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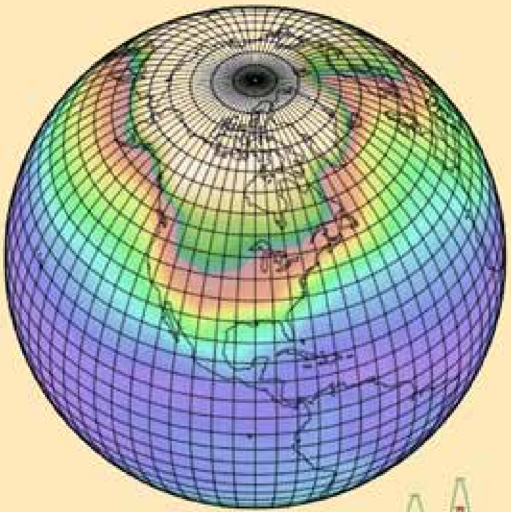
HYDROLOGICAL AND CLIMATE MODELING OF SOLAPUR AND VIJAYAWADA CITIES

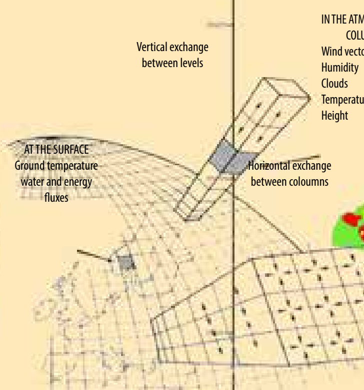
IIT MADRAS REPORT

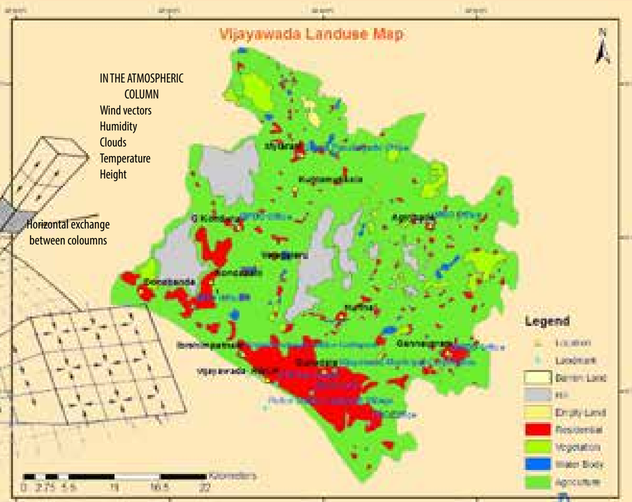
INDIAN INSTITUTE OF TECHNOLOGY MADRAS

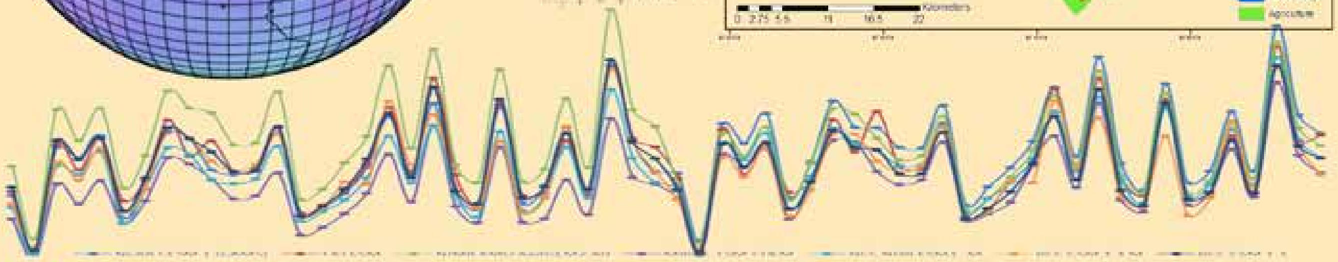
सिद्धिर्भवति कर्मजा

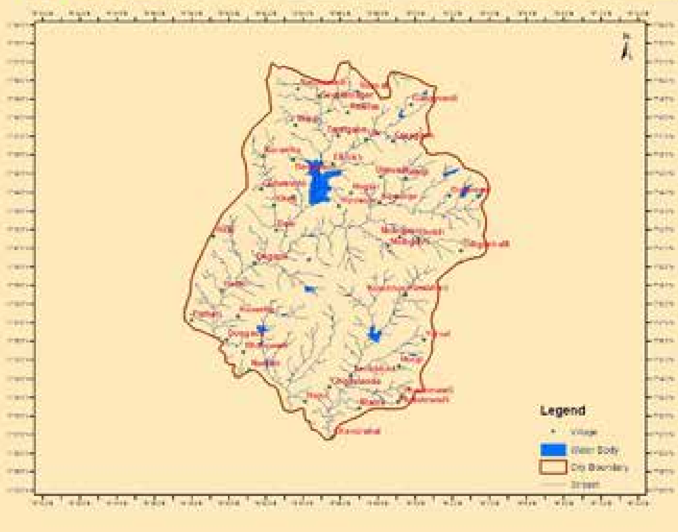
FEBRUARY 2019

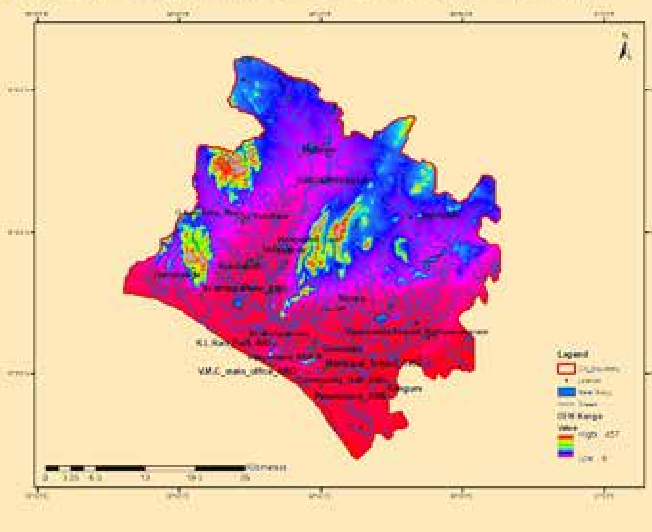












INTEGRATED RURAL URBAN WATER MANAGEMENT FOR CLIMATE BASED ADAPTATIONS IN INDIAN CITIES (IAdapt)

Hydrological and Climate Modeling of Solapur and Vijayawada Cities

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Submitted to:	International Development Research Centre (IDRC) Canada
Submitted by:	Environmental & Water Resources Engineering, Dept. Of Civil Engineering, Indian Institute of Technology, Madras (IIT-M)
Project Investigator	Prof. S. Mohan
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Project Consortium:	ICLEI South Asia (Lead Member) Athena Infonomics LLC International Water Management Institute (IWMI) Indian Institute of Technology, Madras (IIT M)

Disclaimer

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1 INTRODUCTION

1.1 General

Climate change is currently a key issue in almost all parts of the world. Frequent drought and flood, the rise in sea levels are a major concern for a country like India. It can be observed that within a country only, at a time when one part of the country is completely flooded other is suffering from drought. All these phenomena is a clear sign of need of a sustainable management plan. This plan can be made only when there is a proper assessment of demand and supply is available.

In the last 100 years, some parts of the county have seen a clear decline in rainfall pattern while others have seen an increase in rainfall. Hence, it is important to bring climate change into consideration to assess water availability. These days GCM models are available which can be coupled with different GHGs emission scenarios, to get a better estimate of the hydrological variable.

Impact of climate change can be incorporated in hydrological models to check the correlation and dependence of one parameter on another.

1.2 Climate Change and Its Impact

The Earth's climate is changing throughout time. In the last 650,000 years, there have been seven cycles of glacial advance and retreat, with the end of last ice age about 7,000 years ago which marks the beginning of the modern climate era.

The current warming trend is of prime significance as most of it is extremely likely to be the result of human activity, since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia**.**

Evidence for rapid climate change:

- Global temperature rise (rise of about 2 degrees Fahrenheit)
- Shrinking ice sheets
- Sea level rise (rise of about 8 inches)
- Extreme events (more flood and drought)
- Ocean acidification (About 30% increase)

Anthropogenic greenhouse gas emissions have a significant impact on climate change. Based on the IPCC report, GHG emission from 1750 to 2011, is about 2040 ± 310 $GtCO^2$, out of which 405 remained in the atmosphere, 30% has been absorbed by the ocean.

GHG emission, climate change, and our hydrological system are interdependent. Increase in GHGs emission has resulted in climate change which now has altered the hydrological system. Changes in many extreme weather and climate events, increase in high sea levels have been observed since about 1950. Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system.

IPCC baseline report indicates a strong, consistent, almost linear relationship between cumulative CO^2 emissions and global temperature change to the year 2100.

Baes on IPCC report, the Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions.

1.3 Assessment of Water Availability

Water availability can be assessed in two parts, one is by proper estimation of surface water, and the other is by groundwater. Surface water can be estimated using any rainfall-runoff relation. SCS-CN is one such a good option. Surface water for the current study area largely depends on rainfall. While groundwater assessment requires estimation of groundwater flow, recharge, and pumping.

1.4 Sustainable Development Plan

Integrated Rural-Urban Water Management for Climate-based adaptation in Indian Cities (IAdapt) project is being implemented in two Indian cities - Solapur in Maharashtra, and Vijayawada in Andhra Pradesh and their surrounding catchments – which face issues related to droughts, floods, and water conflicts. The project will support the project cities to move from traditional approaches of water management (that plan, establish and operate water supply, wastewater, and stormwater systems as separate entities) to an 'Integrated Approach' based on the principles of IWRM and IUWM.

1.5 Objectives

The overall objective of the project is to institutionalize climate change adaptation measures by creating an enabling ecosystem within cities to adopt and implement IUWM approaches at a city level and an approach towards IWRM at catchment level guided by participatory Catchment Planning, simple decision support tools, preparation of catchment level action plans and multipronged financing approaches.

The specific objectives of the project include:

- Expanding an existing IUWM framework to catchment area while addressing challenges presented by climate change for improved water security at the catchment level
- Developing multi-stakeholder platforms to bring together rural and urban stakeholders and upstream and down-stream users to enable greater exchange of information and promote collaborative action and planning for improved water management. Special focus will be laid on marginalized communities.
- Scientifically-informed and participatory Catchment Management Plan formulation for long term water security and management at the catchment level by including urban and rural stakeholders
- Capacity building of stakeholders on various aspects of IUWM, climate change, scientific decision making, and project financing.
- Creation of a compendium on 'innovative' financing options for IUWM and IWRM, with focus on innovative approaches, facilitated through cross learning.

Towards fulfilling these objectives, the tasks for IIT Madras was set as follows:

- To estimate the runoff from the watersheds/ sub-watersheds of both the cities and to study its variability over the years.
- To plan the IWRM approaches tail r- made for each of these two watersheds taking into account the existing practices, livelihood, and other potentiality of reuse/regenerate of wastewater.
- To develop strategies for adaptation to climate change vulnerability.

2 METHODOLOGY

2.1 General

The overall methodology can be divided into four sections, namely, catchment delineation, trend analysis of hydrological variable under climate change and climate change projection, estimation of runoff generation and total water availability and sustainable management plan. Catchment delineation is done using ArcGIS, which classify the catchment into various sub zones based on land use, soil type, and infiltration capacity. Trend analysis is done using linear regression, and its significance is tested using student t-test. Further to assess the impact of climate change on rainfall and temperature, suitable GCM model has been adopted for different scenario (RCP) of carbon emission. Runoff generation is calculated using HEC-HMS model. Preliminary runoff estimation every month is done using the SCS-CN method or in some cases using empirical equations. Based on the estimate, a further sustainable management plan is made.

2.2 Watershed Delineation

SRTM Digital Elevation Model (DEM) of 90m resolution for the catchment area is obtained from Earth Explorer. It is then processed in ArcGIS 10.1 for land use and land pattern.ArcGIS 10.1 software is an updated Geographic Information Software released in 2012 by ESRI (Environmental Systems Research Institute) which is useful for creating maps, compiling geographic data, analyzing mapped information, etc. ArcGIS supports DEM, Digital Elevation model that contains all the geographic details for the selected region.

Areas are classified as agricultural, residential, barren land, vegetation, and water body. The land use and Hydrological Soil Group map (HSG) is generated to calculate the Curve Number and for the preparation of the rainfall-runoff model by the mean of HEC-HMS.

The extraction of the drainage network of the study area is carried out from ASTER DEM, in raster format. ArcHYDRO tools in ArcGIS, version 10.1 (ESRI 2008) is used to extract drainage channels. The delineation of the watershed is followed by running the following functions: filling, flow accumulation, flow direction, stream definition, stream Segmentation, catchment grid delineation, catchment Polygon and drainage line. The processes involved in the analysis is shown in Fig. 2.1

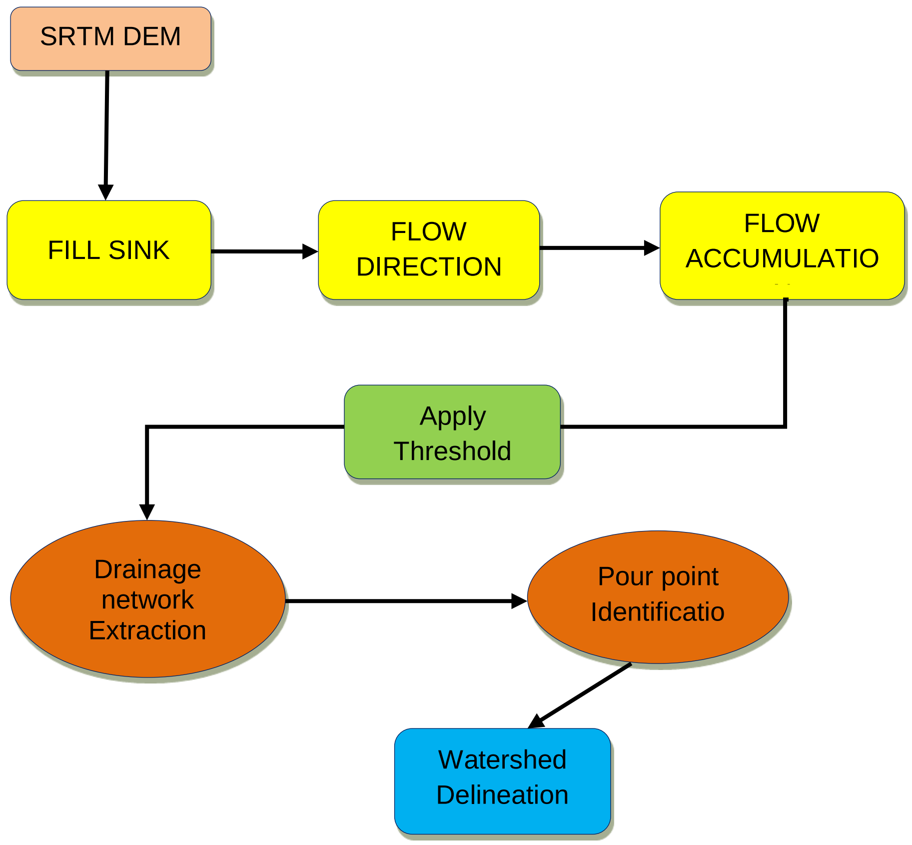

Figure 2.1: Flow Chart for Delineation of Watershed

The watershed (Water basin analysis program) analysis in the Arc GIS raster commands is used to delineate the catchment areas. This water basin analysis generates the following outcome:

- flow accumulation,
- drainage direction, the location of streams and catchment, and
- Slope length, steepness and slope steepness factor for Universal Soil Loss Equation (USLE).

The analysis includes multiple parameters which are extracted from the DEM raster (input) file.

2.3 Trend Analysis

As a preliminary study, a trend analysis is required to check if there is any significant change in hydrological variables with time. The analysis is done using statistical test on time series data of hydrological variable (e.g., rainfall).

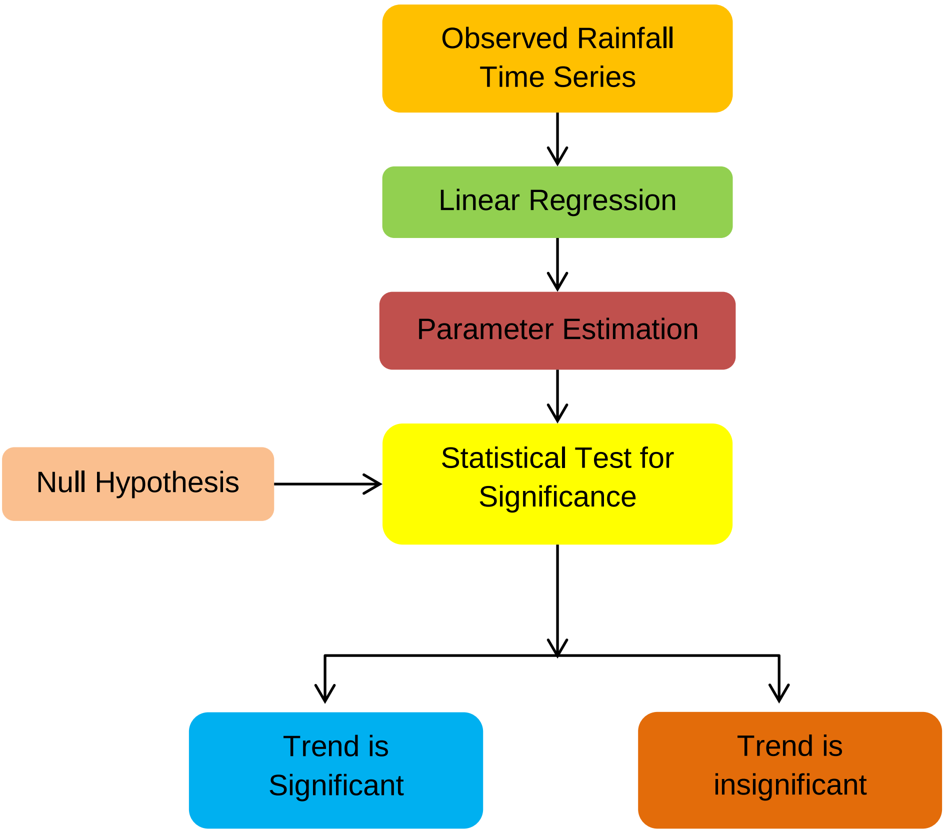

Figure 2.2: Flow chart for Trend analysis

In the present study, the significance of the trend is analyzed using Student T-test. A linear regression is fitted to time series data of rainfall. The null-hypothesis adopted is that the slope of the linear regression line is zero which means that there is no significant change in hydrological variable pattern. Fig. 2.2 shows the flow chart for Trend analysis. Based on a statistical test, it is decided if the change is significant.

2.4 Climate Change and its Assessment

The climate of earth results from complex and extensive interactions between many processes in the atmosphere, ocean, land surface and cryosphere (snow, ice, and permafrost). Due to its complexity, the quantitative predictions of the impact on the climate due to greenhouse gas increases cannot be made just through simple, intuitive reasoning. For this reason, computer models have been developed which try to mathematically simulate the climate, including the interaction between component systems. An ideal model will simulate all of the physical, chemical and biological mechanisms.

Anthropogenic greenhouse gas emissions have a significant impact on climate change. Based on the IPCC report, GHG emission from 1750 to 2011, is about 2040 ± 310 $GtCO^2$, out of which 405 remained in the atmosphere, 30% has been absorbed by the ocean.

GHG emission, climate change, and our hydrological system are interdependent. Increase in GHGs emission has resulted in climate change which now has altered the hydrological system. Changes in many extreme weather and climate events, increase in high sea levels have been observed since about 1950. Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system. GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy.

2.4.1 General Climate Models (GCMs)

Global Climate Models (GCMs) are the primary tool for understanding how the global climate may change in the future. They are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. These are numerical models which represent physical processes in the atmosphere, oceans, cryosphere and land surface. They depict the climate using a three-dimensional grid. These models use quantitative methods to simulate the interactions of the important drivers of climate, including atmosphere, oceans, land surface and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate.

Atmospheric general circulation models (atmospheric GCMs) are mathematical models based on numerically discretized versions of differential equations that describe the atmospheric physics and dynamics, which are utilized to simulate time series of climate variables globally, accounting for the effects of the concentration of greenhouse gases in the atmosphere.

Three-dimensional models which simulate the atmosphere are called Atmospheric General Circulation Models (AGCMs) and have been developed from weather forecasting models. Similarly, Ocean General Circulation Models (OGCMs) have been developed to simulate the ocean. AGCMs and OGCMs can be coupled to form an atmosphere-ocean coupled general circulation model (CGCM or AOGCM).

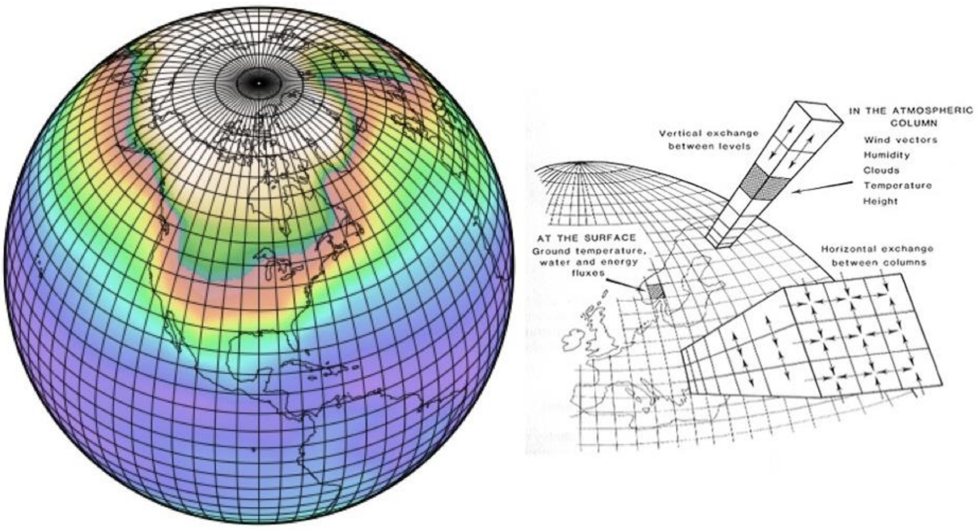

Figure 2.3: **Grid Point Model (Henderson-Sellers, 1985)**

Scenarios have long been used by planners and decision-makers to analyze situations in which outcomes are uncertain. In climate research, emission scenarios are used to explore how much humans could contribute to future climate change gave uncertainties in factors such as population growth, economic development, and development of new technologies. Projections and scenarios of future social and environmental conditions are also used to explore how much impact lesser or greater amounts of climate change would have on different possible states of the world, for example, futures with greater or lesser amounts of poverty. The purpose of using scenarios is not to predict the future, but to explore both the scientific and real-world implications of different plausible futures.

There are several GCM models are available on the IPCC website. Depending upon the study area, a particular RCP scenario can be chosen. Any GCM model can be adopted for the study. It is good to choose several GCM model for the study to get a better forecast band.

2.4.2 Representative Concentration Pathways (RCPs)

The Representative Concentration Pathways (RCP) is the latest generation of scenarios that provide input to climate models. The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing pathway. Radiative forcing is a measure of the additional energy taken up by the Earth system due to an increase in climate change pollution. Studies show that the radiative forces are bound to increase in the future even with the current rate of carbon emission. Fig. 2.4 shows the different representative concentration pathways and the radiative forces at which these scenarios will stabilize with the rate of sustainable consumptions and production (SCP) rate.

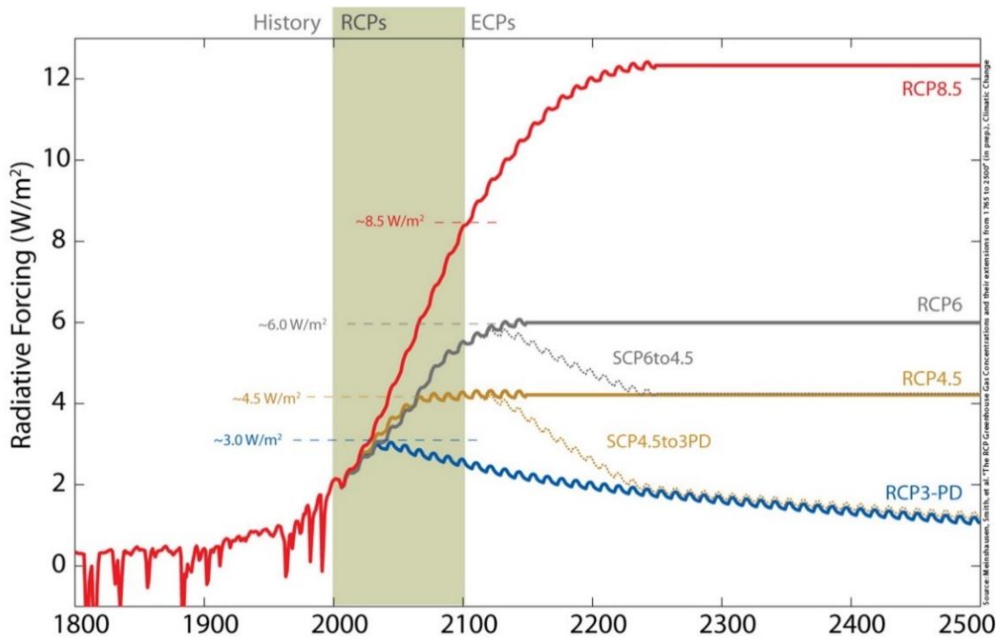

Figure 2.4: **Radiative forcing for different climate scenarios**

RCPs are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emission Scenarios (SRES) projections published in 2000. The pathways describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs RCP2.6, RCP4.5, RCP6, and RCP8.5 are named after a possible range of radiative forcing values in the year

2100 relative to pre-industrial values. For RCP2.6, the radiative forcing first reaches a value around 3.1 W/m mid-century, returning to 2.6 W/m^2 by 2100. Under this scenario greenhouse, gas emissions and emissions of air pollutants are reduced substantially over time. RCP4.5 is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing greenhouse gas emissions. RCP6 is again a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing greenhouse gas emissions. RCP8.5 is characterized by increasing greenhouse gas emissions over time representative of scenarios in the literature leading to high greenhouse gas concentration levels.

2.4.3 Downscaling GCM

There occurs a general mismatch between the spatial resolution of output from global climate models and the scale of interest in regional assessments of climate change impacts. To overcome the problem, various downscaling techniques were developed to bridge the resolution gap. These downscaling methods are used to obtain local scale weather and climate. In statistical downscaling, a range of techniques has been proposed to model the relationship between predictors and the predictand. They include multiple regression models. Regression-based downscaling methods rely on empirical relationships between local-scale predictand and regional-scale predictor(s).

Any information that is presented at spatial scales finer than 100 km x 100 km and temporal scales finer than monthly values have undergone a process called downscaling.

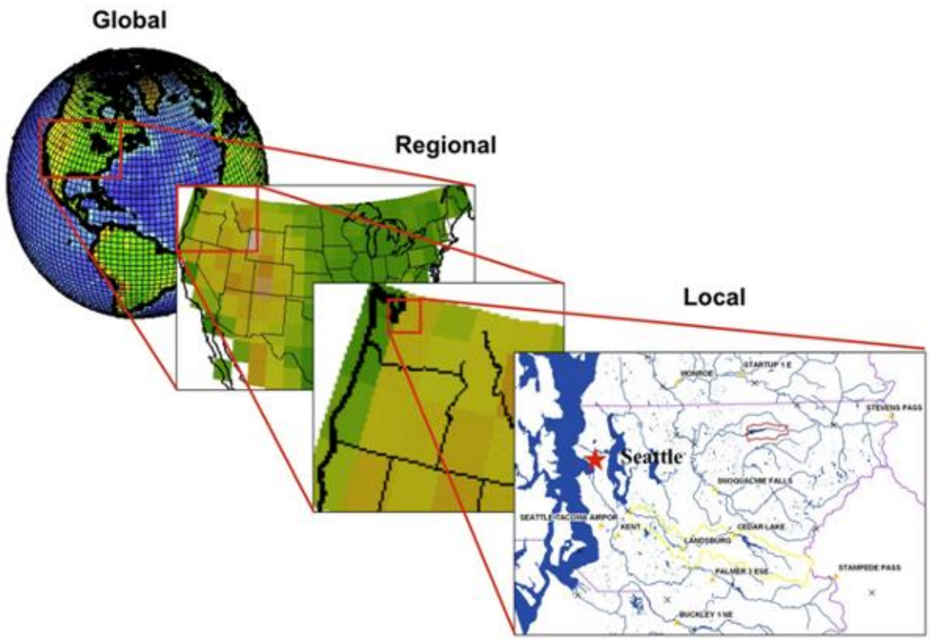

Figure 2.5: Downscaling Global Climate Model

Downscaling is based on the assumption that the local climate is a combination of large-scale atmospheric and local conditions. It can be applied either spatially or temporally or both. Broadly, there are two methods of downscaling, Dynamical downscaling and Statistical downscaling. Dynamic downscaling is computationally intensive and requires large data.

Statistical downscaling establishes a statistical relationship between large-scale climate features and local climate characteristics. Statistical methods are easy to implement and interpret. There are different techniques available for downscaling depending on the purpose.

In statistical downscaling empirical relationships between historical large-scale atmospheric and local climate characteristics is established. The basic assumptions in this method are as follow:

- Statistical relationship between the predictor and predictand does not change over time.
- A strong relationship exists between the predictor and predictand.
- GCMs can accurately simulate the predictor.

Statistical downscaling can be Methods can be classified into three main categories, i.e., linear methods, weather classifications, and weather generators. In the present study, a linear method is applied as this method is suitable for the downscaling of data on a monthly scale. In the linear method, change factor method is used.

The various predictor variables for stations is obtained from different GCM models. Using different models, data for various variables for both historical as well as future scenarios are obtained for all the different scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.

Change factor Method (CFM)

CFM is widely applicable and used in impact analysis studies. CFM is categorized by its mathematical formulation (additive or multiplicative) out of which multiplicative change factor is used for rainfall prediction. The ratio between future and current GCM simulations is calculated and multiplied to the observed values to obtain local scaled future values. This method assumes that the GCM produces a reasonable estimate of the relative change in the value of a variable, and is typically used for precipitation. The mean values of GCM simulated baseline (current GCM simulation) and future climates are estimated.

$$GCMb_{mean} = \sum_{i=1}^{Nb} \frac{GCMb_i}{Nb} \quad (2.1)$$

$$GCMf_{mean} = \sum_{i=1}^{Nf} \frac{GCMf_i}{Nf} \quad (2.2)$$

Where GCM_b and GCM_f represent the values from the GCM baseline and GCM future climate scenario respectively for a temporal domain (20 years). N_b and N_f are the number of values in the temporal domain of the GCM baseline and GCM future scenario.

Multiplicative change factor (CF_{mul}) is given by Eq. 2.3,

$$CF_{mul} = \frac{GCMf_{mean}}{GCMb_{mean}} \quad (2.3)$$

The local scaled future values can be computed as follow,

$$LSf_i = LOb_i * CF_{mul} \qquad (2.4)$$

Where LOb_i represents the observed values of the variable.

2.5 Runoff Generation Using SCS CN Method

The SCS curve number method, an event-based model, chosen from empirical studies have been used for small agricultural watershed management [SCS, 1985]. It estimates excess precipitation as a function of cumulative precipitation, soil cover, land use, etc. This method is based on the assumption of a direct relationship between precipitation and storage.

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad (2.5)$$

Where, F = Actual retention, S = Potential retention, Q = Actual runoff, P = Precipitation, I_a= Initial abstraction. The basic equations to calculate S and I_a are

$$S = \frac{1000}{CN} - 10 \qquad (2.6)$$

$$I_a = 0.2S \qquad (2.7)$$

The final equation for runoff calculation is

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (2.8)$$

The only parameter needed is curved number which can be obtained directly from SCS (Soil Conservation Service) developed by USDA Natural Resource Conservation Service or can be computed for areas having composite geology.

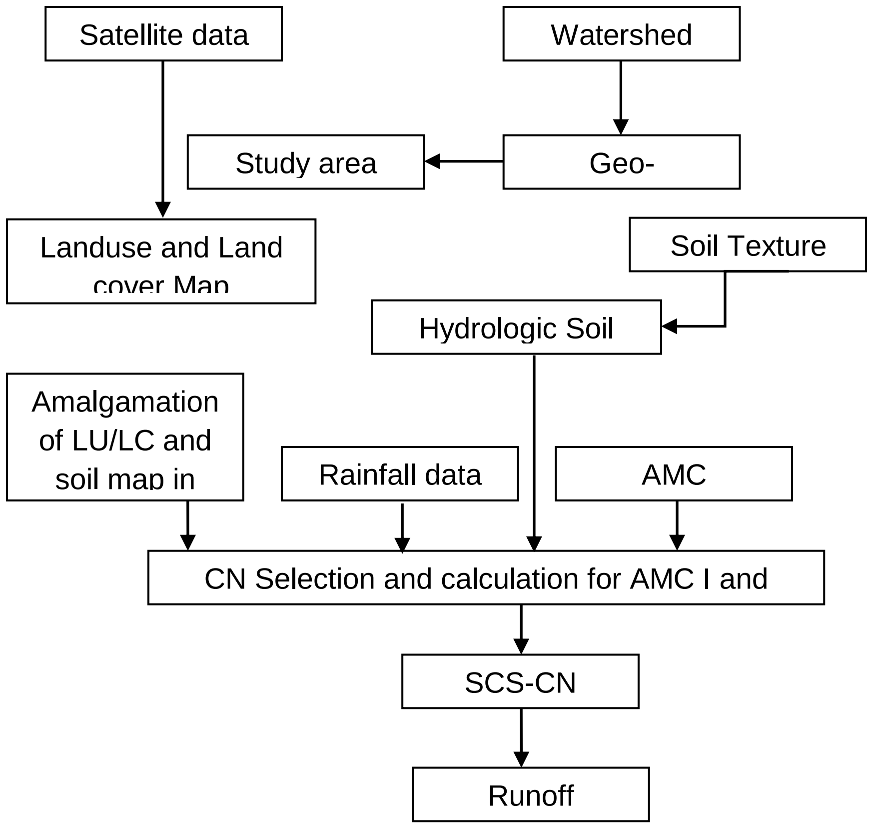

Figure 2.6: Flow chart for SCS-CN Method

Curve Number and Impervious Areas

The selection of suitable curve number depends on land use and soil cover of that area. Composite curve number can also be computed manually using equations which deals individually with impervious surface, soil and land type. According to Hydrologic soil groups, clay loam comes under Group C and Loamy sand comes under Group A and loam comes under Group B. Table 2.1 provides the selection of curve number and percent impervious for the basin.

Table 2-1: Selection of curve number and average % impervious

Land use type	Average impervious (%)	Hydrologic soil group			
		A	B	C	D
Agriculture	5	67	77	83	87
Barren land	5	39	61	74	80
Residential (Plot size 0.1 - 0.4 ha)	30	57	72	81	86
Residential (Plot size >0.4 ha)	15	48	66	78	83
Vegetation – Woods (Thin cover)	5	43	65	76	76
Water body	100	100	100	100	100

Initial abstraction

The definition of initial abstraction in the NRCS Runoff Curve Number method follows from the method's original development as "For a given storm depth P and runoff curve number CN, the initial abstraction I_a is the fraction of the storm depth after which runoff begins, regardless of the storm duration. Initial loss can be computed from equation 3.3.

2.6 Runoff Generation Using Empirical Formula

There are several empirical formulas available for runoff estimation. SCS curve number method works well under all conditions provided all the necessary data required is available. Under such condition where daily rainfall data is not available any empirical equation with proper analysis can be used to estimate runoff generation from a catchment.

2.6.1 Inglis and Desouza Formula

Based on careful stream gauging in 53 sites in Western India, Inglis and DeSouza (1929) evolved two regional formulae, between Runoff R in mm and Rainfall P in mm as follows:

For Ghat regions of western India usually Highlands

$$R = (0.85 \times P) - 30.5 \qquad (2.9)$$

For Deccan plateau usually Plain areas

$$R = P(P - 17.8)/254 \qquad (2.10)$$

Where R is the runoff in mm and P is rainfall in mm

2.6.2 Indian Irrigation Department

Indian Irrigation Department uses the following equation between Rainfall and Runoff

$$R = P - (1.17 \times P^{0.86}) \qquad (2.11)$$

Where R is the runoff in mm and P is rainfall in mm

2.7 HEC HMS Hydrologic Modelling

Watershed can be sub divided into sub watershed for modeling purpose at our convenience so that the parameters representing the entire watershed can be approximated to be homogenous. However, the size of a sub watershed affects the homogeneity assumption because larger sub-basins are more likely to have variable conditions than the smaller one. Mainly three elements constitute the basin model, namely Sub-basin, Junction and Reach.

2.7.1 Reach Characteristics

A reach performs an independent hydrograph routing through an open channel, natural streams, etc. Routing accounts for changes in flow hydrograph as a flood wave pass the downstream. This helps in accounting for storages and studying the attenuation of peak discharge.

- Method of selection of routing techniques is based on input data available for the watershed. Table 2.2 provides guidelines for the routing selection procedure. Fing

Muskingum method is selected for routing. The two parameters namely x and K parameters are evaluated theoretically where x is constant coefficient, and K is the time of the passing of a wave in reach length. For natural stream, X value is 0.1 to 0.3, average of 0.2 [KishorChoudhari, 2014].

Precipitation data plays an important role as an input. Precipitation for each sub-basin is calculated by Thiessen Polygon method. It is an interpolation method which assigns Thiessen weights for precipitation value to calculate average area precipitation. Mean precipitation over a catchment is calculated by equation 3.8.

$$P_{mean} = \sum_{i}^{n} P_i \frac{A_i}{A} \tag{2.12}$$

Where, P_{mean} = mean precipitation over catchment in mm, P_i = Precipitation in mm, A_i is the Thiessen area, and A is the total area.

Table 2-2: Guidelines for routing method selection

Model	Criteria
Modified Puls	Backwater influence discharge hydrograph
Lag	The ratio of length of stream to flow velocity less than analysis time step
Muskingum	i. The ratio of length of stream to flow velocity greater than analysis time step ii. The product of 2 times of Muskingum K and X should be less than analysis time step
Muskingum Cunge	i. Known cross-sectional characteristics of stream ii. Non-linear flow
Kinematic	known cross-sectional characteristics of the stream
Straddle Stagger	To obtain composite unit hydrographs at various locations in a basin

2.7.2 Running Control Parameter for Simulation

The period of a simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and a time interval. The model is simulated for some time of 28 years from 01 Jun 1967 to 31 May 1997 for one-day interval. A simulation run is created by combining a basin model, meteorological model, and control specifications. The basin model represents physical watershed. In this study, the basin model was developed in HEC-GeoHMS which was imported into the HEC-HMS. The meteorological model calculates the precipitation input required by a sub-basin element. Time series data from precipitation gauges was taken into the model.

However, two similar storm events were selected for validation of the model. One day time step for rainfall was chosen for calibration, validation, and simulation of the model. SCS Curve Number method was used to calculate losses, SCS unit hydrograph method was used to determine transformation and Recession method was used to account for base flow in the model.

