Chapter 3
STUDY AREA AND DATASETS

3.1 General

The geological conditions, climate, topography, 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. The Damodar River Basin, situated in eastern India, is a significant geographical and hydrological region. The basin, a sub-basin of the Ganges River, is characterized by a funnel-shaped topography. It spans Jharkhand and West Bengal, encompassing diverse landscapes and ecosystems. The Damodar River, a major tributary of the Ganges, flows through this basin, playing a crucial role in the region's water resources and ecosystem dynamics. The Damodar River Basin is renowned for its rich mineral resources, including coal reserves, fire clay, bauxite, mica, and limestone. This abundance of natural resources has historically influenced the region's economic activities and industrial development. However, exploiting these resources has also resulted in environmental challenges, such as water pollution from industrial effluents and coal mining activities. The basin's hydrology is impacted by monsoon-dominated climate patterns, leading to annual floods of varying magnitudes in the lower basin areas. The existing canal system, streams, and the Damodar River have encountered challenges due to over-siltation and drainage congestion, affecting the region's flood management strategies. Additionally, dam-induced changes have modified the Damodar River's ecomorphological behaviour and fluvial functionality, influencing its overall hydrological dynamics. The

3.2 Study Area

Damodar River Basin is a crucial water source and supports diverse ecosystems and biodiversity. Studies have highlighted the impact of coal mine water irrigation on soil health and crop growth in the region, underscoring the necessity for sustainable agricultural practices. Furthermore, the basin's geological characteristics, including shale gas potential and organic richness, have attracted research attention for energy exploration and environmental management. In recent years, the Damodar River Basin has faced environmental challenges, including water quality degradation from industrial effluents and urban sewage (Chakraborty et al., 2021; Chakraborty et al., 2021). Efforts towards eco-restoration and water quality assessment have become imperative to mitigate the adverse impacts of pollution and ensure the sustainability of the basin's ecosystems (Chakraborty et al., 2021; Sreeja et al., 2012). Overall, the Damodar River Basin is a complex and dynamic region where geological, hydrological, and anthropogenic factors intersect to shape its landscape and environmental conditions. Understanding the basin's diverse characteristics and challenges is crucial for effective water resource management, environmental conservation, and sustainable development in the region. The climate over the Damodar River basin is spatially variable, with a predominantly humid subtropical climate and a hot semi-arid climate in parts of the basin's western region. The DRB experiences cyclones, floods, and droughts of varying severity annually. 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 trends in multiple climate extremes in DRB and 3D pattern characterization of multiple extremes over DRB. In addition, a comprehensive analysis of the impacts of extreme rainfall on crop yield in the study region was conducted over DRB. The 8 synoptic locations were selected spatially to represent the whole basin. Therefore, these 8 synoptic locations have been chosen to comprehend better the spatial and temporal variability of meteorological variables and meteorological drought indices in the current and changing climate.

3.2.1 Physical Characteristics of the study area

The Damodar River Basin in India showcases a variety of physical characteristics that influence its hydrological processes and environmental dynamics. The basin's topography significantly impacts flow patterns and habitat quality within the river system. Known for its funnel-shaped structure, the Damodar River Basin contributes to the region's high-moderate flash flood zone. The lower basin of the Damodar River, encompassing Bardhaman, Hooghly, and Howrah districts of West Bengal, faces annual floods and overflow conditions due to over-siltation and drainage congestion, leading to a reduced carrying capacity for excess water Ghosh & Mistri (2015).

