Government of India
Ministry of Jal Shakti
Department of Water Resources,
River Development & Ganga Rejuvenation

ASSESSMENT OF WATER RESOURCES OF INDIA

Central Water Commission
August, 2024

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MESSAGE

Water resources are vital for human survival, economic development, and environmental sustainability particularly for a tropical country like India.

Assessment of Water Resources is a critical component of managing India's water resources effectively. However, country's diverse geology, climate, and hydrology add to the complexity of Water Resources Assessment. Furthermore, the dynamic nature of water resources requires continuous updating of assessment methodologies to keep pace with technological advancements, data availability, and planning requirements.

Central Water Commission has assessed the country's water resources from time to time with last such assessment made during the year 2019. This year, CWC has made Assessment of India's Water Resources with available dataset of 38 years based on the advanced Remote sensing technology. The assessment has covered all Basins in the country and has given detailed estimation of Basin wise Precipitation, Water availability, and Evapo-transpiration.

I am certain that the present Assessment of India's Water Resources will be a very useful reference document towards optimal planning of water resources, besides playing a vital role in assessing the impact of climate change, population growth, and urbanization on India's water resources. I wholeheartedly congratulate the Officers from CWC who were involved in the present assessment for carrying out this valuable study.

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FOREWORD

The optimal development and management of country's water resources has been inhibited by several factors like uneven rainfall pattern, rapid population growth, and changes in the land use pattern including urbanization. The emerging challenge of Climate Change has further accentuated the problem.

Detailed assessment of Water resources of the country is one of the prerequisites towards development and management of water resources effectively amidst such challenges. Central Water Commission (CWC) has come out with the present publication "Assessment of Water Resources" which is the result of the intense efforts put in by various officers of CWC. The document has been prepared after extensive discussions and consultations with a Multi-Disciplinary Consultative Coimmittee; drawing experts from various organizations e.g. IMD, NRSC, CGWB, NIH etc.

In the present publication, the latest assessment of Country's water resources has been made based on the up-to-date datasets and remote sensing applications with an in-house developed modelling tool. Further, the basin-wise estimation of Water Availability, Precipitation, Evapo-transpiration, etc. have been thoroughly discussed which are crucial for region-wise water resources management.

This publication will definitely serve as a guiding document for facilitating better decision-making, improved water governance, and enhanced water security in India. I acknowledge and congratulate CWC for accomplishing this splendid task offering valuable insights into availability of water resources across the country.

(Debashree Mukherjee)

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OVERVIEW OF THE STUDY

Kushvinder Vohra

Chairman,
Central Water Commission

Water is recognized as critical for economic growth, well- being of people, and sustainability of ecosystems. However, in addition to vagaries of nature, water resources are also susceptible to Land Use changes including urbanization, river channelization, anthropogenic activities, and climate change, which influence the storage capacity of catchments and impact high flows as well as groundwater recharge and low flows. An in-depth assessment of water resources is, therefore, imperative to understand status, challenges, and opportunities for sustainable management of Water Resources in the country.

Time to time different agencies, and researchers have estimated water resources of the country using different approaches. First Irrigation Commission (1901-03), Dr.AN Khosla (1949), Central Water and Power Commission (1954-66), study done by Dr. K L Rao, National Commission on Agriculture (1976), Central Water Commission (1988) and Reassessment of Average Annual Water Resources Potential (1993) are some of the studies conducted. Reassessment of Water Availability of River Basins in India using Space Inputs with technical support of NRSC was the last study done by CWC in June 2019.

Considering the importance of up-to-date estimation, assessment of basin-wise water availability in the country has been undertaken by Central Water Commission for the period 1985-86 to 2022-23 (38 years) using open source Remote Sensing products which offer valuable insights and capabilities for assessing water potential in India, providing broad basin-wise information about water resources.

With this in mind, an in-house Water Resources Assessment Tool (WRAT) was developed in CWC using Python Script, a versatile programming language for hydrological model development, offering numerous advantages in terms of flexibility, scalability, and extensibility. The in-house development of the software allows us the flexibility to suitably refine the model as per the requirements such as data format, frequency, spatial, resolution etc. This also would be quite a handy tool to update the assessment in future easily and expeditiously.

The tool estimates the basin annual net-runoff using precipitation, evapotranspiration (Actual Evapotranspiration, AET), land use and land cover (LULC) and soil datasets as major inputs. Daily precipitation data of 0.25^{o} X 0.25^{o} grids was used which was obtained from the India Meteorological Department (IMD) and converted into compatible format.

Simplified Surface Energy Balance Operational (SSEBop) ET product of USGS (1 Km x 1 Km) - an open source remotely sensed product- has been used in the study. Land Use and Land Cover map for the period from 2004-05 to 2022-23 prepared under Natural Resources Census (NRC) project of NRSC using IRS AWiFS satellite data (56 m x 56 m resolution) was used in the study. Command area boundaries for estimation of evapotranspiration from irrigation input, water body and reservoir maps from India- WRIS for estimating reservoir evaporation were also used. The results obtained were duly validated with ground hydrological data using standardized statistical tests.

This study is an assessment of country's basin-wise water availability considering the last 38 years (1985-2023). Since the SSEBoP ET product was only available from 2003 onwards, the same was used for study for 20 years (2003-04 to 2022-23). For the earlier period (1985-86 to 2002-03), the results of previous study (1985-2015) have been used with suitable incorporation of Trans-boundary water, wherever not taken in the previous study. The current study is an updation over previous study with the use of globally available Gridded ET product from USGS for actual Evapotranspiration estimation.

The average annual water resources of the country for the period 1985-2023 have been assessed as about **2116 BCM** in this study against an average annual precipitation of about **3729 BCM**. The top three basins with highest water availability across the country are Brahmaputra (592.32 BCM), Ganga (581.75 BCM), and Godavari (129.17 BCM) respectively. However due to high population density, Ganga basin is water stressed while Brahmaputra and Godavari are in relatively better situation. Similarly, the bottom three basins in the country in terms of water availability are Sabarmati (9.87 BCM), Pennar (10.42 BCM), and Mahi (13.03 BCM) which is primarily due to comparatively lesser catchment area and moderate rainfall. With higher population density these basins also face water stress quite often.

The study report "**Assessment of Water Resources of India**" is the culmination of the tireless efforts put in by Core team of officers and meticulous supervision by the Steering group of officers. I would like to extend my heartiest thanks to all the involved officers and sincerely acknowledge the immense contribution and support from various officers from Multi-disciplinary Consultative Committee, who have actively participated and provided guidance during the study.

(Kushvinder Vohra)
Chairman, Central Water Commission

ACKNOWLEDGEMENT

Navin Kumar

Member (WP&P), Central Water Commission

Central Water Commission has carried out the up-to-date Assessment of Water Resources of the country with latest available datasets based on the advanced remote sensing technology. The present report presents a comprehensive picture of various River Basins of the country in terms of Water Availability, Precipitation, Reservoir Evaporation, Reservoir Flux, Ground Water Flux etc. The details of different features of various basins in the country will provide many novel insights, making it valuable for decision makers, policy planners and other stakeholders who are engaged in the development and management of water resources of the country.

I would like to express my deepest gratitude to Sh. K. Vohra, Chairman, CWC for his invaluable guidance, expertise, and unwavering support throughout the course of this study. His insights and feedback have been instrumental in shaping the direction and outcome of this study.

I would also like to express my sincere appreciation to Shri Ashok Kharya, Chief Engineer (Basin Planning & Management Organisation) and Shri Rishi Srivastava, Chief Engineer (Environment Management Organization), for their thoughtful insights and continuous supervision for completion of this study.

I would specially like to compliment the entire core team of young officers for their dedicated efforts and collaborative spirit for conducting this comprehensive and informative study during past 18 months. Their hard work, commitment, and technical skills have significantly contributed to the progress and success of this study.

Special thanks to members of the Multidisciplinary Consultative Committee for their unwavering support, insightful contributions and guidance. Their expertise and feedback have greatly enriched the quality of this study.

I look forward to suggestions and feedback for improvement in content and quality of this report.

नवीन कुमार

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[Disclaimer: *This water resources assessment is purely for research and study purpose only, and cannot be used for any specific claims/counter claims.*]

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ABBREVIATIONS

AET	Actual Evapotranspiration
AwiFS	Advanced Wide Field Sensor
BCM	Billion Cubic Meter
BPMO	Basin Planning & Management Organisation
CGWB	Central Ground Water Board
CWC	Central Water Commission
CW&PC	Central Water & Power Commission
DIL	Domestic, Industrial, and Livestock
EMO	Environmental Management Organisation
E_R	Evaporation in Reservoirs
ET_{II}	Evapotranspiration from Irrigation Input
ET_{IRR}	ET from irrigated areas (Natural + Manmade)
E_{WB}	Evaporation from lakes / other natural water bodies (Natural)
ET_{Peff}	ET Resulting from Effective Precipitation
EFR	East Flowing Rivers
ET	Evapotranspiration (Actual)
ET_N	Natural Evapotranspiration Over Land Surfaces (Natural)
G&D	Gauge and Discharge
GDQ	Gauge, Discharge and Water Quality
GDSQ	Gauge, Discharge, Sediment and Water Quality
GIS	Geographic Information System
Ha	Hectare
I	Import
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing
Km	Kilometer
LPCD	Litres per Capita per Day
LULC	Land Use and Land Cover
MCM	Million Cubic Meter
NCIWRD	National Commission on Integrated Water Resources Development
NDDB	National Dairy Development Board
NRSC	National Remote Sensing Centre
P	Precipitation
P_{eff}	Effective Precipitation
PET	Potential Evapotranspiration
Q_M	Modelled Discharge
Q_{OBS}	Observed Discharge
R_M	Modelled Runoff
SM	Soil Moisture
ΔSM	Change in Soil Moisture
ΔS_{GW}	Change in Groundwater Storage
ΔS_R	Change in Reservoir Storage
T	Trans-boundary Water Entering India
USGS	United States Geological Survey

W	Available Water
WP&P	Water Planning & Projects
WFR	West Flowing Rivers
WRA	Water Resources Assessment
X	Export from the basin upstream of G&D site

CHAPTER 1: BACKGROUND AND REVIEW OF EARLIER STUDIES

1.1 Background

Water Resources Assessment is a prerequisite for sustainable development and management of water resources of any region. It provides a sound basis for proper planning, implementation and maintenance of Water Resources Schemes and Projects.

The Assessment of Water Resources is also necessitated for promotion of basin level integrated water resources management and for dealing with the emerging challenge of climate change. The same has been recognized by National Water Mission also which is one of the eight National Missions to meet the challenges of climate change as per National Action Plan on Climate Change (NAPCC).

1.2 Previous estimates

The water resources potential in the river basins of the country has been assessed from time to time by various agencies. These studies adopted - empirical formula, aggregation of observed basin terminal flow with upstream abstractions etc. Table 1.1 shows glimpses of earlier assessment studies.

Table 1.1: Earlier assessment studies

S. No.	Year	Authority/Method of estimation	Quantity (BCM)
1.	1901 - 03	First Irrigation Commission/using coefficients of runoff	1443.2
2.	1949	Khosla's empirical formula	1673
3.	1960	CW& PC/Statistical analysis of flow data wherever available and rainfall-runoff relationships wherever data were meager	1881
4.	1988	Central Water Commission/General water balance approach	1880
5.	1993	Central Water Commission	1869
6.	1999	National Commission for Integrated Water Resources Development (NCIWRD)	1953
7.	2019	Reassessment of Water Availability in India Using Space Inputs	1999.2

1.3 Reassessment of Water Availability in India Using Space Inputs (2019)

The last study on Assessment of Water Availability in India was conducted by CWC in 2019 using modified Thornthwaite Mather Equation along with geospatial products e.g. Precipitation grid, Temperature grid, LULC map, Soil map etc. and other available non-geospatial data using Water Resources Assessment Tool developed by NRSC. The previous study had some constraints wherein the modified Thornthwaite & Mather empirical equation was used for estimation of the potential ET based on just one parameter i.e. monthly average temperature only. The potential ET was then estimated using soil parameters, crop or vegetation type, Kc (crop coefficient), etc. This required tweaking various parameters for calibration purpose. The study estimated average annual water resources of India as 1999.20 BCM.

However, since then, various global gridded ET products have come up and are extensively being used globally to give actual ET directly over an area / pixel eliminating the need of simultaneous adjustment of various parameters for calibration purpose. Accordingly, in the present study, the ET product of USGS namely SSEBop has been used.

1.4 Objectives of the present study

The present study has following objectives:

i. Development of in-house model/tool, which can be used over time, with modifications as and when required.

ii. To assess the long-term average annual water resources availability in the river basins of India during the period from 1985-86 to 2022-23.

CHAPTER 2: INPUT DATA AND METHODOLOGY

2.1 Input Data

Input data describes a set of variables that form the basis of a modeling framework. These variables are utilized to conduct relevant studies and draw conclusions. Table 2.1 shows the summary of data source, type and resolution used in present study.

Table 2.1: Summary of data used in the study

Data; Source	Type	Resolution	Remarks
Basin Boundary; India-WRIS	Vector	Delineated by SRTM 90 m DEM	
Precipitation; Indian Meteorological Department (IMD) (available since 1901)	Raster	Daily, 0.25° X 0.25°	For estimation of Modelled Runoff (R_M)
SSEBop ET; United States Geological Survey (USGS), USA (available since 2003)	Raster	Monthly, 1Km X 1Km	For estimation of R_M and Reservoir Evaporation (E_R)
LULC; National Remote Sensing Centre (NRSC) (available since 2004-05)	Raster	Annual, 56 m X 56 m	For estimation of Evapotranspiration from Irrigation Input (ET_{II})
Soil Map; National Bureau of Soil Survey & Land Use Planning (NBSS & LUP)	Vector; Converted into Raster (56m x 56 m)		For estimation of Soil Moisture (SM)
Command Area; National Water Informatics Centre (NWIC)	Vector		For estimation of ET_{II}

Reservoir shape file; India-WRIS	Vector		For estimation of E_R
Ground Water Flux; Central Ground Water Board (CGWB)	Vector	District-wise	For estimation of Groundwater flux (ΔS_{GW})
Reservoir flux; CWC	Excel based	Yearly	Annual change in live storage of the reservoirs (ΔS_R)
Census data, 2011; Census Commission of India	Vector	District-wise	For estimation of Domestic, Industrial and livestock consumption (DIL)

Note: *To estimate Trans-boundary contribution for Nepal in Ganga basin and contribution from un-gauged rivers entering India from Bhutan, open-source satellite precipitation (GPM, Global Precipitation Measurement) has been used; available monthly at 0.1° X 0.1° (Source: https://gpm.nasa.gov/missions/GPM)*

2.2 Broad Methodology

2.2.1 Equations used:

Total ET = ET_N + ET_{II} + E_R……..(1)

ET is Total Evapotranspiration

ET_N is Natural Evapotranspiration over land surfaces (Natural) including ET from effective precipitation (P_{eff}) and ET from natural water bodies.

ET_{II} is ET from Irrigation Input (Manmade)

E_R is Evaporation in Reservoirs (Manmade)

Note:

a) P_{eff} is assumed as 70% of precipitation occurring over irrigated areas (as per FAO for India)

b) Components in Blue are part of Water Availability (as they are resulting from human intervention or manmade).

General Monthly Water Balance Equation

$P+T = ET+ R_M \pm \Delta SM$ ……(2)

P is Precipitation

ET is Total Evapotranspiration

T is Trans-boundary water entering India from upstream countries, if any

R_M is Modelled Runoff

ΔSM is Change in Soil Moisture

Here R_M = P+T-ET (ΔSM at annual scale is found to be negligible)

Water Availability Equation (WA)

$\mathbf{WA = R_M + ET_{II} + E_R - I}$……..(3)

I is Import from other basins

Other Equations

$\mathbf{Q_M = R_M – DIL \pm \Delta S_{GW} \pm \Delta S_R – X}$ ……(4)

Q_M is Modelled discharge

DIL is Consumptive use from Domestic, Industrial, Livestock usage

ΔS_{GW} is change in groundwater storage

ΔS_R is change in reservoir storage

X is the Export from the basin upstream of G&D site where Q_M is calculated

$Q_{M,}$ the modelled discharge is calculated to perform T-test vis-à-vis the observed discharge (Q_{OBS})

2.2.2 Methodology:

i. An in-house Water Resources Assessment tool based on Python is developed in BPMO, CWC.

ii. **Resampling**: To run any geospatial tool, it is imperative to bring all geo-spatial datasets on to a common resolution (resampling). Since P (IMD) is at 0.25° x 0.25°, ET (SSEBop: USGS) is at 1km x 1km and LULC (NRSC) is at 56m x 56m, hence, all datasets have to be brought at finest resolution i.e. 56m x 56m. This resampling is done at finest resolution, otherwise at coarser resolution, the LULC details will be missed out, affecting many components of water availability equation such as ET_{II}, E_R, that are governed by LULC.

iii. **Precipitation (P)**: The monthly / annual precipitation (mm) at each pixel is derived after resampling & data processing; and is multiplied by basin area to get the values in BCM. Effective precipitation is taken as 70% of the precipitation (as per FAO estimate for India).

iv. **Total Evapotranspiration (ET)**: The monthly / annual ET (mm) at each pixel is derived after resampling & data processing; and is multiplied by basin area to get the values in BCM.

v. **Modelled Runoff (R_M)**: On annual scale, R_M is equal to P-ET.

vi. **Evaporation in Reservoirs (E_R)**: The ET over reservoirs (E_R) is extracted using the shape-file of reservoir(s) and ET data.

vii. **Domestic, Industrial, Livestock (DIL) consumptive Use**: The domestic demand is estimated taking into account the data provided by Census of India. This dataset had shape file of district boundaries with attributes of population for the year 2001 and 2011. Population statistics for intervening period and for the period beyond census year (2011) are calculated using standard population projection methods. Domestic demand of 140 litres per capita per day (LPCD) for urban population, 70 LPCD for rural population has been considered. The industrial demand data is not readily available, so the same is assumed as 50% of the domestic demand for each year. The livestock population is considered to be about 50% of human population as per 18th Livestock Census data of National Dairy Development Board and livestock demand of 30 LPCD (NCIWRD) has been considered. The consumptive-use portion from domestic, livestock, and industrial demands have been appropriately considered in the study; which is

used for calculating Q_M for performing T-test between Q_{OBS} against Q_M. This component (consumptive use of DIL) is just a small fraction of total water availability of the basin.

viii. **Reservoir Flux:** Monthly reservoir level data is available in Central Water Commission for 150 major reservoirs.

Reservoir flux = Reservoir volume on 1st June of succeeding year - Reservoir volume on 1st June of preceding year.

ix. **Groundwater flux:**

The district-wise groundwater flux data prepared by CGWB was used in this study for estimating yearly groundwater fluxes.

x. **Change in Soil Moisture (ΔSM)**: SM for each month (in mm) is estimated using the formula:

$$SM = W * e^{(-La/W)}$$

Where,

La = Accumulated potential water loss (APWL); estimated as the difference between precipitation and ET for each month

W = Available water in mm; Estimated using root-zone depth for the different land use class (Kharif, Rabi, double-triple cropped, built-up, forests etc.) and soil texture information (sandy, loamy, clayey, etc.)

The ΔSM is factored into monthly water balance equation.

However, ΔSM has been found to be negligible on annual scale. Accordingly, the same has been neglected in Annual Water Balance Equation.

xi. **Trans-boundary Water**

a. **From China in Brahmaputra**: The modelled runoff (R_M) for the Indian portion between Indo-China border and three sites close to the border (in India) namely Lemeking, Tuting, and Kibithu was subtracted from the observed discharges (Q_{OBS}) at these sites to get the Trans-boundary

component from China in Brahmaputra. This component was also included in the 2019 WR Assessment.

b. **From Bhutan in Brahmaputra**: This component was NOT included in the 2019 WR Assessment. However, the same has been included in the present study. The modelled runoff (R_M) for the Indian portion between Indo-Bhutan border and 7 sites close to the border (in India) namely NH31, Hasimara, Barabisha, Sankosh, Kokrajhar, Manas NH Crossing, and Beki Road Bridge (gauged rivers) was subtracted from the observed discharges (Q_{OBS}) at these sites to get the Trans-boundary component from Bhutan in Brahmaputra. In addition, for un-gauged rivers entering India from Bhutan, P-ET in the catchments (lying in Bhutan) of these un-gauged rivers was added to get the total contribution from Bhutan in Brahmaputra.

c. **From Nepal in Ganga**: As there are many streams entering India from Nepal which do not have CWC gauging stations, a different approach has been adopted. The contribution from Nepal has been estimated using T=P-ET- (GW Use). This contribution is then added to water availability of Ganga (Indian portion). This component was partially taken in the study of 2019.

d. **From China in Sutlej**: For estimation of trans-boundary component in Sutlej, observed data at Khab site of Satluj Jal Vidyut Nigam Limited (SJVNL) has been directly used.

xii. **ET from Irrigation Input (ET_{II})**: ET due to irrigation of cropped area inside command area boundaries has been considered. In addition, ET is also considered from Double/Triple crops, Rabi Only and Zaid only, happening outside the command area (assumed as irrigated either by surface or groundwater) and all other crops are assumed as rain-fed. ET resulting from irrigation input (ET_{II}) is estimated by using effective precipitation, ET data, Command Area, and LULC data.

If in a month $P_{eff} \geq ET_{IRR}$ then $ET_{II}=0$

Otherwise, $ET_{II} = ET_{IRR} - P_{eff}$

ET_{IRR} is ET from irrigated areas (Natural + Manmade)

The annual ET_{II} is then calculated by summing up the monthly values.

2.2.3 Validation of modelled results

The modelled discharge (Q_M) is tested against the observed discharge (Q_{OBS}) at the terminal G&D site(s) of CWC on annual scale by performing T-test which is an inferential statistic used to determine if there is a significant difference between the means of two groups and how they are related. Here, t-test is performed for checking the homogeneity of two sets of samples for the period 2003-2023 (the new ET product). If T-test in any basin fails, then ET values are suitably adjusted so that the new Q_M passes the T-test vis-à-vis Q_{OBS}.

CHAPTER 3: ABOUT INDIA AND ITS WATER AVAILABILITY

Water resources (surface water and groundwater) are renewed through the continuous cycle of evaporation, precipitation and runoff. The water cycle is driven by global and climatic forces that introduce variability in precipitation and evaporation, which in turn define runoff patterns and water availability over space and time (modulated by natural and artificial storage). Using water balance approach, it is possible to make a quantitative evaluation of water resources in the basins and their change under the influence of people's activities.

3.1 India-Physiography

India, with a geographical area of about 329 Million Hectare (Mha), is a land of many mountains and rivers, some of them figuring amongst the mightiest in the world. India's physiography is marked by a striking diversity of landscapes, encompassing towering Himalayan peaks in the north, sprawling Indo-Gangetic plains teeming with life, and the rugged Deccan Plateau dominating the southern peninsula. The majestic Himalayas form a formidable barrier in the north, while the fertile plains of the Ganges and Brahmaputra rivers provide a crucial lifeline for agriculture and civilization. To the west, the arid expanse of the Thar Desert stretches across Rajasthan, contrasting sharply with the lush Western Ghats and Eastern Ghats flanking the peninsular plateau. Along its extensive coastline, India boasts fertile coastal plains, mangrove forests, and vibrant coral reefs, while offshore islands like the Andaman and Nicobar Islands and Lakshadweep offer unique ecosystems and biodiversity. India's diverse physiography not only influences its climate and vegetation but also plays a crucial role in shaping its culture, economy, and way of life.

3.2 Climate

India has diversity of climate and weather conditions. The climate in the country ranges from extremes of heat to extremes of cold; from extreme aridity and negligible precipitation to excessive humidity and torrential rainfall. The great mountain mass of Himalayas in the north and the ocean in the south are the two major influences operating on the climate of India. The Himalayas pose an effective barrier to the influence of cold winds from central Asia and gives the sub-continent the elements of tropical type of climate. The climatic condition influences to a great extent the water resources availability and utilization in the country.

3.3 Soil Texture

The main soil textural classes in India are Loamy and clayey. Soil textural classes of India are shown in Figure 3.1.

The soil map generated by National Bureau of Soil Survey & Land Use Planning (NBSS & LUP) was used in this study. A particular soil textural class can have particular water holding capacity, and a certain vegetation type can have a certain root zone depth. The water holding capacities for different soils are taken from available literature.

The available water for vegetation is computed as follows:

Available water (mm) = Water holding capacity (%) x Root zone depth (mm)

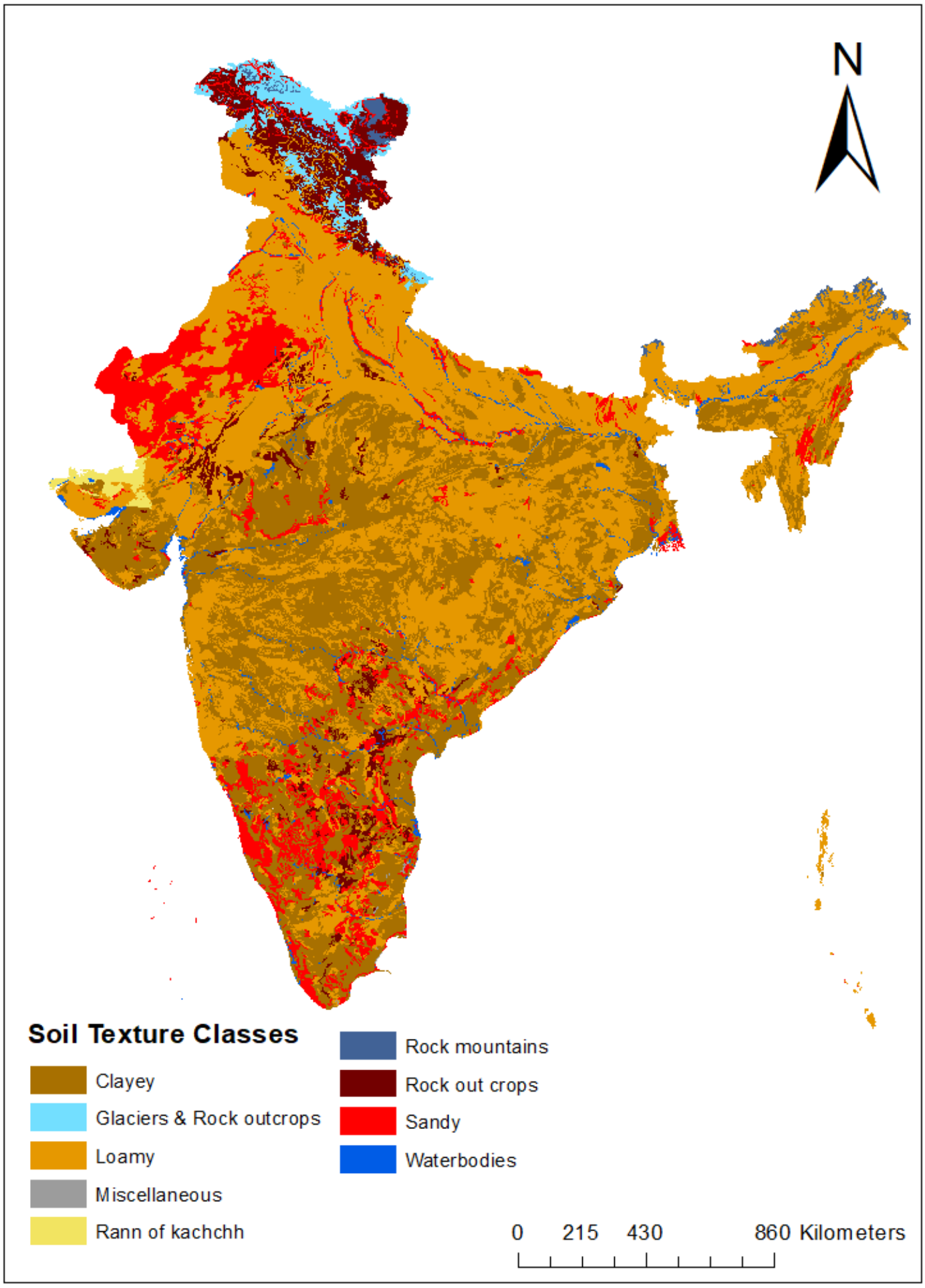


Figure 3.1: Soil textural map of India

Source: NBSS & LUP

3.4 Rivers Basins of India

India is blessed with many rivers, which serve as a lifeline for millions of Indians. Table 3.1 shows major river basins of India.

Table 3.1: Major River basins of India

S. No.	River Basin
1.	Barak & Other Basin
2.	Brahmani- Baitarani Basin
3.	Brahmaputra Basin
4.	Cauvery Basin
5.	East Flowing rivers between Mahanadi and Pennar
6.	East Flowing rivers between Pennar and Kanyakumari
7.	Ganga Basin
8.	Godavari Basin
9.	Indus Basin
10.	Krishna Basin
11.	Mahanadi Basin
12.	Mahi Basin
13.	Minor Rivers draining into Myanmar and Bangladesh
14.	Narmada Basin
15.	Pennar Basin
16.	Sabarmati Basin
17.	Subarnarekha Basin
18.	Tapi Basin
19.	West flowing rivers between Tadri to Kanyakumari
20.	West flowing rivers between Tapi to Tadri
21.	West flowing river Kutch and Saurashtra including Luni
22.	Area of inland drainage in Rajasthan Desert

3.5 Elevation

Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with 90 m resolution was used by India-WRIS for delineating basin boundaries of Indian River Basins. Digital Elevation map of India is shown in Figure 3.2.

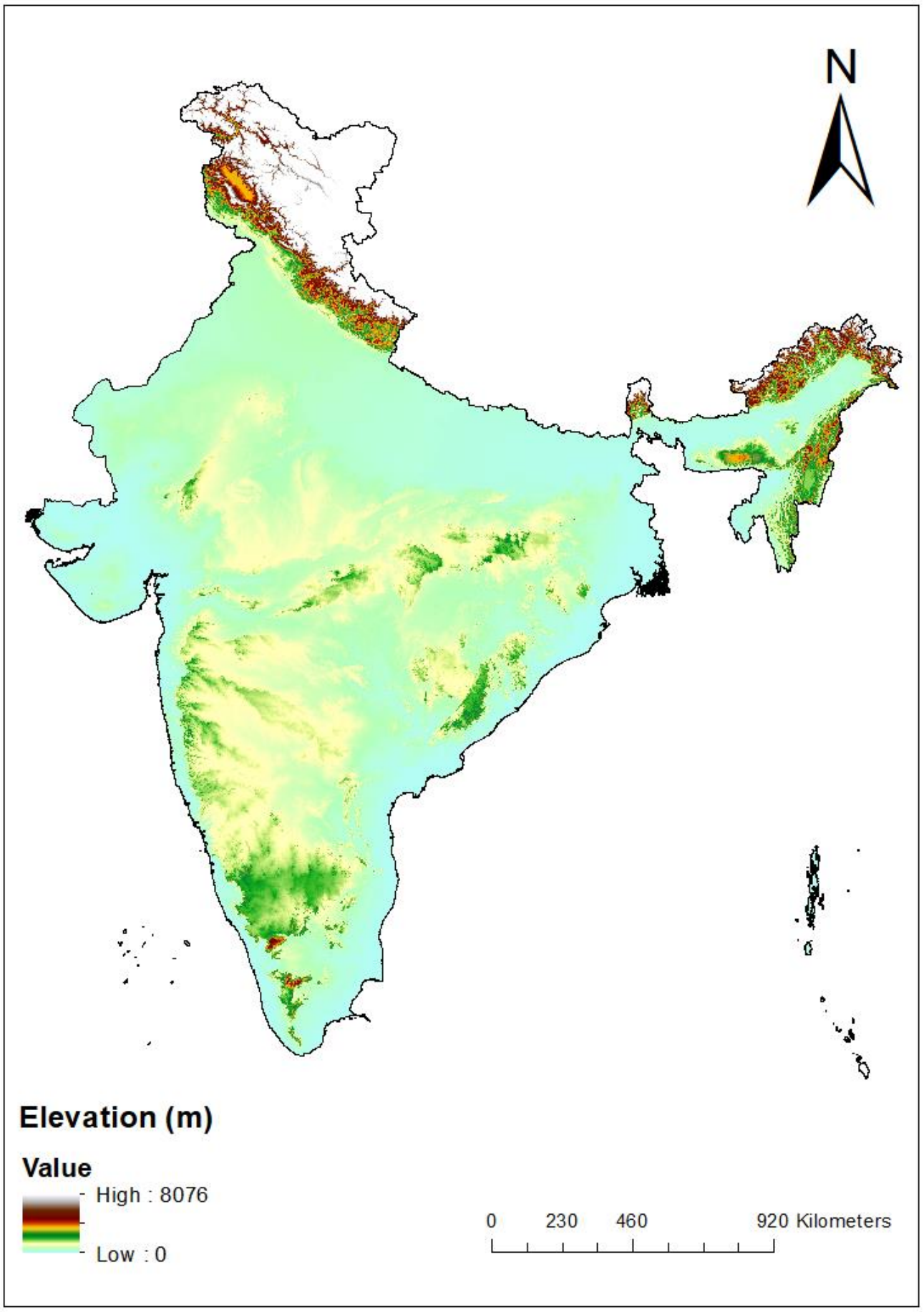


Figure 3.2: Elevation map of India

Source: India-WRIS / NRSC

3.6 Land Use and Land Cover

The yearly Land Use and Land Cover (LULC) data of NRSC using Indian Remote Sensing (IRS) Advanced Wide Field Sensor (AWiFS) was used in this study. The LULC data was available for the years from 2004-05 to 2022-23. The LULC map of year 2022-23 is shown in Figure 3.3. The major land use classes consist of Double/ Triple/ Annual cropland, Kharif crop land and deciduous woodland etc.

Table 3.2 shows the percentage area of each land use class in India for year 2022-23.

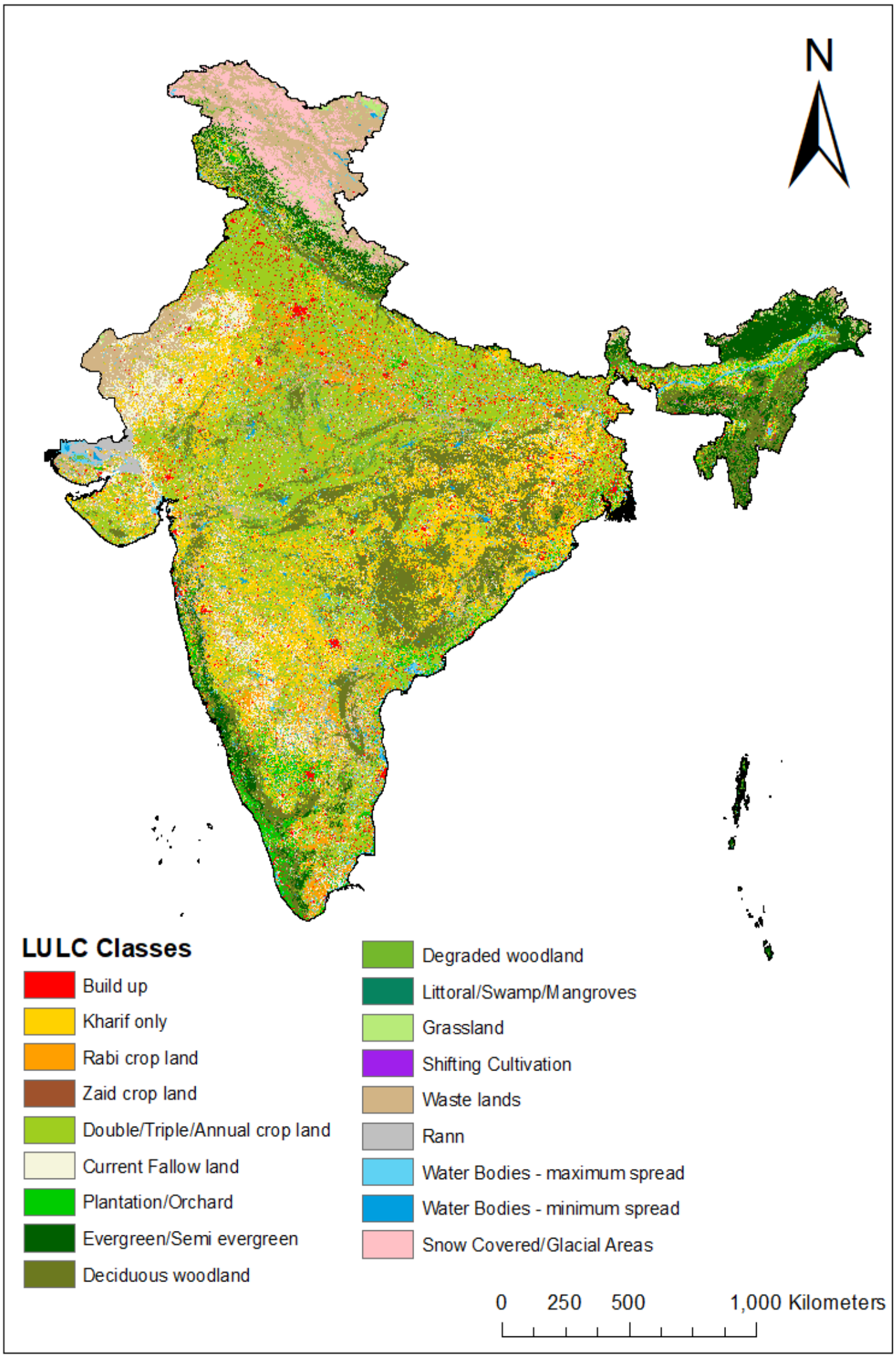


Figure 3.3: LULC map of India

Source: NRSC

Table 3.2 Percentage area of Land Use Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	0.44
2.	Kharif only	4.27
3.	Rabi crop land	1.82
4.	Zaid crop land	0.01
5.	Double/Triple/Annual crop land	17.01
6.	Current Fallow land	6.09
7.	Plantation/Orchard	2.62
8.	Evergreen/Semi evergreen woodland	5.80
9.	Deciduous woodland	16.99
10.	Degraded woodland	4.85
11.	Littoral/Swamp/Mangroves	0.16
12.	Grassland	1.22
13.	Shifting Cultivation	0.04
14.	Waste lands	22.14
15.	Rann	1.04
16.	Water Bodies - maximum spread	6.29
17.	Water Bodies - minimum spread	1.91
18.	Snow Covered/Glacial Areas	7.30

3.7 Precipitation

Precipitation in India is dependent on the South-West and North-East monsoons, on shallow cyclonic depressions and disturbances and on violent local storms which form regions where cool humid winds from the sea meet hot dry winds from the land and occasionally reach cyclonic dimensions. Most of the precipitation in India takes place under the influence of South-West monsoon (June-September) except in Tamil Nadu where it is under the influence of North-East monsoon (October-December). However, there is considerable spatial variation in precipitation that ranges from less than 100 mm in the western Rajasthan to more than 2,500 mm in North-Eastern areas.

High spatial resolution (0.25^{o} X 0.25^{o}) daily gridded Precipitation data sets for the period of 38 years (1985-86 to 2022-23) over India prepared by India Meteorological Department (IMD) were used in this study. The daily data has been processed and converted into the monthly scale for calculations in the software and results have been aggregated on annual scale. The annual average precipitation of 38 years is about **3728.78** BCM. The gridded precipitation map of India for the year 2022-23 has been shown in Figure 3.4. The variations in the annual precipitation during 1985-2023 are shown in Figure 3.5.

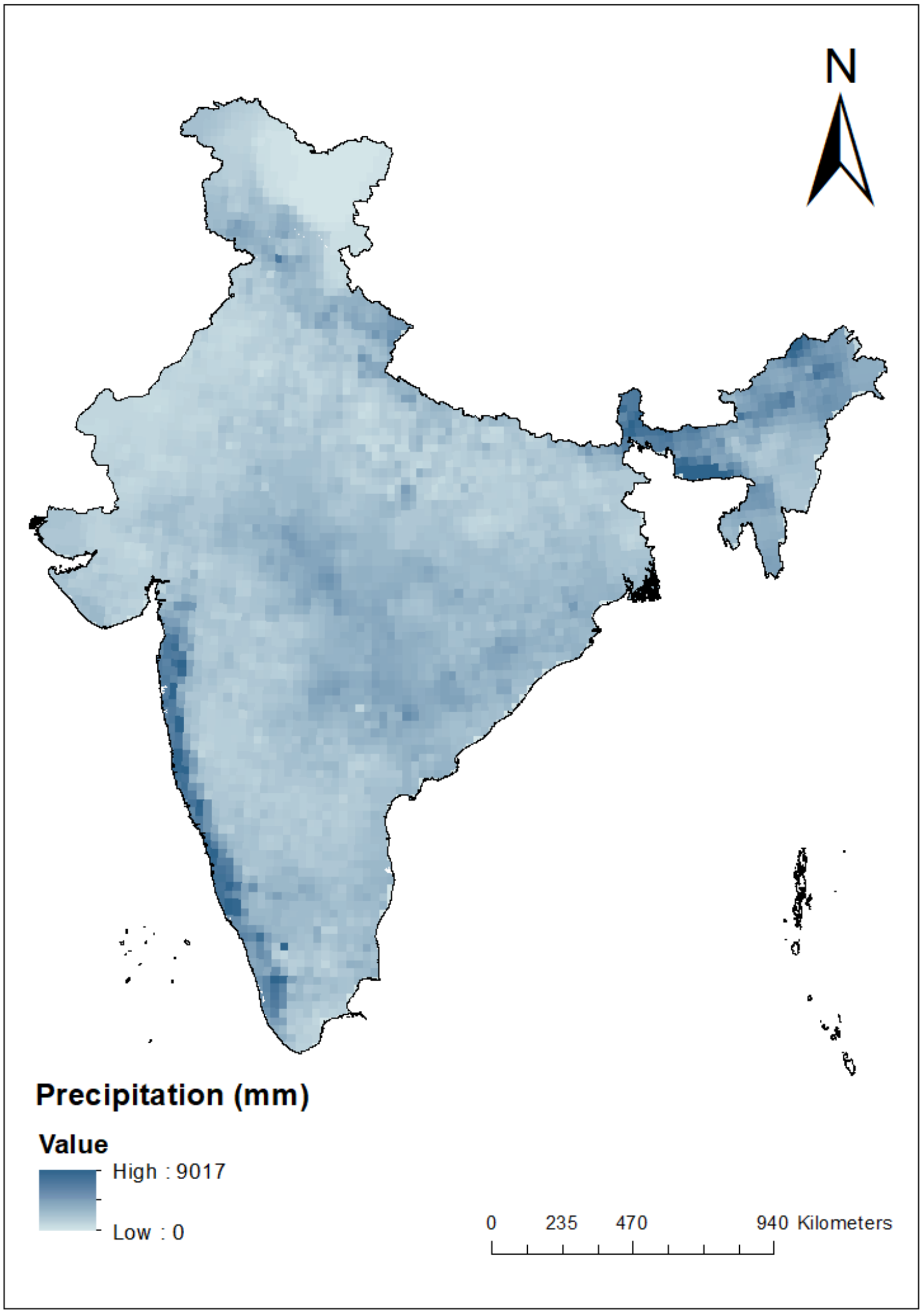


Figure 3.4: Precipitation map of India

Source: IMD

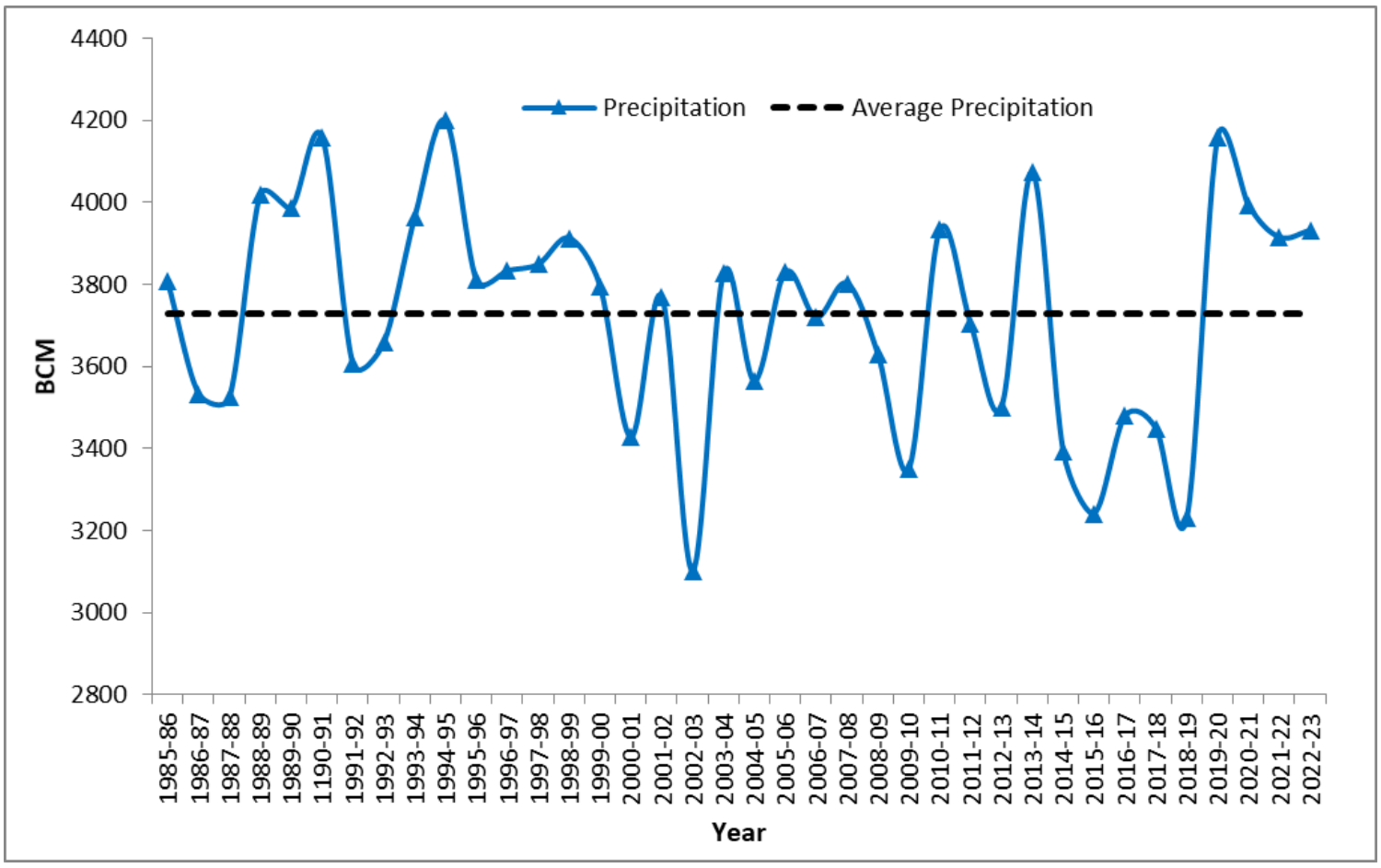


Figure 3.5: Annual Precipitation of India

3.8 Evapotranspiration

Evapotranspiration is the combined process of water vapor loss from the Earth's surface through both evaporations from soil & open water bodies and transpiration from plants. It is a crucial component of the water balance equation, representing the loss of water to the atmosphere. Accurate estimation of evapotranspiration is essential for water resource management, especially in regions with limited water availability.

The study uses **Simplified Surface Energy Balance Operational (SSEBop) Evapotranspiration product developed by USGS,** which is a remote sensing based product (1 Km x 1 Km) to estimate actual evapotranspiration at regional and global scales. It relies on satellite imagery and meteorological data to calculate Actual Evapotranspiration.

The gridded Evapotranspiration map of India for year 2022-23 is shown in Figure 3.6. Average annual ET is estimated as **2279.32** BCM. Variations in annual ET (1985-2023) are shown in Figure 3.7.

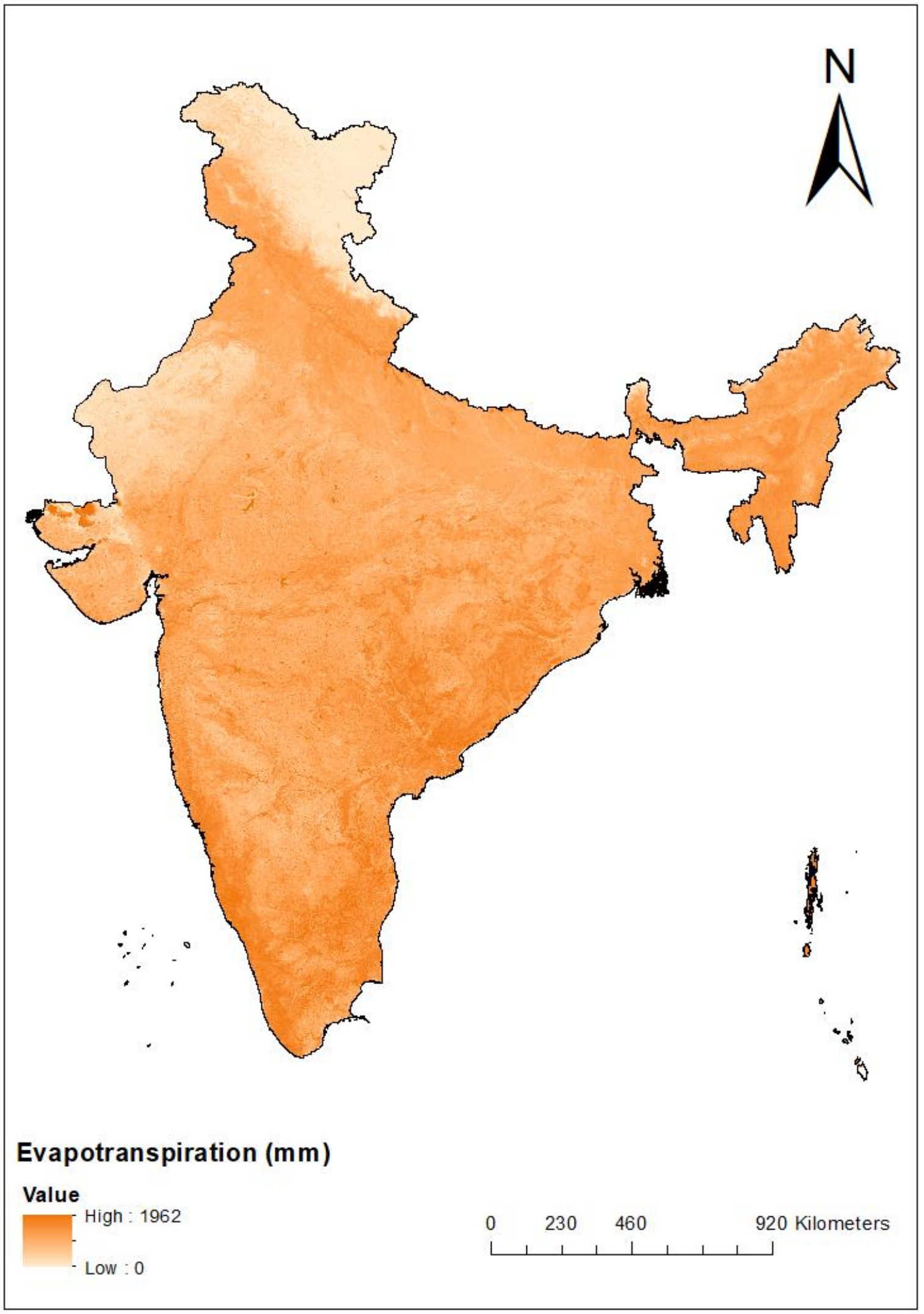


Figure 3.6: Gridded Evapotranspiration map of India

Source: USGS SSEBop

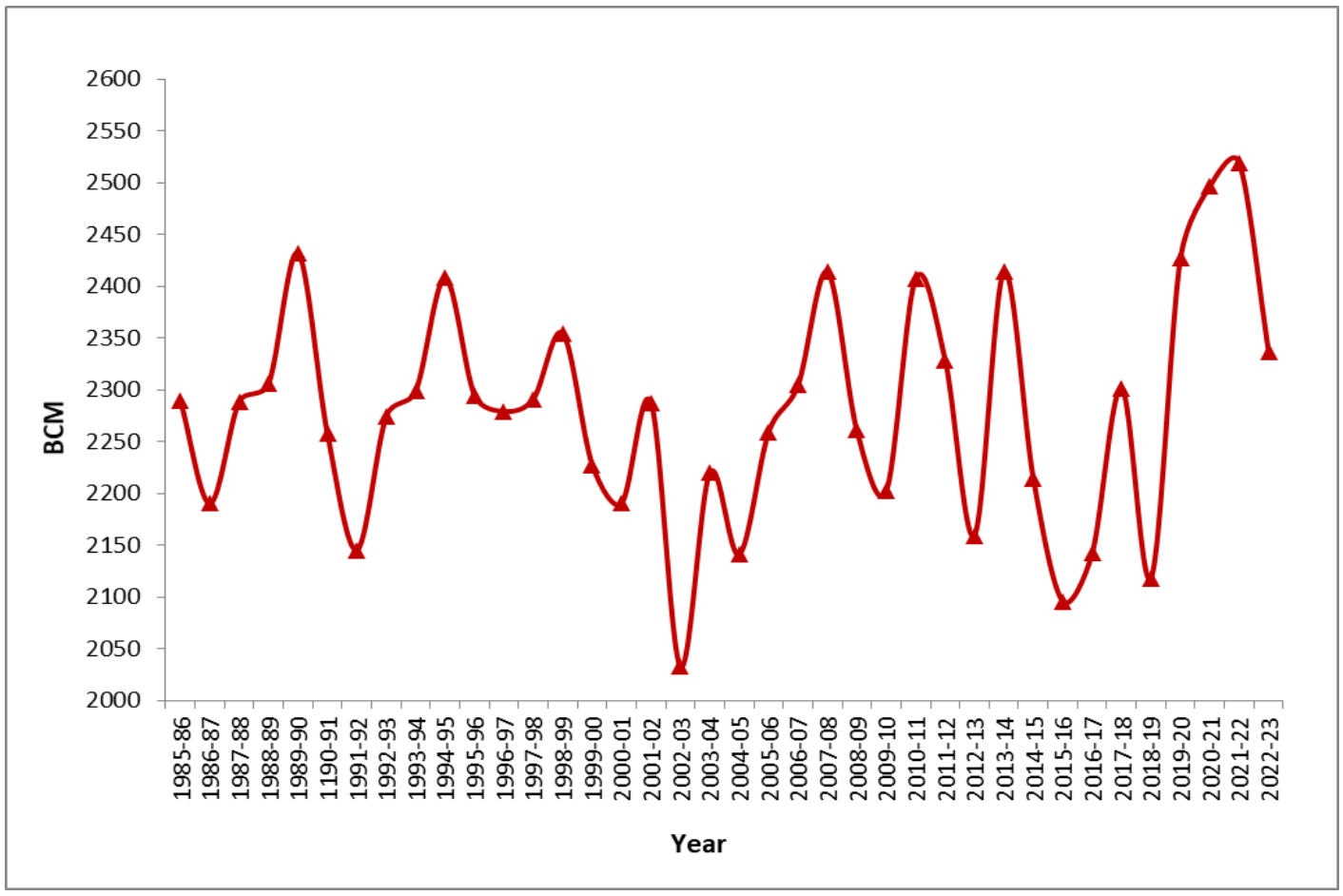


Figure 3.7: Annual Evapotranspiration of India

Note: *From 1985-2003, ET was estimated using modified Thornthwaite-Mather equation which uses only the Temperature as the factor causing ET.* ***From 2003-2023, ET has been taken from ET product namely SSEBoP (USGS) that estimates actual ET based upon energy balance approach, which uses land surface temperature to estimate ET by comparing the actual surface temperature to a reference wet surface temperature.***

3.9 Reservoir Evaporation

The reservoirs having area greater than 100 hectare (Figure 3.8) have been considered for the estimation of reservoir evaporation. The reservoir evaporation (E_R) is estimated using the shape file of reservoir(s) and ET data. The average annual reservoir evaporation in India has been estimated as 27.56 BCM.

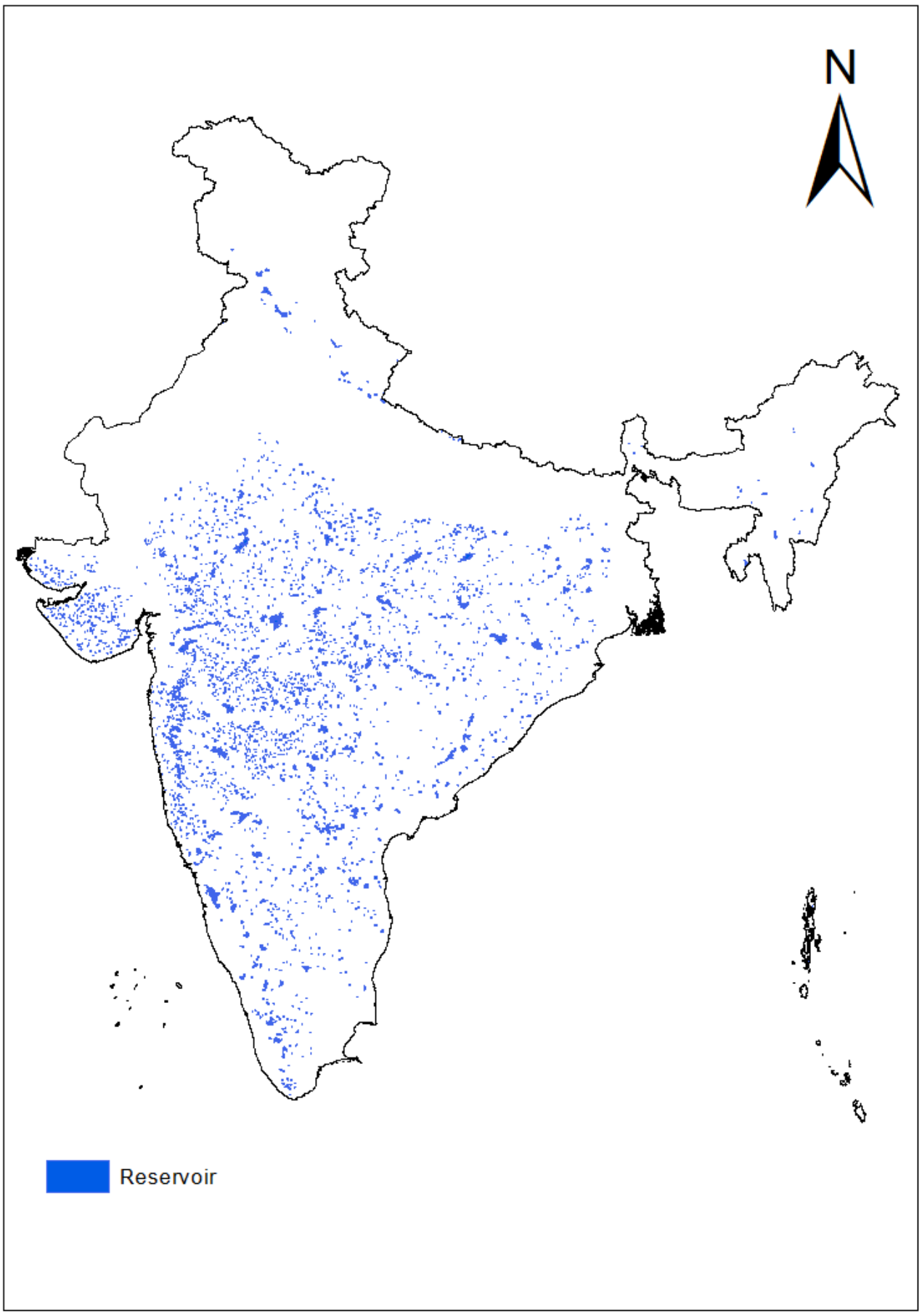


Figure 3.8: Reservoir map of India

Source: NWIC

3.10 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) is estimated using effective precipitation data, ET data, LULC data and command area map. The command area map used for the estimation of ET_{II} is shown in Figure 3.9. Average annual ET_{II} of India for the years 1985-2023 has been estimated as **447.04** BCM. The annual variation in ET_{II} is shown in Figure 3.10.