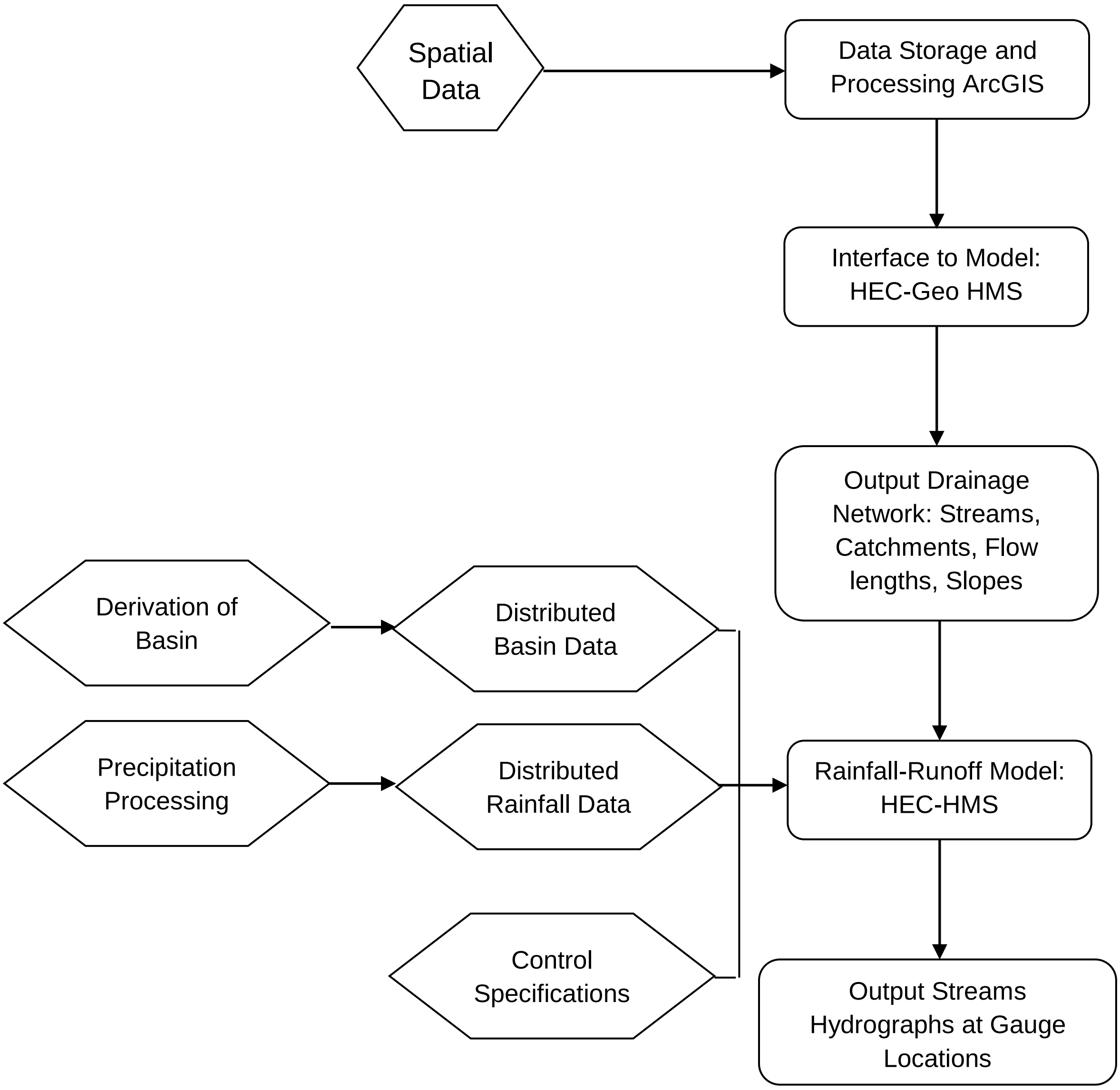

Figure 2.7: Flow chart for HEC HMS Modelling

2.8 Urban Heat Island

An urban area is said to be an urban heat island (UHI) if it is found significantly warmer than its surrounding areas. The assessment of urban heat island is mainly based on region. The temperature variation over the different months was used to assess the urban heat island. The urban heat island effect is also linked to the characteristic land use within a city/urban area as such. Land surface temperature, as defined by Barun refers to the temperature measured in the air close (1 m) to the earth surface in an open area rather at a higher level at which recorded temperature by weather stations. If a city has a good network of weather stations for every land use type, UHI can be directly measured. However, for most of the cities, the measurement of temperature in a spatial network is not available. Therefore, UHI is determined by processing thermal remote sensing image for each of the cities using GIS.

The study employed to generate the Land Surface Temperature (LST) maps from Landsat satellites thermal infrared with 100 m and 120 m spatial resolution. Higher LST is seen in areas with less vegetated land use and land cover (LULC) and vice versa. LST and Normalized Difference Vegetation Index (NDVI) have widely been accepted as reliable indicators of UHI and vegetation abundance respectively.

Quality of urban life and energy cost are mainly affected by Urban Heat Island. With each degree temperature, the power used for air conditioning is enhanced. The level of atmospheric temperature gets elevated due to the subsequent increased use of electricity for cooling. The earth's rising temperature is the hot issue today in the world since the industrial revolution the temperature of the planet has been increased.

The very low value of NDVI (0.1 and below) corresponds to the barren area of rock, sand or snow. Moderate values of NDVI represent shrub and grassland (0.2 to 0.3), while large values of NDVI (>0.3) indicate temperate and tropical rainforests. From the LST images, it is clearly understood that surface temperature is more in an urban area compared to rural areas. It is necessary to estimate the urban heat island so that planning of remedial measures like planting trees, the revival of water bodies, etc. can be suggested and implemented.

The study analyses and verifies the spatial pattern of surface temperature with urban spatial information related to to land use/land cover and NDVI using remotely sensed data and GIS. The various steps involved in the assessment of urban heat island are as follows:

- To determine the NDVI value
- To determine the Brightness temperature
- To determine the Land Surface Temperature
- To estimate the urban heat Island Effect using remote sensing data of temperature map and emissivity map

2.8.1 Normalized Difference Vegetation Index (NDVI)

The derivation of Normalized Difference Vegetation Index (NDVI) is a standard procedure and has already been enlightened in the literature. Because the mean of land, water, forest, and other things are all reduces from band4 to band5 on the TM and ETM+ images. NDVI maps using Landsat 8 satellite images downloaded from USGS site. The study adopted this standard mathematical formula for NDVI as below.

- $NDVI = \frac{TM5-TM4}{TM5+TM4}$ (2.13)

Where TM5- Band 5 Satellite Data; TM4- Band 4 Satellite Data; NDVI- Normalized Difference Vegetation Index. Fig. 2.8 shows a flow chart for the estimation of urban heat island index.

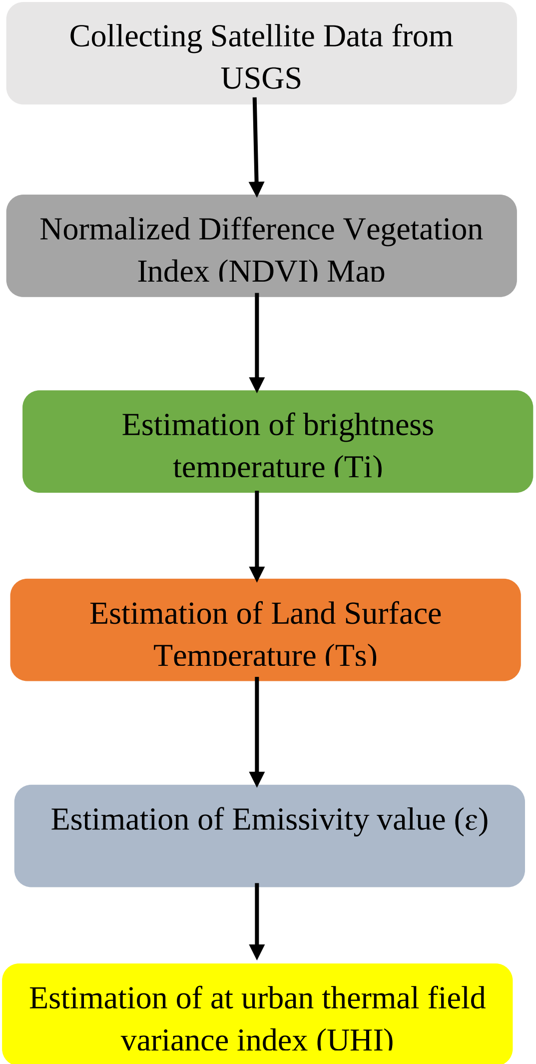

Figure 2.8: Flowchart for estimation of UHI Index

2.8.2 Brightness Temperature (T_i)

The temperature detected by the remote sensor is the radiation temperature of the urban surface features (brightness temperature), this radiation temperature is the average surface radiation temperature which takes the pixel as a unit and considers the features as black bold without the atmospheric correction. It can express the urban temperature field. If the study area is small and the image quality is good, brightness temperature can be directly used to compare and analyze; this method is convenient, simple and easy. Thermal band of TM and ETM+ are used to retrieve brightness temperature, band10 is the thermal band for the TM and ETM+ data. First, formula (2) is used ETM+ uses the formula (2) to turn the DN values into radiation temperature and then formula (3) is used to turn the radiation temperature into brightness temperature.

$$L_\lambda = M_c Q_{cal} + A_L \tag{2.14}$$

where, L_λ = TOA spectral radiance (Watts/(m^2.srad.μm)); M_C = Band-specific multiplicative rescaling factor from the metadata; A_L = Band-specific additive rescaling factor from the metadata; and Q_{cal} = Quantized and calibrated standard product pixel values (DN)

The spectral radiance of thermal infrared bands was converted into active radiance at sensor brightness temperature (the temperature values of a black body) using Planck's function equation as follows:

$$T_i = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda}\right) + 1} - 272.15 \qquad (2.15)$$

In Landsat 8, the bands 10 and 11 are used to determine the brightness temperature, respectively; equations were simplified to the following form and used to convert Landsat data where constant parameter value used for band 10 and band 11 the λ value for band 10 is 10.6 μm, and band 11 is 11.3 μm for respectively); and L_λ is spectral radiance, where K_2 represents the calibration constant 2 is 1321.08 in Kelvin; K_1 is the calibration constant 1 is 774.89 in W/ (m^2.sr.mm).

Mean-Standard Deviation Method for average temperature is an ideal method for temperature grade classification (Songlin and WANG, 2009). Classify urban brightness temperature into the low-temperature area, secondary low-temperature area, medium temperature, secondary high-temperature area, and high-temperature area. The basic principle of using Mean-Standard Deviation Method for temperature classification is shown in Table 2.3

Table 2-3: Heat island temperature classification using mean-standard deviation method

Temperature Classification	Interval of Temperature Classification
High-temperature area	Ts>μ+std
Secondary high-temperature area	μ+0.5std<Ts≤ μ+std
Medium temperature area	μ-0.5std≤Ts≤ μ+0.5std
Secondary low temperature area	μ-std≤Ts< μ-0.5std
Low-temperature area	Ts< μ-std

2.8.3 Land Surface Temperature (T_s)

The LST data is derived from the thermal infrared (TIR) Band 10 of brightness temperature. The satellite thermal infrared sensors measure Top of the Atmosphere (TOA) radiances, from which brightness temperature (known as blackbody temperatures) can be derived based on Plank's law. The TOA radiances are the result of mixing three parts of energy. The first is the emitted radiance from the earth's surface, the second is the upwelling radiance from the atmosphere, and the third is the downscaling radiance from the sky. The difference between TOA and land surface brightness temperature is subject to the influence of atmospheric conditions. Therefore, to obtain an actual land surface brightness temperature, atmospheric effects, including upward absorption-emission and downward irradiance reflected from the surface, should be corrected first. This correction is done by calculating spectral emissivity (e), (Weng and Larson, 2005; Al Kuwari et al., 2016; Van and Bao, 2010). LSTs were obtained by recovering satellite temperature T_i by applying the correction for emissivity.

Emissivity as a function of wavelength is controlled by several environmental factors such as surface water content, chemical composition, structure, and roughness. For vegetated areas, emissivity varies significantly with plant species, areal densities, and growth rates.

Land surface emissivity is closely related to. Therefore, the emissivity can be estimated from NDVI as shown in Table 2.4 (Liu and Zhang, 2011). The emissivity-corrected land surface temperature can be obtained using the following equation

$$T_s = \frac{T_i}{1 + \left(\lambda \frac{T_i}{\rho}\right) ln\varepsilon} \qquad (2.16)$$

where T_s represents land surface temperature; T_i indicates sensor brightness temperature in Kelvin, λ is the wavelength of the emitted radiance; e is the land surface spectral emissivity, and ρ is the Plank's constant = $1.438*10^{-2}$mk.

Table 2-4: NDVI values and its corresponding values of Land-surface spectral emissivity

NDVI	Land surface Emissivity(e)
NDVI<-0.185	0.995
-0.185≤NDVI<0.157	0.970
0.157≤NDVI≤0.727	1.0094+0.047ln(NDVI)
NDVI>0.727	0.990

2.8.4 LST Normalization Urban Heat Island (UHI)

Finally, the effect of UHI, at district level taking into consideration socio-economic parameter, can be quantitatively described using urban thermal field variance index (UTFVI) given by (Liu and Zhang, 2011; Zhang, 2006):

$$UTFVI = \frac{T_s - T_m}{T_s} \qquad (2.17)$$

where is the land surface temperature, T_m is the mean of the land surface temperature of the study area. UTFVI is divided into six levels by six different ecological evaluation indices (Liu and Zhang, 2011; Zhang, 2006). Thresholds in the six UTFVI levels are shown in Table 2.5

Table 2-5: Threshold values of urban thermal field variance index

Urban Heat Island Phenomena	Urban thermal field variance index
Very Weak	<0
Weak	0 – 0.005
Medium	0.005 – 0.01
Strong	0.01 -0.015
Stronger	0.015 – 0.2
Strongest	>0.2

2.9 Sustainable Management Plan and Wastewater Reuse

Once an overall estimate of total water available is done, then the only a proper plan can be made. These management plans include management of demand side as well as on the supply side. In demand side, another requirement like irrigation, etc. can be optimized. While on the supply side, a lot of works can be done which include, groundwater recharge, modification of storage structures, rainwater harvesting, etc. Wastewater reuse is another good option to be adopted. These wastewater even when it is partially treated can be used for irrigation purpose. There is a wide scope in wastewater uses.

3 STUDY AREA

3.1 General

The study area consists of two Indian cities - Solapur in Maharashtra, and Vijayawada in Andhra Pradesh. Solapur lies in the basin of river Bhima and the municipal jurisdiction of the Solapur city, encompasses an area of 164.64 km^2. Solapur is well connected by neighboring major cities in Maharashtra as well as Andhra Pradesh and Karnataka. The city is connected with Pune through national highway 9 (NH-9) which also passes through Hyderabad. The city lies centrally in the basin of river Bhima and the watershed of river Adila (a tributary of river Sina). It is located at 17°10" and 18°32" N and 74°.42" and 76°.15" E. It has an average elevation of 457 meters above mean sea level. Vijayawada city situated at the geographical center of Andhra Pradesh state in India on the banks of Krishna River with latitude 16°31'N and longitude 80°39'E, encompasses an area of 62.55 km^2. Fig. 3.1 shows the location of the study area.

3.2 Solapur Climate

Solapur has a tropical climate with very hot summers and pleasant winters. In summers, the maximum temperature is 42° C and minimum temperature is 28° C while in winters the maximum temperature is 27°C and the minimum is 13°C. The humidity is in the range of 51-82%, and the average evaporation is 7.6 mm/day. Fig. 3.2 shows the boundary of the Solapur city considered in the study.

Rainfall pattern

Meteorological data from 1969 to 2009 is available for Solapur city. The statistics of historical monthly rainfall data is shown in Table 3.4. The annual average rainfall for Solapur city is 800 mm. It has received a maximum rainfall of 1400 mm in 1998 and driest year with rainfall of 300 mm in 1972. Most of the rainfall it received during the monsoon. August and September are the month in which it receives maximum rainfall. The rainfall pattern is more like uniformly distributed. Though it receives most of the rainfall in monsoon periods, it does receive some rainfall in the non-monsoon period too.

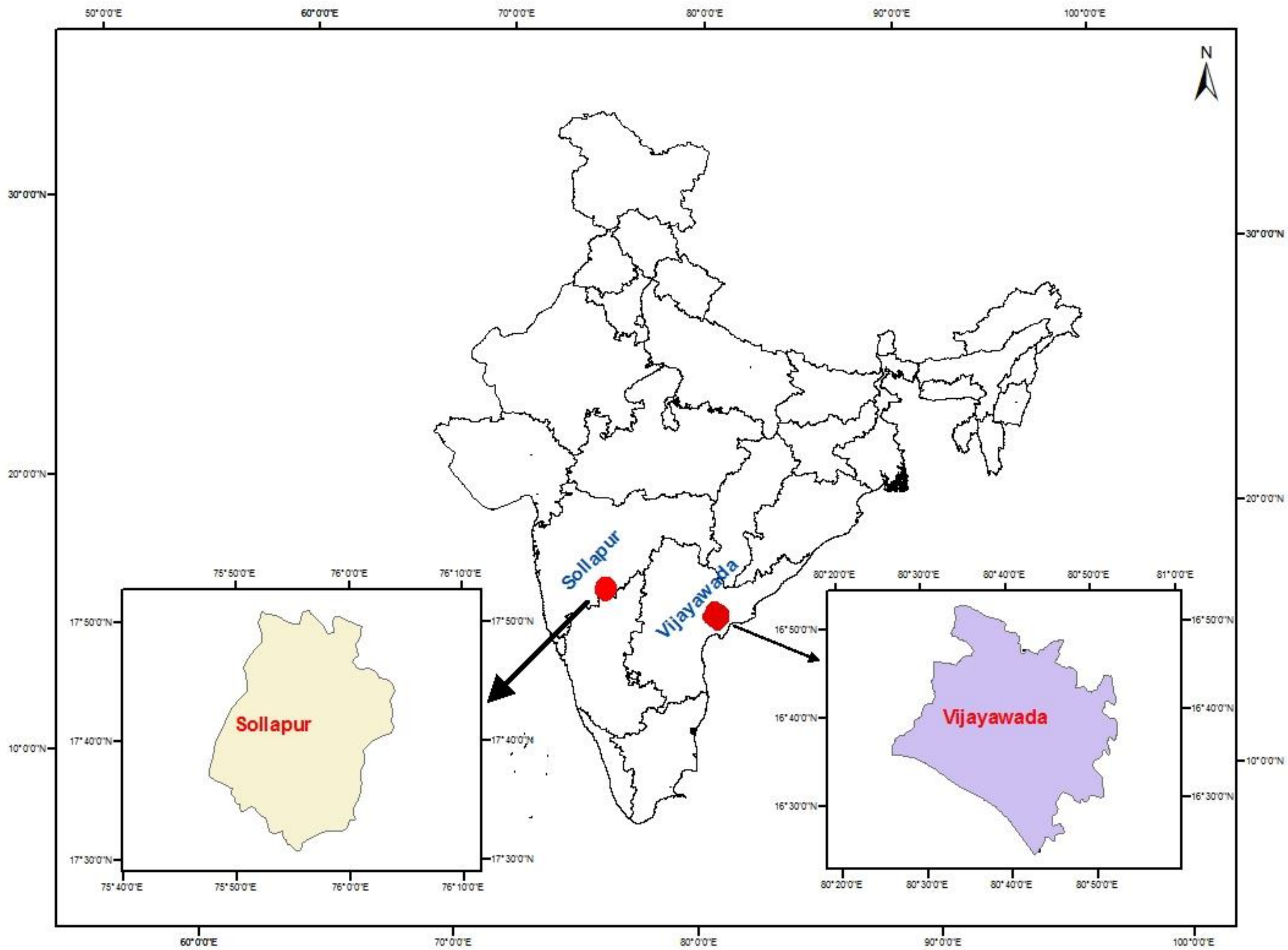

Figure 3.1: Location of study area

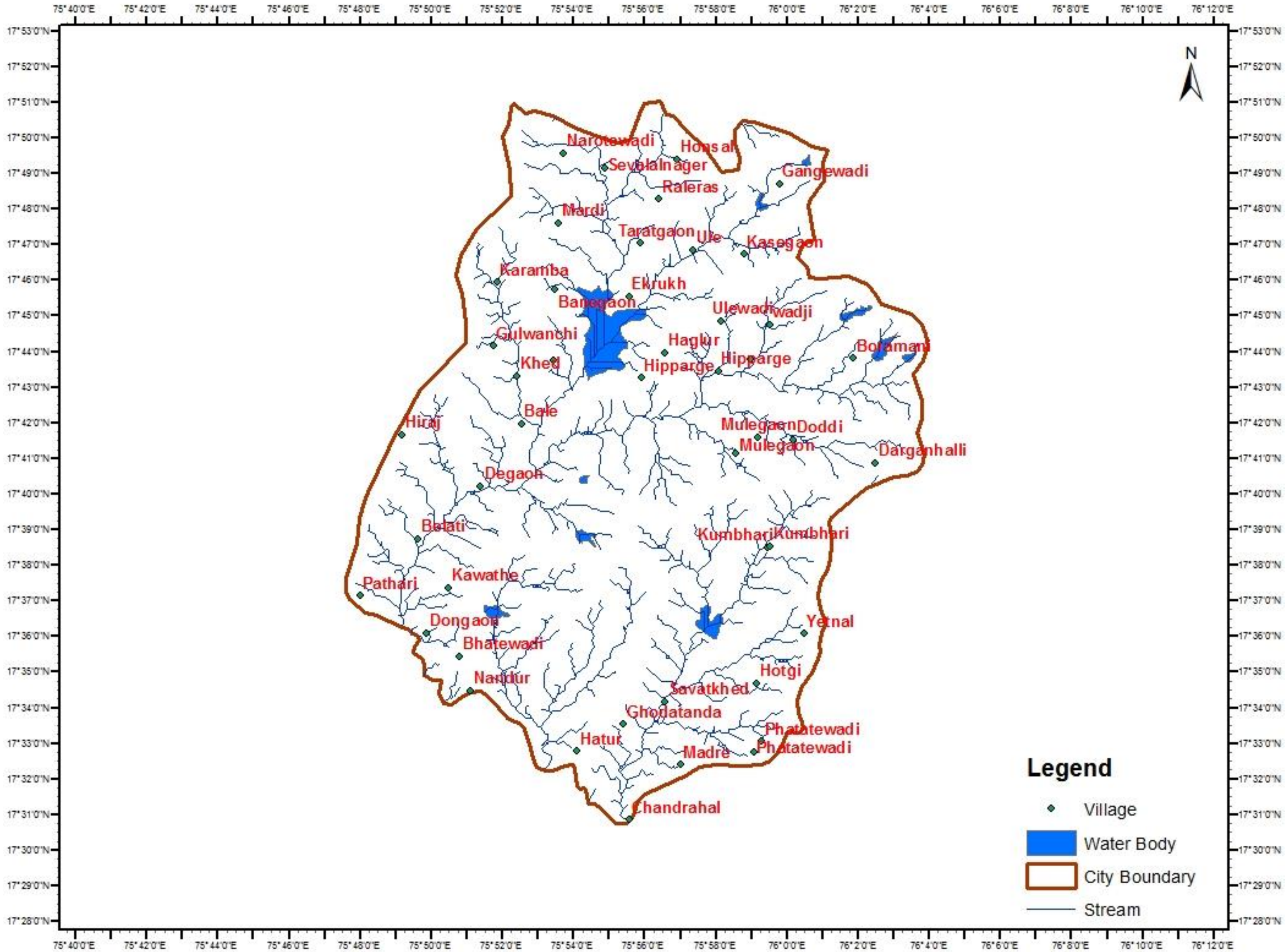

Figure 3.2: Solapur City

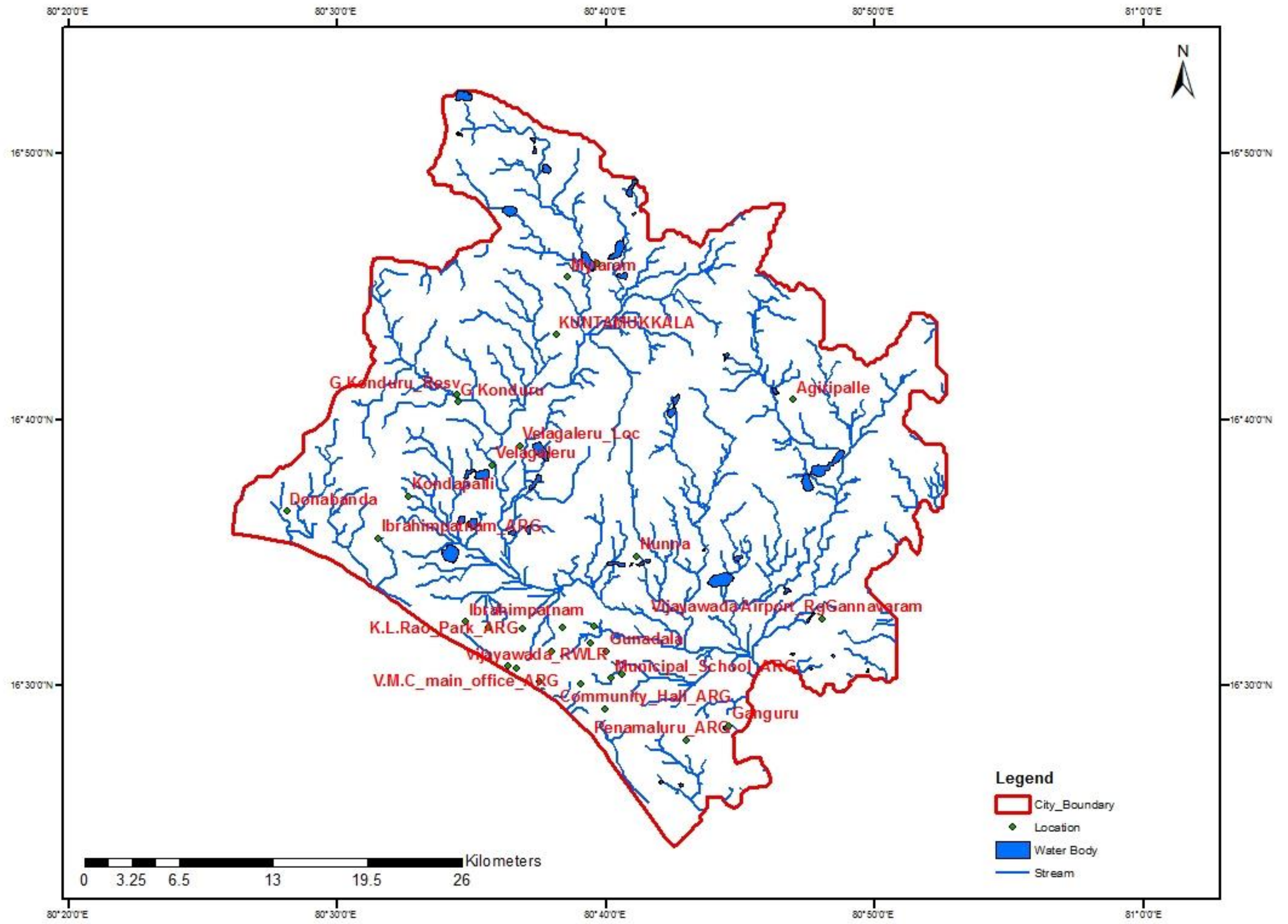

Figure 3.3: Vijayawada city

The monthly variation of rainfall for Solapur city is given in Fig. 3.4. It can be observed that the mean monthly rainfall is almost at the center of maximum and minimum rainfall for most of the months, except for August and September.

Table 3-1: Statistics of historical monthly rainfall for Solapur

	Mean (mm)	Std. dev (mm)	Max (mm)	Min (mm)
Jan	2.1	4.6	17.1	0.0
Feb	1.0	3.3	19.5	0.0
Mar	4.0	8.0	31.7	0.0
Apr	6.3	8.7	36.1	0.0
May	27.0	42.1	216.3	0.0
Jun	123.0	49.0	236.4	40.8
Jul	144.4	69.8	278.8	12.5
Aug	177.2	112.5	487.6	25.0
Sep	193.0	109.0	453.5	43.9
Oct	95.5	73.5	291.7	0.3
Nov	22.0	46.8	260.3	0.0
Dec	3.0	7.1	31.5	0.0
Annual	798.6	225.1	1412.7	306.4

Table 3.2 shows the historical flood and droughts for Solapur city in the past 35 years from 1971 to 2005. For Solapur, the pattern is uniformly distributed, and it has witnessed the almost equal number of flood and droughts.

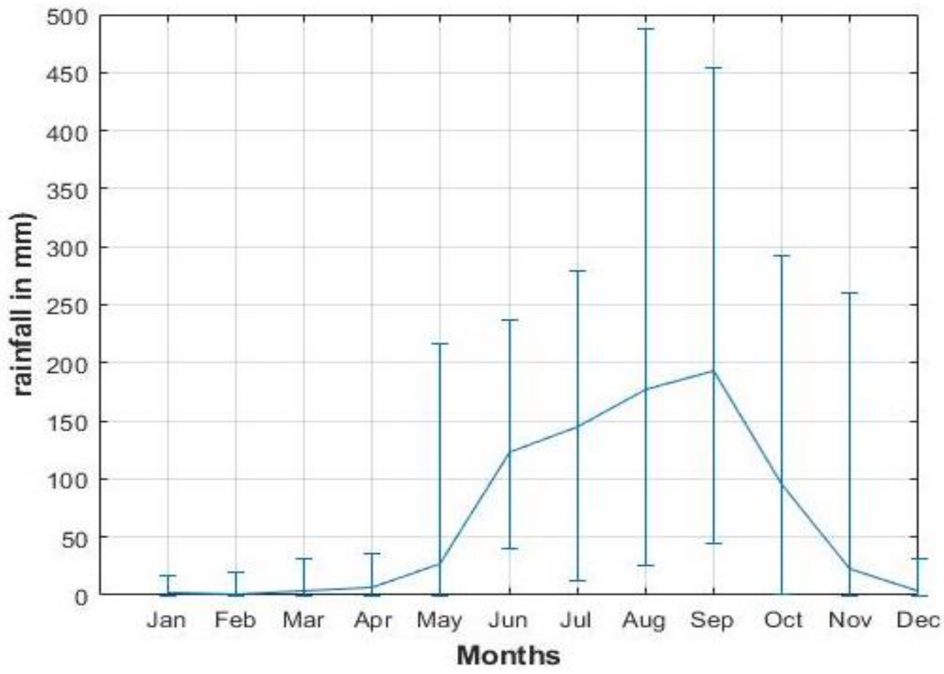

Figure 3.4: Monthly variation of rainfall in Solapur

Table 3-2: Number of Historical Floods and Droughts in Past in Solapur

Events	Frequency (No. of years)
Extreme Drought	1
Severe Drought	5
Moderate Drought	7
Normal	11
Moderate flood	6
Severe flood	3
Extreme flood	2

Historical Monthly Maximum Temperature

The monthly maximum temperature of Solapur city is about 35^{0}C. The maximum temperature goes to 40^{0}C during summer while in rest of the time it is around 30-35^{0}C. The variability in maximum temperature is very less. Solapur has witnessed a maximum temperature of 46^{0}C in May and June. Table 3.3 shows monthly maximum temperature and its variation.

Table 3-3: Statistics of monthly maximum temperature of Solapur in the past

	Mean (^{0}C)	Std. dev (^{0}C)	Max (^{0}C)	Min (^{0}C)
Jan	33.1	0.9	35.2	30.6
Feb	35.7	1.1	38.4	33.5
Mar	38.7	0.8	40.4	36.9
Apr	40.5	0.7	42.4	39.1
May	40.9	0.9	42.6	39.3

	Mean (^{0}C)	Std. dev (^{0}C)	Max (^{0}C)	Min (^{0}C)
Jun	37.7	2.1	41.9	33.5
Jul	32.6	1.1	35.2	30.5
Aug	31.9	1.0	34.2	30.0
Sep	33.2	1.0	35.4	31.2
Oct	33.8	1.1	36.3	31.7
Nov	32.7	0.7	34.1	30.7
Dec	31.8	0.8	33.8	30.3

Fig. 3.5 shows a variation of the monthly maximum temperature of Solapur. The variability in temperature is maximum in June. The mean of monthly maximum temperature lies mostly in the range of 30-40^{0}C.

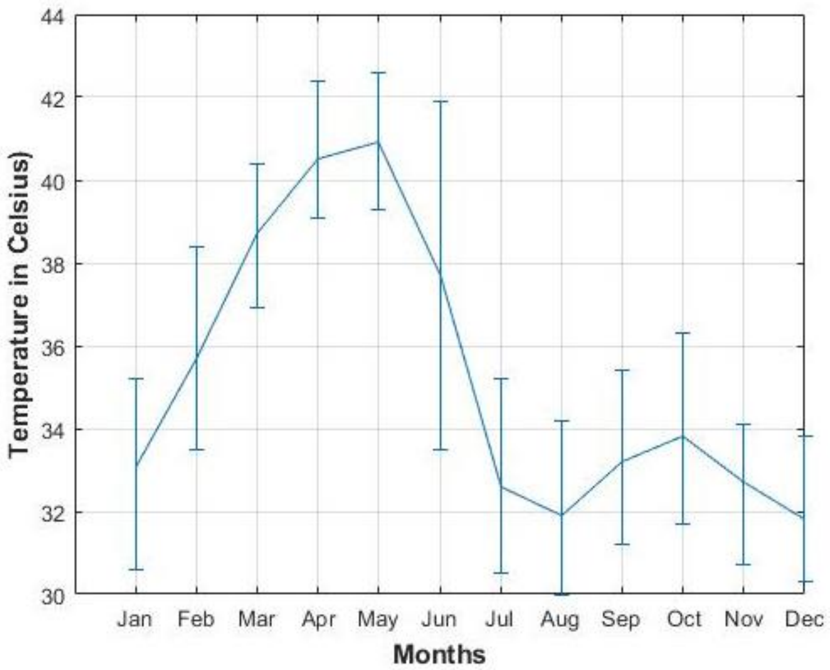

Figure 3.5: Variation of Monthly maximum temperature in Solapur

Historical Monthly Minimum Temperature

The variability in monthly minimum temperature is comparatively high during winter. During summer time the minimum temperature fluctuates around 20 ^{0}C, while in the rest of the years, it is around 10 to 15^{0}C. Table 3.4 shows the monthly minimum temperature and its deviation.

Table 3-4: Statistics of monthly Minimum Temperature for Solapur

	Mean (^{0}C)	Std. dev (^{0}C)	Max (^{0}C)	Min (^{0}C)
Jan	12.3	1.4	15.1	8.6
Feb	13.7	1.2	16.7	11.0
Mar	16.6	1.3	19.2	13.3
Apr	20.4	1.1	23.8	18.0

	Mean (^{0}C)	Std. dev (^{0}C)	Max (^{0}C)	Min (^{0}C)
May	21.9	0.8	23.8	19.7
Jun	21.7	0.5	23.0	20.4
Jul	21.3	0.5	22.2	20.1
Aug	20.9	0.5	22.1	19.7
Sep	20.0	0.7	21.2	17.9
Oct	17.6	1.2	20.2	15.5
Nov	14.3	1.9	18.9	9.8
Dec	12.2	1.3	14.7	9.0

Fig. 3.6 shows a variation of monthly minimum temperature for Solapur city. The variability is comparatively high in the non-monsoon period that that in monsoon. In January, and December month, the minimum temperature has gone even below 10^{0}C.

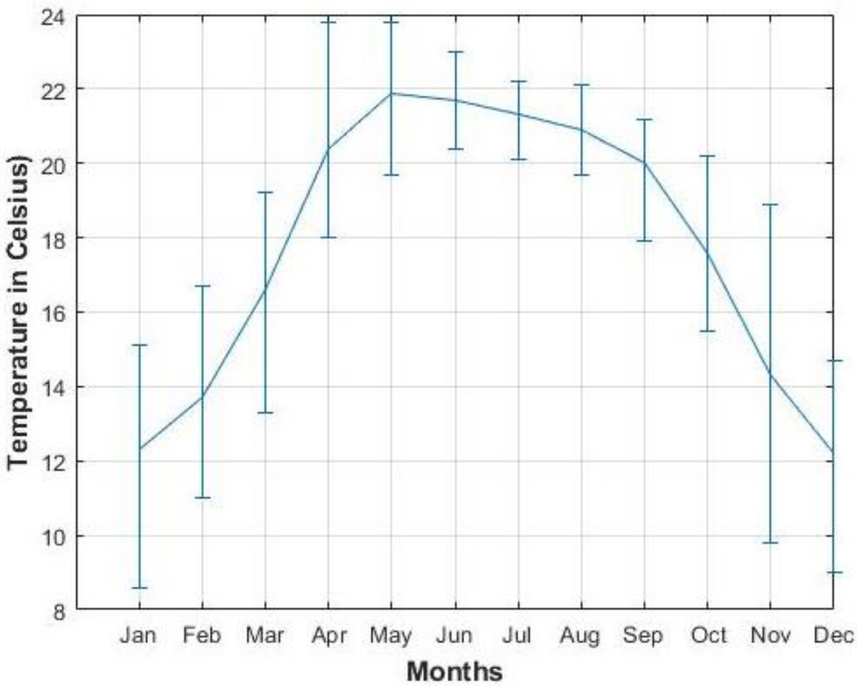

Figure 3.6: Variation of monthly minimum temperature

3.3 Vijayawada Climate

Vijayawada city has a climate with very hot summers and pleasant winters. The total area has been divided into two categories high temperature and low temperature. The maximum temperature is 30°C-39°C and minimum temperature is 24°C-30°C.

Rainfall Pattern

Meteorological data from 1969 to 1997 for Vijayawada city has been used in the study. The statistics of historical rainfall data as shown in Table 3.7 reveals that the rainfall in the region has very high variability. Vijayawada has witnessed an extreme annual rainfall of 1450 mm in 1969 while an extreme drought of 600 mm in 1979. It mostly receives rainfall from June to October. Even the month wise rainfall has a very high standard deviation.

Table 3-5: Statistics of historical rainfall for Vijayawada city

Month	Mean (mm)	Std. dev (mm)	Max (mm)	Min (mm)
Jan	1.9	5.2	23.5	0.0
Feb	8.0	17.5	69.4	0.0
Mar	9.8	22.1	88.0	0.0
Apr	16.7	24.5	83.6	0.0
May	45.6	76.1	397.0	0.5
Jun	121.5	60.6	263.5	22.6
Jul	184.5	113.8	575.3	45.9
Aug	171.4	90.9	377.2	9.8
Sep	142.0	83.8	316.7	16.0
Oct	131.1	98.6	364.9	1.4
Nov	43.7	48.2	187.4	0.0
Dec	9.9	20.9	93.1	0.0
Annual	906.3	236.1	1455.0	600.5

The month-wise variation of rainfall for Vijayawada city is given in Fig. 3.7. It can be seen that the mean of the rainfall during the monsoon season is more inclined towards the higher values. It is also evident that for the city during monsoon, though sometimes the monthly rainfall was more than the annual average rainfall of the city there are also cases of very few rainfall.