Geologically, the Damodar River Basin exhibits a diverse composition that affects its physical attributes. The river's bed load mainly comprises sands, reflecting the quartz-rich gneissic terrain in the upstream sector and sandstone-rich Gondwana sedimentaries in the lower reach. Mineralogical analysis of sediment samples from the Damodar River indicates the presence of quartz, kaolinite, and calcite minerals, underscoring the geological diversity of the basin (Pal & Maiti, 2018). Human activities, such as the construction of dams and barrages under the Damodar Valley Project, have notably changed flow patterns and flood frequencies in the river, impacting its physical characteristics. The environmental flow in the Damodar River has been affected by dam construction, leading to alterations in flow duration, flood frequency, and magnitude. Urban-industrial development in the basin has also contributed to water pollution in the river, resulting in decreased dissolved oxygen levels and increased biological oxygen demand (Hoque et al., 2022).

The physical habitat quality in the Damodar River Basin varies across different areas, ranging from excellent in forested spring regions to moderate to poor in inhabited parts due to flood control weirs, straightened river channels, and artificial embankments. The geomorphological evolution of the Quaternary to Recent floodplains and channel bed of the Damodar River in West Bengal is influenced by a complex interplay of fluvial hydrogeomorphic processes and anthropogenic activities (Ghosh et al., 2021). Efforts to comprehend and conserve the physical characteristics of the Damodar River Basin are crucial for sustainable management and conservation. By taking into account the basin's topography, geology, and human impacts, stakeholders can collaborate to preserve the ecological integrity of the river system and ensure the well-being of both the environment and the communities dependent on it.