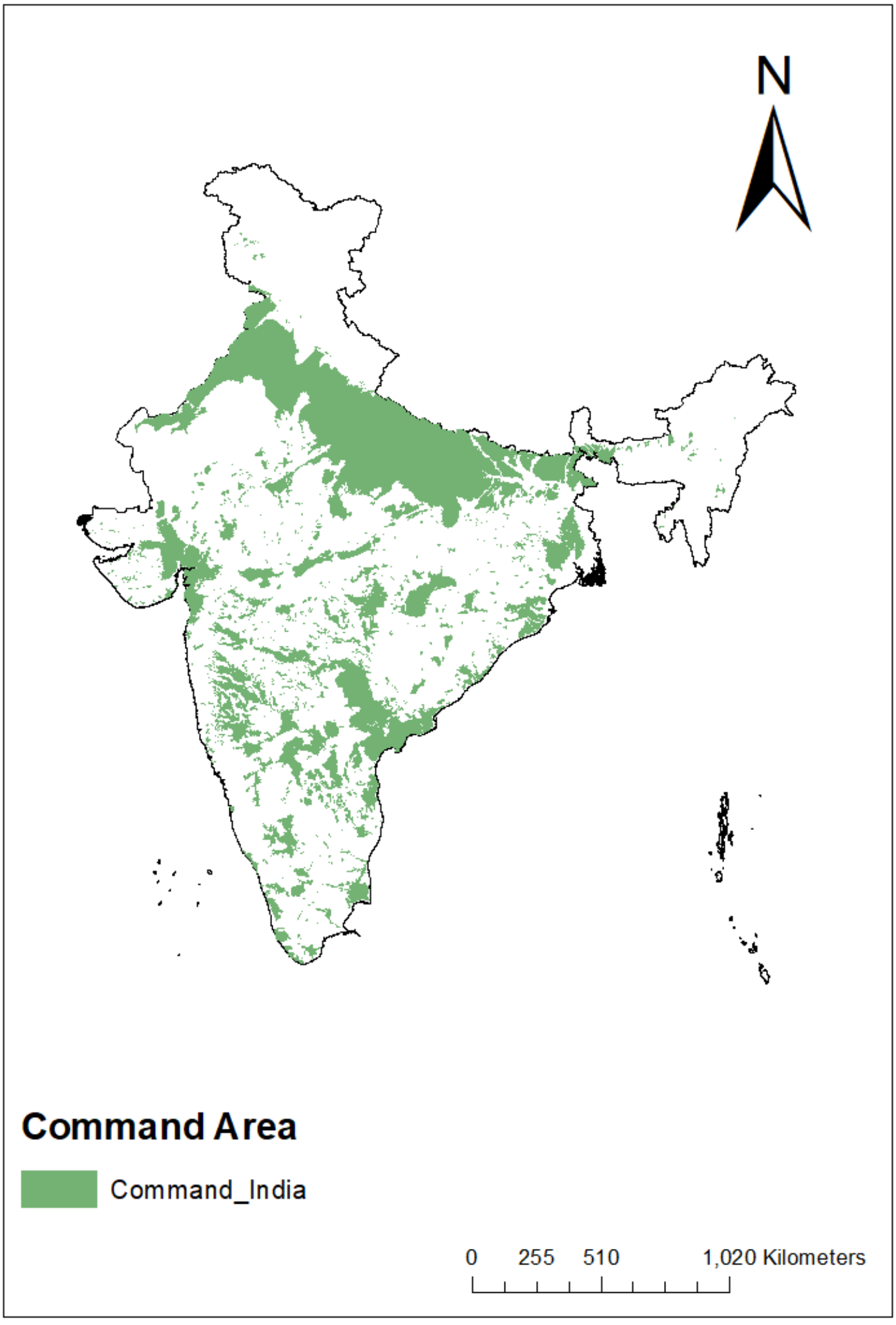


Figure 3.9: Irrigation Command area map of India

Source: India-WRIS

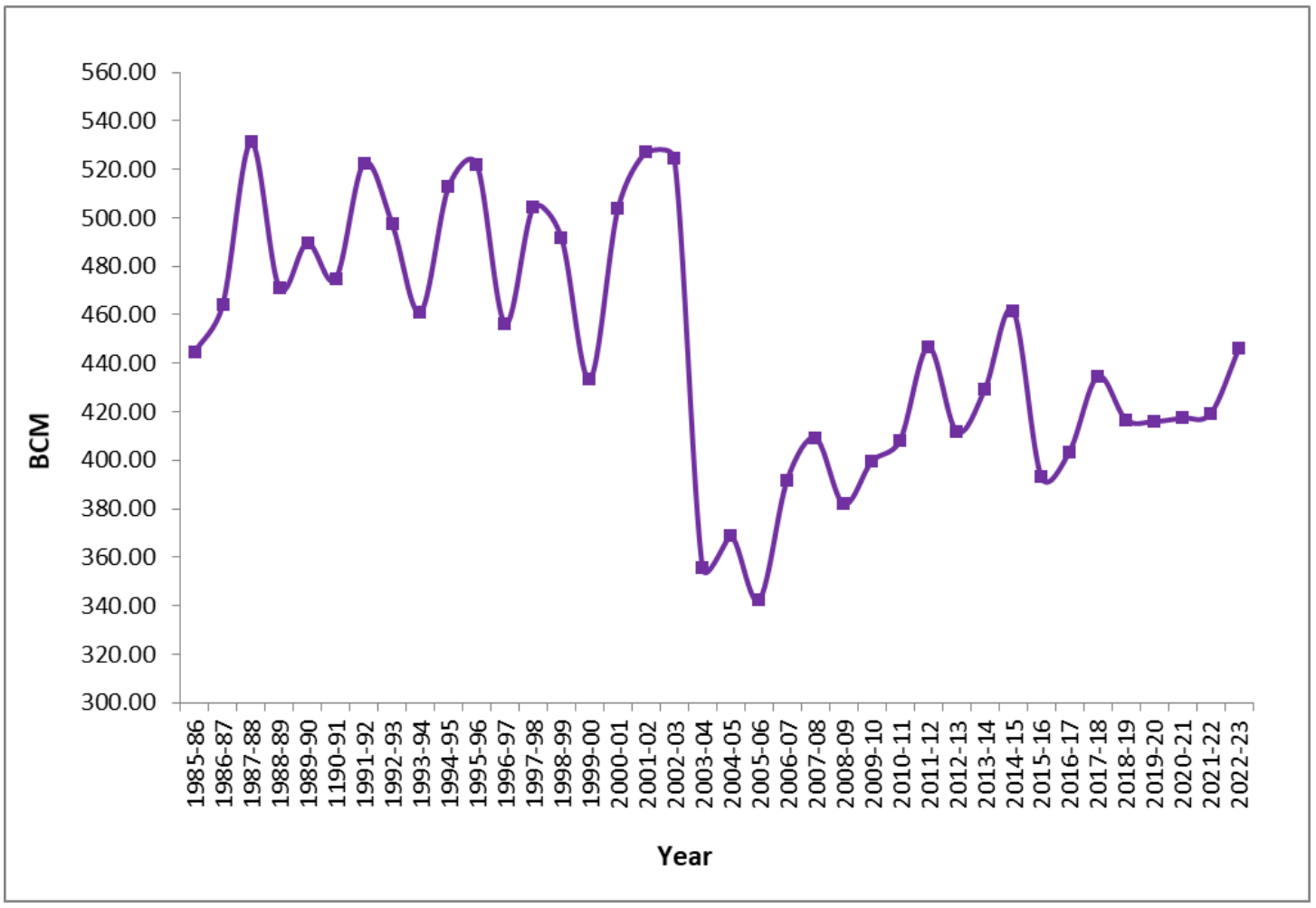


Figure 3.10: Annual Evapotranspiration from Irrigation Input of India

Note: *From 1985-2003, ET was estimated using modified Thornthwaite-Mather equation which uses only the Temperature as the factor causing ET.* ***From 2003-2023, ET has been taken from ET product namely SSEBoP (USGS) that estimates actual ET based upon energy balance approach, which uses land surface temperature to estimate ET by comparing the actual surface temperature to a reference wet surface temperature.***

3.11 Reservoir flux

Monthly reservoir level data is available in Central Water Commission for 150 major reservoirs. The reservoir level and corresponding volume data for the water year (June to May) has been used in estimating the yearly reservoir flux.

Reservoir flux = Reservoir volume on 1st June of succeeding year - Reservoir volume on 1st June of preceding year.

The average annual reservoir flux of India has been estimated as 0.07 BCM

3.12 Groundwater flux

The district-wise groundwater flux data prepared by CGWB was used in this study for estimating yearly groundwater fluxes. The basin-wise yearly groundwater flux is then estimated using geo-processing tools. The average annual groundwater flux has been estimated as (-) 0.49 BCM.

3.13 Domestic, Industrial and Livestock (DIL) demand

The domestic, industrial and livestock demand has been estimated using the Census of India data for the year 2001 and 2011 with appropriate considerations. District map of India (2011 census) is shown in Figure 3.11. The DIL consumption for 2022-23 has been estimated as 32.14 BCM.

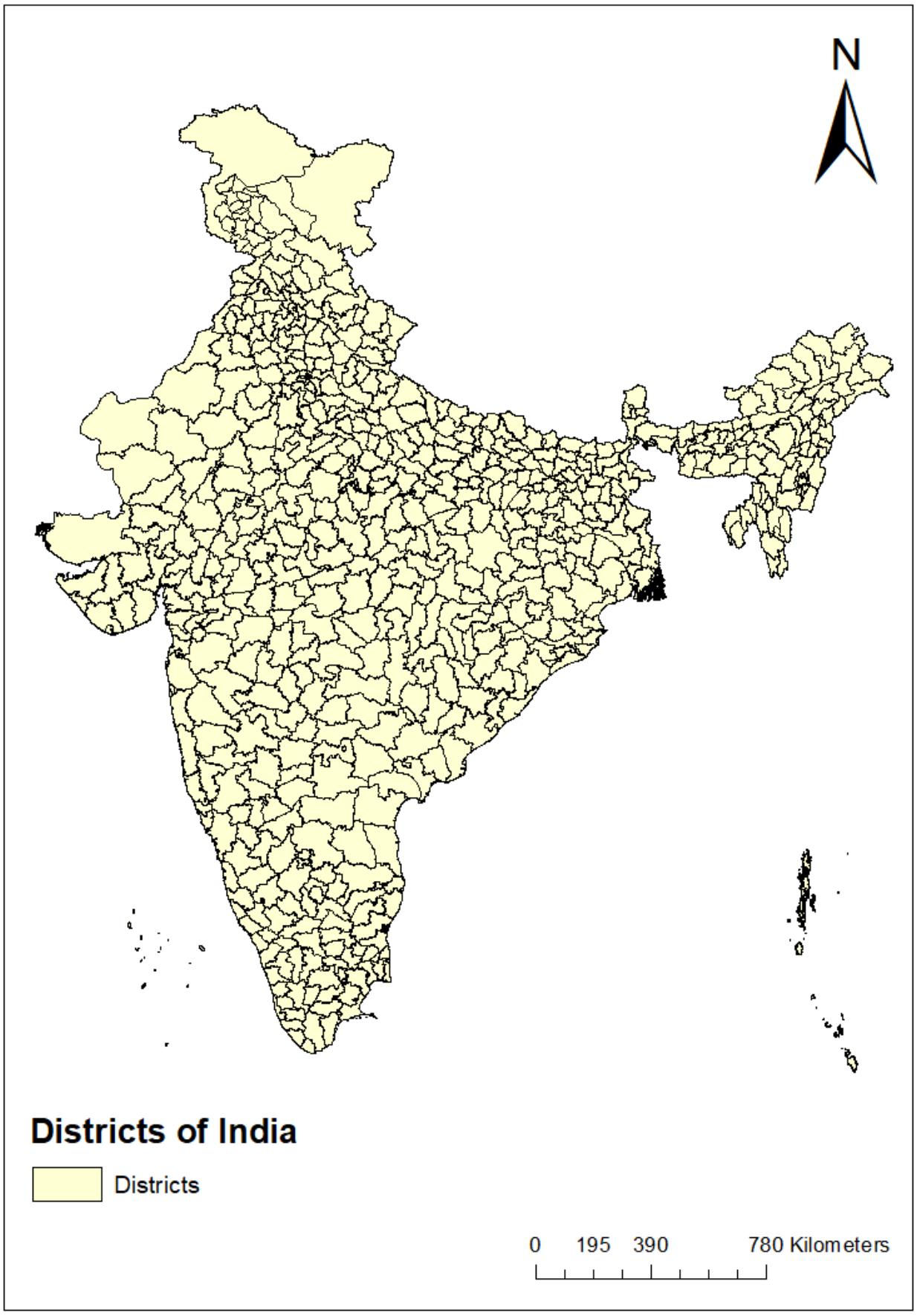


Figure 3.11: District map of India

Source: Census of India

3.14 Previous estimates

The average annual water availability of India was estimated as 1999.20 BCM in 2019. However, this estimation did not include the following trans-boundary water entering India:

- From Bhutan in Brahmaputra basin
- From Nepal in Ganga basin (not fully taken into account)

3.15 Annual Water Availability of India

The current study estimates the average annual water availability of India as 2115.95 BCM (excluding water availability of Indus-western rivers i.e. Indus, Jhelum, Chenab) from 1985-2023 (38 years). The current study includes all trans-boundary water entering India in Brahmaputra basin, in Ganga basin and in Indus basin (eastern rivers).

The annual variation in Water availability (WA) is shown in Figure 3.12. The basin wise results are shown in Table 3.4.

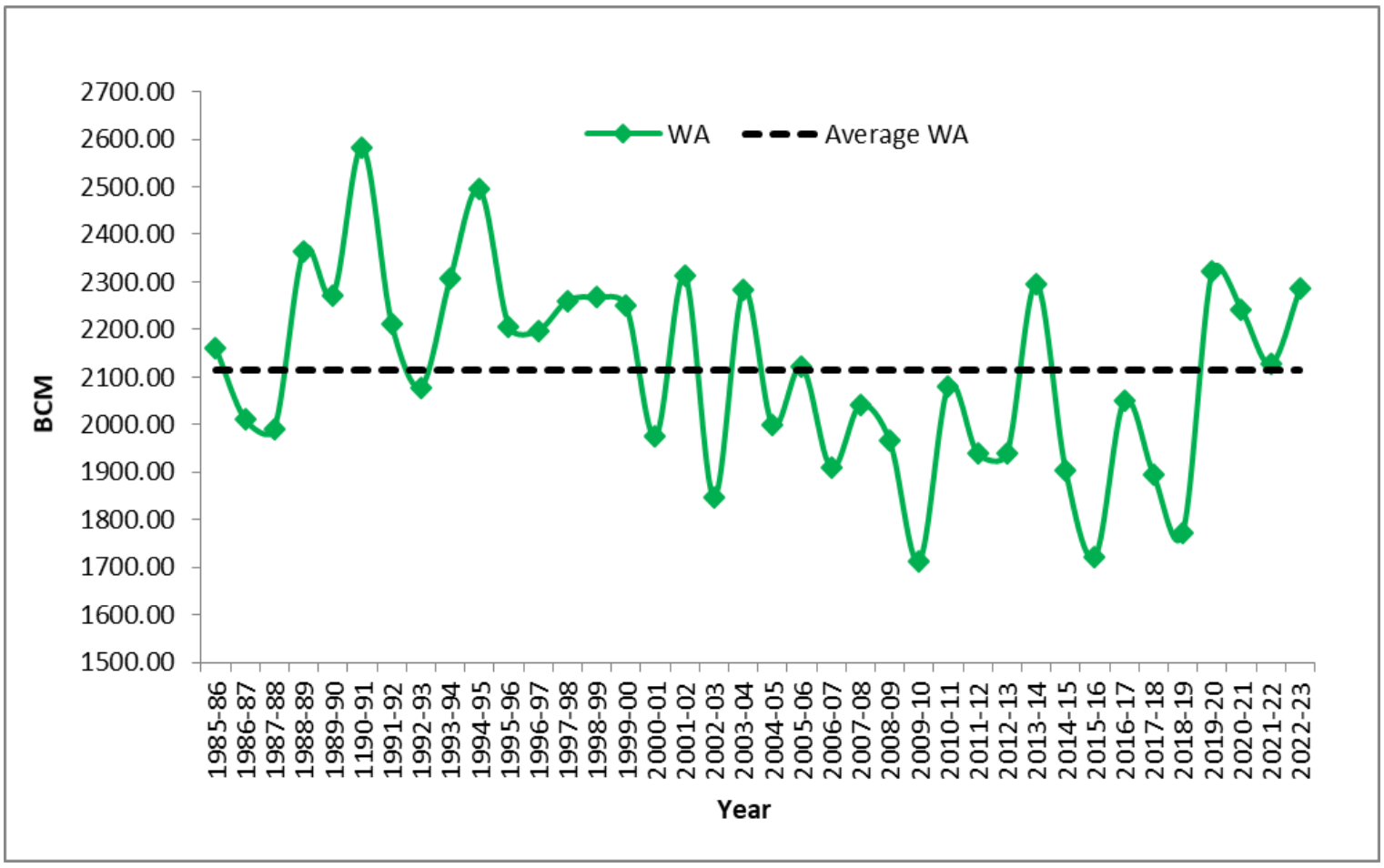


Figure 3.12: Water Availability of India

3.16 Moving average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of India is given at Table 3.3. A line diagram of moving average of P and WA is shown in Figure 3.13.

Table 3.3: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	3743.14	2132.94
1986-2016	3724.28	2118.32
1987-2017	3722.47	2119.63
1988-2018	3719.96	2116.41
1989-2019	3693.67	2096.66
1990-2020	3699.40	2098.31
1991-2021	3693.85	2086.95
1992-2022	3704.15	2084.13
1993-2023	3713.28	2091.01

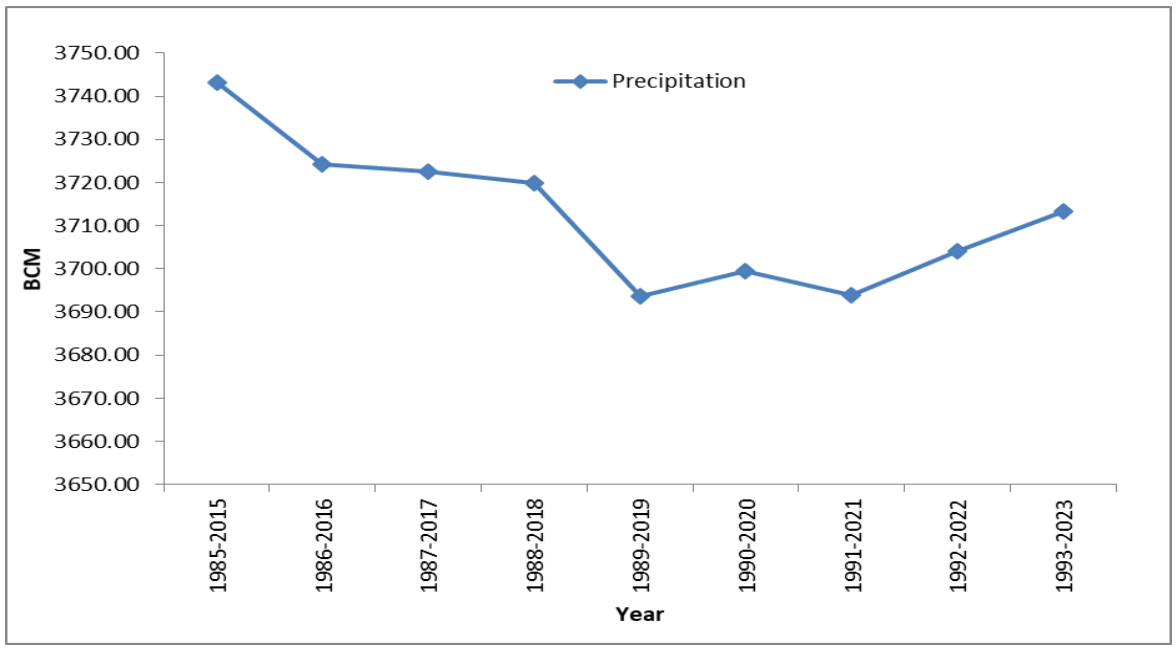


Figure 3.13: Moving Average of P and WA for 30 years

3.17 Conclusion

The study has achieved both the objectives set out initially. An efficient Water Resources Assessment (WRA) model/tool has been developed in-house based on Python script and set up at BPMO, CWC which can be used over time, with modifications/refinements as and when required.

Further the study has also assessed long-term average annual water resources availability in the river basins of India during the period from 1985-86 to 2022-23 using global gridded ET product. The water availability has been worked out by combining results from previous study (1985-2015) as well as current study (2003-2023). By evolving the methodology, this assessment has come closer to the ground situation.

The precipitation, ET_N and water availability of India is estimated as 3728.78 BCM, 1723.62 BCM and 2115.95 BCM respectively. Specific training is required for future assessments of water availability and the updation of model.

3.18 Limitations of the study

i. The accuracy of water availability estimates directly depends upon the accuracy of various datasets e.g. Gridded Precipitation (0.25° x 0.25°), Gridded ET (1 km x 1 km), LULC (56m x 56m), observed discharge and other products.

ii. In some trans-boundary basins, there is no G&D site in India immediately after entry of trans-boundary rivers / streams, which leads to indirect estimation of trans-boundary component through P-ET.

iii. The model is setup on monthly time-step and the results are aggregated on annual time-step.

iv. T-test could not be performed on monthly time-step to check homogeneity of two data samples (Q_{OBS} and Q_M) at G&D site.

v. Kharif crop land outside the command area boundary is assumed as rain-fed. Kharif crop land within command boundary, Double/Triple crops, Rabi, and Zaid crop land are considered as irrigated, either by surface or groundwater.

vi. The groundwater flux has been estimated using area proportionate method by using district-wise groundwater flux, which may not follow the basin boundary.

vii. ΔSM has been neglected in Annual Water Balance Equation.

3.19 Broad updations over previous study

The broad updations over previous study (2019) are tabulated below:

S. No.	Component	2019 study (1985-2015)	Current Study (1985-2023)
1.	Water Availability	1999.2 BCM	2115.95 BCM
2.	ET Estimation	Modified Thornthwaite equation	SSEBop ET product from USGS
3.	China's contribution in Brahmaputra	Included	Included
4.	Bhutan's contribution in Brahmaputra	Not included	Included
5.	China's contribution in Sutlej	Included	Included
6.	Nepal's contribution in Ganga	Partially included	Fully included
7.	Study duration	30 years	18 years from previous study (+ missing transboundary contributions) **+** 20 years in current study including all transboundary contribution

Table 3.4: Summary of Annual Water Availability of India

(All values in BCM)

S. No.	Basin	Area (sq. km)	P	ET_N	WA*
1.	Barak & Others	86,335	134.46	40.81	93.65
2.	Brahmani-Baitarani	53,902	80.24	48.96	31.27
3.	Brahmaputra	1,93,252	473.40	105.70	592.32
4.	Cauvery	85,167	82.95	56.43	26.53
5.	EFR between Mahanadi & Pennar	82,073	95.49	66.91	23.33
6.	EFR between Pennar & Kanyakumari	1,01,657	99.55	72.49	27.06
7.	Ganga	8,38,803	886.37	412.63	581.75
8.	Godavari	3,12,150	364.43	235.27	129.17
9.	Indus (Eastern)#	1,25,067	95.39	50.13	47.30
10.	Indus (Western)##	1,49,660	148.01	-	-
11.	Krishna	2,59,439	218.77	132.45	86.32
12.	Mahanadi	1,44,905	194.70	120.82	72.82
13.	Mahi	39,566	34.77	21.74	13.03
14.	Minor rivers draining into Myanmar & Bangladesh	31,382	59.76	27.91	31.86
15.	Narmada	96,660	107.89	57.93	49.95
16.	Pennar	54,905	41.33	30.20	10.42
17.	Sabarmati	31,901	24.20	14.33	9.87
18.	Subernarekha	26,804	39.43	24.96	14.48
19.	Tapi	65,806	58.52	37.54	20.98
20.	WFR from Tadri to Kanyakumari	54,231	149.57	33.10	116.47
21.	WFR from Tapi to Tadri	58,360	159.69	49.26	110.44
22.	WFR of Kutch & Saurashtra including Luni	1,92,112	111.00	84.06	26.95
23.	Area of inland drainage in Rajasthan	1,44,836	48.78	-	Negligible
24.	Area of North Ladakh not draining into Indus	42,981	20.07	-	Negligible
	Total	**32,71,954**	**3728.78**	**1723.62**	**2115.95**

** including trans-boundary contribution*

 # Ravi, Beas, Satluj & Ghaggar

Indus, Jhelum & Chenab

CHAPTER 4: BASIN-WISE WATER RESOURCE ASSESSMENT

Basin-wise water resources assessment has been carried out according to the Basin map of India as shown in Figure 4.1.

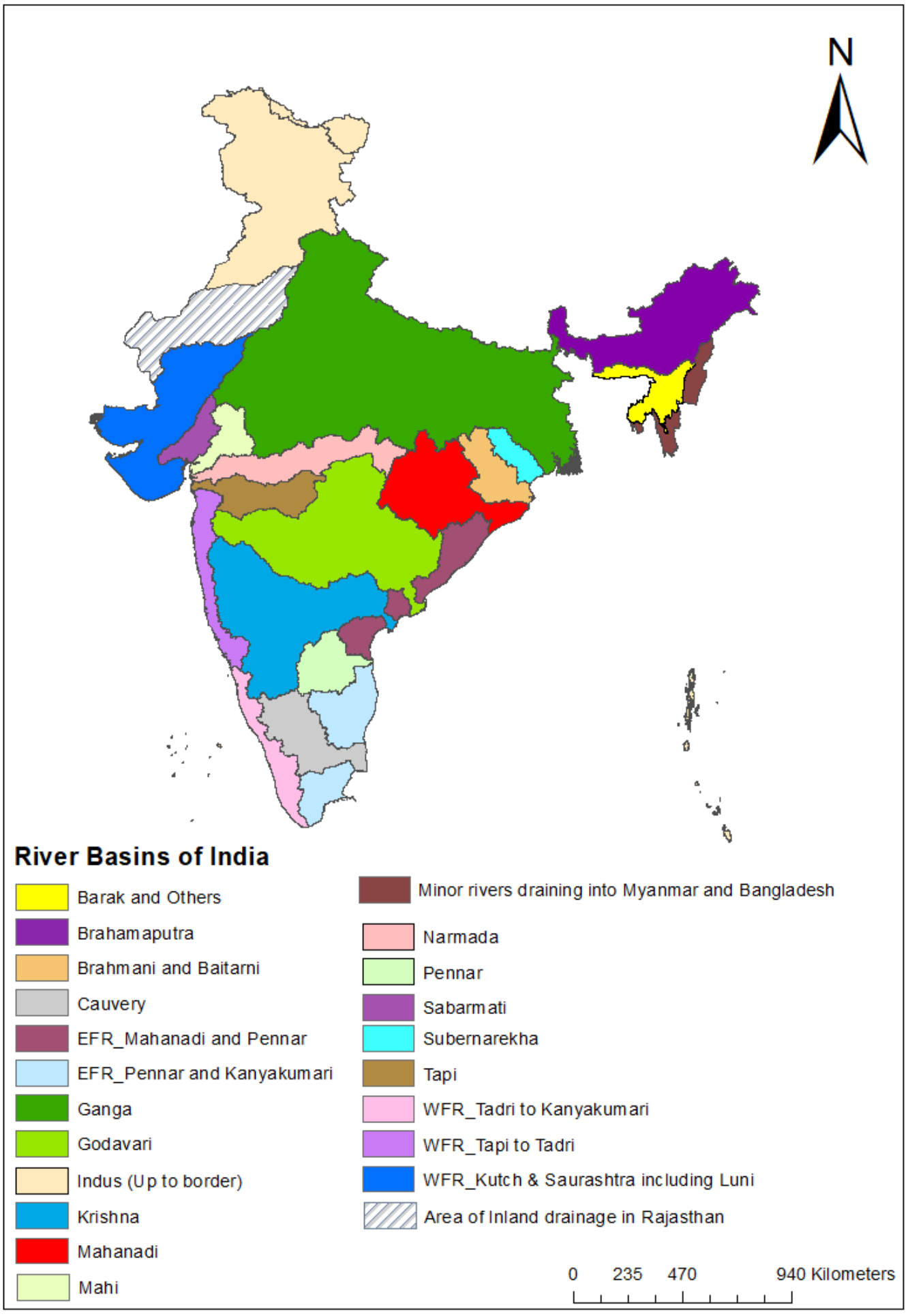
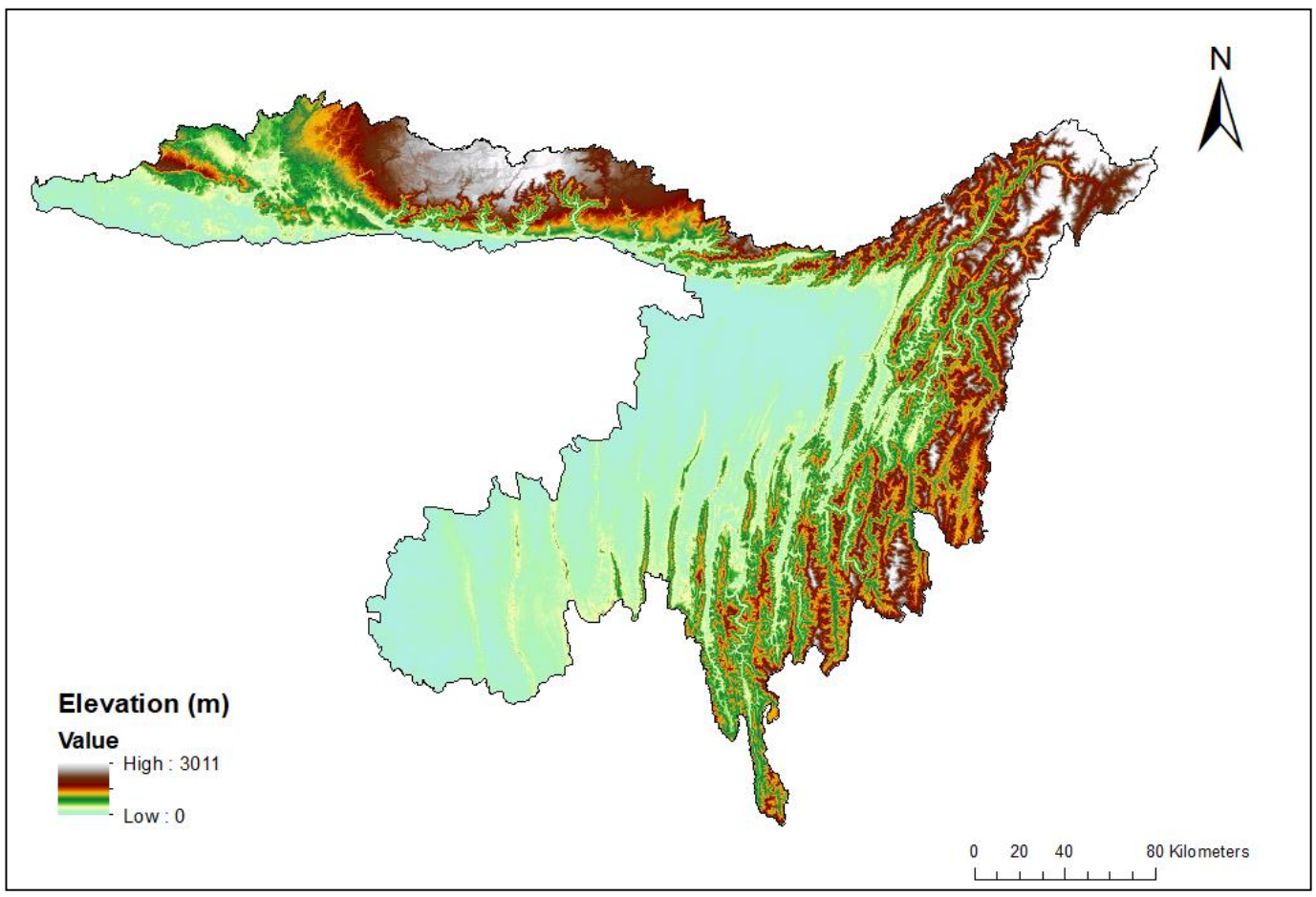


Figure 4.1: Major River Basins of India

4.1 BARAK & OTHERS BASIN



HIGHLIGHTS

- *Average annual water resources availability of Barak & Others basin is 93.65 BCM.*
- *Maximum annual water availability is 127.74 BCM during 1987-88.*
- *Minimum annual water availability is 52.02 BCM during 1994-95.*
- *Average annual precipitation is 134.46 BCM (2834.28 mm).*
- *Maximum annual precipitation is 176.36 BCM (3718 mm) during 1987-88.*
- *Minimum annual precipitation is 98.51 BCM (2077 mm) during 1994-95.*

4.1.1 About Barak & others Basin

The Barak & others basin extends over an area of 47,440 sq. km, which is nearly 1.44% of the total geographical area of the country. The basin covers the States of Meghalaya (24%), Manipur (20%), Mizoram (19%), Tripura (18%), Assam (17%) and Nagaland (2%). The Barak River rises from the Manipur Hills, south of Mao in Senapati District at an elevation of 2,331 m. Then it flows along Nagaland-Manipur border through hilly terrains and enters Assam. It further enters Bangladesh where it is known by the name -Surma and the Kushiyara and later is called the Meghna before receiving combined flow of the Ganga and the Brahmputra. The length of Barak River from its origin up to the border of Assam along the Kushiyara is 564 km. The principal tributaries from right side are the Jiri, the Chiri, the Modhura, the Jatinga, the Harang whereas the Dhareshwari, the Singla, the Longai, the Sonai are principal tributaries joining from the left side.

4.1.2 Geo-Spatial Datasets

4.1.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Barak & others basin for year 2022-23 is shown in Figure 4.1.1. The map indicates various land classes and land use patterns in the basin. The major land use classes consist of Kharif only, Double/Triple, waste lands etc.

Table 4.1.1 shows the percentage area of each land use class in the basin for year 2022-23.

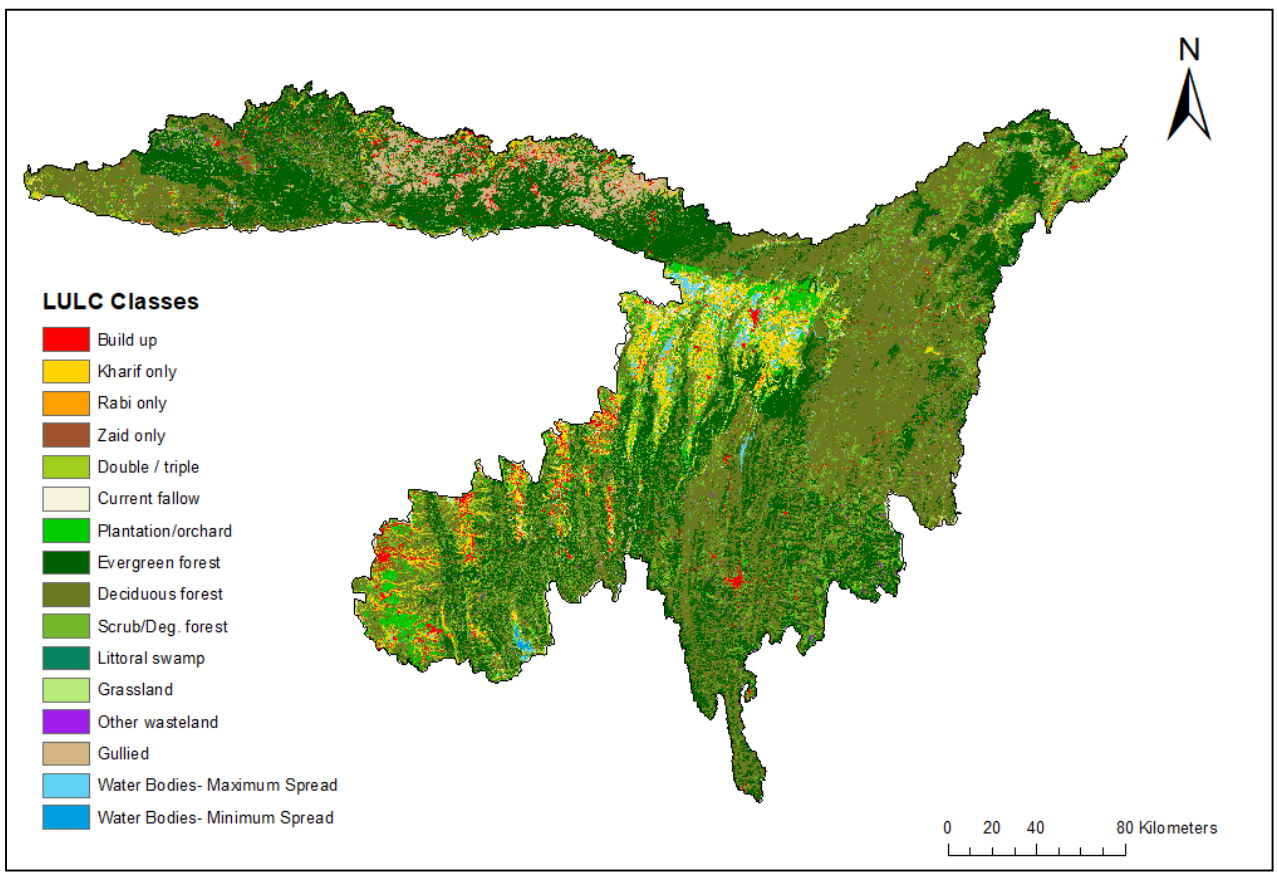


Figure 4.1.1: LULC Map of Barak & Others basin

Table 4.1.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	2.23
2.	Kharif only	3.78
3.	Rabi crop land	0.06
4.	Double/Triple/Annual crop land	3.9
5.	Current Fallow land	1.21
6.	Plantation/Orchard	3.08
7.	Evergreen/Semi evergreen	30.41
8.	Deciduous woodland	40.16
9.	Degraded woodland	10.06
10.	Grassland	0.02
11.	Shifting Cultivation	0.41
12.	Waste lands	3.52
13.	Water Bodies - maximum spread	1.07
14.	Water Bodies - minimum spread	0.09

4.1.3 Hydro-Meteorological and other Input Data

4.1.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.1.2. The variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.1.3. The average precipitation of 38 years is approximately 134.46 BCM (2834.28 mm).

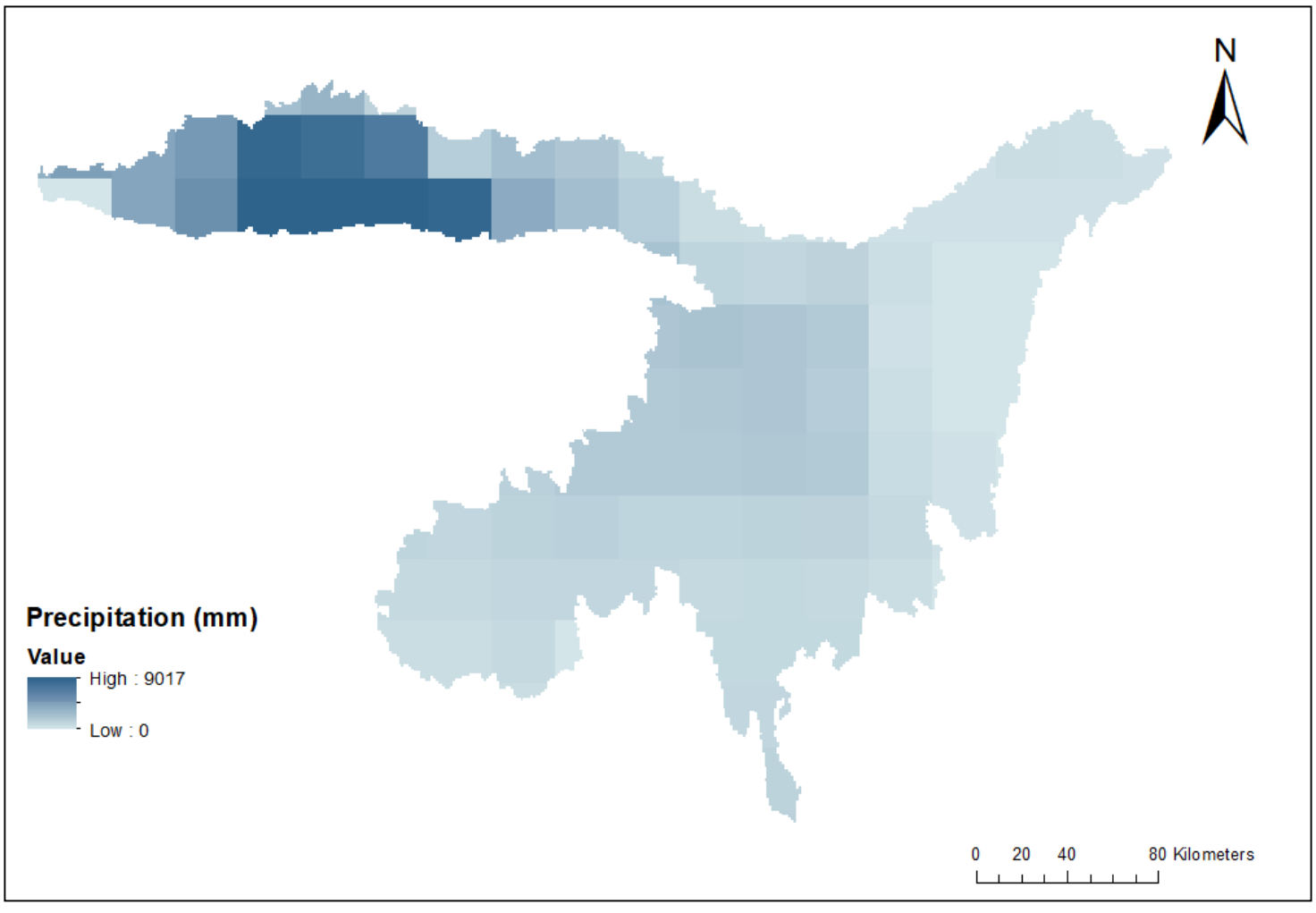


Figure 4.1.2: Precipitation map of Barak & Others basin

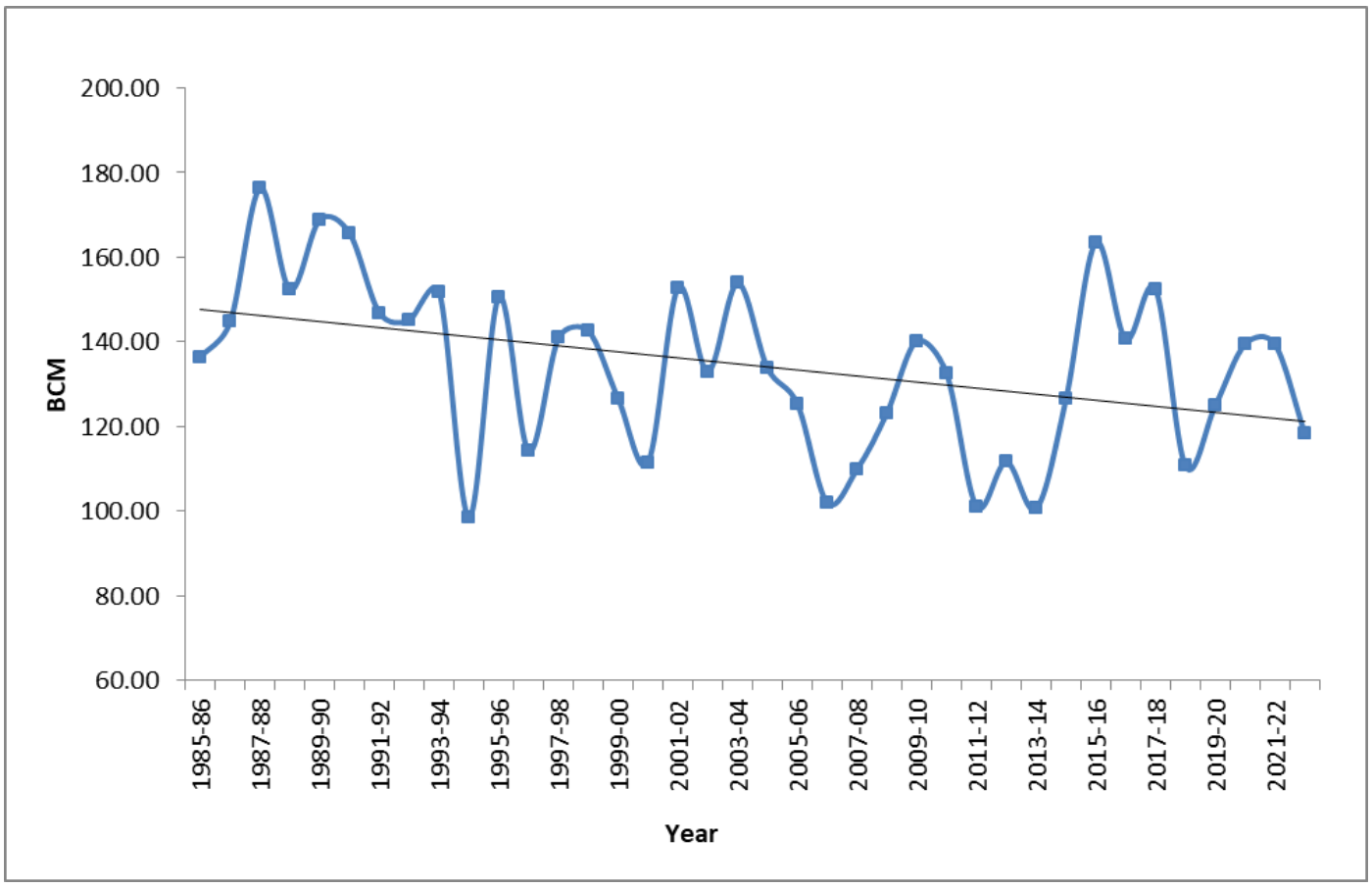


Figure 4.1.3: Annual Precipitation in Barak & Others basin

4.1.3.2 Actual Evapotranspiration

The spatial variation of actual evapotranspiration in the basin for the year 2022-23 has been shown in Figure 4.1.4. The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.1.5. The average ET of 38 years is 41.85 BCM (828.23 mm).

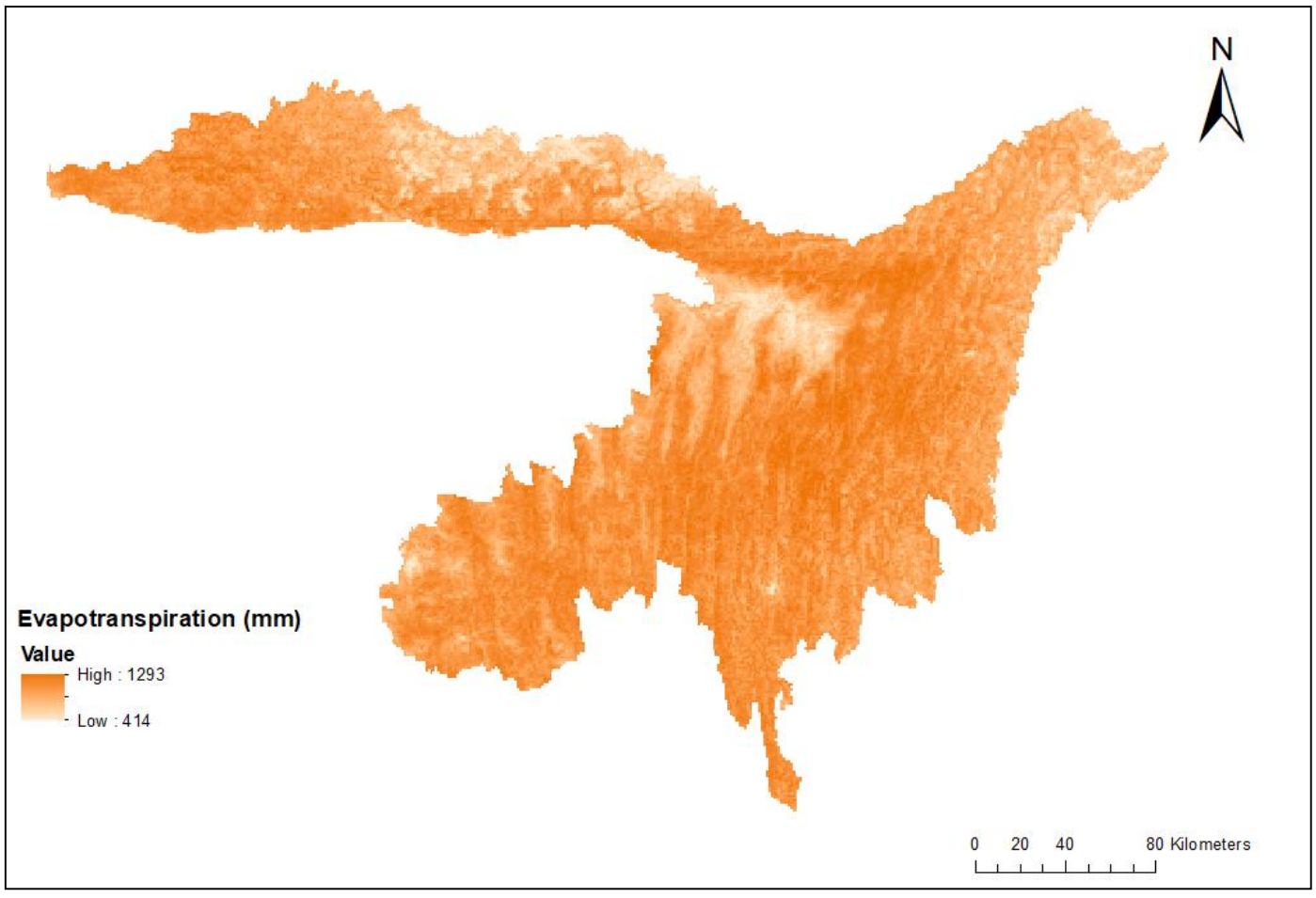


Figure 4.1.4: Evapotranspiration map of Barak & Others basin

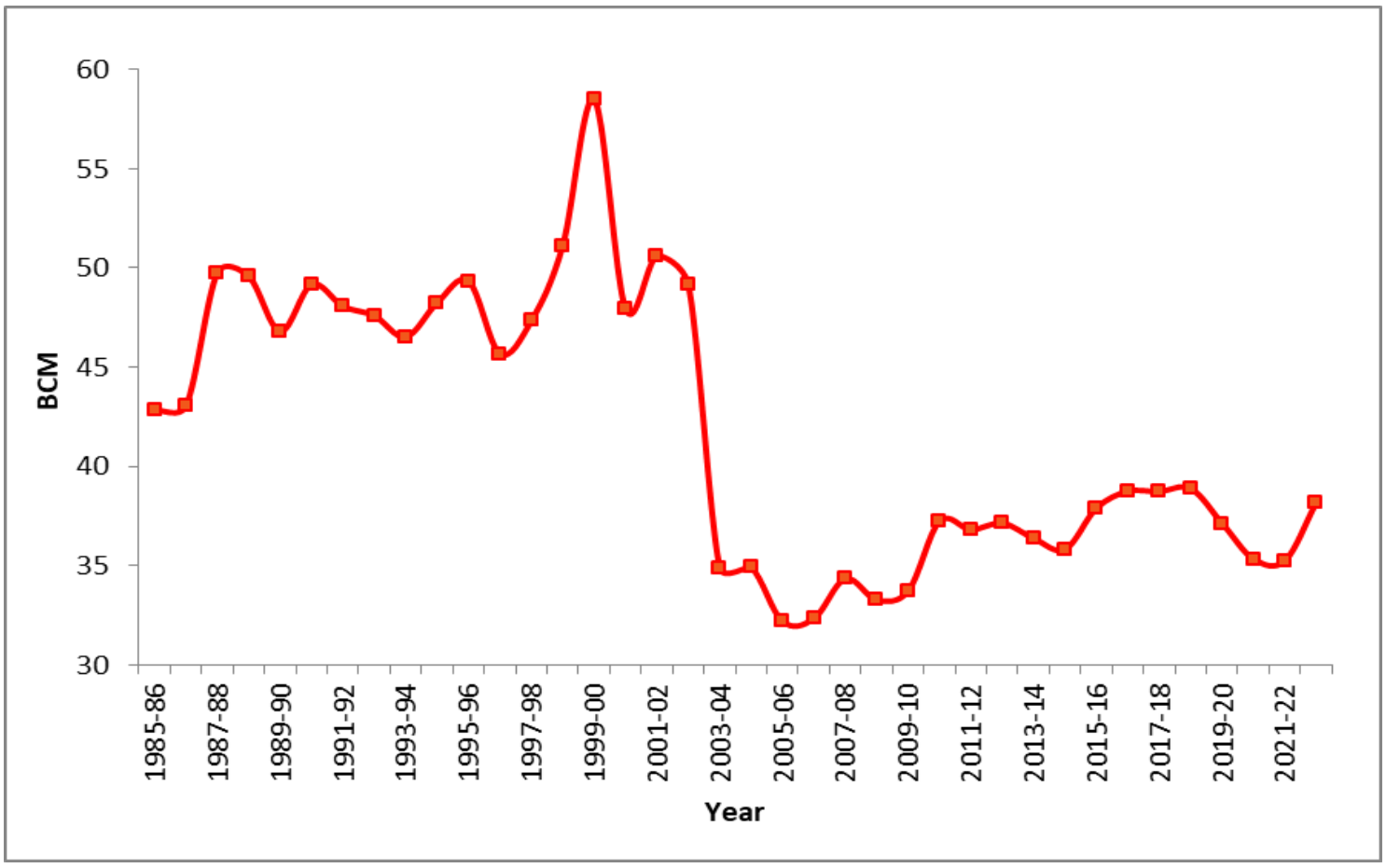


Figure 4.1.5: Annual Evapotranspiration in Barak & Others basin

4.1.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.1.6. The average evaporation from the reservoirs in the basin is 0.61 BCM.

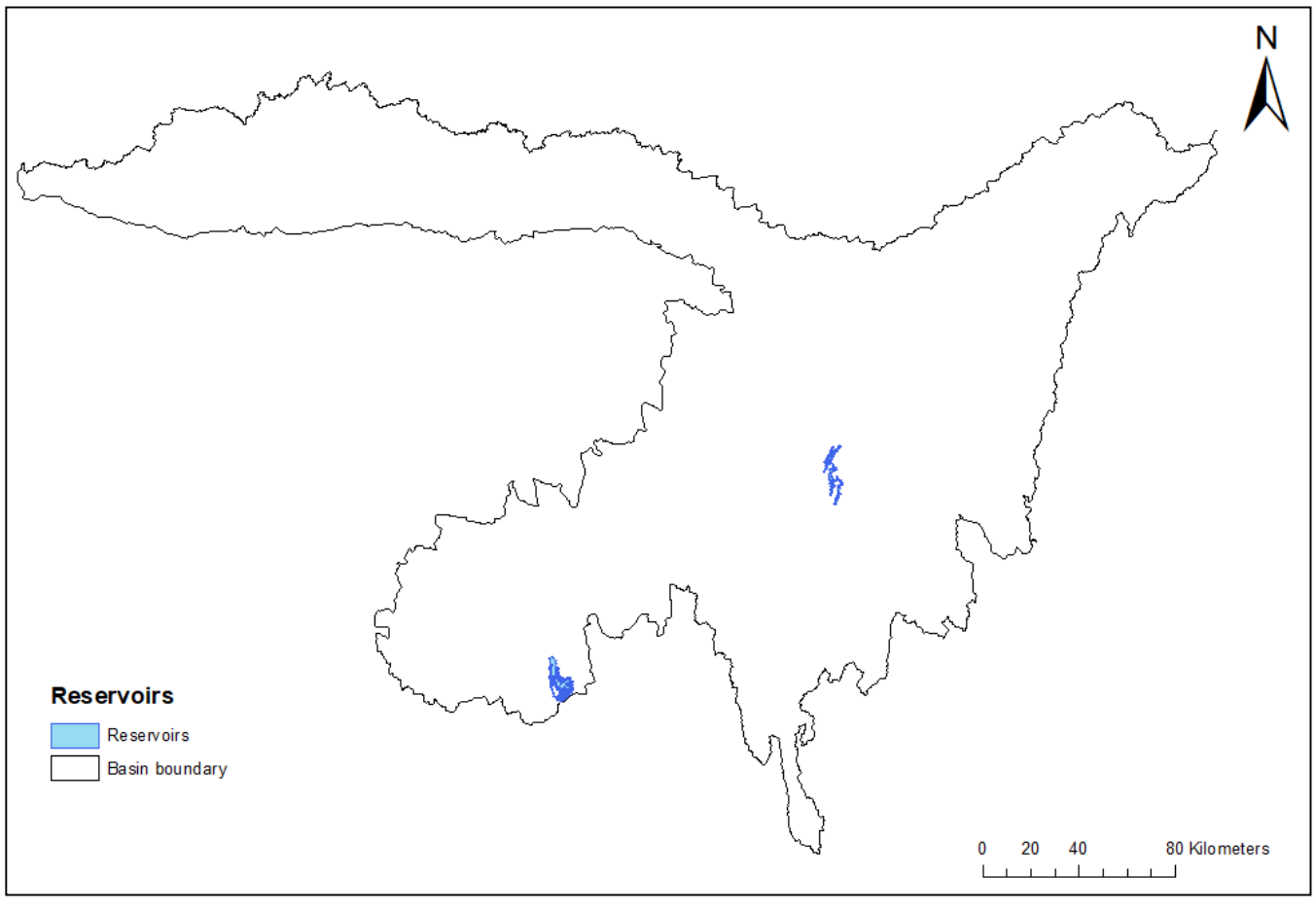


Figure 4.1.6: Reservoir map of Barak & Others Basin

4.1.3.4 Evapotranspiration from Irrigation Input

The Average Annual Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 0.44 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.1.7. Yearly variations in ET_{II} are shown in Figure 4.1.8.

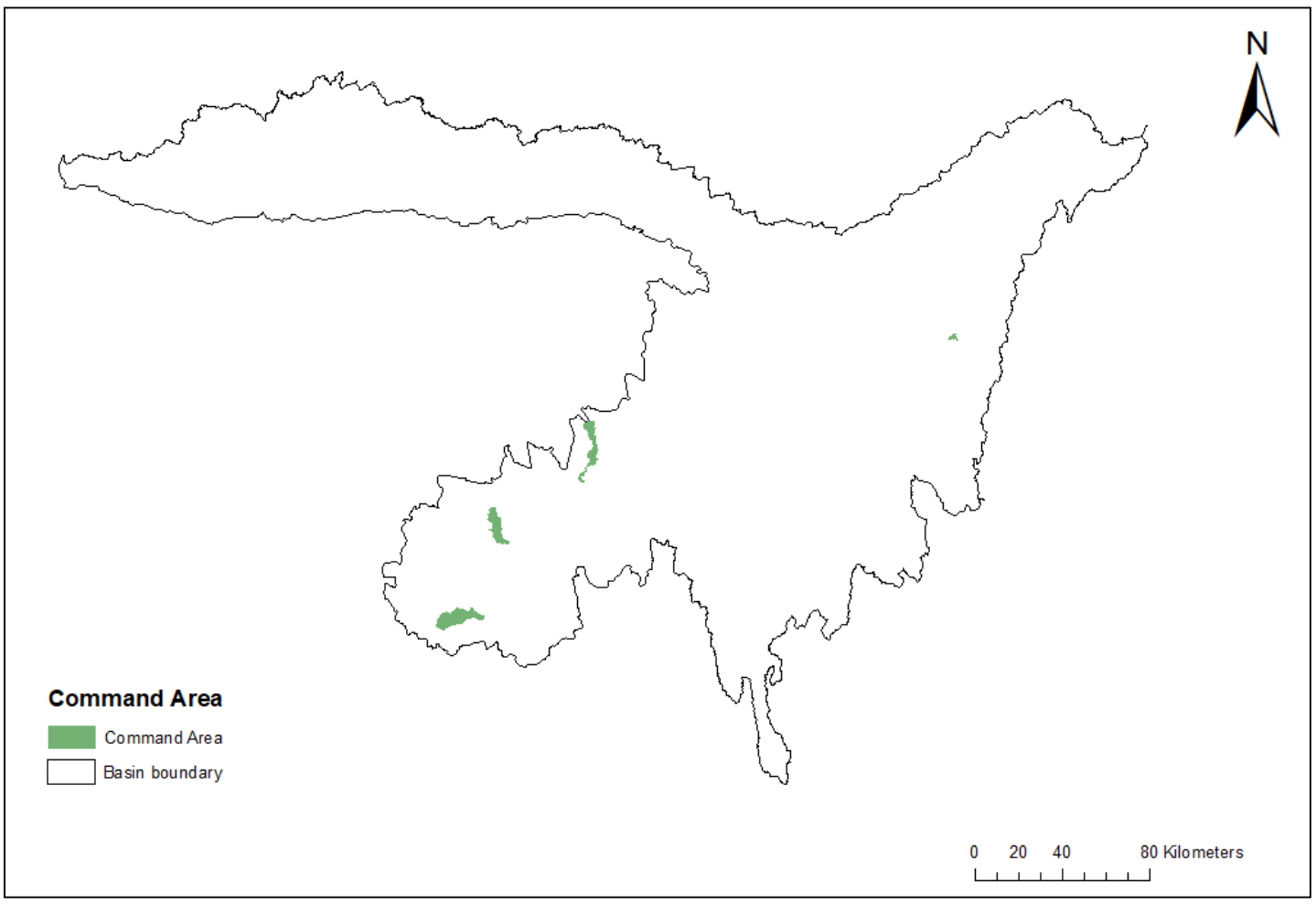


Figure 4.1.7: Command Area map of Barak & Others basin

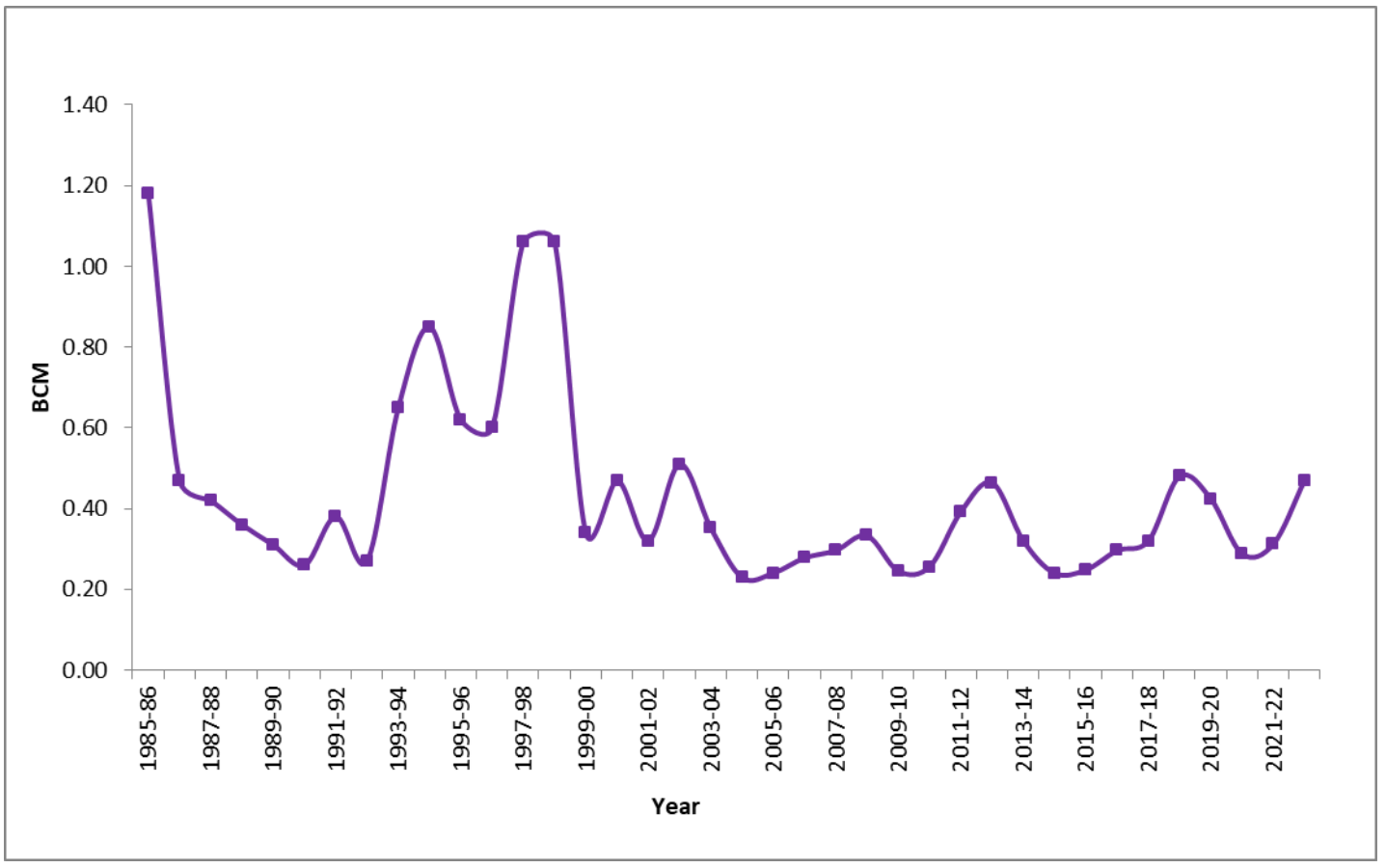


Figure 4.1.8: ET from Irrigation Input in Barak & Others basin

4.1.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is 0.05 BCM and 0.07 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.25 BCM.