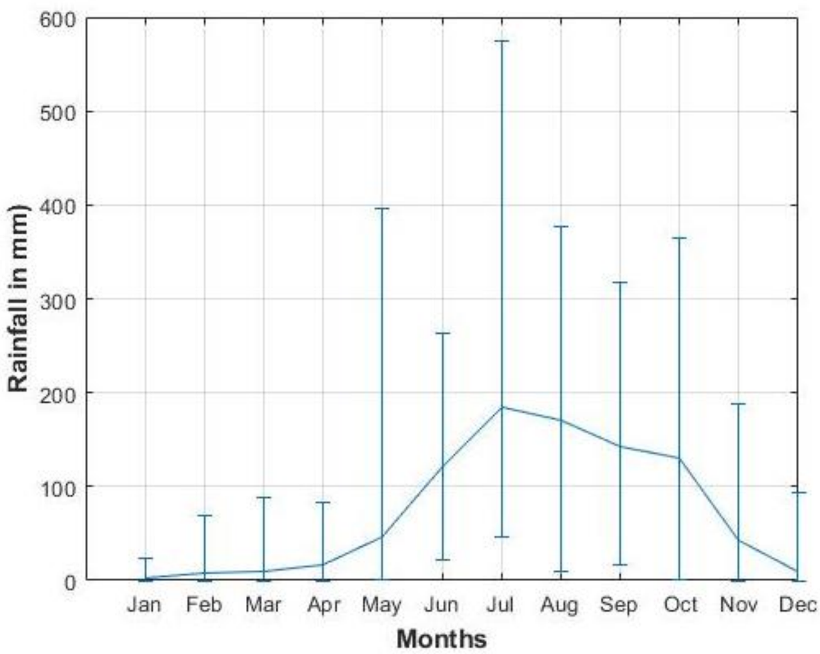

Figure 3.7: Monthly variation of rainfall in Vijayawada

In the last29 years, three times an extreme flood of corresponding to rainfall more than 1200 mm has occurred, while four times severe flood has occurred. Table 3.8 shows historical floods and droughts for Vijayawada in the last29years. The data shows that a large number of floods have occurred in the region with a high magnitude.

Table 3-6: Historical Floods and Droughts in Vijayawada

Events	**Frequency (No of years)**
Extreme Drought	0
Severe Drought	3
Moderate Drought	11
Normal	6
Moderate flood	2
Severe flood	4
Extreme flood	3

4 CLIMATE CHANGE MODELLING

4.1 General

The GCM models developed by IPCC were used for the prediction of climate variables. Depending upon the geographical coordinates of the study area, the historical (from 1970 to 1999) and projected (from 2020 to 2079) data for all the RCP scenarios were extracted from the nearest GCM location to the study area. A total of 7 GCM models were used. These models were selected from a total of 56 models on the condition, that it has variables of same realizations.

Presently there are as many as 56 models available under IPCC based on the Fifth Assessment Report (AR5). And almost 30 different institutions is involved in the development of these models. In AR5, the simulation is done for the historical data and four different future scenarios, i.e. RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. These models are developed for almost all the climate and hydrological variable. Out of the 56 different models, presently only 21 models have future scenarios for all the RCPs condition. In fact, these 21 models also have a future scenario for a limited number of variables. In the present study, five variable is considered, rainfall, maximum temperature, minimum temperature, Following models have been used in the study:

- BCC CSM 1.1 M (Beijing Climate Centre, China)
- BCC CSM 1.1 (Beijing Climate Centre, China)
- FIO ESM (The First Institute of Oceanography, SOA China)
- MIROC ESM CHEM (Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan)
- NCAR CESM 1 (CAM5) (National Center for Atmospheric Research, USA)
- NCC NOR ESM1 -M (Bjerknes Centre for Climate Research, , Norway)
- NIMR KMO KadGEM2 A0 (National Institute of Meteorological Research, Korea Meteorological Administration, South Korea)

4.2 Procedure

The methodology consists of five steps:

Step 1. Data filling and error checking

The meteorological data obtained from IMD was first checked of any data error and missing data. These values were filled based on temporal interpolation and statistical properties

Step 2. Trend analysis

Once a time series is obtained, trend analysis was done on a monthly basis using Student t-test. Three variables were considered: monthly rainfall, monthly maximum temperature, and Monthly minimum temperature. The null hypothesis is, the slope of the trend is 0, and, i.e. there is no net change in the pattern.

Step 3. GCM downscaling

For downscaling the GCM variable, change factor method has been used. In this approach, for rainfall, multiplicative change factor is used, and for temperature, the additive change factor has been used. These change factors recalculated based on the change in the mean monthly value of the variable.

Step 4. Predictions

Based on the change factor calculated, the projection for the variables was made using the same factor to the historical data of the study area.

Step 5. Indices

To identify the extreme events, the rainfall of the region is divided into seven categories, i.e. Extreme drought, severe drought, moderate drought, normal rainfall, moderate flood, severe flood, and extreme flood.

The threshold value for this division is based on the deviation of total annual rainfall from the mean, i.e. mean ± 0.5 std. dev, mean ± std. dev and mean ± 1.5 std. dev.

4.3 Climate Change Modelling For Solapur

Rainfall data for Solapur from 1971 to 2005 (35 years) is used for trend analysis, while for temperature, 1969 to 2009 data are available. The statistical test for trend is done using Student t-test. Climate change projection is done for 60 years from 2020.

4.3.1 Trend Analysis

Trend analysis for rainfall, monthly maximum, and minimum temperature was done using the student-test. The null hypothesis is taken that there is no significant change in the climate pattern.

Monthly rainfall

Fig. 4.1shows a linear regression fit for monthly rainfall as:

- $y(t) = \hat{\alpha} + \hat{\beta}t + \varepsilon(t)$
- α = 61.18, β = 0.023(Slope of line)
- Null Hypothesis: β = 0, i.e., Mean of the annual rainfall remains the same
- Using Student-t-test, (for a significance level of 0.05%)
- T_score = 0.68 <T_critical = 1.965
- Hence, the hypothesis is accepted. So, the change in the monthly rainfall is **statistically significant**

Monthly Maximum Temperature

Fig. 4.2 shows a linear regression fit for monthly maximum temperature as:

- $y(t) = \hat{\alpha} + \hat{\beta}t + \varepsilon(t)$
- α = 35, β = 0.001(Slope of line)

- Null Hypothesis: β = 0, i.e., Mean of the monthly maximum temperature remains the same
- Using Student-t-test, (for a significance level of 0.05%)
- T_score = 0.95<T_critical = 1.96
- Hence, the hypothesis is rejected. So, the change in the monthly maximum temperature is statistically significant.

Monthly Minimum Temperature

Fig. 4.3 shows a linear regression fit for monthly minimum temperature as:

- $y(t) = \hat{\alpha} + \hat{\beta}t + \varepsilon(t)$
- α = 17.76, β = -0.0001(Slope of line)
- Null Hypothesis: β = 0, i.e. Mean of the monthly minimum temperature remains same
- Using Student-t-test, (for a significance level of 0.05%)
- T_score = -0.11 <T_critical = 1.964
- Hence, the hypothesis is rejected. So, the change in the mean annual rainfall is **significant.**

4.3.2 GCM Projections for Solapur

GCM projection for rainfall, maximum temperature, and minimum temperature was carried out for all the RCP scenarios by all the seven GCM models.

RCP 2.6

Projection for Rainfall

The projection of all the seven GCM models shows that annual average rainfall in the next 60 years is going to decrease by about 40 mm. Except for NIMR KMO HadGEM2 A0 and NCAR CESM 1 model, all others show a decreasing trend. As per NIMR KMO HadGEM2 A0, the annual maximum rainfall may go up to 1650 mm. The annual rainfall may go to 270 mm by 2050. Fig. 4.4 shows annual rainfall projection for the RCP 2.6 scenario.

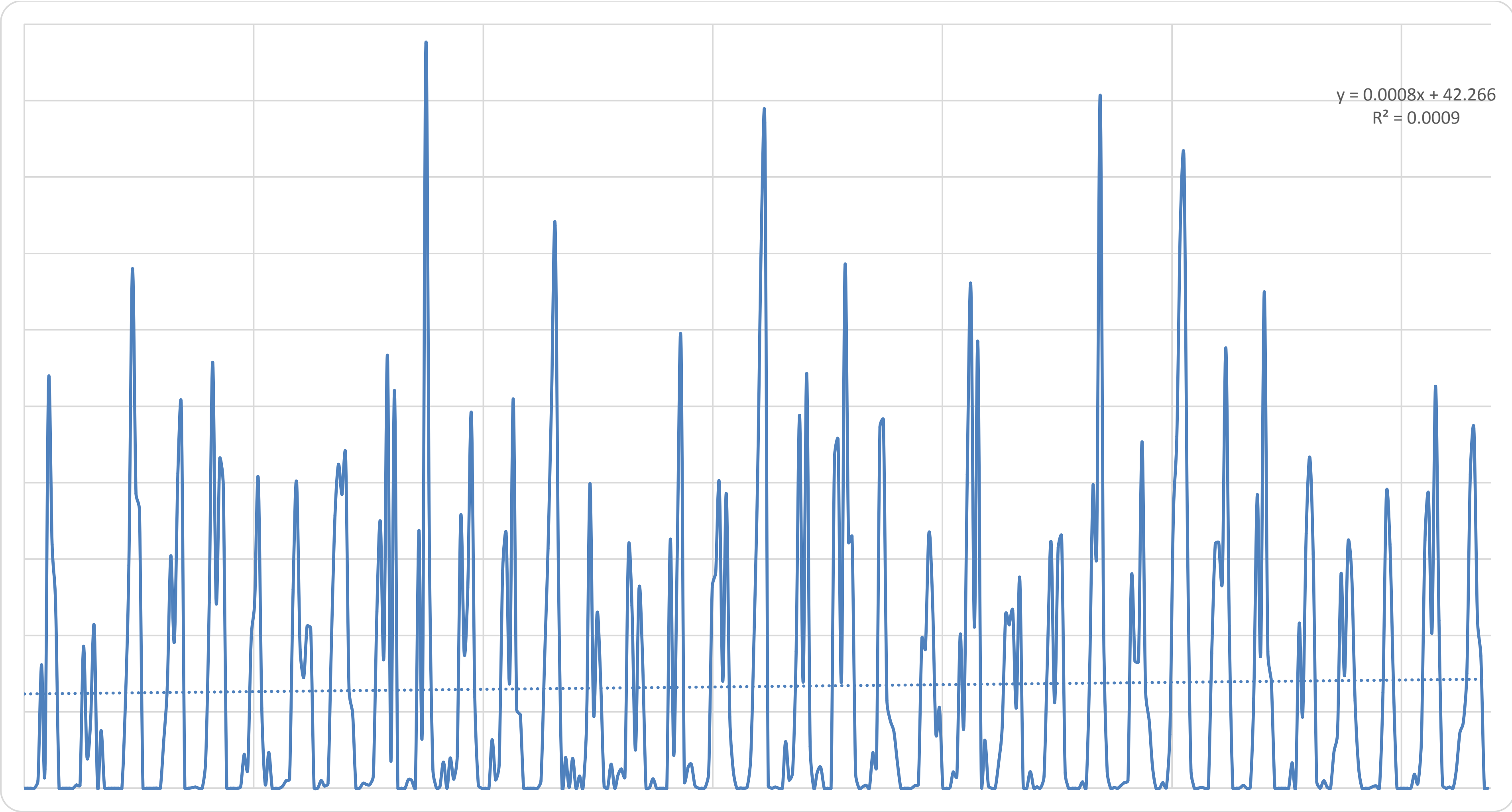

Figure 4.1: linear regression fit for monthly rainfall for Solapur

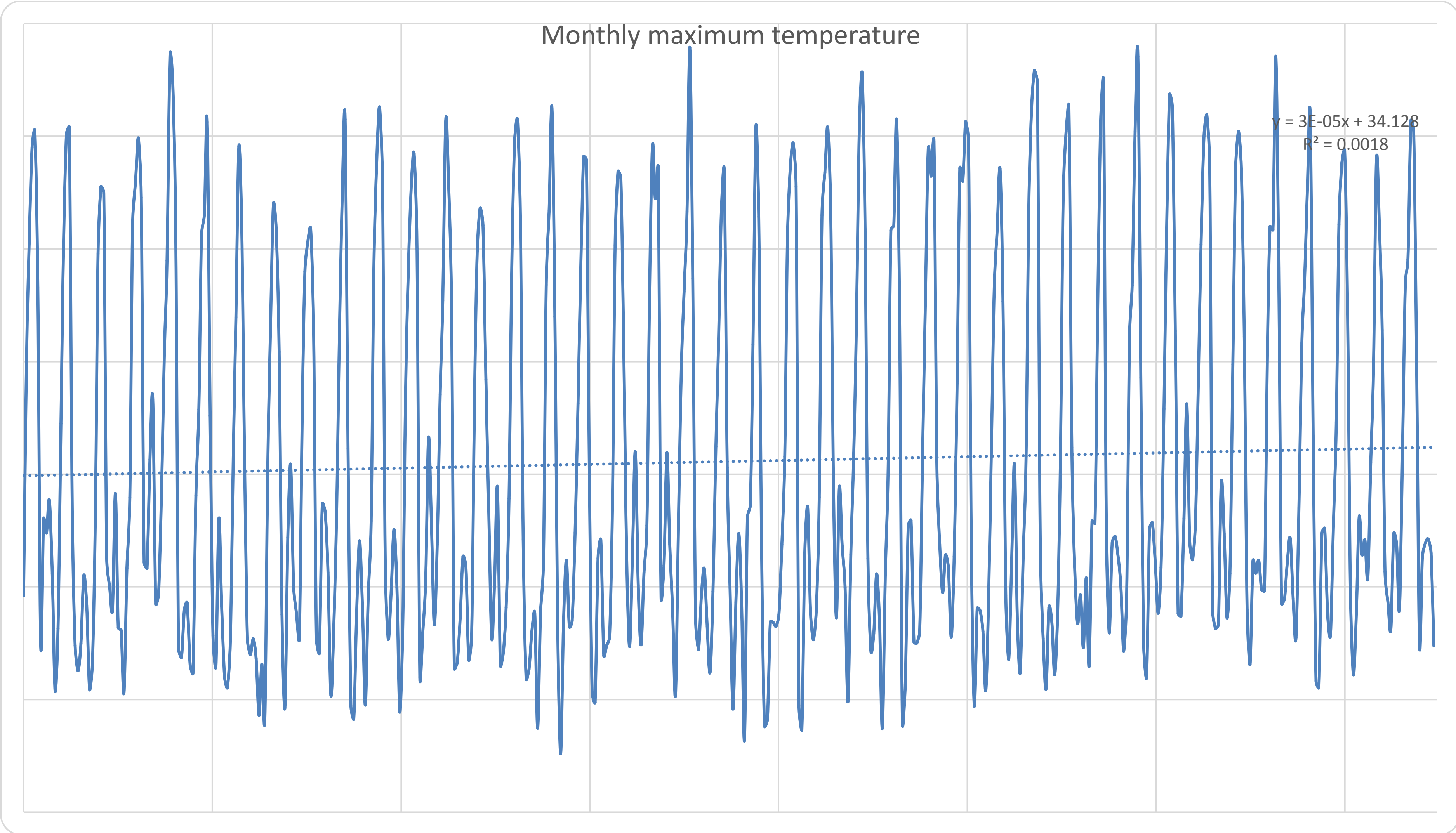

Figure 4.2: linear regression fit for monthly maximum temperature for Solapur

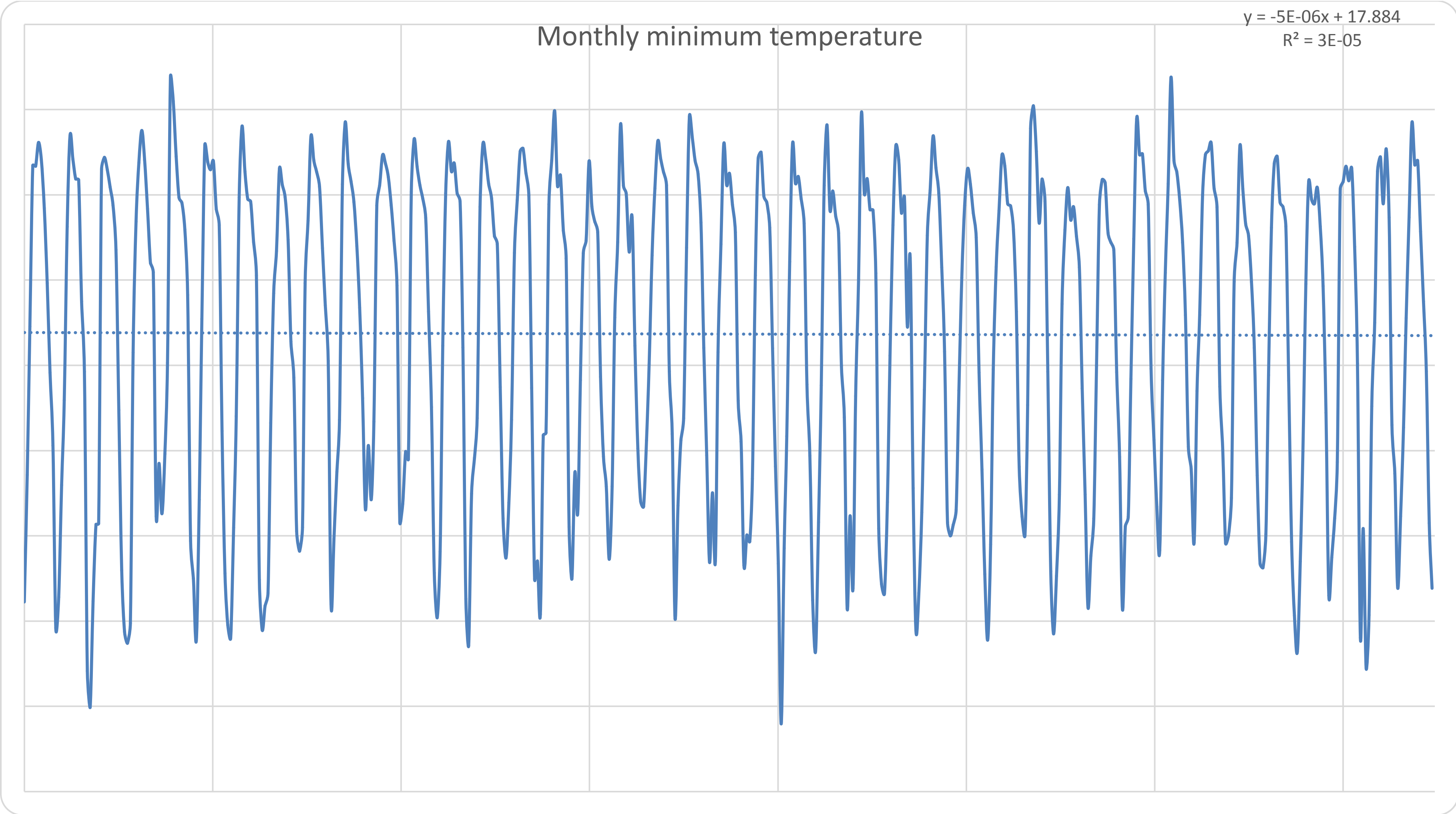

Figure 4.3: Linear regression fit for monthly minimum temperature for Solapur

Table 4.1 shows some floods and droughts estimated from the predicted values. These projections are made based on the historical mean and standard deviation. The above result shows that an overall number of floods as well as droughts are going to increase, i.e. frequent droughts can be observed in the future. On an average, about 20-25 drought episodes are supposed to occur in the next 60 years as per RCP 2.6 scenario.

Table 4-1: Number of floods and droughts per RCP 2.6 for Solapur

	Global Climate Models						
	NCAR CESM 1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 - M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	3	2	2	11	4	3	3
Severe drought	6	7	4	13	10	13	9
Moderate drought	9	14	10	14	15	12	14
Normal	21	22	20	16	20	18	21
Moderate flood	9	6	6	3	6	9	6
Severe flood	7	4	9	2	3	3	3
Extreme flood	5	5	9	1	2	2	4

Table 4.2 shows the percentage change in mean monthly rainfall from that of historical rainfall. It can be seen that there is a decrease in mean monthly rainfall almost for all the months. The city receives most of the rainfall from monsoon where there is a significant decrease in rainfall of about 10%.

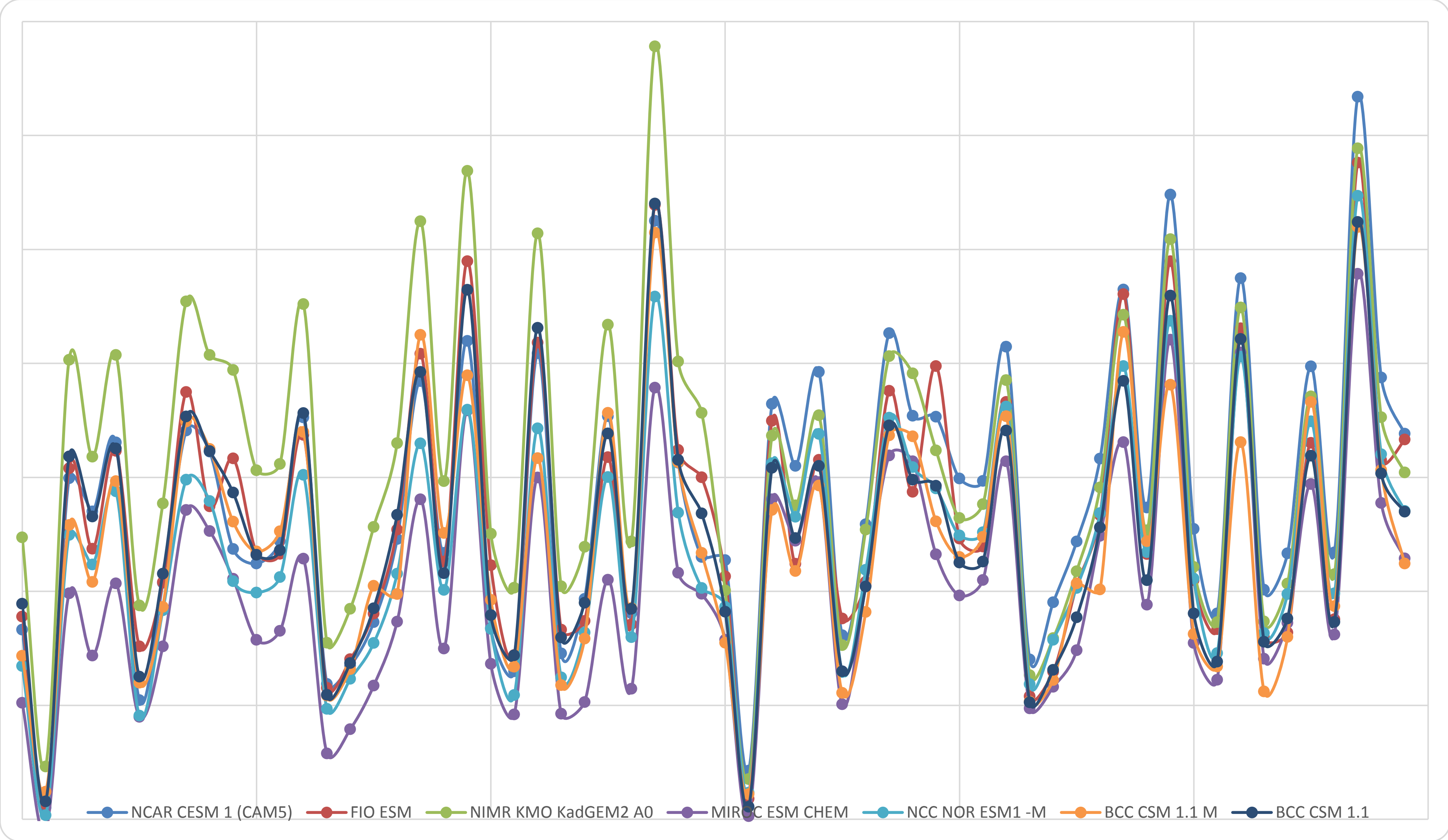

Figure 4.4: Annual rainfall projection (in mm) for RCP 2.6 scenario for Solapur

Table 4-2: Percentage change in Monthly rainfall for the RCP 2.6 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM 2 A0	MIRO C ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	-8.1	-34.4	19.3	33.3	-5.2	-44.1	14.8	-3.5
	Feb	8.4	-11.1	-18.3	16.4	-3.2	-24.3	-5.5	-5.4
	Mar	22.4	-17.7	9.5	17.0	-7.2	-13.2	-8.5	0.3
	Apr	-10.8	30.0	-0.8	-9.1	7.3	3.1	4.3	3.4
	May	0.8	28.2	16.2	12.1	-26.8	-7.6	5.3	4.0
	Jun	-28.1	8.7	9.8	-21.6	-12.7	-3.1	-12.9	-8.6
	Jul	-4.1	6.3	13.3	-22.0	-11.3	1.1	-14.5	-4.5
	Aug	-21.3	7.2	26.6	-17.6	-32.3	-22.1	-1.6	-8.7
	Sep	0.9	-26.5	7.8	-43.2	-14.1	12.4	-10.6	-10.5
	Oct	12.6	-21.7	4.3	-46.1	-4.3	-55.0	12.8	-13.9
	Nov	-2.2	-40.3	11.4	3.6	-15.2	-21.7	4.4	-8.6
	Dec	-26.5	-50.4	-15.2	5.6	0.6	-42.3	-13.3	-20.2
2050-2079	Jan	-9.9	-33.7	16.9	16.6	-15.2	-31.6	12.1	-6.4
	Feb	-9.6	-35.6	-16.1	25.5	2.3	-23.2	-13.8	-10.1
	Mar	15.1	35.3	2.8	0.7	1.2	-9.4	6.0	7.4
	Apr	-26.2	-5.0	-22.0	-11.2	17.2	-10.3	29.6	-4.0
	May	9.0	-9.6	17.8	7.0	-31.0	-16.7	7.7	-2.3
	Jun	37.5	2.7	6.6	-26.4	14.4	-20.8	-11.7	0.3
	Jul	-0.4	0.2	1.7	-16.6	-9.6	-9.8	-13.8	-6.9
	Aug	4.1	42.9	4.3	-15.0	-10.9	-17.5	2.6	1.5
	Sep	-1.0	-25.7	-5.3	-23.7	-7.9	19.6	-18.4	-8.9
	Oct	15.5	-36.7	-3.0	16.3	8.2	-42.5	1.2	-5.9
	Nov	-15.9	-34.1	30.6	23.0	-20.3	-7.9	-8.2	-4.7
	Dec	-21.2	-49.4	-3.4	25.2	1.7	-18.4	-10.3	-10.8

Projection for Maximum Temperature

Table 4.3 shows the increase in monthly maximum temperature for the RCP 2.6 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase of about 152^{0}C in the first 30 years and rises to 2^{0}C in the next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 0.9^{0}C – 1^{0}C in 2020 to 2049 and 1^{0}C – 1.5^{0}C in 2050-2079.

Projection for Minimum Temperature

Table 4.4 shows the increase in monthly minimum temperature for the RCP 2.6 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1^{0}C in the first 30 years and rises to 1.5^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by

$0.7^0C – 0.1^0C$ in the next 60 years. It can also be observed that the rise in monthly maximum temperature is much more than the rise in monthly minimum temperature.

Table 4-3: Increase (^0C) in monthly maximum temperature for RCP 2.6 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.4	0.6	0.9	0.8	1.1	0.7	0.6	0.9
	Feb	1.3	0.8	0.9	0.9	2.1	0.6	0.6	1.0
	Mar	0.4	0.7	0.6	0.8	0.9	0.5	0.6	0.6
	Apr	1.2	0.7	0.7	0.9	1.3	0.8	0.6	0.9
	May	1.2	0.6	0.8	0.8	1.3	0.9	0.6	0.9
	Jun	1.4	0.6	0.7	0.9	1.2	0.8	0.6	0.9
	Jul	1.5	0.8	0.7	0.9	1.3	0.6	0.7	0.9
	Aug	1.7	0.7	0.8	0.9	1.2	0.8	0.7	1.0
	Sep	1.0	0.7	0.7	1.0	1.7	0.9	0.6	0.9
	Oct	0.6	0.7	0.7	1.0	1.4	0.8	0.6	0.8
	Nov	0.8	0.6	0.6	1.0	1.4	0.7	0.6	0.8
	Dec	1.9	0.6	0.8	0.9	1.3	0.6	0.6	0.9
2050-2079	Jan	2.1	0.7	0.9	1.0	1.5	0.8	0.7	1.1
	Feb	2.0	0.8	0.9	1.1	2.1	0.8	0.6	1.2
	Mar	1.7	0.8	0.7	1.1	0.6	0.9	0.6	0.9
	Apr	2.3	0.7	0.7	1.0	0.9	1.0	0.6	1.0
	May	2.3	0.7	0.7	1.0	1.6	0.9	0.8	1.1
	Jun	2.2	0.7	0.8	0.9	1.3	0.9	0.9	1.1
	Jul	1.4	0.8	0.7	1.0	1.1	0.7	0.9	0.9
	Aug	1.8	0.9	0.8	1.1	0.9	0.8	0.8	1.0
	Sep	1.6	0.8	0.7	1.1	1.5	0.9	0.7	1.1
	Oct	1.2	0.8	0.9	1.1	1.0	0.8	0.7	0.9
	Nov	1.7	0.7	0.7	1.2	1.8	0.7	0.7	1.1
	Dec	2.1	0.6	0.6	1.1	1.2	0.7	0.6	1.0

Table 4-4: Increase (^{0}C) in monthly minimum temperature for RCP 2.6 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.6	0.7	1.0	0.8	1.0	0.7	0.6	0.9
	Feb	1.9	0.8	0.9	0.9	1.6	0.6	0.6	1.0
	Mar	1.1	0.6	0.7	0.8	0.7	0.5	0.6	0.7
	Apr	1.8	0.7	0.7	0.9	1.3	0.8	0.6	1.0
	May	1.2	0.6	0.8	0.8	0.8	0.9	0.6	0.8
	Jun	0.9	0.6	0.7	0.9	1.0	0.8	0.6	0.8
	Jul	1.4	0.8	0.7	0.9	0.7	0.6	0.7	0.8
	Aug	1.5	0.7	0.8	0.9	0.3	0.8	0.7	0.8
	Sep	1.2	0.7	0.6	1.0	1.0	0.9	0.6	0.9
	Oct	1.3	0.7	0.6	1.0	1.0	0.8	0.6	0.8
	Nov	1.0	0.6	0.5	1.0	0.7	0.7	0.6	0.7
	Dec	1.6	0.6	0.8	0.9	0.9	0.6	0.6	0.8
2050-2079	Jan	2.2	0.7	1.0	1.1	0.8	0.8	0.7	1.0
	Feb	1.9	0.9	0.9	1.1	1.8	0.8	0.6	1.1
	Mar	2.0	0.8	0.7	1.1	0.5	0.9	0.6	0.9
	Apr	2.0	0.7	0.7	1.0	1.1	1.0	0.6	1.0
	May	1.9	0.7	0.8	1.0	1.0	0.9	0.8	1.0
	Jun	1.7	0.7	0.8	0.9	1.5	0.9	0.9	1.0
	Jul	1.5	0.8	0.6	1.0	0.6	0.7	0.9	0.9
	Aug	1.7	0.9	0.7	1.1	0.5	0.8	0.8	0.9
	Sep	1.6	0.8	0.7	1.1	0.9	0.9	0.8	1.0
	Oct	1.8	0.8	0.7	1.1	0.7	0.8	0.7	0.9
	Nov	1.8	0.8	0.6	1.1	1.0	0.7	0.7	1.0
	Dec	1.8	0.7	0.6	1.1	0.8	0.7	0.6	0.9

RCP 4.5

Projection for rainfall

The projection of all the seven GCM models shows that annual average rainfall in the next 60 years is going to decrease. As per RCP 4.5, the average rainfall is going to be around 760 mm. Though NIMR KMO KadGEM2 A0 shows a very high average annual rainfall of 865 mm but rest, all models are showing lower values.

Annual rainfall projection for RCP 4.5 scenario is given in Fig. 4.5. The figure shows two extreme peaks in the annual rainfall. The annual rainfall as per RCP 4.5 scenario, might go as high as 1500 m during the wet year and as low as 270 mm during a dry year.

Table 4-5: Number of floods and droughts as per RCP 4.5 for Solapur

	Global Climate Models						
	NCAR CESM 1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 - M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	3	3	2	7	4	7	4
Severe drought	8	6	3	8	12	11	9
Moderate drought	12	13	8	14	12	13	15
Normal	22	21	22	17	23	17	21
Moderate flood	7	7	9	6	4	7	5
Severe flood	4	6	8	4	3	3	2
Extreme flood	4	4	8	4	2	2	4

Table 4.5 shows a number of floods and droughts estimated from the predicted values. These projections are made based on the historical mean and standard deviation. The above result shows that an overall number of floods and droughts both are going to decrease. It is also observed for the analysis that there is a significant increase in the number of moderate droughts. On an average, about 25 to 30 drought episodes are supposed to occur in the next 60 years as per RCP 4.5 scenario.

Table 4.6 shows the percentage change in mean monthly rainfall for that of historical rainfall. As per the average projection of all models, the monthly average rainfall is mostly decreasing in almost all months except in February, March, and April in the first 30 years while in the next 30 years it is decreasing in all months. The monsoon rainfall is about to decrease by about 10%.

Projection for Maximum Temperature

Table 4.7 shows the increase in monthly maximum temperature for RCP 4.5 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.5^{0}C in the first 30 years and rises to 2.5^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2049 and 1.5^{0}Cby 2050-2079.

Projection for Minimum Temperature

Table 4.8 shows the increase in monthly minimum temperature for the RCP 2.6 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1^{0}C to 1.5^{0}C in the first 30 years and rises to 2^{0}C in the next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2049 and 1.5^{0}C in 2050-2079.

