droughts and floods caused by less predictable rains. The state has scorching hot summers and bitterly cold winters. The hottest months are usually May and June, with the coldest months being December and January. Due to a lack of clouds and radiation from stony soils or outcrops, temperatures are much higher locally. Squalls are common in the summer, forming a dense cloud of dust that becomes hazy throughout the day. The average annual temperature is higher than 27°C, and there is a wide temperature range because the mean monthly values significantly differ from the annual averages. Summer temperatures average around 35°C, with highs of 45°C possible in May and June. According to IMD, four climatological seasons are defined for statistical analysis: Season 1 refers to the pre-monsoon (summer) season (March to May); season 2 resembles the monsoon (rainy) season (June to September); season 3 resembles the post-monsoon season (October to November); and season 4 corresponds the winter season (December to February). Monthly precipitation time series is assessed for all seasons, (i) Monsoon, (ii) Pre-monsoon, (iii) post-Monsoon, (iv) Winter, and (v) Annual time series.

The average annual rainfall over the districts of the U.P. ranges between 896 to 1667 mm, and most of the rain occurs during the monsoon season. Western U.P. receives an average annual precipitation of 750 mm, whereas eastern U.P. receives an average annual rainfall of 1250 mm. Precipitation significantly varies spatially over Uttar Pradesh demonstrated in Table 3.1. The monsoons bring temperatures down to approximately 23°C-27°C between June and September, with relative humidity ranging between 68% to 80 %. During the Southwest monsoon (June, July, August, and

September) state receives 84.4 % rainfall (799mm) of annual rainfall (946 mm), which considerably decreases towards the western region of the state where Gorakhpur district has the highest mean southwest monsoon rainfall (1117.5 mm), whereas Raebareli district has the lowest mean southwest monsoon rainfall (420.8 mm). Winter rain is provided by a few shallow westerly depressions, which is highly beneficial for the rabi crop.

## 3.3 Agroclimatic Zones

The Food and Agriculture Organization (FAO) 1983 has defined an "Agroclimatic zone" as a land unit in major climates suitable for a specific range of crops and cultivars. Planned management of regional resources aims to protect natural resources and the environment while providing enough food, fiber, fodder, and fuel. Soil types, rainfall, temperature, and water availability are the primary determinants of vegetation type in agroclimatic conditions. The state's total cultivated area is 16.33 lakh ha, with a gross cropping area of 255.24 lakh ha and a cropping intensity is 153%. Agriculture contributes the most to the Gross State Domestic Product (GSDP). Given the size of the state and the wide variations in its temperature, topography, and geography, Uttar Pradesh is divided into nine agroclimatic zones, as detailed in Table 3.1. Bundelkhand region is prone to drought occurrence of various categories, whereas the eastern region of U.P is frequently flooded and has flash drought conditions.

**Table 3.1 Agroclimatic zones of Uttar Pradesh**

| Agroclimatic Zone | Districts/Region | Climate | Soil Type | Annual Rainfall (mm) |
|---|---|---|---|---|
| **Tarai Zone** | Saharanpur etc | moist sub humid | Alluvial and clayey alluvial | 1150mm |
| **North Eastern Plains Zone** | Basti, Gonda, Gorakhpur etc | moist sub-humid to dry sub-humid | sand, alluvial, and clayey. | 1,210 mm |
| **Eastern Plain Zone** | Azamgarh, Faizabad, Varanasi etc | dry to moist subhumid | sand, alluvial, and clayey | 1,025 mm |
| **Vindhyan Zone** | Mirzapur and Sonbhadra | dry to moist subhumid | undulating and rocky, light black clayey and red alluvial | 1100mm |
| **Central Plain** | Allahabad (Prayagraj), Lucknow, Kanpur etc. | dry sub-humid to semi-arid | saline and sodic soil are the main issues. | 850-979 mm |
| **Central Western Plain** | Bareilly, Meerut etc | dry sub-humid to semi-arid | Clayey-alluvial Sandy alluvial, sandy | 600-959mm |
| **Western Plains Zone** | Bareilly, | Sub-humid to semi-arid | Sandy, clayey soil | 700-1000mm |
| **South-Western Plains** | Aligarh, Agra etc | Semi-arid | Sandy, alluvial, clayey sandy, clayey | 700mm |
| **Bundelkhand Zone** | Jhansi, Chitrakoot etc | hot semi-arid | Rocky, soil erodes rapidly | 800-1000mm |