4.1.4 Previous Estimates

In 1993 estimate, water resources up to Badarpurghat (Catchment area = 25,070 sq.km) were directly taken from report on Master Plan for Barak sub basin-1988 submitted by Brahmaputra Board. The total catchment area of Barak in India was considered as 41,723 sq. km. For rest of the region (Meghalaya and Tripura) no direct estimate was available. A proportionate approach was adopted to estimate the water resources of the remaining basin area. Accordingly, the potential was estimated as 48.36 BCM. In 2019, CWC study estimated water availability of the total basin as 86.67 BCM (catchment area = 47440 sq.km.).

4.1.5 Annual Water Availability of Barak & other Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs, the average annual water availability from year 1985-86 to 2022-23 is estimated as 93.65 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.1.9. The results of Barak and other basin are shown in Table 4.1.3.

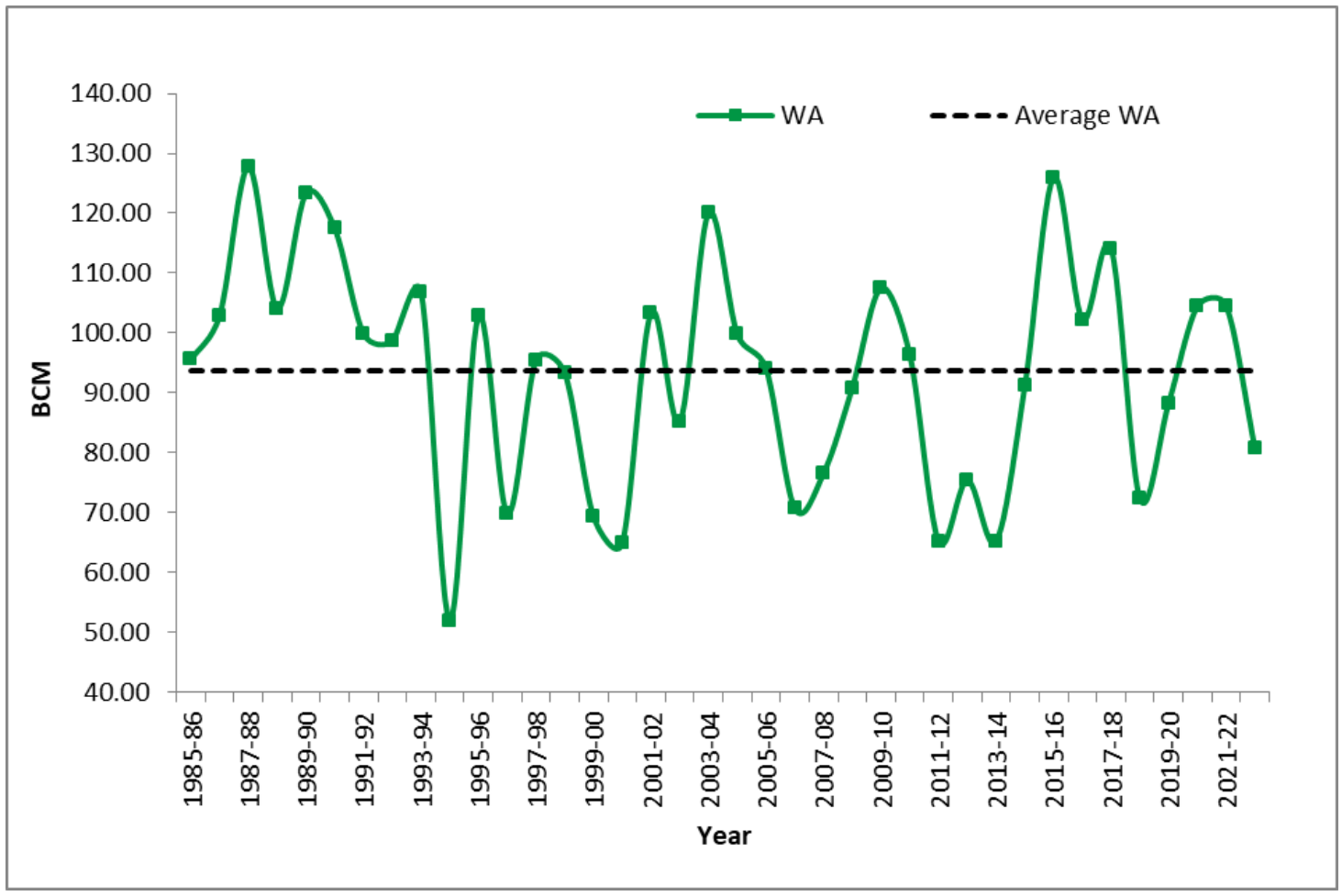


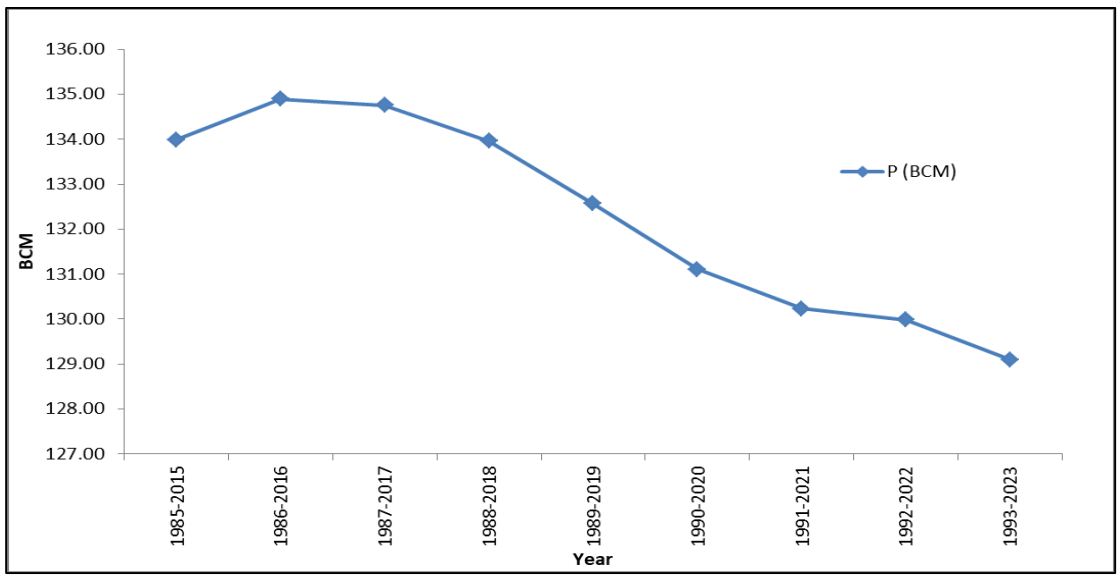
Figure 4.1.9: Water Availability of Barak & Others basin

4.1.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Barak & Others Basins is given at Table 4.1.2. A line diagram of moving average of P and WA is shown in Figure 4.1.10.

Table 4.1.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	134.00	92.19
1986-2016	134.90	93.21
1987-2017	134.76	93.19
1988-2018	133.96	92.73
1989-2019	132.57	91.67
1990-2020	131.11	90.50
1991-2021	130.23	90.07
1992-2022	129.99	90.23
1993-2023	129.10	89.63



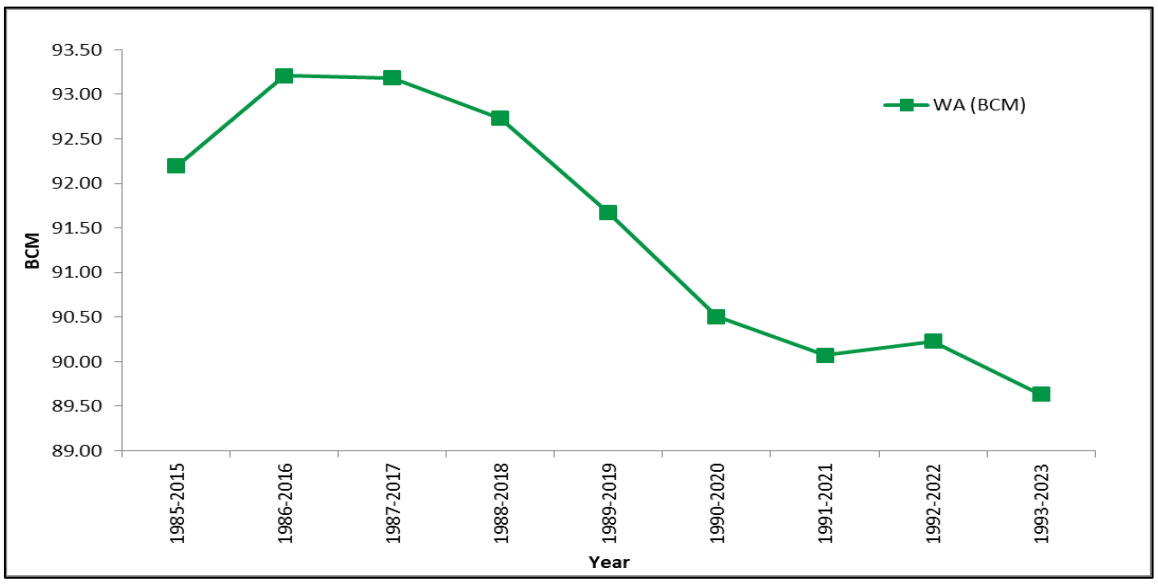


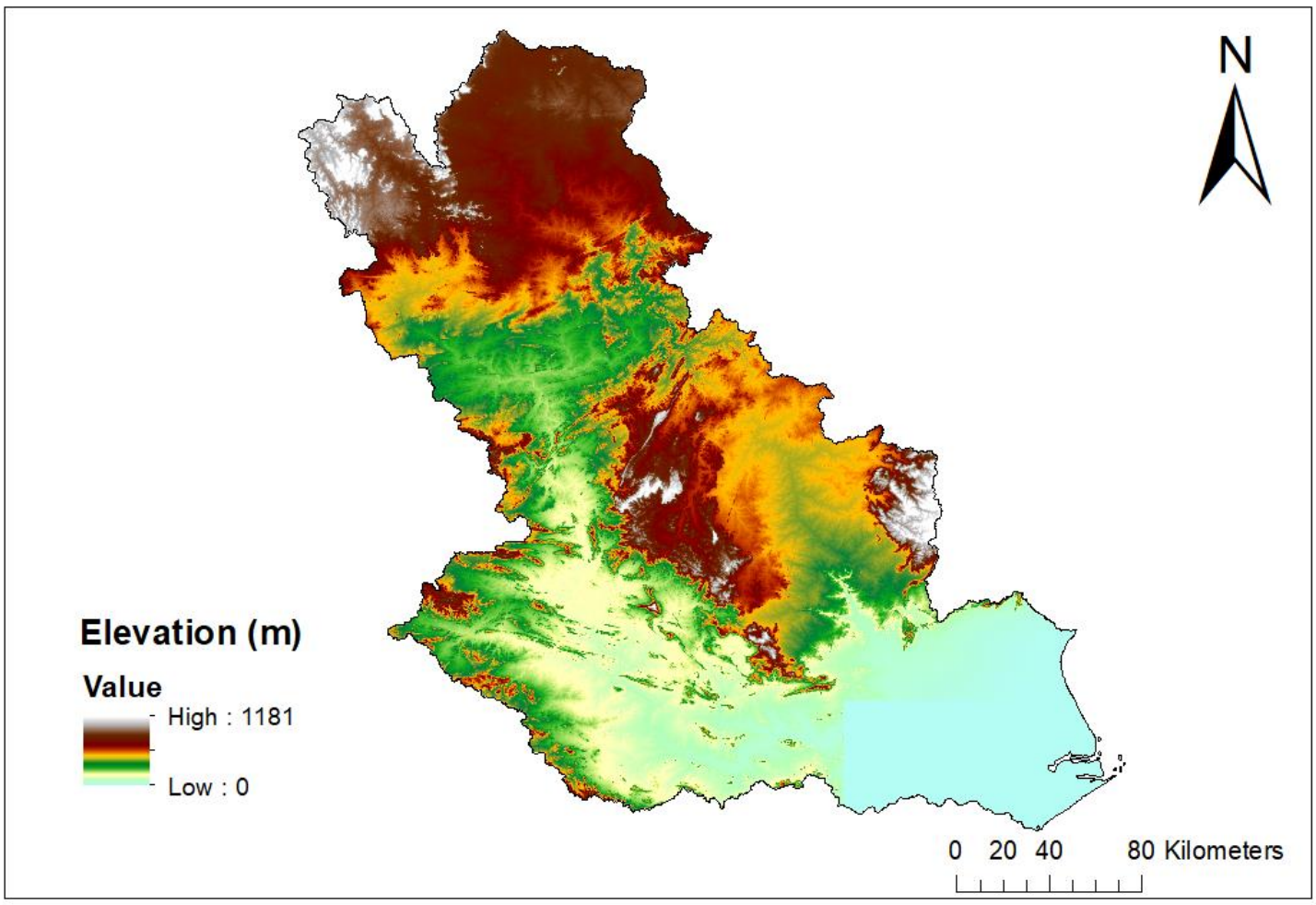
Figure 4.1.10: Moving Average of P and WA for 30 years

Table 4.1.3: Water Availability of Barak and Others basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	136.46	40.89	95.57
1986-87	144.74	41.79	102.95
1987-88	176.36	48.62	127.74
1988-89	152.41	48.29	104.12
1989-90	168.93	45.64	123.29
1990-91	165.66	48.20	117.46
1991-92	146.87	46.98	99.89
1992-93	145.08	46.47	98.61
1993-94	151.85	45.05	106.80
1994-95	98.51	46.49	52.02
1995-96	150.63	47.83	102.80
1996-97	114.23	44.39	69.84
1997-98	140.96	45.40	95.56
1998-99	142.60	49.28	93.32
1999-00	126.55	57.25	69.30
2000-01	111.59	46.62	64.97
2001-02	152.79	49.44	103.35
2002-03	132.96	47.78	85.18
2003-04	153.89	33.86	120.03
2004-05	133.82	34.07	99.75
2005-06	125.35	31.29	94.06
2006-07	102.03	31.32	70.71
2007-08	109.91	33.31	76.60
2008-09	123.15	32.25	90.90
2009-10	140.24	32.69	107.55
2010-11	132.55	36.27	96.28
2011-12	101.17	35.91	65.26
2012-13	111.62	36.18	75.44
2013-14	100.59	35.34	65.25
2014-15	126.43	35.19	91.24
2015-16	163.53	37.57	125.96
2016-17	140.64	38.37	102.27
2017-18	152.40	38.33	114.07
2018-19	110.69	38.32	72.37
2019-20	124.94	36.65	88.29
2020-21	139.45	34.97	104.48
2021-22	139.42	34.86	104.56
2022-23	118.42	37.63	80.79
Average	**134.46**	**40.81**	**93.65**

4.2 BRAHMANI-BAITARANI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Brahmani-Baitarani basin is 31.27 BCM.*
- *Maximum annual water availability is 55 BCM during 1994-95.*
- *Minimum annual water availability is 13 BCM during 2010-11.*
- *Mean annual precipitation is 80.24 BCM (1489 mm).*
- *Maximum annual precipitation is 108.45 BCM (2012 mm) during 1994-95.*
- *Minimum annual precipitation is 61.67 BCM (1144 mm) during 2010-11.*

4.2.1 About Brahmani-Baitarani Basin

The combined Brahmani-Baitarani river basin extends over a geographical area of 53,902 sq. km and the basin is bounded on the north by the Chhotanagpur Plateau, on the west and south by the ridge separating it from Mahanadi basin and on the east by the Bay of Bengal. The drainage area of the basin lies in the states of Odisha (33,923 sq.km.), Jharkhand (15,479 sq.km.) and Chhattisgarh (1,367 sq.km.). Out of the total basin area, major part of 66.82% is covered in Odisha, 30.49% in Jharkhand and 2.69% in Chhattisgarh. The basin is bounded by 20^{o} 29' 00" to 23^{o} 37' 47" North latitude and 83^{o} 53' 49" to 87^{o} 1' 27" East longitude.

4.2.2 Geo-Spatial Datasets

4.2.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Brahmani-Baitarani basin for year 2022-23 is shown in Figure 4.2.1. Major land use classes consist of Kharif only and deciduous woodland etc.

Table 4.2.1 shows the percentage area of each land use class in the basin for year 2022-23.

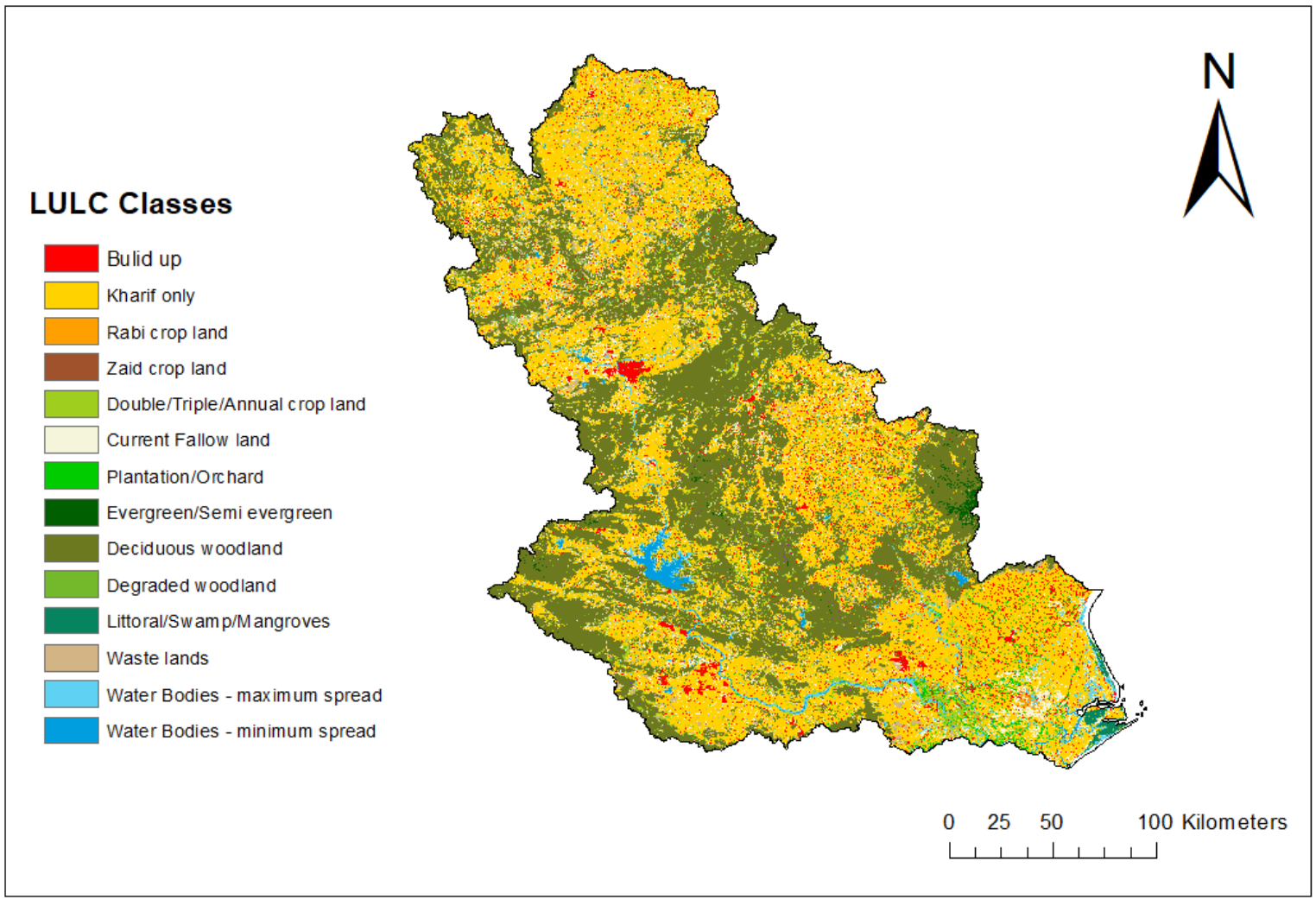


Figure 4.2.1: LULC Map of Brahmani-Baitarani basin

Table 4.2.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Built-up land	4.07
2.	Kharif only	27.15
3.	Rabi crop land	0.20
4.	Zaid crop land	0.09
5.	Double/Triple/Annual crop land	2.86
6.	Current fallow land	18.76
7.	Plantation/Orchid	0.90
8.	Evergreen/Semi-evergreen woodland	0.32
9.	Deciduous woodland	35.45
10.	Degraded woodland	1.31
11.	Littoral/Swamp/Mangroves	0.30
12.	Shifting Cultivation	0.11
13.	Waste lands	5.50
14.	Water Bodies - maximum spread	2.52
15.	Water Bodies - minimum spread	0.46

4.2.3 Hydro-Meteorological and other Input Data

4.2.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.2.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.2.3. The average precipitation of 38 years is approximately 80.24 BCM (1489 mm).

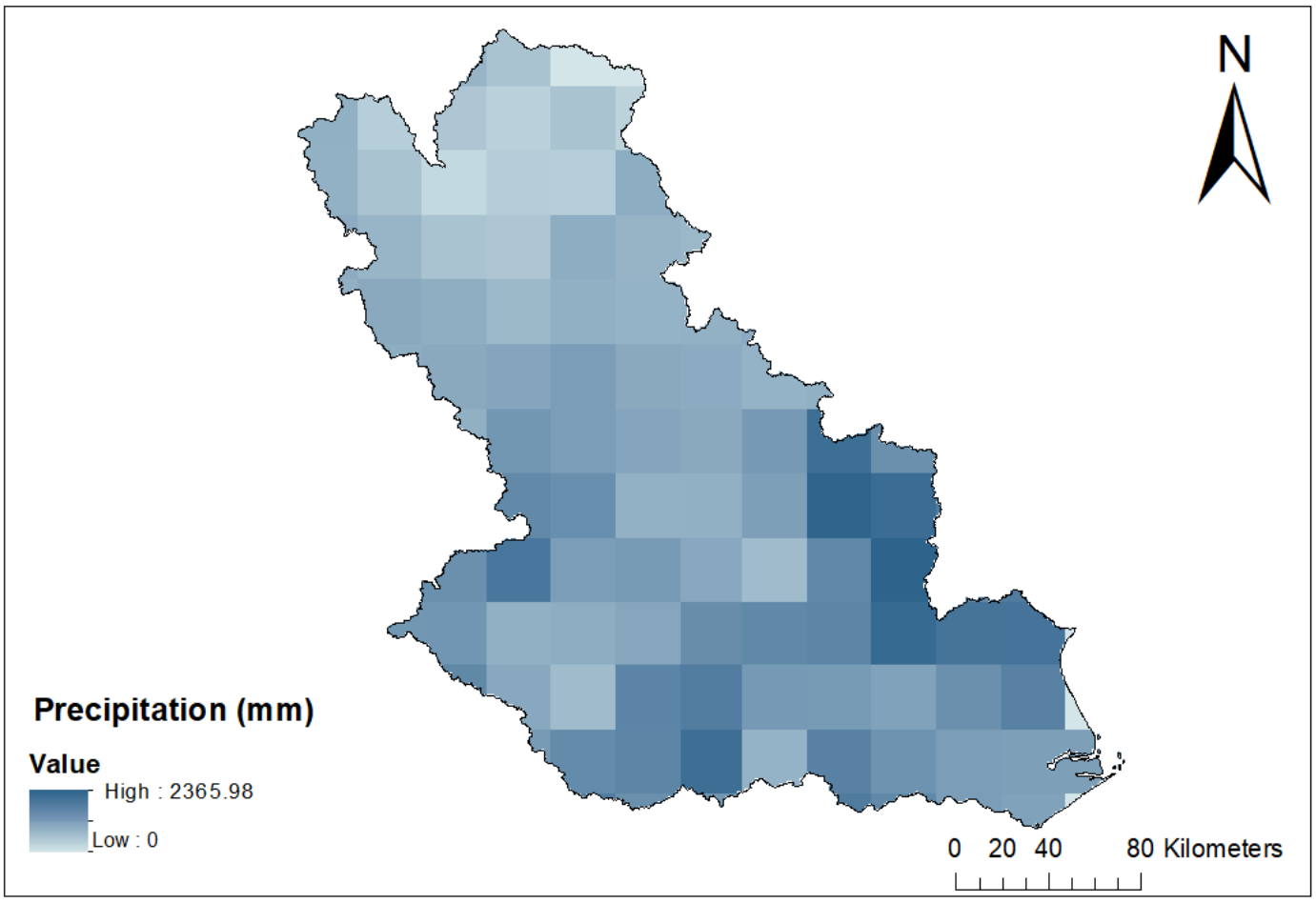


Figure 4.2.2: Precipitation map of Brahmani-Baitarani basin

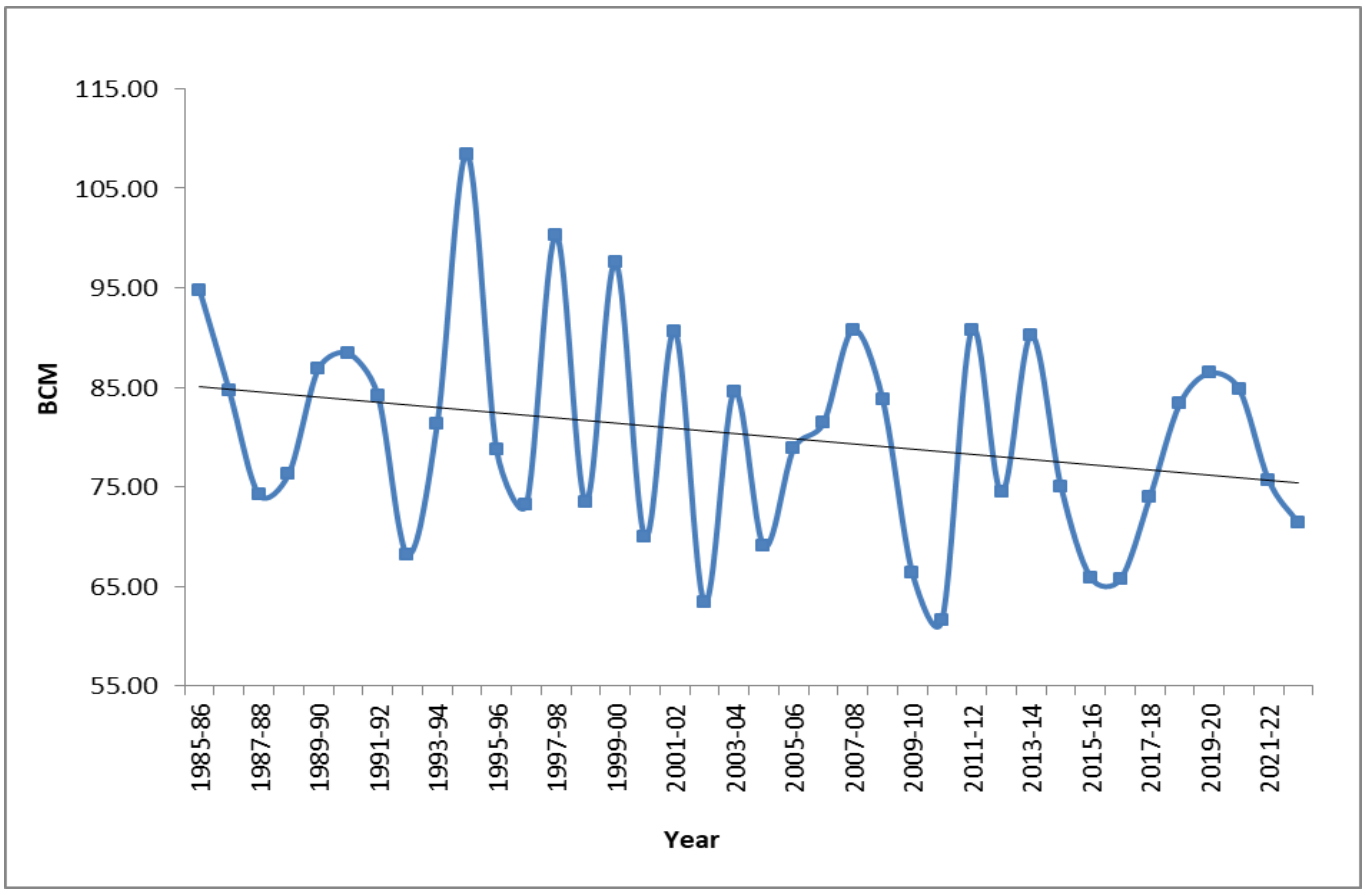


Figure 4.2.3: Annual Precipitation in Brahmani-Baitarani basin

4.2.3.2 Actual Evapotranspiration

The spatial variation of actual evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.2.4. The variation in the annual actual evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.2.5. The average ET of 38 years is approximately 53.64 BCM (995 mm).

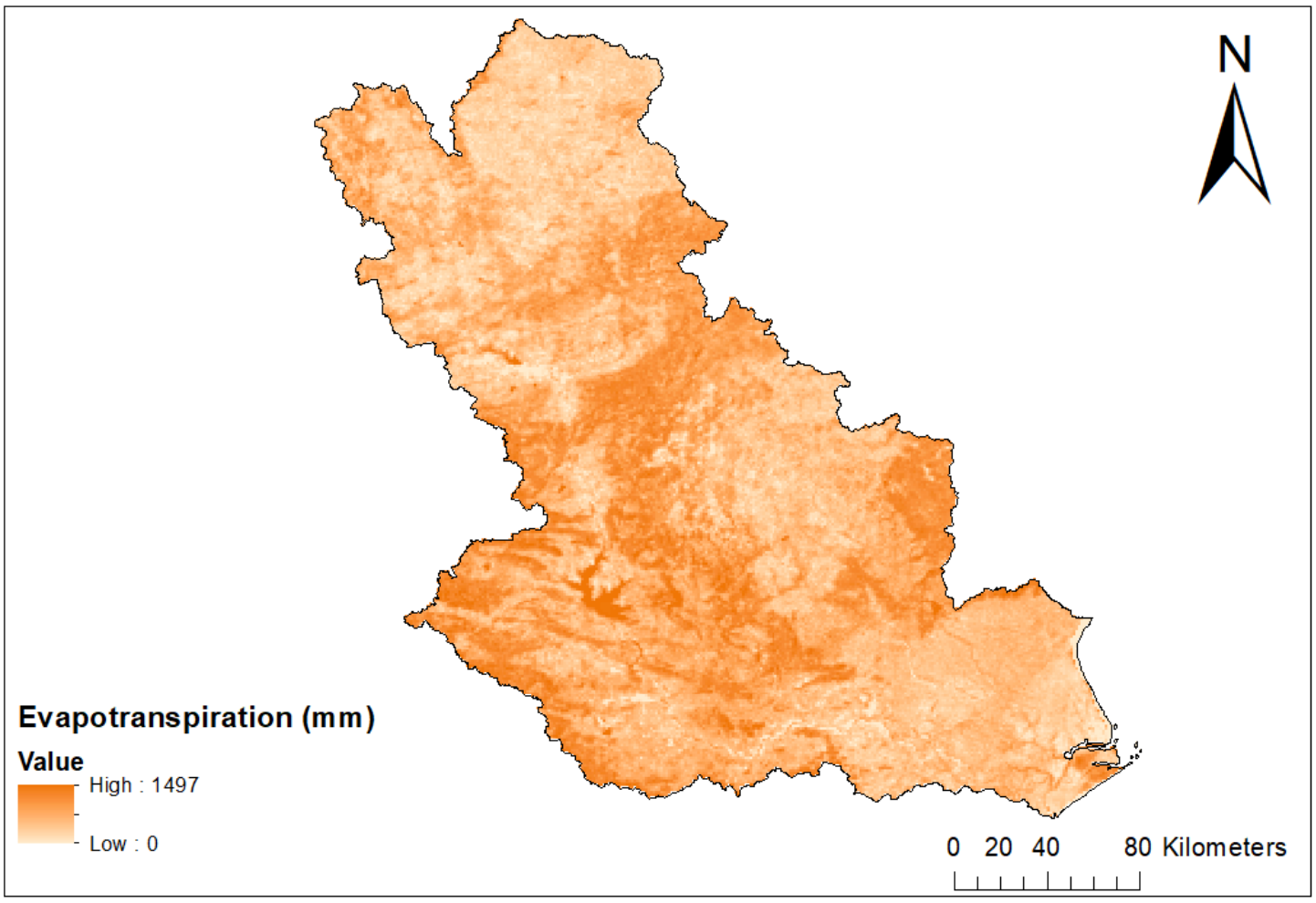


Figure 4.2.4: Evapotranspiration map of Brahmani-Baitarani basin

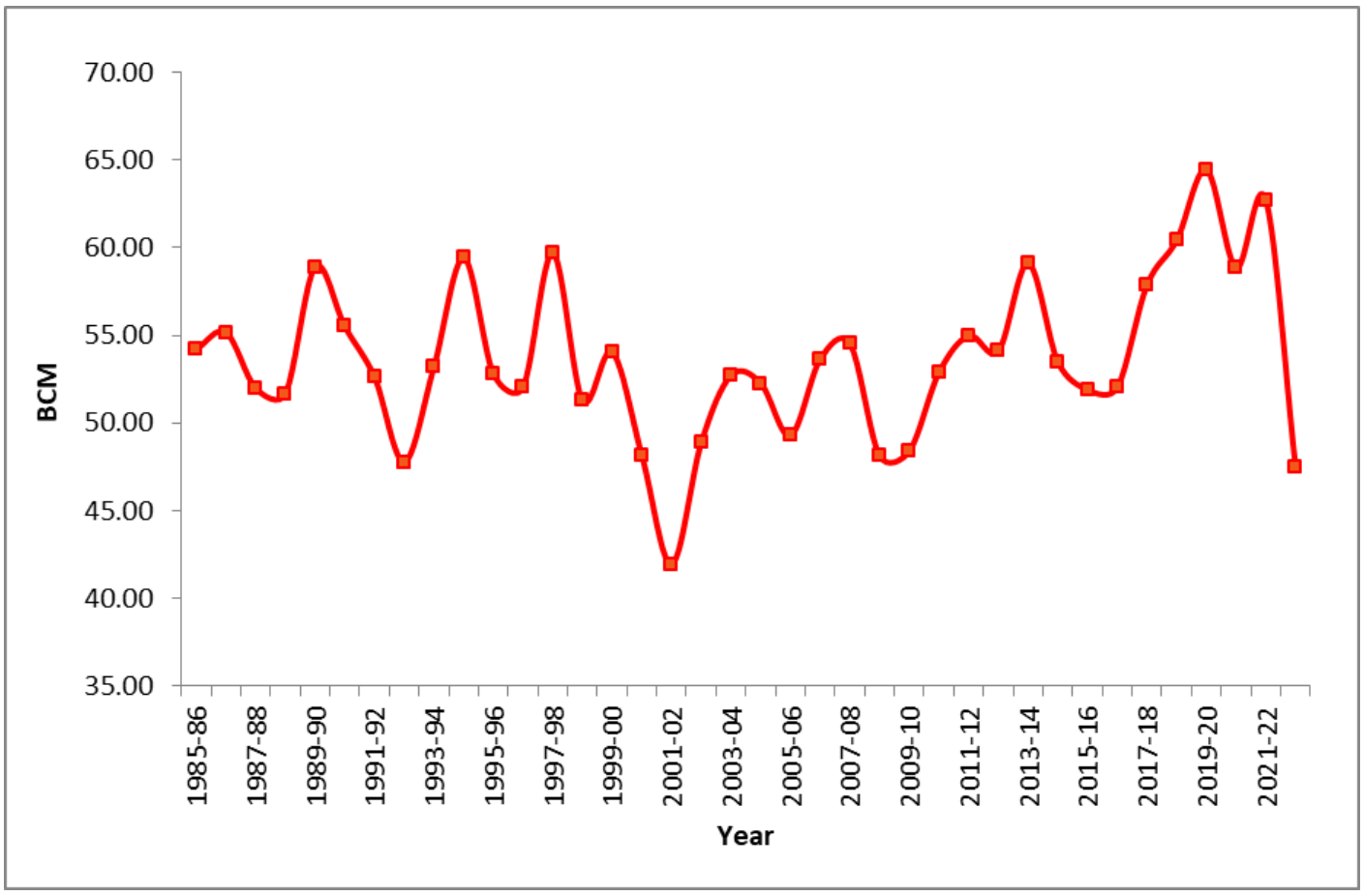


Figure 4.2.5: Annual Evapotranspiration in Brahmani-Baitarani basin

4.2.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.2.6. The average annual evaporation from the reservoirs in the basin is 0.87 BCM.

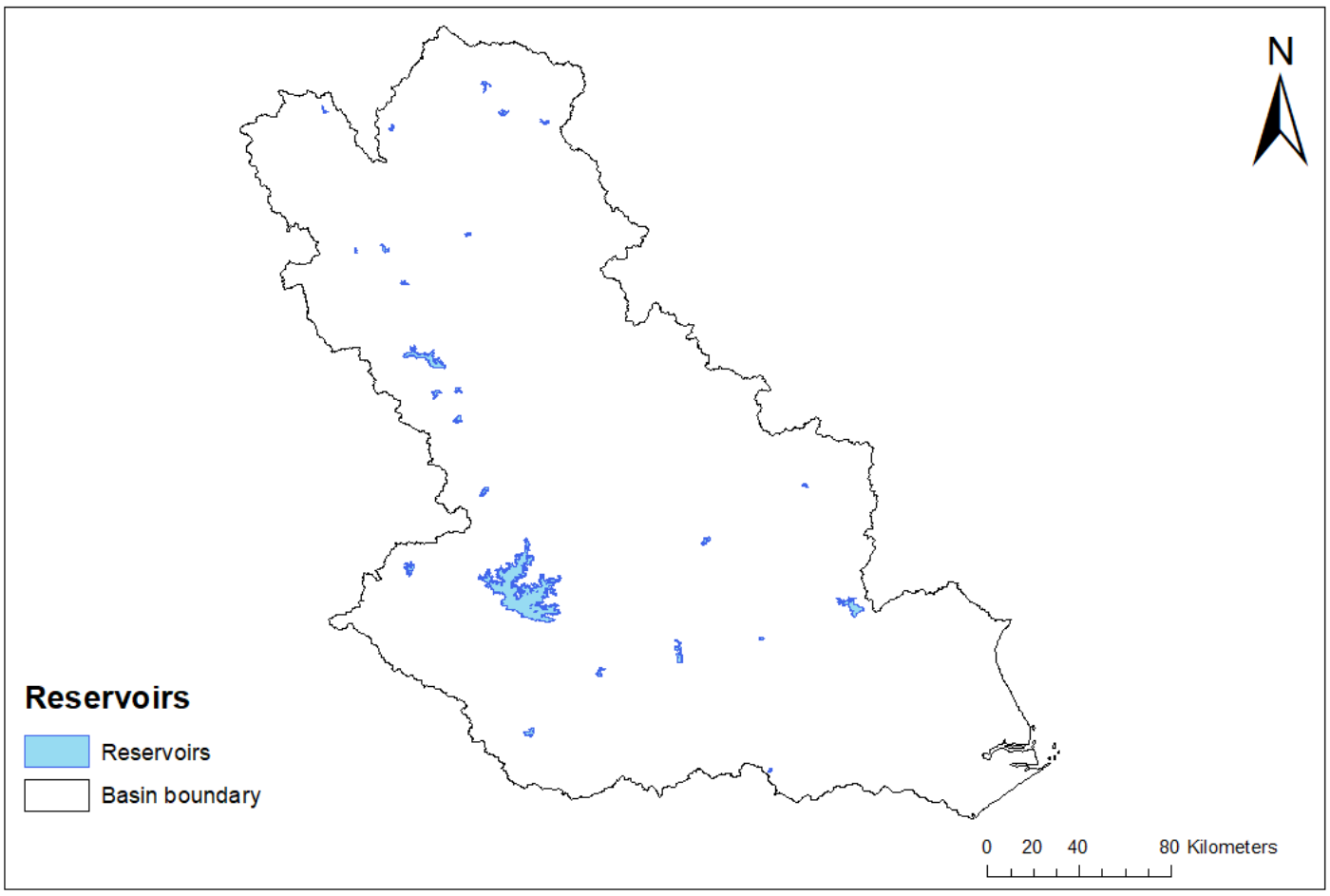


Figure 4.2.6: Reservoir map of Brahmani-Baitarani basin

4.2.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 3.81 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.2.7. The annual variation in ET_{II} is shown in Figure 4.2.8.

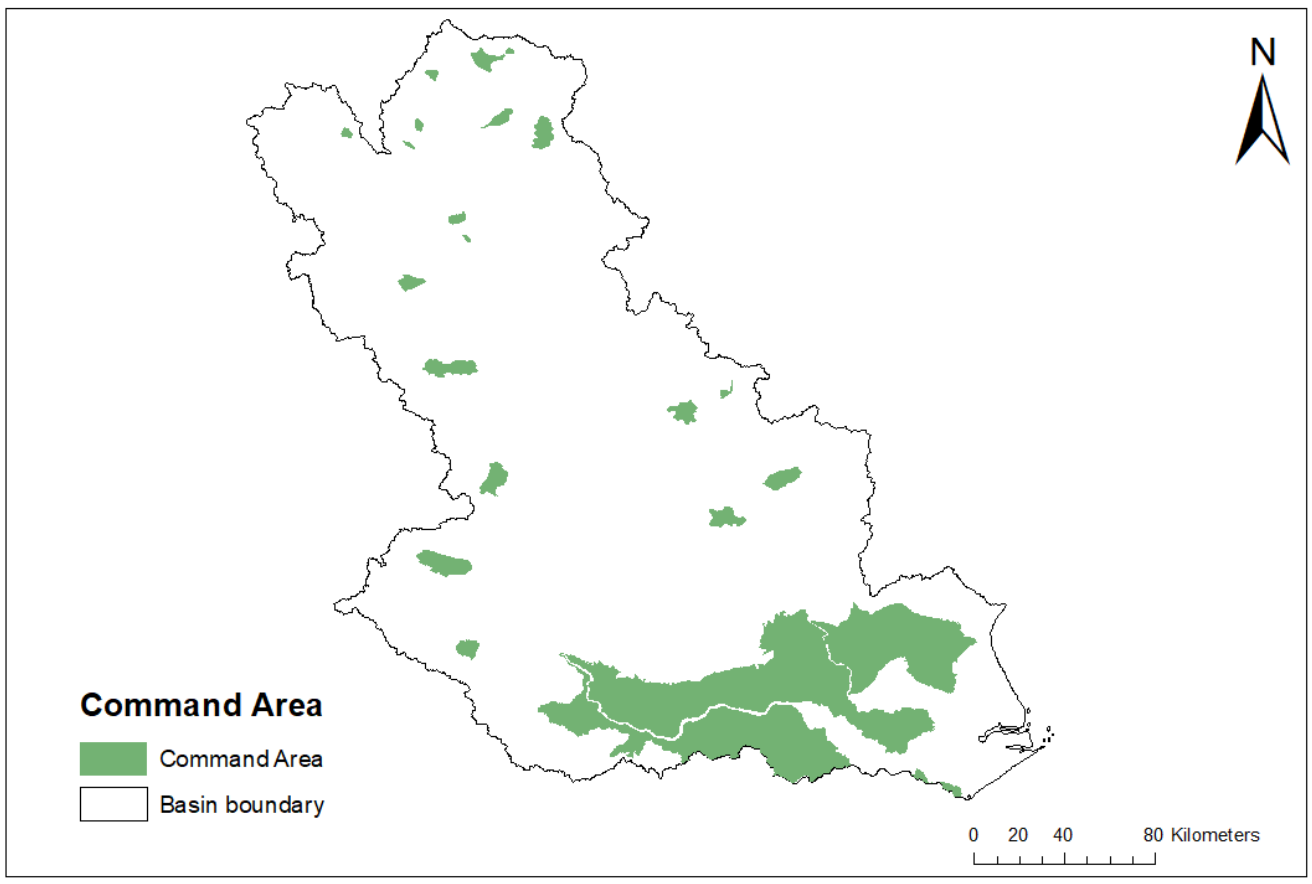


Figure 4.2.7: Command area map of Brahmani-Baitarani basin

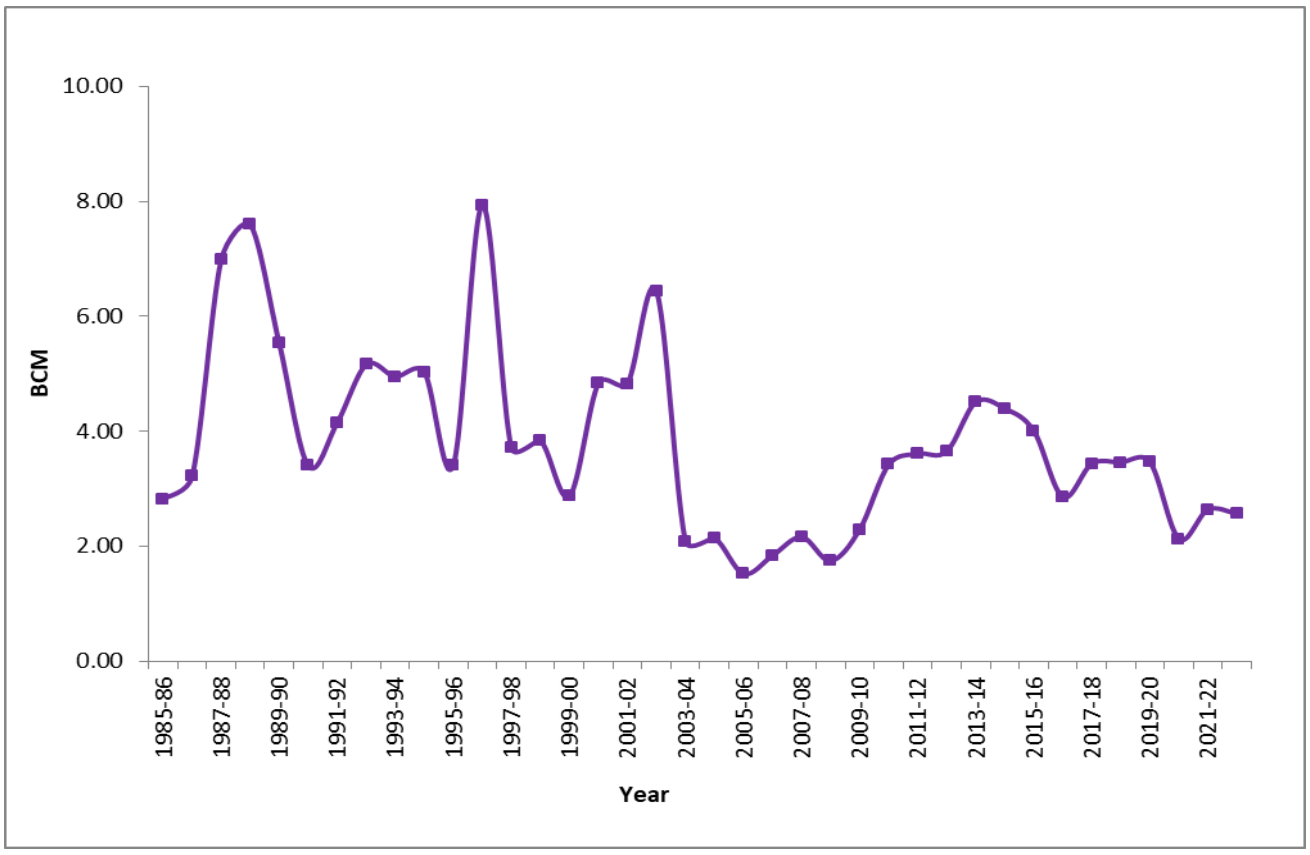


Figure 4.2.8: ET from Irrigation Input in Brahmani-Baitarani basin

4.2.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is 0 BCM and -0.02 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.25 BCM.

4.2.4 Previous Estimates

In 1949, using Khosla's empirical formula basin-wise water resources assessment of the Brahmani-Baitarani basin was estimated as 39.225 BCM. In 1960, Central Water & Power Commission while conducting irrigation potential studies assessed the total annual runoff of the basin as 28.69 BCM on the basis of Strange's precipitation-runoff coefficients. In 1988, CWC reported 36.23 BCM as average water resources of the Brahmani-Baitarani basin using Khosla's formula. In 1993 study, for the Brahmani portion, flow data at Jenapur, available for the period 1964-65 to 1984-85 and for the Baitarani portion, flow data at Biridi, available for the period 1964-65 to 1984-85 were used. The total water resource available was estimated as 28.48 BCM in the basin.

In 2019 study, the water availability of Brahmani-Baitarani basin was estimated as 35.65 BCM.

4.2.5 Annual Water Availability of Brahmani-Baitarani Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs, the average annual water availability from year 1985-86 to 2022-23 is estimated as 31.27 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.2.9. The results of Brahmani-Baitarani basin are shown in Table 4.2.3.

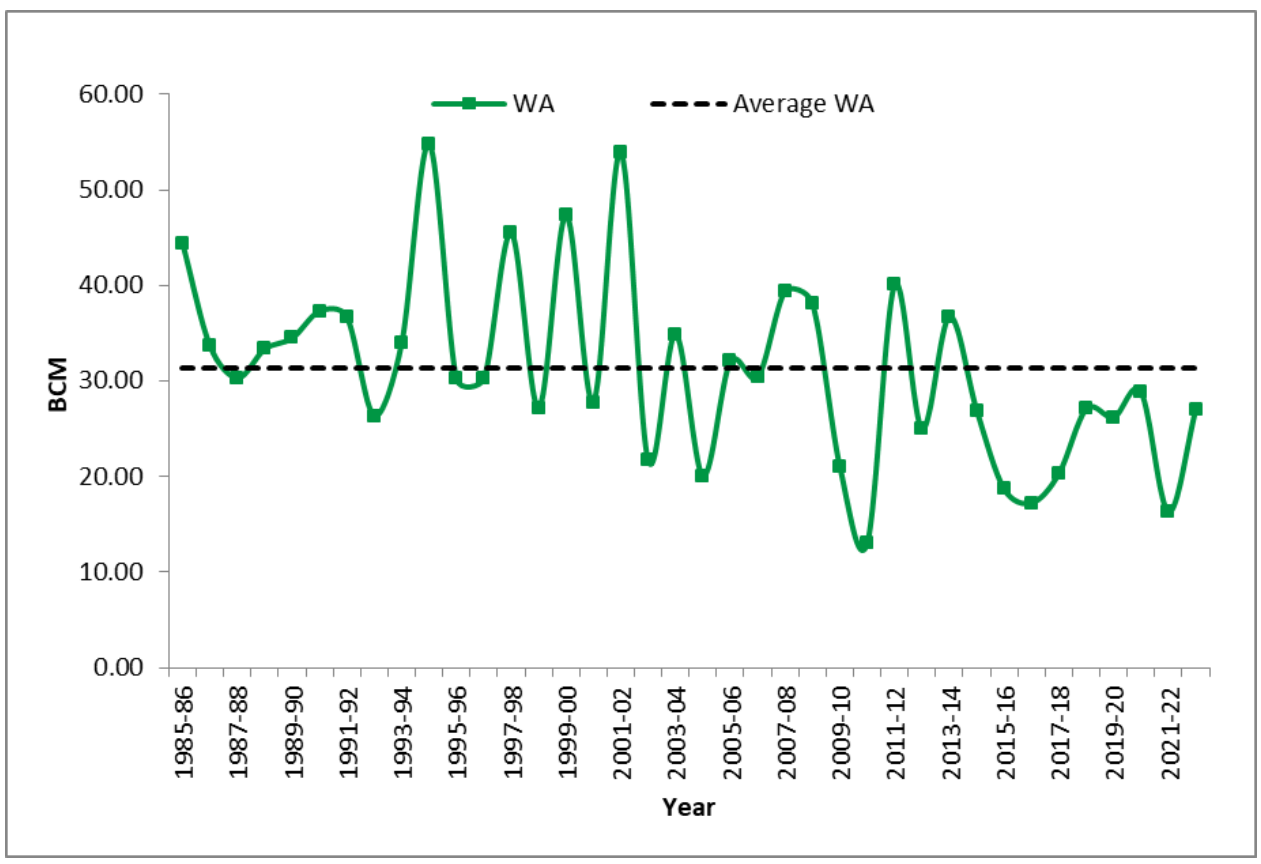


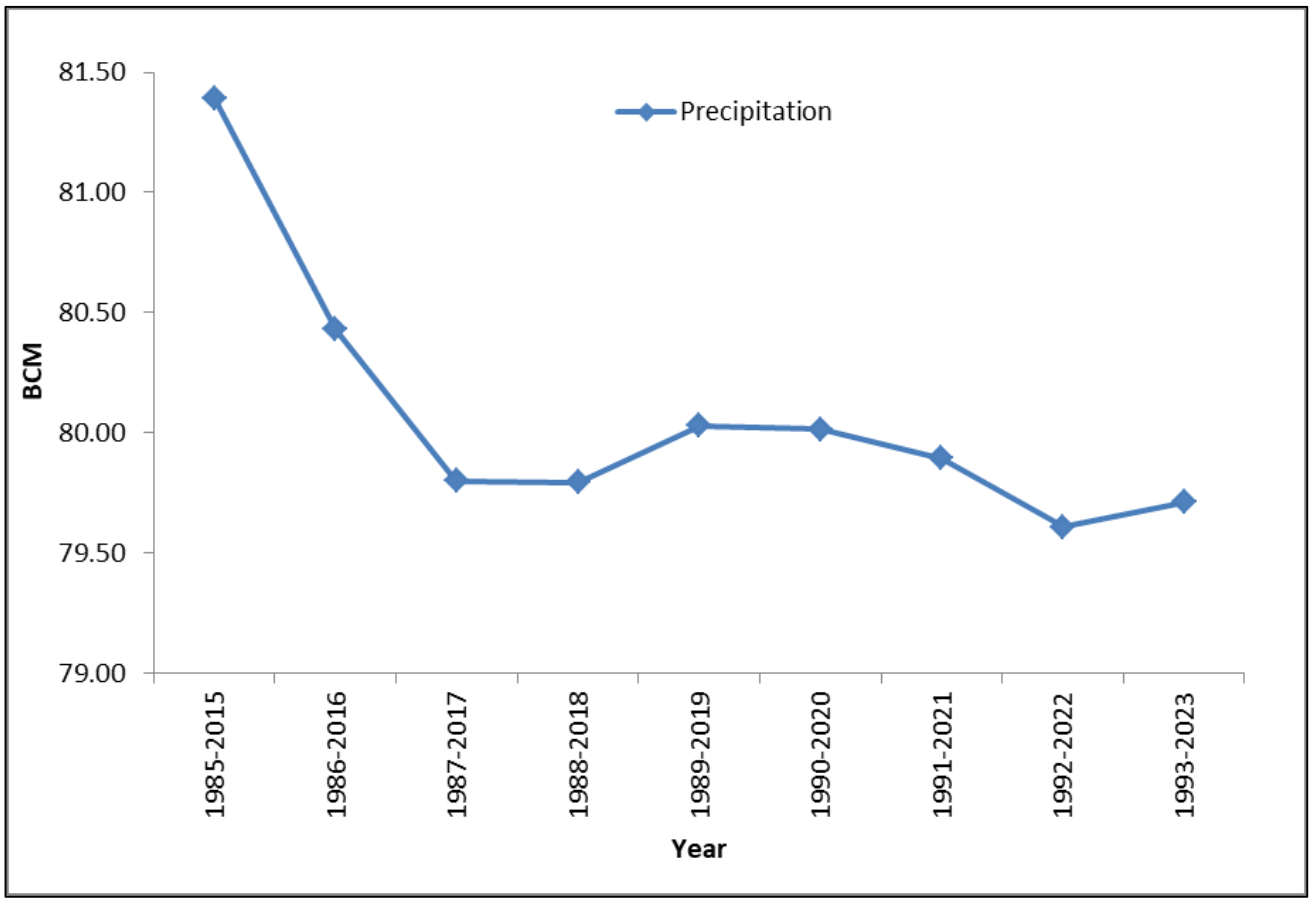
Figure 4.2.9: Water Resources Availability of Brahmani-Baitarani basin

4.2.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Brahmani-Baitarani basin is given at Table 4.2.2. A line diagram of moving average of P and WA is shown in Figure 4.2.10.

Table 4.2.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	81.39	33.56
1986-2016	80.43	32.70
1987-2017	79.80	32.15
1988-2018	79.79	31.82
1989-2019	80.03	31.61
1990-2020	80.02	31.34
1991-2021	79.89	31.05
1992-2022	79.61	30.37
1993-2023	79.71	30.40



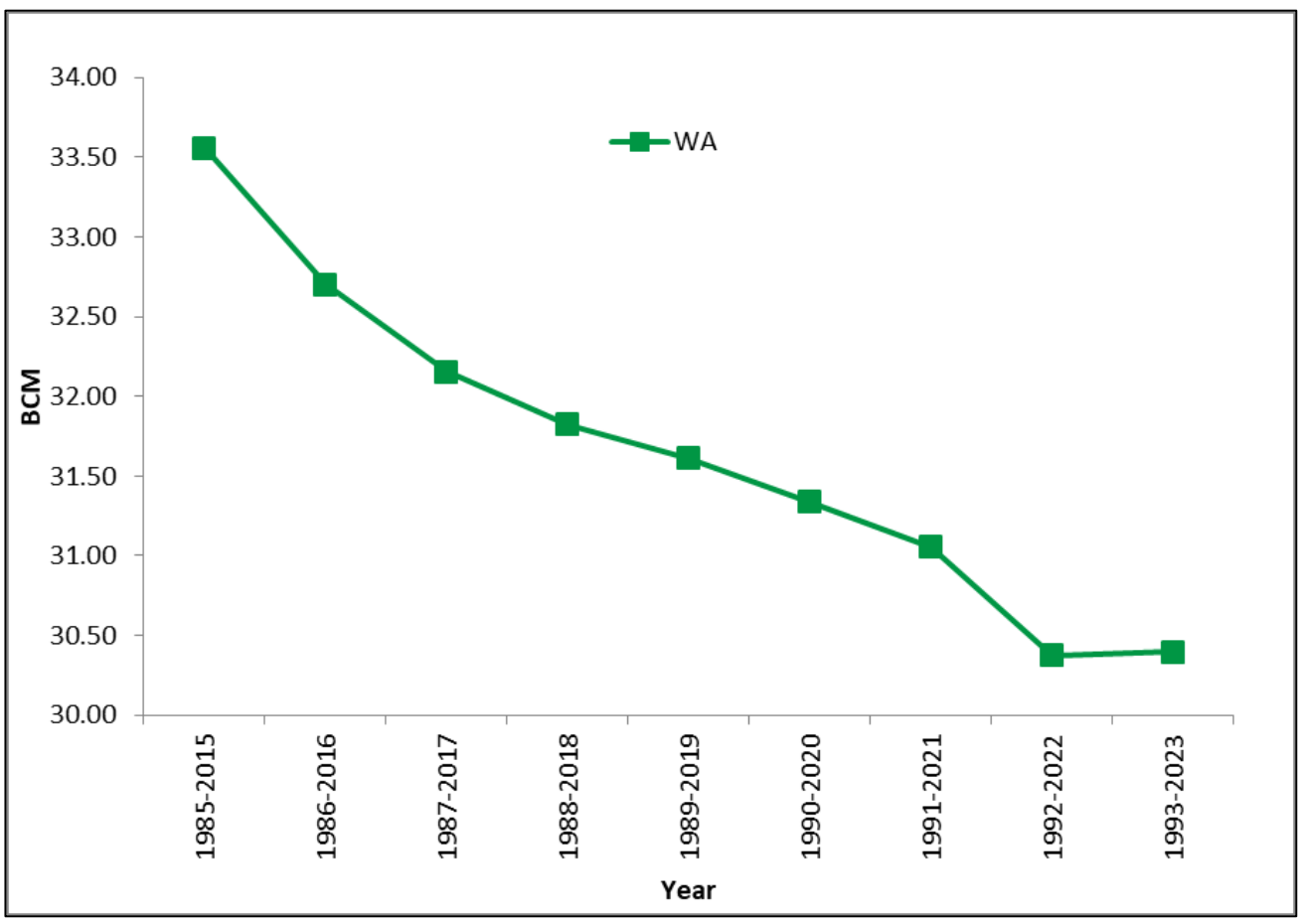


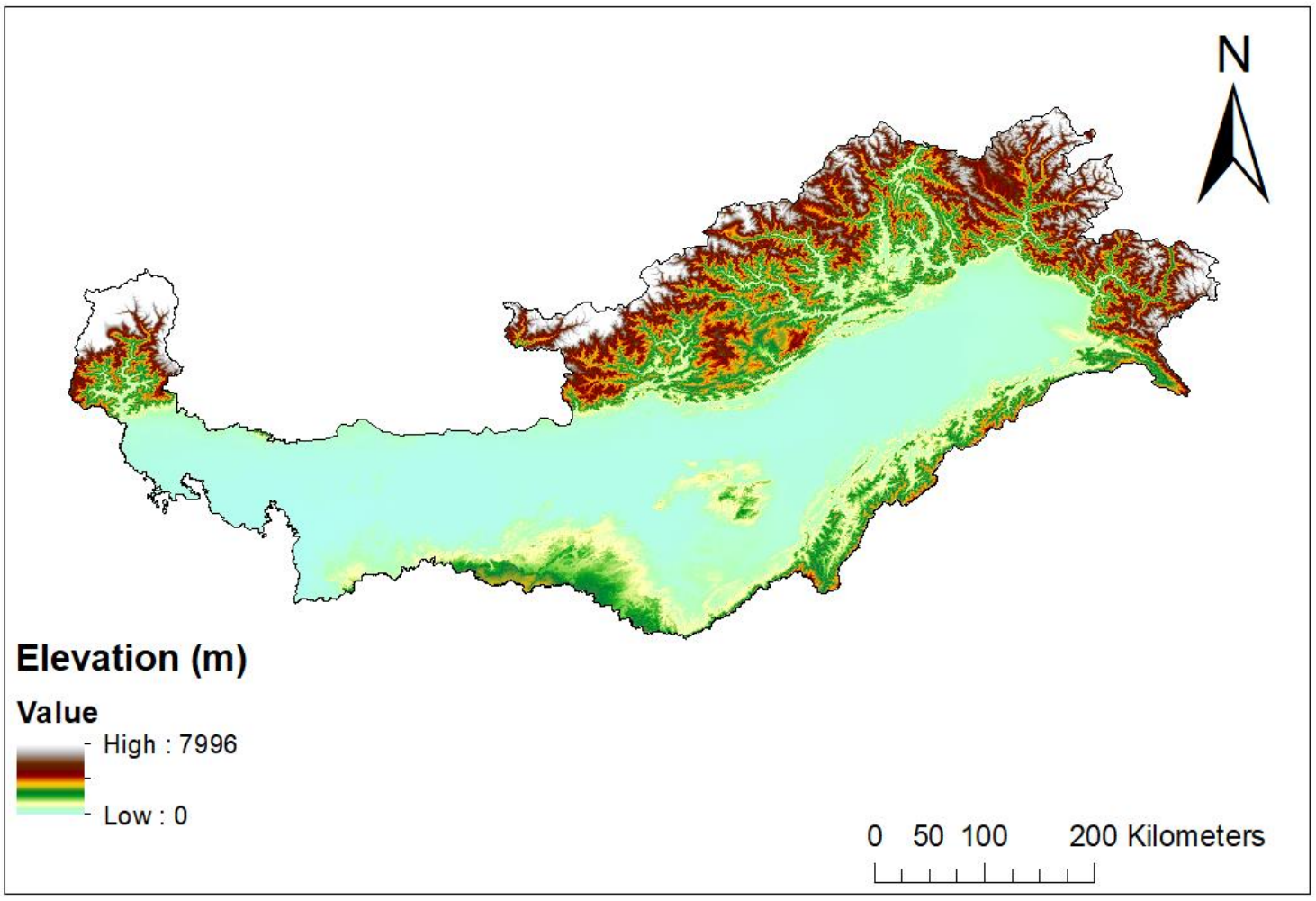
Figure 4.2.10: Moving Average of P and WA for 30 years

Table 4.2.3: Water Availability of Brahmani-Baitarani basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	94.79	50.40	44.39
1986-87	84.63	50.98	33.65
1987-88	74.19	43.88	30.31
1988-89	76.30	42.95	33.35
1989-90	86.86	52.38	34.48
1990-91	88.45	51.15	37.30
1991-92	84.22	47.55	36.67
1992-93	68.23	41.88	26.35
1993-94	81.33	47.34	33.99
1994-95	108.45	53.67	54.78
1995-96	78.72	48.49	30.23
1996-97	73.22	42.99	30.23
1997-98	100.30	54.84	45.46
1998-99	73.52	46.36	27.16
1999-00	97.53	50.17	47.36
2000-01	69.97	42.21	27.76
2001-02	90.66	36.67	53.99
2002-03	63.39	41.71	21.68
2003-04	84.58	49.68	34.90
2004-05	69.08	49.01	20.07
2005-06	78.83	46.76	32.06
2006-07	81.42	51.04	30.37
2007-08	90.79	51.42	39.38
2008-09	83.75	45.67	38.08
2009-10	66.33	45.31	21.02
2010-11	61.67	48.62	13.06
2011-12	90.81	50.75	40.05
2012-13	74.45	49.46	24.99
2013-14	90.24	53.50	36.74
2014-15	75.07	48.17	26.89
2015-16	65.91	47.24	18.67
2016-17	65.72	48.49	17.23
2017-18	74.02	53.71	20.31
2018-19	83.35	56.27	27.07
2019-20	86.45	60.24	26.21
2020-21	84.83	56.01	28.82
2021-22	75.64	59.36	16.29
2022-23	71.35	44.31	27.04
Average	**80.24**	**48.96**	**31.27**

4.3 BRAHMAPUTRA BASIN



HIGHLIGHTS

- *Average annual water resources availability of Brahmaputra basin is 592.32 BCM.*
- *Maximum annual water availability is 725.88 BCM during 2001-02.*
- *Minimum annual water availability is 417.33 BCM during 2011-12.*
- *Average annual precipitation is 473.40 BCM (2450 mm).*
- *Maximum annual precipitation is 613.38 BCM (3174 mm) during 1993-94.*
- *Minimum annual precipitation is 333.43 BCM (1725 mm) during 2011-12.*

4.3.1 About Brahmaputra Basin

The Brahmaputra basin spreads over countries of Tibet (China), Bhutan, India and Bangladesh having a total area of 5,80,000 sq. km. In India, it spreads over states of Arunachal Pradesh (42.60%), Assam (36.46%), West Bengal (5.92%), Meghalaya (5.70%), Nagaland (5.63%) and Sikkim (3.69%) and extends over an area of 1,93,252 sq.km which is nearly 5.9% of the total geographical area of the country. It is bounded by the Himalayas on the north, the Patkari range of hills on the east running along the India-Myanmar border, the Assam range of hills on the south and the Himalayas and the ridge separating it from Ganga basin on the west. The Brahmaputra River originates in the north from Kailash ranges of Himalayas at an elevation of 5,150 m and flows for about a total length of 2,900 km. In India, it flows for 916 km. The principal tributaries of the river joining from right are the Lohit, the Dibang, the Subansiri, the Jiabharali, the Dhansiri, the Manas, the Torsa, the Sankosh and the Teesta whereas the Burhidihing, the Disang, the Dikhow, the Dhansiri and the Kopili joins it from left.