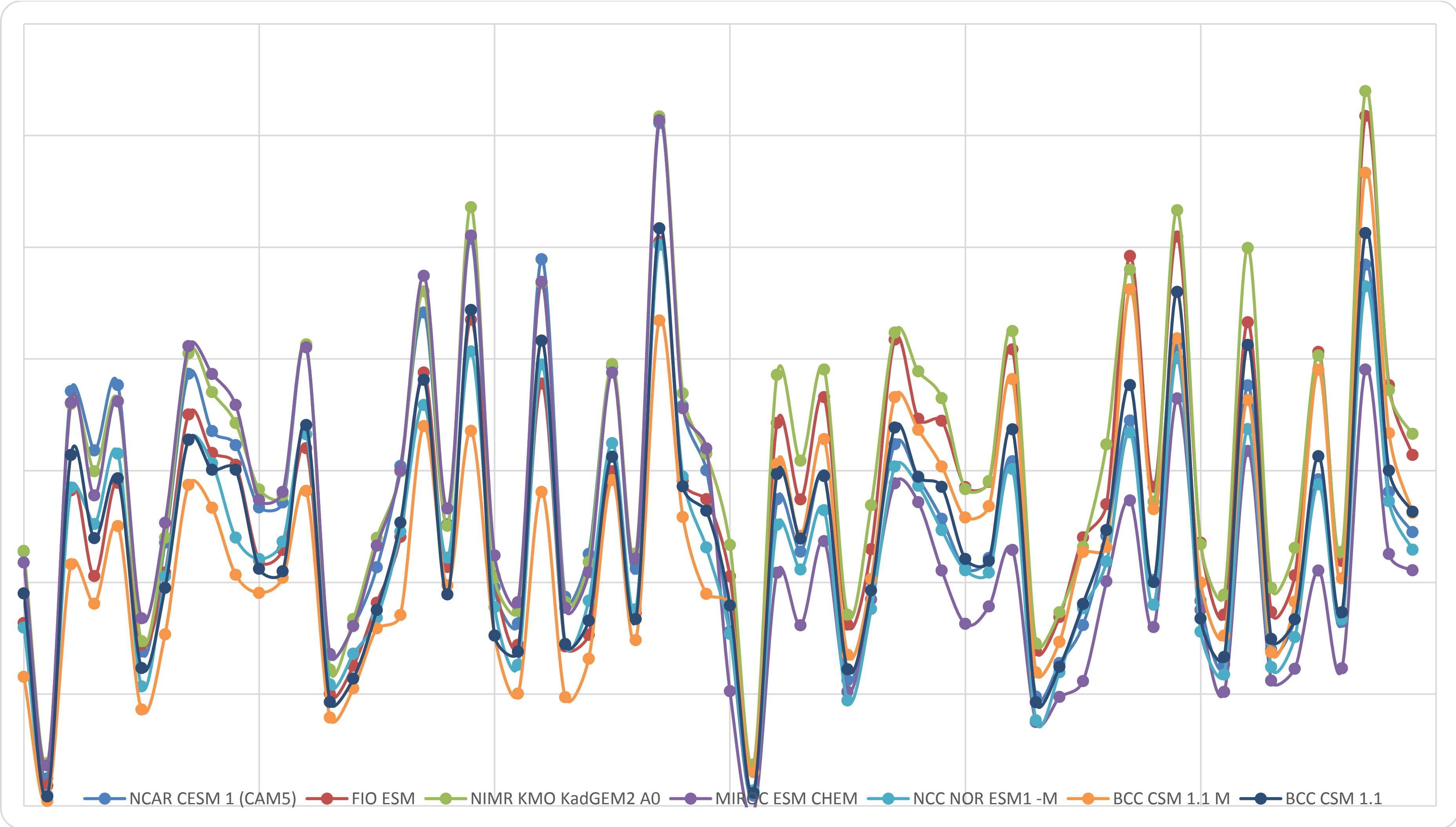

Figure 4.5: Annual rainfall projection for RCP 4.5 scenario for Solapur

Table 4-6: Percentage change in rainfall for RCP 4.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM 2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	-25.3	-43.6	44.4	27.1	-1.5	-40.6	6.8	-4.7
	Feb	33.4	4.5	-17.6	15.3	-3.4	-32.6	11.8	1.6
	Mar	35.5	3.9	-4.7	9.3	43.8	-15.6	-15.0	8.2
	Apr	-5.6	34.9	-13.1	0.9	8.7	4.0	7.1	5.3
	May	0.6	-2.8	16.3	1.2	-13.6	-18.1	-7.1	-3.3
	Jun	-8.3	6.2	7.2	1.9	-13.3	-13.6	-23.6	-6.2
	Jul	-11.7	-4.7	-19.1	4.4	-8.6	-16.8	-26.4	-11.8
	Aug	6.0	4.3	8.7	18.8	-21.4	-33.9	11.3	-0.9
	Sep	3.4	-26.4	9.0	-2.1	-11.7	-5.6	-17.6	-7.3
	Oct	37.9	-34.8	15.6	-7.4	9.2	-42.6	4.3	-2.5
	Nov	-10.0	2.2	10.0	19.1	-4.0	-26.8	4.1	-0.8
	Dec	-24.8	7.4	-9.2	36.4	4.2	-37.7	-8.0	-4.5
2050-2079	Jan	-13.0	-15.6	21.3	14.1	-2.9	-22.9	-1.1	-2.9
	Feb	9.9	-7.7	-5.4	15.0	21.9	-43.7	-10.2	-2.9
	Mar	30.7	5.7	12.8	7.7	-5.3	-11.0	-4.3	5.2
	Apr	-23.5	16.1	-10.7	-7.6	-17.2	3.1	34.5	-0.7
	May	-13.7	17.4	0.5	0.7	-14.9	-25.1	16.4	-2.7
	Jun	0.6	11.2	4.4	-4.6	4.7	-2.2	-12.1	0.3
	Jul	-11.4	9.2	8.1	-4.9	-39.0	0.0	-24.9	-9.0
	Aug	-13.6	5.5	20.0	-21.5	-20.4	-7.1	-0.3	-5.4
	Sep	-26.3	11.9	-2.9	-55.1	-13.5	18.1	-14.7	-11.8
	Oct	-3.5	-24.4	14.8	-34.0	-8.5	-36.2	-0.9	-13.2
	Nov	-4.2	-29.1	16.6	12.9	-3.8	-24.3	-6.4	-5.5
	Dec	-15.8	-36.6	-9.4	-6.8	-1.8	-36.9	19.4	-12.6

Table 4-7: Increase (0C) in monthly maximum temperature for RCP 4.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.8	0.8	1.4	1.0	1.4	0.8	0.8	1.2
	Feb	0.8	0.9	1.4	1.1	2.0	0.8	0.8	1.1
	Mar	0.5	0.8	1.0	1.0	0.7	0.8	0.9	0.8
	Apr	1.4	0.8	1.1	1.0	0.6	1.0	0.8	1.0
	May	1.3	0.8	1.3	0.9	1.1	0.9	0.9	1.1

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	Jun	1.6	0.7	1.2	1.0	1.3	0.8	1.0	1.1
	Jul	1.8	0.7	1.1	1.0	1.1	0.8	1.0	1.1
	Aug	1.5	0.8	1.1	1.1	1.0	0.9	0.9	1.0
	Sep	0.4	0.8	1.2	1.0	1.6	0.9	0.9	1.0
	Oct	0.5	0.9	1.1	1.1	1.5	0.9	0.9	1.0
	Nov	0.9	0.8	1.1	1.2	1.1	0.8	0.9	1.0
	Dec	1.4	0.8	0.9	1.1	1.2	0.7	0.8	1.0
2050-2079	Jan	2.9	1.1	1.8	1.7	1.8	1.2	1.1	1.7
	Feb	2.6	1.2	1.7	1.7	2.8	1.1	1.1	1.7
	Mar	1.4	1.1	1.5	1.6	1.2	1.2	1.1	1.3
	Apr	2.4	1.1	1.5	1.5	1.6	1.2	1.1	1.5
	May	2.6	1.2	1.8	1.6	2.0	1.2	1.2	1.6
	Jun	2.3	1.2	1.8	1.5	1.6	1.2	1.3	1.6
	Jul	2.1	1.1	1.7	1.6	1.6	1.1	1.2	1.5
	Aug	2.2	1.1	1.9	1.6	1.9	1.1	1.1	1.6
	Sep	2.4	1.2	1.7	1.5	2.4	1.2	1.1	1.6
	Oct	2.2	1.1	1.9	1.6	2.0	1.3	1.1	1.6
	Nov	2.1	1.1	1.4	1.8	2.0	1.2	1.1	1.5
	Dec	2.6	1.2	1.5	1.7	1.7	1.1	0.9	1.5

Table 4-8: Increase (0C) in monthly minimum temperature for RCP 4.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.5	0.9	1.5	1.0	1.2	0.8	0.8	1.1
	Feb	1.6	0.9	1.4	1.1	1.5	0.8	0.8	1.1
	Mar	1.1	0.8	1.1	1.0	1.1	0.8	0.9	1.0
	Apr	1.6	0.8	1.2	1.0	1.1	1.0	0.8	1.1
	May	1.2	0.8	1.4	0.9	1.0	0.9	0.9	1.0
	Jun	1.1	0.7	1.2	1.0	0.7	0.8	1.0	0.9
	Jul	1.4	0.7	1.1	1.0	0.4	0.8	0.9	0.9
	Aug	1.3	0.8	1.1	1.1	0.2	0.9	0.9	0.9
	Sep	1.0	0.7	1.1	1.0	1.0	0.9	0.9	1.0
	Oct	1.2	0.8	1.1	1.1	1.1	0.9	0.9	1.0
	Nov	1.2	0.8	1.0	1.1	0.6	0.8	0.9	0.9
	Dec	1.1	0.7	0.9	1.1	0.6	0.7	0.8	0.9

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2050-2079	Jan	2.4	1.2	1.9	1.7	1.6	1.2	1.1	1.6
	Feb	2.7	1.3	1.7	1.7	2.3	1.2	1.1	1.7
	Mar	1.6	1.2	1.5	1.6	0.9	1.2	1.1	1.3
	Apr	2.5	1.1	1.6	1.6	1.2	1.2	1.1	1.5
	May	2.0	1.1	1.9	1.6	1.4	1.2	1.2	1.5
	Jun	1.6	1.2	1.9	1.5	1.3	1.2	1.3	1.4
	Jul	1.7	1.1	1.7	1.6	0.4	1.1	1.2	1.3
	Aug	1.7	1.2	1.9	1.6	0.7	1.1	1.1	1.3
	Sep	2.0	1.2	1.7	1.5	1.7	1.2	1.1	1.5
	Oct	1.9	1.2	1.7	1.6	1.4	1.3	1.1	1.4
	Nov	2.0	1.1	1.4	1.8	1.4	1.2	1.1	1.4
	Dec	2.2	1.2	1.6	1.7	1.3	1.1	0.9	1.5

RCP 6.0

Projection for Rainfall

RCP 6.0 projection also shows a decreasing trend in rainfall pattern in the next 60 years. The annual average rainfall for RCP 6.0 is around 630 mm which is almost 30 mm less than its historical mean. NIMR KMO KadGEM2 A0 is the only model which predicts a very high annual average rainfall of 850 mm while all other models are showing a decreasing trend. Comparing with the other RCP scenario RCP 6.0 shows a better rainfall pattern.

Annual rainfall projection for RCP 6.0 scenario is given in Fig. 4.6. The maximum rainfall as per RCP 6.0 scenario may go to 1500 mm in future. For drought year, the annual rainfall might goes as low as 250 mm.

Table 4.9 shows the projection of the number of floods and droughts. These projections are made based on the historical mean and standard deviation. The above result shows the same result again that an overall number of flood and droughts are going to decrease. On an average, about 25 to 30 drought episodes are supposed to occur in the next 60 years as per RCP 6.0 scenario. Another important conclusion is that the drought magnitude, which is going to be much lower than the historical droughts. It can also be observed that a number of moderate droughts are on the rise.

Table 4-9: Number of flood and droughts as per RCP 6.0 for Solapur

	Global Climate Models						
	NCAR CESM 1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 -M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	3	2	2	8	2	4	3
Severe drought	9	8	3	11	10	11	9
Moderate drought	13	13	9	14	11	10	11
Normal	20	19	23	17	22	21	19
Moderate flood	9	9	6	7	8	7	9
Severe flood	3	4	9	1	3	3	4
Extreme flood	3	5	8	2	4	4	5

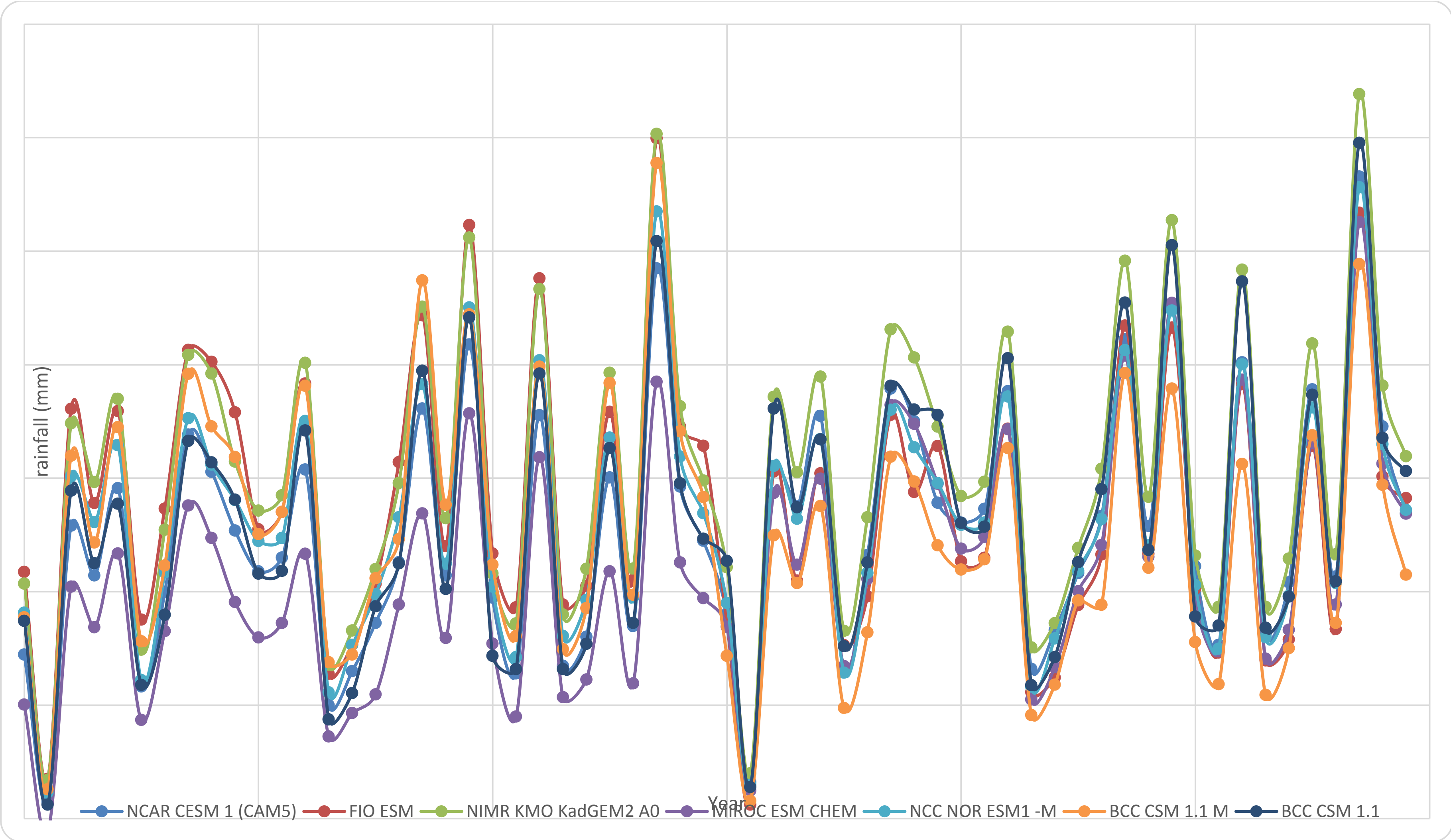

Figure 4.6: Annual rainfall projection for RCP 6.0 scenario for Solapur

Table 4-10: Percentage change in monthly rainfall for RCP 6.0 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM 2 A0	MIROC ESM CHEM	NCC NOR ESM1-M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	-16.5	-45.7	30.1	16.3	-12.5	-46.8	4.1	-10.1
	Feb	11.9	-27.0	-7.0	20.3	10.9	-9.7	-9.6	-1.5
	Mar	11.1	-9.4	14.0	12.7	5.5	-14.9	-13.7	0.7
	Apr	-11.3	22.5	1.5	-1.4	-8.8	1.1	51.4	7.9
	May	4.3	10.0	19.5	7.5	-13.1	-2.7	20.0	6.5
	Jun	5.6	7.0	-3.2	-16.7	16.1	-7.6	-30.9	-4.2
	Jul	-6.1	4.0	1.9	-11.8	-15.1	24.8	-29.7	-4.6
	Aug	-18.7	22.4	0.4	-28.0	-13.9	3.6	0.7	-4.8
	Sep	-19.1	-20.7	3.9	-45.9	-10.9	3.3	-0.7	-12.9
	Oct	-25.1	4.5	10.4	-26.8	8.9	-43.3	-16.7	-12.6
	Nov	-5.6	47.8	25.3	-4.6	-11.5	-19.6	5.2	5.3
	Dec	-13.6	-38.3	-9.2	6.0	3.5	-35.9	20.8	-9.5
2050-2079	Jan	-16.0	-9.1	22.1	8.6	-7.2	-23.7	46.9	3.1
	Feb	17.7	-29.3	15.1	23.6	8.9	-16.3	47.7	9.6
	Mar	-18.0	-17.0	-14.4	21.7	6.0	-20.7	20.0	-3.2
	Apr	-10.5	13.9	-9.1	4.7	15.6	-7.1	23.6	4.4
	May	-11.6	-9.4	14.8	14.3	-22.5	-7.7	1.9	-2.9
	Jun	14.7	-9.3	-1.1	-1.4	14.9	-14.3	-16.9	-1.9
	Jul	1.0	10.6	12.4	-10.2	-16.3	-19.4	-22.0	-6.3
	Aug	-20.3	15.8	10.5	-2.8	-11.4	-25.0	24.6	-1.2
	Sep	5.3	-17.5	9.0	-7.7	2.3	12.2	1.0	0.7
	Oct	-0.7	-47.6	2.7	-29.8	1.8	-39.0	6.1	-15.2
	Nov	-7.0	-34.4	20.3	14.6	-13.0	-24.3	18.2	-3.7
	Dec	-7.3	-36.5	3.9	18.2	10.9	-35.4	52.8	0.9

Table 4.10 shows the percentage change in mean monthly rainfall for that of historical rainfall. Compared to other RCPs, here the decrease in rainfall during the monsoon period is very less in 2020 to 2049. The percentage decrease in the monthly average rainfall is having a mixed view in different models. But on an average, monsoon rainfall decreases significantly during the first 30 years.

The projection for Maximum Temperature

Table 4.11 shows the increase in monthly maximum temperature for RCP 6.0 scenario. Out of the seven models, here also NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.5^{0}C in the first 30 years and rises to 2.5^{0}C in next 30 years. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2049 and 1.5^{0}C in 2050-2079.

The projection for Minimum Temperature

Table 4.12 shows the increase in monthly minimum temperature for RCP 6.0 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1^{0}C in the first 30 years and rises to 1.5^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 0.1^{0}C in 2020 to 2049 and 1.5^{0}C in 2050-2079. The increasing pattern in minimum temperature is similar to that of maximum temperature.

Table 4-11: Increase (^{0}C) in monthly maximum temperature for RCP 6.0 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.2	0.9	1.2	0.8	1.2	0.9	0.7	1.0
	Feb	1.0	0.9	0.9	0.8	1.8	0.8	0.6	1.0
	Mar	0.4	0.8	0.8	0.8	0.7	0.9	0.7	0.7
	Apr	1.2	0.8	0.8	0.7	1.0	0.9	0.6	0.9
	May	1.1	0.7	0.9	0.7	1.1	0.8	0.8	0.9
	Jun	1.5	0.8	0.9	0.8	1.2	0.9	0.9	1.0
	Jul	1.2	0.8	0.9	0.9	1.1	0.8	0.8	0.9
	Aug	1.8	0.7	0.9	0.8	0.8	0.8	0.8	1.0
	Sep	1.0	0.8	0.9	0.8	1.1	1.0	0.9	0.9
	Oct	1.5	0.9	1.0	0.9	1.2	0.9	0.8	1.0
	Nov	1.4	0.9	0.8	0.9	1.2	0.8	0.7	1.0
	Dec	1.9	0.9	0.8	0.8	1.3	0.8	0.7	1.0
2050-2079	Jan	2.7	1.3	2.0	1.6	1.7	1.3	1.2	1.7
	Feb	2.0	1.3	1.8	1.7	1.9	1.2	1.2	1.6
	Mar	2.0	1.3	1.3	1.5	1.4	1.3	1.2	1.4
	Apr	2.1	1.2	1.5	1.5	1.1	1.4	1.1	1.4
	May	2.4	1.1	1.4	1.4	2.0	1.4	1.3	1.6
	Jun	2.4	1.2	1.5	1.5	1.9	1.2	1.5	1.6
	Jul	2.2	1.2	1.4	1.6	1.7	1.1	1.5	1.5
	Aug	2.6	1.2	1.5	1.6	1.3	1.2	1.4	1.5
	Sep	2.0	1.1	1.4	1.6	1.5	1.3	1.3	1.5
	Oct	1.9	1.1	1.5	1.6	1.8	1.3	1.3	1.5
	Nov	2.2	1.1	1.4	1.7	1.8	1.1	1.3	1.5
	Dec	2.7	1.3	1.5	1.6	1.2	1.1	1.2	1.5

Table 4-12: Increase (^{0}C) in monthly minimum temperature for RCP 6.0 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.2	0.8	1.2	0.8	1.1	0.9	0.7	1.0
	Feb	1.6	0.9	0.9	0.8	1.5	0.8	0.6	1.0
	Mar	1.0	0.8	0.7	0.8	0.5	0.9	0.7	0.7
	Apr	1.5	0.8	0.8	0.7	0.9	0.8	0.6	0.9
	May	1.1	0.7	1.0	0.8	0.9	0.8	0.8	0.9
	Jun	1.0	0.8	0.9	0.8	1.1	0.9	0.9	0.9
	Jul	1.1	0.8	0.8	0.9	0.5	0.8	0.8	0.8
	Aug	1.3	0.7	1.0	0.8	0.3	0.8	0.8	0.8
	Sep	1.2	0.8	0.8	0.8	0.8	1.0	0.9	0.9
	Oct	1.2	0.8	0.9	0.9	1.0	0.9	0.8	0.9
	Nov	1.2	0.9	0.7	0.8	0.7	0.8	0.7	0.9
	Dec	1.9	0.8	0.9	0.8	1.0	0.8	0.7	1.0
2050-2079	Jan	2.7	1.3	2.1	1.6	1.3	1.3	1.2	1.6
	Feb	2.4	1.3	1.8	1.6	1.6	1.2	1.2	1.6
	Mar	2.2	1.2	1.3	1.6	1.0	1.3	1.2	1.4
	Apr	2.4	1.2	1.6	1.5	1.2	1.4	1.1	1.5
	May	2.2	1.1	1.5	1.4	1.3	1.4	1.3	1.4
	Jun	1.9	1.2	1.6	1.5	1.6	1.2	1.5	1.5
	Jul	1.9	1.2	1.4	1.6	0.9	1.1	1.5	1.4
	Aug	2.1	1.2	1.5	1.6	0.6	1.2	1.4	1.4
	Sep	2.1	1.1	1.4	1.6	1.1	1.3	1.3	1.4
	Oct	1.8	1.1	1.4	1.6	1.3	1.3	1.3	1.4
	Nov	2.3	1.1	1.3	1.6	1.2	1.1	1.3	1.4
	Dec	2.7	1.2	1.6	1.6	1.1	1.1	1.2	1.5

RCP 8.5

Projection for Rainfall

The projection shows that the annual average rainfall in the next 60 years is going to decrease. The mean annual rainfall is around 750 mm. The maximum rainfall as per RCP 8.5 scenario, may go to 1500 mm. Annual rainfall projection for RCP 8.5 scenario is given in Fig. 4.29. The figure shows that 2 to 3 peaks in the annual rainfall. As far as droughts are concerned, the rainfall may go to 250 mm.

Table 4-13: Number of flood and droughts as per RCP 8.5 for Solapur

	Global Climate Models						
	NCAR CESM 1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 - M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	2	3	2	11	5	5	2
Severe drought	8	7	5	16	12	13	8
Moderate drought	11	10	10	15	14	14	10
Normal	23	23	20	12	17	21	19
Moderate flood	10	5	11	4	7	4	10
Severe flood	3	6	5	1	4	1	4
Extreme flood	3	6	7	1	1	2	7

Table 4.13 shows a projection of some floods and droughts. Here also an overall number of drought events are going to increase. Severe droughts are more frequent in the RCP 8.5 scenario. A number of moderate droughts is also on the rise. Table 4.14 shows the percentage change in mean monthly rainfall for that of historical rainfall. The maximum decrease is in July, August, September, and February.

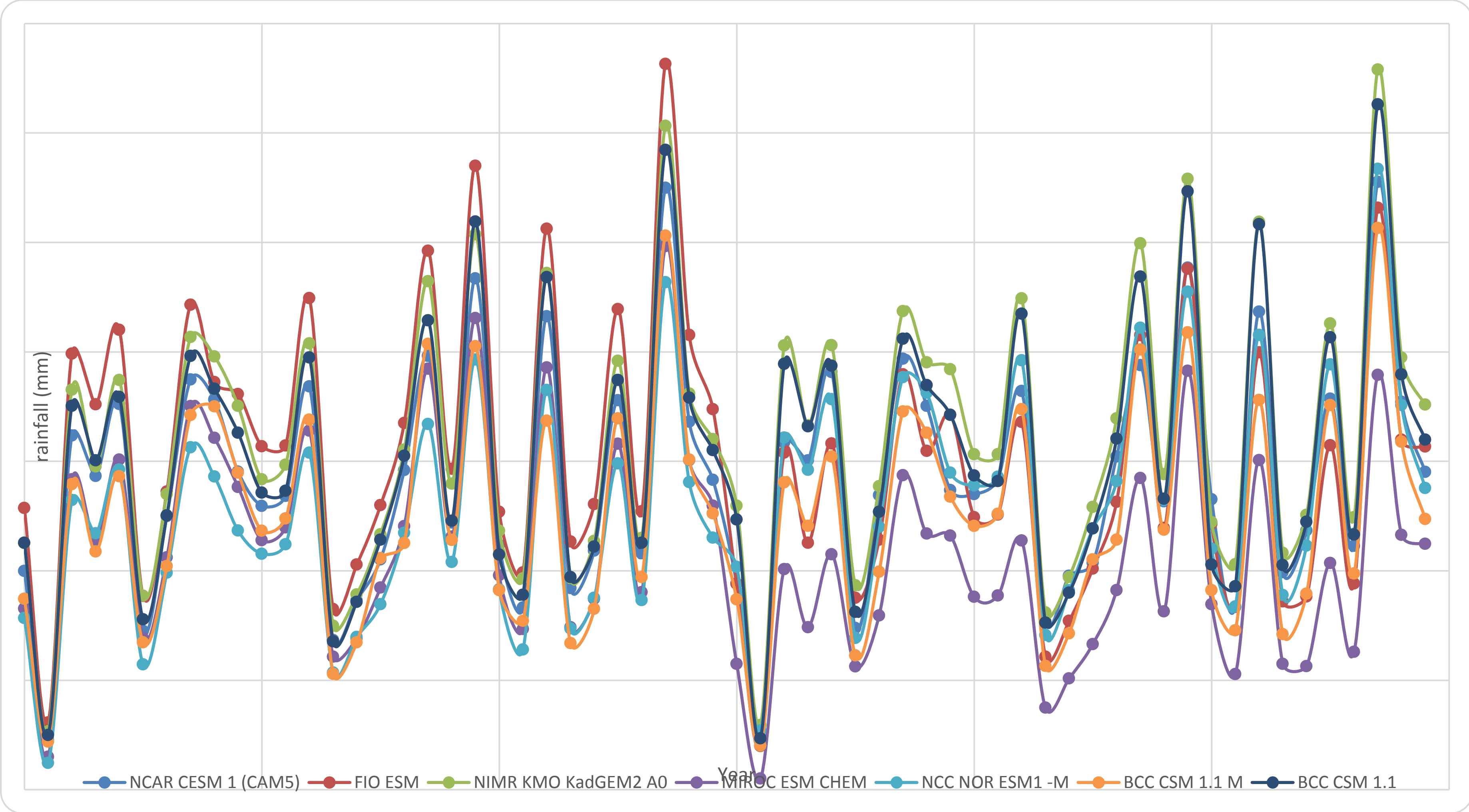

Figure 4.7: Annual rainfall projection for RCP 8.5 scenario for Solapur

Table 4-14: Percentage change in monthly rainfall for RCP 8.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM 2 A0	MIROC ESM CHEM	NCC NOR ESM1-M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	3.8	-42.3	20.6	21.3	-2.8	-30.4	-3.7	-4.8
	Feb	5.2	-24.6	-32.0	28.3	-18.3	-28.9	6.7	-9.1
	Mar	-3.5	-7.9	42.5	15.0	12.7	-12.3	-14.8	4.5
	Apr	2.4	16.9	-5.4	-14.3	17.4	-8.9	1.9	1.4
	May	-10.4	19.6	-1.8	7.7	-15.9	-19.2	14.4	-0.8
	Jun	5.4	13.8	-3.6	-16.8	-11.3	-9.9	0.5	-3.1
	Jul	-11.6	-6.5	3.3	-4.7	-20.6	-23.7	-20.9	-12.1
	Aug	-15.9	2.1	8.7	-11.1	-28.3	-12.1	-1.1	-8.3
	Sep	-13.7	10.0	-7.7	-21.5	-23.3	-1.5	-6.5	-9.2
	Oct	12.8	29.8	-2.5	-30.4	-5.8	-41.5	16.5	-3.0
	Nov	9.3	-18.9	19.8	-3.5	-15.2	9.4	11.6	1.8
	Dec	1.3	-52.9	-9.0	5.4	-0.1	-47.6	6.9	-13.7
2050-2079	Jan	-6.4	-31.8	24.3	8.8	-4.9	-48.5	89.4	4.4
	Feb	0.4	-49.9	-12.0	32.8	30.7	-23.7	10.0	-1.7
	Mar	-2.7	11.9	3.3	20.7	5.0	-8.2	-21.5	1.2
	Apr	-25.7	18.5	-5.9	0.3	5.5	-21.1	6.8	-3.1
	May	-6.0	5.0	4.4	19.8	-21.6	-4.0	22.4	2.9
	Jun	28.2	15.4	2.3	-7.3	9.5	-10.0	-22.3	2.3
	Jul	8.3	1.3	-2.3	-24.7	-18.5	-22.3	-13.1	-10.2
	Aug	-29.8	8.2	17.9	-20.7	-23.8	-23.3	9.0	-8.9
	Sep	-21.2	-33.8	1.5	-52.6	7.4	3.9	5.0	-12.8
	Oct	16.9	-41.4	17.6	-56.4	7.4	-25.7	28.5	-7.6
	Nov	-5.9	-22.3	2.4	-23.2	-3.2	-13.6	2.2	-9.1
	Dec	-4.7	-41.4	-1.5	-10.8	28.8	-29.9	15.5	-6.3

Projection for Maximum Temperature

Table 4.15 shows the increase in monthly maximum temperature for RCP 8.5 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.5^{0}C in the first 30 years and may rise maximum to 3.4^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C – 1.2^{0}C in 2020 to 2049 and 2^{0}C – 2.3^{0}C in 2050-2079.

Projection for Minimum Temperature

Table 4.16 shows the increase in monthly minimum temperature for RCP 8.5 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.5^{0}C in first 30 years and may rise to a maximum of 3^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the temperature will rise by one

^{0}C – 1.2^{0}C in 2020 to 2049 and 2^{0}C in 2050-2079. The pattern is almost similar to that of maximum temperature.

Table 4-15: Increase (^{0}C) in monthly maximum temperature for RCP 8.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	1.7	0.9	1.3	1.2	1.9	1.1	1.0	1.3
	Feb	1.3	0.9	1.0	1.2	2.4	1.0	0.8	1.2
	Mar	1.0	0.9	0.8	1.1	1.4	1.0	0.9	1.0
	Apr	1.8	0.9	1.0	1.1	1.1	1.1	0.9	1.1
	May	1.5	0.9	1.1	1.1	1.6	1.1	1.0	1.2
	Jun	1.8	0.8	0.9	1.1	1.5	1.0	1.0	1.2
	Jul	1.8	0.8	0.9	1.2	1.4	0.9	1.0	1.1
	Aug	1.9	0.8	1.0	1.1	1.2	0.9	0.9	1.1
	Sep	0.8	0.8	1.0	1.1	2.1	1.1	1.0	1.1
	Oct	0.7	0.9	0.9	1.1	1.4	1.0	1.0	1.0
	Nov	1.1	1.0	0.8	1.2	2.3	0.9	1.0	1.2
	Dec	1.2	1.0	0.7	1.2	1.2	0.9	0.8	1.0
2050-2079	Jan	3.2	1.7	2.6	2.5	2.3	1.9	1.8	2.3
	Feb	3.2	1.8	2.5	2.5	2.6	1.7	1.7	2.3
	Mar	2.7	1.8	2.0	2.5	1.8	1.7	1.7	2.0
	Apr	3.9	1.9	2.1	2.4	2.7	1.9	1.7	2.3
	May	3.3	1.8	2.1	2.4	2.6	2.0	1.8	2.3
	Jun	3.4	2.0	2.1	2.4	2.6	1.9	1.8	2.3
	Jul	3.2	1.9	2.1	2.3	2.5	1.8	1.8	2.2
	Aug	3.3	1.9	2.2	2.3	2.7	1.8	1.8	2.3
	Sep	2.8	1.8	2.0	2.3	2.3	1.9	1.8	2.1
	Oct	2.6	1.8	2.1	2.4	2.5	1.9	1.9	2.2
	Nov	3.7	1.8	1.7	2.5	2.3	1.8	1.9	2.3
	Dec	3.0	1.8	2.0	2.5	1.7	1.8	1.7	2.1

Table 4-16: Increase (^{0}C) in monthly minimum temperature for RCP 8.5 scenario for Solapur

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2049	Jan	2.1	0.9	1.3	1.2	1.2	1.1	1.0	1.2
	Feb	1.9	0.9	1.0	1.2	1.7	1.0	0.8	1.2
	Mar	1.4	0.9	0.8	1.2	1.1	1.0	0.9	1.0

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	Apr	2.1	0.9	1.0	1.1	1.4	1.1	0.9	1.2
	May	1.3	0.9	1.2	1.1	1.4	1.1	1.0	1.1
	Jun	1.2	0.8	0.9	1.1	1.2	1.0	1.0	1.0
	Jul	1.3	0.8	0.9	1.2	0.4	0.9	1.0	0.9
	Aug	1.5	0.8	0.9	1.1	0.3	0.9	0.9	0.9
	Sep	1.2	0.8	1.0	1.2	1.1	1.1	1.0	1.0
	Oct	1.2	0.9	0.8	1.1	1.0	1.0	1.0	1.0
	Nov	1.5	1.0	0.7	1.2	1.7	0.9	1.0	1.1
	Dec	1.5	1.0	0.8	1.2	1.1	0.9	0.8	1.0
2050-2079	Jan	3.4	1.8	2.6	2.5	2.2	1.9	1.8	2.3
	Feb	3.4	1.8	2.5	2.5	2.4	1.7	1.7	2.3
	Mar	2.7	1.8	2.0	2.5	1.6	1.7	1.7	2.0
	Apr	3.7	1.9	2.2	2.5	2.4	1.9	1.7	2.3
	May	2.9	1.8	2.2	2.4	2.0	2.0	1.8	2.2
	Jun	3.1	2.0	2.1	2.4	2.2	1.9	1.8	2.2
	Jul	2.6	1.9	2.0	2.3	1.4	1.7	1.8	2.0
	Aug	3.0	1.9	2.0	2.3	1.6	1.8	1.8	2.1
	Sep	2.7	1.8	1.9	2.3	2.0	1.9	1.8	2.1
	Oct	2.7	1.9	1.9	2.4	2.1	1.9	1.9	2.1
	Nov	3.7	1.8	1.6	2.5	2.1	1.8	1.9	2.2
	Dec	3.2	1.8	2.1	2.5	2.0	1.8	1.7	2.2

4.3.3 Summary

Rainfall

Table 4.17 shows the percentage change in monthly rainfall in the next 60 years. From the figures shown above, it can be predicted that the rainfall overall is going to decrease. In all the RCPs, the annual average rainfall is decreasing by 40 mm which is maximum for RCP 8.5. The number of drought events is also going to be frequent, almost 25-30 events in the next 60 years. The magnitude of the droughts will go to a very low level of 200 to 300 mm, and the flood magnitude will go to a very high level of 1500 mm.

Maximum Temperature

Table 4.18 shows the increase in monthly maximum temperature for all the RCP scenarios. It is evident that if RCP 2.6 follows, the minimum temperature will rise by about 1^0C. From 2020 t0 2049, the change in temperature for RCP 4.5 and RCP 6.0 is around 1^0C which will rise to 1.5^0C in 2050-2079. RCP 8.5 is the extreme case wherein the first 30 years the rise is more than 1^{0}C, but in the next 30 years, the rise will be around 2^{0}C. For a few months, it may rise by 2.3^{0}C also.

Minimum Temperature

Table 4.19 shows the increase in monthly minimum temperature for all the RCP scenarios. It is evident that if RCP 2.6 follows, the minimum temperature will rise by about 1^{0}C. From 2020 t0 2049, the change in temperature for RCP 4.5 and RCP 6.0 is around 1^{0}C which will rise to 1.5^{0}C in 2050-2079. RCP 8.5 is the extreme case wherein the first 30 years the rise is more than 1^{0}C, but in the next 30 years, the rise will be around 2^{0}C. The pattern of minimum temperature is the same as that of maximum temperature.

Table 4-17: Percentage change in monthly rainfall for all RCPs for Solapur

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2049	Jan	-3.5	-4.7	-10.1	-4.8
	Feb	-5.4	1.6	-1.5	-9.1
	Mar	0.3	8.2	0.7	4.5
	Apr	3.4	5.3	7.9	1.4
	May	4.0	-3.3	6.5	-0.8
	Jun	-8.6	-6.2	-4.2	-3.1
	Jul	-4.5	-11.8	-4.6	-12.1
	Aug	-8.7	-0.9	-4.8	-8.3
	Sep	-10.5	-7.3	-12.9	-9.2
	Oct	-13.9	-2.5	-12.6	-3.0
	Nov	-8.6	-0.8	5.3	1.8
	Dec	-20.2	-4.5	-9.5	-13.7
2050-2079	Jan	-6.4	-2.9	3.1	4.4
	Feb	-10.1	-2.9	9.6	-1.7
	Mar	7.4	5.2	-3.2	1.2
	Apr	-4.0	-0.7	4.4	-3.1
	May	-2.3	-2.7	-2.9	2.9
	Jun	0.3	0.3	-1.9	2.3
	Jul	-6.9	-9.0	-6.3	-10.2
	Aug	1.5	-5.4	-1.2	-8.9
	Sep	-8.9	-11.8	0.7	-12.8
	Oct	-5.9	-13.2	-15.2	-7.6
	Nov	-4.7	-5.5	-3.7	-9.1
	Dec	-10.8	-12.6	0.9	-6.3

Table 4-18: Increase (0C) in monthly maximum temperature for all RCPs for Solapur

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2049	Jan	0.9	1.2	1.0	1.3
	Feb	1.0	1.1	1.0	1.2
	Mar	0.6	0.8	0.7	1.0
	Apr	0.9	1.0	0.9	1.1
	May	0.9	1.1	0.9	1.2
	Jun	0.9	1.1	1.0	1.2
	Jul	0.9	1.1	0.9	1.1
	Aug	1.0	1.0	1.0	1.1
	Sep	0.9	1.0	0.9	1.1
	Oct	0.8	1.0	1.0	1.0
	Nov	0.8	1.0	1.0	1.2
	Dec	0.9	1.0	1.0	1.0
2050-2079	Jan	1.1	1.7	1.7	2.3
	Feb	1.2	1.7	1.6	2.3
	Mar	0.9	1.3	1.4	2.0
	Apr	1.0	1.5	1.4	2.3
	May	1.1	1.6	1.6	2.3
	Jun	1.1	1.6	1.6	2.3
	Jul	0.9	1.5	1.5	2.2
	Aug	1.0	1.6	1.5	2.3
	Sep	1.1	1.6	1.5	2.1
	Oct	0.9	1.6	1.5	2.2
	Nov	1.1	1.5	1.5	2.3
	Dec	1.0	1.5	1.5	2.1

Table 4-19: Increase (0C) in monthly minimum temperature for Solapur

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2049	Jan	0.9	1.1	1.0	1.2
	Feb	1.0	1.1	1.0	1.2
	Mar	0.7	1.0	0.7	1.0
	Apr	1.0	1.1	0.9	1.2
	May	0.8	1.0	0.9	1.1
	Jun	0.8	0.9	0.9	1.0
	Jul	0.8	0.9	0.8	0.9
	Aug	0.8	0.9	0.8	0.9
	Sep	0.9	1.0	0.9	1.0
	Oct	0.8	1.0	0.9	1.0
	Nov	0.7	0.9	0.9	1.1
	Dec	0.8	0.9	1.0	1.0
2050-2079	Jan	1.0	1.6	1.6	2.3
	Feb	1.1	1.7	1.6	2.3

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
	Mar	0.9	1.3	1.4	2.0
	Apr	1.0	1.5	1.5	2.3
	May	1.0	1.5	1.4	2.2
	Jun	1.0	1.4	1.5	2.2
	Jul	0.9	1.3	1.4	2.0
	Aug	0.9	1.3	1.4	2.1
	Sep	1.0	1.5	1.4	2.1
	Oct	0.9	1.4	1.4	2.1
	Nov	1.0	1.4	1.4	2.2
	Dec	0.9	1.5	1.5	2.2

4.4 Climate Modelling for Vijayawada (Gannavaram Station)

For Vijayawada, only daily rainfall data is available from 1967 to 1997. Climate change projection is done for all the RCPs using al the seven models. For temperature, only the change is evaluated for the future scenario,

4.4.1 Trend Analysis

Monthly rainfall

Fig. 4.8 shows the variation of monthly rainfall.