## 3.4 Geology

The state of Uttar Pradesh (U.P.) is located in northern India. Its 2,40,928 square kilometers territory is made up of various rock types ranging from the oldest Archean metamorphites to the youngest Quaternary alluvium. Geographically, the majority of this state is covered by the alluvium of the Ganga Plain, which divides the Himalayan or Extra Peninsula from the Peninsula of India and the rest of India. The Archean to Mesozoic period rocks of the peninsular region of Uttar Pradesh are exposed. The state may be classified as either an Indo-Gangetic alluvial plain or hills/plateau based on its geology and geomorphology. In the north, an Indo-Gangetic alluvial plain occupies nearly two-thirds of the state. This area lacks a significant mineral resource. The Bundelkhand granite and Vindhyan sandstone plateau in the southern highlands. Approximately 51,393 square kilometers of land surrounding the southern boundary of the state is comprised of hard rock, which contains the state's mineral reserves. The Indo-Gangetic alluvial plain, which occupies 1,89,975 $km^2$ of the state's central and northern regions, consists of a thick layer of Pleistocene and recent sediments of an unconsolidated character. Its northern boundary with the Himalayas is considered promising for the hunt for petroleum, although no mineral deposits are known to exist there. However, it is a common practice in the building business to employ riverbed rocks, sand, and gravel from the plains.

## 3.5 Meteorological Data Sources

The meteorological (precipitation and temperature) dataset is required for the current study to monitor and assess drought characteristics over historical and future time periods. The drought indices SPI was calculated with precipitation as an input climatic variable, whereas SPEI required precipitation (P) and potential evapotranspiration (PET). PET was calculated in this study using the Thornthwaite method, which includes average temperature as the input variable. In addition, dry and wet characteristics were estimated based on SPEI at a monthly timescale. Precipitation and temperature have the most significant influence on water availability compared to other hydro-climatic elements. A rise in temperature causes water to evaporate at an alarming rate resulting in the dropping of reservoir level rapidly. The situation worsens dramatically when a rise in temperature gets coupled with a lack of rainfall. So, the researchers focused on weather conditions by measuring precipitation and temperature.

Figure 3.1 details the 18 synoptic locations situated over Uttar Pradesh, India. Monthly time series of precipitation and temperature for 48 years (1971–2018) and daily time series of precipitation and temperature for the years (1971 to 2005) were obtained from the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology, and the India water portal (http://indiawaterportal.org/metdata) to determine the temporal changes in long-term climatic variables over the study area. A simple summation process was used to convert the monthly precipitation and temperature time series into seasonal and annual time series. Monthly data were used to calculate the annual precipitation magnitude for each district as well as dataset characteristics such as mean, standard deviation (SD), coefficient of variation, and percentage contribution to annual precipitation. Precipitation, average temperature, and potential evapotranspiration were considered for trend analysis. The four climatological seasons are considered for statistical analysis: season 1 refers to the pre-monsoon (summer) season (March to May); season 2 resembles the monsoon (rainy) season (June to September); season 3 resembles the post-monsoon season (October to November), and season 4 resembles the winter season (December to February).

### 3.5.1 Data used in SDSM

The daily precipitation, maximum temperature (Tmax), and minimum temperature (Tmin) from the CanESM2 model were downscaled using SDSM from 2019 to 2050 to assess the likelihood of drought in the near future. Daily precipitation, maximum temperature (Tmax), and minimum temperature (Tmin) data records sourced from India Meteorological Department (IMD), Pune, were utilized as predictand variables for 18 synoptic stations from 1971 to 2005. The Second-Generation Canadian Earth System Model (CanESM2) is the climate model used in this investigation. The

CanESM2 output at a station is utilized as an input to SDSM for downscaling. The large-scale atmospheric predictor variables provide the primary input for the SDSM model. Large scale atmospheric variables provided by the NCEP/NCAR reanalysis were used to create statistical relationships with the station predictand data. The Canadian Centre for Climate Modeling and Analysis (CCCma) generates 26 predictors for CanESM2 and NCEP/NCAR data from 1961 to 2005. The SDSM website (http://co-public.lboro.ac.uk/cocwd/SDSM/), which was created from the reanalysis data of NCEP, was therefore used to acquire a total of 26 standardized large-scale surface and atmospheric predictor variables (Table 4.3) for the GCM model over the same time period (1971-2005). Section 4.6.1 provides a detailed description of the data used in the downscaling procedure. Under RCP 4.5 and RCP 8.5, simulated data from 2019 to 2050 was obtained using SDSM downscaling.