4.3.2 Geo-Spatial Datasets

4.3.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Brahmaputra basin for year 2022-23 is shown in Figure 4.3.1. Major land use classes consist of Evergreen/Semi-evergreen woodland, Deciduous woodland and Kharif only etc.

Table 4.3.1 shows the percentage area of each land use class in the basin for year 2022-23.

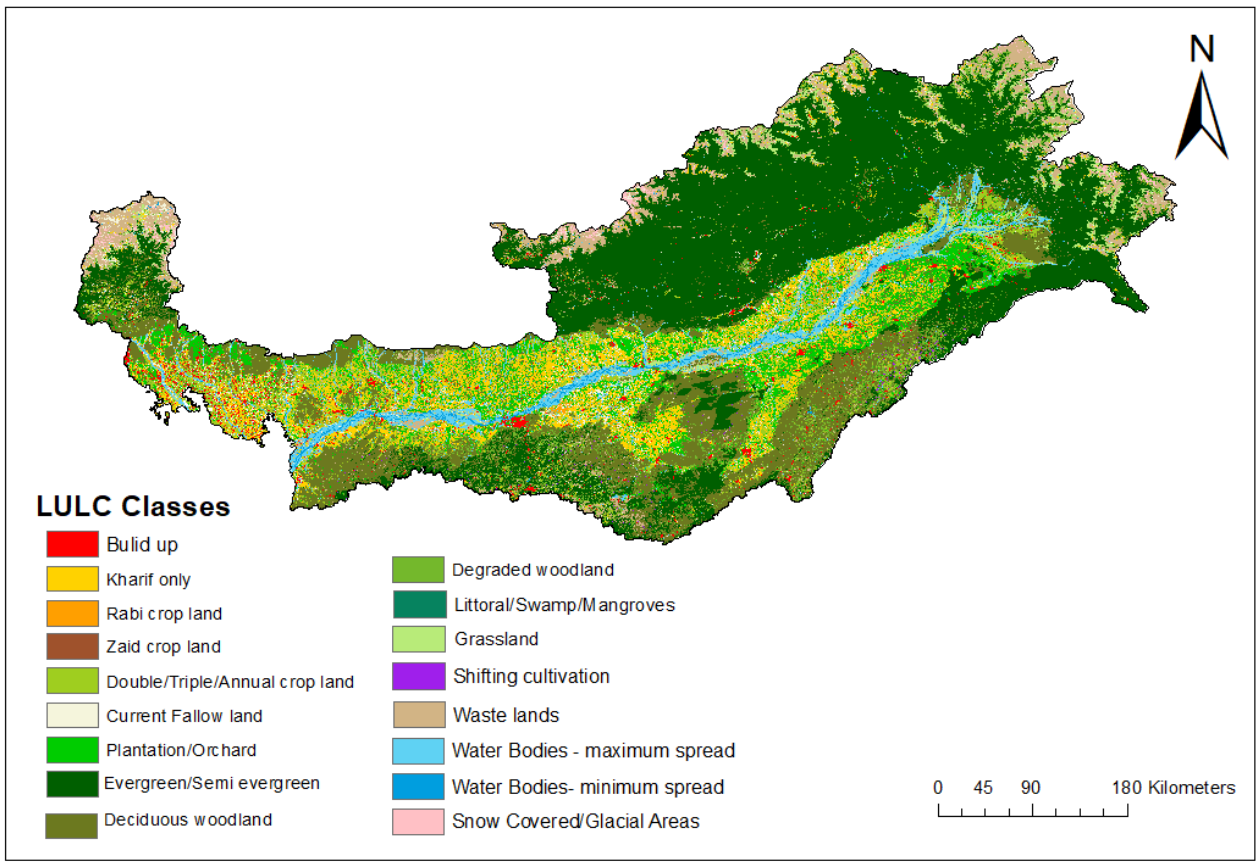


Figure 4.3.1: LULC Map of Brahmaputra basin

Table 4.3.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Built-up land	1.56
2.	Kharif only	7.95
3.	Rabi crop land	0.35
4.	Zaid crop land	0.01
5.	Double/Triple/Annual crop land	7.06
6.	Current fallow land	2.22
7.	Plantation/Orchid	7.54
8.	Evergreen/Semi-evergreen woodland	37.80
9.	Deciduous woodland	17.15
10.	Degraded woodland	4.03
11.	Grassland	2.27
12.	Shifting Cultivation	0.14
13.	Waste lands	6.24
14.	Water Bodies - maximum spread	4.31
15.	Water Bodies - minimum spread	0.81
16.	Snow covered/Glacial areas	0.55

4.3.3 Hydro-Meteorological and other Input Data

4.3.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.3.2. The variation in the annual precipitation during study period of 37 years (1986-87 to 2022-23) is shown in the Figure 4.3.3. The average precipitation of 37 years is approximately 473.40 BCM (2450 mm).

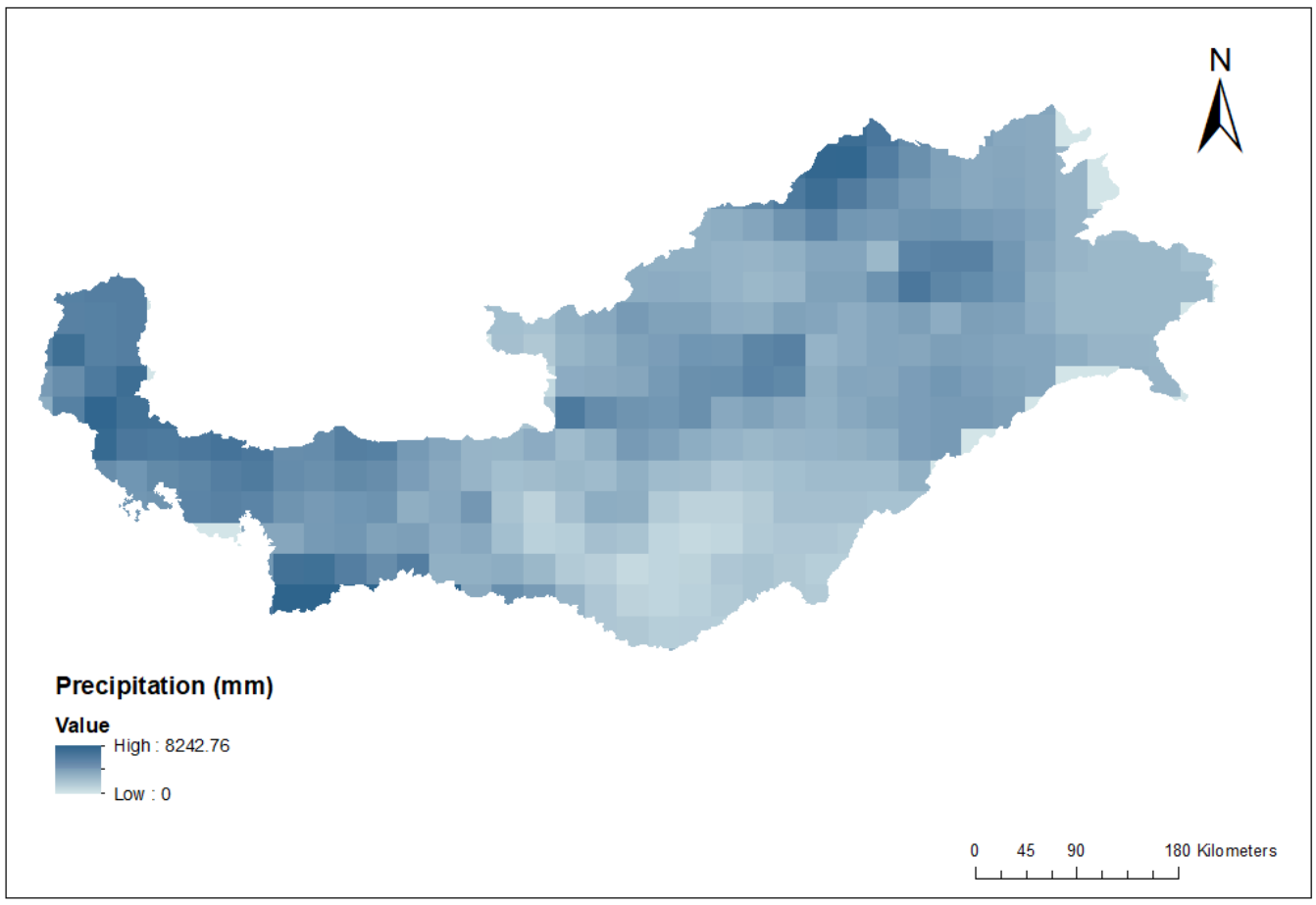


Figure 4.3.2: Precipitation map of Brahmaputra basin

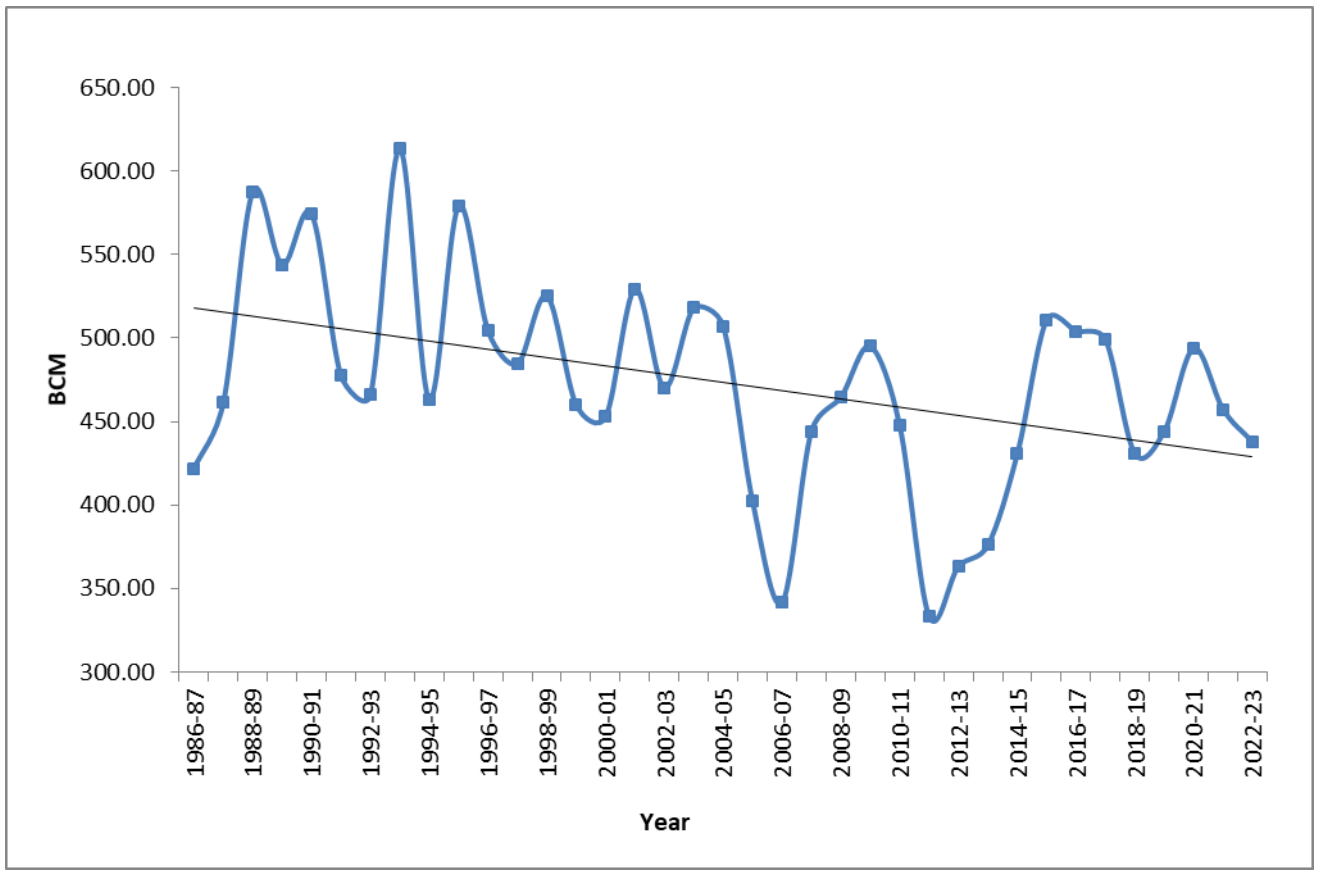


Figure 4.3.3: Annual Precipitation in Brahmaputra basin

4.3.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.3.4. The variation in the annual actual Evapotranspiration (ET) during study period of 37 years (1986-87 to 2022-23) is shown in the Figure 4.3.5. The average ET of 37 years is approximately 110.35 BCM (571 mm).

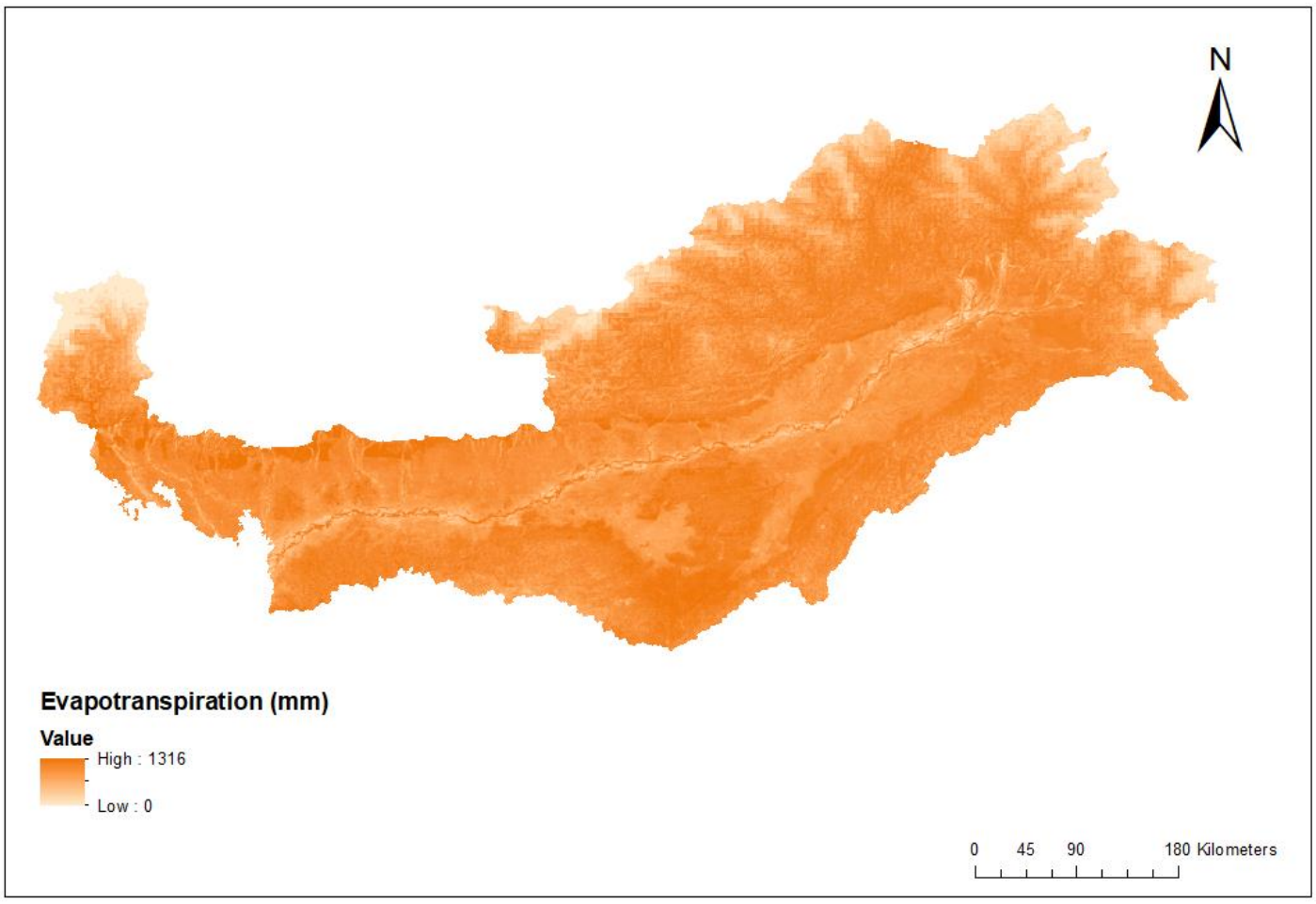


Figure 4.3.4: Evapotranspiration map of Brahmaputra basin

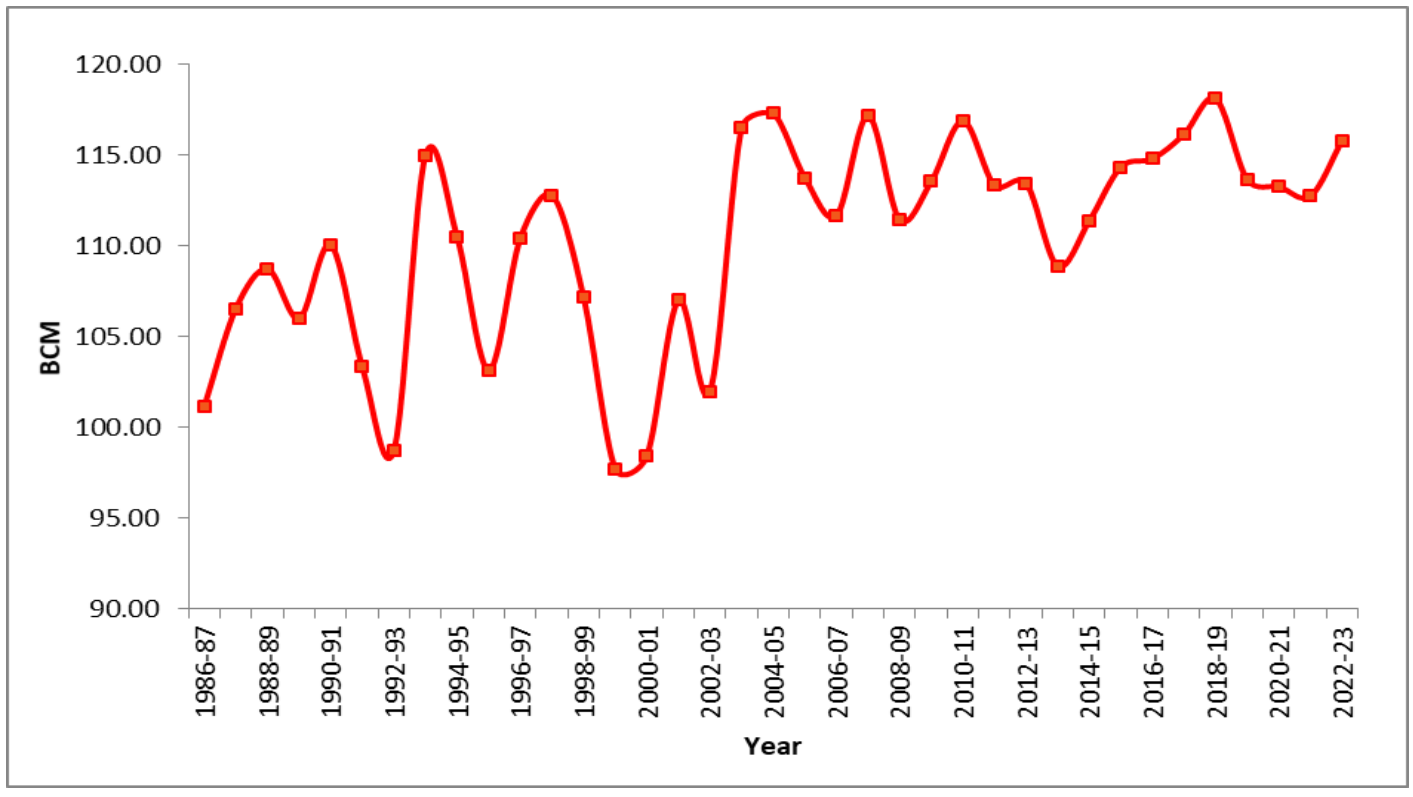


Figure 4.3.5: Annual Evapotranspiration in Brahmaputra basin

4.3.3.3 Reservoir Evaporation

The reservoirs having area equal to or greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.3.6. The average annual evaporation from the reservoirs in the basin is 0.02 BCM.

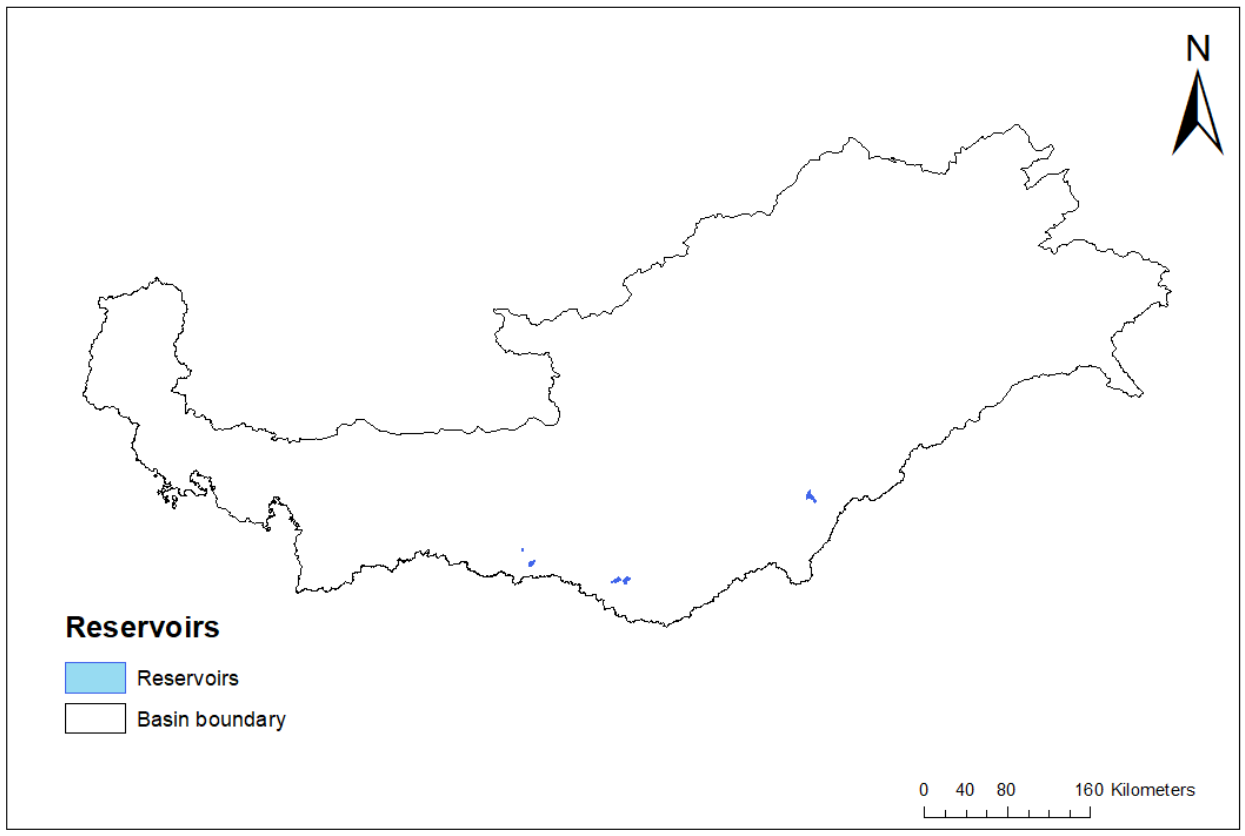


Figure 4.3.6: Reservoir map of Brahmaputra basin

4.3.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1986-2023 has been estimated as 2.52 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.3.7. The annual variation in ET_{II} is shown in Figure 4.3.8.

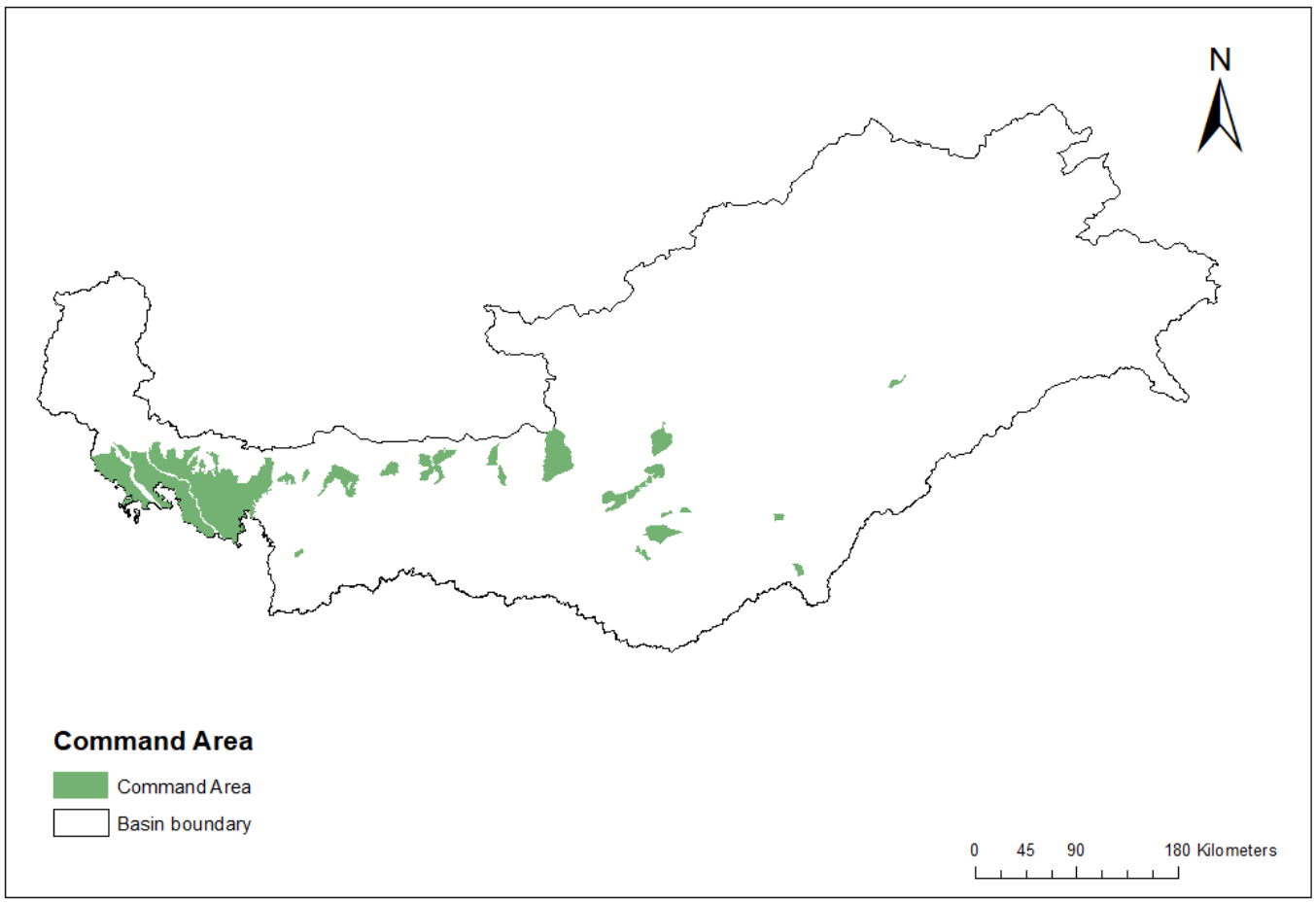


Figure 4.3.7: Command area map of Brahmaputra basin

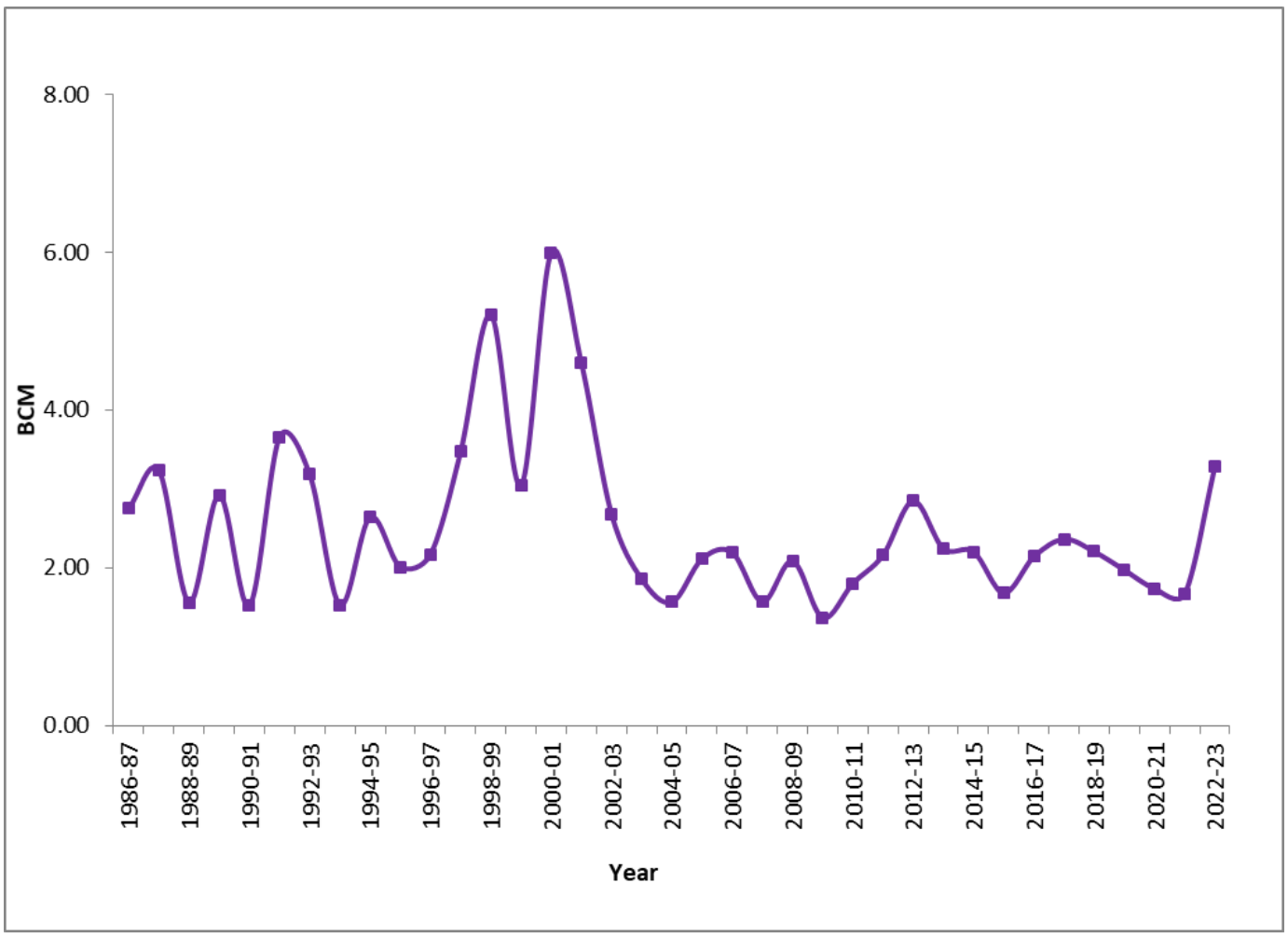


Figure 4.3.8: ET from Irrigation Input in Brahmaputra basin

4.3.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux) and Reservoir flux for the basin for 1986-87 to 2022-23 is 0.19 BCM and 0 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 1.04 BCM.

4.3.4 Previous Estimates

During 1993 study, no separate assessment was made for estimating water resources of the Brahmaputra basin. The Brahmaputra Board in their report of 1987 on “Master Plan of Brahmaputra Basin: Part 1 Main Stem” has reported the average annual flow at Jogighopa (Pancharatna) on Brahmaputra as 537.067 BCM.

In 2019 study, the water availability of Brahmaputra basin was estimated as 527.28 BCM.

4.3.5 Annual Water Availability of Brahmaputra Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs, the average annual water availability from year 1986-87 to 2022-23 is estimated as 592.32 BCM. The annual variations from year 1986-87 to 2022-23 are shown in Figure 4.3.9. The results of Brahmaputra basin are shown in Table 4.3.3.

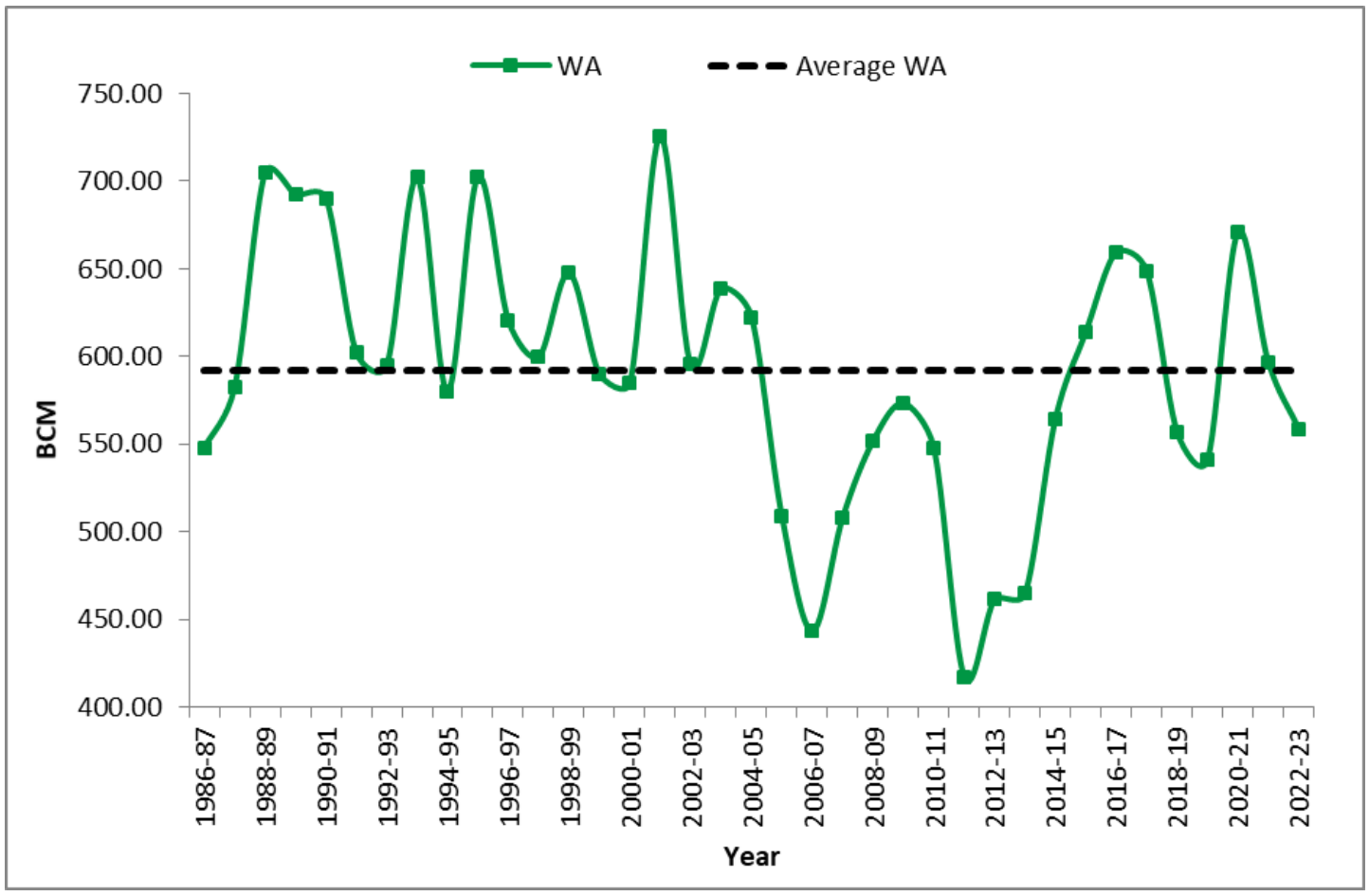


Figure 4.3.9: Water Availability of Brahmaputra basin

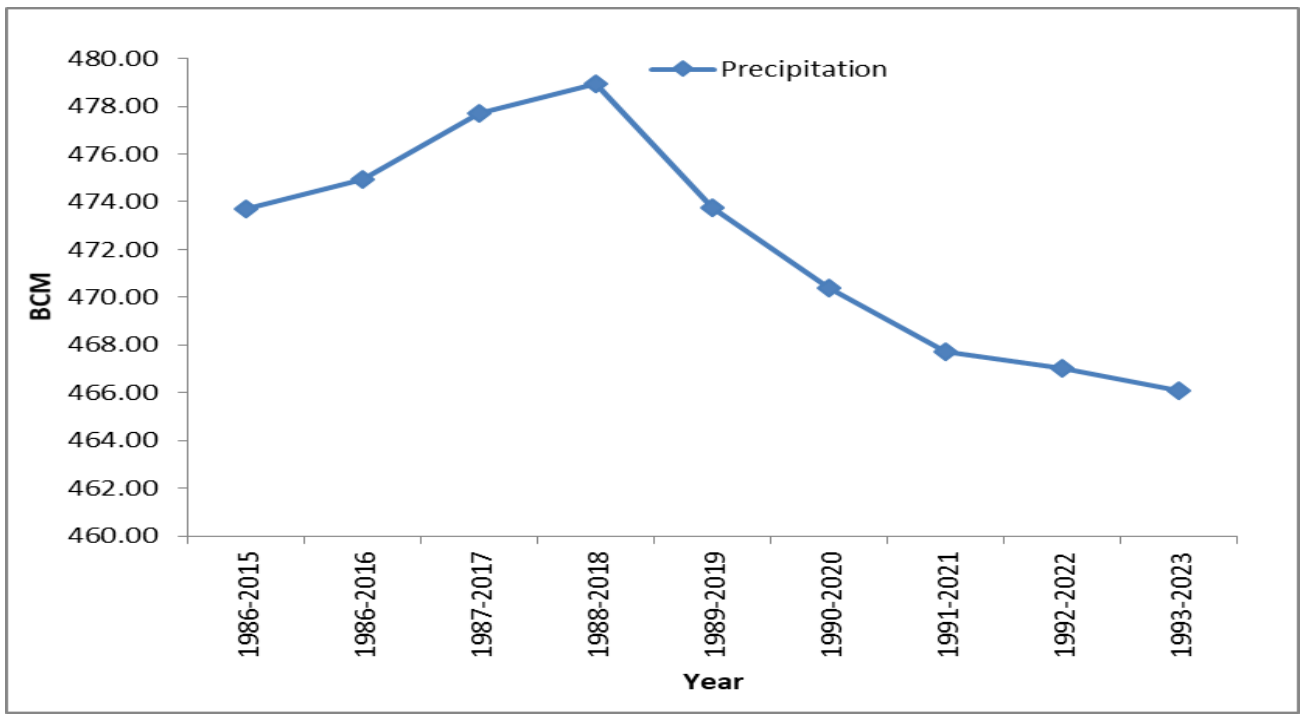
4.3.6 Moving Average of 30 years from 1986-2015 to 1993-2023

Moving average of precipitation and water availability of Brahmaputra basin is given at Table 4.3.2. A line diagram of moving average of P and WA is shown in Figure 4.3.10.

Table 4.3.2 Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)*
1986-2015	473.72	589.42
1986-2016	474.96	593.14
1987-2017	477.70	595.35
1988-2018	478.96	590.41
1989-2019	473.73	585.37
1990-2020	470.40	584.72
1991-2021	467.72	584.54
1992-2022	467.04	583.33
1993-2023	466.11	579.24

**including trans-boundary contribution*



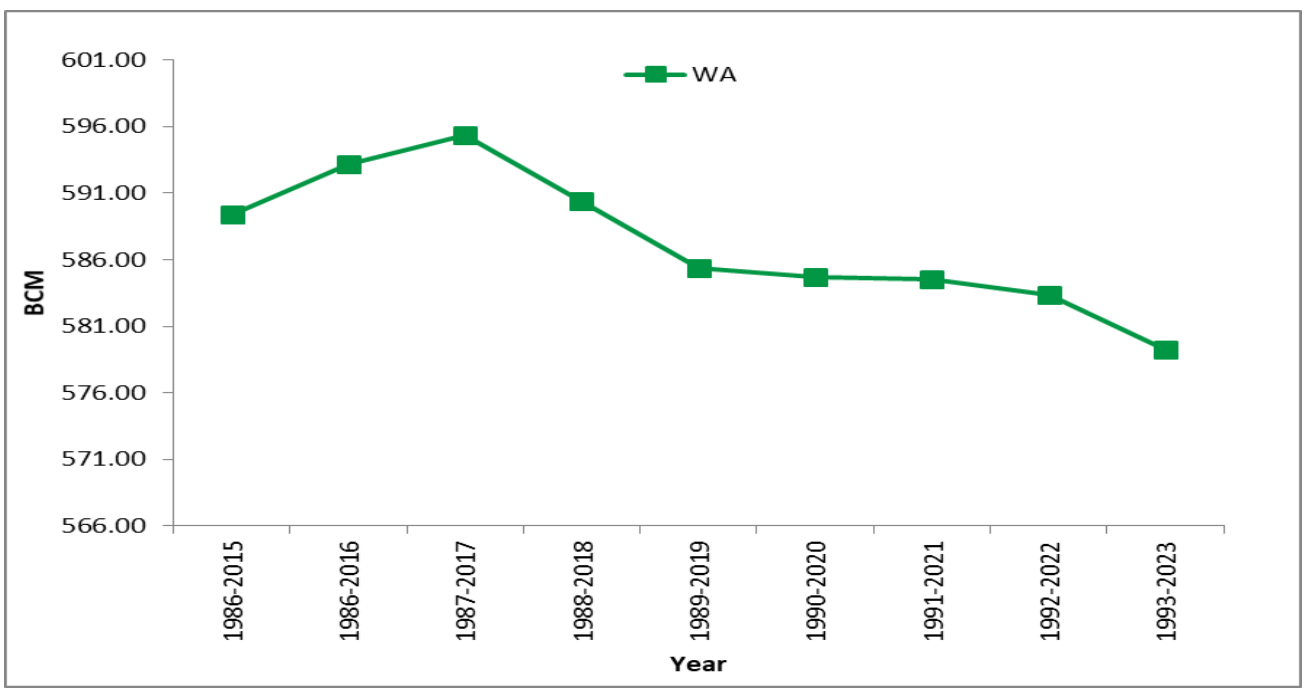


Figure 4.3.10: Moving Average of P and WA for 30 years

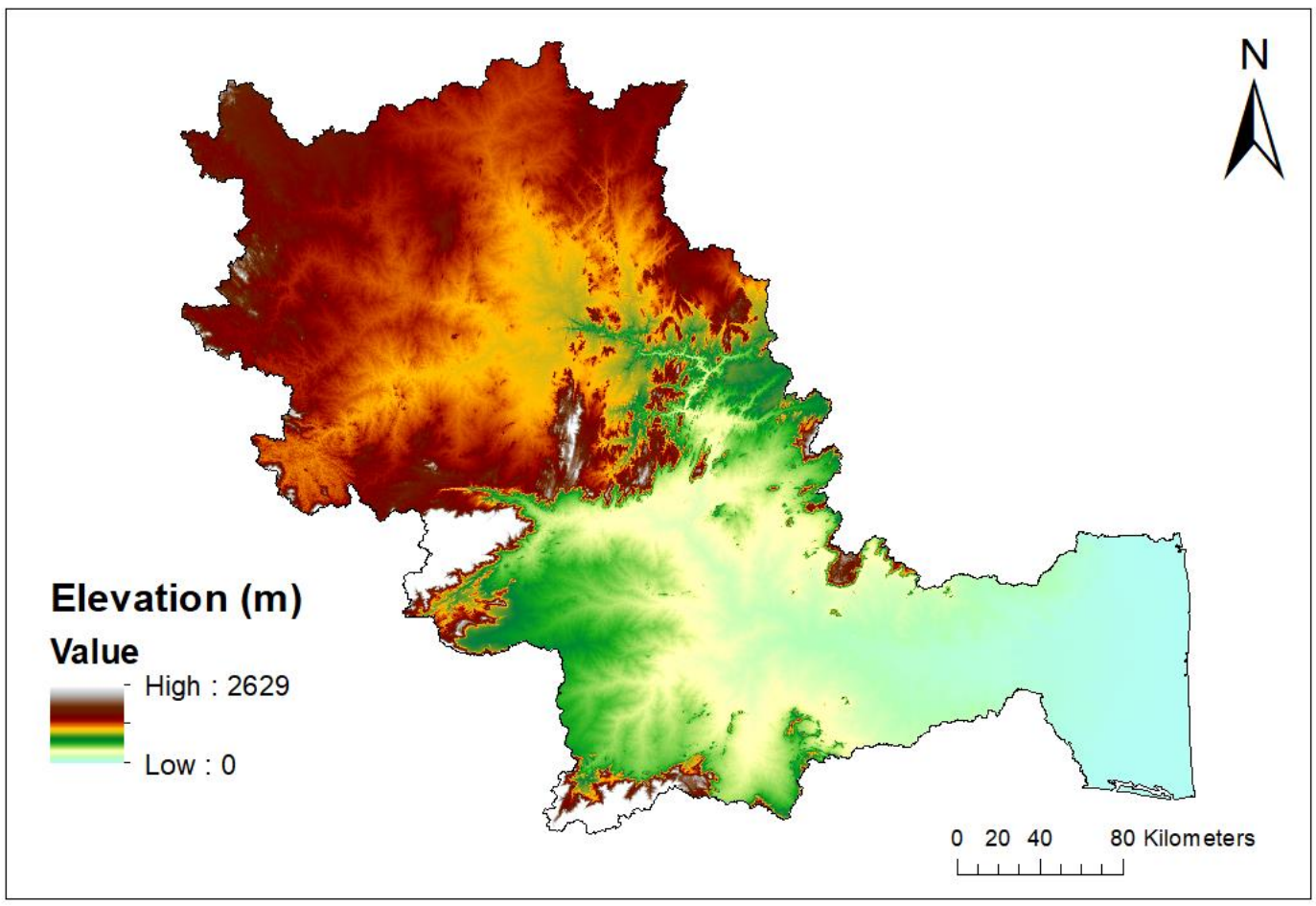
Table 4.3.3: Water Availability of Brahmaputra basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability*
1986-87	421.96	98.42	548.17
1987-88	461.30	103.32	582.61
1988-89	587.60	107.17	705.05
1989-90	543.99	76.45	692.16
1990-91	574.27	108.54	690.36
1991-92	477.45	99.67	602.41
1992-93	465.89	95.56	594.95
1993-94	613.38	135.93	702.07
1994-95	463.16	107.86	579.92
1995-96	578.98	101.13	702.47
1996-97	504.35	108.26	620.71
1997-98	484.57	109.33	599.86
1998-99	525.14	101.95	647.81
1999-00	459.96	94.67	589.91
2000-01	452.85	92.42	585.05
2001-02	529.34	28.09	725.88
2002-03	470.15	99.30	595.47
2003-04	517.99	114.64	638.84
2004-05	507.10	115.72	622.59
2005-06	402.14	111.63	509.21
2006-07	341.67	109.46	443.41
2007-08	444.27	115.60	508.24
2008-09	464.36	109.35	551.91
2009-10	494.98	112.17	573.54
2010-11	447.85	115.07	547.70
2011-12	333.43	111.16	417.33
2012-13	363.20	110.60	461.58
2013-14	375.99	106.62	464.85
2014-15	430.49	109.16	564.54
2015-16	511.01	112.66	614.10
2016-17	504.15	112.65	659.64
2017-18	498.98	113.79	648.90
2018-19	430.73	115.90	556.86
2019-20	444.17	111.67	541.10
2020-21	493.78	111.51	670.72
2021-22	457.26	111.06	596.95
2022-23	437.85	112.52	558.81
Average	**473.40**	**105.70**	**592.32**

**including trans-boundary contribution*

4.4 CAUVERY BASIN



HIGHLIGHTS

- *Average annual water resources availability of Cauvery basin is 26.53 BCM.*
- *Maximum annual water availability is 43.20 BCM during 2021-22.*
- *Minimum annual water availability is 12.23 BCM during 2016-17.*
- *Average annual precipitation is 82.95 BCM (974 mm).*
- *Maximum annual precipitation is 118.14 BCM (1387 mm) during 2021-22.*
- *Minimum annual precipitation is 38.93 BCM (457 mm) during 2002-03.*

4.4.1 About Cauvery Basin

The river Cauvery is biggest river in south India. It rises at Talakaveri on the Brahmagiri range in the Western Ghats in Karnataka at an elevation of about 1,341 m above Mean Sea Level and flows for about 800 km, before its outfall into the Bay of Bengal.

The Cauvery basin extends over states of Tamil Nadu (55.28%), Karnataka (41.24%), Kerala (3.26%) and Union Territory of Puducherry (0.22%), draining an area of 85,167sq.km which is nearly 2.59% of the total geographical area of the country. The total length of the river Cauvery from the head to its outfall into the sea comprises a length of 320 km in Karnataka, 416 km in Tamil Nadu and remaining length of 64 km forms the common boundary between states of Karnataka and Tamil Nadu. Its principal tributaries are Shimsa, Arkavathi, Hemavathi, Kabini, Amravati, Noyil and Bhavani.

4.4.2 Geo-Spatial Datasets

4.4.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Cauvery basin for year 2022-23 is shown in Figure 4.4.1. Major land use classes consist of Double/Triple/Annual crop land, deciduous woodland, Rabi crop land etc.

Table 4.4.1 shows the percentage area of each land use class in the basin for year 2022-23.

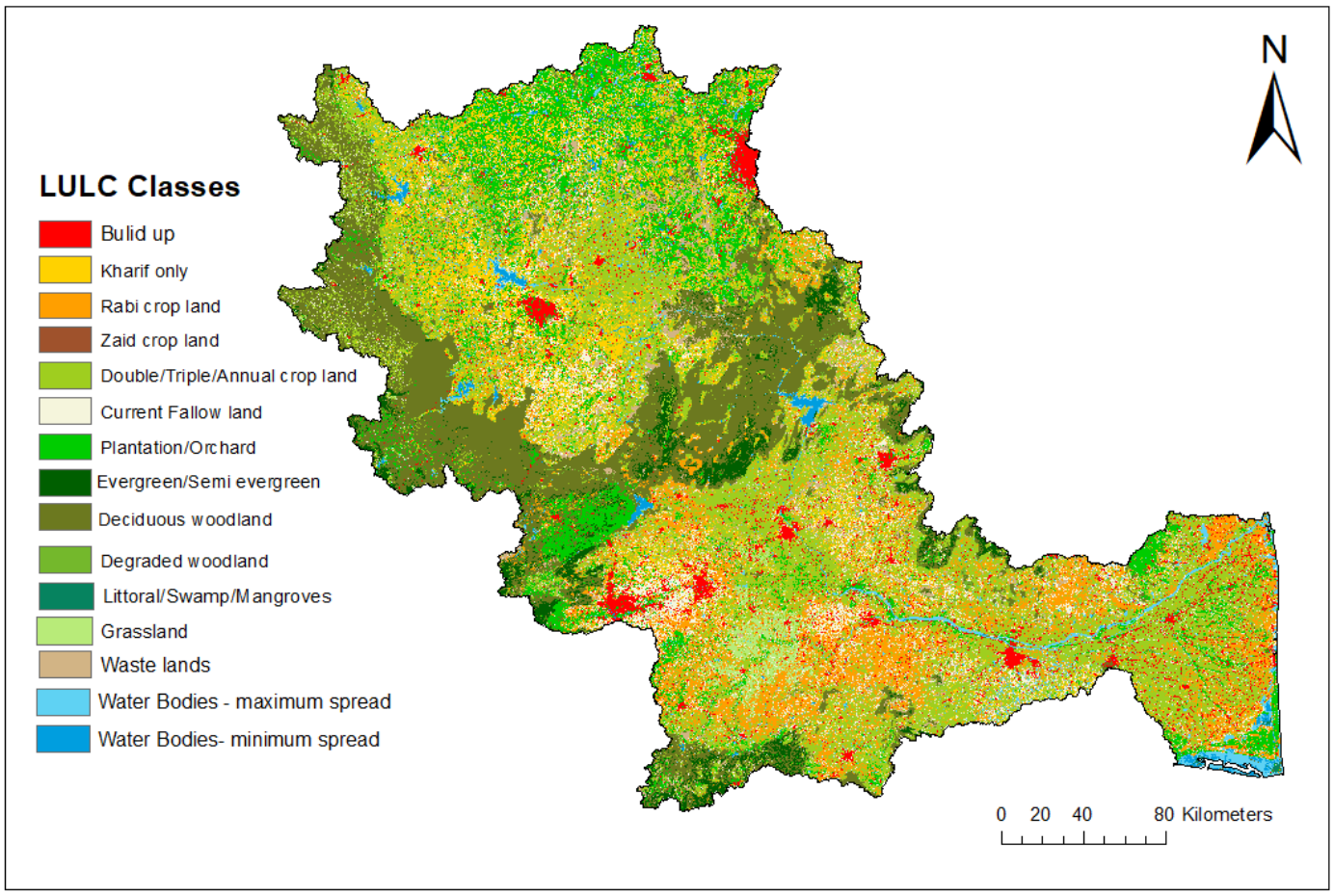


Figure 4.4.1: LULC Map of Cauvery basin

Table 4.4.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Built-up land	3.51
2.	Kharif only	10.61
3.	Rabi crop land	9.26
4.	Double/Triple/Annual crop land	14.32
5.	Current fallow land	16.83
6.	Plantation/Orchid	11.32
7.	Evergreen/Semi-evergreen woodland	3.10
8.	Deciduous woodland	18.68
9.	Degraded woodland	0.60
10.	Littoral/Swamp/Mangroves	0.07
11.	Waste lands	6.60
12.	Water Bodies - maximum spread	3.69
13.	Water Bodies - minimum spread	0.23

4.4.3 Hydro-Meteorological and other Input Data

4.4.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.4.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.4.3. The average precipitation of 38 years is approximately 82.95 BCM (974 mm).