Mean annual rainfall: 906.3 mm

Standard deviation: 236.1 mm

- Linear regression,
- $y(t) = \hat{\alpha} + \hat{\beta}t + \varepsilon(t)$
- α = 71.75; β = 0.02(Slope of line)
- Null Hypothesis:
- β = 0, i.e. Mean of the annual rainfall remains same
- Using Student-t-test, (for a significance level of 0.05%)
- T_score = 0.42 <T_critical = 1.96
- Hence, the hypothesis is accepted. So, the change in the mean annual rainfall is **statistically significant.**
-

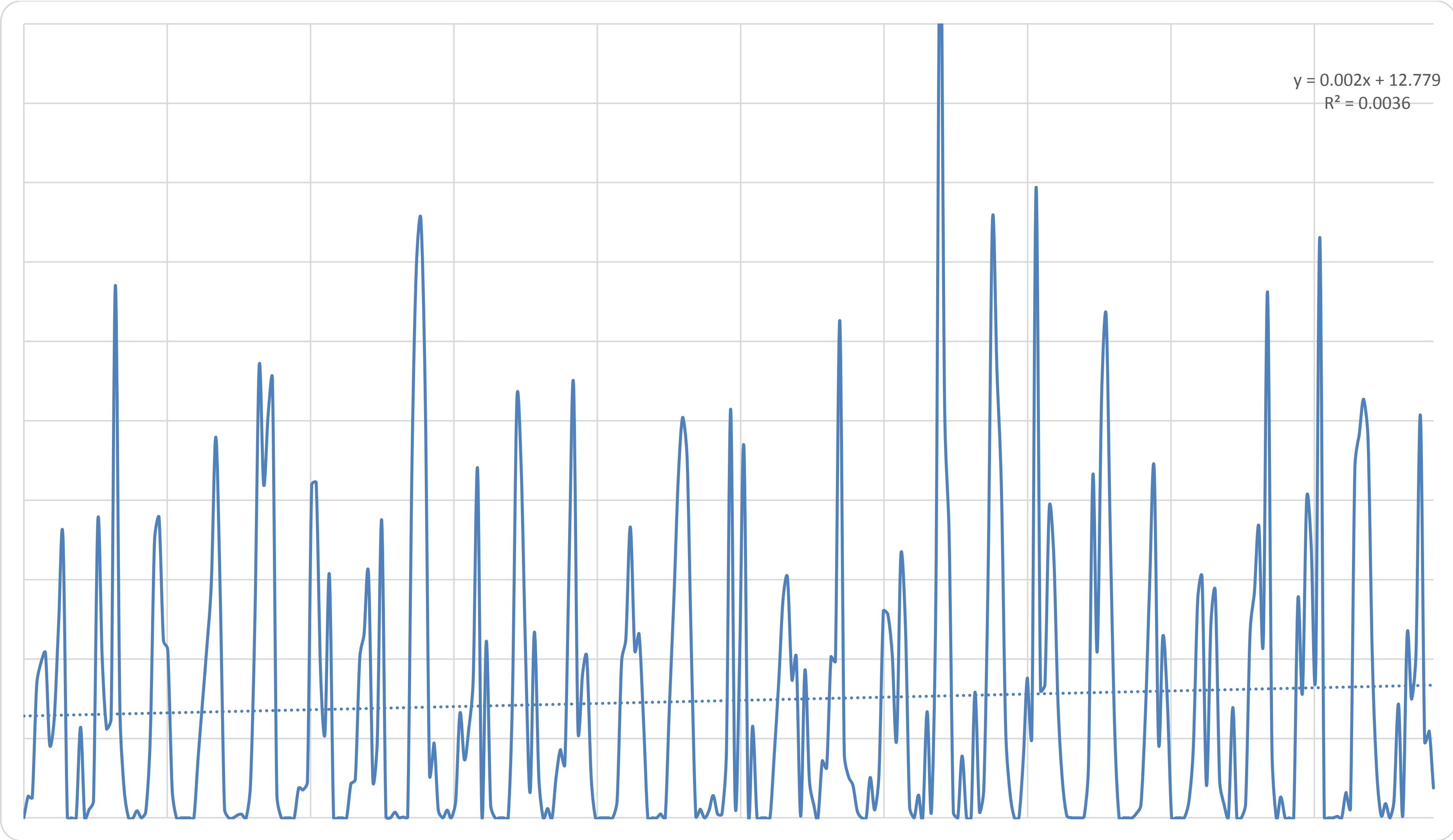

Figure 4.8: Trend of monthly rainfall for Vijayawada

4.4.2 GCM Projections

GCM projection for rainfall, maximum temperature, and minimum temperature was done for all the RCP scenarios, taking into account all the 7 GCM models.

RCP 2.6

Projection for Rainfall

The projection shows that annual average rainfall in the next58 years is going to decrease on an average by 40mm. In the last 29 year, the mean annual rainfall was around 900 mm. Fig. 4.9 shows a projection of annual rainfall for the RCP 2.6 scenario. Considering all the experiments, the results show peak rainfalls of 1650 mm in the wet year and low rainfall of 500 mm during the dry year.

Table 4-20: Number of floods and droughts as per RCP 2.6 for Vijayawada

	Global Climate Models						
	NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 - M	BCC CSM 1.1 M	BCC CSM 1.1
Extreme drought	0	3	0	0	1	12	5
Severe drought	7	22	5	2	11	15	21
Moderate drought	15	10	20	18	14	8	8
Normal	16	13	15	16	16	17	15
Moderate flood	6	6	4	6	6	4	6
Severe flood	5	3	7	6	3	2	1
Extreme flood	9	1	7	10	7	0	2

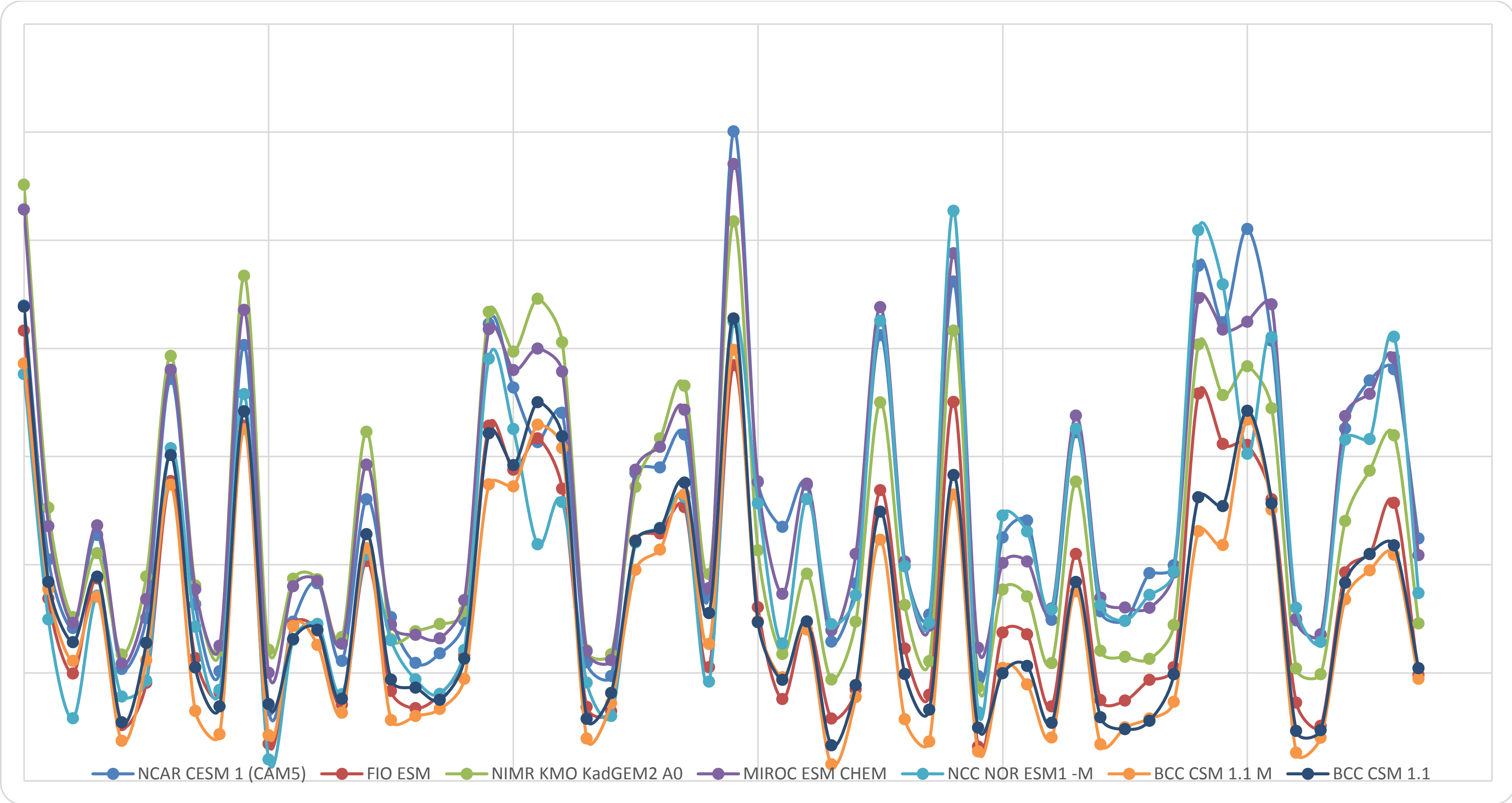

Figure 4.9: Annual rainfall projection for RCP 2.6 scenario for Vijayawada

The projection for flood and droughts are projected based on the historical mean and standard deviation. Table 4.20shows the number of floods and droughts in the next 58 years. For Vijayawada under RCP 2.6, the first four models are showing a large number of floods while the rest are showing a large number of droughts. But one conclusion can be made that large number (about 25-30) of moderate to severe drought is expected to occur in the near future.

Table 4.21 shows the percentage change in mean monthly rainfall from that of historical rainfall. It can be seen that the rainfall during monsoon is decreasing, though there is little increase in rainfall during the non-monsoon period. In the later 30 years, all months are showing decreasing rainfall, except for April where is hardly receive rain.

Projection for Maximum Temperature

Table 4.22 shows the increase in monthly maximum temperature for the RCP 2.6 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.1^{0}C in the first 30 years and rises to 1.2^{0}C in next 30 years. Overall the maximum temperature will rise by 1^{0}C in the future.

Projection for Minimum Temperature

Table 4.23 shows the increase in monthly minimum temperature for the RCP 2.6 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1^{0}C in the first 30 years and rises to 1.2^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the minimum temperature will rise by 1^{0}C.

RCP 4.5

Projection of rainfall

Fig. 4.10 shows annual rainfall projection for RCP 4.5 for all the seven models. The projection shows that the annual average rainfall in the next 60 years is going to decrease by about 50mm. Though MIROC ESM CHEM shows a very high annual average rainfall of 1022 mm but rests all models are shows fewer values. The figure shows 8-10 peaks of high annual rainfall of 1500mm and more. During the dry year, the rainfall may go as low as 450 mm.

Table 4-21: Percentage change in monthly rainfall for the RCP 2.6 scenario for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	29.6	-19.1	28.7	18.6	-17.6	-8.6	-6.4	3.6
	Feb	12.2	34.2	-15.4	11.8	-25.4	-11.0	13.2	2.8
	Mar	15.3	-1.2	-13.1	9.5	1.9	-2.5	-0.1	1.4
	Apr	55.8	8.3	-8.2	4.1	-24.4	-8.5	23.7	7.2

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	May	-39.5	-6.6	29.4	4.6	-50.7	1.7	-0.3	-8.8
	Jun	-21.7	-2.1	-2.0	-3.6	-29.7	24.8	-0.3	-5.0
	Jul	1.7	-13.9	-5.5	-5.5	14.7	-41.0	-29.7	-11.3
	Aug	-5.3	-19.4	7.5	0.8	-10.3	-28.0	-26.6	-11.6
	Sep	6.2	-23.7	31.0	13.9	-29.0	5.8	16.6	3.0
	Oct	10.9	-14.8	-12.8	0.4	-8.1	-20.6	-13.4	-8.3
	Nov	-1.6	-0.2	3.5	15.5	0.2	-33.3	-7.2	-3.3
	Dec	-5.9	-26.1	1.5	19.5	16.4	-36.5	6.5	-3.5
2049-2078	Jan	19.7	-15.5	-0.9	15.2	-29.0	-5.9	-6.2	-3.2
	Feb	-2.3	5.9	-29.6	7.5	-26.2	0.7	-3.9	-6.8
	Mar	51.7	10.9	-22.2	-0.7	12.2	-14.5	21.1	8.4
	Apr	142.5	-4.0	-22.2	-0.7	-13.2	7.5	2.2	16.0
	May	27.4	-9.7	20.0	3.3	-51.6	16.8	10.5	2.4
	Jun	11.8	-10.0	-5.5	0.6	36.2	-2.3	-23.4	1.0
	Jul	-5.5	-4.9	1.3	-7.3	20.0	-48.7	-32.1	-11.0
	Aug	18.4	-6.9	-5.8	15.7	22.7	-24.3	-25.9	-0.9
	Sep	-3.8	-26.6	5.1	29.1	-11.0	-13.5	-7.4	-4.0
	Oct	18.1	-32.7	-14.9	17.0	0.5	-23.9	-18.5	-7.8
	Nov	2.2	-7.1	8.4	16.2	-4.5	-24.9	8.1	-0.2
	Dec	-8.3	-13.5	-3.7	16.2	-15.0	-14.1	-29.3	-9.7

Table 4-22: Increase (0C) in monthly maximum temperature for RCP 2.6 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.1	0.7	1.3	0.8	1.1	0.2	0.6	0.8
	Feb	1.2	0.7	1.1	0.8	1.1	0.1	0.6	0.8
	Mar	0.9	0.6	0.8	0.7	1	0.2	0.6	0.7
	Apr	1.3	0.7	0.7	0.8	1.2	0.8	0.8	0.9
	May	1.2	0.6	1	0.8	1.1	1.1	0.6	0.9
	Jun	1.1	0.8	1	0.9	1	1	0.7	0.9
	Jul	1.3	0.9	0.8	0.8	1.2	0.9	0.7	0.9
	Aug	1.3	0.7	1.1	1	0.9	0.8	0.6	0.9

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	Sep	1.1	0.8	0.9	1.1	1.2	0.8	0.6	0.9
	Oct	1	0.7	0.7	1.1	1.4	0.8	0.7	0.9
	Nov	1	0.6	0.7	0.9	1.2	0.5	0.6	0.8
	Dec	0.9	0.6	1	1	1	0.3	0.6	0.8
2049-2078	Jan	1.5	0.9	0.9	1	1.2	0.6	0.7	1.0
	Feb	1.6	0.9	0.7	1.1	1.7	0.5	0.7	1.0
	Mar	1.7	0.7	0.8	1	1.1	0.6	0.7	0.9
	Apr	1.8	0.8	0.7	0.9	1.1	1	0.9	1.0
	May	1.9	0.9	0.7	1	1.3	1.1	0.7	1.1
	Jun	1.8	0.9	1	0.9	1.4	1	0.7	1.1
	Jul	1.5	1	0.6	1.1	1	0.8	0.7	1.0
	Aug	1.6	0.9	0.8	1.3	0.9	0.8	0.6	1.0
	Sep	1.5	0.9	0.6	1.2	1.2	1	0.6	1.0
	Oct	1.5	0.9	0.6	1.2	1.3	0.9	0.7	1.0
	Nov	1.7	0.8	0.5	1.2	1.4	0.8	0.7	1.0
	Dec	1.4	0.9	0.6	1.2	1.2	0.6	0.6	0.9

Table 4-23: Increase (0C) in monthly minimum temperature for RCP 2.6 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.0	0.8	0.8	0.9	1.5	0.8	0.6	0.9
	Feb	1.3	0.8	0.8	0.9	1.9	0.8	0.6	1.0
	Mar	1.0	0.7	0.7	0.8	1.0	0.8	1.0	0.9
	Apr	1.1	0.7	0.8	0.9	1.7	0.9	0.8	1.0
	May	1.6	0.6	0.9	0.9	1.9	0.9	0.7	1.1
	Jun	1.8	0.7	0.8	1.0	1.7	0.7	0.7	1.1
	Jul	1.9	0.8	0.8	0.9	1.4	0.6	0.6	1.0
	Aug	1.7	0.8	0.8	1.0	0.9	0.6	0.5	0.9
	Sep	1.0	0.7	0.7	1.1	1.7	0.7	0.7	0.9
	Oct	0.7	0.7	0.7	1.0	1.9	0.9	0.9	1.0
	Nov	1.3	0.7	0.6	1.0	1.7	1.0	0.8	1.0
	Dec	1.8	0.8	0.7	0.9	1.4	0.9	0.7	1.0
2049-2078	Jan	1.4	0.8	0.9	1.0	2.0	0.9	0.8	1.1
	Feb	2.0	0.8	1.0	1.0	2.5	1.0	0.9	1.3
	Mar	1.6	0.7	0.8	1.0	1.1	1.1	1.0	1.1
	Apr	1.4	0.8	0.7	1.1	1.6	1.0	0.9	1.0

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	May	1.7	0.8	0.9	1.0	2.2	0.9	0.8	1.2
	Jun	2.2	0.8	0.8	1.0	2.1	0.7	0.8	1.2
	Jul	1.8	0.8	0.8	1.1	0.8	0.3	0.7	0.9
	Aug	1.9	0.8	0.9	1.2	0.9	0.5	0.6	0.9
	Sep	1.7	0.7	0.9	1.2	1.0	0.5	0.8	1.0
	Oct	1.1	0.7	1.0	1.2	1.7	0.9	0.9	1.1
	Nov	1.8	0.7	0.8	1.2	2.0	1.0	0.9	1.2
	Dec	2.3	0.8	0.8	1.1	2.0	1.0	0.8	1.2

Table 4-24: Number of floods and droughts as per RCP 4.5 for Vijayawada

	Global Climate Models						
	NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 - M	BCC CSM 1.1 M	BCC CSM 1.1
Extreme drought	4	6	0	0	0	21	2
Severe drought	13	10	9	1	12	12	18
Moderate drought	10	15	18	11	17	11	13
Normal	17	14	13	22	11	12	14
Moderate flood	4	4	7	5	9	1	7
Severe flood	5	6	7	6	4	1	2
Extreme flood	5	3	4	13	5	0	2

Table 4.24 shows a projection of some floods and droughts. These projections are made based on the historical mean and standard deviation. As per the prediction, the city has a high risk of frequent (about 20-25) moderate to severe droughts in the next 58 years with a magnitude of 450 mm or less. During the dry year, the rainfall is expected to decrease by the ¼ amount of any past driest year. A number of the extreme floods are also on the rise with the much higher magnitude to 1600 mm or more.

Table 4.25 shows the percentage change in mean monthly rainfall for that of historical rainfall. The rainfall is showing a significant increase in January to May, but a fair amount is decreasing in the monsoon period. This also shows that in the future the city will receive more rainfall during the non-monsoon period than that in monsoon. As per the average projection, January, June, and November have the highest decrease in rainfall of around 10%.

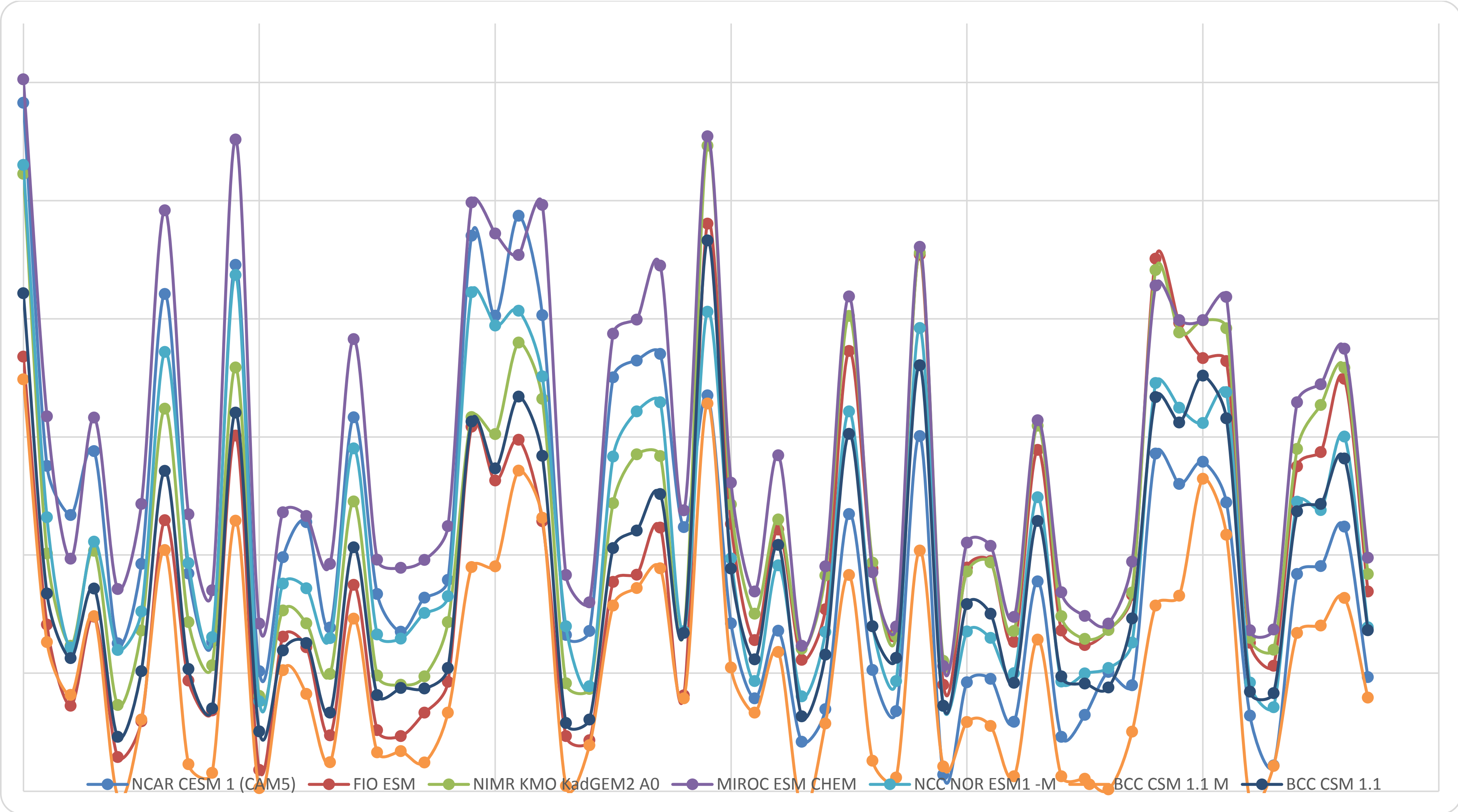

Figure 4.10: Annual rainfall projection for RCP 4.5 scenario for Vijayawada

Table 4-25: Percentage change monthly rainfall for RCP 4.5 scenario for Vijayawada

Period	Global Climate Models								Mean
	Month	NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	0.5	-18.0	24.1	14.9	-16.2	-16.5	31.4	2.9
	Feb	79.9	34.7	-22.7	20.6	-7.0	-7.8	12.1	15.7
	Mar	19.2	-2.0	-18.2	8.0	26.7	-5.5	-0.9	3.9
	Apr	132.2	3.3	-17.9	-1.6	-19.6	-9.2	33.8	17.3
	May	17.7	-4.5	22.7	-1.0	11.0	-5.0	-2.7	5.4
	Jun	-4.7	0.0	-8.9	12.2	-23.6	13.1	-8.4	-2.9
	Jul	-3.3	-14.4	-24.1	-1.6	3.3	-54.6	-30.7	-17.9
	Aug	4.5	-25.1	-10.8	31.2	25.9	-43.2	-16.9	-4.9
	Sep	15.8	-34.7	1.4	35.9	-13.9	-18.2	-5.3	-2.7
	Oct	23.4	-35.4	0.2	26.7	0.5	-17.8	-17.7	-2.9
	Nov	-9.3	-3.9	21.4	19.7	11.1	-32.7	-6.3	0.0
	Dec	-21.3	-30.4	-22.2	18.5	-6.0	-15.3	28.3	-6.9
2049-2078	Jan	9.2	-4.5	16.9	25.7	-23.6	-33.6	-26.5	-5.2
	Feb	-8.4	10.5	-15.4	10.5	21.9	0.8	16.1	5.1
	Mar	18.1	5.8	-28.0	7.6	-10.0	-7.4	14.9	0.2
	Apr	35.4	7.0	6.5	2.7	-34.3	-12.2	-7.8	-0.4
	May	-28.0	-9.8	10.1	-3.2	-21.9	-5.6	1.0	-8.2
	Jun	-22.0	1.1	-10.5	14.5	-7.1	-11.0	6.3	-4.1
	Jul	-36.7	8.6	4.1	-6.8	-23.4	-61.4	-19.9	-19.4
	Aug	7.5	3.4	2.2	0.0	2.9	-48.6	-18.0	-7.2
	Sep	-33.8	2.8	20.9	17.9	8.2	-2.0	-6.6	1.1
	Oct	-22.1	-12.6	2.0	18.8	-15.9	-26.9	-13.0	-10.0
	Nov	-9.9	19.1	16.8	18.5	5.4	-14.6	29.2	9.2
	Dec	3.1	-3.8	-14.9	14.1	4.4	-29.5	2.8	-3.4

Projection for Maximum Temperature

Table 4.26 shows the increase in monthly maximum temperature for RCP 4.5 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is about 1^0C to in the first 30 years and rises to 1.3^0C to 1.7^0C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by about 1^{0}C in 2020 to 2048 and by 1.5^{0}C in 2049-2078.

Projection for Minimum Temperature

Table 4.27 shows the increase in monthly minimum temperature for the RCP4.5 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.4^{0}C in the first 30 years and rises to2.7^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2048 and by 1.5^{0}C in 2049-2078.

Table 4-26: Increase (0C) in monthly maximum temperature for RCP 4.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.7	0.9	1.5	1.0	1.9	1.0	0.8	1.2
	Feb	0.1	0.9	1.4	1.0	1.9	1.0	0.9	1.0
	Mar	1.0	0.8	1.2	0.9	0.8	1.0	1.0	1.0
	Apr	1.0	0.8	1.1	1.0	1.2	1.0	0.9	1.0
	May	1.3	0.8	1.3	1.0	1.5	1.0	0.9	1.1
	Jun	1.9	0.7	1.1	1.0	1.7	0.8	0.9	1.2
	Jul	2.1	0.7	1.1	1.0	1.2	0.5	0.7	1.0
	Aug	1.7	0.7	1.1	1.0	0.8	0.6	0.7	1.0
	Sep	0.6	0.6	1.2	1.1	1.1	0.8	0.9	0.9
	Oct	0.5	0.8	1.1	1.2	1.8	1.0	1.0	1.1
	Nov	1.4	0.8	1.1	1.1	1.0	1.0	1.0	1.0
	Dec	1.7	0.8	0.9	1.0	1.6	1.0	0.9	1.1
2049-2078	Jan	2.2	1.1	1.7	1.5	2.3	1.3	1.1	1.6
	Feb	2.7	1.1	1.7	1.5	2.2	1.4	1.3	1.7
	Mar	1.6	1.1	1.4	1.4	1.0	1.4	1.3	1.3
	Apr	2.5	1.1	1.4	1.5	1.9	1.4	1.3	1.6
	May	3.0	1.1	1.9	1.5	2.4	1.3	1.2	1.8
	Jun	2.6	1.2	1.8	1.5	2.0	1.1	1.1	1.6
	Jul	2.6	1.1	1.7	1.6	1.7	0.6	1.0	1.5
	Aug	2.5	1.1	1.9	1.6	1.9	0.5	1.0	1.5
	Sep	2.9	1.1	1.8	1.6	1.9	0.8	1.3	1.6
	Oct	2.1	1.1	1.9	1.7	2.2	1.2	1.4	1.7
	Nov	2.6	1.1	1.5	1.7	2.3	1.3	1.3	1.7
	Dec	2.7	1.2	1.4	1.6	1.9	1.2	1.1	1.6

Table 4-27: Increase (^0C) in monthly minimum temperature for RCP 4.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.4	0.8	1.6	0.9	1.5	1.0	0.8	1.1
	Feb	1.2	0.9	1.4	1.0	1.9	1.0	0.8	1.2
	Mar	1.5	0.8	1.2	0.9	1.8	1.0	1.0	1.2
	Apr	2.0	0.8	1.2	1.0	1.4	1.0	0.9	1.2
	May	1.3	0.8	1.3	1.0	1.3	1.0	0.9	1.1
	Jun	1.3	0.7	1.2	1.0	1.1	0.8	0.9	1.0
	Jul	1.4	0.7	1.1	1.0	0.4	0.5	0.7	0.8
	Aug	1.5	0.7	1.1	1.0	0.6	0.7	0.7	0.9
	Sep	1.2	0.6	1.1	1.0	1.0	0.8	0.9	1.0
	Oct	1.5	0.7	1.1	1.1	1.4	1.0	1.0	1.1
	Nov	1.1	0.7	1.0	1.1	1.1	1.0	1.0	1.0
	Dec	1.2	0.8	1.0	1.0	1.4	1.1	0.9	1.0
2049-2078	Jan	2.3	1.1	1.9	1.5	1.6	1.3	1.1	1.6
	Feb	2.7	1.1	1.6	1.5	2.5	1.4	1.3	1.7
	Mar	1.6	1.2	1.5	1.5	1.5	1.4	1.3	1.4
	Apr	2.7	1.1	1.5	1.6	1.2	1.4	1.3	1.5
	May	2.4	1.1	1.9	1.6	1.3	1.3	1.2	1.5
	Jun	1.9	1.2	1.8	1.5	1.6	1.1	1.1	1.5
	Jul	1.8	1.1	1.8	1.6	0.3	0.6	1.0	1.2
	Aug	1.8	1.1	1.9	1.6	0.8	0.5	1.0	1.2
	Sep	2.2	1.1	1.8	1.6	1.6	0.8	1.3	1.5
	Oct	1.9	1.1	1.8	1.7	1.7	1.2	1.4	1.6
	Nov	2.1	1.1	1.5	1.7	2.0	1.3	1.3	1.6
	Dec	2.2	1.2	1.6	1.6	1.8	1.2	1.1	1.5

RCP 6.0

Projection of Rainfall

This scenario also shows almost no change in mean annual rainfall. NIMR KMO KadGEM2 A0 predicts a very high annual rainfall of 1043 mm. Annual rainfall projection for RCP 6.0 scenario is given in Fig. 4.11. The figure shows that 7 to 8 peaks in the annual rainfall and 10-15 severe droughts. The maximum rainfall as per RCP 6.0 scenario, may go to 1700 mm. For drought year, the annual rainfall will go as low as 450 mm.

Table 4.28 shows Number of floods and droughts estimated from the predicted value as per RCP 6.0. These projections are made based on the historical mean and standard deviation. The above result shows a large number of moderate to severe droughts.

Table 4-28: Number of floods and droughts as per RCP 6.0 for Vijayawada

	Global Climate Models						
	NCAR CESM 1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 -M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	0	6	0	0	0	17	9
Severe drought	12	20	9	0	4	16	12
Moderate drought	16	9	18	10	23	10	15
Normal	14	15	12	23	12	10	13
Moderate flood	7	5	5	4	5	4	5
Severe flood	4	2	8	6	10	1	3
Extreme flood	5	1	6	15	4	0	1

Table 4.29 shows the percentage change in mean monthly rainfall from that of historical rainfall. The decrease is maximum for July and November while the increase in maximum in February month. The next 30 years shows a large decrease in rainfall during the monsoon period.

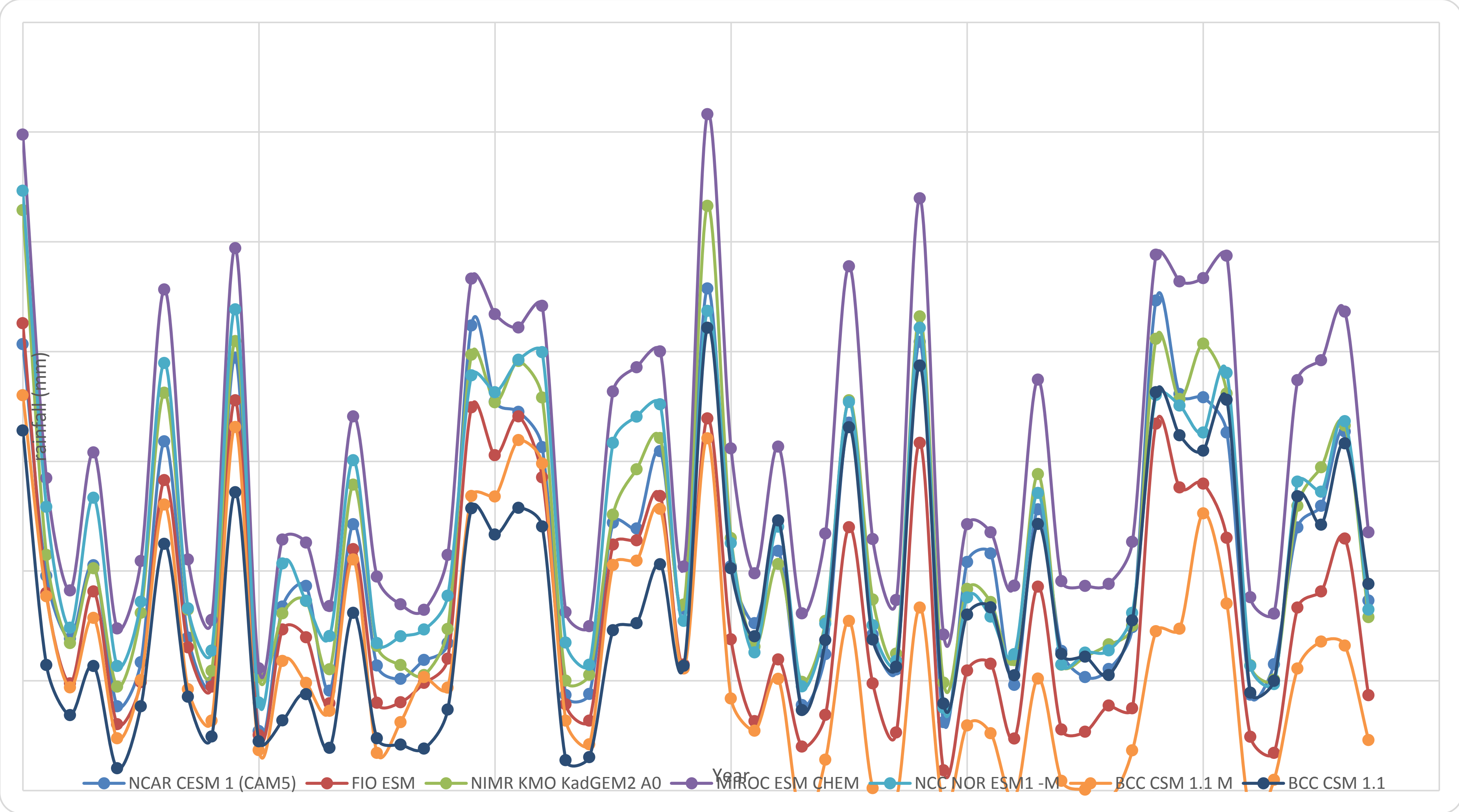

Figure 4.11: Annual rainfall projection for RCP 6.0 scenario for Vijayawada

Table 4-29: Percentage change in monthly rainfall for RCP 6.0 scenario for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 - M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	0	-17	20	21	-24	-4	-13	-2
	Feb	44	45	-21	10	-1	10	-25	9
	Mar	28	-4	-14	14	-23	-8	7	0
	Apr	78	2	-2	1	-30	-4	17	9
	May	-22	0	16	-1	10	-9	-27	-5
	Jun	10	-4	-14	9	16	2	-28	-1
	Jul	-2	-13	-4	3	-21	-49	-36	-17
	Aug	-12	-9	-13	13	17	6	-32	-4
	Sep	-9	-19	23	15	-4	-12	4	0
	Oct	-20	-24	-7	31	18	-22	-32	-8
	Nov	-8	7	15	19	4	-20	5	3
	Dec	7	-12	0	17	4	-33	-2	-3
2049-2078	Jan	0	13	4	13	-34	-7	6	-1
	Feb	4	15	3	12	0	-13	32	8
	Mar	-3	-11	-43	15	8	4	10	-3
	Apr	78	6	-7	1	-13	-10	44	14
	May	-4	-15	26	9	-28	0	-38	-7
	Jun	31	-19	-2	20	21	-12	22	9
	Jul	10	-9	-4	-3	-29	-55	-29	-17
	Aug	-29	-15	4	24	9	-55	-17	-11
	Sep	-8	-25	6	32	4	-26	11	-1
	Oct	-19	-40	-16	23	1	-27	-3	-12
	Nov	-4	-21	15	26	10	-32	20	2
	Dec	-10	-23	-1	23	22	-29	57	6

Projection for Maximum Temperature

Table 4.30 shows the increase in monthly maximum temperature for RCP 6.0 scenario. Out of the seven models, here also NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.9^{0}C in the first 30 years and rises to 2.7^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2048 and 1.5^{0}C to 1.7^{0}C in 2049-2078.

Projection for Minimum Temperature

Table 4.31 shows the increase in monthly minimum temperature for RCP 6.0 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is at most of 1.2^{0}C in the first 30 years and rises to 2.5^{0}C in the next 30 years. BCC CSM 1.1

shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^0C in 2020 to 2048 and 1.5^0C – 1.6^0C in 2049-2078.

Table 4-30: Increase (0C) in monthly maximum temperature for RCP 6.0 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	0.8	1	1.2	0.7	0.8	0.7	0.7	0.8
	Feb	1	0.9	1	0.7	1.5	0.5	0.5	0.9
	Mar	0.9	0.9	0.9	0.7	1.1	0.5	0.7	0.8
	Apr	1.4	0.7	0.9	0.7	1	0.9	1	0.9
	May	1.2	0.9	1.1	0.7	1.1	1.1	0.8	1.0
	Jun	1.2	0.8	1.2	0.8	1.4	1.1	0.7	1.0
	Jul	1.1	0.9	0.9	0.8	1.2	1	0.6	0.9
	Aug	1.4	0.7	1.1	0.9	0.9	1	0.7	1.0
	Sep	1	0.9	0.9	0.9	1.2	1.1	0.8	1.0
	Oct	1.1	0.9	0.7	1	1.3	1	0.7	1.0
	Nov	1.1	1	0.7	0.9	1.2	0.8	0.6	0.9
	Dec	0.9	1	0.8	0.8	1.2	0.5	0.6	0.8
2049-2078	Jan	1.8	1.4	2.1	1.6	1.1	1	1.2	1.5
	Feb	1.9	1.3	2.2	1.6	1.8	0.9	1.2	1.6
	Mar	1.9	1.2	1.8	1.4	1.5	0.9	1.2	1.4
	Apr	2.2	1.3	1.7	1.4	1.4	1.3	1.3	1.5
	May	2.1	1.2	1.7	1.4	1.8	1.3	1.2	1.5
	Jun	2.2	1.3	1.8	1.5	1.9	1.3	1.2	1.6
	Jul	2	1.3	1.6	1.5	1.8	1.3	1.2	1.5
	Aug	2.2	1.2	1.7	1.5	1.5	1.3	1.1	1.5
	Sep	2.1	1.2	1.3	1.7	1.5	1.4	1.3	1.5
	Oct	1.9	1.3	1.2	1.7	1.9	1.3	1.3	1.5
	Nov	1.8	1.2	1.2	1.7	1.9	1.1	1.2	1.4
	Dec	1.6	1.4	1.7	1.7	1.2	1	1.2	1.4

Table 4-31: Increase (^{0}C) in monthly minimum temperature for RCP 6.0 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.1	0.9	1.3	0.8	1.1	1.0	0.8	1.0
	Feb	1.1	0.8	1.0	0.8	1.7	1.0	0.9	1.0
	Mar	1.1	0.8	0.8	0.8	1.2	1.0	1.1	1.0

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
	Apr	1.4	0.7	0.8	0.9	1.4	1.0	0.8	1.0
	May	0.8	0.8	0.9	0.8	1.4	0.9	0.8	0.9
	Jun	0.9	0.8	0.9	0.8	1.5	0.8	0.7	0.9
	Jul	1.2	0.8	0.9	0.9	0.6	0.6	0.5	0.8
	Aug	1.2	0.8	0.9	0.8	0.6	0.6	0.6	0.8
	Sep	1.0	0.8	0.8	0.9	0.7	0.7	0.9	0.8
	Oct	1.0	0.8	0.9	0.9	1.5	0.9	0.8	1.0
	Nov	1.0	0.8	0.6	0.9	1.3	0.9	0.8	0.9
	Dec	1.4	0.9	0.8	0.8	1.2	1.0	0.7	1.0
2049-2078	Jan	2.5	1.2	2.0	1.5	1.5	1.2	1.1	1.6
	Feb	2.2	1.2	1.7	1.5	1.9	1.3	1.2	1.6
	Mar	2.3	1.2	1.3	1.4	1.5	1.4	1.4	1.5
	Apr	2.5	1.2	1.6	1.5	1.1	1.4	1.2	1.5
	May	2.2	1.1	1.4	1.4	1.5	1.4	1.3	1.5
	Jun	1.8	1.2	1.6	1.4	2.0	1.1	1.3	1.5
	Jul	2.1	1.1	1.5	1.5	1.1	0.9	1.2	1.3
	Aug	2.1	1.1	1.5	1.5	0.9	0.7	1.1	1.3
	Sep	2.1	1.0	1.5	1.6	1.1	0.8	1.3	1.4
	Oct	1.9	1.0	1.4	1.7	1.8	1.2	1.5	1.5
	Nov	2.3	1.1	1.5	1.6	1.9	1.4	1.4	1.6
	Dec	2.7	1.3	1.6	1.5	1.7	1.4	1.3	1.6

RCP 8.5

Projection of Rainfall

The projection shows that annual average rainfall in the next 60 years is going to decrease to 830 mm, almost 70 mm less than the historical mean. Table 3.16 shows annual rainfall projection for the RCP 8.5 scenario.