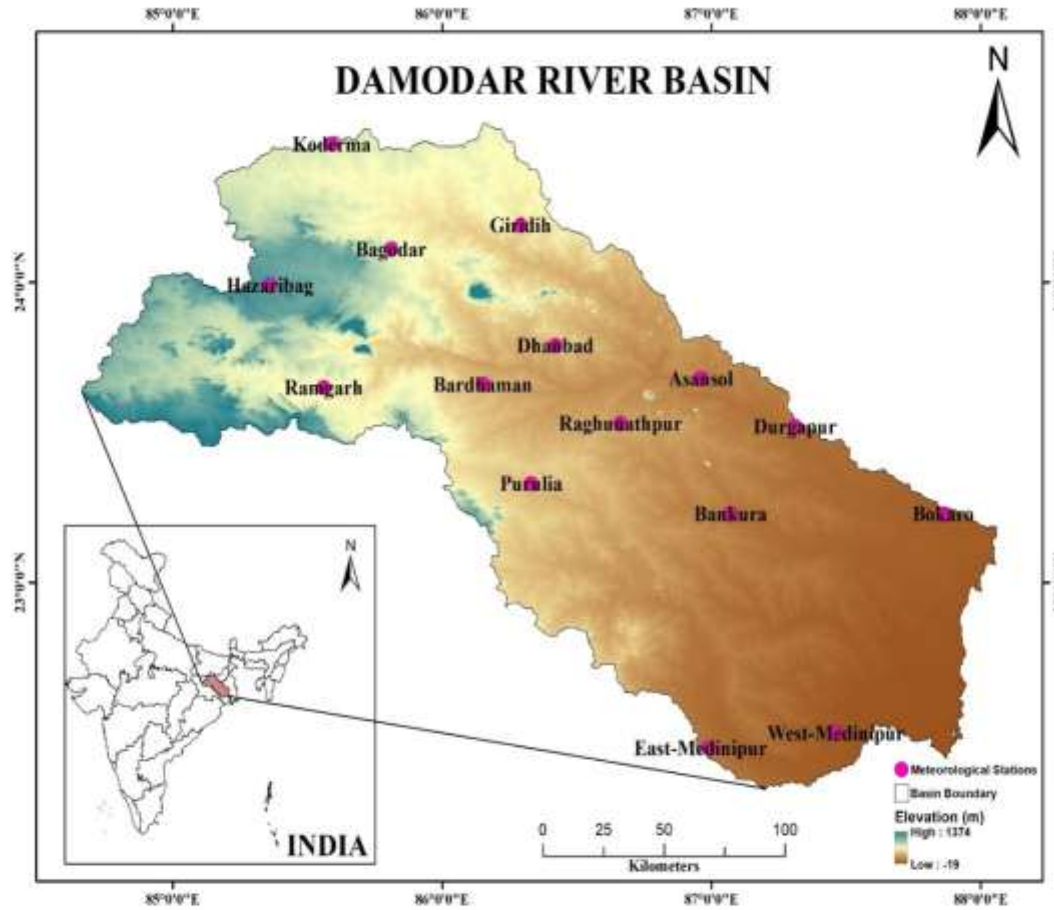

Figure 3.1 Location of the study area along with meteorological stations

3.2.2 Climatic condition of the study area

The Damodar River Basin in Eastern India faces a high-moderate flash flood risk due to intense rainfall events (Ghosh & Mistri, 2015). Climate change significantly influences hydrological conditions in river basins like the Damodar, leading to increased variability in rainfall and temperature (Jha & Goyal, 2019). Recent studies have demonstrated that applying machine learning techniques can improve the simulation of precipitation and temperature patterns in the Damodar River Basin, emphasizing the importance of advanced modelling methods in understanding climatic trends (Dey et al., 2022). Moreover, the construction of dams in the Damodar River has modified its ecomorphological behavior, affecting environmental flow and fluvial functionality (Ghosh et al., 2022). Sediment analysis has revealed the presence of heavy metal pollutants such as quartz, kaolinite, and calcite minerals in the Damodar River, indicating potential water quality issues (Pal & Maiti, 2018). Industrial activities have been identified as a major contributor to the deterioration of river water quality over the years (Chakraborty et al., 2021). In terms of climate trends, despite a warmer climate in the Godavari River Basin, evaporation rates have notably decreased, suggesting complex interactions between temperature and hydrological processes (Jhajharia et al., 2013). The spatial variability of vegetation growth in river basins like the Yarlung Zangbo in the Tibetan Plateau reflects the diverse climatic conditions present in these regions (Sun et al., 2019). Additionally, the impact of climate change on snow cover in basins such as the Jhelum River, located in the Himalayas, highlights the vulnerability of mountainous areas to changing climatic conditions (Munawar et al., 2022). In summary, the Damodar River Basin encounters challenges related to flood risk, water quality degradation, and ecological impacts from human activities and climate change. Understanding the intricate relationships between climate, hydrology, and human interventions is essential for promoting sustainable management and conservation efforts in river basins like the Damodar.

3.2.3 Geological Condition of the study area

The Damodar River Basin, located in eastern India, is one of the most significant river basins in the country. Spanning parts of Jharkhand and West Bengal states, it covers an area of approximately 24,235 square kilometers. The geological conditions of this basin play a crucial role in shaping its landscape, hydrology, and socio-economic aspects. In this report, we delve into the geological characteristics of the Damodar River Basin, focusing on its geological history, rock formations, structural features, and their implications.

3.2.4 Geological History

The geological history of the Damodar River Basin is intertwined with the tectonic evolution of the Indian subcontinent. It primarily comprises rocks of the Gondwana Supergroup, deposited during the Paleozoic and Mesozoic eras. The basin's formation can be traced back to the breakup of the supercontinent Gondwana and subsequent rifting during the Jurassic-Cretaceous period. The collision between the Indian Plate and the Eurasian Plate during the Cenozoic era further influenced the basin's geological evolution, leading to uplift, folding, and faulting processes.

3.2.5 Rock Formations

The Damodar River Basin is characterized by diverse rock formations, reflecting its complex geological history. The predominant rock types include sedimentary, metamorphic, and igneous rocks. The Gondwana Supergroup dominates the basin's stratigraphy, comprising coal-bearing sedimentary rocks such as sandstones, shales, and coal seams. These rocks hold significant economic importance due to their extensive coal reserves, fuelling industrial development in the region.