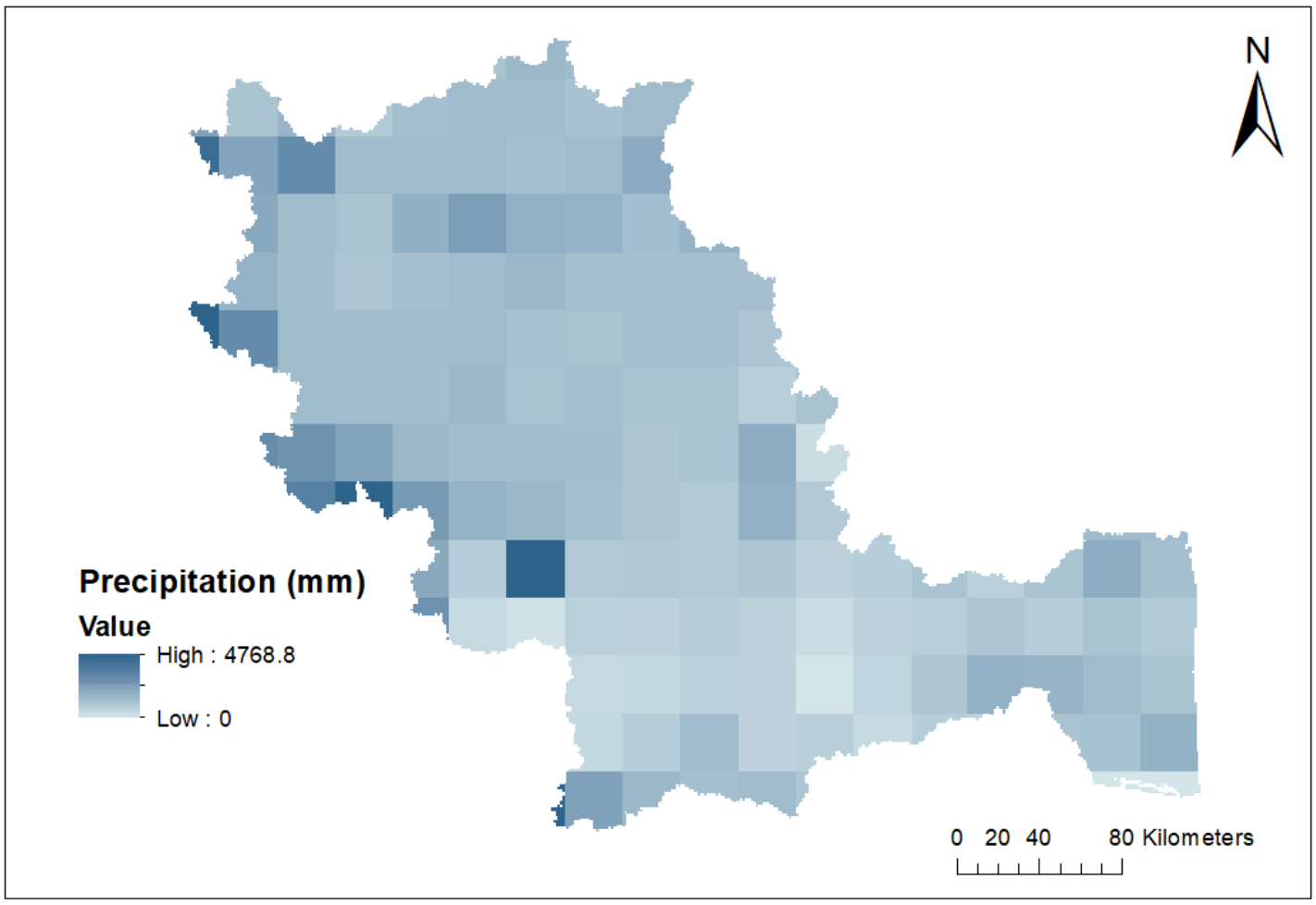


Figure 4.4.2: Precipitation map of Cauvery basin

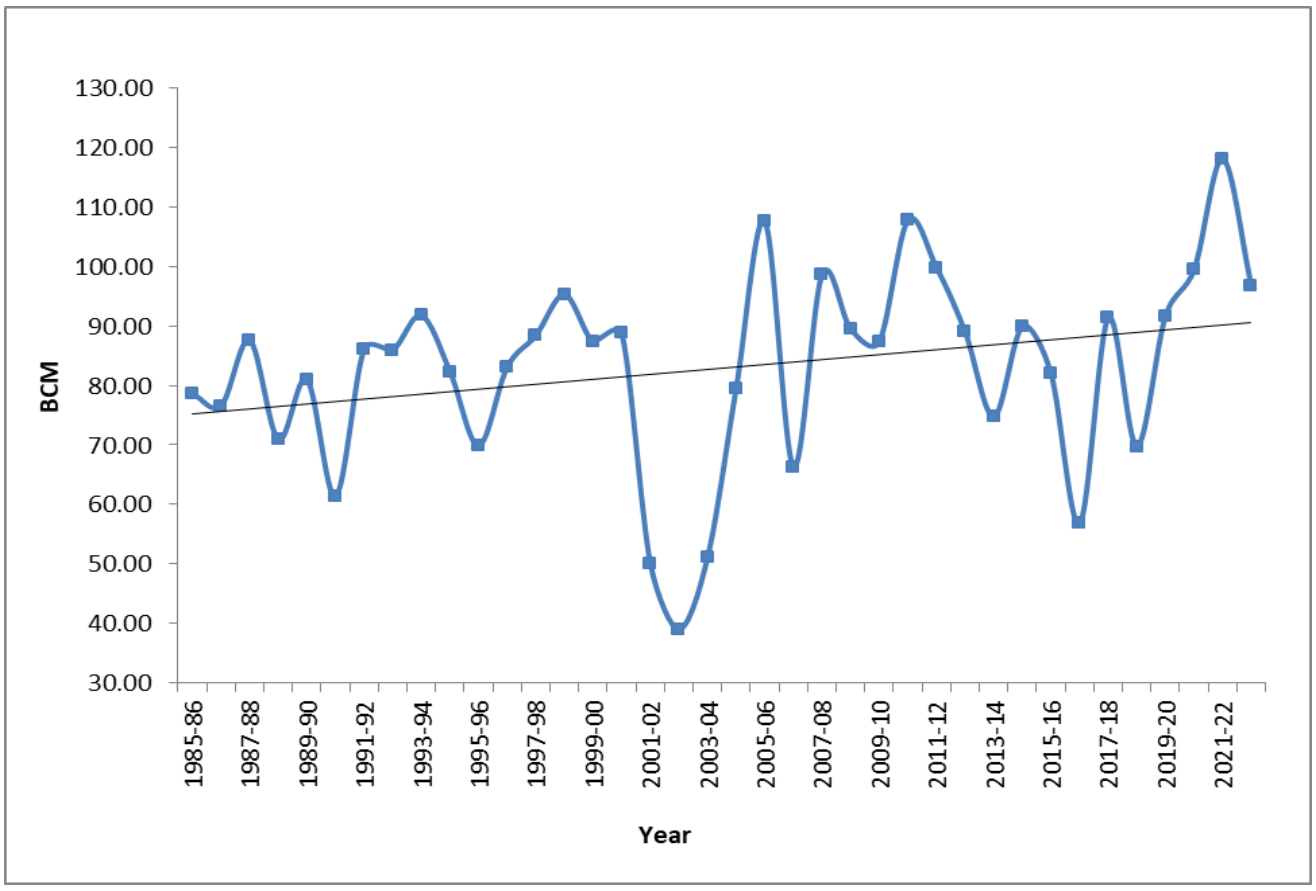


Figure 4.4.3: Annual Precipitation in Cauvery basin

4.4.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.4.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.4.5. The average ET of 38 years is approximately 71.54 BCM (840 mm).

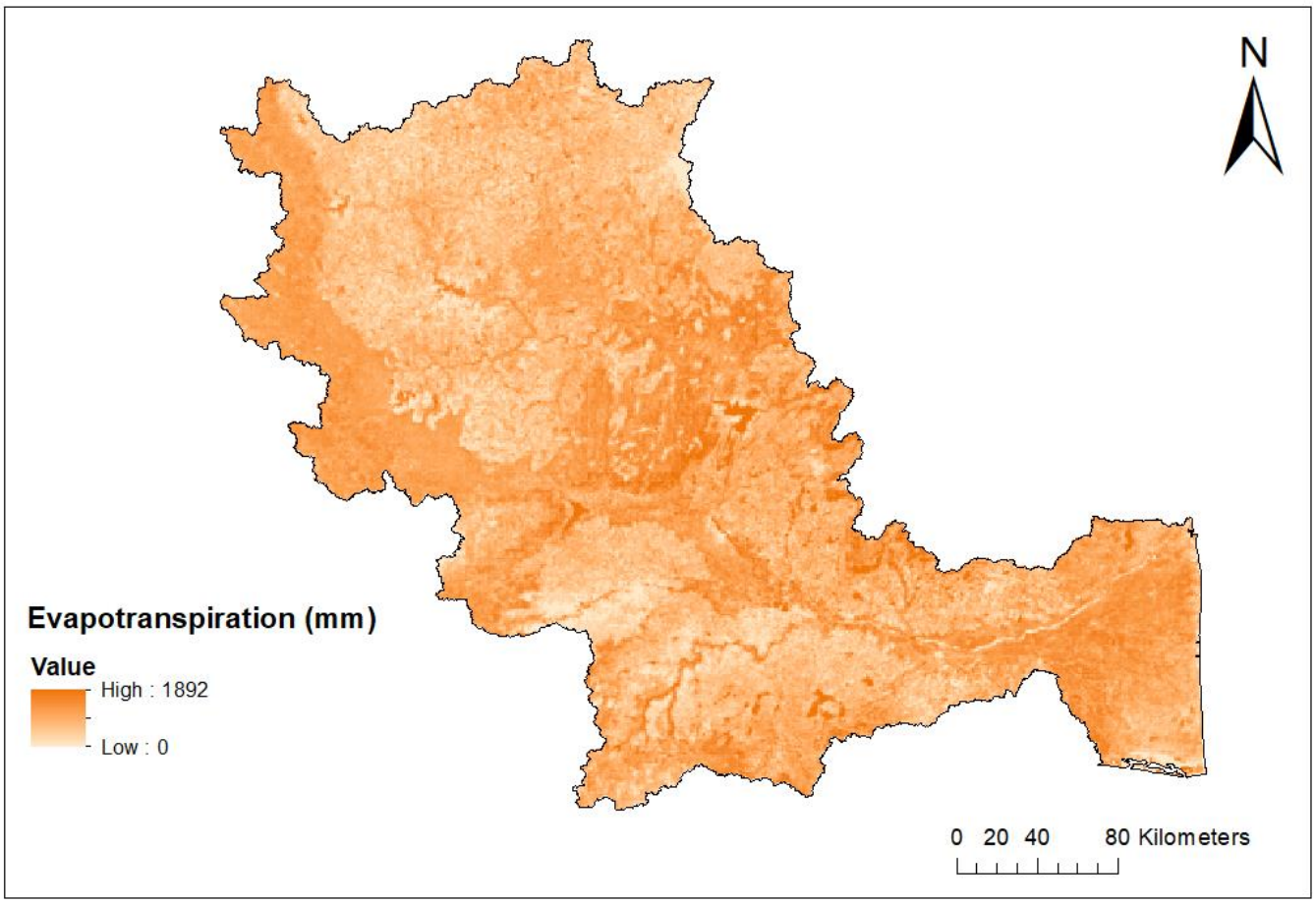


Figure 4.4.4: Evapotranspiration map of Cauvery basin

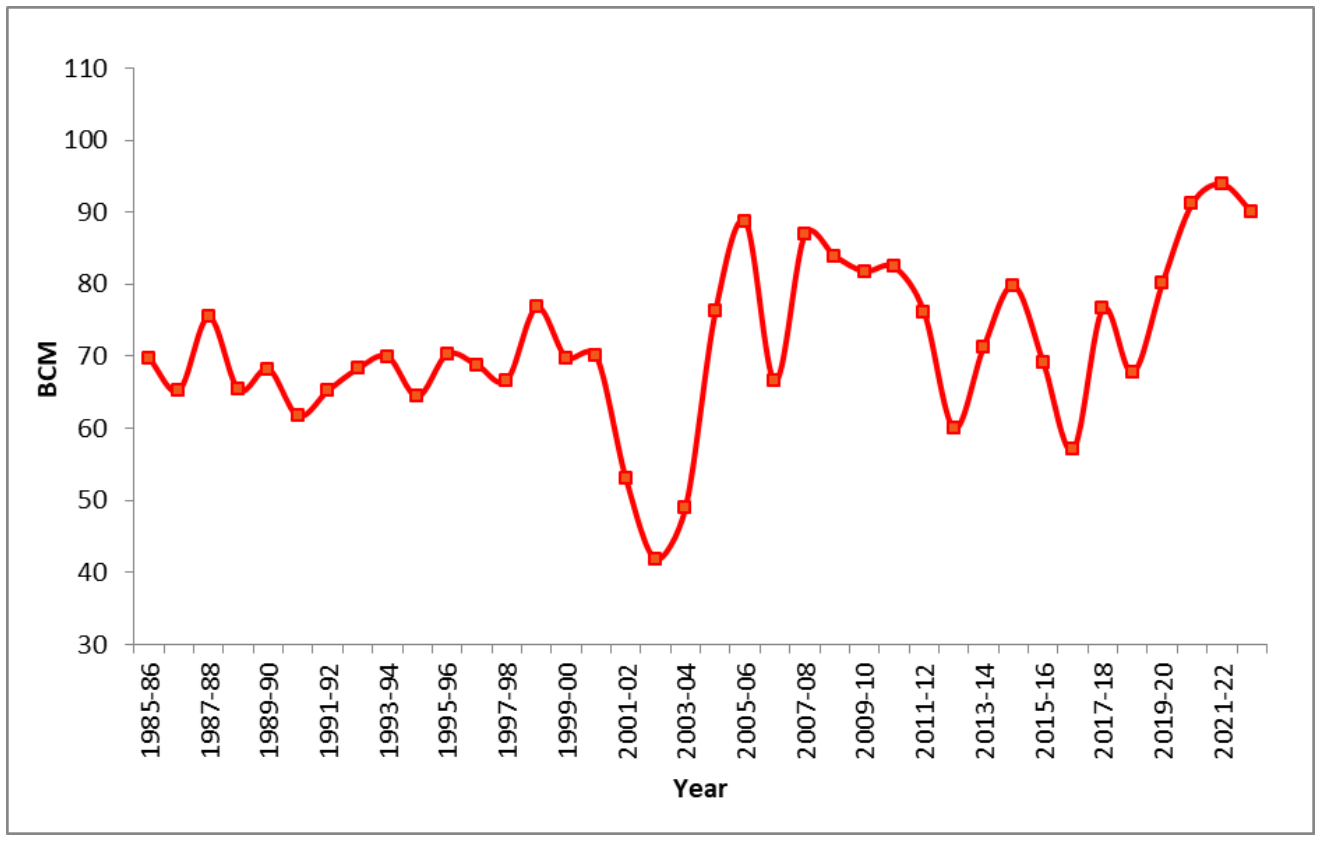


Figure 4.4.5: Annual Evapotranspiration in Cauvery basin

4.4.3.3 Reservoir Evaporation

The reservoirs having area equal to or greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.4.6. The average annual evaporation from the reservoirs in the basin is 0.77 BCM.

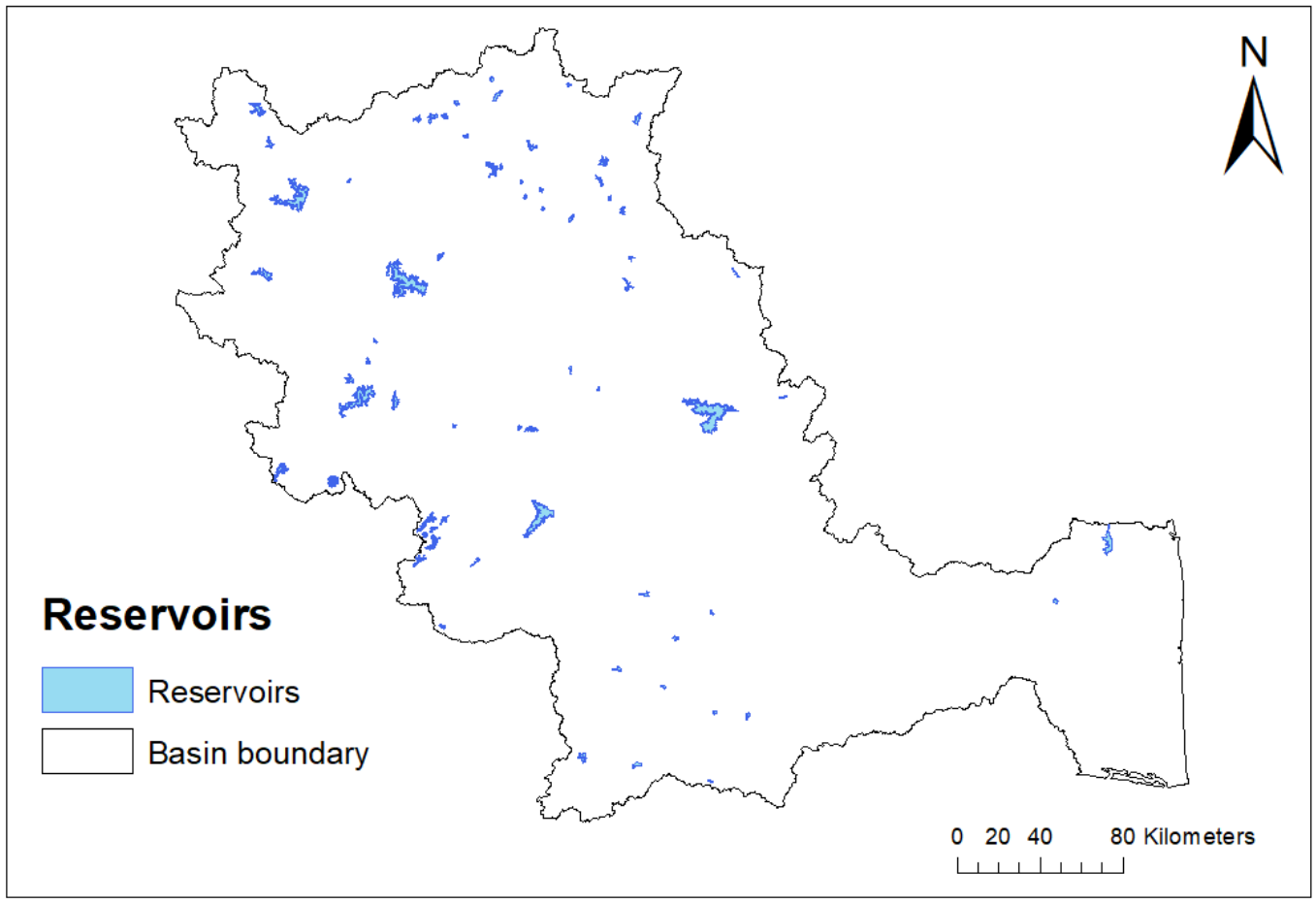


Figure 4.4.6: Reservoir map of Cauvery basin

4.4.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 14.35 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.4.7. The annual variation in ET_{II} is shown in Figure 4.4.8.

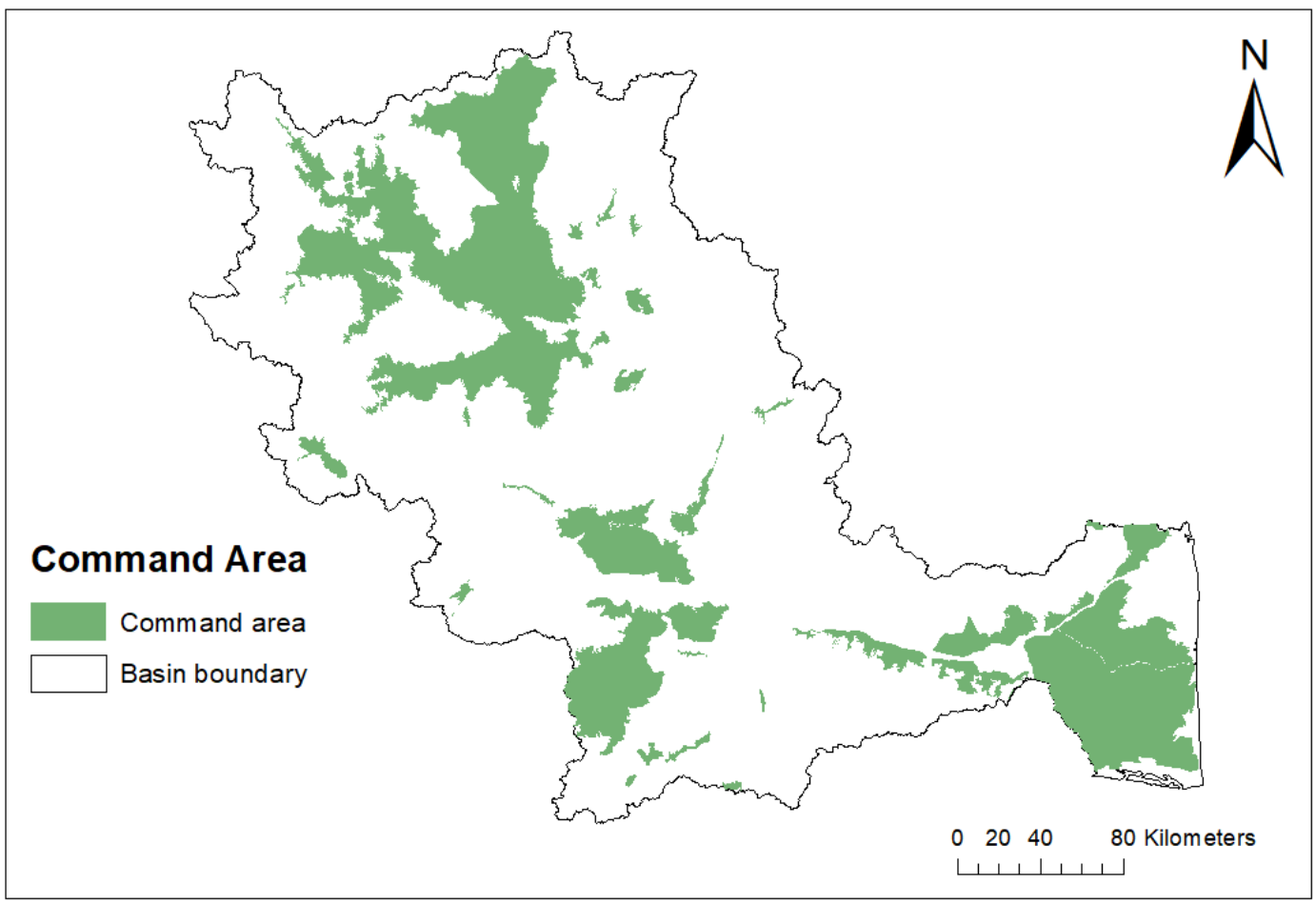


Figure 4.4.7: Command area map of Cauvery basin

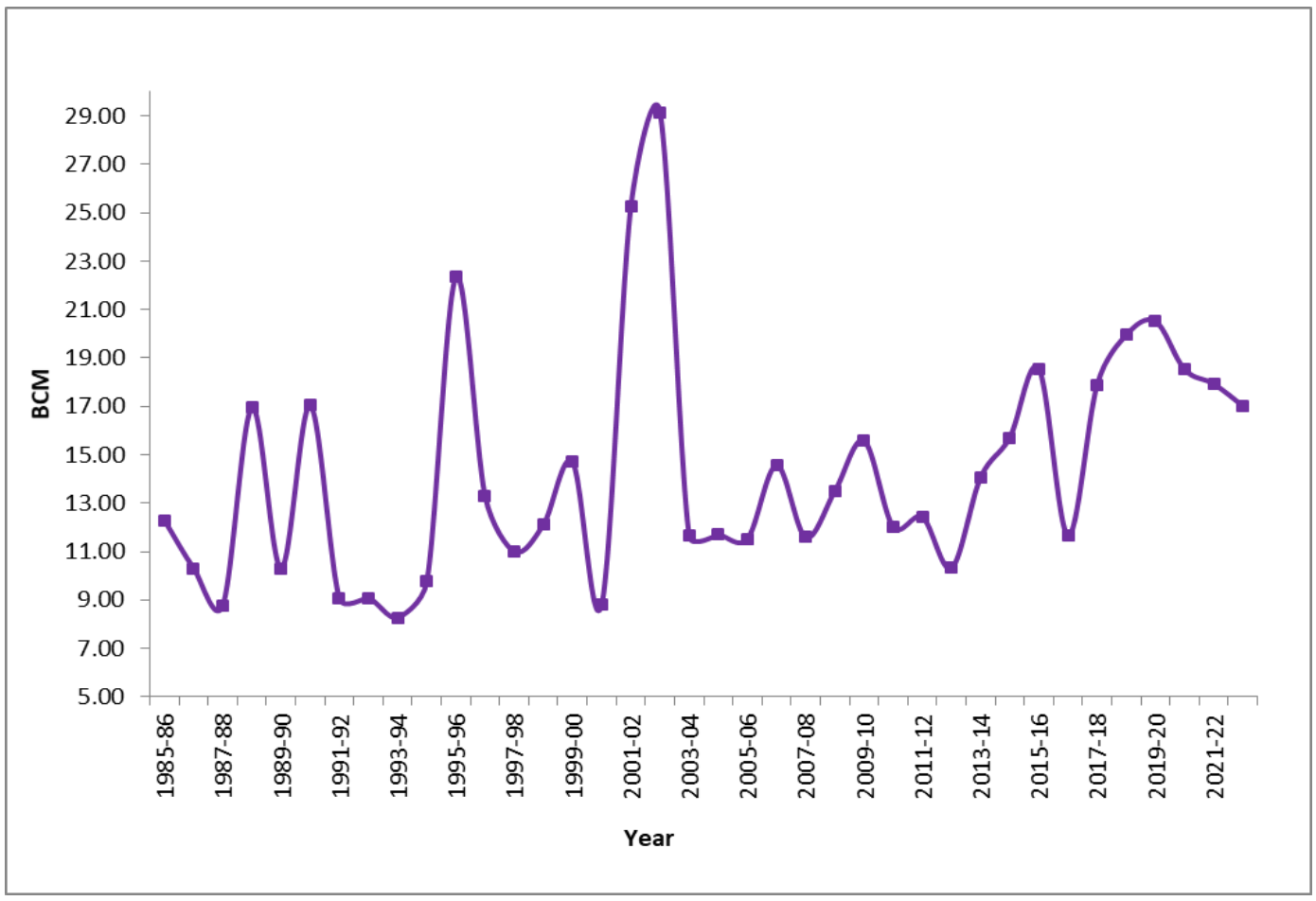


Figure 4.4.8: ET from Irrigation Input in Cauvery basin

4.4.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux) and Reservoir flux for the basin for 1985-86 to 2022-23 is 0.03 BCM and -0.02 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 1.49 BCM.

4.4.4 Previous Estimates

The water potential of the Cauvery river system has been assessed at different times by different authorities. The first assessment was made by the First Irrigation commission. The Commission assessed the total annual surface flow in the Cauvery river system as 56.634 BCM. In 1949 when the assessment of the basin wise water resources of the country (basin wise) was made on the basis of Khosla's formula, the annual runoff of the Cauvery river system was estimated to be 9.99 BCM. The assessment done by Cauvery Fact Finding Committee (CFFC) in 1972 was around 20.95 BCM.

In 1993 and 2007, CWC and Cauvery Water Dispute Tribunal (CWDT) have not undertaken the assessment of water resources in Cauvery basin; instead they decided to use the assessment done by CFFC. In 2019 study, the water availability of Cauvery basin was estimated as 27.67 BCM.

4.4.5 Annual Water Availability of Cauvery Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs, the average annual water availability from year 1985-86 to 2022-23 is estimated as 26.53 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.4.9. The results of Cauvery basin are shown in Table 4.4.3.

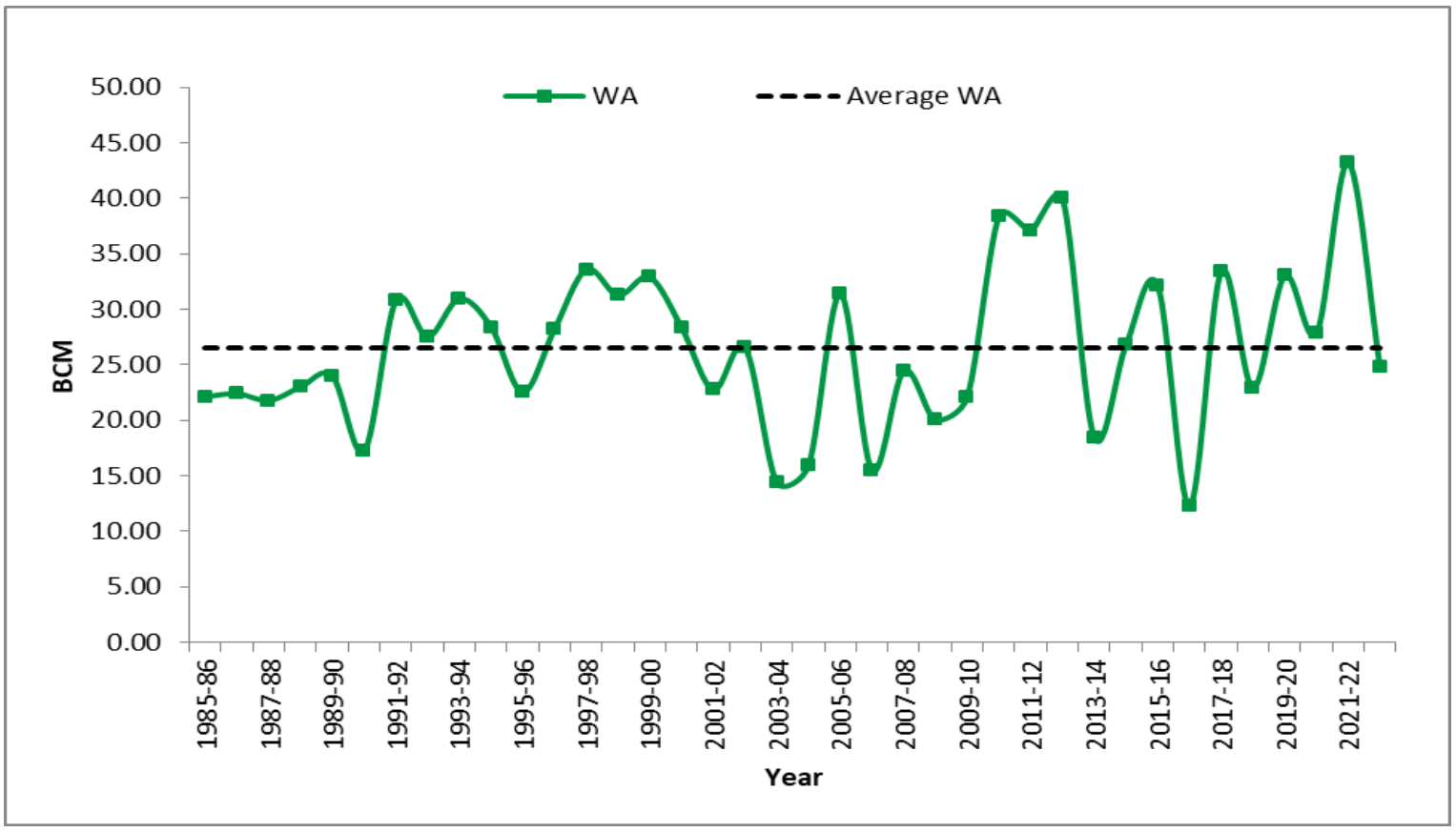


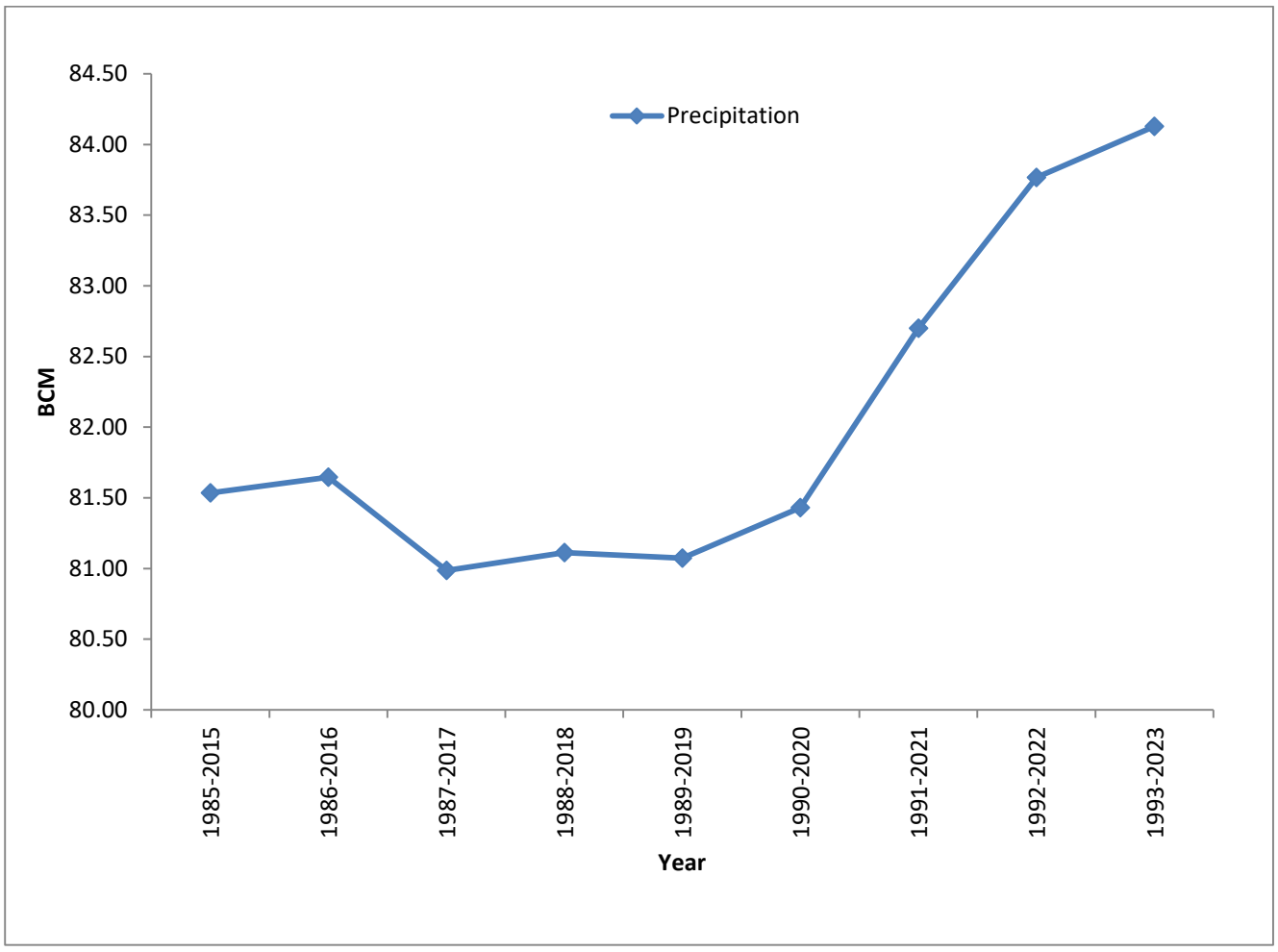
Figure 4.4.9: Water availability of Cauvery basin

4.4.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average for the precipitation and water availability of Cauvery basin is given at Table 4.4.2. A line diagram of moving average is shown in Figure 4.4.10.

Table 4.4.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	81.53	26.17
1986-2016	81.65	26.50
1987-2017	80.99	26.17
1988-2018	81.11	26.55
1989-2019	81.07	26.55
1990-2020	81.43	26.85
1991-2021	82.70	27.19
1992-2022	83.77	27.61
1993-2023	84.13	27.52



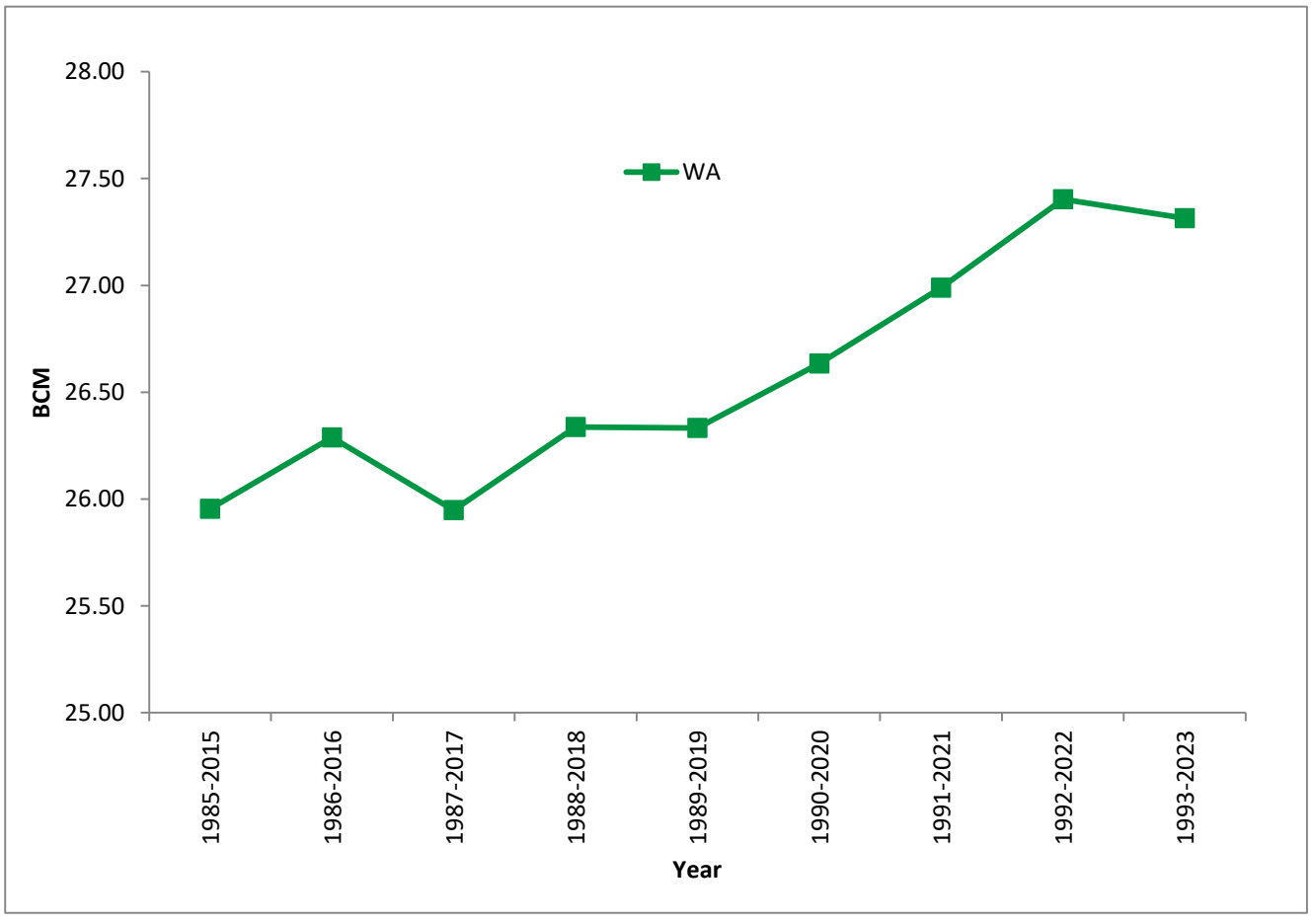


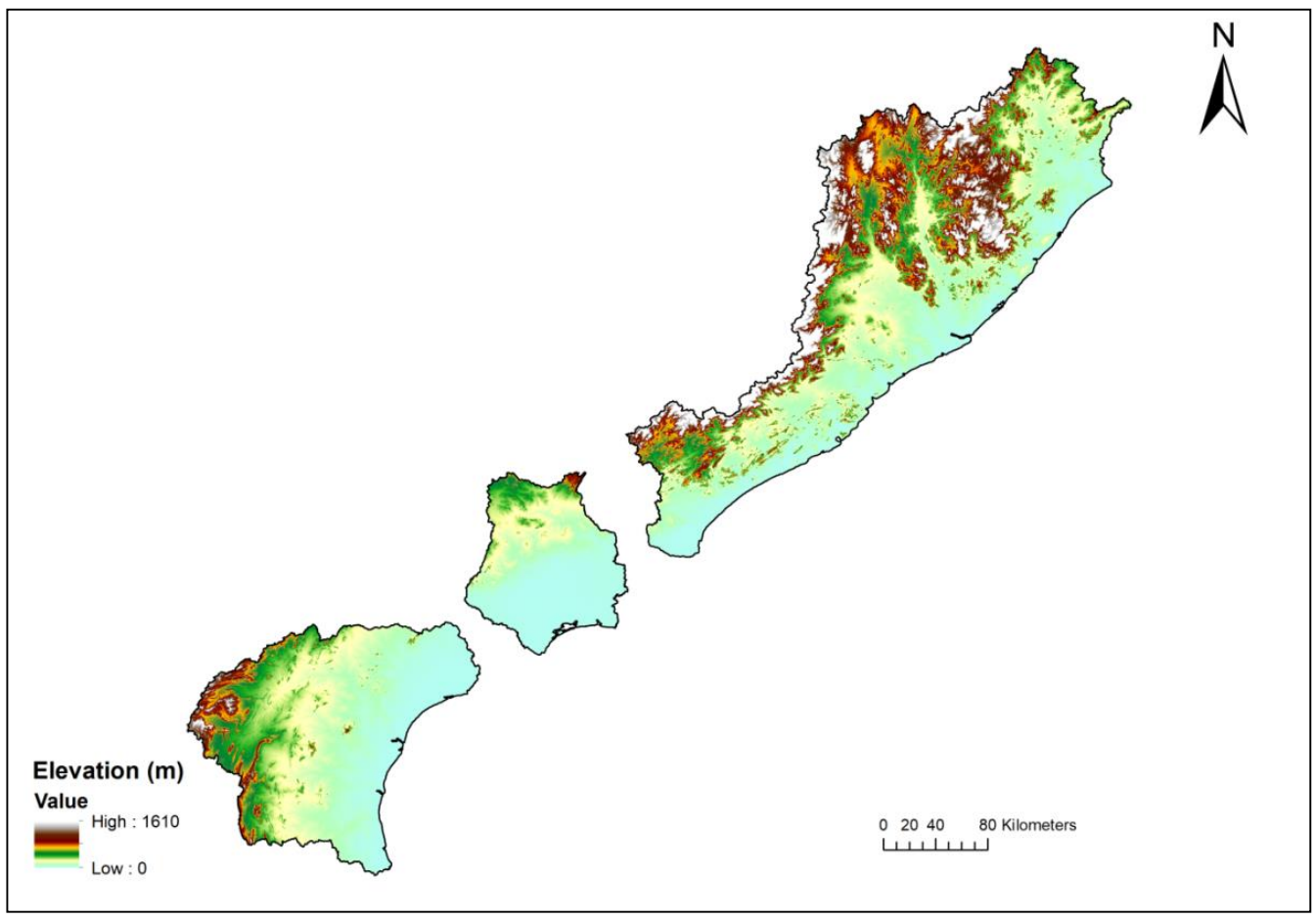
Figure 4.4.10: Moving Average of P and WA for 30 years

Table 4.4.3: Water Availability of Cauvery basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	78.65	56.53	22.12
1986-87	76.59	54.19	22.40
1987-88	87.62	65.85	21.77
1988-89	70.94	47.94	23.00
1989-90	81.03	57.04	23.99
1990-91	61.37	44.18	17.19
1991-92	86.16	55.38	30.78
1992-93	86.00	58.48	27.52
1993-94	91.79	60.84	30.95
1994-95	82.35	53.95	28.40
1995-96	69.90	47.37	22.53
1996-97	83.12	54.90	28.22
1997-98	88.44	54.85	33.59
1998-99	95.30	64.05	31.25
1999-00	87.41	54.52	32.89
2000-01	88.79	60.43	28.36
2001-02	50.07	27.33	22.74
2002-03	38.93	12.37	26.56
2003-04	51.08	36.73	14.35
2004-05	79.57	63.65	15.92
2005-06	107.58	76.19	31.39
2006-07	66.33	51.02	15.48
2007-08	98.69	74.25	24.44
2008-09	89.52	69.50	20.02
2009-10	87.39	65.29	22.10
2010-11	107.81	69.39	38.42
2011-12	99.86	62.79	37.07
2012-13	89.03	49.05	39.98
2013-14	74.79	56.34	18.45
2014-15	89.94	63.17	26.77
2015-16	82.00	49.89	32.11
2016-17	56.80	44.77	12.23
2017-18	91.38	57.97	33.41
2018-19	69.78	46.88	22.89
2019-20	91.71	58.70	33.01
2020-21	99.49	71.65	27.84
2021-22	118.14	74.94	43.20
2022-23	96.86	72.02	24.84
Average	**82.95**	**56.42**	**26.53**

4.5 EAST FLOWING RIVERS B/W MAHANADI & PENNAR



HIGHLIGHTS

- *Average annual water resources availability of* East Flowing Rivers *b/w Mahanadi & Pennar basin is 23.33 BCM.*
- *Maximum annual water availability is 42.58 BCM during 1989-90.*
- *Minimum annual water availability is 2.74 BCM during 2011-12.*
- *Average annual precipitation is 95.49 BCM (1163.45 mm).*
- *Maximum annual precipitation 130.81 BCM (1594 mm) during 1989-90.*
- *Minimum annual precipitation 63.53 BCM (774.00 mm) during 2002-03.*

4.5.1 About East Flowing Rivers b/w Mahanadi & Pennar Basin

The composite basin extends over an area of 82,073 sq.km. and is nearly 2.50% of the total geographical area of the country. The basin lies in the states of Andhra Pradesh (71.00%), Odisha (28.00%) and Telangana (1.00%) and stretches between 78°40' to 85°1' East longitudes and 14°34' to 20°22' North latitudes. It is bounded by the Eastern Ghats on the north and west, Nallamala Range and Andhra plains on the south and the Bay of Bengal on the east. This composite basin comprises of three river systems: between Mahanadi and Godavari, between Krishna and Pennar and between Godavari and Krishna drained mainly by the small stream of Palleru. The independent rivers (directly draining into Bay of Bengal) in the basin from north to south are the Rushikulya, the Bahuda, the Vamsadhara, the Nagavali, the Sarada, the Varaha, the Tandava, the Eluru, the Gundlakamma, the Musi, the Paleru and the Manneru.

4.5.2 Geo-Spatial Datasets

4.5.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of EFR b/w Mahanadi & Pennar basin for year 2022-23 is shown in Figure 4.5.1. The major land use classes consist of Kharif only, Double/Triple, waste land etc.

Table 4.5.1 shows the percentage area of each land use class in the basin for year 2022-23.

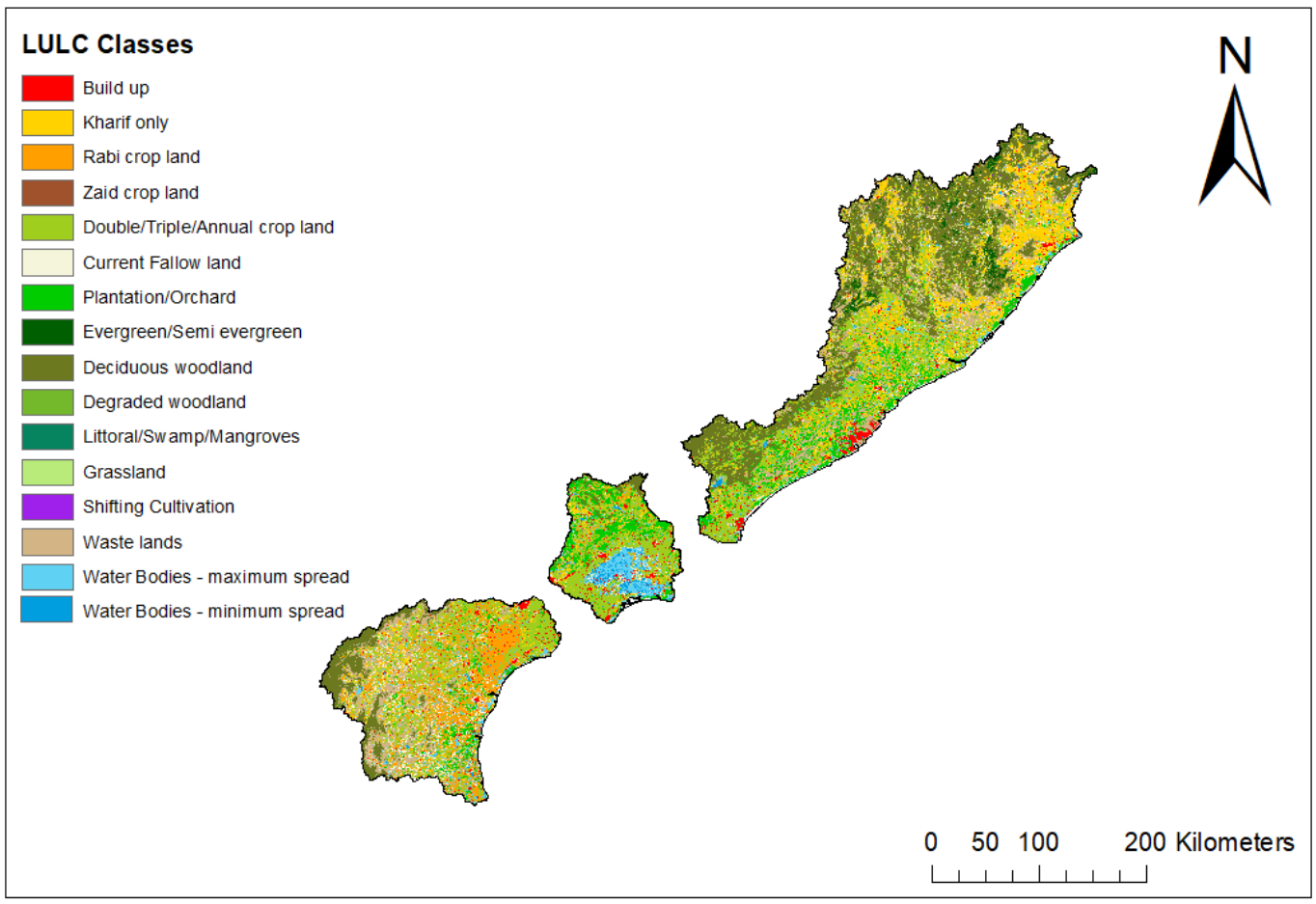


Figure 4.5.1: LULC Map of EFR b/w Mahanadi & Pennar basin

Table 4.5.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	2.67
2.	Kharif only	15.67
3.	Rabi crop land	4.32
4.	Zaid crop land	0.01
5.	Double/Triple/Annual crop land	20.28
6.	Current Fallow land	4.77
7.	Plantation/Orchard	5.20
8.	Evergreen/Semi evergreen	0.83
9.	Deciduous woodland	31.14
10.	Degraded woodland	1.67
11.	Littoral/Swamp/Mangroves	0.05
12.	Shifting Cultivation	0.03
13.	Waste lands	8.36
14.	Water Bodies - maximum spread	3.93
15.	Water Bodies - minimum spread	1.07

4.5.3 Hydro-Meteorological and other Input Data

4.5.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.5.2. The variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.5.3. The average precipitation of 38 years is approximately 95.49 BCM (1163.44 mm).

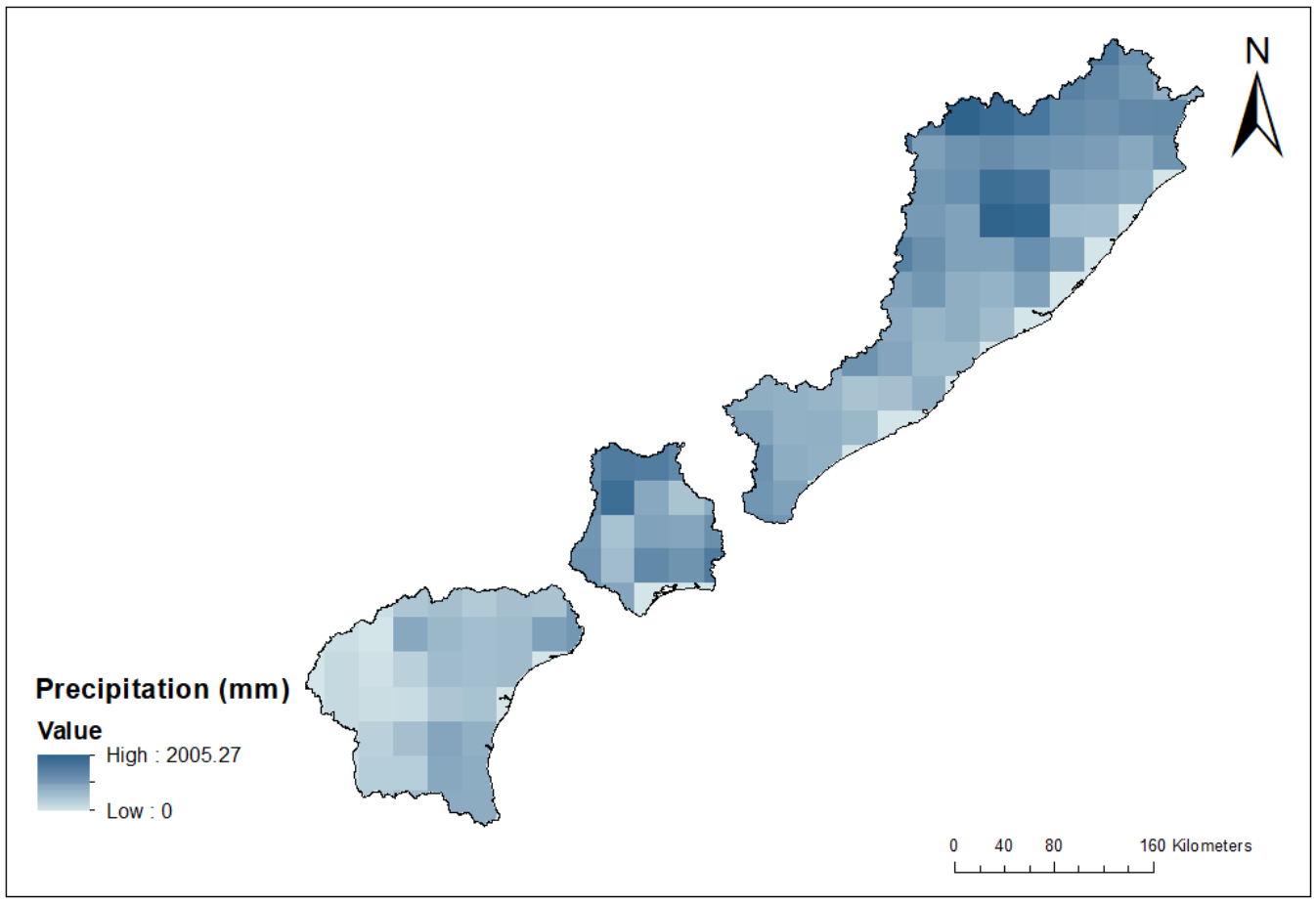


Figure 4.5.2: Precipitation map of EFR b/w Mahanadi & Pennar basin

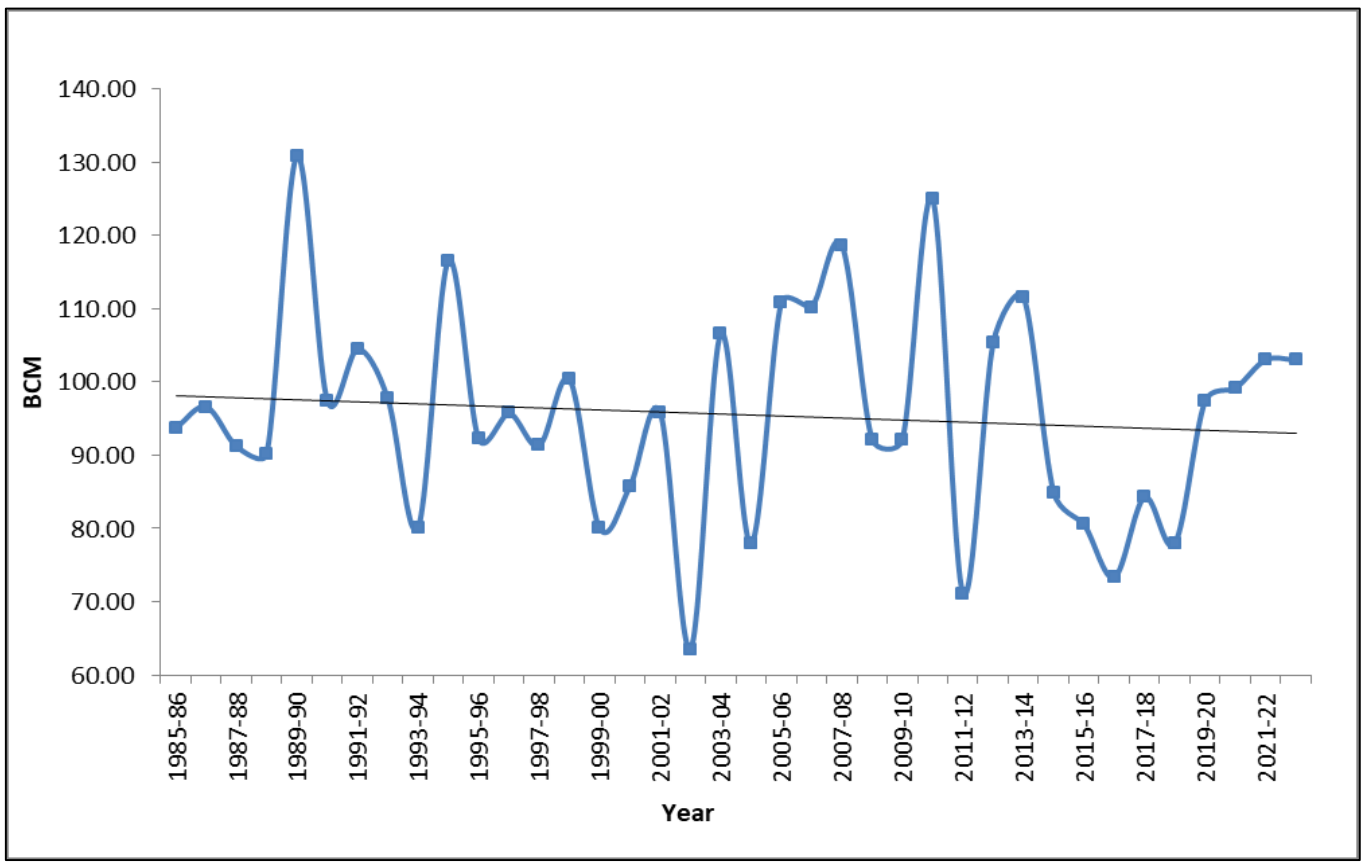


Figure 4.5.3: Annual Precipitation in EFR b/w Mahanadi & Pennar basin

4.5.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.5.4.The variations in the annual actual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.5.5. The average ET of 38 years is approx. 76.98 BCM (940.90 mm).

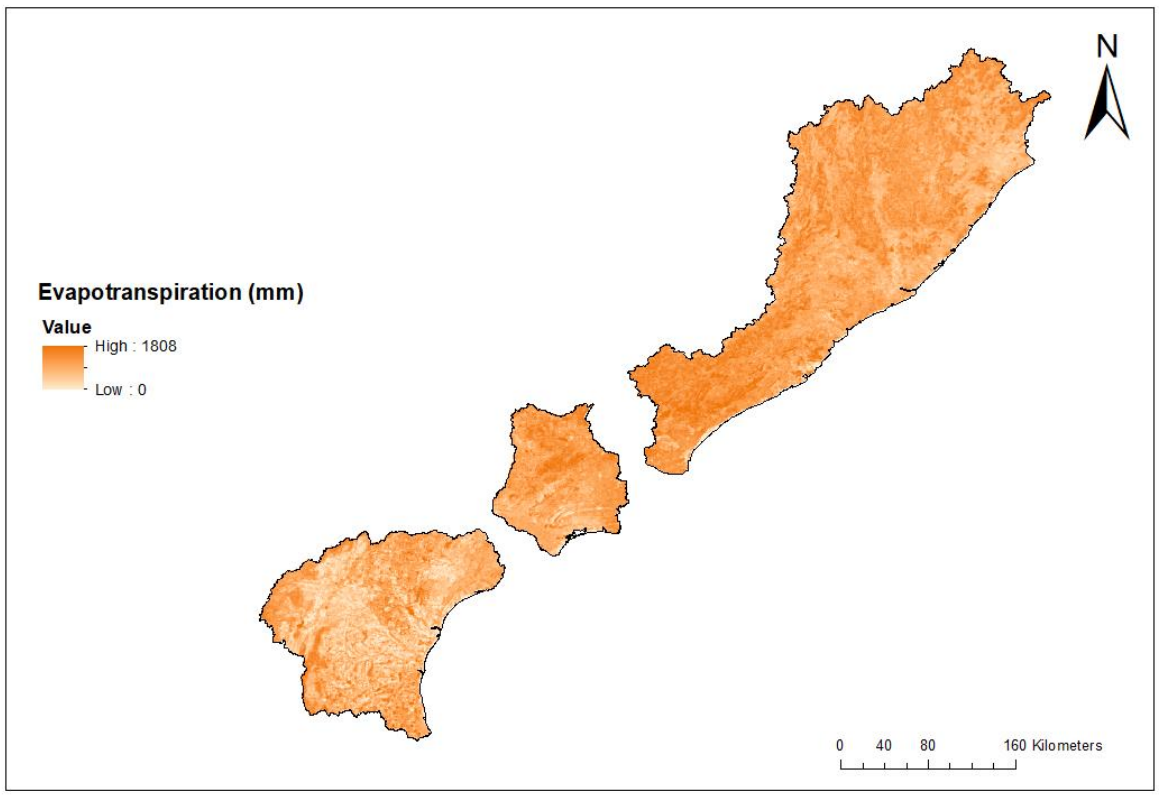


Figure 4.5.4: Evapotranspiration map of EFR b/w Mahanadi & Pennar basin

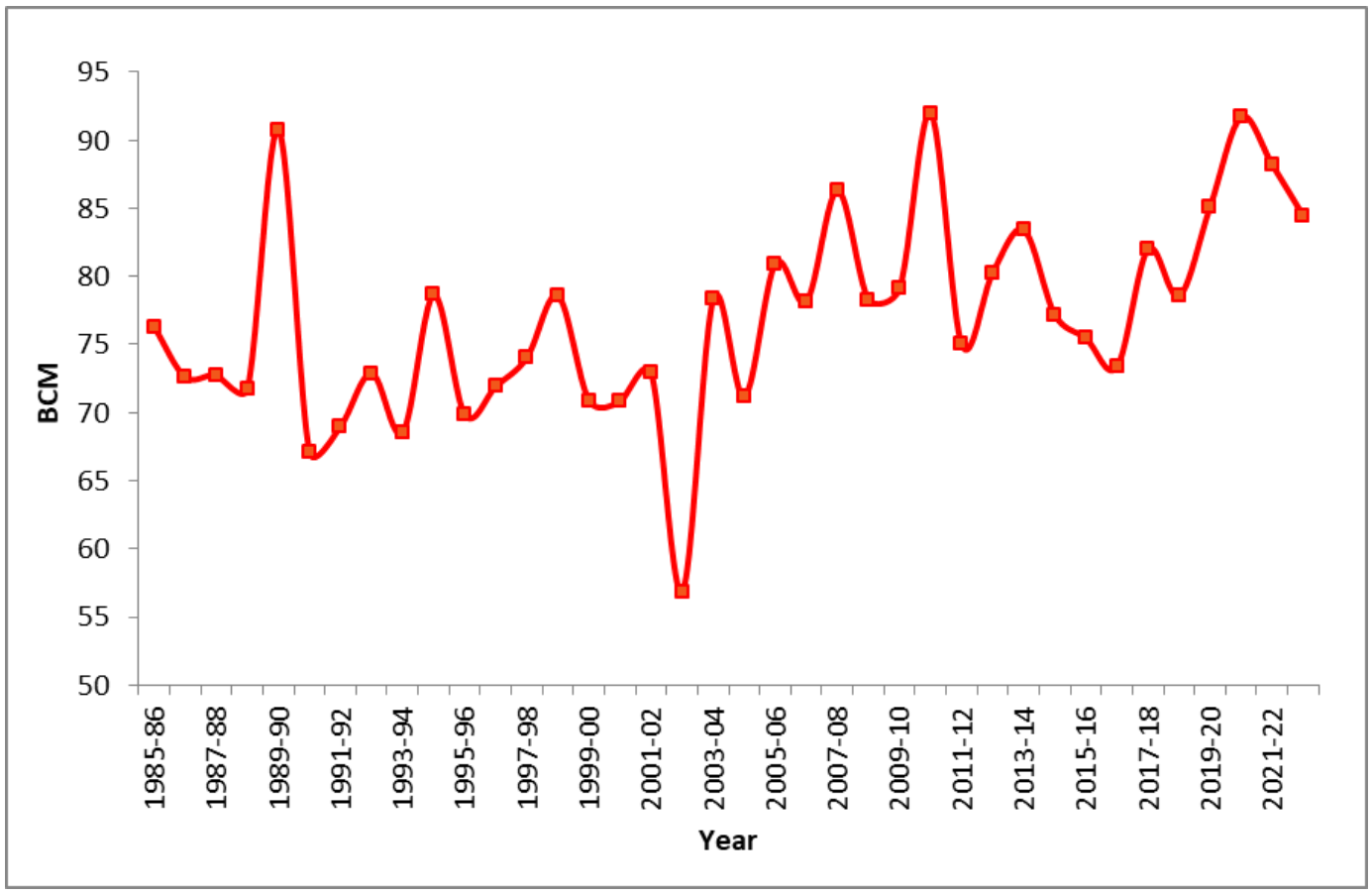


Figure 4.5.5: Annual Evapotranspiration in EFR b/w Mahanadi & Pennar basin

4.5.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.5.6. The average annual evaporation from the reservoirs in the basin is 0.96 BCM.