Fig 4.12 shows a graph of annual rainfall projection for 8.5 scenarios. As per RCP 8.5, the peak rainfall of 1500 mm might occur during the wet year. The drought year with rainfall of 450 mm is also frequent.

Table 4-32: Number of floods and droughts as per RCP 8.5 for Vijayawada

	Global Climate Models						
	NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 - M	BCC CSM 1.1 M	BCC CSM 1.1
Extreme drought	0	4	0	0	1	25	4
Severe drought	6	22	10	6	16	9	17
Moderate drought	16	9	19	18	12	9	12
Normal	15	13	12	14	15	12	15
Moderate flood	8	5	6	8	7	2	5
Severe flood	9	4	8	4	5	1	3
Extreme flood	4	1	3	8	2	0	2

Table 4.32 shows a projection of some floods and droughts.RCP 8.5 indicates number of moderate to severe droughts, almost 25-30 drought years. The peak of flood and drought are also higher from that occurred in the past. Table 4.33 shows the percentage change in mean monthly rainfall for that of historical rainfall. The decrease in maximum in July and August month in first 30 years while in the next 30 years, it is maximum in May, July, and August.

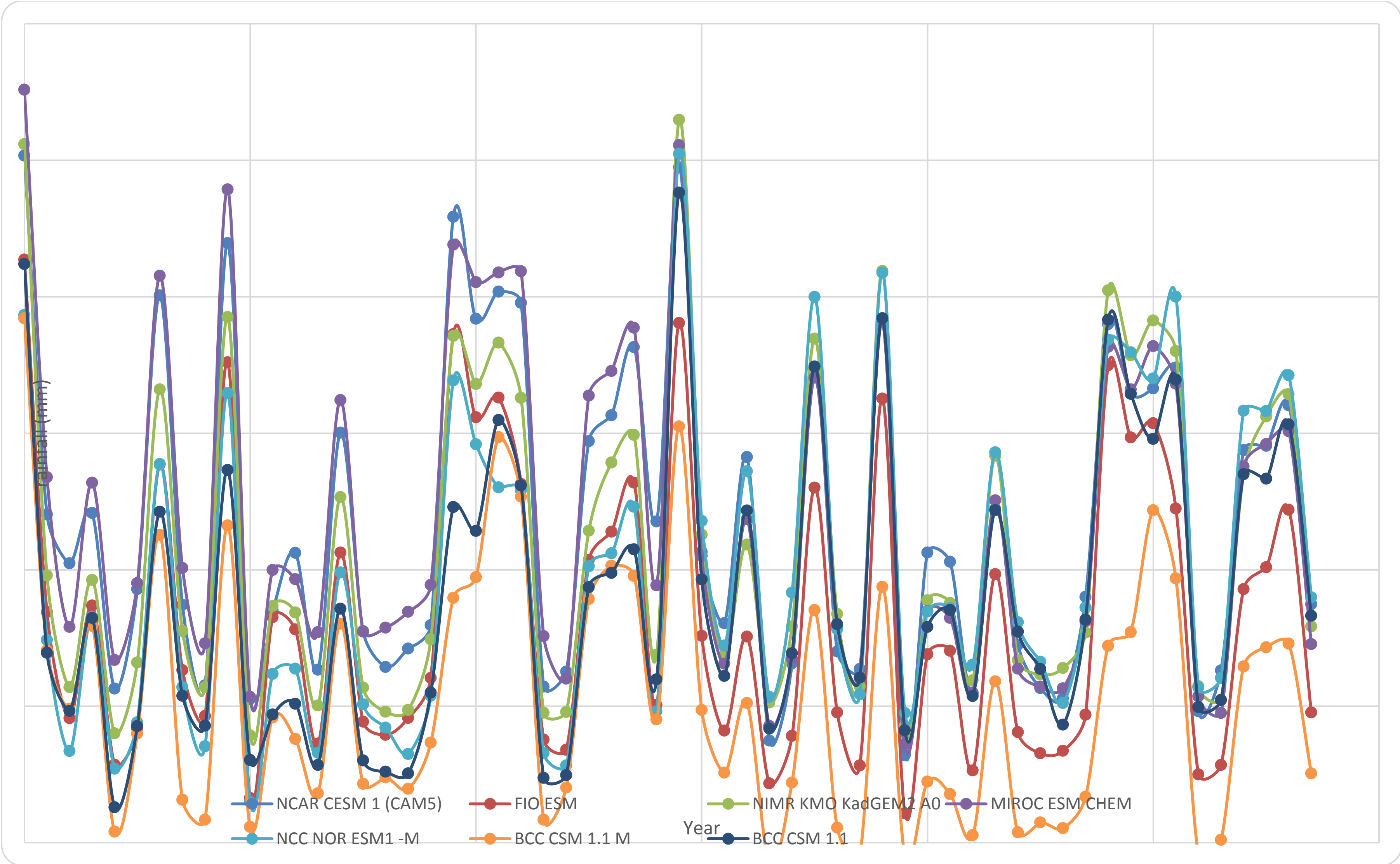

Figure 4.12: Annual rainfall projection for RCP 8.5 scenario for Vijayawada

Table 4-33Table 4.33 Percentage change in monthly rainfall for RCP 8.5 scenario for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM 2 A0	MIROC ESM CHEM	NCC NOR ESM 1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	12.2	-16.9	23.2	20.3	-28.9	3.0	-1.5	1.6
	Feb	0.4	14.9	-47.5	12.9	-1.7	-20.3	-4.2	-6.5
	Mar	-0.1	-2.8	-8.1	7.9	1.6	2.1	-3.2	-0.4
	Apr	131.1	6.4	-17.0	-4.9	-24.6	-3.4	20.1	15.4
	May	-10.9	1.2	16.6	2.2	-27.6	-0.5	-2.6	-3.1
	Jun	-5.6	3.5	-2.4	0.6	-16.5	-0.2	-18.8	-5.6
	Jul	-6.9	2.0	-2.3	-8.5	-6.2	-64.0	-40.8	-18.1
	Aug	-5.1	-17.3	-17.3	24.6	-20.3	-30.5	-31.5	-13.9
	Sep	31.6	-33.5	-2.3	11.1	-19.2	-11.1	-5.0	-4.1
	Oct	8.3	-26.9	-10.5	11.4	-17.6	-2.9	-14.6	-7.6
	Nov	-5.0	0.4	21.6	16.8	-2.0	-34.5	35.1	4.6
	Dec	0.8	-13.9	-19.5	20.8	22.1	-4.4	-3.7	0.3
2049-2078	Jan	63.5	-24.4	32.8	12.1	-16.3	-29.1	-13.8	3.6
	Feb	18.1	21.3	-18.7	13.6	11.5	-8.6	4.7	6.0
	Mar	-1.0	13.8	-25.4	6.6	7.5	-6.2	-6.9	-1.6
	Apr	48.5	4.0	-0.3	3.4	-28.3	-21.3	8.6	2.1
	May	-16.4	-7.3	11.9	0.1	-23.5	-11.4	-31.1	-11.1
	Jun	40.7	-3.4	-7.7	-2.2	1.2	-22.0	-2.6	0.6
	Jul	-11.4	-2.9	-3.6	-14.1	-19.7	-64.2	-7.5	-17.6
	Aug	-33.3	-26.9	0.4	-6.0	-9.7	-33.6	-23.7	-19.0
	Sep	-11.0	-23.2	5.1	-9.5	27.9	-19.0	6.8	-3.3
	Oct	12.7	-31.5	1.1	6.4	24.5	-22.2	5.9	-0.5
	Nov	23.2	-22.4	6.2	23.6	12.2	-38.9	35.1	5.6
	Dec	14.5	-14.3	0.0	14.3	20.4	-16.8	60.1	11.2

Projection for Maximum Temperature

Table 4.34 shows the increase in monthly maximum temperature for RCP 8.5 scenario. Out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 2.3 ^{0}C in the first 30 years and may rise maximum to 3.4^{0}C in the next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1.2^{0}C – 1.3^{0}C in 2020 to 2048 and 2.2^{0}C – 2.4^{0}C in 2049-2078.

Projection for Minimum Temperature

Table 4.35 shows the increase in monthly minimum temperature for RCP 8.5 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is almost 1.8^{0}C in first 30 years and may rise to a maximum of 3.9^{0}C in next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the temperature will rise by 1^{0}C – 1.2^{0}C in 2020 to 2048 and 2^{0}C – 2.3^{0}C in 2049-2078.

Table 4-34: Increase (^{0}C) in monthly maximum temperature for RCP 8.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.5	1.0	1.2	1.0	2.4	0.9	1.0	1.3
	Feb	1.6	0.9	1.1	1.0	1.8	1.1	1.0	1.2
	Mar	1.5	0.9	1.0	1.0	1.6	1.1	1.1	1.2
	Apr	1.7	1.0	1.0	1.1	1.7	1.1	1.1	1.2
	May	1.7	0.9	1.1	1.1	2.1	1.1	1.0	1.3
	Jun	2.2	0.9	0.9	1.1	2.0	0.9	0.9	1.3
	Jul	2.3	0.8	0.9	1.2	1.6	0.5	0.8	1.1
	Aug	2.2	0.8	0.9	1.1	1.2	0.5	0.7	1.1
	Sep	1.0	0.7	1.1	1.2	1.9	0.5	0.9	1.1
	Oct	0.8	0.9	1.0	1.2	2.0	1.0	1.2	1.1
	Nov	1.9	0.9	0.8	1.2	2.2	1.2	1.1	1.3
	Dec	1.2	1.0	0.7	1.1	1.3	1.1	1.0	1.1
2049-2078	Jan	2.4	1.9	2.5	2.3	2.9	1.9	1.8	2.2
	Feb	2.8	1.8	2.4	2.3	2.3	1.9	2.0	2.2
	Mar	3.0	1.8	2.0	2.2	2.1	2.0	2.0	2.1
	Apr	3.7	1.8	2.0	2.3	2.9	2.0	2.0	2.4
	May	3.4	1.8	2.1	2.2	2.9	2.0	1.9	2.3
	Jun	3.4	1.9	2.1	2.3	3.2	1.6	1.8	2.3
	Jul	3.2	1.8	2.1	2.2	2.7	1.1	1.7	2.1
	Aug	3.4	1.8	2.2	2.2	2.8	1.1	1.6	2.1
	Sep	3.1	1.7	2.2	2.2	1.8	1.6	2.0	2.1
	Oct	2.6	1.8	2.2	2.3	2.8	1.9	2.2	2.3
	Nov	3.7	1.8	1.8	2.3	2.4	1.9	2.0	2.3
	Dec	3.0	2.0	2.1	2.3	2.0	2.0	1.9	2.2

Table 4-35: Increase (^{0}C) in monthly minimumtemperaturefor RCP 8.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	2.0	1.0	1.4	1.0	1.3	0.9	1.0	1.2
	Feb	1.6	0.9	1.1	1.0	1.8	1.1	1.0	1.2
	Mar	1.4	0.9	0.9	1.0	1.7	1.1	1.1	1.2
	Apr	2.0	0.9	1.0	1.2	1.5	1.1	1.1	1.3
	May	1.8	0.9	1.1	1.1	1.4	1.1	1.0	1.2
	Jun	1.4	0.9	0.9	1.1	1.3	0.9	0.9	1.1
	Jul	1.3	0.8	0.9	1.2	0.5	0.5	0.8	0.9
	Aug	1.3	0.8	0.9	1.1	0.2	0.5	0.7	0.8
	Sep	1.3	0.7	1.1	1.2	0.9	0.5	0.9	1.0
	Oct	1.2	0.8	0.8	1.2	1.4	0.9	1.2	1.1
	Nov	1.6	0.9	0.7	1.2	1.9	1.2	1.1	1.2
	Dec	1.4	1.0	0.7	1.1	1.6	1.1	1.0	1.1
2049-2078	Jan	2.9	1.9	2.7	2.3	2.3	1.9	1.8	2.3
	Feb	3.2	1.8	2.5	2.3	2.7	1.9	2.0	2.3
	Mar	2.9	1.8	2.0	2.2	2.5	2.0	2.0	2.2
	Apr	3.9	1.8	2.1	2.3	2.8	2.0	2.0	2.4
	May	2.7	1.8	2.1	2.3	2.4	2.0	1.9	2.2
	Jun	2.8	1.9	2.1	2.3	2.6	1.6	1.8	2.2
	Jul	2.8	1.8	2.0	2.3	1.5	1.1	1.7	1.9
	Aug	2.9	1.8	2.1	2.3	2.0	1.1	1.6	2.0
	Sep	2.7	1.7	2.0	2.3	2.1	1.6	2.0	2.0
	Oct	2.6	1.8	2.0	2.4	2.9	1.9	2.2	2.2
	Nov	3.4	1.8	1.6	2.3	3.0	1.9	2.0	2.3
	Dec	3.3	2.0	2.2	2.3	2.5	2.0	1.9	2.3

4.4.3 Summary

Rainfall

Table 4.36 shows the percentage change in monthly rainfall in next 60 years for all RCPs scenarios. As per the projection for all RCP scenarios, the mean annual rainfall for Vijayawada city is likely to decrease by 50-70 mm in the near future. Presently, the mean annual rainfall of Vijayawada is 900 mm. RCP 8.5 predicts the maximum decrease in annual rainfall by 70 mm.

Maximum Temperature

Table 4.37 shows the increase in monthly maximum temperature for all the RCP scenarios. It is evident that in any case the maximum temperature is bound to rise at least by 1^{0}C. From 2020 to 2048, the change in temperature for RCP 2.6 is 0.9^{0}C, change in temperature for RCP 4.5 and RCP 6.0 is around 1^{0}C-1.2^{0}C which will rise to 1.5^{0}C in 2050-2079. RCP 8.5 is the extreme case wherein the first 30 years the rise is more than 1^{0}C, but in the next 30 years, the rise will be around 2^{0}C. For a few months, it may rise by 2. 2^{0}C also.

Minimum Temperature

Table 4.38 shows the increase in monthly minimum temperature for all the RCP scenarios. It is evident that even if RCP 2.6 follows, the minimum temperature will rise by about 0.8^{0}C to 0.9^{0}C. From 2020 to 2049, the change in temperature for RCP 4.5 and RCP 6.0 is around 1^{0}C which will rise to 1.5^{0}C in 2050-2079. RCP 8.5 is the extreme case wherein the first 30 years the rise is more than 1^{0}C, but in the next 30 years, the rise will be around 2^{0}C. The increase in maximum temperature and minimum temperature is almost the same. Fig. 4.42 shows a projection of monthly minimum temperature for all RCPs.

Table 4-36: Percentage change in monthly rainfall for all RCPs for Vijayawada

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2048	Jan	3.6	2.9	-2.3	1.6
	Feb	2.8	15.7	8.8	-6.5
	Mar	1.4	3.9	0.1	-0.4
	Apr	7.2	17.3	8.9	15.4
	May	-8.8	5.4	-4.7	-3.1
	Jun	-5.0	-2.9	-1.2	-5.6
	Jul	-11.3	-17.9	-17.4	-18.1
	Aug	-11.6	-4.9	-4.2	-13.9
	Sep	3.0	-2.7	-0.3	-4.1
	Oct	-8.3	-2.9	-8.2	-7.6
	Nov	-3.3	0.0	3.1	4.6
	Dec	-3.5	-6.9	-2.8	0.3
2049-2078	Jan	-3.2	-5.2	-0.7	3.6
	Feb	-6.8	5.1	7.7	6.0
	Mar	8.4	0.2	-2.8	-1.6
	Apr	16.0	-0.4	14.1	2.1
	May	2.4	-8.2	-7.1	-11.1
	Jun	1.0	-4.1	8.6	0.6
	Jul	-11.0	-19.4	-17.1	-17.6
	Aug	-0.9	-7.2	-11.3	-19.0
	Sep	-4.0	1.1	-1.0	-3.3
	Oct	-7.8	-10.0	-11.6	-0.5
	Nov	-0.2	9.2	1.9	5.6
	Dec	-9.7	-3.4	5.5	11.2

Table 4-37: Increase (0C) in maximum temperature for all RCPs for Vijayawada

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2048	Jan	0.9	1.2	1.1	1.3
	Feb	1.0	1.0	1.0	1.2
	Mar	0.9	1.0	1.0	1.2
	Apr	1.0	1.0	1.0	1.2
	May	1.1	1.1	1.0	1.3
	Jun	1.1	1.2	1.0	1.3
	Jul	1.0	1.0	0.9	1.1
	Aug	0.9	1.0	0.9	1.1
	Sep	0.9	0.9	0.9	1.1
	Oct	1.0	1.1	1.1	1.1
	Nov	1.0	1.0	1.0	1.3
	Dec	1.0	1.1	1.0	1.1
2049-2078	Jan	1.1	1.6	1.7	2.2
	Feb	1.3	1.7	1.5	2.2
	Mar	1.1	1.3	1.5	2.1
	Apr	1.0	1.6	1.5	2.4
	May	1.2	1.8	1.7	2.3
	Jun	1.2	1.6	1.6	2.3
	Jul	0.9	1.5	1.5	2.1
	Aug	0.9	1.5	1.4	2.1
	Sep	1.0	1.6	1.4	2.1
	Oct	1.1	1.7	1.6	2.3
	Nov	1.2	1.7	1.7	2.3
	Dec	1.2	1.6	1.6	2.2

Table 4-38: Increase (0C) in monthly minimum temperature for all RCPs for Vijayawada

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2048	Jan	0.9	1.1	1.0	1.2
	Feb	1.0	1.2	1.0	1.2
	Mar	0.9	1.2	1.0	1.2
	Apr	1.0	1.2	1.0	1.3
	May	0.8	1.1	0.9	1.2
	Jun	0.7	1.0	0.9	1.1
	Jul	0.8	0.8	0.8	0.9
	Aug	0.7	0.9	0.8	0.8
	Sep	0.9	1.0	0.8	1.0
	Oct	0.9	1.1	1.0	1.1
	Nov	0.9	1.0	0.9	1.2
	Dec	1.0	1.0	1.0	1.1
2049-2078	Jan	1.0	1.6	1.6	2.3
	Feb	1.1	1.7	1.6	2.3
	Mar	1.1	1.4	1.5	2.2

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
	Apr	1.1	1.5	1.5	2.4
	May	1.1	1.5	1.5	2.2
	Jun	1.1	1.5	1.5	2.2
	Jul	0.9	1.2	1.3	1.9
	Aug	0.9	1.2	1.3	2.0
	Sep	1.0	1.5	1.4	2.0
	Oct	1.1	1.6	1.5	2.2
	Nov	1.0	1.6	1.6	2.3
	Dec	1.0	1.5	1.6	2.3

5 RUNOFF ESTIMATION

5.1 CATCHMENT DELINEATION

For catchment delineation, SRTM DEM 30m resolution is used as input data. HEC Geo HMS in ArcGIS is the tool for catchment delineation. The terrain processing (TPr) is the first step in HEC Geo HMS. A terrain model is used as an input device that describes the drainage pattern of the catchment using six additional data sets, i.e. fill sinks, flow direction, flow accumulation, stream delineation, stream segmentation, and catchment grid delineation. The result acquired after HEC Geo HMS is the catchment area of each sub-basin which is used as the input data for the HEC-HMS.

The inputs to the model included land use information, hydrologic soil groups and rainfall events, all of which were permitted to vary in space and time. In this study, land use data were acquired by digitizing the satellite image and were reclassified into five types including residential, agricultural, water bodies, vegetation, and barren land. Soil classification maps were used, and these soil types were converted into the hydrologic soil groups for the watershed according to US Natural Resource Conservation Service (NRCS). Then, based on the land use data and the hydrologic soil groups, the lumped CN value for each sub-basin was generated. All the above information was incorporated into the basin model of HEC-HMS.

5.1.1 Catchment Boundary

The google map for both the cities are collected, and the city boundary was marked and the digital elevation model was developed. The delineated map for both Solapur and Vijayawada cities are shown in Fig. 5.1 and Fig.5.2 respectively. The DEM (digital elevation model) map for Solapur and Vijayawada city is shown in Figure 5.3 and 5.4, respectively.

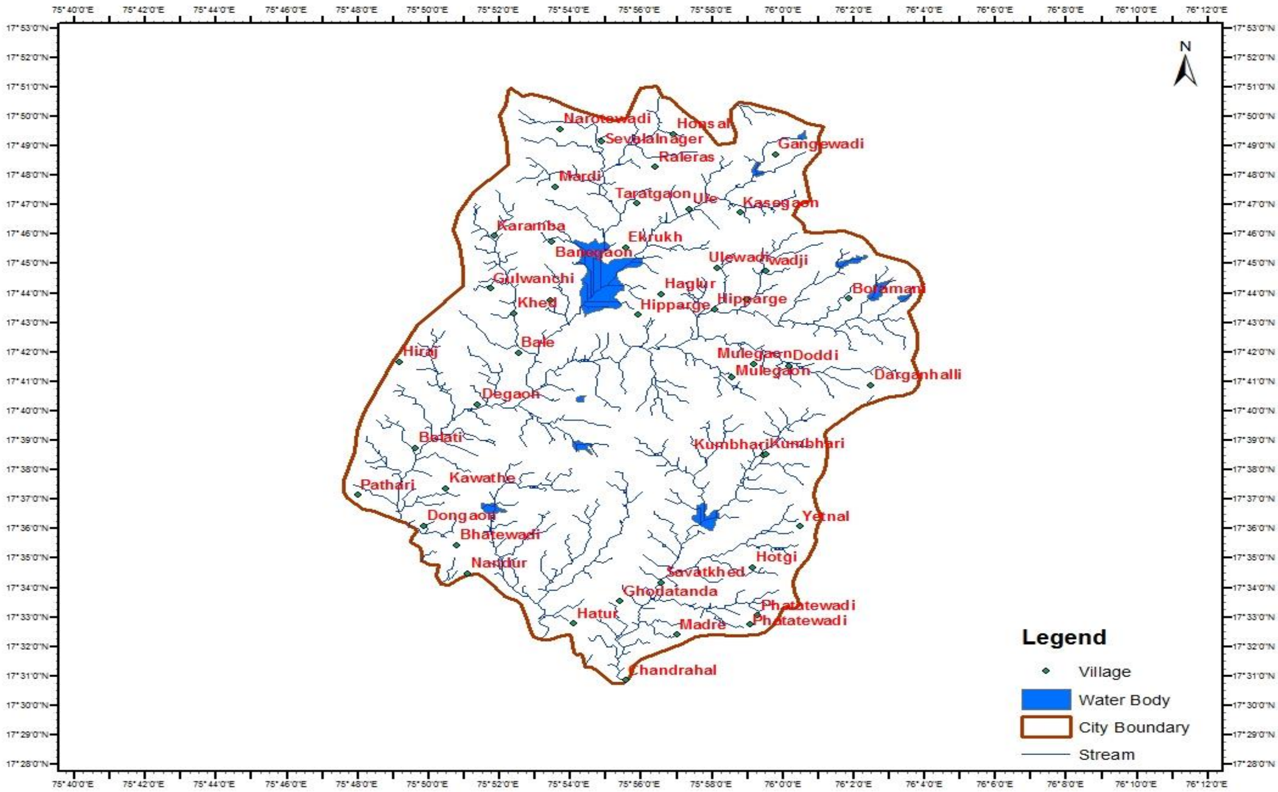

Figure 5.1: Solapur city boundary

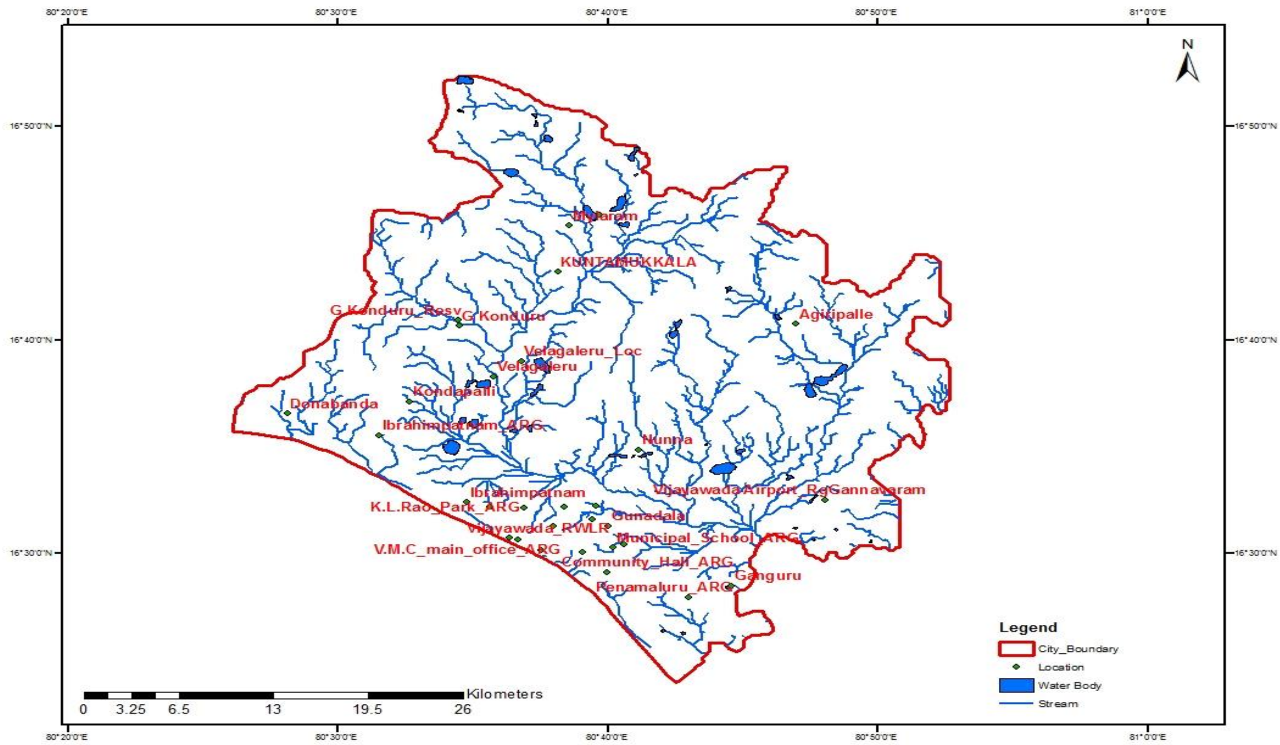

Figure 5.2: Vijayawada City boundary

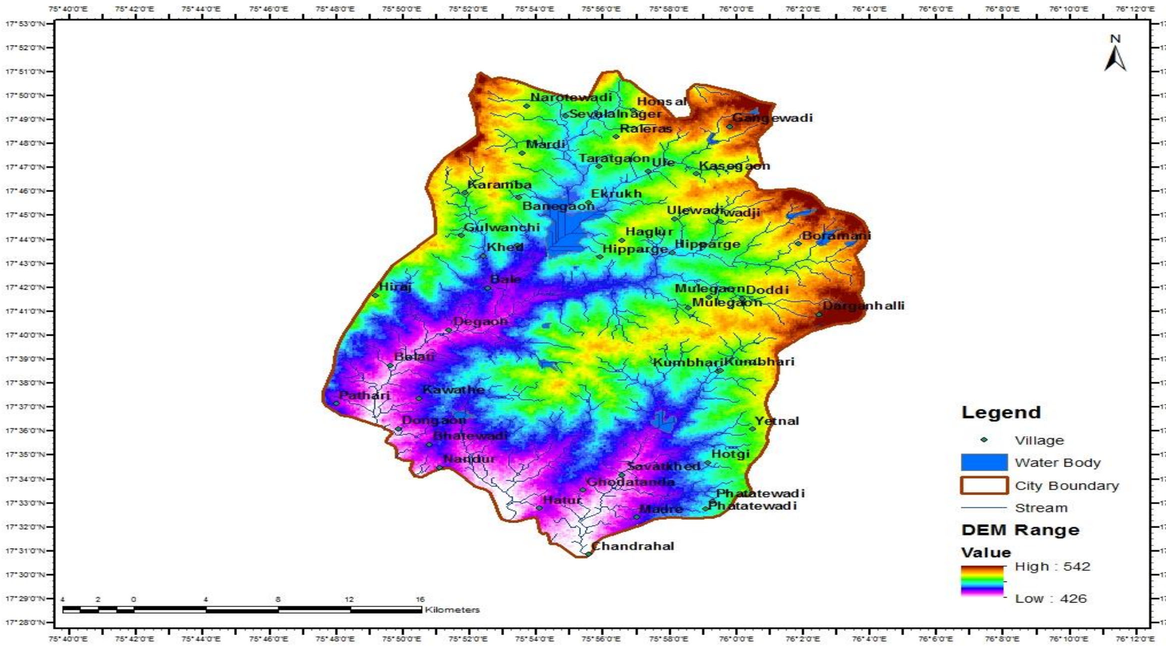

Figure 5.3: Digital Elevation Model (DEM) for Solapur city

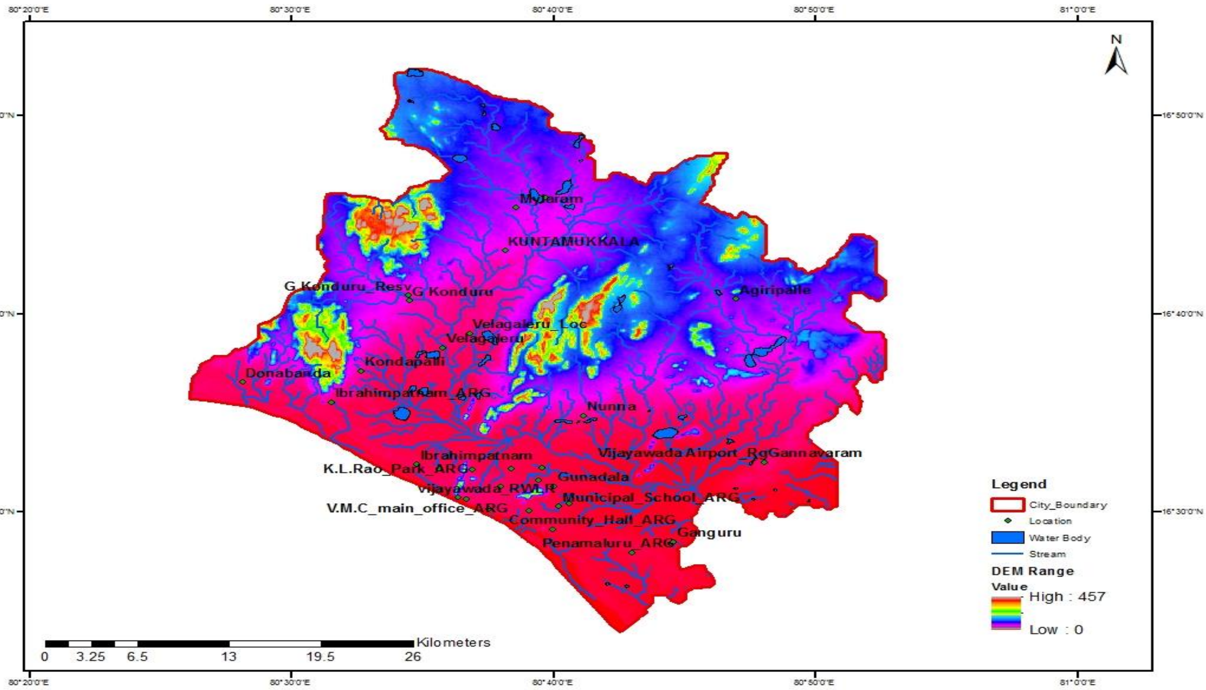

Figure 5.4: Digital Elevation Model (DEM) for Vijayawada City

5.1.2 Land Use Pattern

Land use map was generated from Spot-5 image satellite data from 1979-2007 with a resolution of 2.5 m. The supervised classification method with maximum likelihood clustering was employed for image classification through ArcGIS 10.1 Software. The Land use identified in the watershed is primarily urban, bare soil, agricultural and forest areas. Land use classification for Solapur and Vijayawada is shown in Fig. 5.5 and Fig. 5.6 respectively.

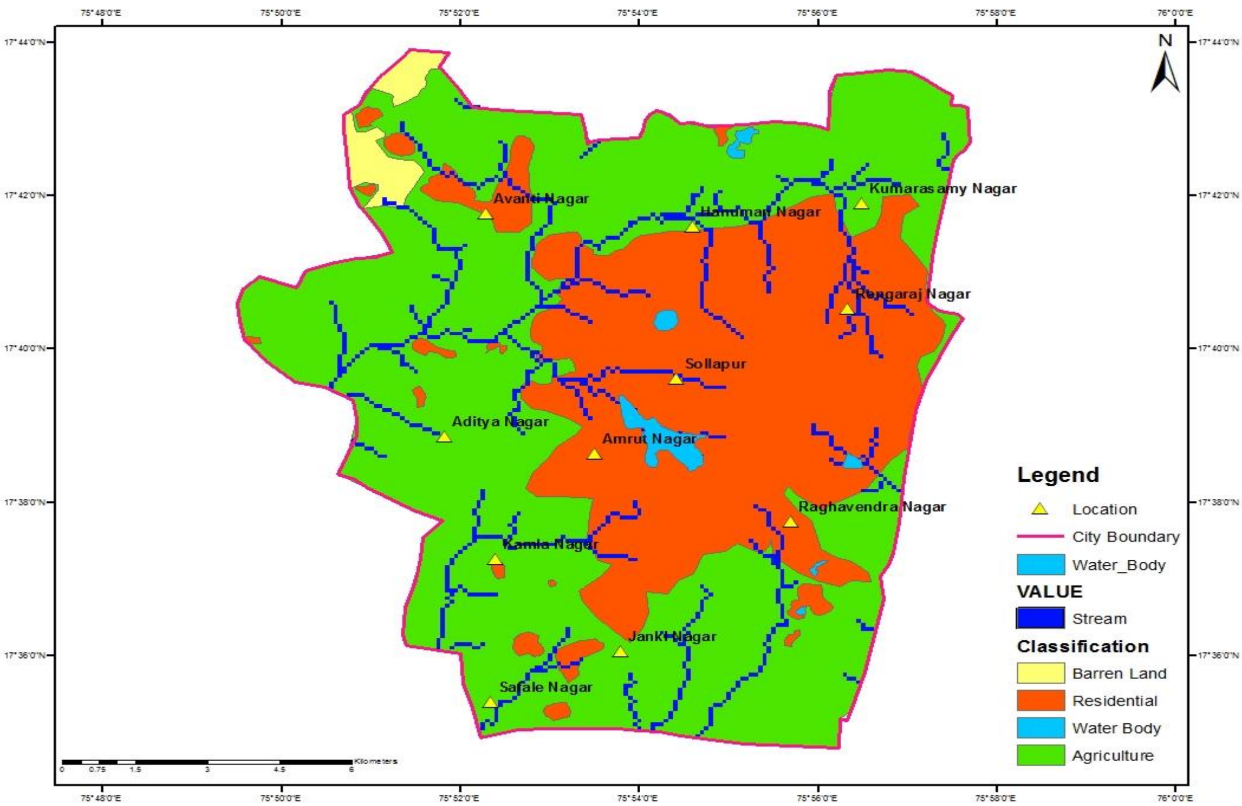

Figure 5.5: Land use map for Solapur City

The land use pattern in the study area is divided into agricultural land, residential land, barren land, water bodies, and vegetation. Most of the study area included in the agricultural land. Barren land in the study area less than 5percentage. About ten percent of the study area is a residential area. Water bodies in the area vary between 1 to 10 percentage, and vegetation in the area varies 7-20 percentages.

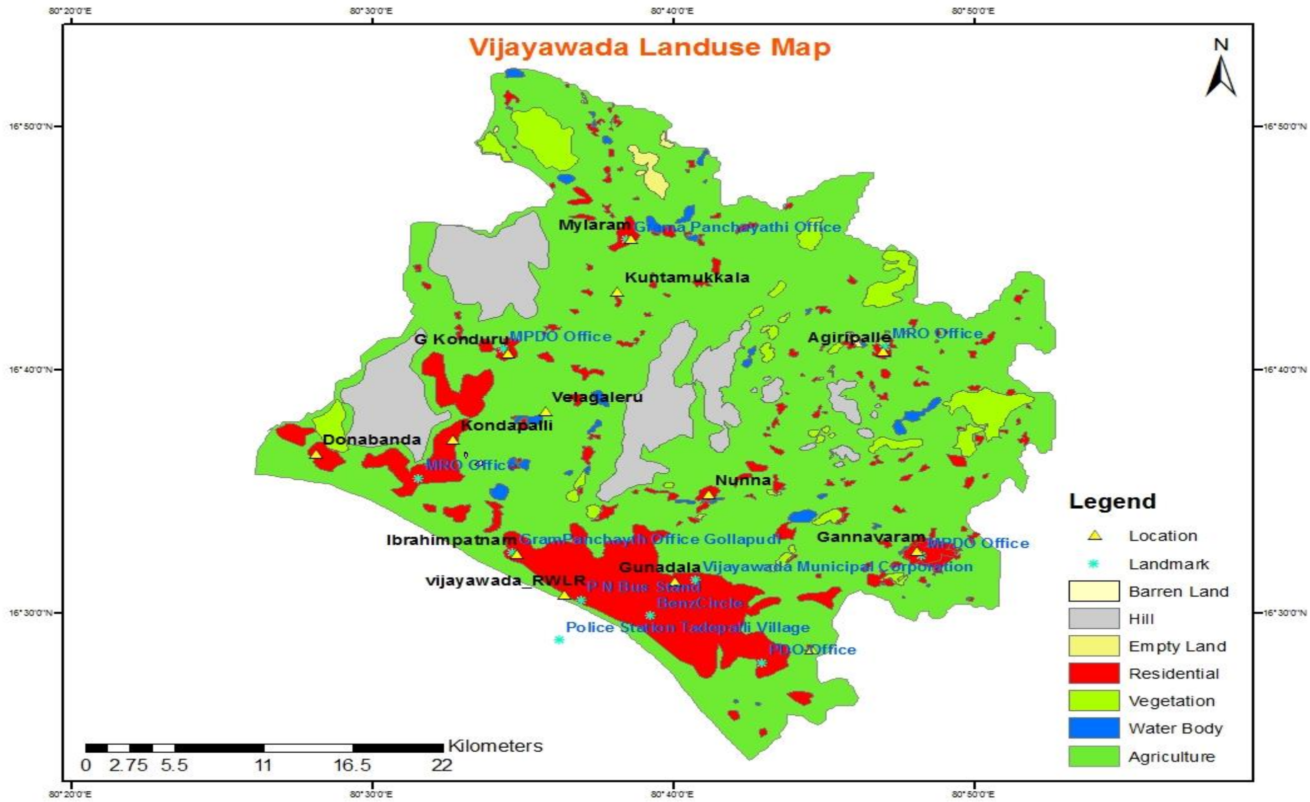

Figure 5.6: Land use map for Vijayawada City

5.1.3 Hydrologic Soil Groups Map

Different soil textures were digitized based on the rules of hydrologic soil group classifications developed by the US Natural Resource Conservation Service (NRCS), Infiltration rates of soils are affected by subsurface permeability. As defined by SCS soil scientists, Soils may be classified into four hydrologic groups (A, B, C and D), (USDA, 1986): A soil having high infiltration rates, B soils having moderate infiltration rates, C soils having slow infiltration rates, and D soils having very slow infiltration rates . The hydrologic soil group of Krishna river basin corresponds to the soil class that was obtained as shown in Table 5.1.