In addition to sedimentary rocks, the basin also contains metamorphic rocks, including schists, gneisses, and quartzites, originating from the metamorphism of pre-existing sedimentary and volcanic rocks. Intrusive igneous rocks such as granites and dolerites are also present in some basins, indicating past magmatic activity associated with tectonic processes.

3.2.6 Structural Features

Structural features play a vital role in controlling the hydrogeological characteristics and landforms of the Damodar River Basin. The basin is marked by various structural elements, including faults, folds, and fractures, which influence the distribution of groundwater, sedimentation patterns, and landscape morphology. The major structural features of the basin include:

1. Dip Slopes and Escarpments: The basin exhibits prominent dip slopes and escarpments resulting from the differential erosion of tilted sedimentary rock layers. These landforms contribute to the basin's topographic diversity and are essential groundwater recharge zones.

2. Anticlines and Synclines: Anticlines and synclines are standard structural features observed in the basin formed by the folding of sedimentary rock layers during tectonic events. These structural features often control the occurrence of coal seams and groundwater flow paths within the basin.

3. Faults and Fractures: Faults and fractures are prevalent throughout the Damodar River Basin, affecting aquifers' permeability and hydraulic conductivity. These

structural discontinuities influence the region's groundwater movement, mineralization processes, and seismic hazards.

3.2.7 Geological Hazards

The geological conditions of the Damodar River Basin also pose various hazards, including landslides, floods, and seismic events. The basin's steep topography, coupled with intense monsoonal rainfall, makes it prone to landslides and soil erosion, particularly in the hilly terrain of the Chota Nagpur Plateau. Moreover, active faults increase the region's susceptibility to seismic activity, with historical records documenting several moderate to large earthquakes in the vicinity.

In conclusion, the geological conditions of the Damodar River Basin are diverse and dynamic, reflecting its complex tectonic history and diverse rock assemblages. The basin's geological features, including rock formations, structural elements, and associated hazards, significantly affect the region's water resources management, land use planning, and environmental conservation efforts. Understanding these geological conditions is essential for sustainable development and effective risk mitigation strategies in the Damodar River Basin.

This report provides a comprehensive overview of the geological conditions of the Damodar River Basin, covering its geological history, rock formations, structural features, and associated hazards. Further research and field investigations may be required to delve deeper into specific aspects of the basin's geology and their implications for various socio-economic and environmental factors.

3.3 Data Collection

While many other hydro-climatic factors, such as streamflow, evaporation, humidity, and soil moisture, affect water supplies, temperature and rainfall have the most significant impact. Increased temperatures increase evaporation, which results in dangerously low water levels in reservoirs. When coupled with less rainfall, this exacerbates the issue. As a result, rainfall and temperature were chosen as variables for calculating multiple climatic extreme indices based on rainfall and temperature for investigation in this research.

In this study, the aim was to use a more accurate and consistent dataset with minimal artifacts. Therefore, any accumulations were defined as missing data in this study. The fifteen synoptic stations of DRB of India were selected as study stations, shown in Figure 3.1. For determining the temporal changes in the long-term climatic variables over the basin area, the daily rainfall data was collected from the Indian Meteorological Department (IMD), Pune website (http;//www.imdpune.gov.in) from 1923 to 2022. The (IMD) is a government-funded body responsible for acquiring meteorological observations and forecasting weather patterns and seismology. Inverse Distance Weighting (IDW) was utilized to fill in the missing data from weather stations during the study. The average yearly rainfall in DRB ranges between 1189 and 1734 mm, with most occurring during the season. Each station's data series consists of 100 years' worth of information. Further, the precipitation for each station was calculated by aggregating the data into monthly and yearly totals. As per IMD, there are four climatological seasons with some local adjustments: Season 1 refers to the pre-monsoon (summer) season from March to May; Season 2 resembles the monsoon (rainy) season from June to September; Season 3 resembles the post-monsoon season from October to November, Season 4 resembles the winter season from December to February and annually from January to December are considered for analysis.