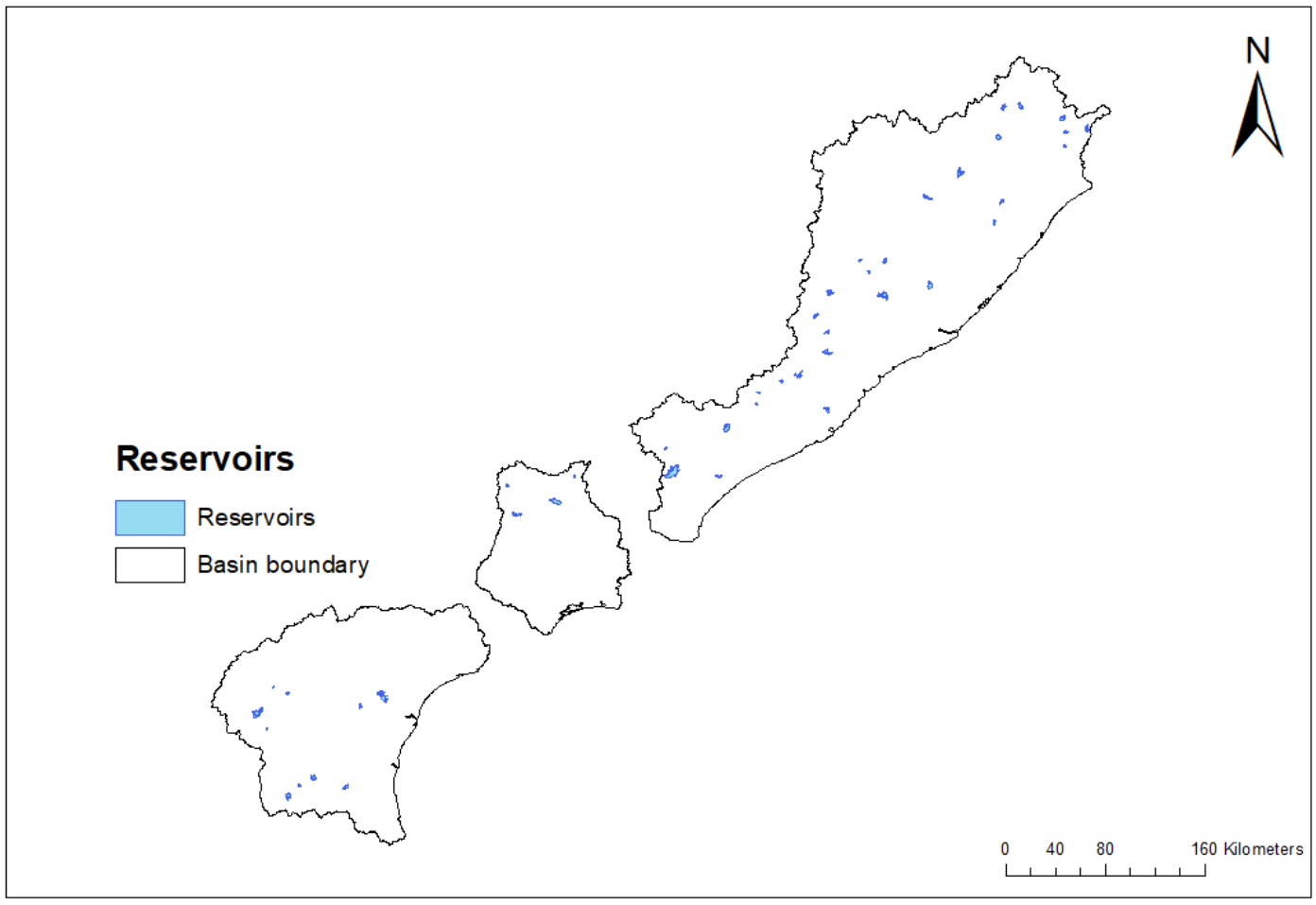


Figure 4.5.6: Reservoir map of EFR b/w Mahanadi & Pennar Basin

4.5.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 9.11 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.5.7. Yearly variations in ET_{II} are shown in Figure 4.5.8.

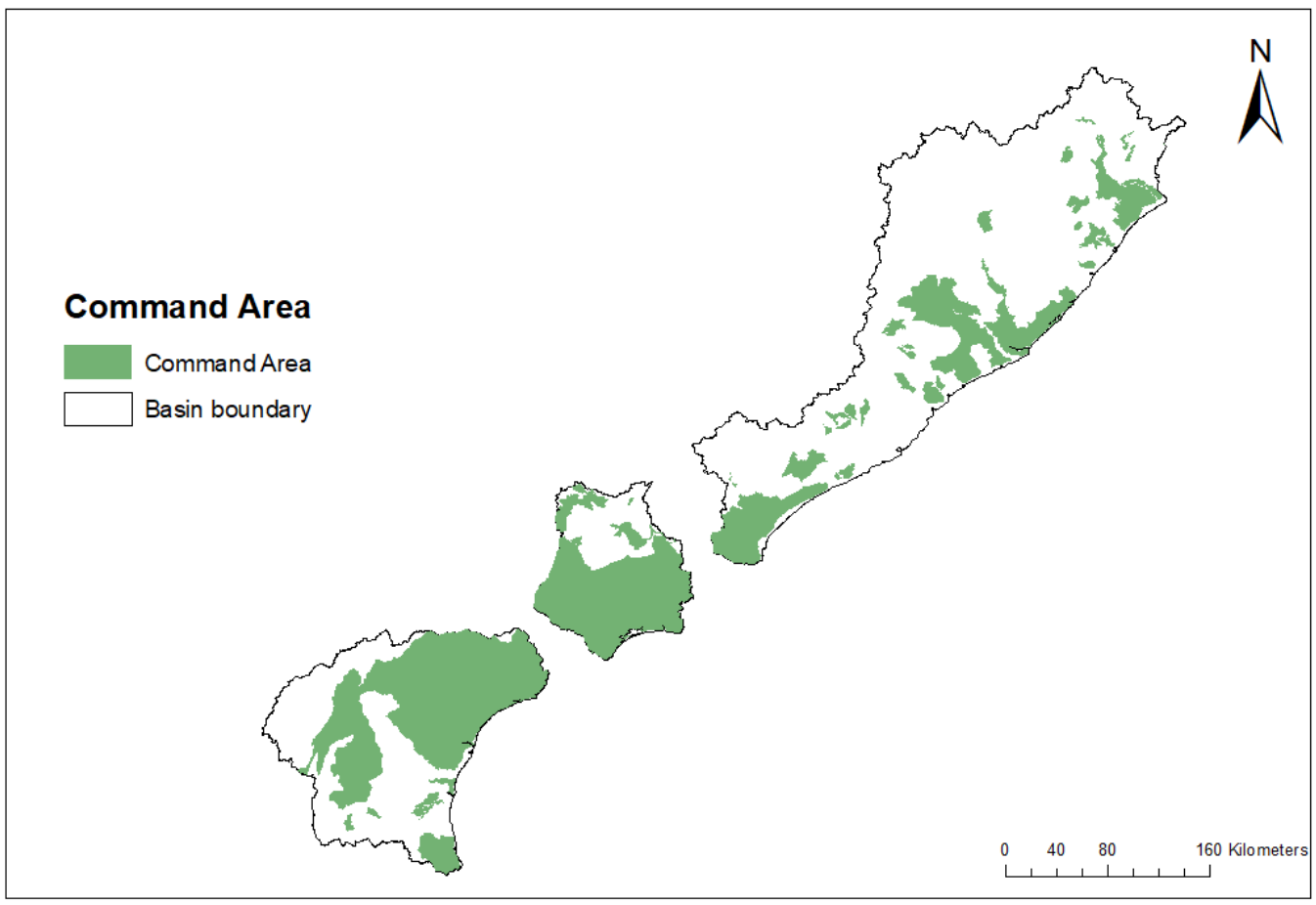


Figure 4.5.7: Command area map of EFR b/w Mahanadi & Pennar basin

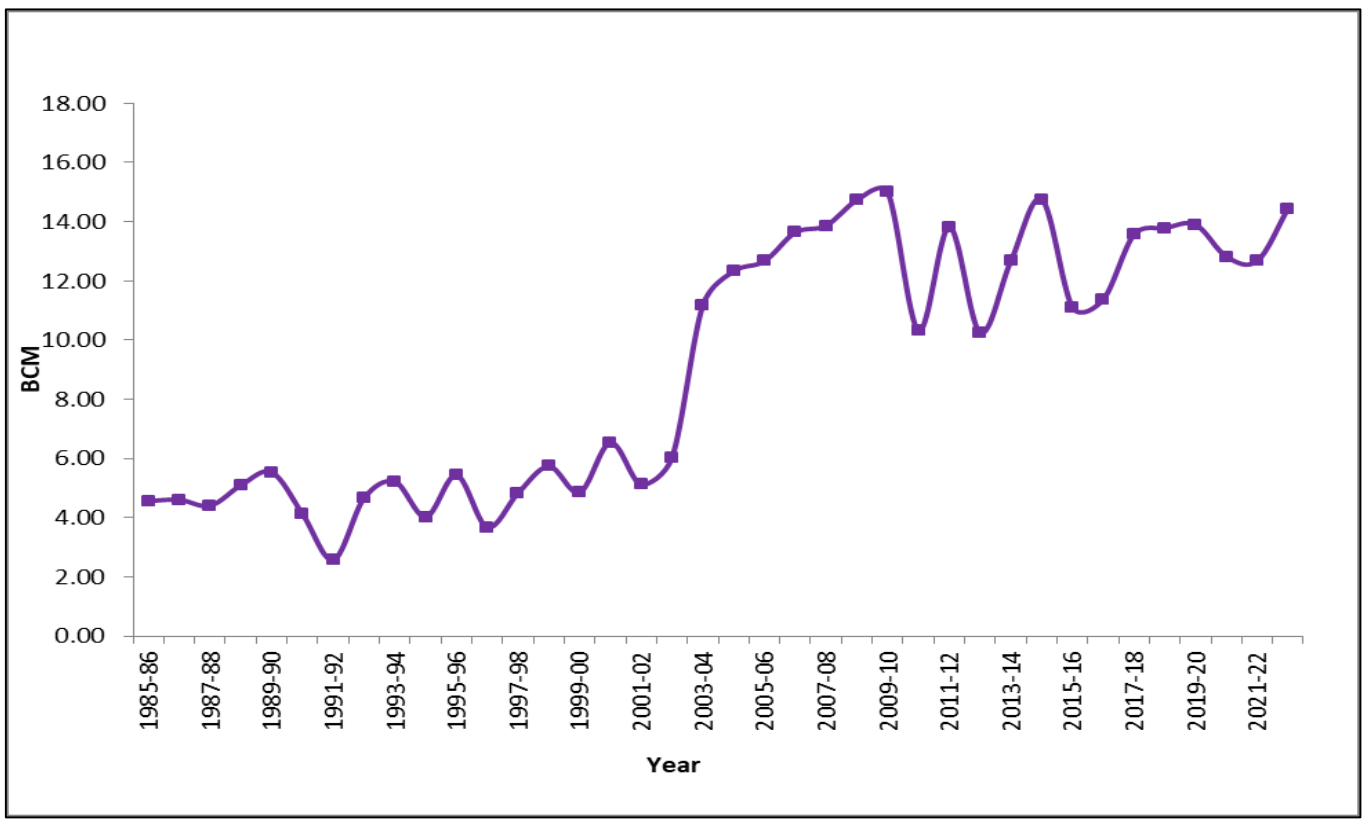


Figure 4.5.8: ET from Irrigation Input in EFR b/w Mahanadi & Pennar basin

4.5.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.30 BCM and -0.01 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.26 BCM.

4.5.4 Previous Estimates

The previous CWC (1993) estimate of available water resources of the total basin was 22.52 BCM while in 2019 study (1985 to 2015) available water resources of the total basin was 26.41 BCM.

4.5.5 Annual Water Availability of EFR b/w Mahanadi and Pennar Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability is estimated to be 23.33 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.5.9. The results of EFR between Mahanadi and Pennar basin are shown in Table 4.5.3.

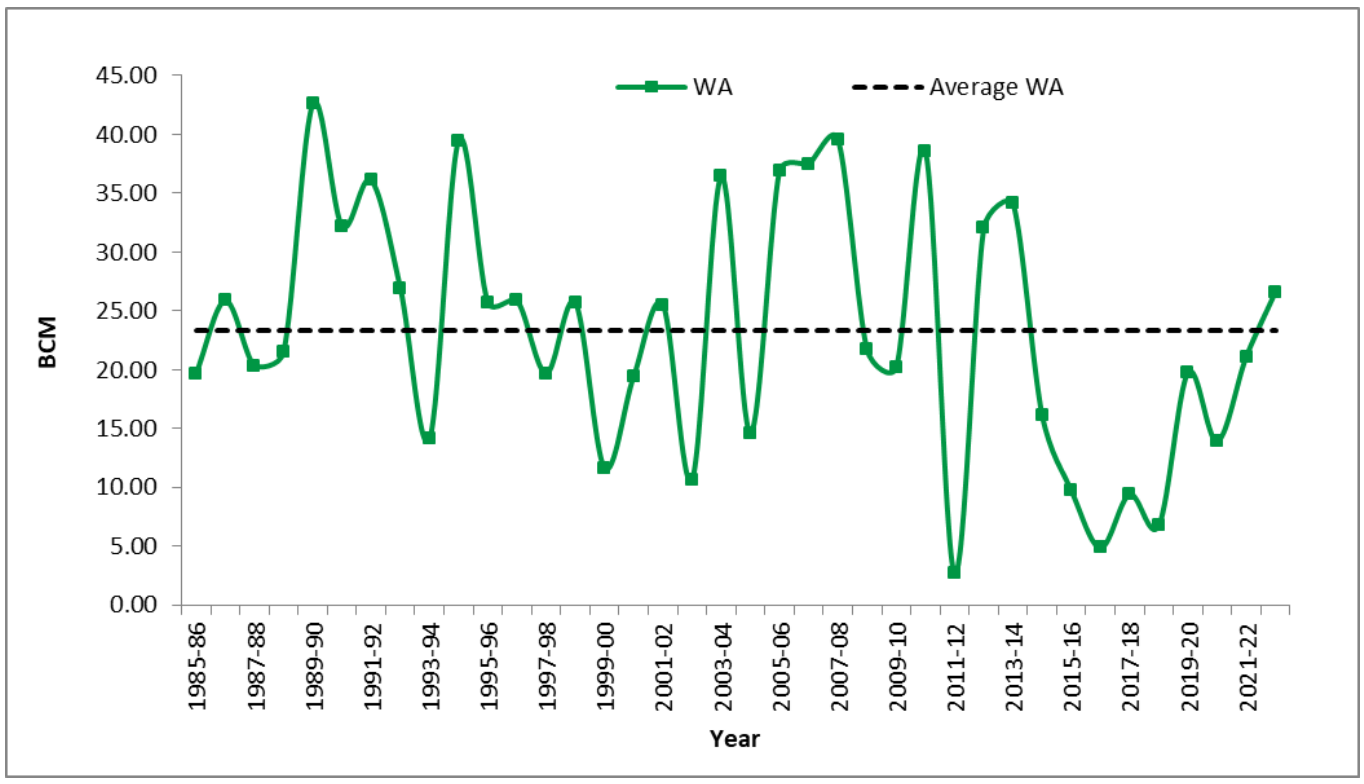


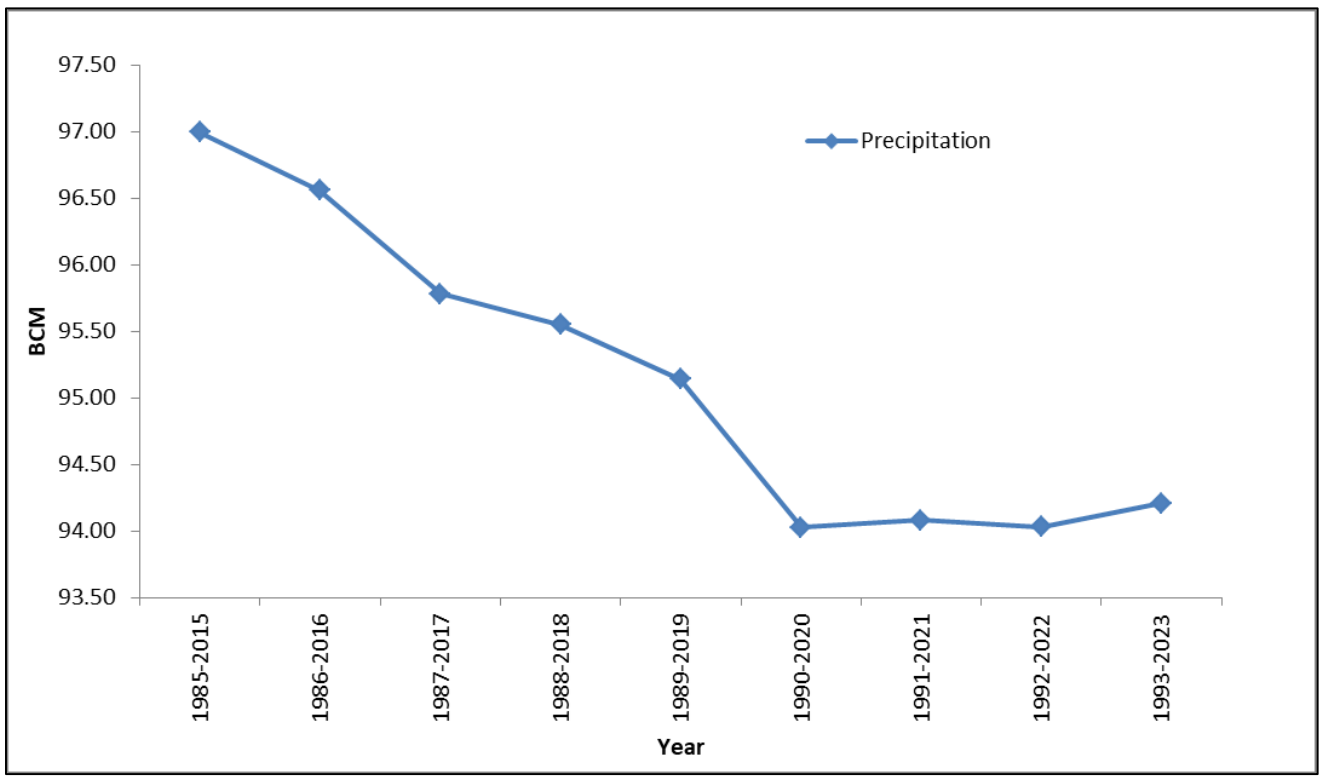
Figure 4.5.9: Water availability of EFR b/w Mahanadi & Pennar basin

4.5.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of EFR b/w Mahanadi & Pennar basin is given at Table 4.5.2. A line diagram of moving average of P and WA is shown in Figure 4.5.10.

Table 4.5.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	97.00	25.60
1986-2016	96.56	25.27
1987-2017	95.78	24.57
1988-2018	95.55	24.21
1989-2019	95.14	23.71
1990-2020	94.03	22.95
1991-2021	93.84	22.34
1992-2022	93.79	21.84
1993-2023	93.96	21.83



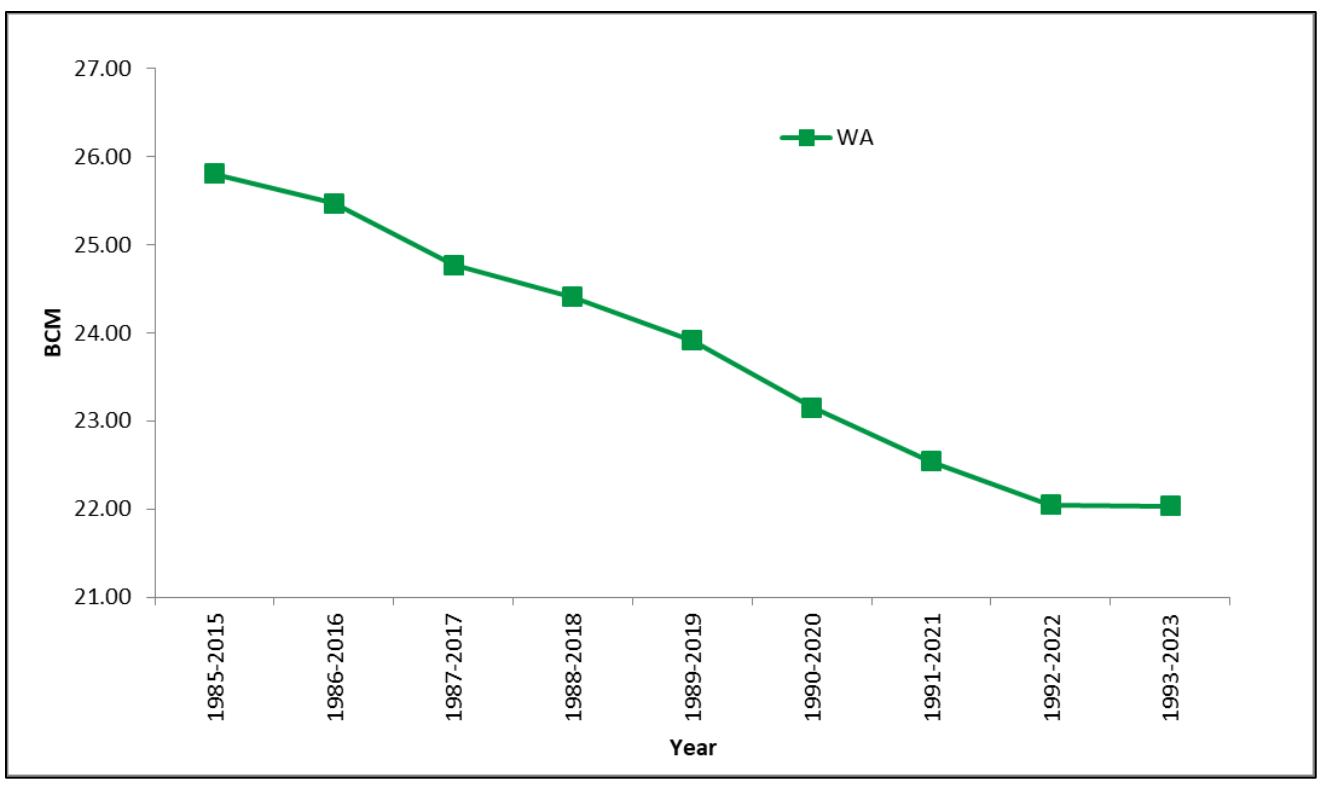


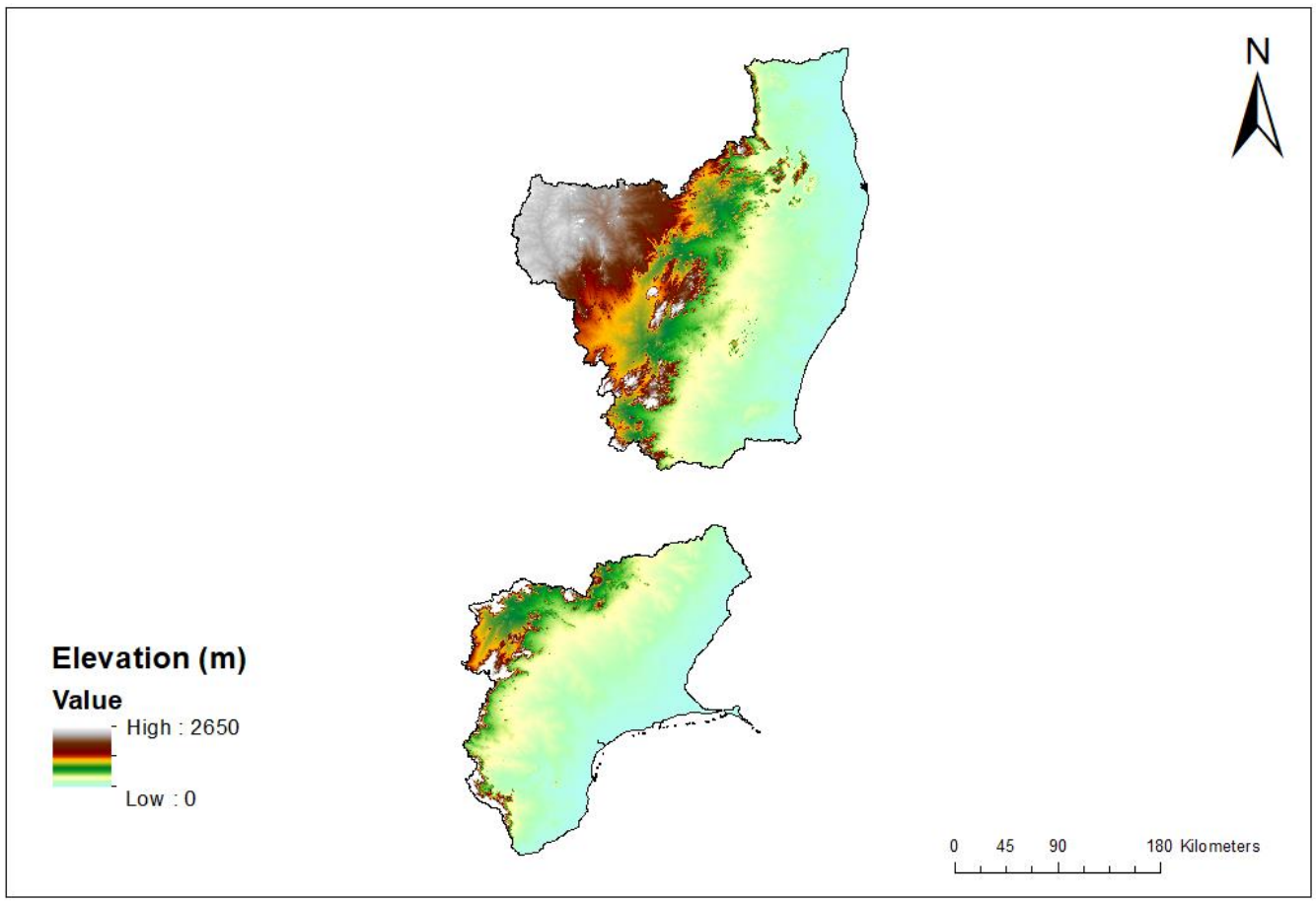
Figure 4.5.10: Moving Average of P and WA for 30 years

Table 4.5.3 Water Availability of EFR b/w Mahanadi & Pennar basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	93.72	70.01	19.70
1986-87	96.60	66.90	25.88
1987-88	91.18	66.99	20.36
1988-89	90.23	64.90	21.55
1989-90	130.81	83.45	42.58
1990-91	97.45	61.68	32.24
1991-92	104.51	64.78	36.10
1992-93	97.71	66.93	26.94
1993-94	80.13	62.36	14.16
1994-95	116.55	72.92	39.49
1995-96	92.20	62.78	25.74
1996-97	95.74	66.04	25.91
1997-98	91.31	67.70	19.71
1998-99	100.33	70.49	25.70
1999-00	80.02	64.62	11.67
2000-01	85.76	62.57	19.46
2001-02	95.76	66.41	25.51
2002-03	63.53	49.84	10.70
2003-04	106.58	66.71	36.43
2004-05	77.87	58.46	14.63
2005-06	110.89	67.82	36.94
2006-07	110.21	64.07	37.47
2007-08	118.65	71.95	39.58
2008-09	92.11	63.13	21.70
2009-10	92.15	63.73	20.23
2010-11	124.92	81.16	38.53
2011-12	71.14	60.75	2.74
2012-13	105.34	69.57	32.05
2013-14	111.61	70.23	34.16
2014-15	84.92	61.99	16.16
2015-16	80.56	63.94	9.77
2016-17	73.31	61.56	4.90
2017-18	84.26	67.98	9.43
2018-19	77.94	64.32	6.77
2019-20	97.37	70.75	19.77
2020-21	99.14	78.36	13.93
2021-22	102.99	75.00	21.14
2022-23	103.02	69.55	26.62
Average	**95.49**	**66.91**	**23.33**

4.6 EAST FLOWING RIVERS FROM PENNAR TO KANYAKUMARI



HIGHLIGHTS

- *Average annual water resources availability of East Flowing Rivers from Pennar to Kanyakumari basin is 27.06 BCM.*
- *Maximum annual water availability is 52.76 BCM during 2011-12.*
- *Minimum annual water availability is 11.96 BCM during 2016-17.*
- *Average annual precipitation is 99.55 BCM (979.26 mm).*
- *Maximum annual precipitation is 145.29 BCM (1429 mm) during 2011-12.*
- *Minimum annual precipitation is 40.80 BCM (401 mm) during 2002-03.*

4.6.1 About East Flowing Rivers from Pennar to Kanyakumari

The composite basin comprises the river systems between Pennar and Kanyakumari having an area of 1,01,657 sq. km. The basin lies in the states of Tamil Nadu (77.45%), Andhra Pradesh (15.83%), Karnataka (6.37%), Puducherry (0.29%) and Kerala (0.06%). The independent rivers (directly draining into Bay of Bengal) are the Kandleru, the Swarnamukhi, the Arani, the Korttalaiyar, the Cooum, the Adyar, the Palar, the Gingee, the Ponnaiyar, the Vellar, the Varshalei, the Vaigai, the Gundar, the Vaippar and the Tambraparni.

Pennar to Cauvery part of this basin is bounded on the north, west and south by the various ranges of the Eastern Ghats. Cauvery to Kanyakumari basin area is bounded by the Varushanad hills, the Andippatti hills, the Cardamom hills and Palani hills on the west, the Indian Ocean on the south, the Palk-Strait, Palk Bay and the Gulf of Mannar on the east and the ridge, which separates it from the Cauvery basin on the north. Shape of the area is irregular; it has a maximum length of 236 km in the northwest-southeast direction and a maximum width of 275 km in the northeast-South-West direction.

4.6.2 Geo-Spatial Datasets

4.6.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of East Flowing Rivers Pennar to Kanyakumari basin for year 2022-23 is shown in Figure 4.6.1. The major land use classes consist of Rabi crop land, Double/ Triple/ Annual cropland and deciduous woodland etc.

Table 4.6.1 shows the percentage area of each land use class in the basin for year 2022-23.

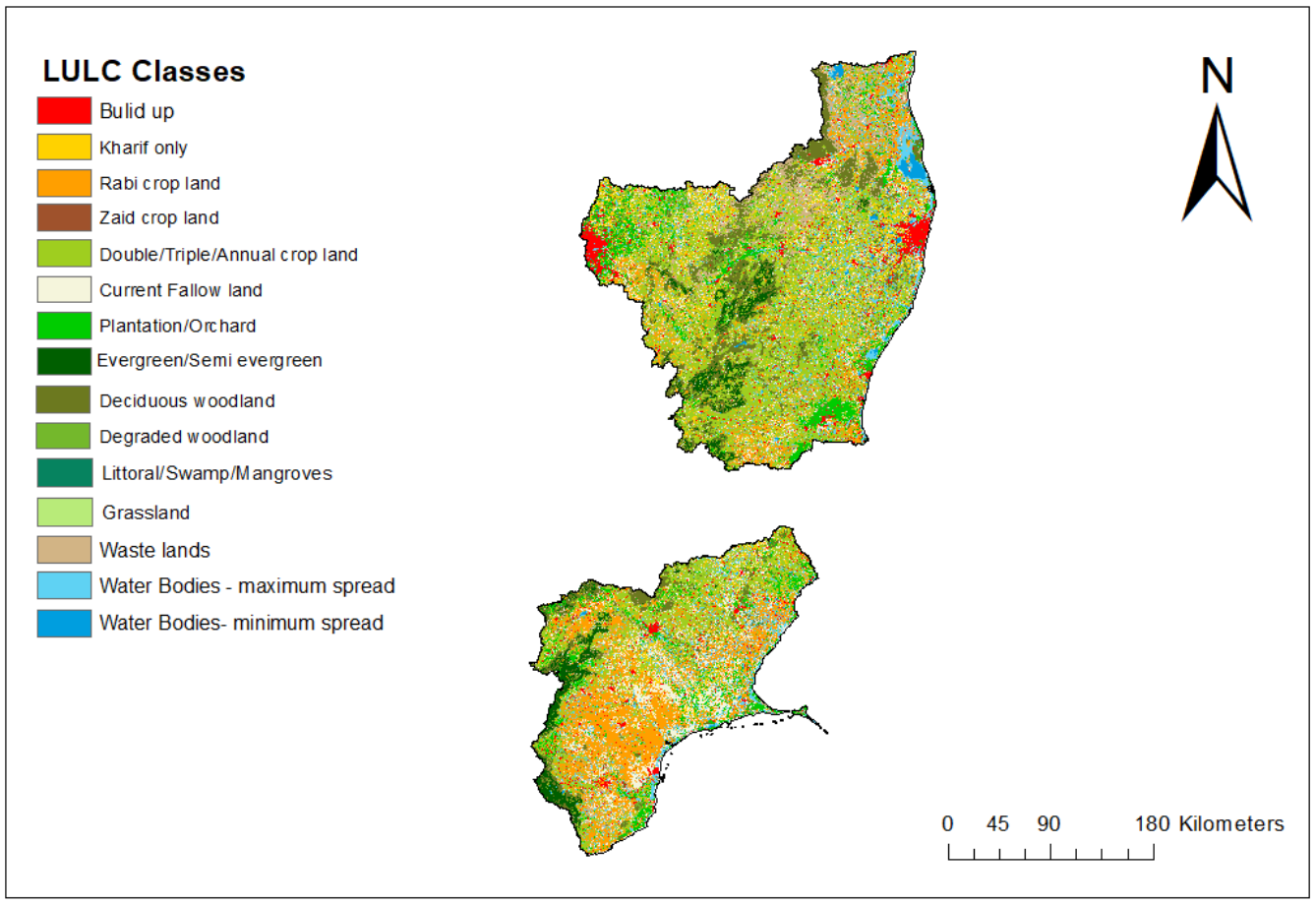


Figure 4.6.1: LULC Map of EFR from Pennar to Kanyakumari basin

Table 4.6.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	4.41
2.	Kharif only	5.90
3.	Rabi crop land	14.78
4.	Zaid crop land	0.04
5.	Double/Triple/Annual crop land	28.48
6.	Current fallow land	10.09
7.	Plantation/orchard	6.53
8.	Evergreen/ Semi Evergreen	3.28
9.	Deciduous woodland	10.28
10.	Degraded woodland	1.63
11.	Littoral/Swamp/Mangroves	0.01
12.	Waste lands	6.56
13.	Water Bodies - maximum spread	6.93
14.	Water Bodies - minimum spread	1.08

4.6.3 Hydro-Meteorological and other Input Data

4.6.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.6.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.6.3. The average precipitation of 38 years is approximately 99.55 BCM (979.26 mm).

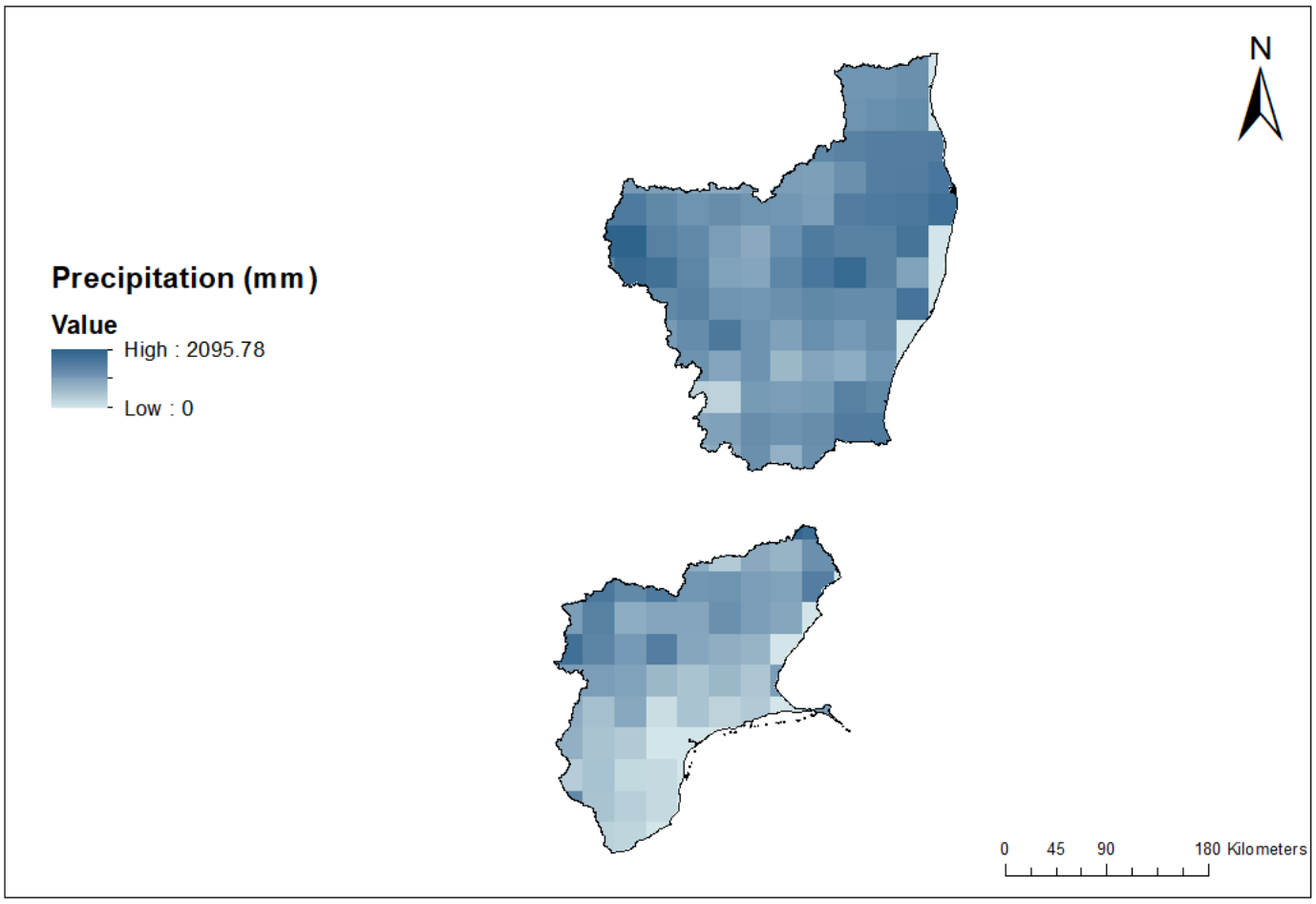


Figure 4.6.2: Precipitation map of EFR from Pennar to Kanyakumari basin

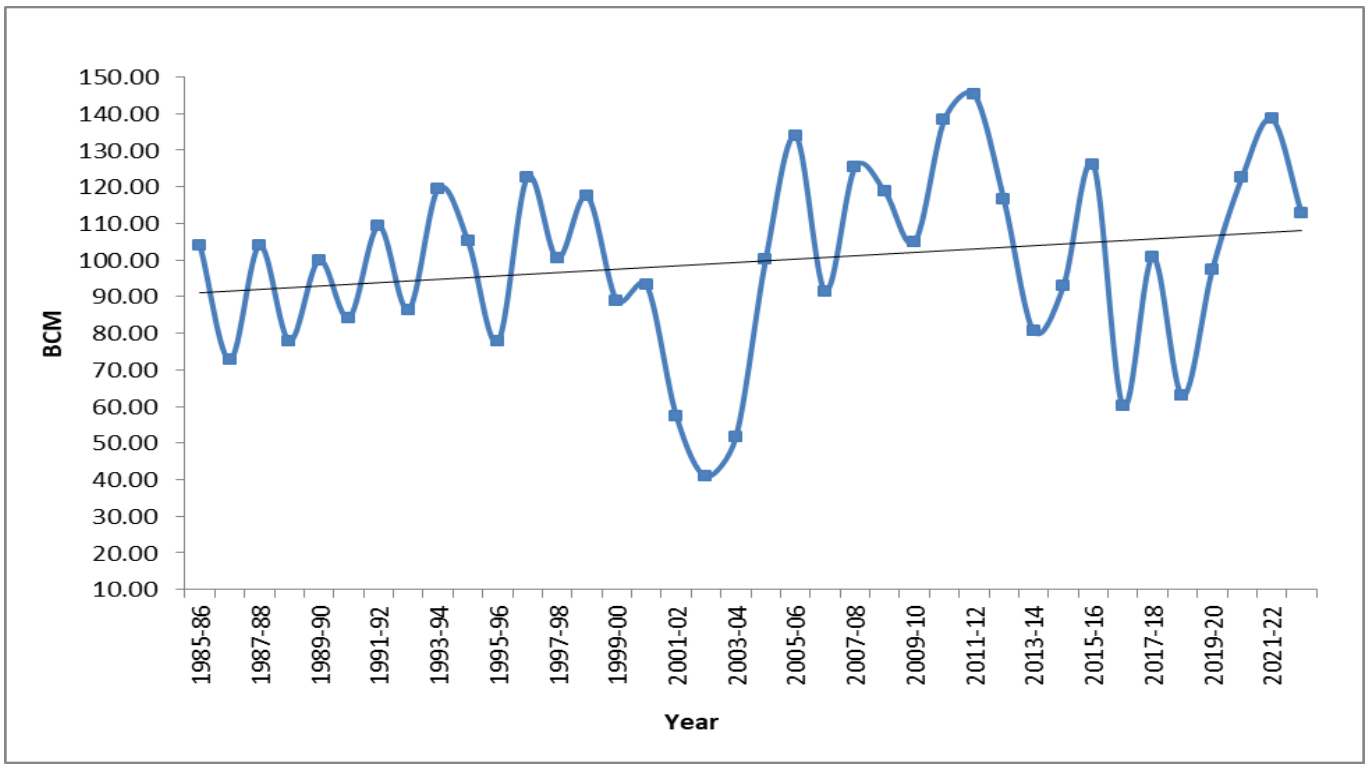


Figure 4.6.3: Annual Precipitation in EFR from Pennar to Kanyakumari basin

4.6.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.6.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.6.5. The average ET of 38 years is approx. 89.66 BCM (881.98 mm).

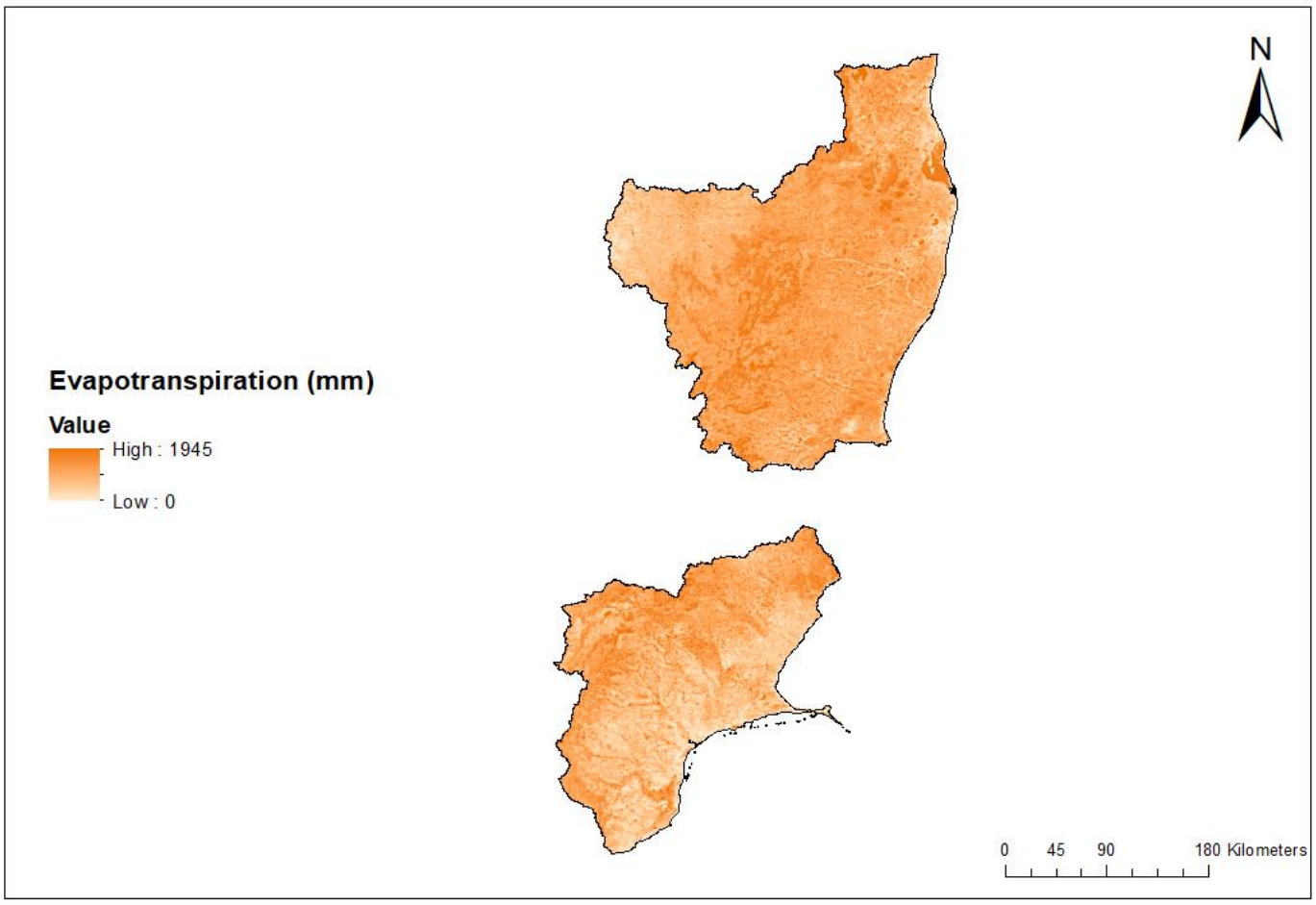


Figure 4.6.4: Evapotranspiration map of EFR from Pennar to Kanyakumari basin

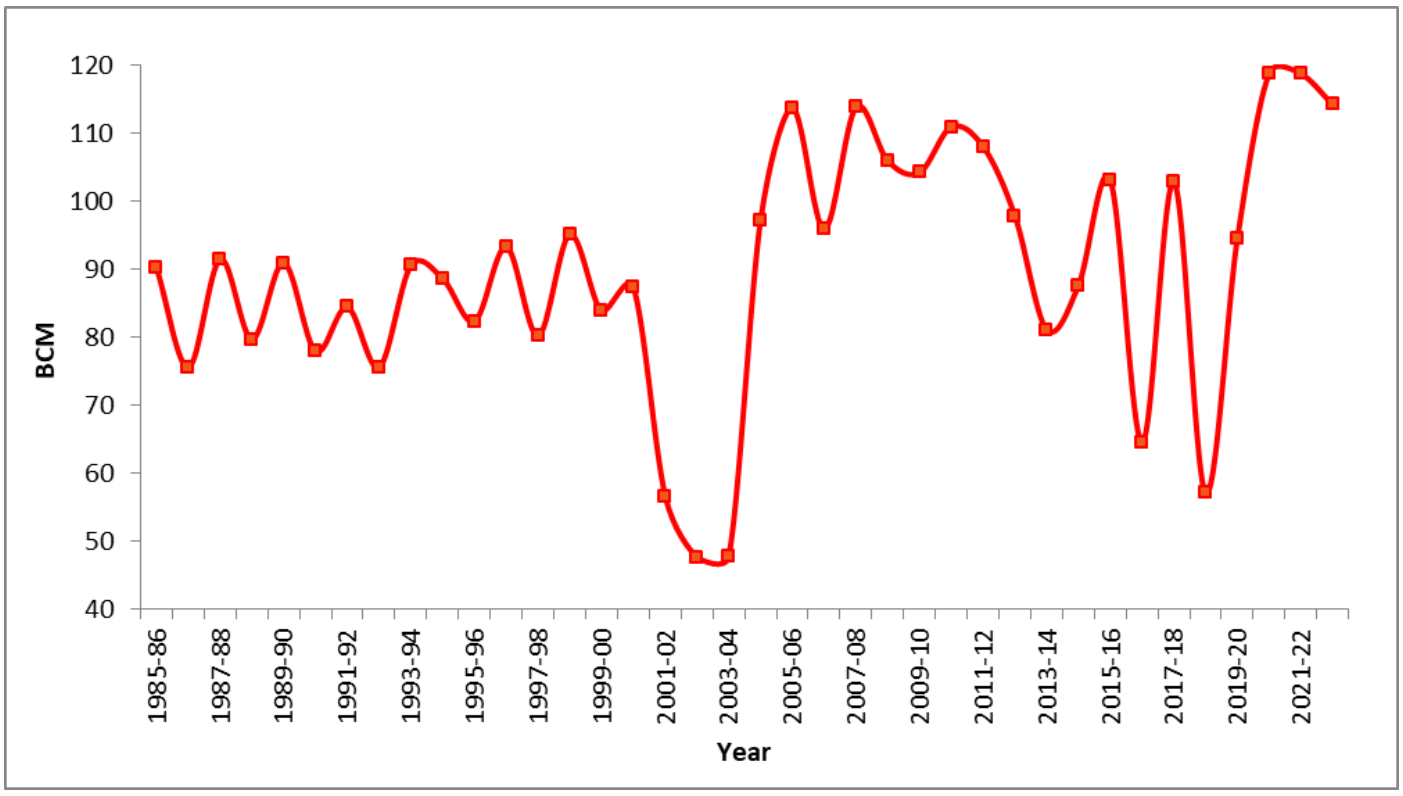


Figure 4.6.5: Annual Evapotranspiration in EFR from Pennar to Kanyakumari basin

4.6.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.6.6. The average annual evaporation from the reservoirs in the basin is 0.42 BCM.

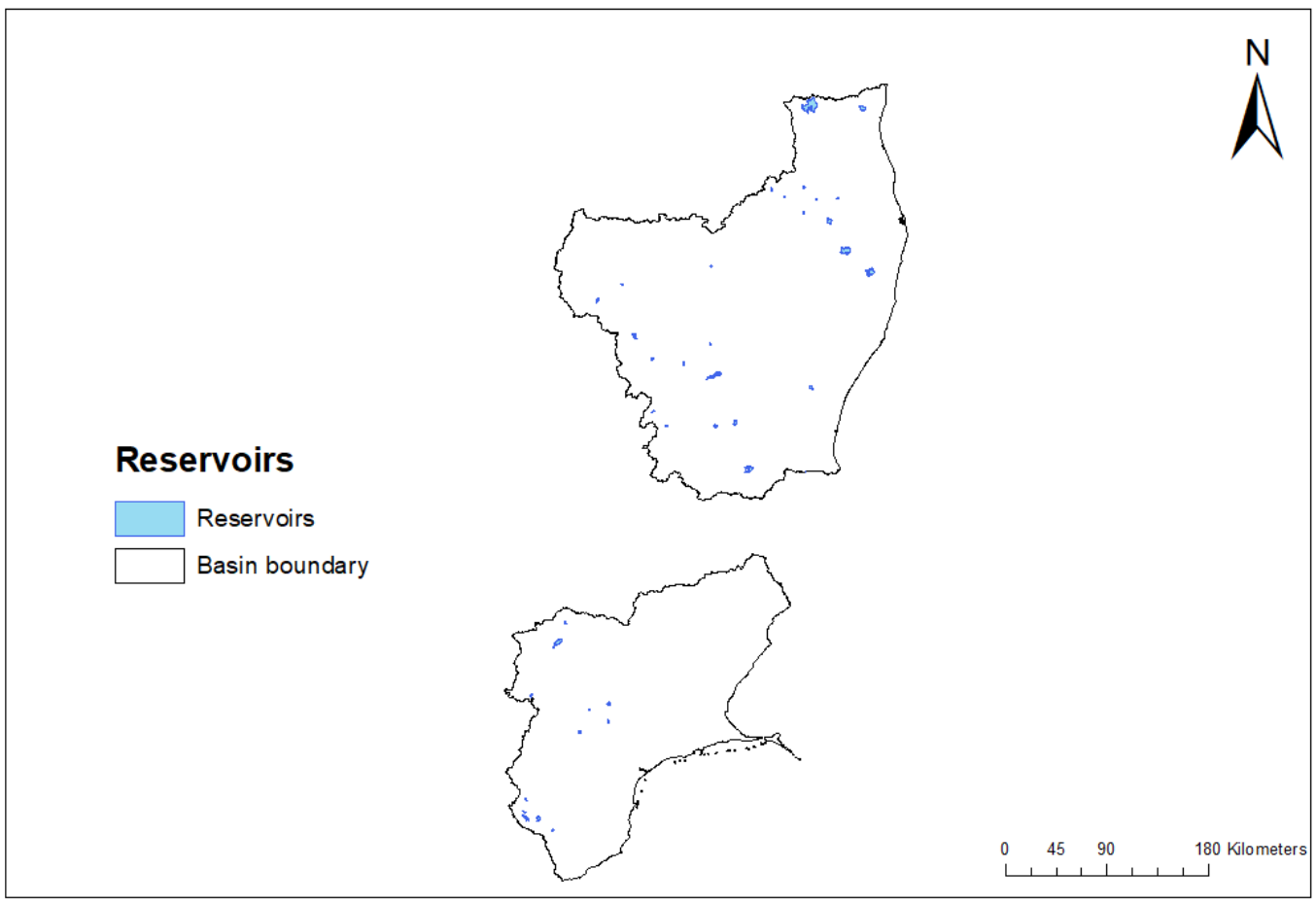


Figure 4.6.6: Reservoir map of EFR from Pennar to Kanyakumari basin

4.6.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 16.75 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.6.7. Yearly variations in ET_{II} are shown in Figure 4.6.8.

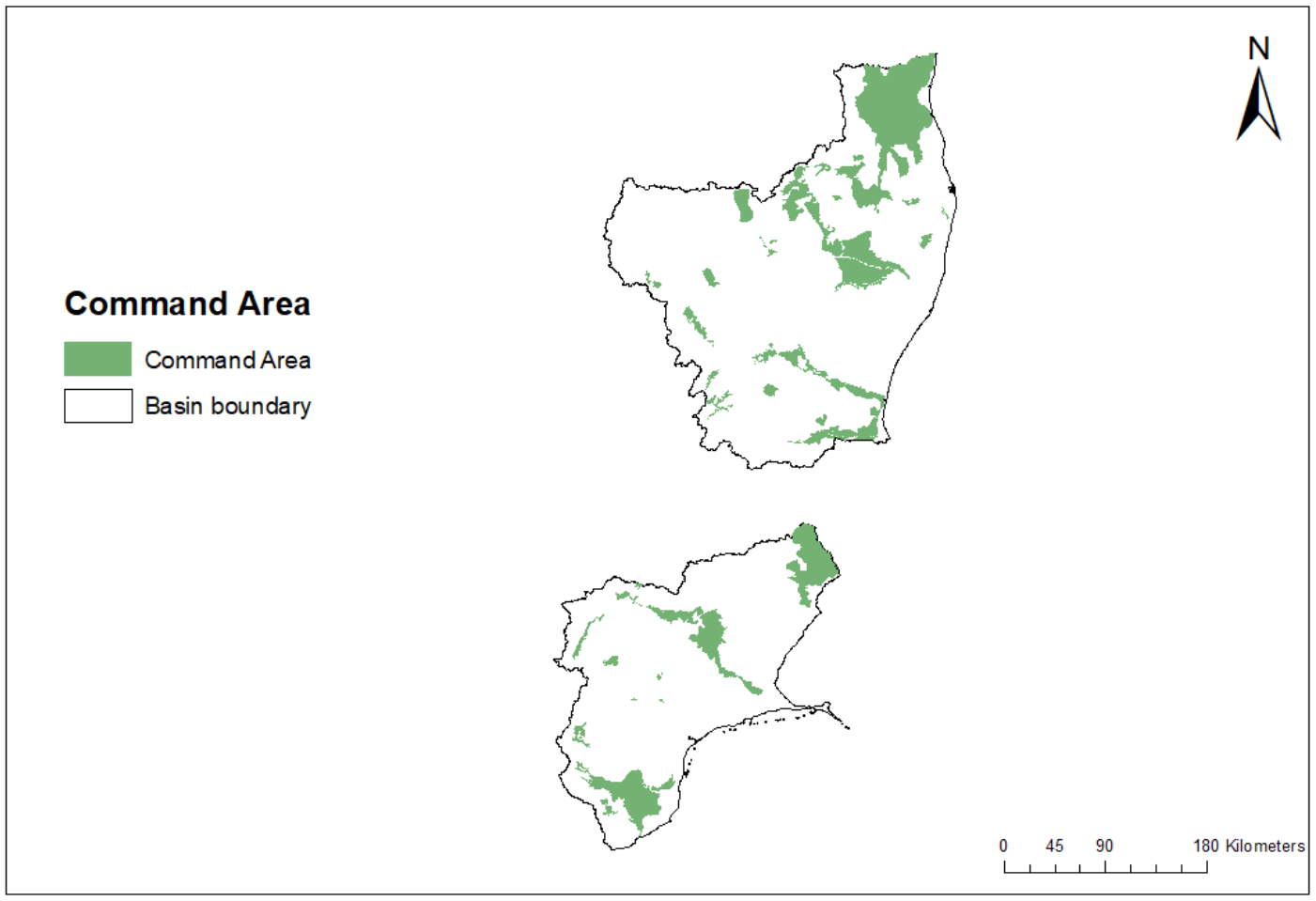


Figure 4.6.7: Command area map of EFR from Pennar to Kanyakumari basin

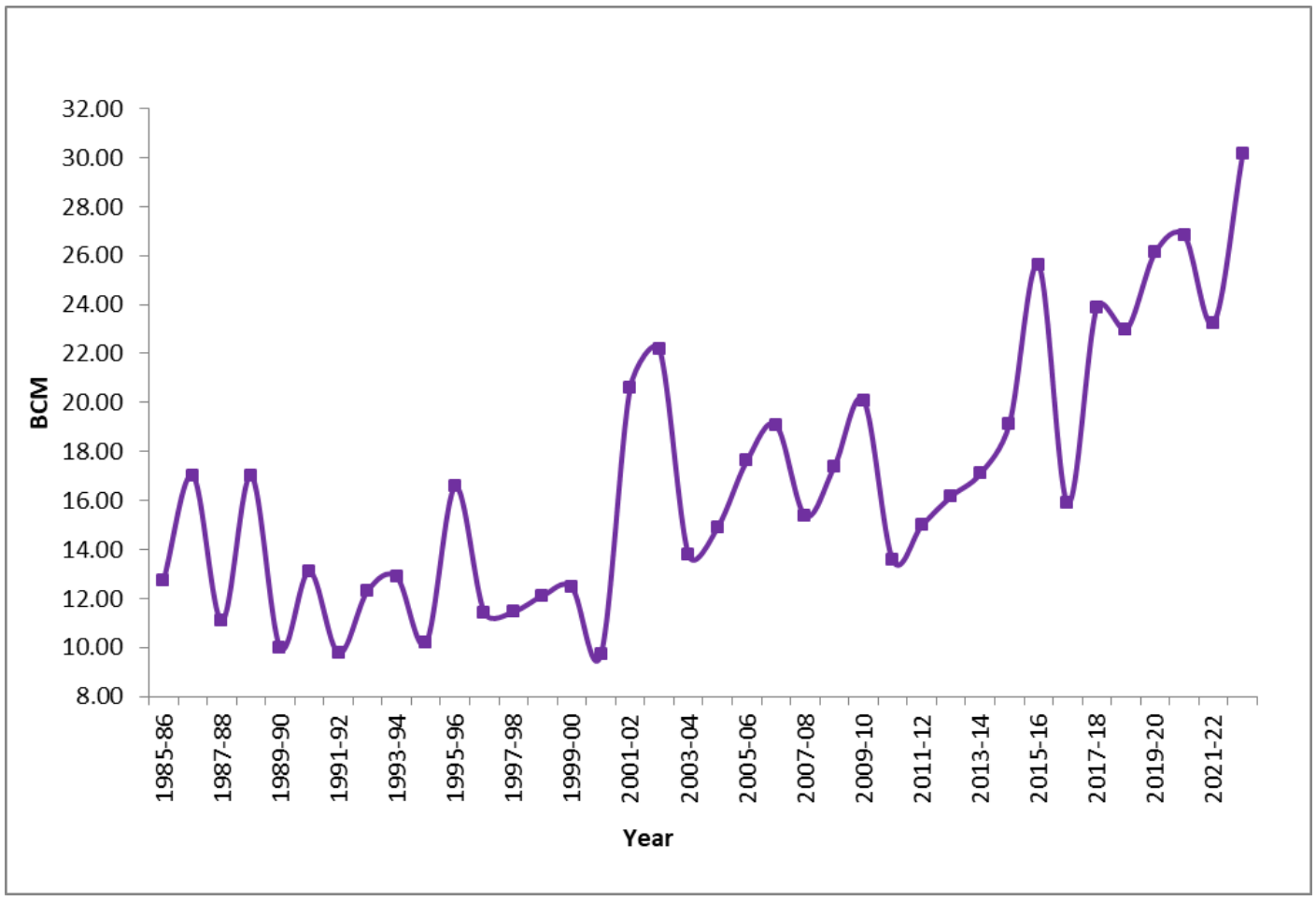


Figure 4.6.8: ET from Irrigation Input in EFR from Pennar to Kanyakumari basin

4.6.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.74 BCM and 0 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 2.55 BCM.

4.6.4 Previous Estimates

The CWC, 1993 estimate of available water resources of the total basin was 16.46 BCM while in CWC, 2019 study, available water resources of the total basin was estimated as 26.74 BCM.

4.6.5 Annual Water Availability of East Flowing Rivers Pennar to Kanyakumari Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability from year 1985-86 to 2022-23 of East Flowing Rivers Pennar to Kanyakumari basin is estimated as 27.06 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.6.9. The results of East Flowing Rivers Pennar to Kanyakumari basin are shown in Table 4.6.3.