Clay, clay loam, loamy sand, loam, sandy loam, silty clay loam, and silty clay are the type of soil available in the environment field. The study area mostly contains loam and Clay loam type soil in the study area.

Table 5-1: Hydrologic soil group classification

Hydrologic soil group	**Soil texture**
A	sand, loamy sand or sandy loam
B	silt loam or loam
C	sandy clay loam
D	soils are clay loam, silty clay loam, sandy clay, silty clay or clay

5.1.4 Catchment Map

Based on catchment runoff generation area, slope and water bodies, the delineation is divided further into subbasin. These subbasin maps are used to estimate runoff generated from each sub-basin separately.

Fig.5.7 and Fig.5.8 show the catchment map of Solapur and Vijayawada city sub-basin wise, respectively. Fig 5.9 and Fig 5.10 shows the subbasin map of Vijayawada and Solapur city used as an input in HEC HMS for estimation of runoff generation.

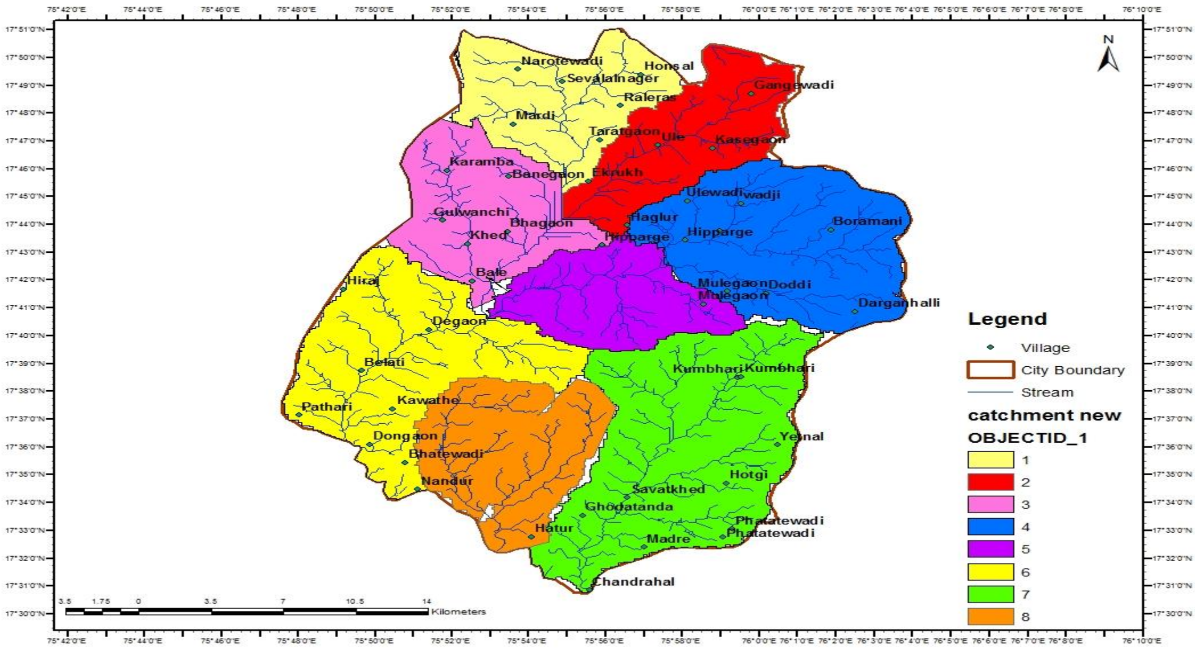

Figure 5.7: Catchment map for Solapur City

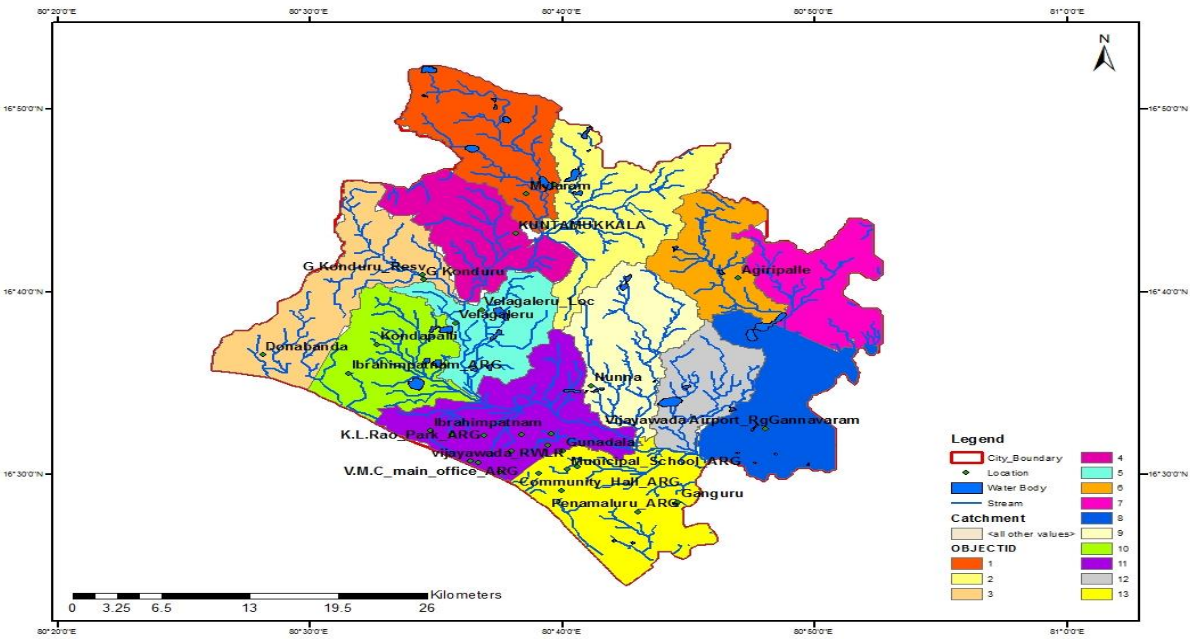

Figure 5.8: Catchment map for Vijayawada City

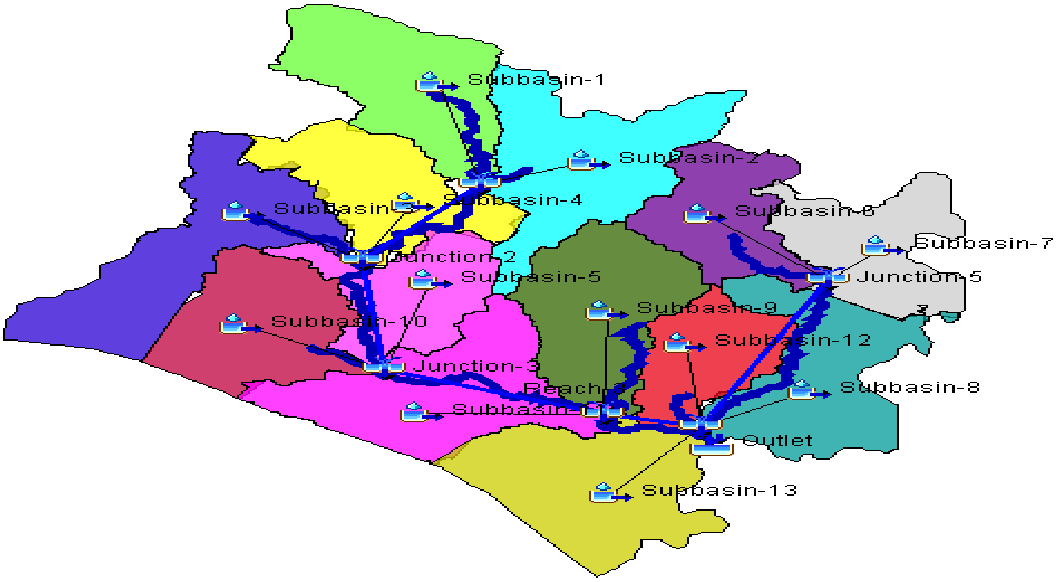

Figure 5.9: HEC-HMS input sub-basin model for Vijayawada basin

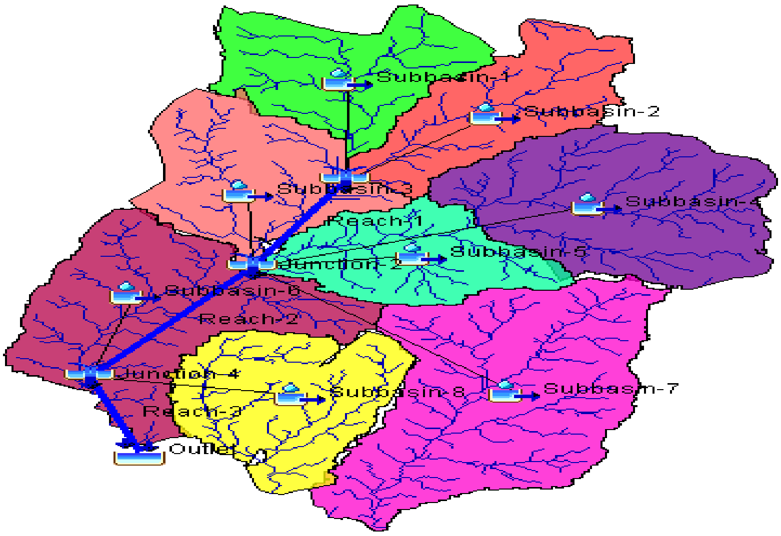

Figure 5.10: HEC-HMS input sub basin model for Solapur basin

5.1.5 Sub Basin Characteristics

Area, Curve number, Initial abstraction, Potential retention, Initial abstraction for Vijayawada and Solapur city are shown in Table 5.2 and Table 5.3.

Table 5-2: Vijayawada basin characteristics

Sub basin	Area (sq.km)	Curve number (AMC-II)	Potential retention (mm)	Initial abstraction (mm)
1	106.48	73	3.70	1.11
2	121.16	53	8.87	2.66
3	126.65	68	4.71	1.41

Sub basin	Area (sq.km)	Curve number (AMC-II)	Potential retention (mm)	Initial abstraction (mm)
4	87.05	74	3.51	1.05
5	72.17	67	4.93	1.48
6	73.38	66	5.15	1.55
7	80.90	61	6.39	1.92
8	108.24	58	7.24	2.17
9	102.84	42	13.81	4.14
10	96.50	48	10.83	3.25
11	121.82	63	5.87	1.76
12	62.80	72	3.89	1.17
13	120.33	60	6.67	2.00

Table 5-3: Solapur basin characteristics

Sub basin	Area (sq.km)	Curve number (AMC-II)	Potential retention (mm)	Initial abstraction (mm)
1	65.20	65	5.38	1.62
2	62.44	72	3.89	1.17
3	68.73	45	12.22	3.67
4	104.72	63	5.87	1.76
5	54.22	54	8.52	2.56
6	105.65	81	2.35	0.70
7	139.62	78	2.82	0.85
8	71.61	69	4.49	1.35

5.1.6 Reach Characteristics

Table 5.4 presents the Muskingum parameters used in the reach elements in for Vijayawada

Table 5-4: Muskingum parameters for study area basin

Muskingum parameter	Value
K (hr)	0.02
X	0.01

5.2 Runoff Generation

Runoff estimated for Vijayawada and Solapur station from HEC-HMS which uses the SCS-CN method. This requires daily rainfall data.

5.2.1 Runoff Estimation

The sub-basin wise runoff calculated for Vijayawada and Solapur station is using the SCS-CN method. The results are shown in Table 5.5 and Table 5.6

Table 5-5: Annual Runoff for Vijayawada Sub Basin wise (in TMC)

Year	Sub basin 1	Sub basin 2	Sub basin 3	Sub basin 4	Sub basin 5	Sub basin 6	Sub basin 7	Sub basin 8	Sub basin 9	Sub basin 10	Sub basin 11	Sub basin 12	Sub basin 13	Outlet
	Unit in TMC													
1969	4.49	5.03	5.69	3.39	2.81	2.86	3.01	4.52	4.68	4.31	5.44	2.44	5.62	54.62
1970	3.37	3.88	4.04	2.72	2.26	2.29	2.53	3.44	3.29	3.08	3.88	1.96	3.84	44.84
1971	2.76	3.16	3.29	2.24	1.86	1.89	2.08	2.80	2.67	2.50	3.16	1.61	3.13	34.64
1972	3.46	3.97	4.12	2.81	2.33	2.37	2.61	3.52	3.35	3.14	3.96	2.03	3.91	44.65
1973	2.46	2.83	2.94	2.01	1.67	1.69	1.87	2.51	2.38	2.24	2.83	1.45	2.79	32.30
1974	2.84	3.26	3.38	2.32	1.92	1.95	2.15	2.89	2.75	2.58	3.25	1.67	3.22	34.84
1975	4.53	5.20	5.40	3.70	3.07	3.12	3.44	4.61	4.38	4.11	5.19	2.67	5.13	57.34
1976	2.93	3.37	3.49	2.40	1.99	2.02	2.23	2.98	2.84	2.66	3.36	1.73	3.32	37.21
1977	2.58	2.96	3.07	2.10	1.75	1.77	1.96	2.62	2.49	2.33	2.95	1.52	2.91	34.06
1978	4.88	5.60	5.81	3.99	3.31	3.36	3.70	4.96	4.72	4.42	5.59	2.88	5.52	59.79
1979	2.36	2.71	2.81	1.92	1.60	1.62	1.79	2.40	2.28	2.14	2.70	1.39	2.67	30.56
1980	3.10	3.56	3.69	2.54	2.10	2.14	2.36	3.15	3.00	2.81	3.55	1.83	3.51	38.85
1981	3.08	3.53	3.66	2.52	2.08	2.12	2.34	3.13	2.98	2.79	3.52	1.81	3.48	38.92
1982	2.60	2.98	3.09	2.12	1.76	1.79	1.97	2.64	2.51	2.35	2.98	1.53	2.94	33.20
1983	3.93	4.51	4.68	3.21	2.67	2.71	2.99	4.00	3.80	3.57	4.50	2.32	4.45	48.15
1984	2.72	3.12	3.24	2.22	1.84	1.87	2.07	2.77	2.63	2.47	3.12	1.60	3.08	34.64
1985	2.64	3.03	3.14	2.16	1.79	1.82	2.01	2.69	2.55	2.40	3.03	1.56	2.99	34.03
1986	2.65	3.04	3.16	2.17	1.80	1.83	2.02	2.70	2.56	2.40	3.03	1.56	3.00	32.38
1987	3.12	3.58	3.71	2.55	2.11	2.15	2.37	3.17	3.01	2.83	3.57	1.84	3.53	38.72
1988	4.82	5.53	5.74	3.94	3.27	3.32	3.66	4.90	4.66	4.37	5.52	2.84	5.45	59.57
1989	4.49	5.15	5.34	3.67	3.04	3.09	3.41	4.56	4.34	4.07	5.14	2.65	5.07	56.44
1990	4.52	5.19	5.38	3.69	3.06	3.11	3.43	4.60	4.37	4.10	5.17	2.67	5.11	56.43
1991	4.58	5.25	5.44	3.74	3.10	3.15	3.48	4.65	4.42	4.14	5.23	2.70	5.17	56.18
1992	2.59	2.97	3.08	2.12	1.75	1.78	1.97	2.63	2.50	2.35	2.96	1.53	2.93	32.66
1993	2.51	2.88	2.98	2.05	1.70	1.73	1.90	2.55	2.42	2.27	2.87	1.48	2.83	31.61
1994	3.83	4.39	4.55	3.13	2.59	2.64	2.91	3.89	3.69	3.46	4.38	2.25	4.33	48.85
1995	3.98	4.56	4.73	3.25	2.69	2.74	3.02	4.04	3.84	3.60	4.55	2.34	4.49	49.20
1996	4.26	4.89	5.07	3.48	2.89	2.94	3.24	4.33	4.11	3.86	4.88	2.51	4.82	52.87
1997	2.88	3.30	3.42	2.35	1.95	1.98	2.18	2.93	2.78	2.61	3.29	1.70	3.25	36.40
Total														**1243.95**
Average														**42.89**
Standard Deviation														**10.08**

The result shows that on an annual basic, there is an average runoff of 42.89 TMC of water with a standard deviation of 10.08. Table 5.5 shows runoff generated from Vijayawada station, sub-basin wise.

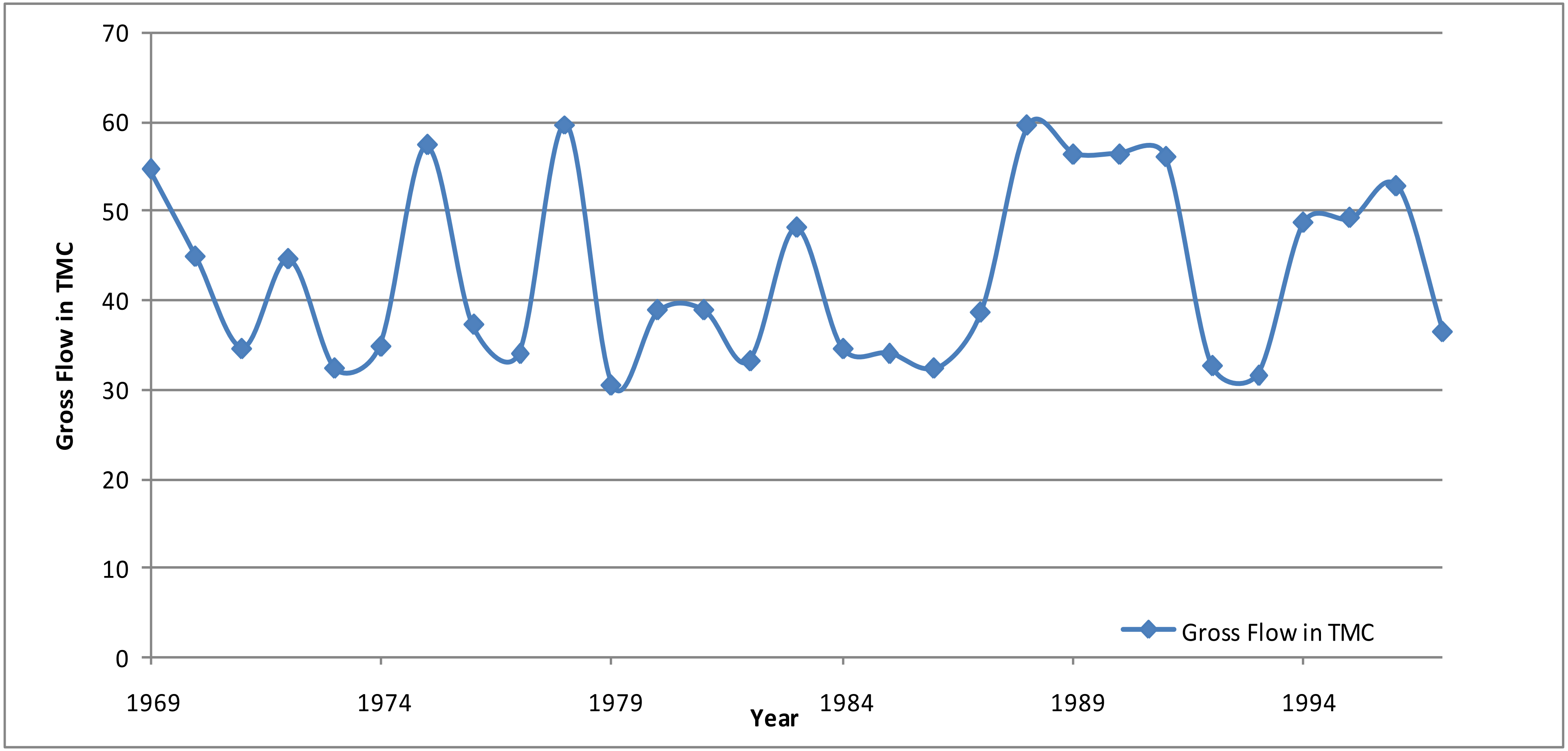

Figure 5.11: Year wise runoff using HEC-HMS model for Vijayawada basin

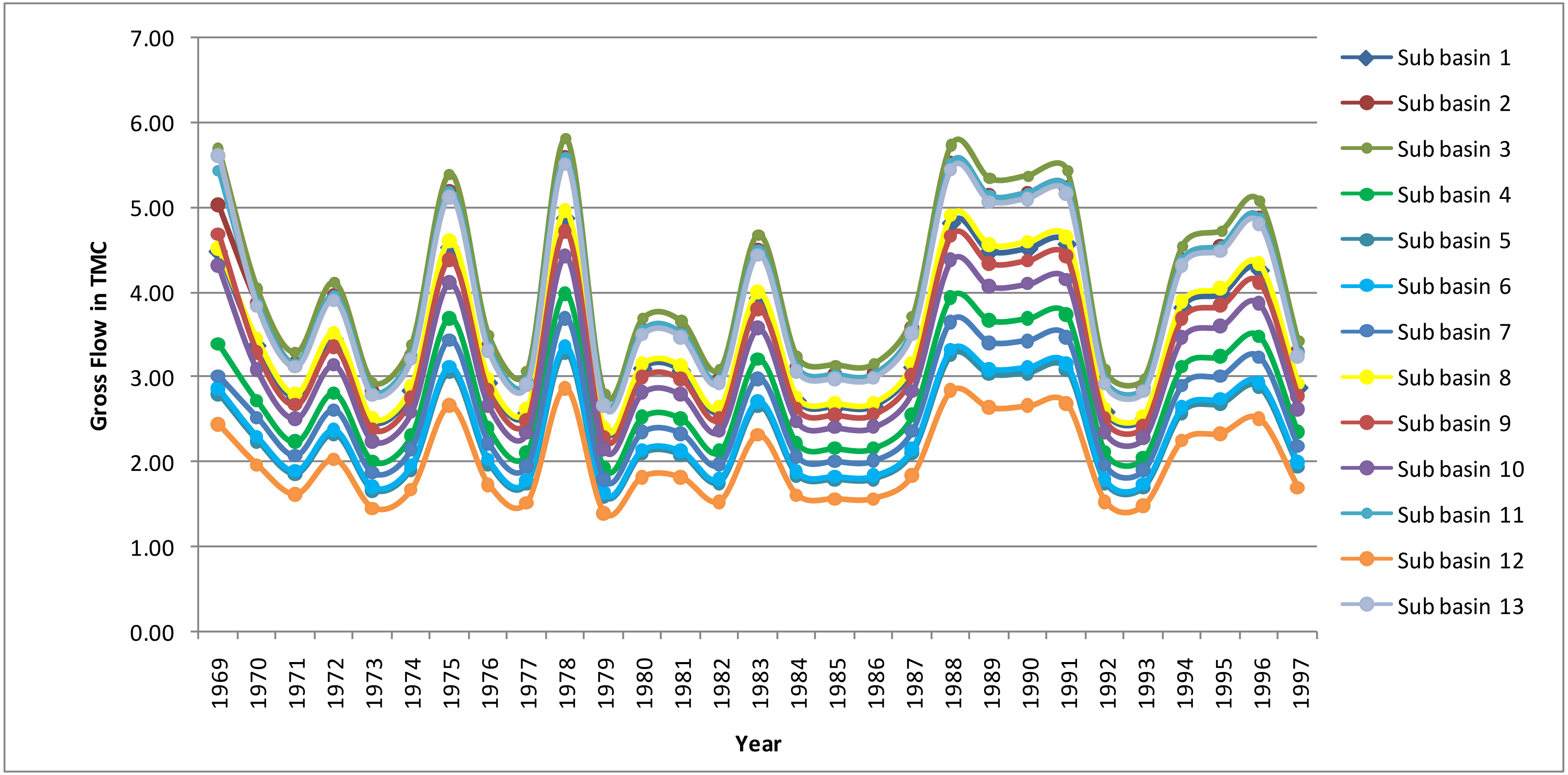

Figure 5.12: Year wise Sub basin runoff using HEC-HMS model for Vijayawada basin

Table 5-6: Annual Runoff for Solapur Sub Basin wise (in TMC)

S. NO	Date	Sub basin 1	Sub basin 2	Sub basin 3	Sub basin 4	Sub basin 5	Sub basin 6	Sub basin 7	Sub basin 8	Outlet
										Units in TMC
1	1971	1.10	0.95	0.91	1.82	0.67	1.75	2.32	1.18	11.02
2	1972	0.70	0.65	0.69	1.13	0.53	1.13	1.49	0.76	7.81
3	1973	2.11	2.00	2.17	3.39	1.69	3.41	4.51	2.31	23.20
4	1974	1.85	1.77	1.93	2.97	1.52	3.00	3.96	2.03	20.56
5	1975	2.24	2.14	2.35	3.60	1.85	3.63	4.80	2.46	23.70
6	1976	1.24	1.18	1.30	1.99	1.02	2.01	2.65	1.36	13.42
7	1977	1.66	1.59	1.74	2.67	1.37	2.69	3.55	1.82	18.00
8	1978	2.39	2.28	2.51	3.83	1.98	3.87	5.11	2.62	25.21
9	1979	2.20	2.10	2.31	3.52	1.82	3.56	4.70	2.41	24.79
10	1980	2.01	1.93	2.12	3.23	1.67	3.26	4.31	2.21	22.23
11	1981	1.78	1.70	1.87	2.86	1.48	2.88	3.81	1.95	18.96
12	1982	1.82	1.74	1.91	2.91	1.51	2.94	3.89	1.99	19.27
13	1983	2.39	2.29	2.52	3.84	1.98	3.87	5.11	2.62	25.49
14	1984	1.17	1.12	1.23	1.88	0.97	1.89	2.50	1.28	12.46
15	1985	1.31	1.25	1.38	2.11	1.09	2.12	2.81	1.44	14.01
16	1986	1.56	1.49	1.64	2.51	1.29	2.53	3.34	1.71	16.67
17	1987	1.85	1.78	1.95	2.98	1.54	3.00	3.97	2.04	20.49
18	1988	2.65	2.53	2.79	4.25	2.20	4.29	5.67	2.91	28.96
19	1989	1.76	1.69	1.85	2.83	1.46	2.86	3.77	1.94	20.17
20	1990	2.79	2.67	2.94	4.49	2.32	4.53	5.98	3.07	30.02
21	1991	1.55	1.48	1.63	2.48	1.28	2.51	3.31	1.70	16.61
22	1992	1.33	1.27	1.40	2.14	1.10	2.16	2.85	1.46	14.00
23	1993	2.65	2.54	2.79	4.26	2.20	4.29	5.67	2.91	28.22
24	1994	1.39	1.33	1.46	2.23	1.15	2.25	2.97	1.52	14.83
25	1995	1.54	1.47	1.63	2.48	1.28	2.50	3.30	1.69	16.56
26	1996	2.31	2.21	2.43	3.70	1.92	3.74	4.94	2.54	24.72
27	1997	1.53	1.47	1.62	2.46	1.27	2.49	3.28	1.68	17.15
28	1998	3.26	3.12	3.43	5.24	2.71	5.28	6.98	3.58	34.49

S. NO	Date	Sub basin 1	Sub basin 2	Sub basin 3	Sub basin 4	Sub basin 5	Sub basin 6	Sub basin 7	Sub basin 8	Outlet
										Units in TMC
29	1999	2.16	2.07	2.28	3.47	1.80	3.51	4.63	2.38	23.00
30	2000	1.94	1.86	2.04	3.11	1.61	3.14	4.15	2.13	20.72
31	2001	1.64	1.57	1.73	2.63	1.36	2.66	3.51	1.80	17.42
32	2002	1.50	1.44	1.58	2.41	1.25	2.43	3.21	1.65	16.08
33	2003	1.13	1.08	1.19	1.81	0.93	1.83	2.41	1.24	11.85
34	2004	2.02	1.93	2.13	3.24	1.67	3.27	4.32	2.22	21.89
35	2005	2.04	1.95	2.15	3.27	1.69	3.30	4.36	2.24	22.03
									Total	**696.00**
									Average	**19.89**
									Standard Deviation	**5.87**

The result shows that on an annual basic, there is an average runoff of 19.89 TMC of water with a standard deviation of 5.87. Table 5.6 shows runoff generated from Solapur station, sub-basin wise.

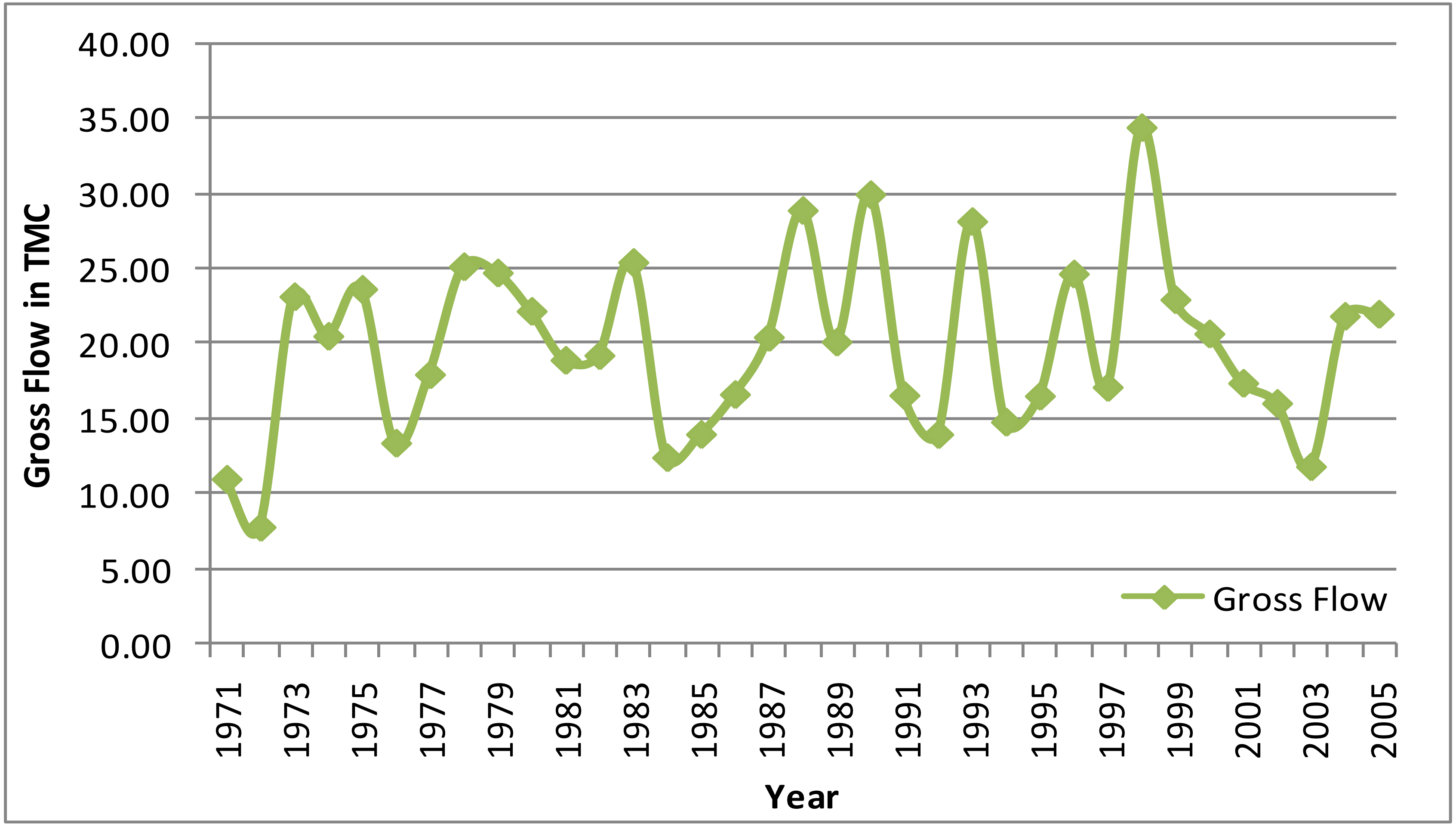

Figure 5.13: Year wise runoff using HEC-HMS model for Solapur basin

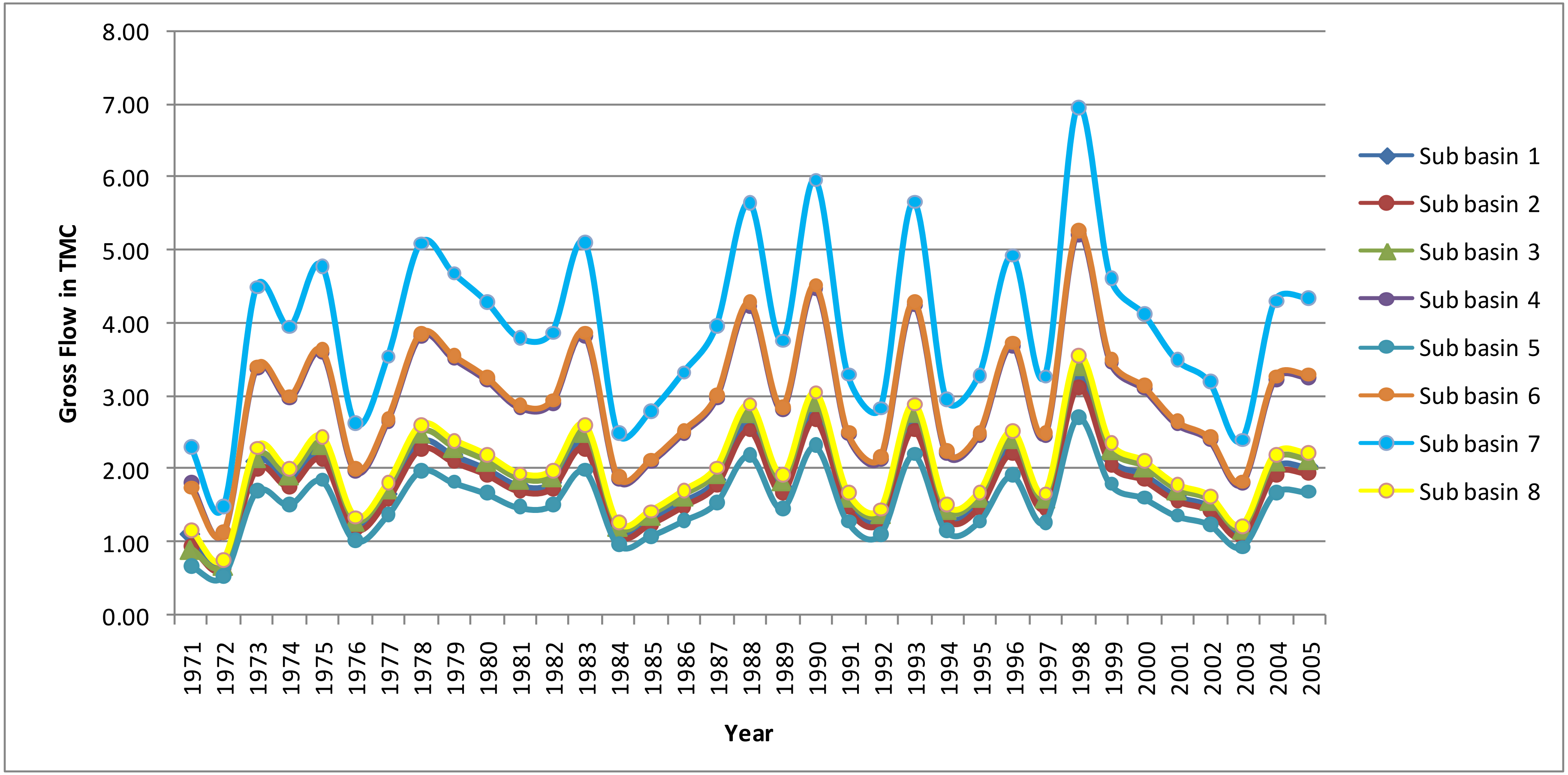

Figure 5.14: Annual Runoff Variation in each Sub basin for Solapur

6 Urban Heat Island

An urban area is said to be an urban heat island (UHI) if it is found significantly warmer than its surrounding rural areas. The aim of the present study was to determine the temperature of the Vijayawada and Solapur cities and their surroundings and the existence of urban heat island. The urban heat island effect is linked to the characteristic land use within a city/urban area as such land surface temperature, as defined by Barun refers to the temperature measured in the air close (1 m) to the earth surface in an open area rather at a higher level at which weather stations record temperature. If a city has a good network of weather stations for every land use type, UHI can be directly measured. However, for any city it is not possible. Therefore, it is determined by processing thermal remote sensing imagery for the city in GIS. It is called the urban heat island. That is, the relative warmth of air temperature near the ground (canopy layer)

The study employed to generate the Land Surface Temperature (LST) maps from Landsat satellites thermal infrared with 100 m and 120 m Spatial resolution. Higher LST is seen in areas with less vegetated LULC and vice versa. LST and Normalized Difference Vegetation Index (NDVI) have widely been accepted as reliable indicators of UHI and vegetation abundance respectively.

Quality of urban life and energy cost are mainly affected by Urban Heat Island. With each degree temperature, the power used for air conditioning is enhanced. The level of atmospheric temperature elevates due to the subsequent increased use of electricity for cooling. The earth's rising temperature is hot issues today in the world. Since the industrial revolution, the temperature of the planet has been increased.

The very low value of NDVI (0.1 and below) correspond to the barren area of rock, sand or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while big values indicate temperate and tropical rainforests. From the LST images, it is clearly understood that surface temperature is more in an urban area compared to rural areas.