3.3.1 Seasons

Indian seasons are often defined as summer, winter, and rainy. For trend analysis purposes, data have been divided into four seasons: summer, winter, monsoon, and post-monsoon. The following sections detail the features of various seasons.

Summer

The summer season begins in March and lasts until mid-June. The study area's greatest temperatures are often reported in May. During the summer season, the study region, like the rest of northern India, suffers dust storms and dust-raising winds. Dust storms with 48-60 kilometers per hour velocities are most common in May, with a second peak in April and June. During April and May, hot winds called loo blow at an average speed of 8-15 kilometers per hour. This scorching wind has significantly impacted human comfort throughout this season.

Winter

Low temperatures experiences in the study region from early November through late February. October and November have a pleasant climate. The days are sunny and pleasant, although the sun hours are not too hot. Once the sun sets, the air temperature declines and the day's heat is replaced with sharp, bracing cold. December and January are the coldest months of the year. The research region basin also has a record low-temperature range from 4 ^{0} C to 6 ^{0} C. The coldest winter was in 1979, with temperatures dipping as low as 2 ^{0} C.

Monsoon

The rainy season begins shortly after mid-June and lasts until September. Monsoon season officially begins when a water-laden storm from the Bay of Bengal passes over the study region. The monsoon season may begin as early as the final week of May or as late as the second week of July. Typically, the rainy season starts around June; July and August are the wettest months. The southwest monsoon is responsible for the rain in DRB.

Post-Monsoon

The incursion of tropical cyclones originating in the Bay of Bengal at about 12 C N latitude is a significant characteristic of the receding monsoon season in the study region. Typhoons originating in the South China Sea also affect the study region. Tropical cyclones occur most often in the study region between September and November, particularly around the asterism known as Hathiya. However, these cyclones seem essential for paddy maturity and for moistening the soil in preparation for Rabi crop farming.

3.4 Software Used

3.4.1 Programming Tools

The variability of the multiple climate extremes was evaluated using various programming tools. MATLAB, used for programming and a numeric computation platform, has been used to analyze data, design algorithms, and create models and graphical presentations. This study used R packages; RClimDex calculated extreme indices based on precipitation and temperature datasets. Origin Lab 2020 was used to create various graphical presentations and visualizations.

3.4.2 Spatial Mapping

Geographic Information System (GIS) is used for various tasks, including making and using maps, digitizing and compiling geographic data, analyzing 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 comprising 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 that 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. 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 15 divisions and used for this study. ArcGIS 10.7.1 interpolated the trend patterns of time series data from 15 stations over 100 years using the inverse distance weighting (IDW) method (1923-2022).

3.5 Summary

This chapter describes the research location, climate, data source, and programming tool. DRB's emphasis on agriculture requires precise prediction and projection of climate extremes. Summer features three seasons, with daily maximum temperatures ranging from 42°C to 45°C and a low average of 28°C. During the southwest monsoon season, the basin receives 84.4%, which decreases in the western part of the basin area. Meteorological data, including precipitation and temperature, were collected daily and converted monthly and yearly. Rainfall and temperature data on a daily scale were taken from IMD, Pune, for all 15 stations from 1923 to 2022. All time-series data were examined for missing values, replaced with average values from surrounding locations, and data quality was rigorously monitored. The selected stations 15 almost cover the whole basin for analysis of extreme climatic indices. The refined data is used for spatiotemporal analysis and also used to check the trend pattern over the basin using non-parametric statistical methods. 3-D pattern characterization of extreme indices has been studied using 100 years of rainfall and temperature data. R packages such as 'trends' and 'trend change' have been used for trend detection, and spatial maps have been done in ArcGIS 10.7.1 For 3-D pattern characterization of extreme climatic indices using MATLAB R2024a. The widely used interpolation technique generated the Spatial maps, i.e., Inverse Distance Weightage (IDW) in ArcGIS 10.7.1.