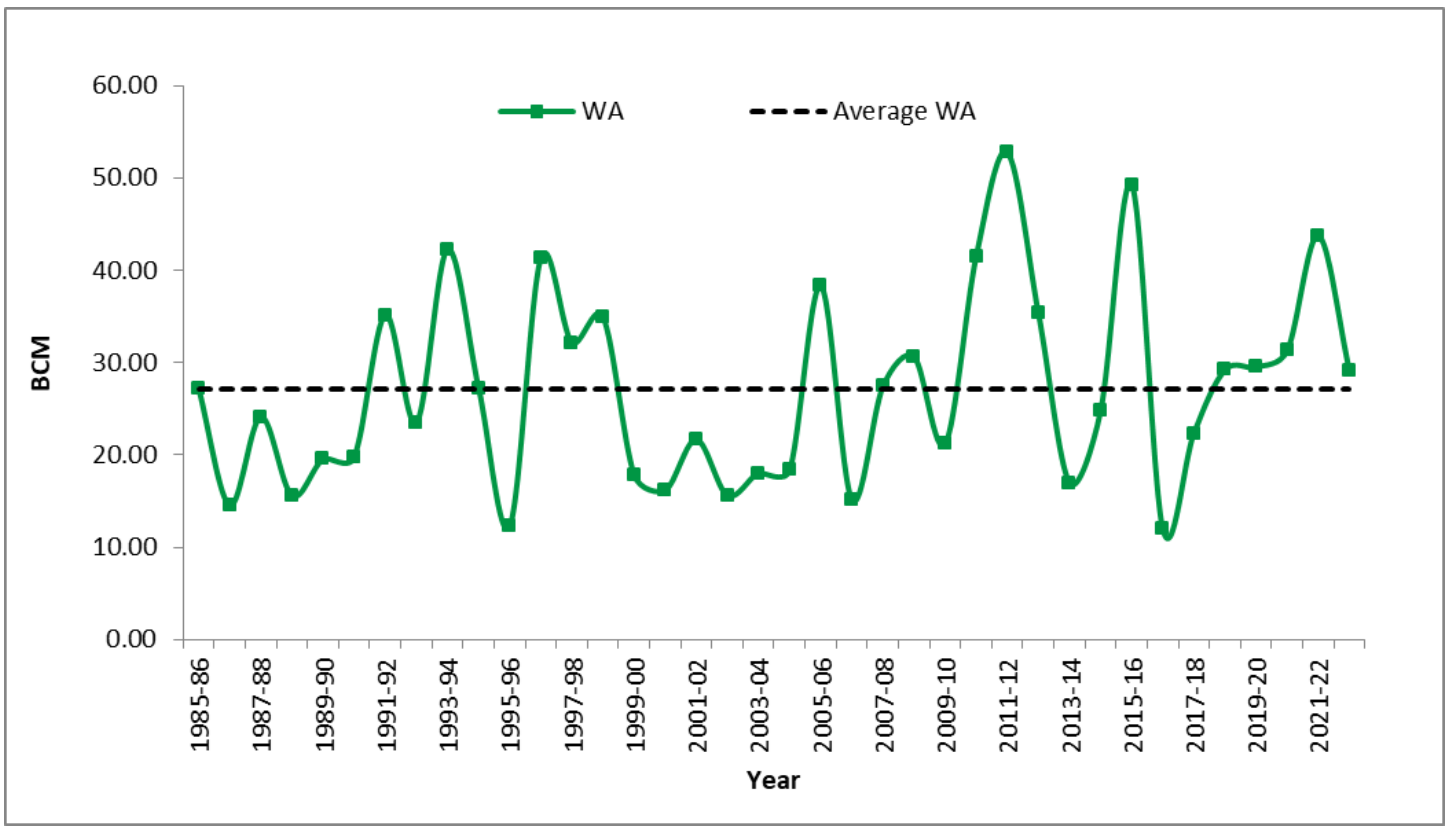


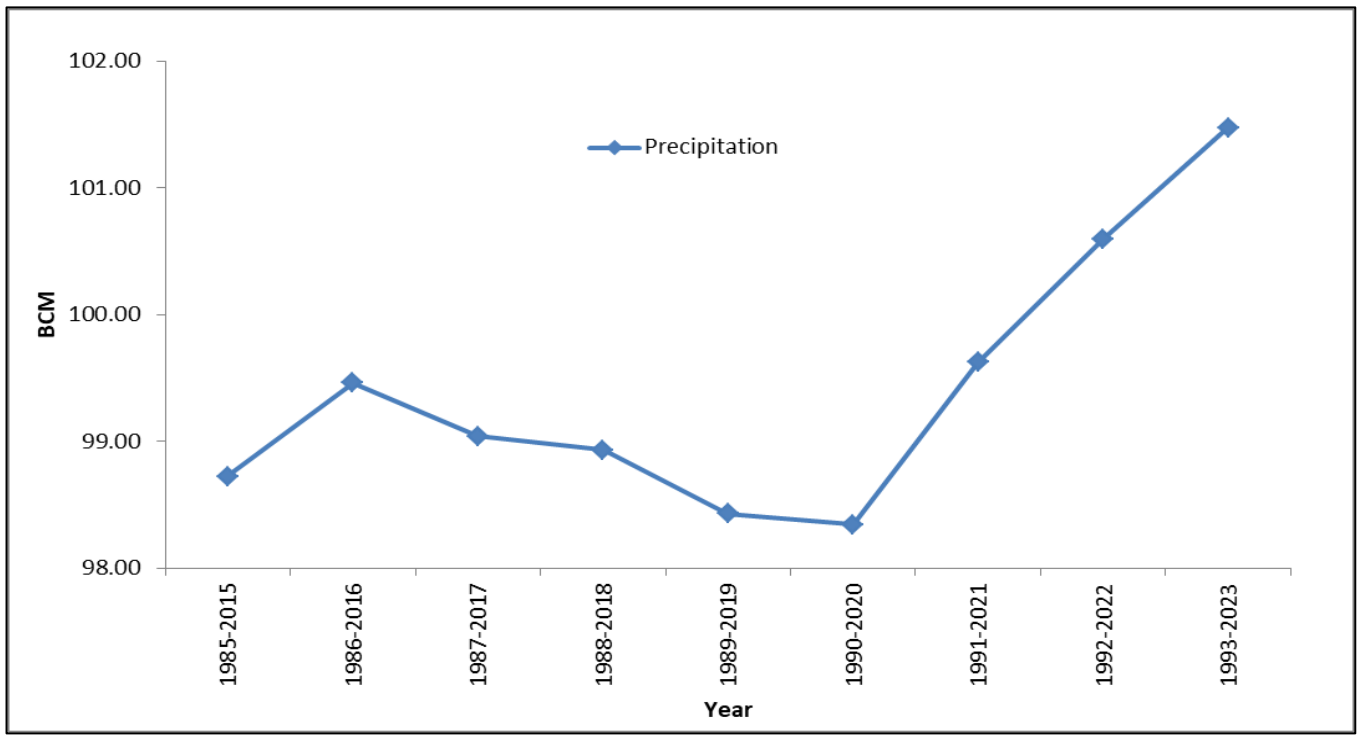
Figure 4.6.9: Water Resources Availability of EFR from Pennar to Kanyakumari basin

4.6.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water resources availability of East Flowing Rivers from Pennar to Kanyakumari basin is given at Table 4.6.2. A line diagram of moving average of P and WA is shown in Figure 4.6.10.

Table 4.6.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	98.72	26.06
1986-2016	99.46	26.79
1987-2017	99.04	26.71
1988-2018	98.93	26.65
1989-2019	98.43	27.10
1990-2020	99.35	27.43
1991-2021	99.63	27.82
1992-2022	100.60	28.11
1993-2023	101.48	28.30



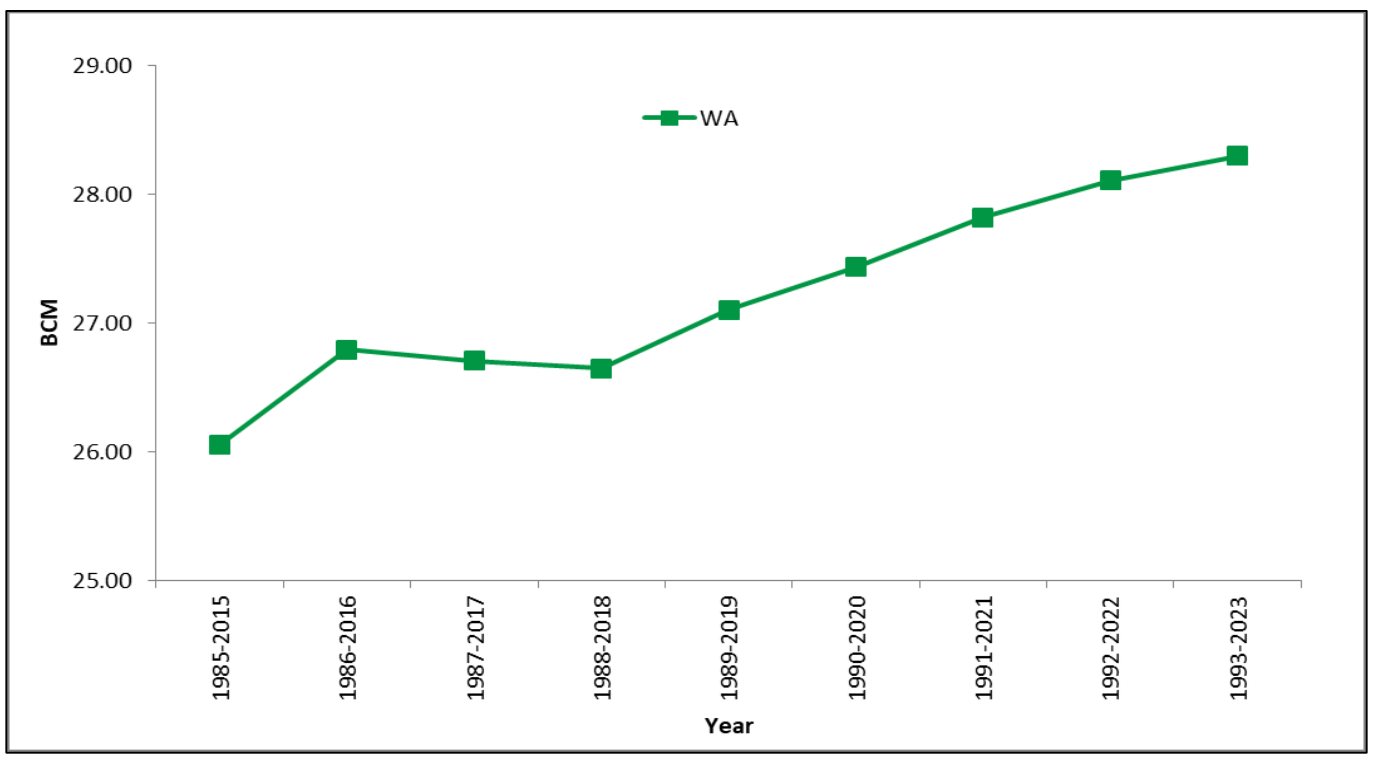


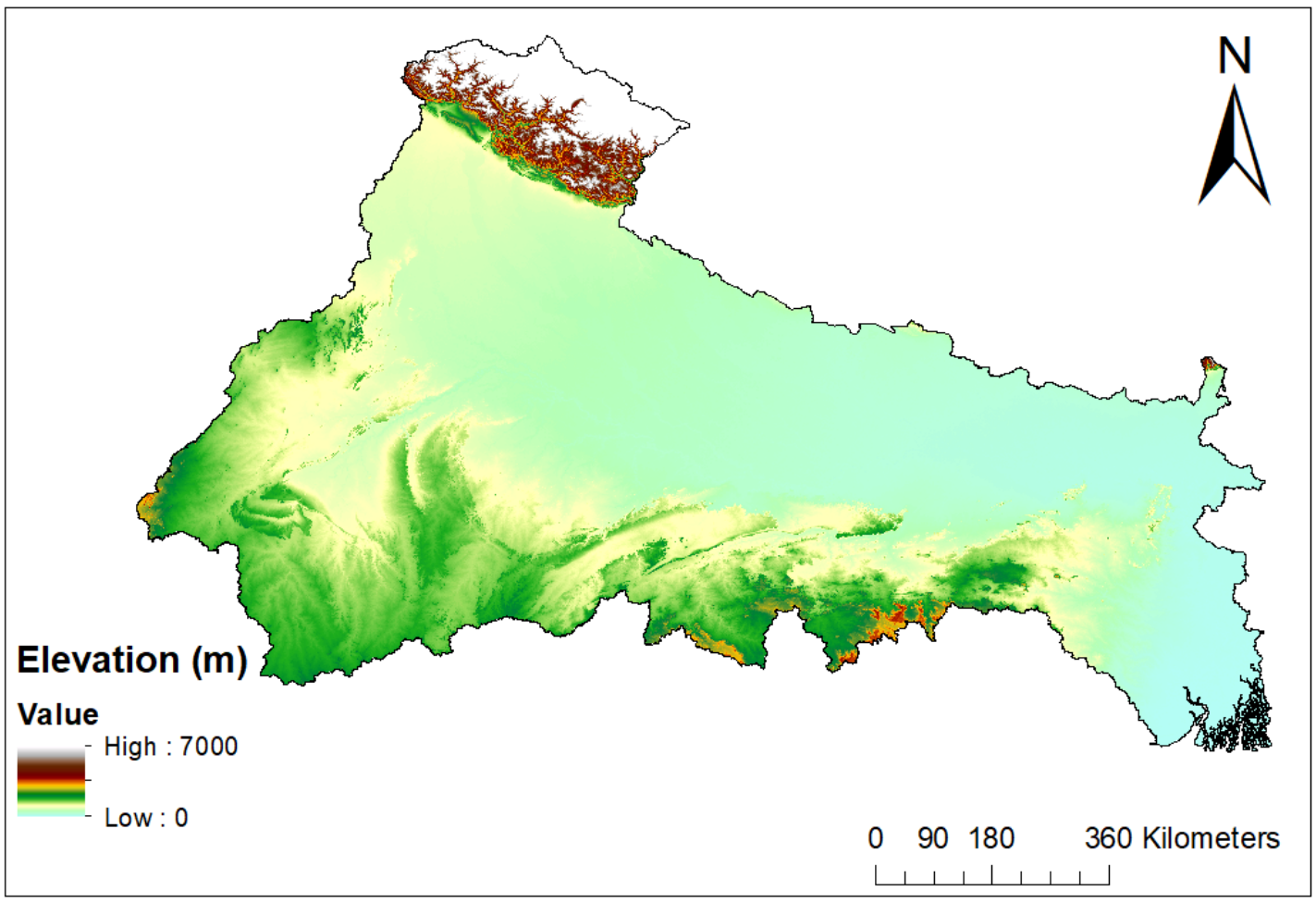
Figure 4.6.10: Moving Average of P and WA for 30 years

Table 4.6.3: Water Availability of EFR from Pennar to Kanyakumari basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	104.04	76.86	27.18
1986-87	72.71	58.15	14.56
1987-88	104.02	79.88	24.14
1988-89	77.89	62.29	15.60
1989-90	100.00	80.43	19.57
1190-91	84.21	64.45	19.76
1991-92	109.30	74.13	35.17
1992-93	86.40	62.93	23.47
1993-94	119.53	77.26	42.27
1994-95	105.19	77.92	27.27
1995-96	77.70	65.38	12.32
1996-97	122.70	81.40	41.30
1997-98	100.46	68.29	32.17
1998-99	117.50	82.56	34.94
1999-00	88.85	70.99	17.86
2000-01	93.24	77.07	16.17
2001-02	57.38	35.70	21.68
2002-03	40.80	25.17	15.63
2003-04	51.64	33.60	18.04
2004-05	100.14	81.78	18.36
2005-06	133.94	95.60	38.34
2006-07	91.52	76.35	15.17
2007-08	125.29	97.85	27.44
2008-09	118.74	88.10	30.64
2009-10	104.88	83.67	21.21
2010-11	138.34	96.84	41.50
2011-12	145.29	92.53	52.76
2012-13	116.54	81.18	35.36
2013-14	80.55	63.55	17.00
2014-15	92.92	68.12	24.80
2015-16	126.17	76.87	49.29
2016-17	60.08	48.12	11.96
2017-18	100.80	78.43	22.37
2018-19	62.86	33.64	29.22
2019-20	97.39	67.86	29.53
2020-21	122.63	91.32	31.31
2021-22	138.54	94.77	43.77
2022-23	112.67	83.49	29.18
Average	**99.55**	**72.49**	**27.06**

4.7 GANGA BASIN



HIGHLIGHTS

- *Average annual water resources availability of Ganga basin is 581.75 BCM.*
- *Maximum annual water availability is 724.49 BCM during 1999-2000.*
- *Minimum annual water availability is 368.27 BCM during 2009-10.*
- *Average annual precipitation is 886.37 BCM (1057 mm).*
- *Maximum annual precipitation is 1120.09 BCM (1335 mm) during 1985-86.*
- *Minimum annual precipitation is 674.68 BCM (804 mm) during 2009-10.*

4.7.1 About Ganga Basin

The Ganga basin outspreads in India, Tibet (China), Nepal and Bangladesh over an area of 10,86,000 sq. km. In India, it covers states of Uttar Pradesh (28.68%), Madhya Pradesh (21.65%), Rajasthan (11.22%), Bihar(12.86%), West Bengal (8.37%), Uttarakhand (6.38%), Jharkhand (6.04%), Haryana (1.59%), Chhattisgarh (2.20%), Himachal Pradesh (0.71%) and Union Territory of Delhi (0.18%) draining an area of 8,38,803 sq.km which is nearly 26% of the total geographical area of the country. The basin is bounded by the Himalayas on the north, the Aravalli on the west, the Vindhyas and Chhotanagpur plateau on the south and the Brahmaputra Ridge on the east.

River Ganga rises in the Gangotri glacier in the Himalayas at an elevation of about 7,010 m in the Uttarkashi district of Uttarakhand. At its source, the river is called as the Bhagirathi. It descends down the valley upto Devprayag where after joining Alaknanda, it is called Ganga. The total length of river Ganga (measured along the Bhagirathi and the Hooghly) up to its outfall into Bay of Bengal is 2,525 km. The principal tributaries joining the river from right are the Yamuna and the Sone. The Ramganga, the Ghaghra, the Gandak, the Kosi and the Mahananda join the river from left. The Chambal and the Betwa are the two other important sub-tributaries.

4.7.2 Geo-Spatial Datasets

4.7.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Ganga basin for year 2022-23 is shown in Figure 4.7.1. Major land use classes consist of Double/Triple/Annual crop land, Kharif only, Rabi crop land etc.

Table 4.7.1 shows the percentage area of each land use class in the basin for year 2022-23.

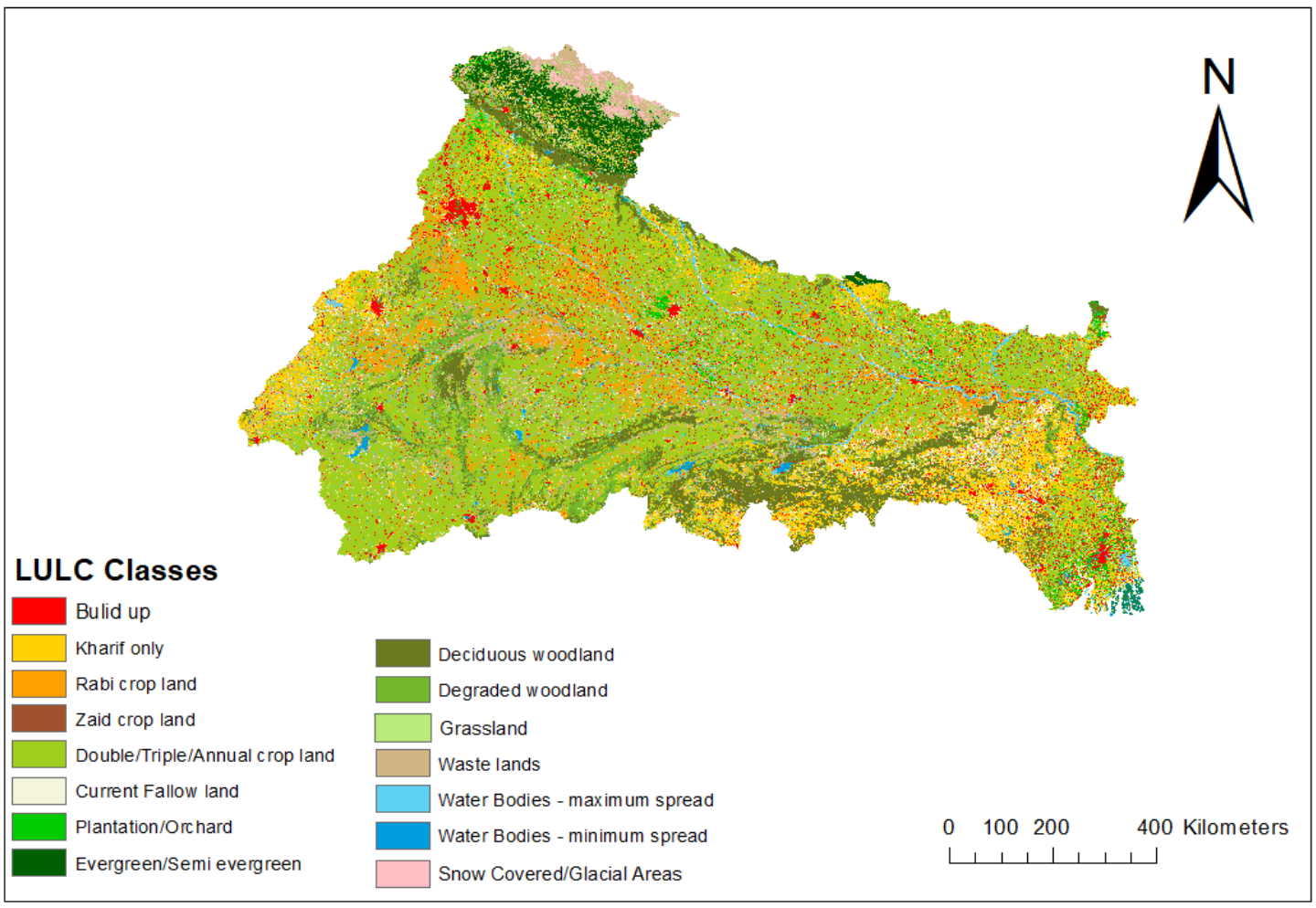


Figure 4.7.1: LULC Map of Ganga basin

Table 4.7.1: Percentage area of Land Use and Land Cover

S. No.	LULC class	Area (%) in 2022-23
1.	Built-up land	5.05
2.	Kharif only	11.80
3.	Rabi crop land	7.26
4.	Zaid crop land	0.02
5.	Double/Triple/Annual crop land	41.32
6.	Current fallow land	4.81
7.	Plantation/Orchid	1.71
8.	Evergreen/Semi-evergreen woodland	2.17
9.	Deciduous woodland	9.93
10.	Degraded woodland	4.71
11.	Littoral/Swamp/Mangroves	0.22
12.	Grassland	0.45
13.	Waste lands	6.42
14.	Water Bodies - maximum spread	3.11
15.	Water Bodies - minimum spread	0.58
16.	Snow covered/Glacial areas	0.43

4.7.3 Hydro-Meteorological and other Input Data

4.7.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.7.2. The variation in the annual precipitation during study period of 38 years (1985-

86 to 2022-23) is shown in the Figure 4.7.3. The average precipitation of 38 years is approximately 886.37 BCM (1057 mm).

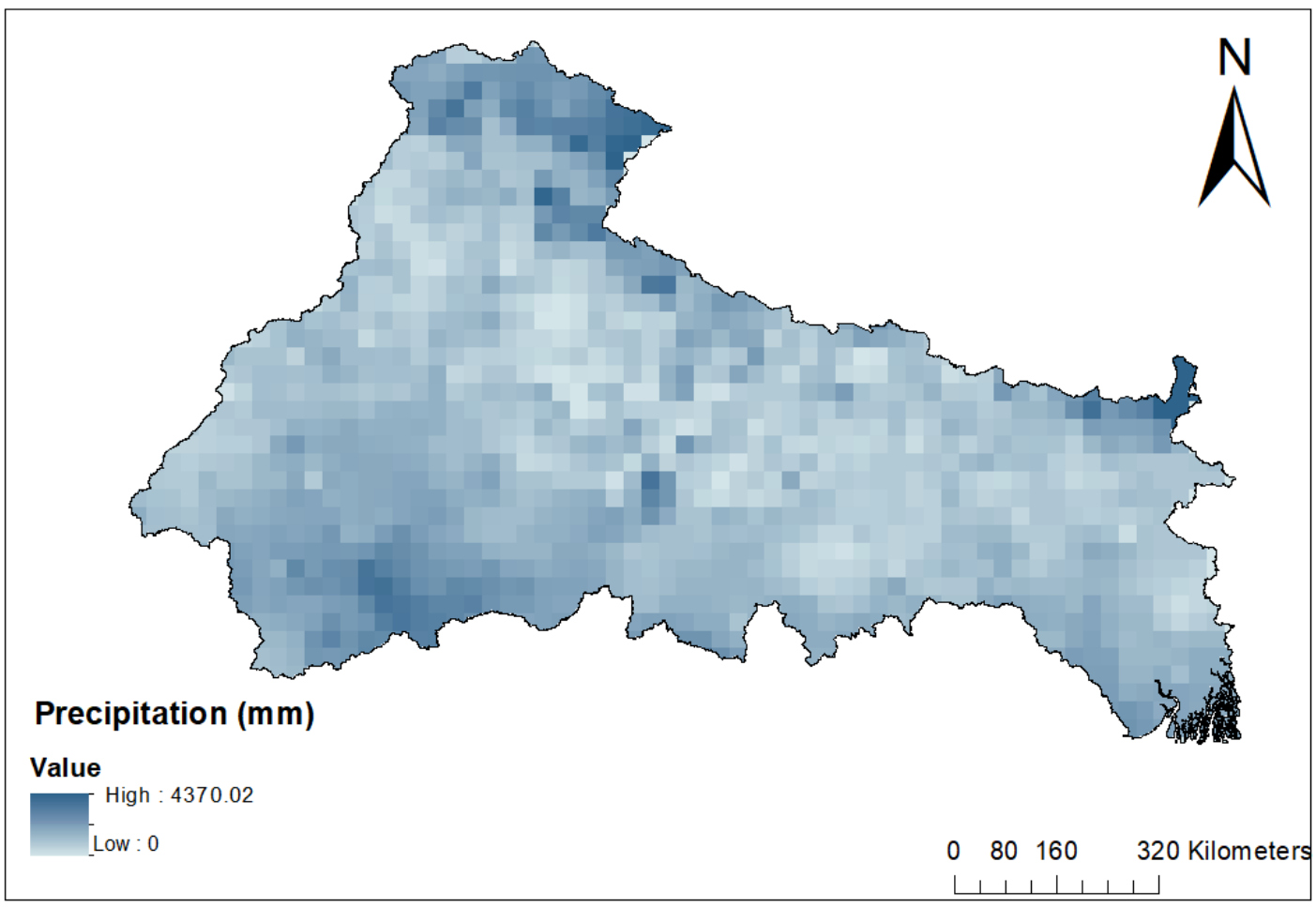


Figure 4.7.2: Precipitation map of Ganga basin

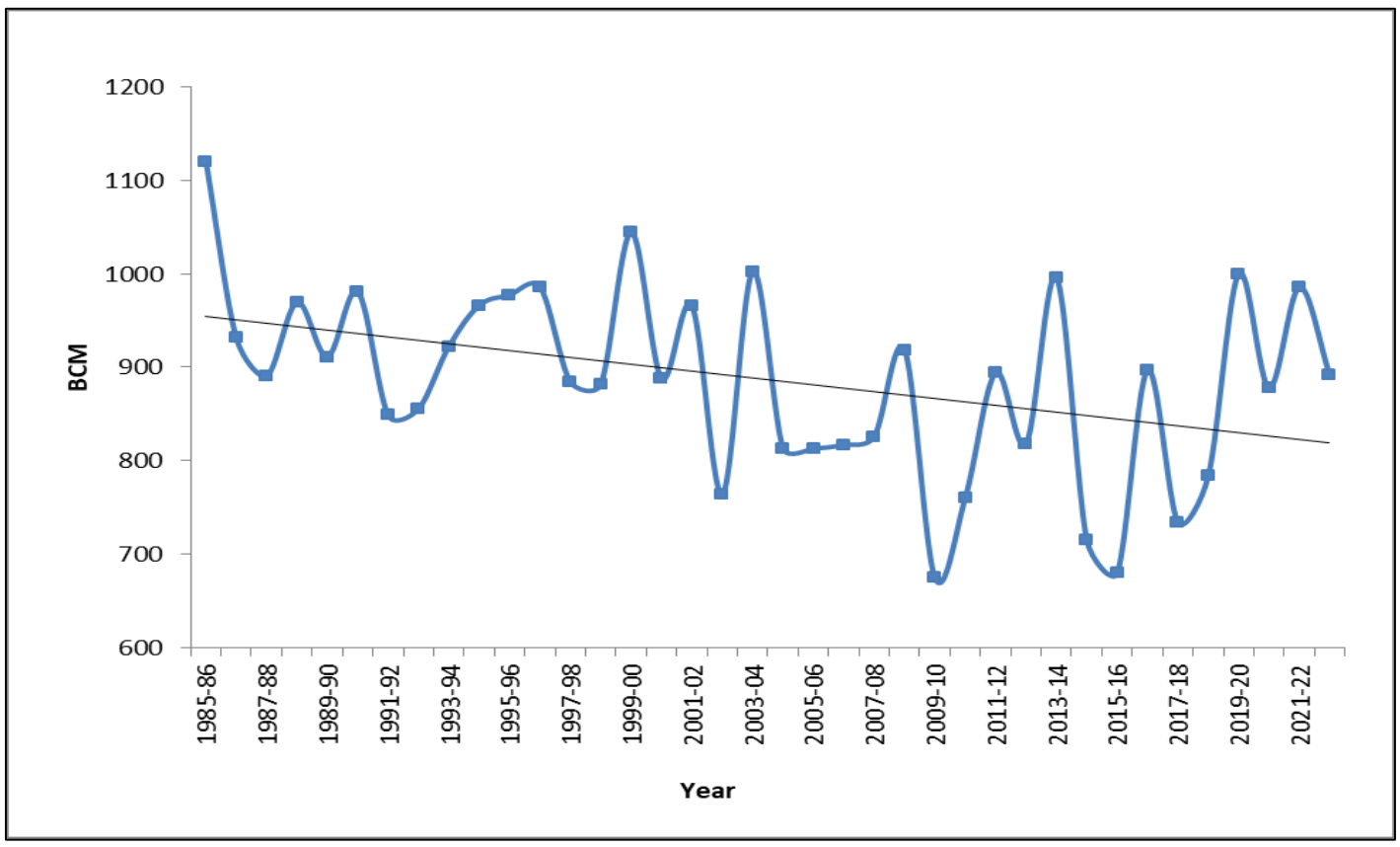


Figure 4.7.3: Annual Precipitation in Ganga basin

4.7.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.7.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.7.5. The average ET of 38 years is approximately 614.88 BCM (733 mm).

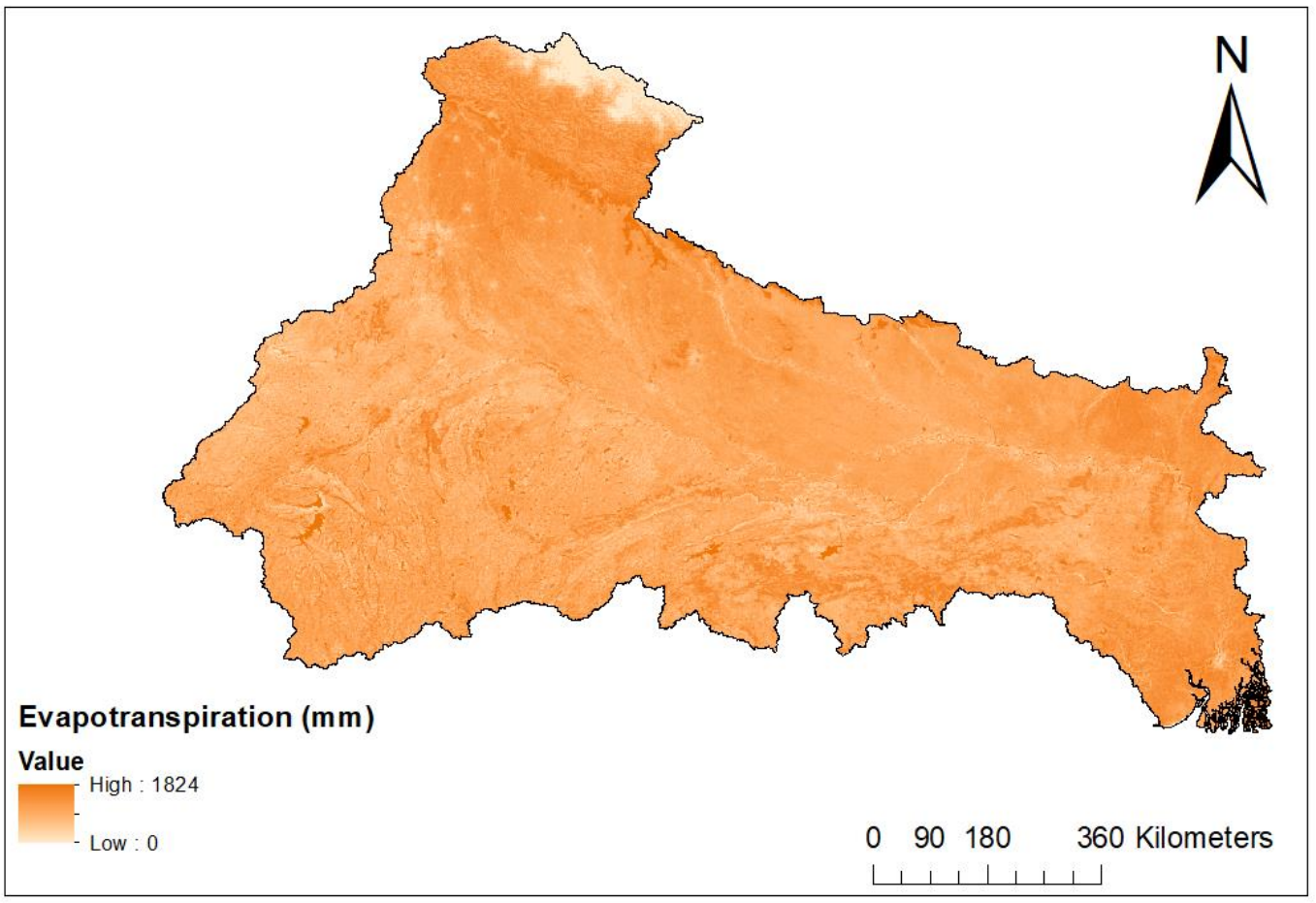


Figure 4.7.4: Evapotranspiration map of Ganga basin

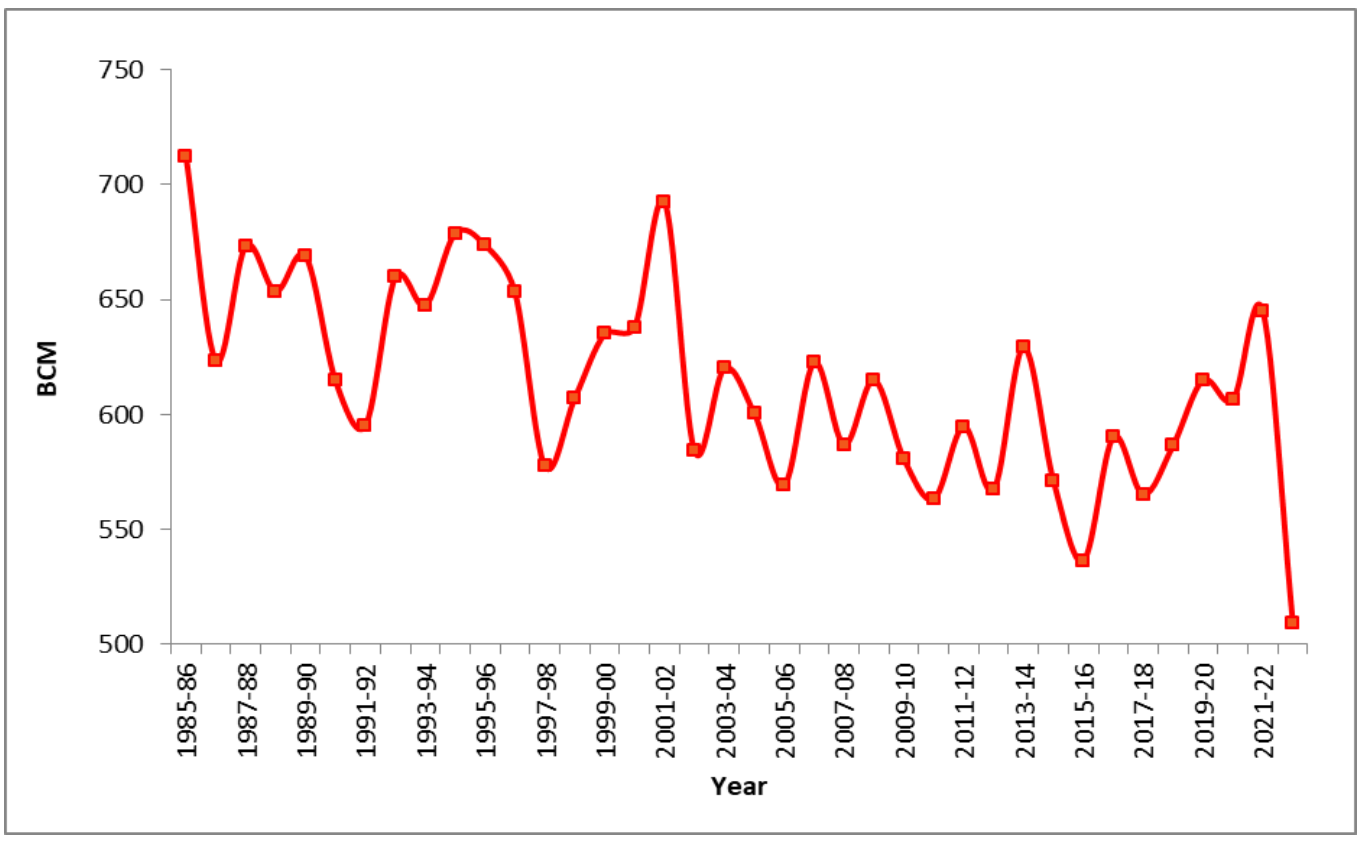


Figure 4.7.5: Annual Evapotranspiration in Ganga basin

4.7.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.7.6. The average annual evaporation from the reservoirs in the basin is 6.56 BCM.

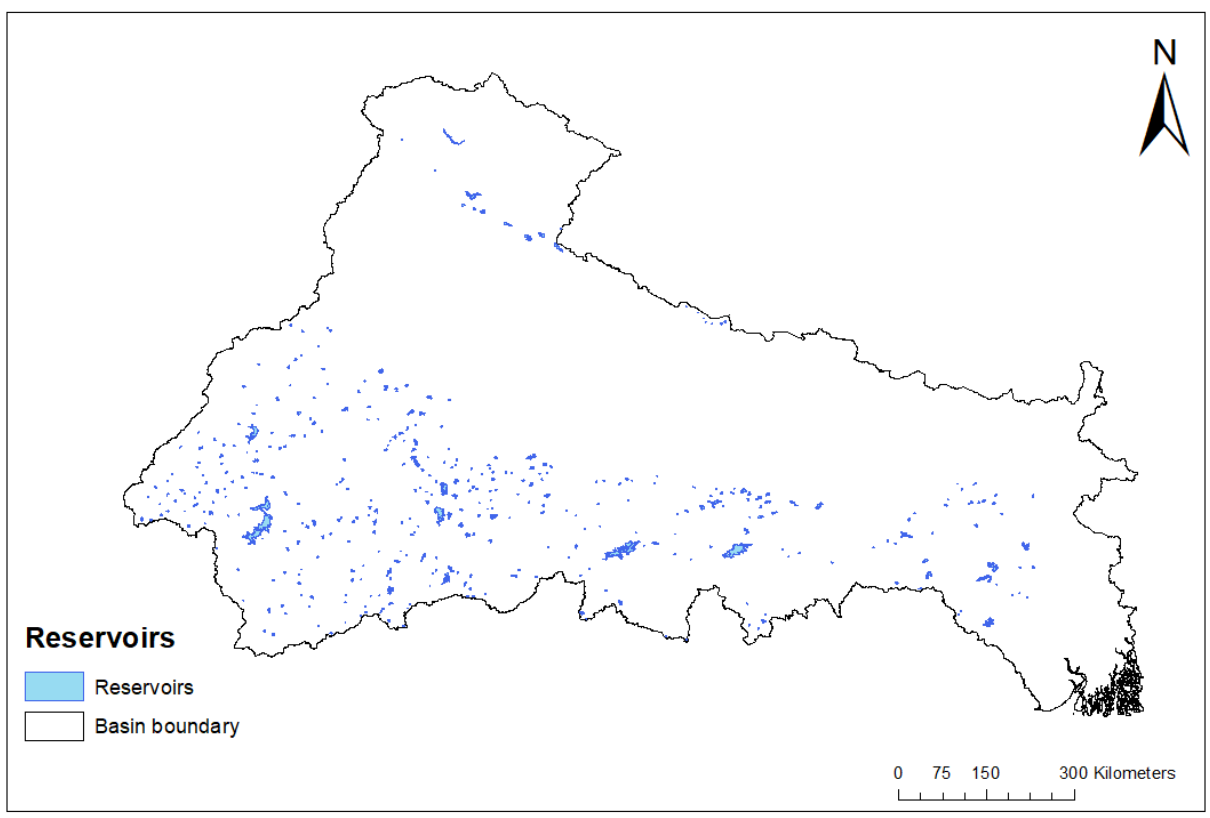


Figure 4.7.6: Reservoir map of Ganga basin

4.7.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1986-2023 has been estimated as 196.46 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.7.7. The annual variation in ET_{II} is shown in Figure 4.7.8.

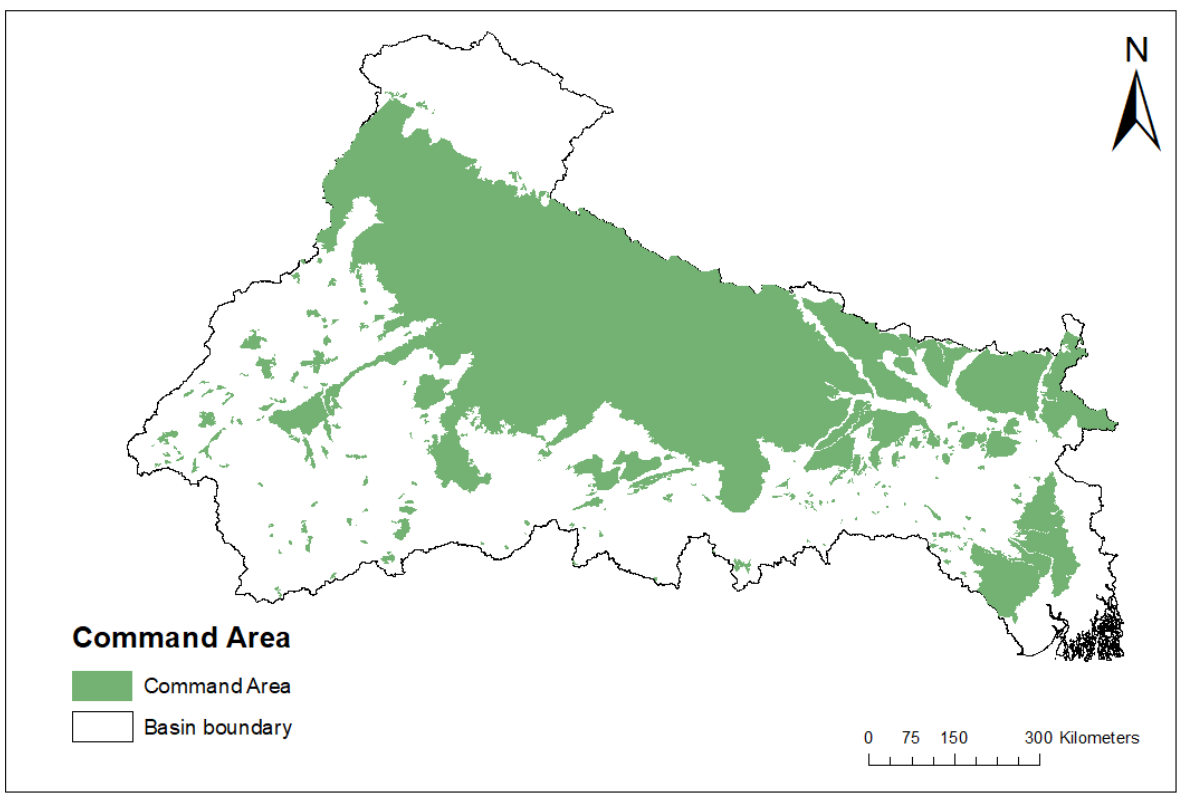


Figure 4.7.7: Command area map of Ganga basin

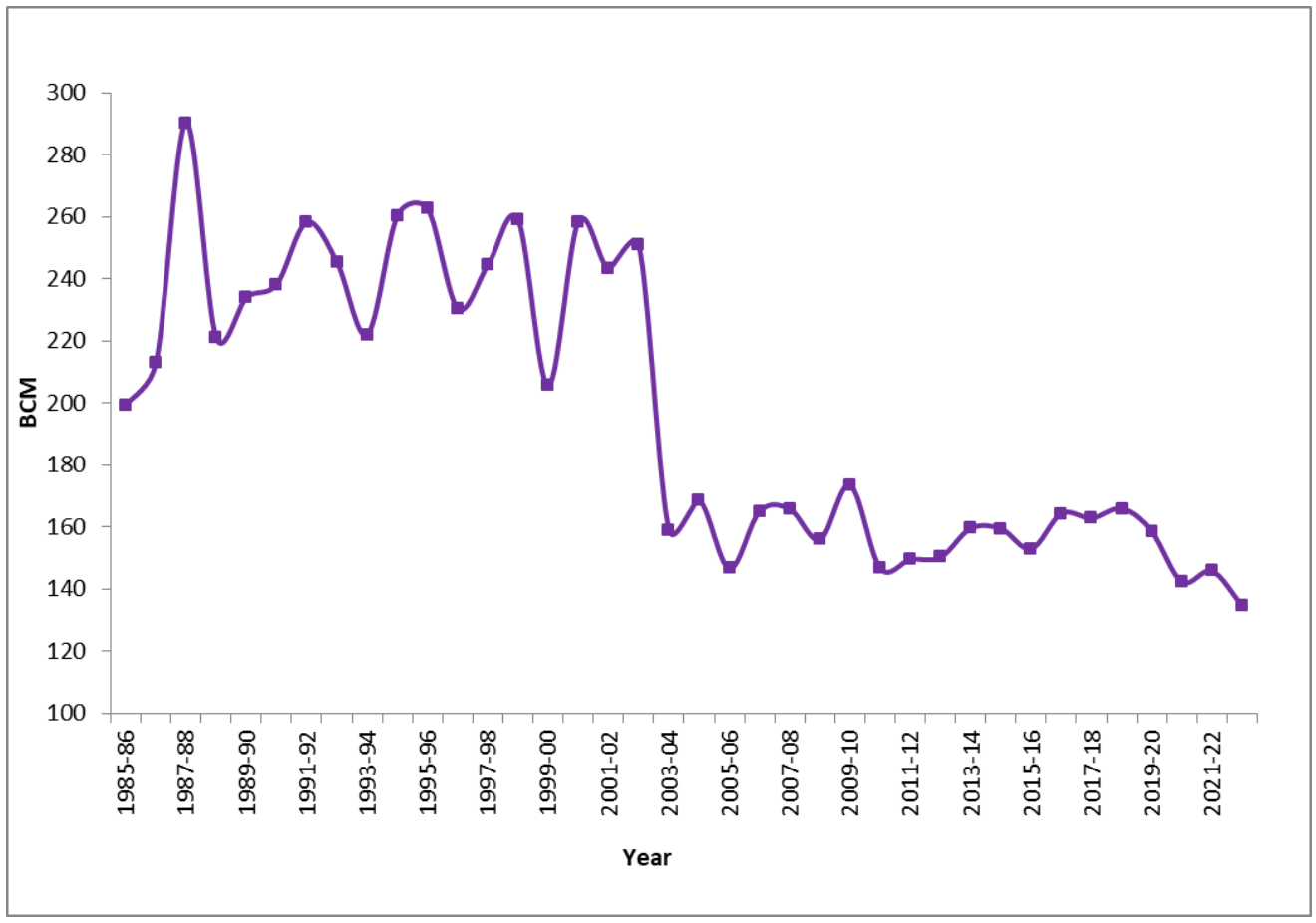


Figure 4.7.8: ET from Irrigation Input in Ganga basin

4.7.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux, Reservoir flux for the basin for 1985-86 to 2022-23 is -4.27 BCM and -0.01 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 14.33 BCM.

4.7.4 Previous Estimates

The erstwhile Ganga Basin Water Studies Organisation of Central Water Commission carried out the assessment of water resources potential and had presented the details of the study in their report of 1986. Ganga basin was divided into ten sub-basins for the study and the assessment was based on the actual observed flow data available at several locations for durations ranging from 5 years to 20-25 years. As per 1993 studies for Reassessment of Water Resources Potential of India, the water resource potential was estimated as 525 BCM for the whole Ganga basin for a catchment area of 8,61,452 sq.km. In 2019 study, the water availability of Ganga basin was estimated as 509.52 BCM.

4.7.5 Annual Water Availability of Ganga Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability from year 1985-86 to 2022-23 is estimated as 581.75 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.7.9. The results of Ganga basin are shown in Table 4.7.3.

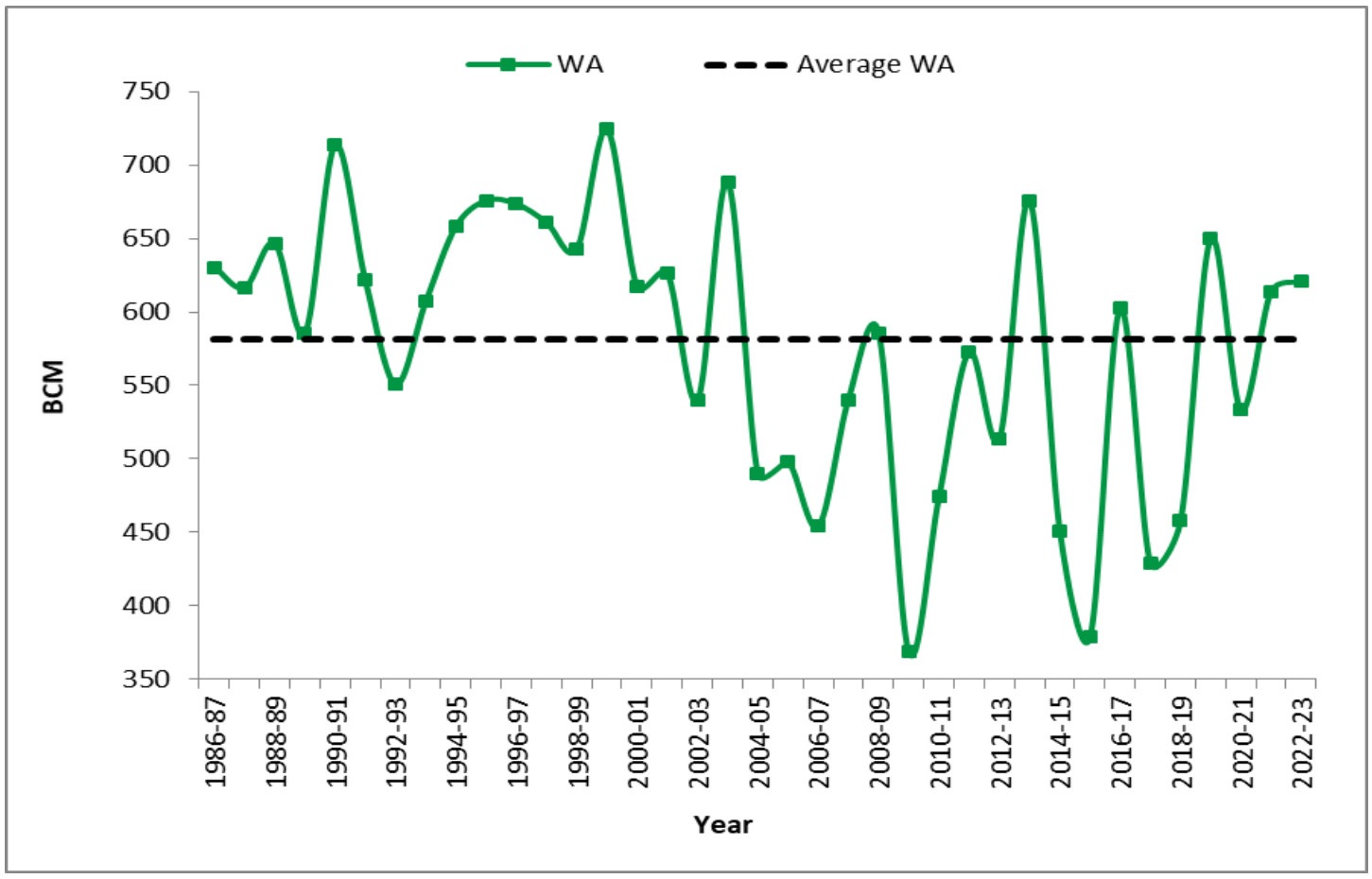


Figure 4.7.9: Water availability of Ganga basin

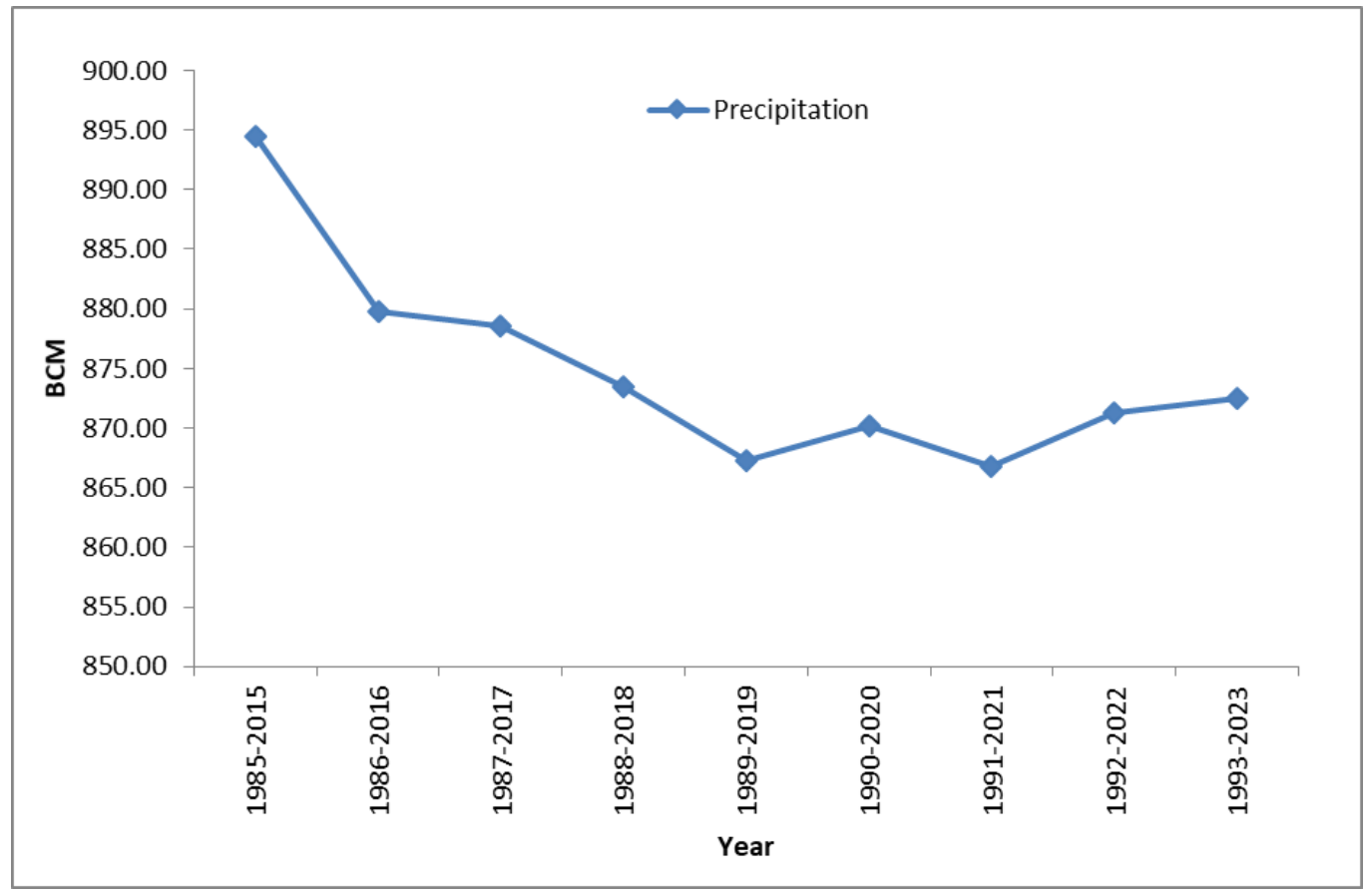
4.7.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Ganga basin is given at Table 4.7.2. A line diagram of moving average of P and WA is shown in Figure 4.7.10.