6.1 Study Area

Vijayawada is a historical city situated at the geographical center of Andhra Pradesh state in India on the banks of Krishna River with latitude 16°31' N and longitude 80°39' E. The climate is tropical, with hot summers and moderate winters. The peak temperature reaches 56°C in May-June, while the winter temperature is 20-27°C. The average humidity is 78%, and the average annual rainfall is 103 cm. Vijayawada gets its rainfall from both the southwest monsoon and north-east monsoon. The topography of Vijayawada is flat, with a few small to medium sized hills. It is also a major railway junction connecting all states in the country. The Vijayawada now has become the capital of the new state called Andhra Pradesh. The population growth has been rapidly registering almost three-fold increase in 3 decades ending 2001 with a population account of 8.45lakhs The overall gross density as of 2001 was 13600 per sq km. Vijayawada has a lot of scope for development and urban growth. The city's population is expected to increase to 16.5 lakh by 2021. With ever-increasing population and unprecedented growth of urban area, the city's landscape is undergoing unwanted changes.

Solapur district is an administrative district in the State of Maharashtra in India. The district headquarter are located at Solapur is bounded by 17° 10'N latitudes and 76° 15'E longitudes. The total geographical area of Solapur district is 14,895 sq. Km. it is divided into 11 tahsils and a total population of 38,55,383 as per 2001 census. The climate of Solapur district is dry as daily mean maximum temperature range between 30°c to 37°c and a minimum temperature range between 18°c to 21°c with the highest temperature about 45°c in May. The study area is mention in Table 6.1.

Table 6-1: Area of the city

Name of the City	City Area(Sq.Km)
Vijayawada	1280.32
Solapur	672.18

6.2 Data available

Landsat satellite images are obtained from USGS earth explorer website. Landsat 8 (OLI/TIRS) image for WGS 84, Zone 43 Date: November 2018 is collected. It has sensors called Multispectral Scanner (MSS) and Thematic Mapper (TM). It has sensors called Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The details of the Landsat satellite images selected for the present work are given in Table 6.2 below. The image quality is better, clear and no cloud. Arc Map 10.2 was used to carry out image processing and GIS procedures. Landsat calibration equations were obtained and corrected from Landsat 8.

Table 6-2: Details about Satellite data

Name of the City	Resolution	No of Band	Band used	Landsat
Vijayawada	30m	11	Band 4,5,10	Landsat 8
Solapur	30m	11	Band 4,5,10	Landsat 8

Table 6-3: Application of satellite Band data

Band	Application
Band 4	NDVI
Band 5	NDVI
Band 10	Brightness Temperature

Table 6-4: Range of NDVI value in Study area

Study Area	NDVI Min	NDVI Max
Vijayawada	-1	0
Solapur	-1	0

NDVI value range from -1 to 1 in our study also the range of NDVI values are mention in table 6.4. Very low value of NDVI (0.1 and below) correspond to the barren area of rock, sand or snow. Moderate values represent shrub and grassland(0.2 to 0.3), while high values indicate temperate and tropical rainforests. From the LST images, it is clearly understood that surface temperature is more in an urban area compared to rural areas. The NDVI images retrieved using the above formula (1). Using the NDVI formula the NDVI map of two cities shown in fig 6.1and fig 6.2

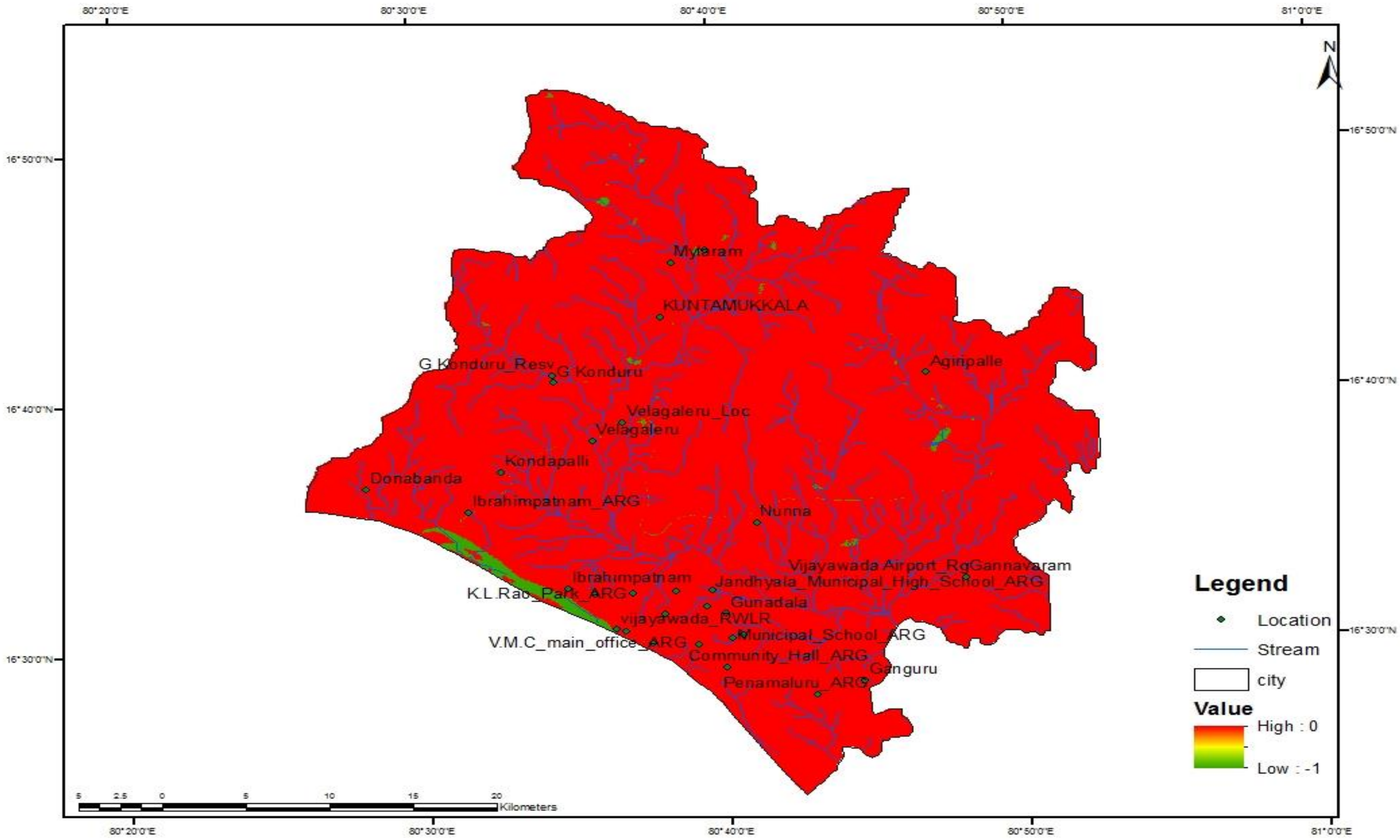

Figure 6.1: NDVI map in Vijayawada City

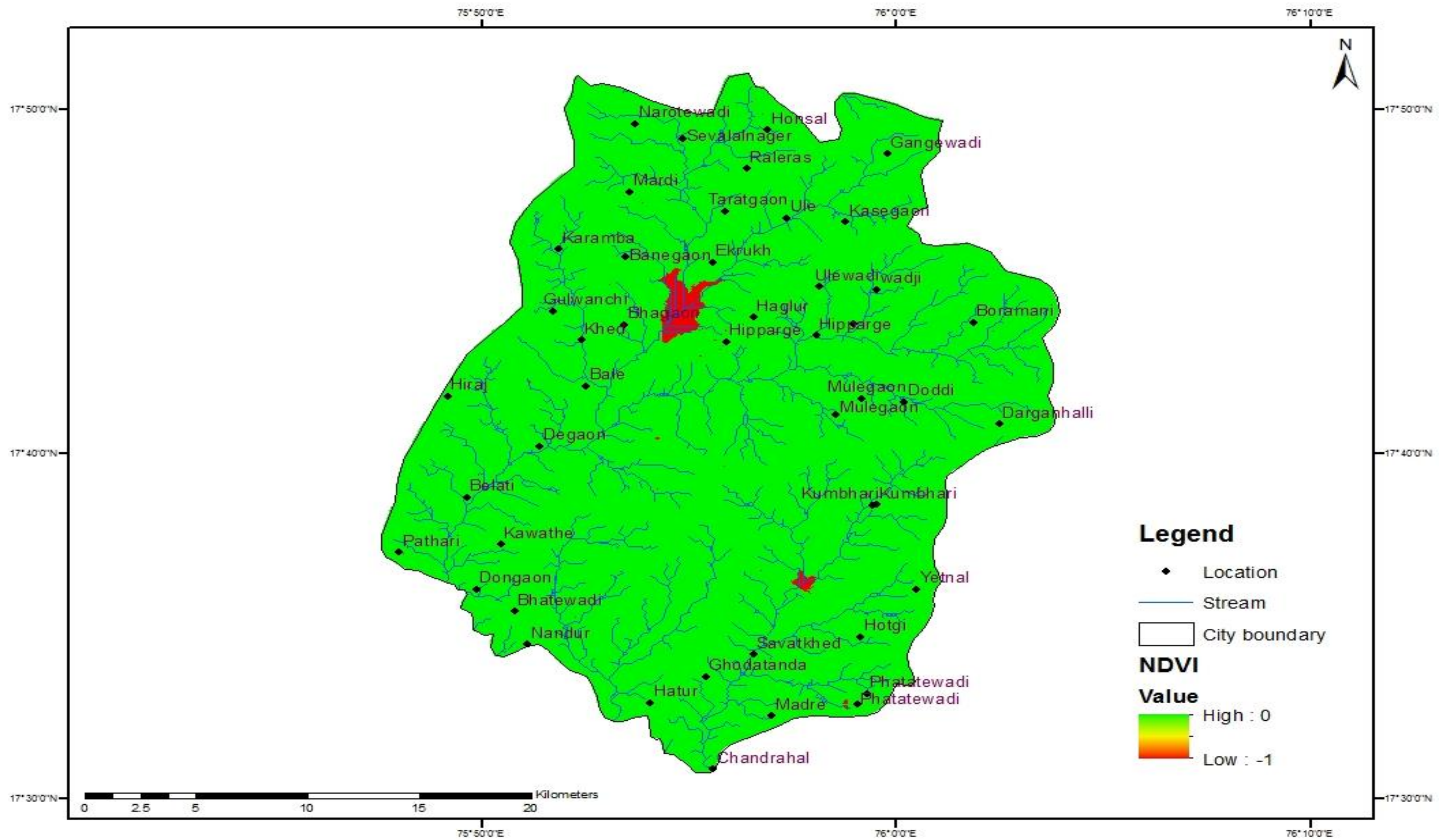

Figure 6.2: NDVI map in Solapur City

6.3 Estimation of at sensor brightness temperature Ti

Classify urban brightness temperature into low-temperature area, secondary low-temperature area, medium temperature, secondary high-temperature area, and high-temperature area. The basic principle of using Mean-Standard Deviation Method for temperature classification is shown in Table 6.5, is the average temperature, std represents the standard deviation of TB and Ts represents TB value of image pixel. Classify TB chart in the research region based on map algebra of GIS and according to Table 6.6. Using the temperature classification the range of TB for study area as shown in fig 6.3 and fig 6.4.

Table 6-5: Heat island temperature classification using mean-standard deviation method

Temperature Classification	Interval of Temperature Classification
High-temperature area	Ts>μ+std
Secondary high-temperature area	μ+0.5std<Ts≤ μ+std
Medium temperature area	μ-0.5std≤Ts≤ μ+0.5std
Secondary low temperature area	μ-std≤Ts< μ-0.5std
Low-temperature area	Ts< μ-std

Table 6-6: Area-proportion statistics of different TB grade in the study area

Temperature Classification	Vijayawada		Solapur	
	Area(Km^2)	Proportion (%)	Area(Km^2)	Proportion (%)
High temperature area	139.87	10.92	263.28	39.17
Secondary high temperature area	357.78	27.94	219.54	32.66
Medium temperature area	385.84	30.14	118.16	17.58
Secondary low temperature area	371.32	29.00	63.88	9.50
Low temperature area	25.51	1.99	7.32	1.09
Total	**1280.32**	**100**	**672.18**	**100**

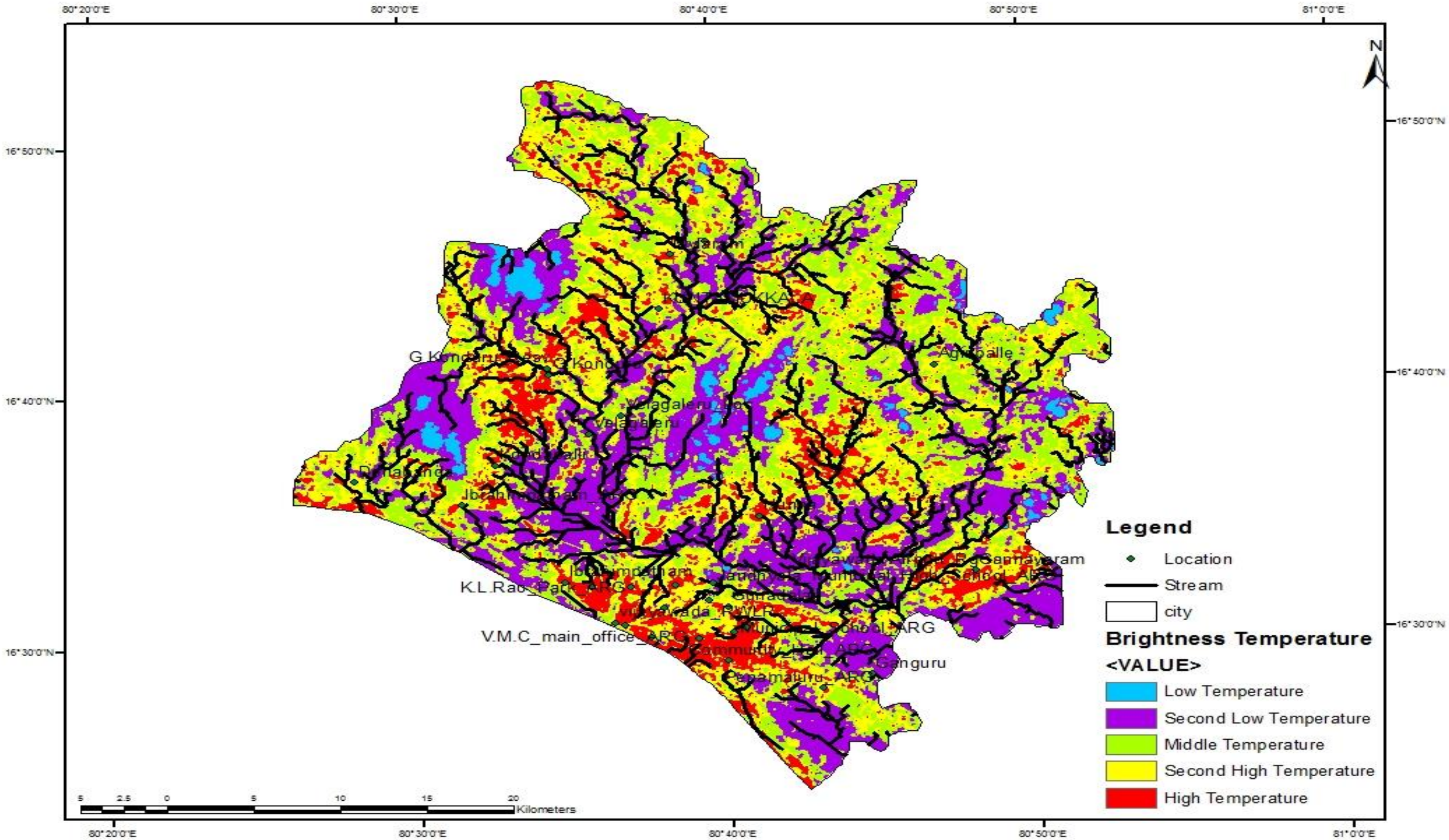

Figure 6.3: Brightness Temperature Map Vijayawada city

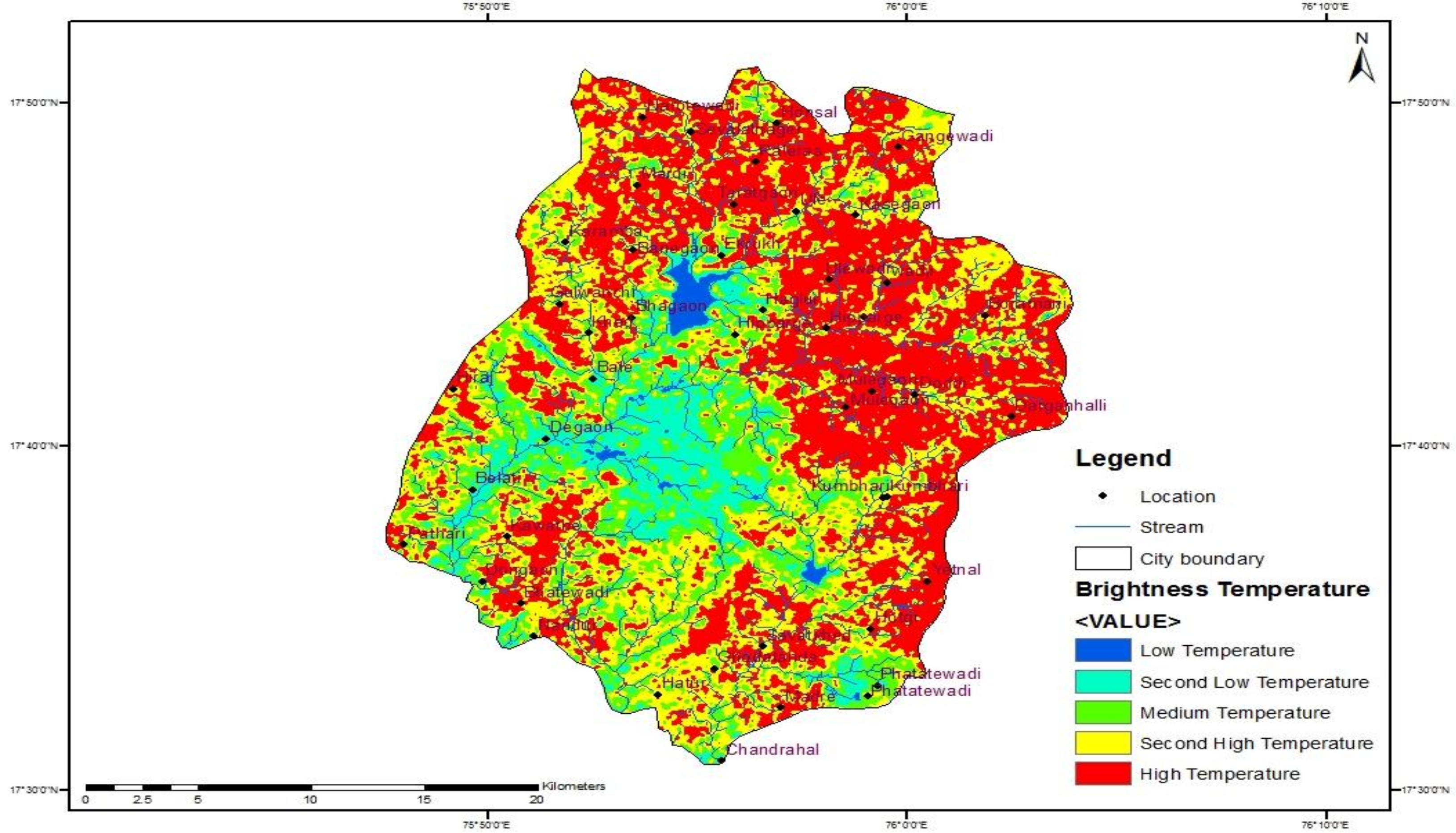

Figure 6.4: Brightness Temperature Map Solapur city

6.4 Retrieving land surface temperature (T_S)

Satellite thermal infrared sensors measure Top of the Atmosphere (TOA) radiances, from which brightness temperature (known as blackbody temperatures) can be derived based on Plank's law. The TOA radiances are the result of mixing three parts of energy. The first is the emitted radiance from the earth's surface, the second is the upwelling radiance from the atmosphere, and the third is the downwelling radiance from the sky. The difference between TOA and land surface brightness temperature is subject to the influence of atmospheric conditions. Therefore, to obtain an actual land surface brightness temperature, atmospheric effects, including upward absorption emission and downward irradiance reflected from the surface, should be corrected first. This correction was conducted by calculating spectral emissivity (e), (Weng and Larson, 2005; Al Kuwari et al., 2016; Van and Bao, 2010). LSTs were obtained by recovering satellite temperature Ti by applying the correction for emissivity.

Emissivity as a function of wavelength is controlled by several environmental factors such as surface water content, chemical composition, structure, and roughness. For vegetated areas, emissivity varies significantly with plant species, areal densities, and growth rates. Land surface emissivity is closely related to. Therefore, the emissivity can be estimated from NDVI used Table 6.7 (Liu and Zhang, 2011). NDVI values and its corresponding values of Land-surface spectral emissivity as shown in table 6.8. The emissivity-corrected land surface temperature was obtained using the following equation 4.

$$T_s = \frac{T_i}{1+\left(\lambda * \frac{T_i}{\rho}\right) * \ln\varepsilon} \text{-------------------(4)}$$

where Ts represents land surface temperature, Ti indicates sensor brightness temperature in Kelvin, λ is the wavelength of the emitted radiance (for peak response and average limiting wavelengths), e represents land surface spectral emissivity, ρ is the Plank's constant = $1.438*10^{-2}$ mk.

Table 6-7: NDVI values and its corresponding values of Land-surface spectral emissivity

NDVI	Land surface Emissivity(e)
NDVI<-0.185	0.995
-0.185≤NDVI<0.157	0.970
0.157≤NDVI≤0.727	1.0094+0.047ln(NDVI)
NDVI>0.727	0.990

Table 6-8: Land surface spectral emissivity range.

Study Area	Land surface Emissivity(e) Min	Land surface Emissivity(e) Max
Vijayawada	0.9860	0.9900
Solapur	0.9860	0.9900

6.5 LST normalizing and obtaining urban heat island (UHI)

Finally, the effect of UHI, at district level taking into consideration socio-economic parameter, was quantitatively described using urban thermal field variance index (UTFVI). UTFVI could be calculated using the following equation (Liu and Zhang, 2011; Zhang, 2006):

$$UTFVI = \frac{T_s - T_m}{T_s}$$

Where,

Ts is the land surface temperature,

Tm is the mean of the land surface temperature of the study area

UTFVI was divided into six levels by six different ecological evaluation indices (Liu and Zhang, 2011; Zhang, 2006). Thresholds in the six UTFVI levels are shown in Table 6.9. And the Threshold values of urban thermal field variance index various range in the study area as shown in Table 6.10, The second level of LST normalization is the ecological evaluation of UHI by calculation of UTFVI at a different level as shown in Fig 6.5 and Fig 6.6displays the resulted of UHFVI range.

Table 6-9: Threshold values of urban thermal field variance index

Urban Heat Island Phenomena	Urban thermal field variance index
Very Weak	<0
Weak	0 – 0.005
Medium	0.005 – 0.01
Strong	0.01 -0.015
Stronger	0.015 – 0.2
Strongest	>0.2

Table 6-10: Threshold values of urban thermal field variance index for the Study area

Urban Heat Island Phenomena	Vijayawada		Solapur	
	Area(Km^2)	Proportion (%)	Area(Km^2)	Proportion (%)
Very Weak	646.63	50.51	249.28	37.09
Weak	39.2	3.06	27.00	4.02
Medium	37.56	2.93	20.87	3.10
Strong	37.99	2.97	29.91	4.45

Urban Heat Island Phenomena	**Vijayawada**		**Solapur**	
	Area(Km^2)	**Proportion (%)**	**Area(Km^2)**	**Proportion (%)**
Stronger	37.74	2.95	32.93	4.90
Strongest	481.2	37.58	312.18	46.44
Total	1280.32	100	672.18	100

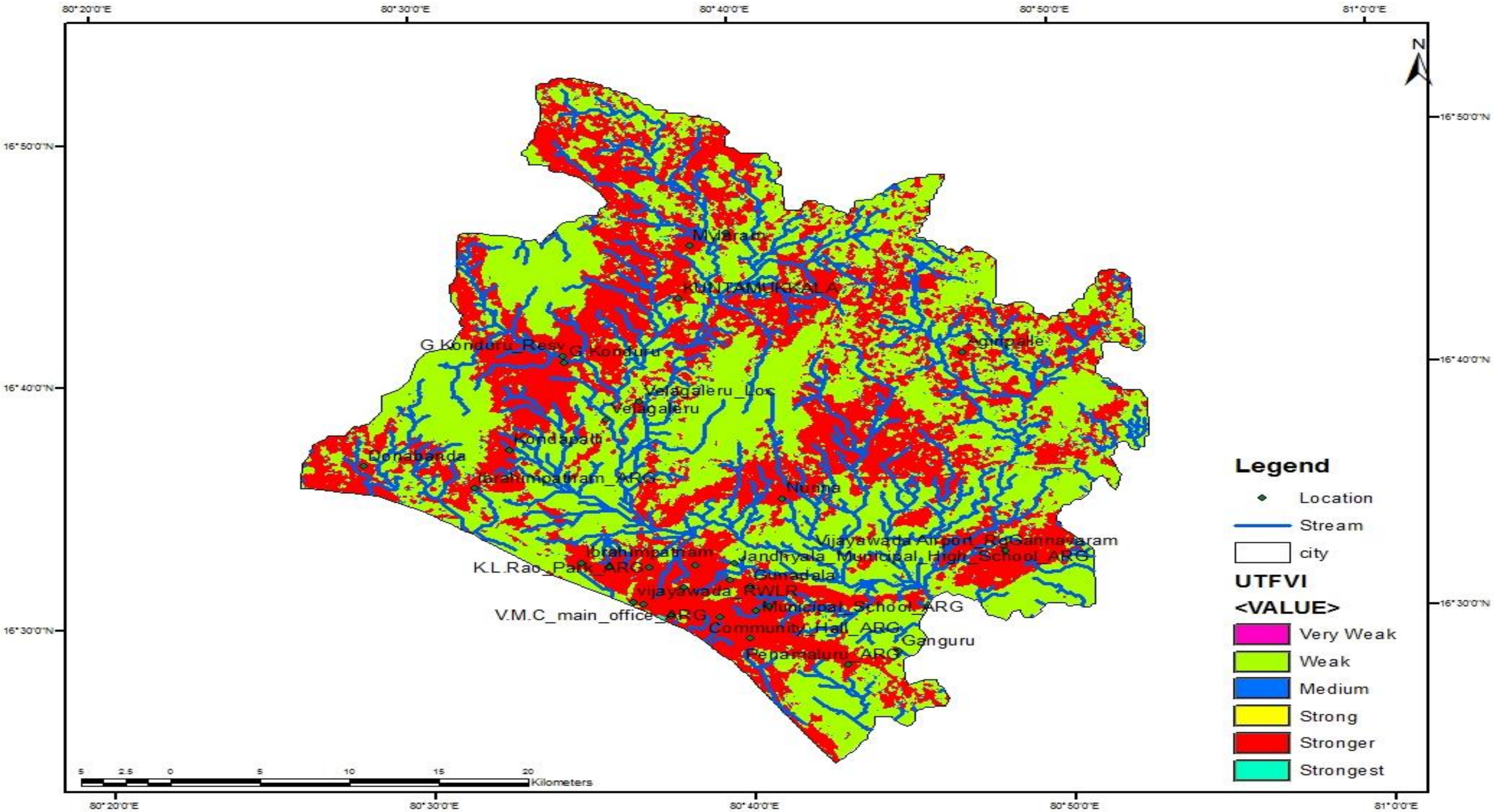

Figure 6.5: Urban Heat Island Index map for Vijayawada city

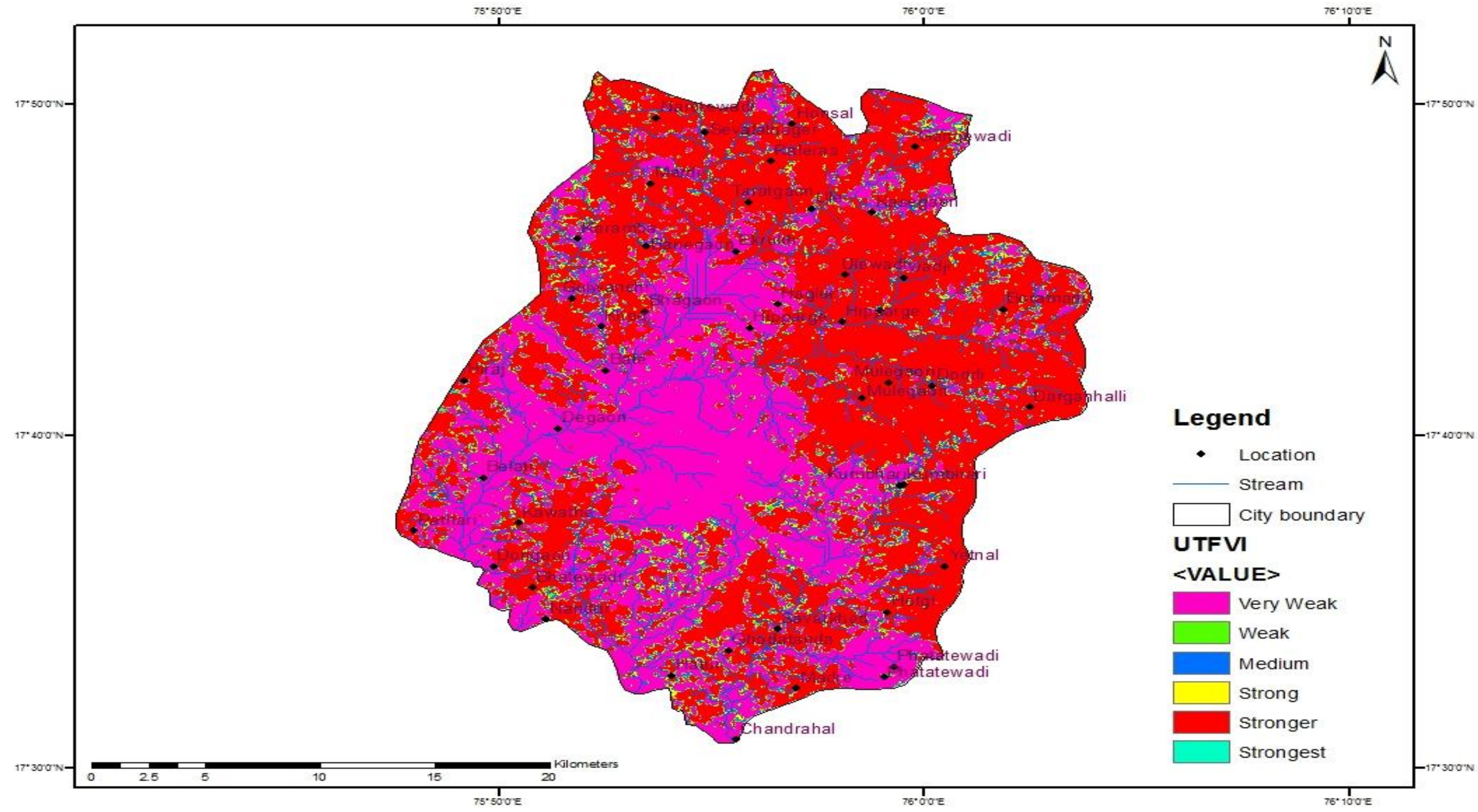

Figure 6.6: Urban Heat Island Index map for Solapur city

7 RESULT AND DISCUSSION

7.1 General

Assessment of climate change and its impact on the hydrology were made in the present work. Two cities, namely, Vijayawada and Solapur were taken as case studies. While Vijayawada is a city in the coastal plain of India which is under the threat of a rise in sea level due to climate change, on the other hand, Solapur, a city in Maharashtra, struggling with frequent droughts. Based on the Climate change forecast and hydrological modeling, suitable sustainable management plan are made.

Minimum temperature, maximum temperature, and rainfall were considered in the present study. Trends of these variables were analyzed using a linear fit. The null hypothesis was tested from the Student t-test. Climate change projection was also made for three variables rainfall, maximum temperature, and minimum temperature. To counter the uncertainty involved in any climate model, an average of seven GCM is considered. These seven GCM models are BCC CSM 1.1 M, BCC CSM 1.1, FIO ESM, MIROC ESM CHEM, NCAR CESM 1 (CAM5), NCC NOR ESM1 –M and NIMR KMO KadGEM2 A0. For downscaling the GCM variable, change factor method was used. The rainfall was projected using the multiplicative change factor, and for temperature, the additive change factor has been used.

Watershed area of the two cities was delineated using ArcGIS 10.1. Hydrological modeling was performed based on catchment using HEC HMS, which uses SCS-CN Method to calculate runoff generation from a catchment.

Based on the change in the earth surface temperature, a heat map was also developed for both the cities. The general conclusion from the study are as follows:

i. For rainfall and temperature, the trend is statistically are significant for both the cities. The annual average rainfall and the maximum temperature are increasing while the mean monthly minimum temperature is falling for Solapur. However, mean annual rainfall for Vijayawada is increasing.
ii. From the detailed RCPs analysis under different condition, it is well established that the temperature for both cities is likely to increase. There will be an increase of 0.9 - 1.2^{0}C in the first 30 years and then by about 1.5 to 3^{0}C depending upon the course of pathways it takes.
iii. It is found that there is most likely to be a shift in the rainfall pattern in the cities. On average, non-monsoon rainfall will increase by 10-15 % while the monsoon rainfall will decrease by 10% which finally results in more frequent floods and droughts with a higher magnitude. Moderate to severe droughts will be more frequent for both the cities.
iv. For Solapur, on an annual basis about 67% of rainfall goes as runoff from the basin and for Vijayawada, it is 72% of total rainfall.
v. As for most of the cases, the rise in temperature is significantly increase for almost all region under all RCPs scenarios; urban heat island is also bound to increase.

The specific conclusions for Vijayawada and Solapur are discussed below under the sections, 7.2 climate change projection, 7.3 Hydrological Modelling, and 7.4 urban head Island map, respectively.

7.2 Climate Change Assessment

Solapur

The annual average rainfall for Solapur city is 800 mm. It receives most of the rainfall during the monsoon period, i.e. from June to October. The maximum temperature 41^{0}C during summer while in rest of the time it is around 30-35^{0}C. Annual rainfall and monthly maximum temperature show an increasing trend while the monthly minimum temperature is showing a slightly negative trend. Statistically, all the trends are significant. The rainfall is decreasing at a rate of about 0.02 mm/year and monthly maximum temperature at a rate of -0.001^{0}C/year. The minimum temperature is decreasing at a rate of 0.0006^{0}C/year.

In RCP 2.6, the projection of all the seven GCM models shows on an average a mixed output in annual rainfall. The mean annual rainfall is expected to be stable at 760 mm, 40 mm less than the historic mean. It also indicates a decrease in some moderate to severe drought events. The magnitude of extreme flood will be very as high as 1600 mm compared to 1400mm in its history. The annual maximum and minimum temperature is expected to a rise by about 1^{0}C.

As per RCP 4.5, the average rainfall is going to be around 760 mm. This scenario also indicates frequent moderate to severe droughts in the future. On average, about 25 to 30 drought episodes are expected to occur in the next 60 years. The maximum temperature will rise by 1^{0}C in the first 30 years and then by 1.5^{0}C – 1.6^{0}C. The monthly minimum temperature is also a more or less the same trend.

RCP 6.0 projection also shows a decreasing trend in rainfall pattern but comparatively less than the previous two scenarios. An overall number of flood events are going to increase without much change in the magnitude. The number of drought events will also increase. The overall temperature will rise by 0.8^{0}C – 1^{0}C in the first 30 years and then by 1.5^{0}C.

The projection of the RCP 8.5 scenario also shows a decline in annual average rainfall by about 50mm. Here also the number of drought events will increase. Flood peak may go as high as 1500 mm, 100 mm higher compared to the historical record. Overall the maximum temperature will rise by 1^{0}C – 1.2^{0}C in the first 30 years and then by 2^{0}C – 2.3^{0}C.

Vijayawada

The annual average rainfall for Vijayawada city is around 900 mm. The monthly rainfall variation shows a high variation of rainfall from June to September. An increasing trend was observed for annual rainfall (+0.02 mm/month. It has witnessed a few moderate droughts and a few flood events in the past.

RCP 2.6 scenario show some peak rainfalls of 1650 mm and a few dry years with annual rainfall less than 550 mm but an overall decline in annual rainfall. Results show that the rainfall during the non-monsoon season will increase by about 10%. The mean temperature will rise by 1^0C.

RCP 4.5 also shows a decline in annual average rainfall by about 40 mm. The city has a high risk of moderate to severe droughts. The maximum temperature may increase by 1^0C in the first 29 years and later stabilizes at 1.5^0C.

As per RCP 6.0 scenario, the mean annual rainfall may rise to 850 mm in the next 58 with 3 to 4 very high peaks of about 1680 mm in the annual rainfall and several severe droughts. The average increase in monthly temperature is around 1^0C in the first 28 years which increases to 1.5-1.8^0C in next 29 years.

The projection of RCP 8.5 shows a decline in annual average rainfall by 70 mm. It also indicates almost 20-25 number of moderate to severe droughts and extreme floods during some years. Results show the temperature to rise by 1.2^0C in the first 29 years and may go to 2.5^0C in the later years.

7.3 Hydrological Modelling

The study area is delineated based on land use and land cover. Solapur city has a total area of 672.18 km^2, in that 43% is agricultural, Residential is 54% and the remaining 3% belongs to another category. Vijayawada has a total area of 1280.32 km^2 out of which about 23 % is agricultural, 73% Residential and 4% comes under other categories. Comparison of these two study area build up area is higher in Vijayawada city and Solapur is having less area. Solapur has mostly loamy soil while Vijayawada has clayey loam.

HEC-HMS model is used for simulation of runoff for the Vijayawada basin for Krishna watershed, which uses SCS-CN Method to calculate runoff generation from a catchment. The mean annual runoff for Vijayawada city is found to be 1243.95 TMC with a standard deviation of 10.08 TMC, against an annual average rainfall of 42.89 TMC. Thus on an annual basic about 72% of rainfall is converted to runoff from the basin.

For Solapur city, the simulation of runoff for Krishna watershed, which uses SCS-CN Method to calculate runoff generation from a catchment. The mean annual runoff for Solapur city is found to be 696 TMC with a standard deviation of 5.87 TMC, against an annual average rainfall of 19.89 TMC. Thus, the results show that on an annual basic about 67% of rainfall goes as runoff from the basin.

Based on an analysis of 29 years of rainfall data in Vijayawada basin, it is found that sub basin-3 contribute maximum runoff compare to another sub basin while sub-basin 12 contributes the least. A similar trend is observed for runoff depth. The runoff is maximum during the monsoon season, i.e. between July-August months, while it is least during the summer season of a year.

Based on an analysis of 35 years of rainfall data in Solapur basin, it is found that sub basin-7 contribute maximum runoff compare to another sub basin while sub-basin 5 contributes the least. A similar trend is observed for runoff depth. The runoff is maximum during the monsoon season, i.e. between July-August months, while it is least during the summer season of a year.

7.4 Urban Heat Island Map

Solapur has 72% of residential land while 12% are water body and 16% with vegetation. Based on the present temperature variation, 38% of the area shows a strong heat island effect. Though the effect is very weak in about 51 % of the area.

Vijayawada has 61% of residential land, 29% water body and 10% with vegetation. Presently, 46% of land has very strong heat island effect and almost 37 % of the land with very weak heat island effect.