## 3.6 Software Used

### 3.6.1 Programming Tools

The spatiotemporal variability of the meteorological variable and the drought characteristics were evaluated using various programming methods. MATLAB, programming, and a numeric computing platform have been used to analyse data, design algorithms, and create models and graphical representations. Different R packages were employed in this work for drought evaluation and statistical analysis of time series data. In this work, the R package "SPEI" was used to calculate the SPI and SPEI at various timescales. Origin lab 2019 was used to create heatmaps and several visualizations.

### 3.6.2 Statistical downscaling model (SDSM)

SDSM version 4.2 (https://sdsm.org.uk/software.html) was utilized in this study to statically downscale the projection from the second-generation Canadian Earth System Model (CanESM2). CanESM2 is one of the GCMs used in Phase 5 of the Coupled Model Inter-comparison Project (CMIP5). SDSM user-friendly, freely available statistical downscaling algorithms generate high-resolution monthly climate information from coarse-resolution climate model (GCM) simulations. Furthermore, the software uses weather generator algorithms to create a range of simulated daily weather sequences (ensembles). The CanESM2 and NCEP reanalysis predictors are exported to the SDSM directory for model calibration and projection.

### 3.6.3 Image processing & Geospatial analysis

Geographic Information System (GIS) is used for various tasks, including making and using maps, digitizing and compiling geographic data, analysing mapped data, sharing and discovering geographic data, integrating maps and geographic information into various applications, and managing geographic data in a database. ArcGIS 10.7.1 is an ESRI software package consisting of a collection of geographic information system (GIS) products used in this study. Spatial interpolation techniques estimate the value on the surface at locations where no observed data exists based on known data values (observations). Several spatial interpolation methods are available for spatial analysis, including inverse distance weighting (IDW), Splines, and kriging. This study used the IDW approach to spatially interpolate drought characteristics such as duration, intensity, frequency, and drought trend across the study area. In this interpolation technique, the contribution of each input (control) point is weighted by the normalized inverse of the distance between the control point and the interpolated point. IDW states each input point has a local influence that decreases with distance. It gives more weight to points closer to the processing points than to those further away. The output value for each location is computed by using a predefined number of points or all points within a predefined radius. The power parameter in the IDW interpolator controls the significance of the surrounding points on the interpolated value. Distanced points have less influence as power increases. We employed the IDW technique to assess drought characteristics over the region using drought indices (SPI and SPEI). The data must be spatially interpolated at the smaller grid due to the scarcity of precipitation and temperature data and the unequal distribution of rain gauge stations in the study area. Therefore, the total area is divided into 18 divisions and used for this study. ArcGIS 10.7.1 interpolated the trend and drought characteristics of SPI and SPEI time series data from 18 stations over 48 years using the inverse distance weighting (IDW) method (1971-2018).

## 3.7 Summary

This chapter describes the research location, climate, agroclimatic zone, data source, and programming tool. Uttar Pradesh's emphasis on agriculture requires precise prediction and projection of climate extremes. The designated study area ranges from humid subtropical with dry winter (Cwa) to hot semi-arid (BSh) in the Western U.P. Summer features three different seasons, with daily maximum temperatures ranging from 42°C to 45°C and a low average of 28°C. During the Southwest monsoon, the state receives 84.4%, which decreases in the west. Meteorological data, including precipitation and temperature, were collected at monthly and daily timescales. Rainfall and temperature data at a monthly scale are taken from IMD, Pune, and India water portals for all 18 districts from 1971 to 2018. All time-series data were examined for missing values, replaced with average values from surrounding locations, and data quality was rigorously monitored. Daily precipitation, Tmax, and Tmin data were recorded from IMD, Pune, from 1971 to 2005 for 18 synoptic stations. Moreover, the reanalysis data are considered surrogates for observed data for the predictor. Therefore, 26 standardized large-scale surface and atmospheric predictor variables for the GCM model for the same time period (1971–2005) were obtained from the SDSM, which were developed from the reanalysis data of NCEP. Data was downscaled from GCM using SDSM for the future period for climate scenario RCP 4.5 and RCP 8.5. SPI and SPEI were estimated at 3, 6, 9 and 12-month timescale using R studio using package "SPEI." The MK test was implemented on precipitation, temperature, PET, SPI, and SPEI time series programmed in MATLAB 2019. The widely used interpolation technique generated the Spatial maps, i.e., Inverse Distance Weightage (IDW) in ArcGIS 10.7.1. SDSM version 4.2 tool is used for statistical downscaling of projection from (CanESM2) for the assessment of drought characteristics in the near future.