Table 4.7.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	894.45	582.76
1986-2016	879.77	581.83
1987-2017	878.62	575.57
1988-2018	873.41	569.26
1989-2019	867.21	571.41
1990-2020	870.17	565.40
1991-2021	866.74	565.14
1992-2022	871.31	567.47
1993-2023	872.51	566.11

**including trans-boundary contribution*



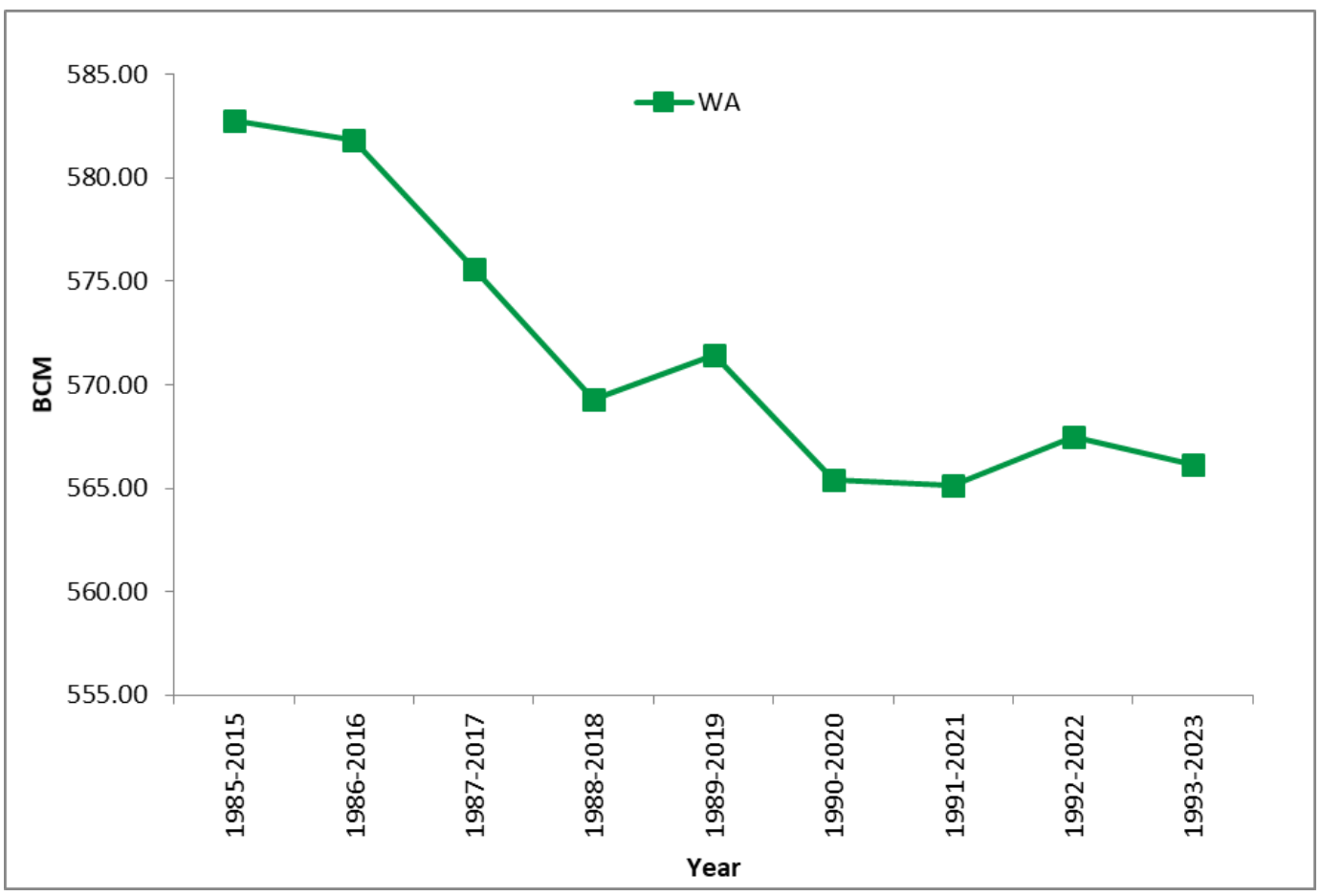


Figure 4.7.10: Moving Average of P and WA for 30 years

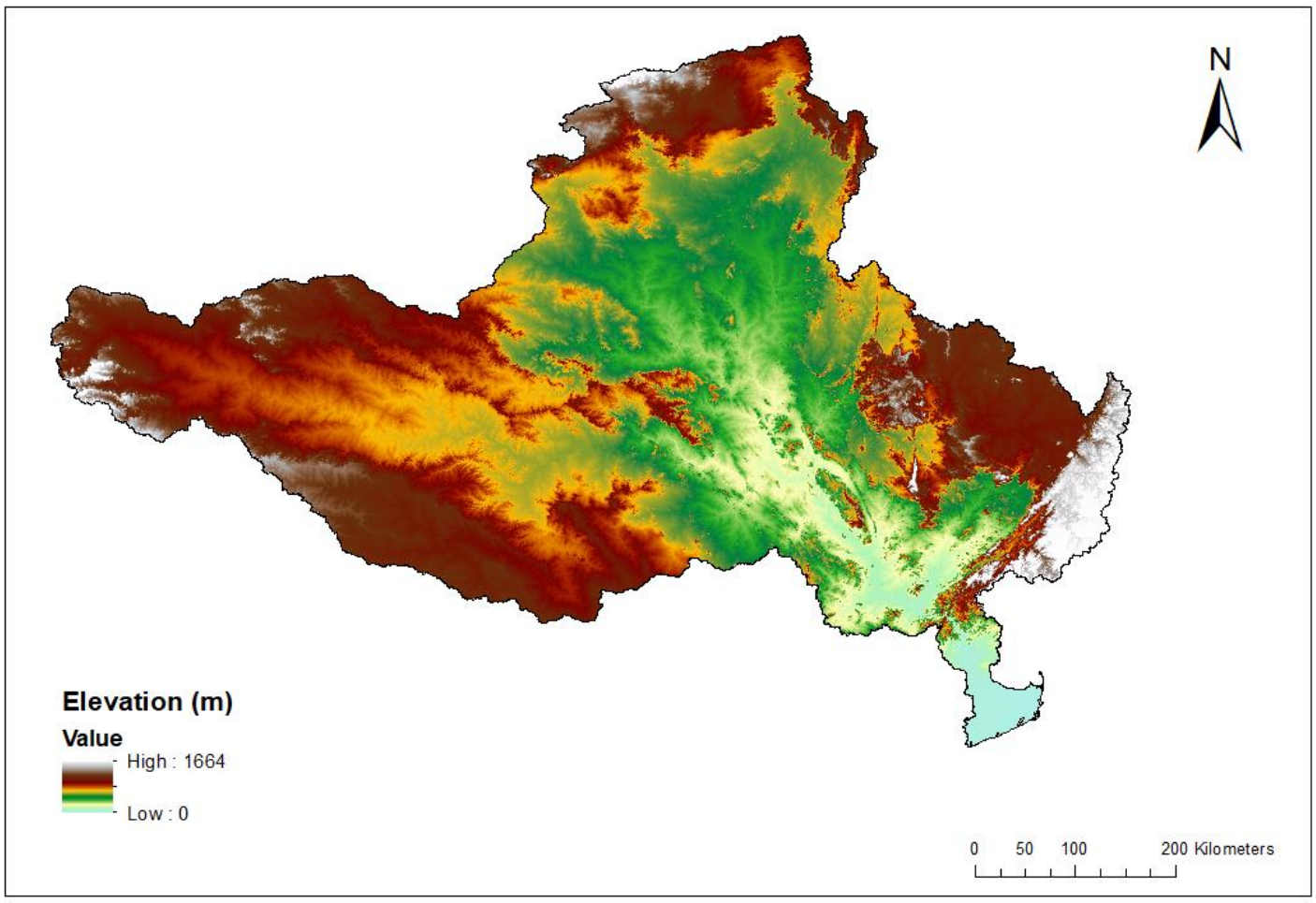
Table 4.7.3: Water Availability of Ganga basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability*
1985-86	1120.09	511.44	716.65
1986-87	931.15	408.69	630.46
1987-88	890.31	381.79	616.52
1988-89	969.48	430.61	646.87
1989-90	911.04	433.46	585.58
1990-91	980.78	375.04	713.74
1991-92	848.52	334.88	621.64
1992-93	855.47	412.62	550.85
1993-94	922.34	423.45	606.89
1994-95	966.20	415.97	658.23
1995-96	977.23	409.37	675.86
1996-97	985.94	420.29	673.65
1997-98	884.01	331.05	660.96
1998-99	881.64	346.81	642.83
1999-00	1044.26	427.77	724.49
2000-01	887.73	378.25	617.48
2001-02	965.69	447.00	626.69
2002-03	763.90	332.11	539.79
2003-04	1002.39	457.15	688.62
2004-05	813.21	427.74	489.49
2005-06	813.02	418.66	498.01
2006-07	816.77	453.07	453.93
2007-08	825.82	416.91	540.34
2008-09	918.51	454.97	585.76
2009-10	674.68	403.20	368.27
2010-11	760.25	412.60	473.95
2011-12	894.20	440.46	572.69
2012-13	818.03	412.16	513.60
2013-14	995.85	438.44	676.03
2014-15	715.07	373.62	451.05
2015-16	679.62	374.87	378.52
2016-17	896.68	416.14	602.53
2017-18	733.89	392.71	428.77
2018-19	783.65	410.59	457.61
2019-20	999.70	445.70	649.98
2020-21	877.92	452.83	533.52
2021-22	985.58	486.58	613.91
2022-23	891.55	370.88	620.74
Average	**886.37**	**412.63**	**581.75**

**including trans-boundary contribution*

4.8 GODAVARI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Godavari basin is 129.17 BCM.*
- *Maximum annual water availability is 245.36 BCM during 2013-14.*
- *Minimum annual water availability is 58.52 BCM during 2009-10.*
- *Average annual precipitation is 364.43 BCM (1167 mm).*
- *Maximum annual precipitation is 482.94 BCM (1484 mm) during 1994-95.*
- *Minimum annual precipitation is 272.08 BCM (914 mm) during 2015-16.*

4.8.1 About Godavari Basin

Godavari is a perennial and the second largest river draining in India. Godavari River originates near Trayambakeswar near Nasik, northeast of Mumbai in the state of Maharashtra at an elevation of 1,067 m and flows for a length of about 1,465 km before joining the Bay of Bengal. It flows through the Eastern Ghats and emerges out at Polavaram into the plains. At Dhawaleswaram the river divides into two branches, the Gautami and Vasishta. Between the two lies the Godavari Central Delta. Pranahita, Manjeera, Sabari, Indravati, Maner and Manar are the main tributaries of the Godavari River. The Godavari basin receives major part of its precipitation during the South-West monsoon period. The other rainy seasons are not so well defined and well spread as the South-West monsoon season. Floods are the regular phenomenon in the basin. Bhadrachalam, Kunavaram, and Deltaic portion of the river are more flood-prone.

4.8.2 Geo-Spatial Datasets

4.8.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Godavari basin for year 2022-23 is shown in Figure 4.8.1. The major land use classes consist of Kharif only, Double/Triple/Annual crop land, Deciduous woodland etc.

Table 4.8.1 shows the percentage area of each land use class in the basin for year 2022-23.

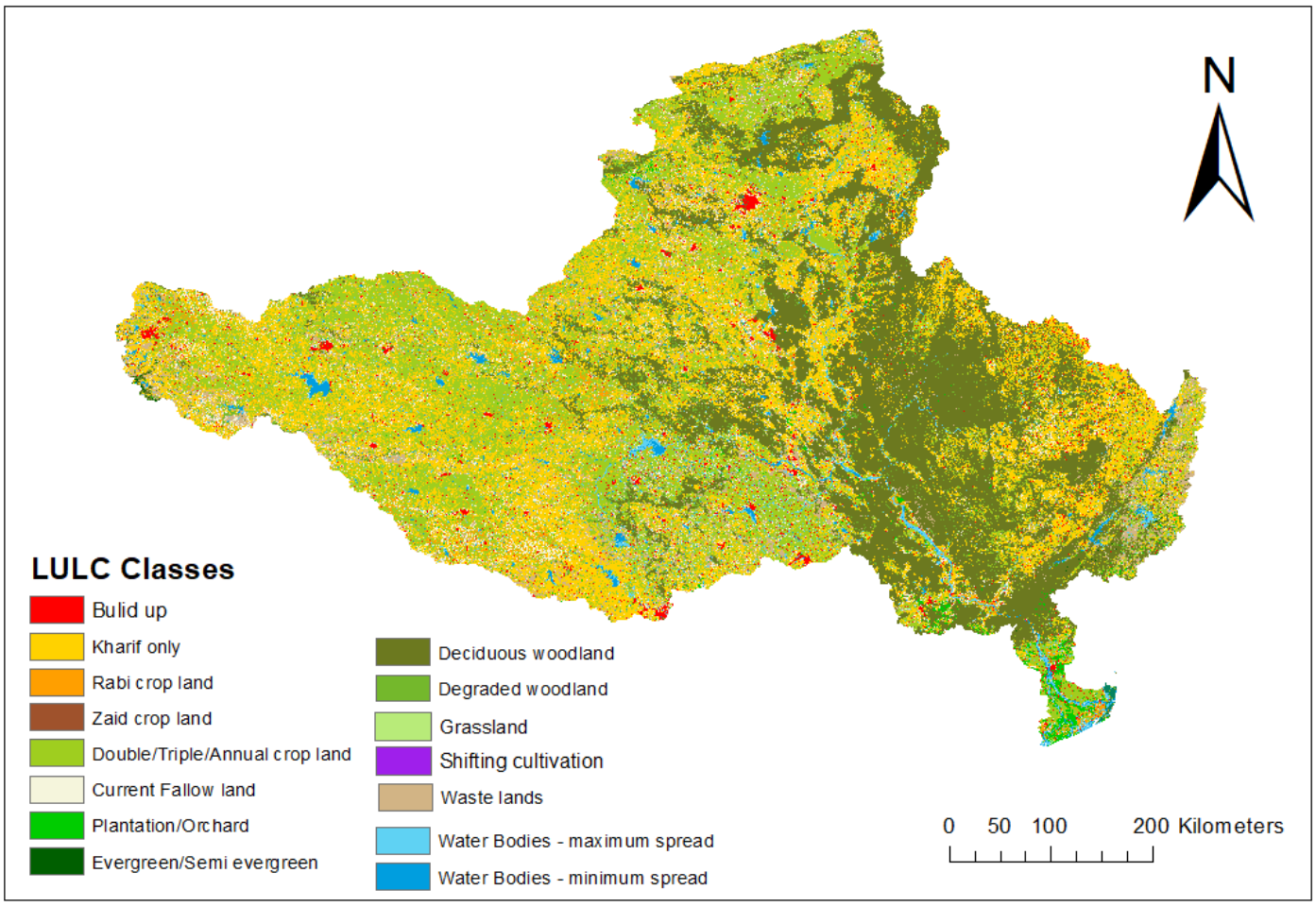


Figure 4.8.1: LULC Map of Godavari basin

Table 4.8.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	2.17
2.	Kharif only	27.74
3.	Rabi crop land	1.77
4.	Double/Triple/Annual crop land	24.84
5.	Current Fallow land	5.39
6.	Plantation/Orchard	0.79
7.	Evergreen/Semi evergreen	0.03
8.	Deciduous woodland	26.04
9.	Degraded woodland	2.35
10.	Littoral/Swamp/Mangroves	0.05
11.	Waste lands	5.15
12.	Water Bodies - maximum spread	2.39
13.	Water Bodies - minimum spread	1.28

4.8.3 Hydro-Meteorological and other Input Data

4.8.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.8.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.8.3. The average precipitation of 38 years is approximately 364.43 BCM (1167 mm).

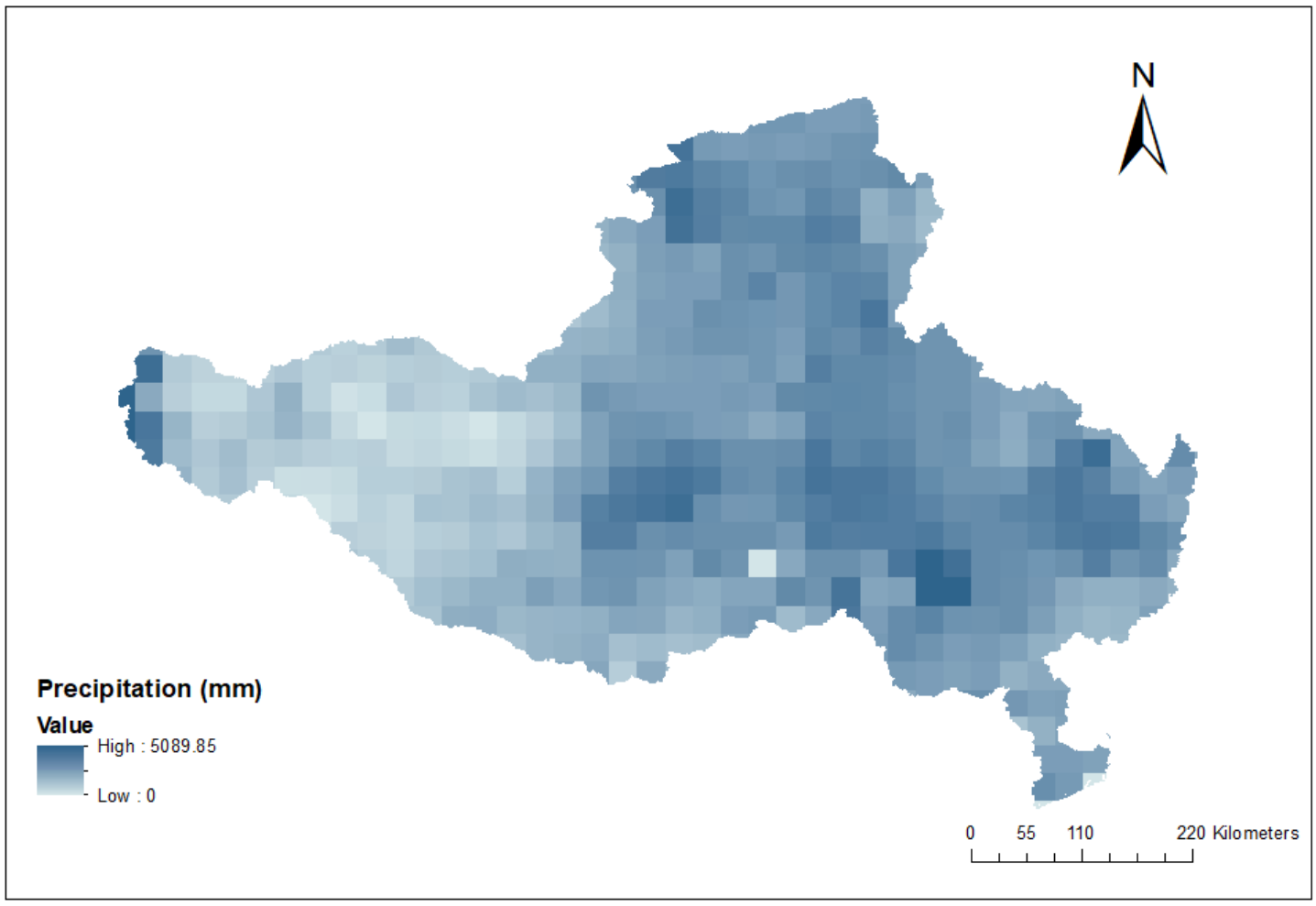


Figure 4.8.2: Precipitation map of Godavari basin

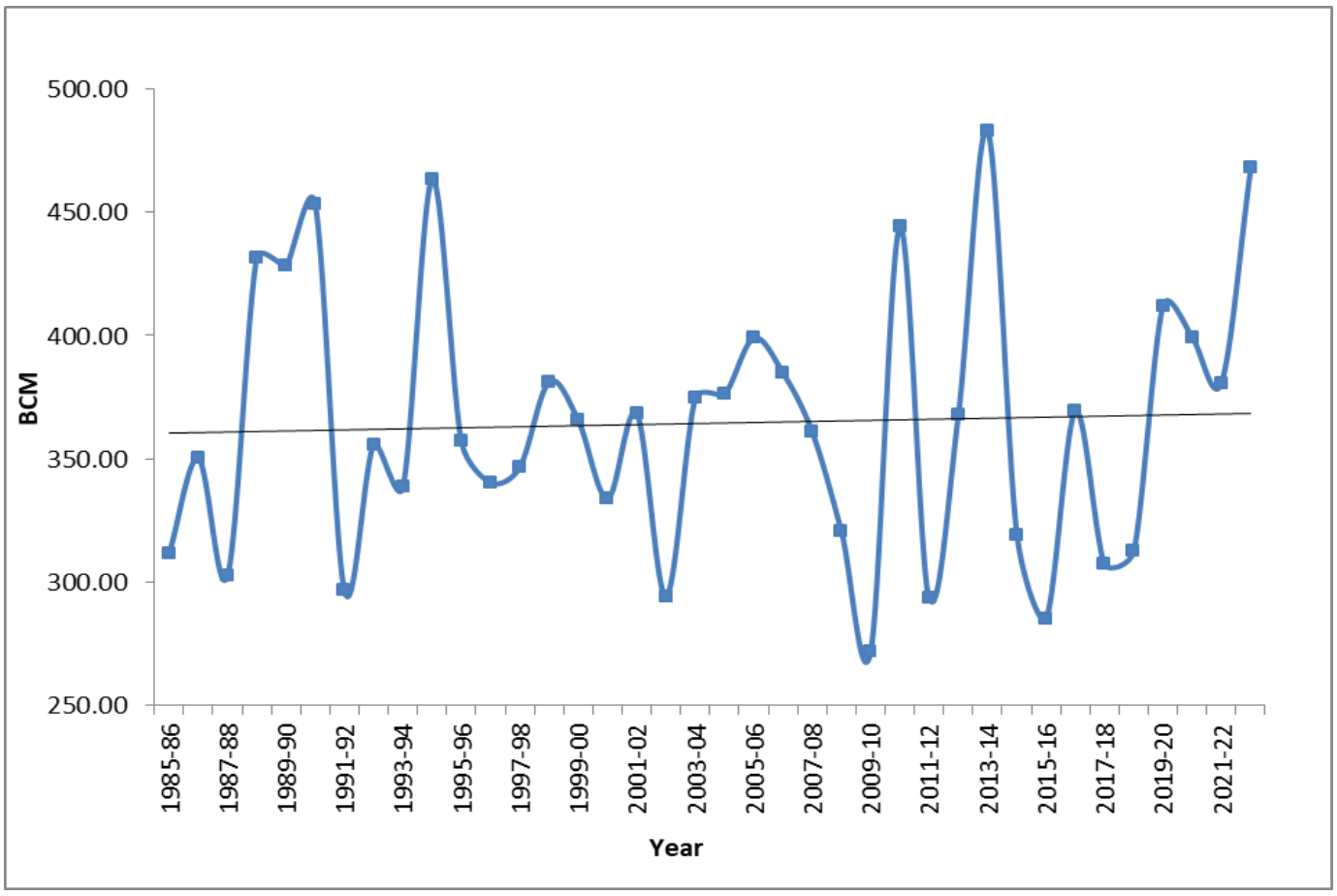


Figure 4.8.3: Annual Precipitation in Godavari basin

4.8.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.8.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.8.5. The average ET of 38 years is approximately 264.48 BCM (847 mm).

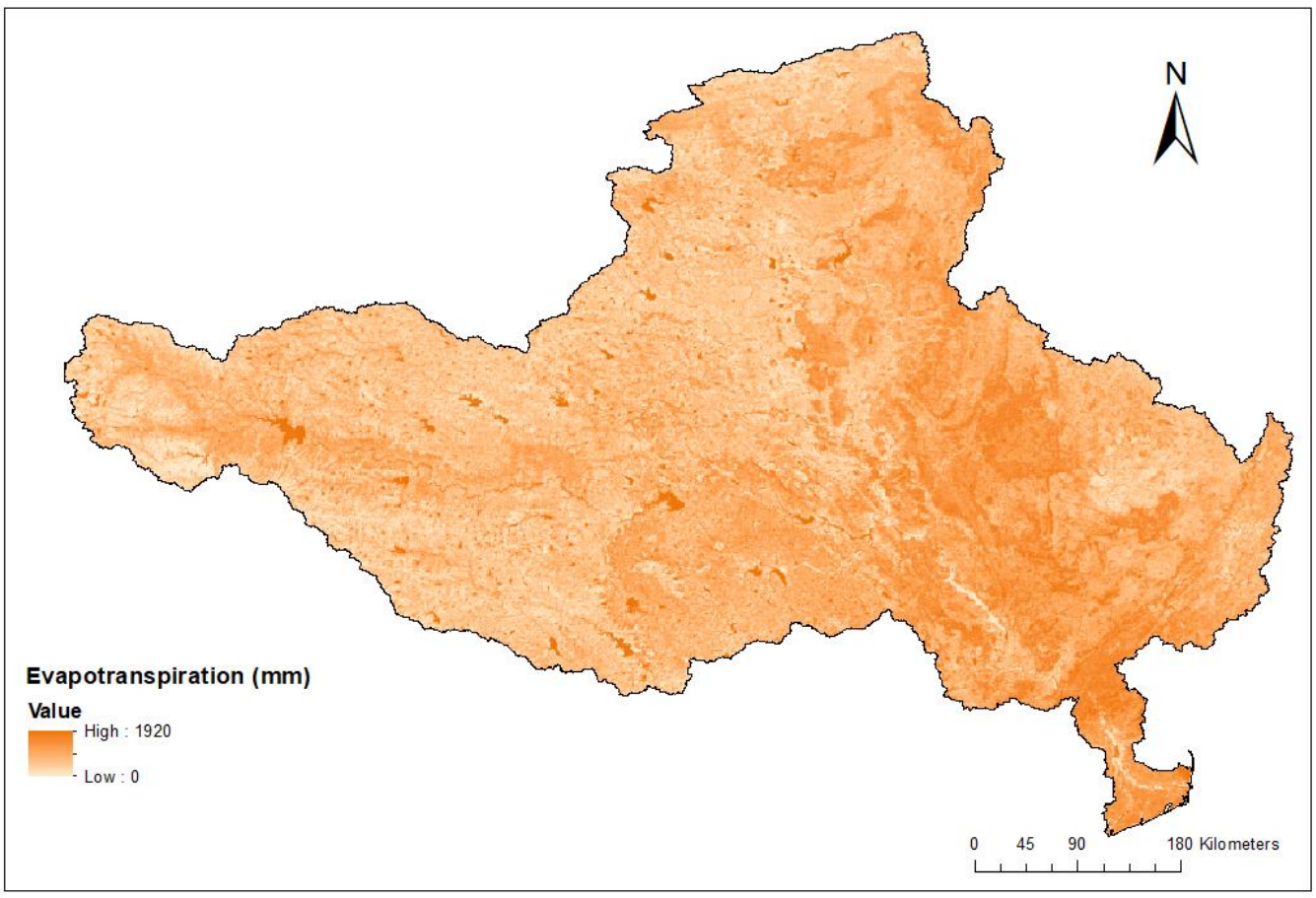


Figure 4.8.4: Evapotranspiration map of Godavari basin

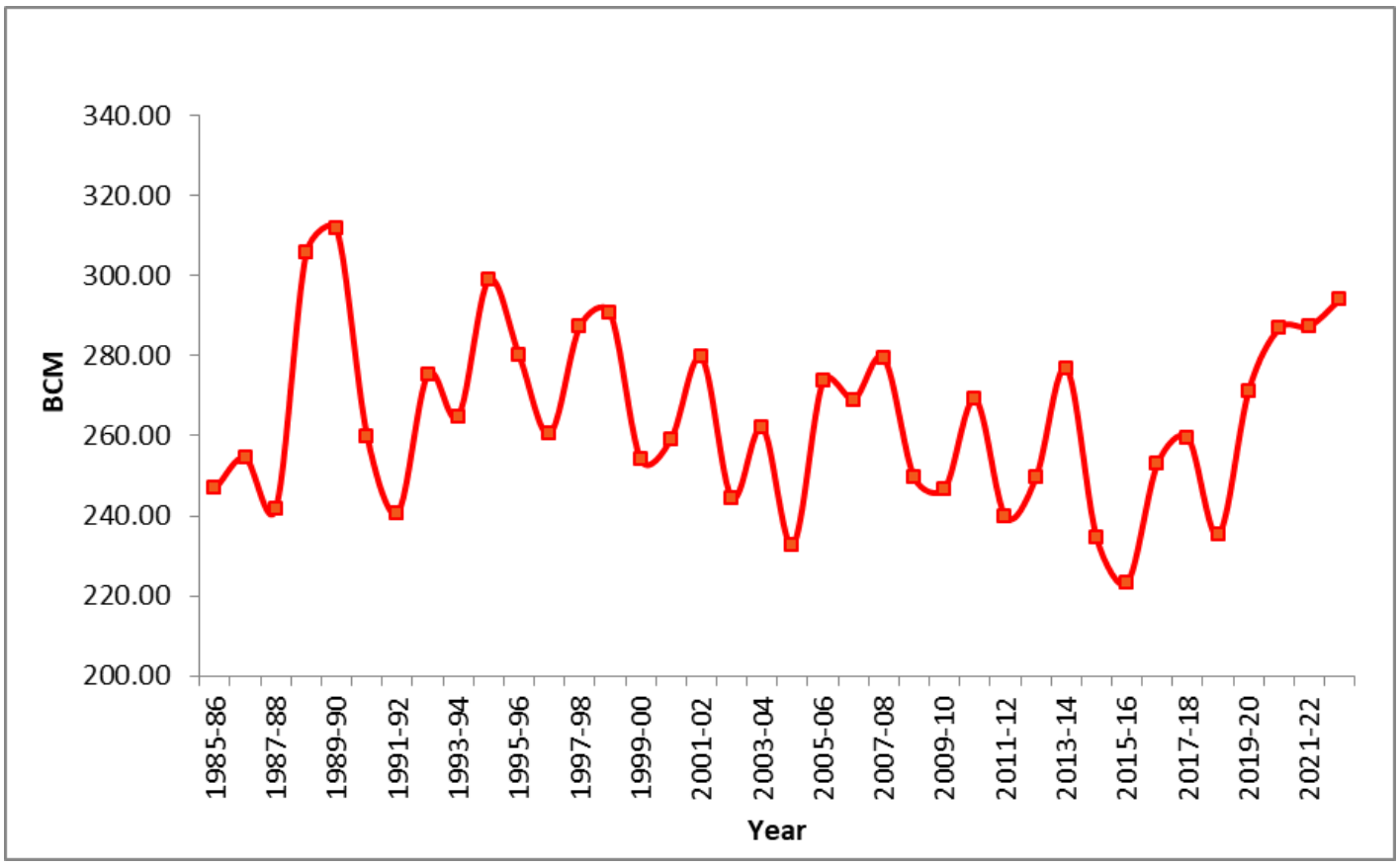


Figure 4.8.5: Annual Evapotranspiration in Godavari basin

4.8.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.8.6. The average annual evaporation from the reservoirs in the basin is 5.14 BCM.

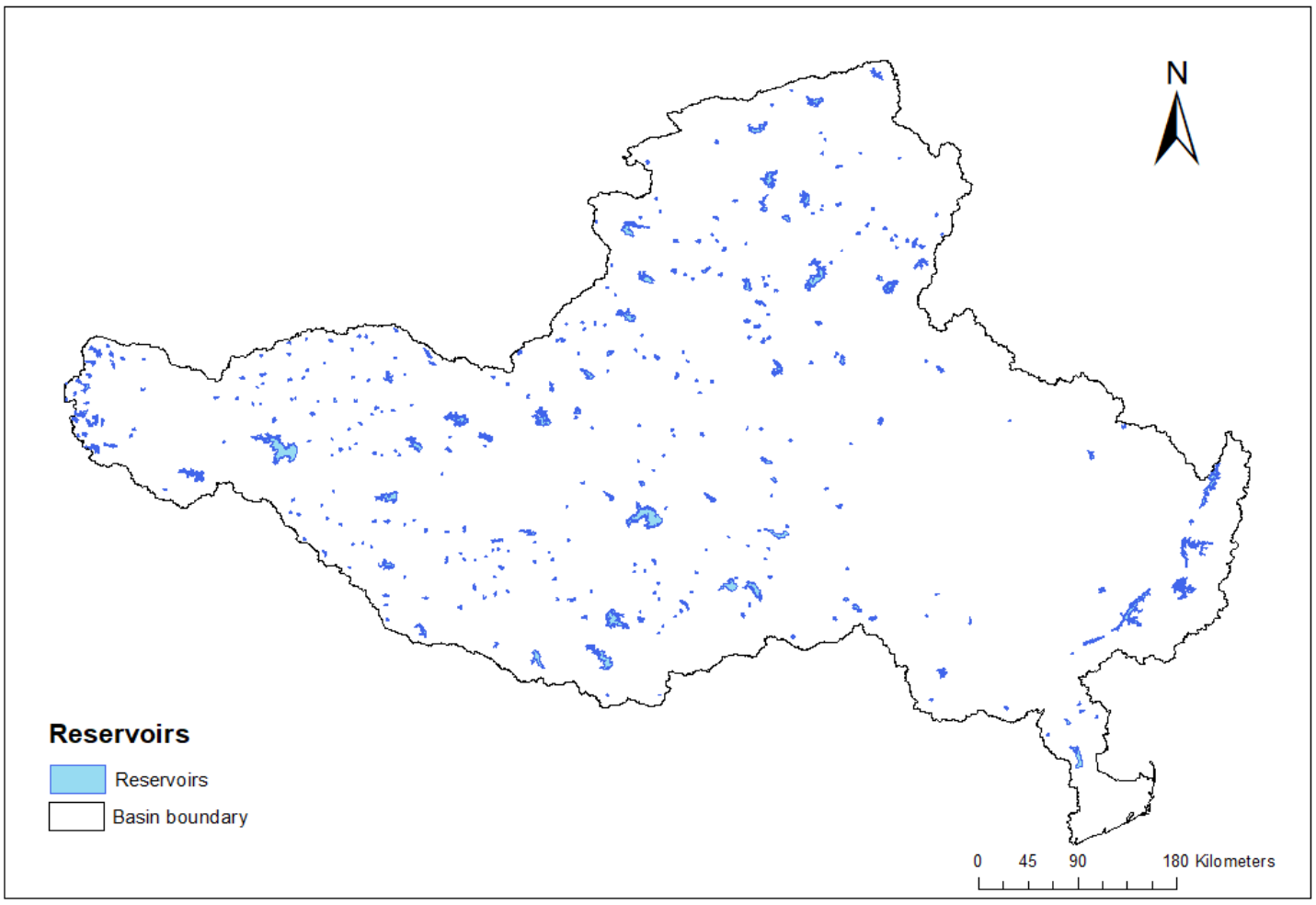


Figure 4.8.6: Reservoir map of Godavari basin

4.8.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 24.08 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.8.7. Yearly variations in ET_{II} are shown in Figure 4.8.8.

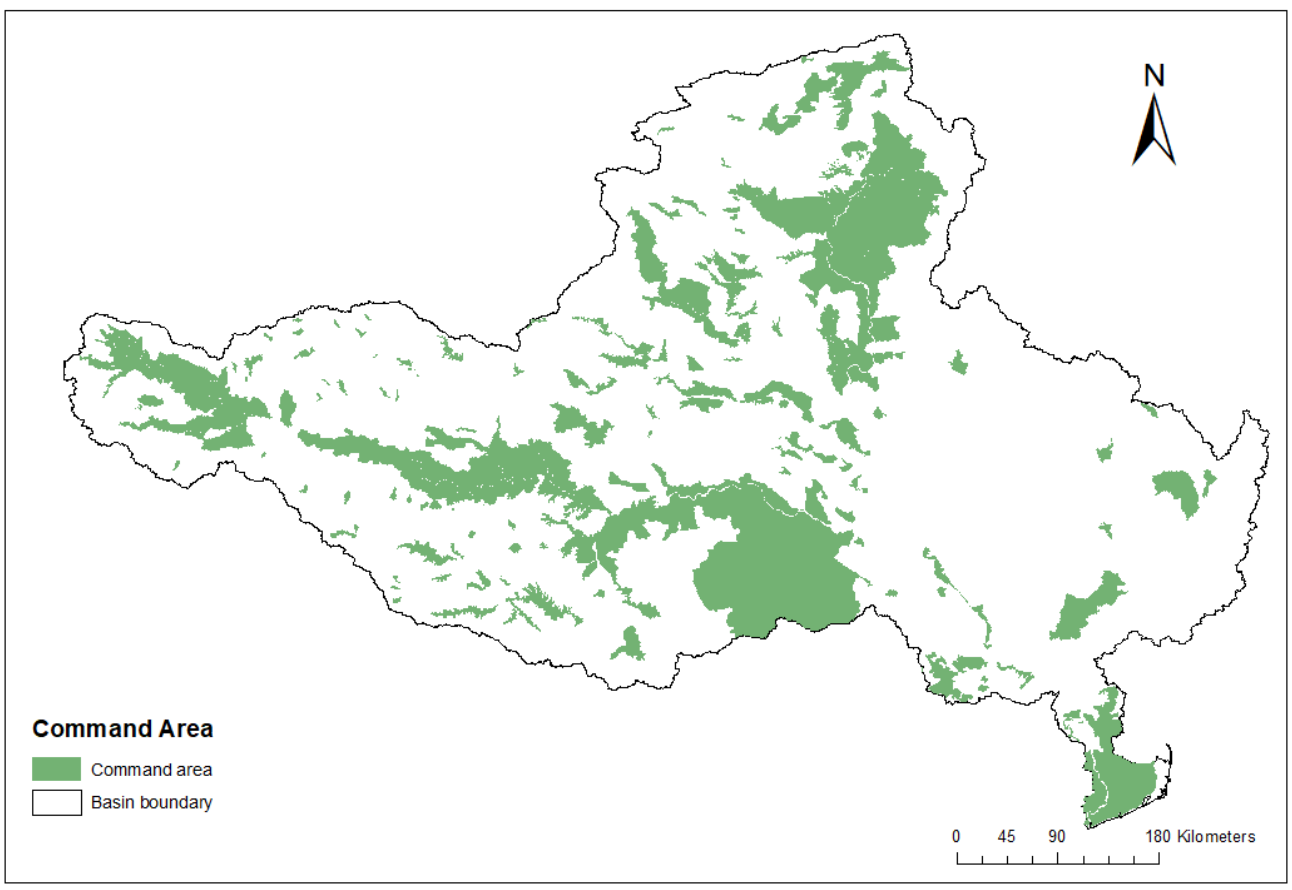


Figure 4.8.7: Command area map of Godavari basin

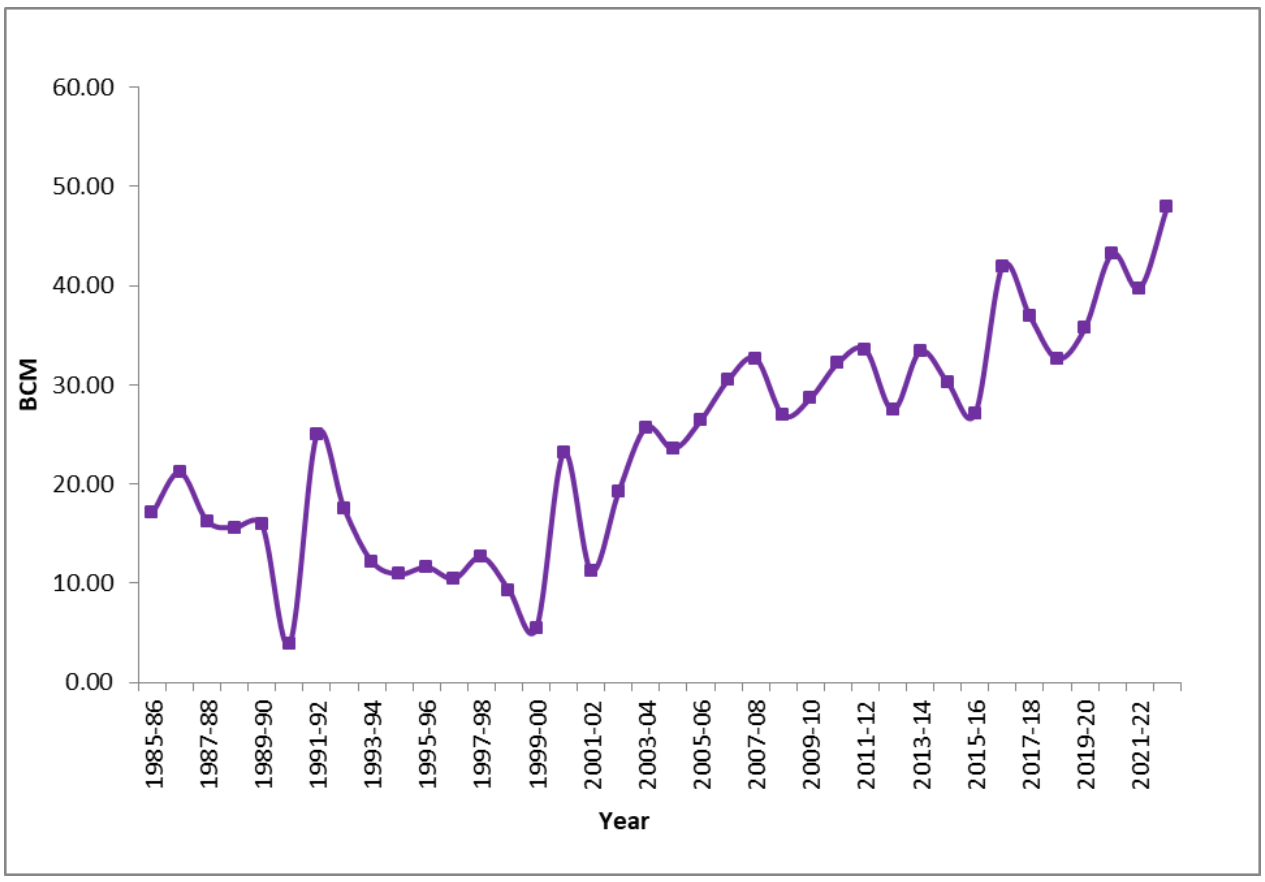


Figure 4.8.8: ET from Irrigation Input in Godavari basin

4.8.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.68 BCM and 0.10 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 1.99 BCM.

4.8.4 Previous Estimates

Previous estimates of Water resources availability in Godavari basin are as given below in Table 4.8.2.

Table 4.8.2: Previous assessments of Godavari basin

S. No.	Year	Authority/Method of estimation	Quantity (BCM)
1.	1901 - 03	First Irrigation Commission/using coefficients of runoff	116.76
2.	1949	Khosla's empirical formula	125.52
3.	1960	CW & PC/Statistical analysis of flow data wherever available and precipitation-runoff relationships wherever data were meagre.	115.33
4.	1962	Krishna Godavari Commission/Aggregation of average annual yields of all sub-basins	117.99
5.	1988	Central Water Commission/General water balance approach	117.99
6.	1993	Central Water Commission	110.54
7.	2019	Central Water Commission	117.74

4.8.5 Annual Water Availability of Godavari Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability from year 1985-86 to 2022-23 of Godavari basin is estimated as 129.17 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.8.9. The results of Godavari basin are shown in Table 4.8.3.

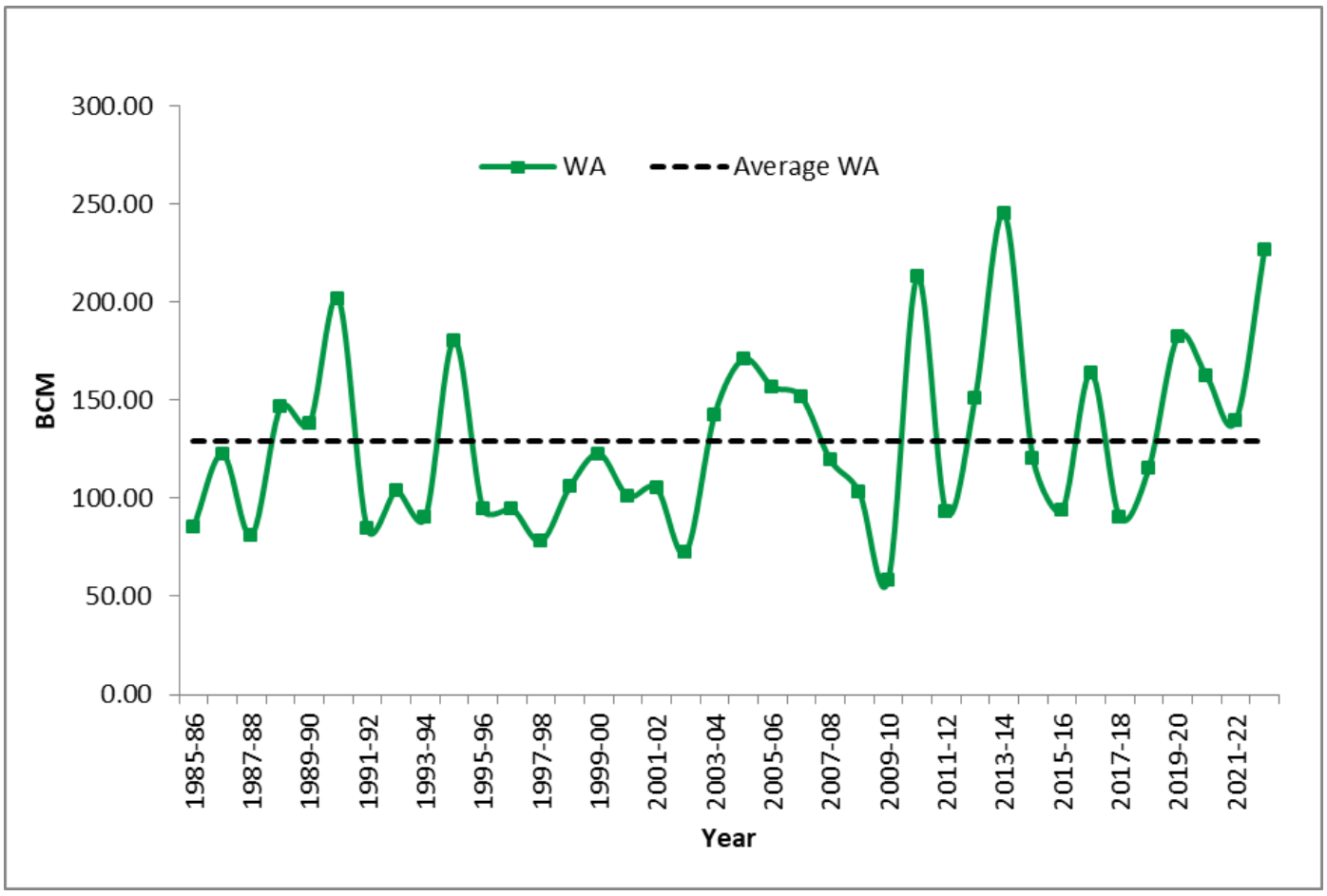


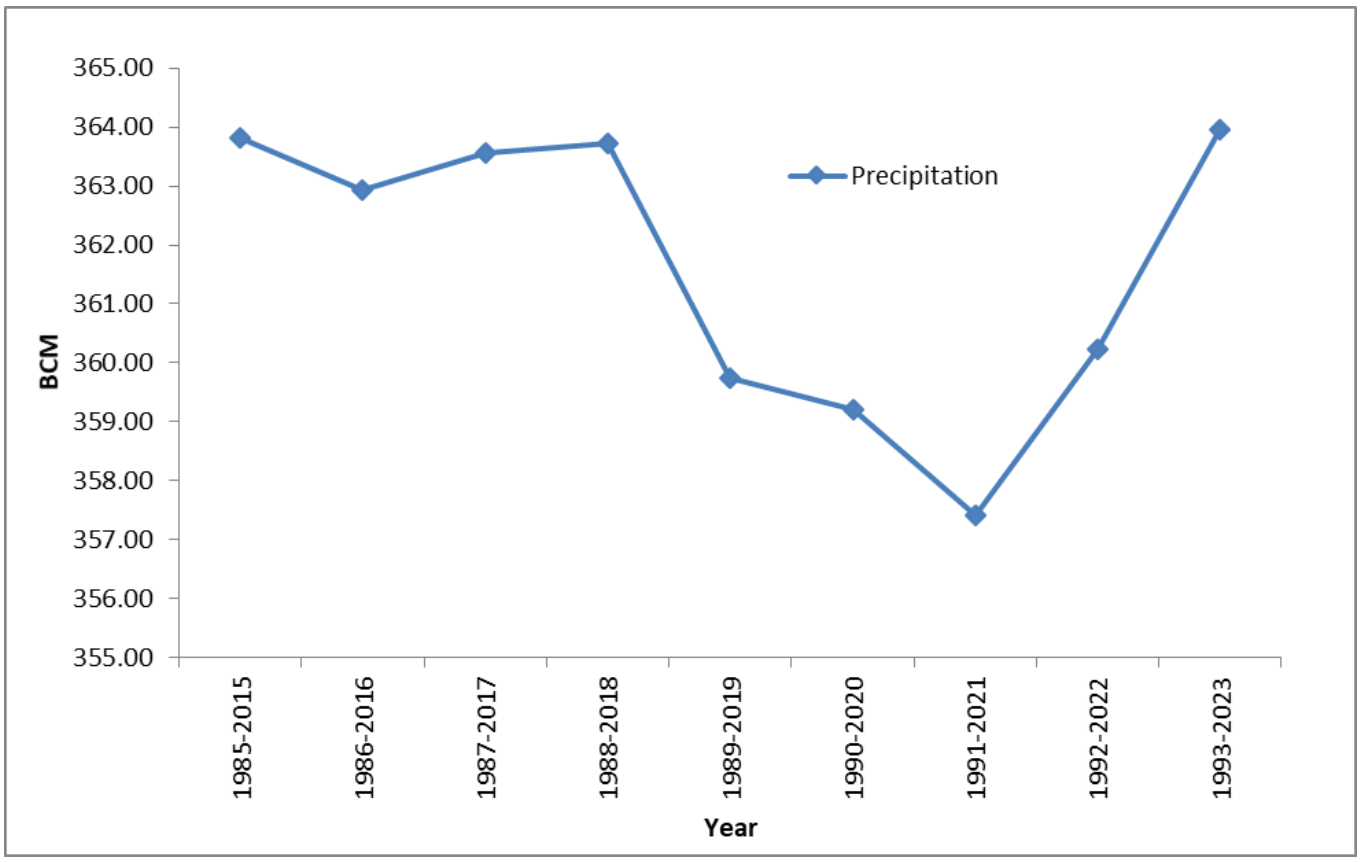
Figure 4.8.9: Water Availability of Godavari basin

4.8.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Godavari basin is given at Table 4.8.3. A line diagram of moving average of P and WA is shown in Figure 4.8.10.

Table 4.8.3: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	363.81	124.49
1986-2016	362.94	124.76
1987-2017	363.57	126.14
1988-2018	363.72	126.44
1989-2019	359.75	125.40
1990-2020	359.22	126.88
1991-2021	357.42	125.56
1992-2022	360.23	127.39
1993-2023	363.96	131.49



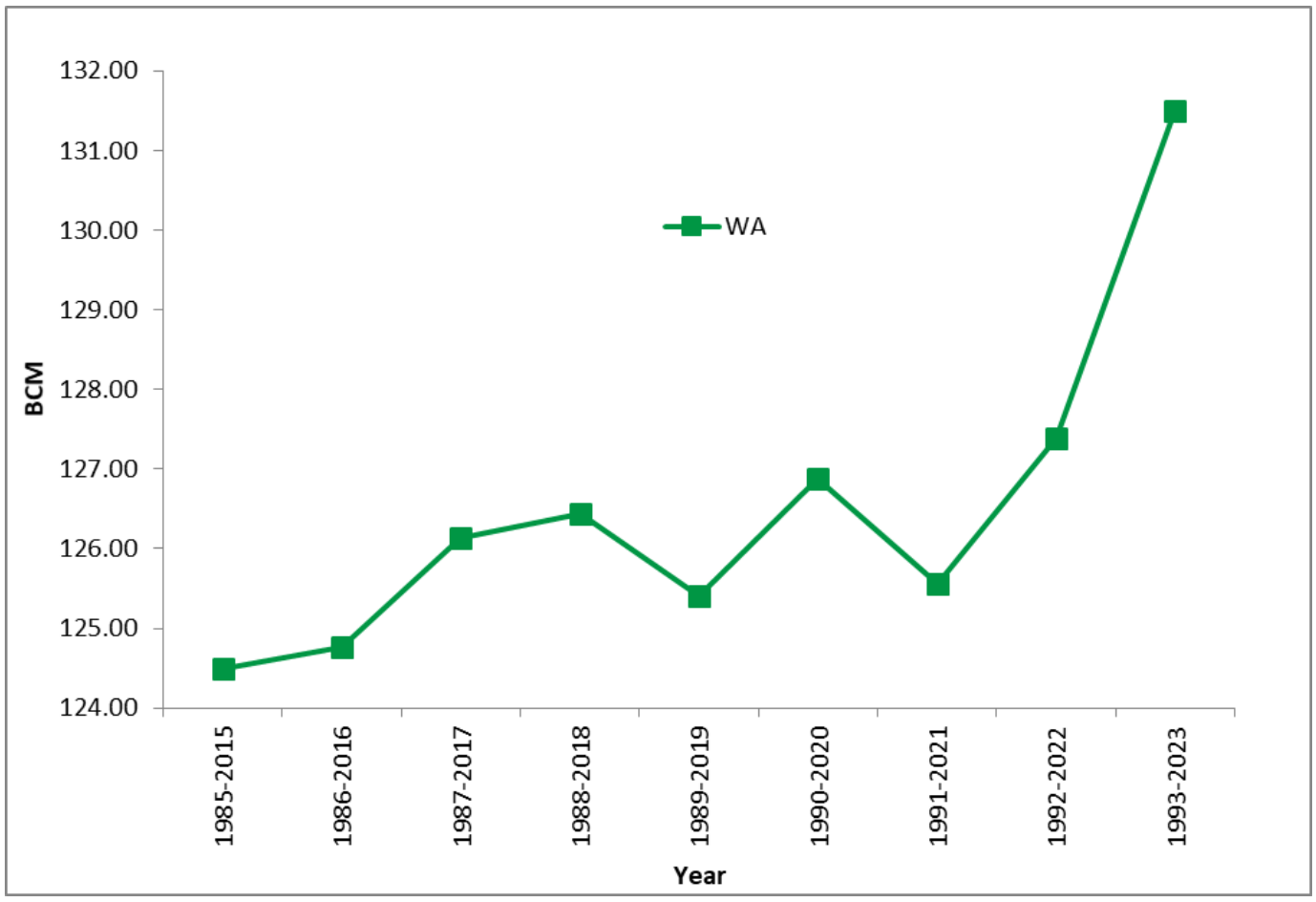


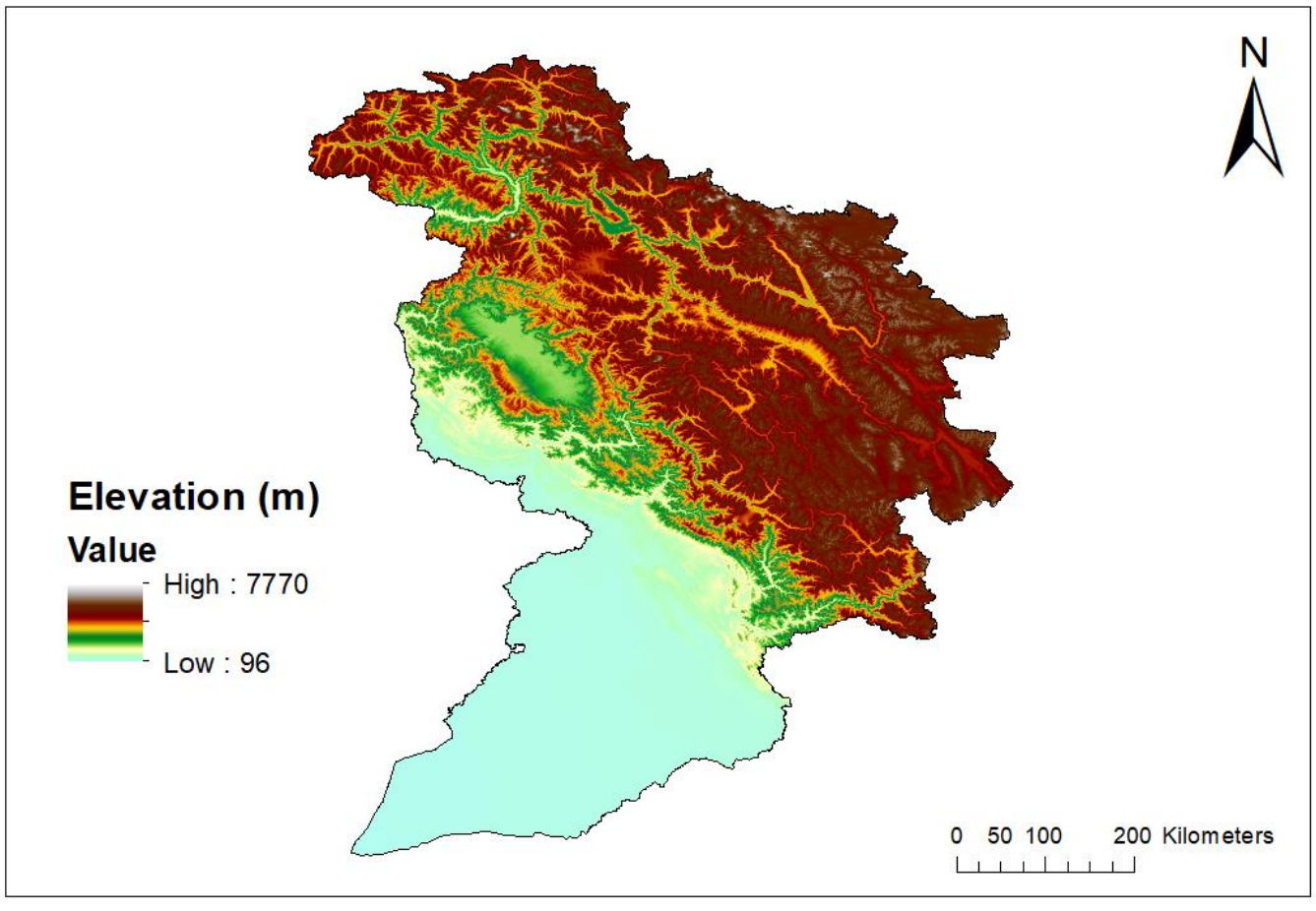
Figure 4.8.10: Moving Average of P and WA for 30 years

Table 4.8.4: Water Availability of Godavari basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	311.42	225.85	85.57
1986-87	350.21	227.57	122.64
1987-88	302.68	221.60	81.08
1988-89	431.71	285.33	146.38
1989-90	428.09	290.18	137.91
1190-91	453.11	251.37	201.74
1991-92	296.56	212.16	84.40
1992-93	355.84	251.97	103.87
1993-94	338.68	248.61	90.07
1994-95	463.30	282.78	180.52
1995-96	356.99	262.56	94.43
1996-97	340.22	245.55	94.67
1997-98	346.64	268.36	78.28
1998-99	381.17	275.26	105.91
1999-00	365.46	242.80	122.66
2000-01	333.79	232.54	101.25
2001-02	368.22	263.09	105.13
2002-03	294.19	221.86	72.33
2003-04	374.51	231.90	142.62
2004-05	376.18	205.15	171.02
2005-06	398.94	242.03	156.91
2006-07	384.79	233.11	151.68
2007-08	360.88	241.36	119.52
2008-09	320.59	217.65	102.94
2009-10	272.08	213.56	58.52
2010-11	444.07	231.24	212.83
2011-12	293.79	200.64	93.15
2012-13	367.96	216.89	151.07
2013-14	482.94	237.58	245.36
2014-15	319.30	199.07	120.23
2015-16	285.20	191.60	93.61
2016-17	369.20	205.24	163.96
2017-18	307.17	216.96	90.21
2018-19	312.68	197.46	115.22
2019-20	412.05	229.73	182.32
2020-21	399.32	237.14	162.18
2021-22	380.74	241.42	139.32
2022-23	467.83	241.03	226.80
Average	**364.43**	**235.27**	**129.17**

4.9 INDUS BASIN



HIGHLIGHTS

- ***In the present study, the water availability of only the eastern rivers of Indus basin (Ravi, Beas, Sutlej and Ghaggar) has been estimated.***
- ***The water availability of western rivers of Indus basin (Indus, Chenab, Jhelum) has not been estimated. However, the precipitation of these basins has been estimated.***
- *Average annual water resources availability of Indus basin (for eastern rivers) is 47.30 BCM.*
- *Maximum annual water availability is 61.75 BCM during 2008-09.*
- *Minimum annual water availability is 37.58 BCM during 2005-06.*
- *Average annual precipitation is 95.39 BCM (763 mm).*
- *Maximum annual precipitation is 117.21 BCM (937 mm) during 2008-09.*
- *Minimum annual precipitation is 76.57 BCM (612 mm) during 2020-21*

4.9.1 About Indus Basin

The Indus basin spreads over states of Jammu & Kashmir (60.31%), Himachal Pradesh (15.98%), Punjab (15.66%), and part of Rajasthan (4.92%), Haryana (3.09%), besides Union Territory of Chandigarh (0.04%) having an area of 3,17,708 sq.km which is nearly 9.8 percent of the total geographical area. The geographical extent of the basin is between 72°28’ to 79°39’ East longitudes and 29°8’ to 36°59’ North latitudes of the country. The upper part of the basin, which lies in Jammu & Kashmir and Himachal Pradesh, is dominated by mountain ranges and narrow valleys. In Punjab, Haryana and Rajasthan, the basin consists of vast plains, which are fertile granary of the country. There are 6 major rivers which are flowing in the basin namely Indus, Jhelum, Chenab, Ravi, Beas and Sutlej. Indus is a trans-boundary river that originates in Tibet, it flows in Jammu & Kashmir region and further goes in Pakistan. Sutlej is also a trans-boundary river originating in Tibet and flows in Himachal Pradesh and Punjab region.

4.9.2 Geo-Spatial Datasets

4.9.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Indus basin for year 2022-23 is shown in Figure 4.9.1. Major land use consists of Double/Triple/Annual crop land, waste lands, snow covered/glacial areas etc.

Table 4.9.1 shows the percentage area of each land use class in the basin for year 2022-23.

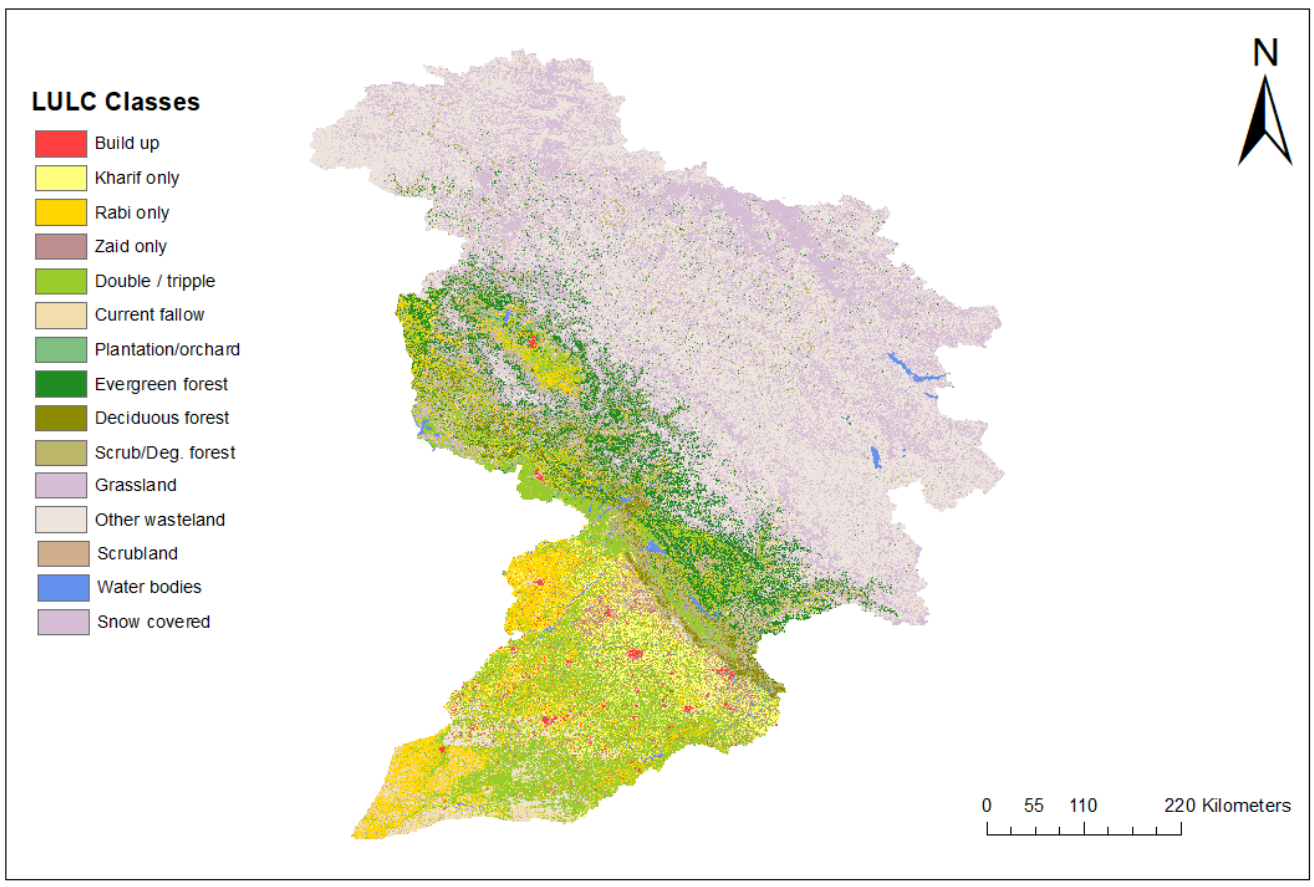


Figure 4.9.1: LULC Map of Indus basin

Table 4.9.1: Percentage area of Land Use and Land Cover

S. No.	LULC class	Area (%) in 2022-23
1.	Built-up land	2.20
2.	Kharif only	1.92
3.	Rabi crop land	1.11
4.	Double/Triple/Annual crop land	19.65
5.	Current fallow land	1.48
6.	Plantation/Orchid	1.00
7.	Evergreen/Semi-evergreen woodland	6.82
8.	Deciduous woodland	3.03
9.	Degraded woodland	3.50
10.	Grassland	2.13
11.	Waste lands	31.59
12.	Water Bodies - maximum spread	1.26
13.	Water Bodies - minimum spread	0.31
14.	Snow covered/Glacial areas	24.00

4.9.3 Hydro-Meteorological and other Input Data

4.9.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.9.2. For present study, the basin has been divided into 07 sub-basins - Ravi, Beas, Sutlej, Ghaggar (eastern rivers of Indus system) and Indus, Jhelum & Chenab (western rivers of Indus system). The variation in the annual precipitation during study period of 20 years (2003-04 to 2022-23) for eastern rivers sub-basins (i.e. Ravi, Beas, Sutlej, Ghaggar) is shown in the Figure 4.9.3. The average precipitation of 20 years for eastern rivers sub-basins is approximately 95.39 BCM (763 mm).

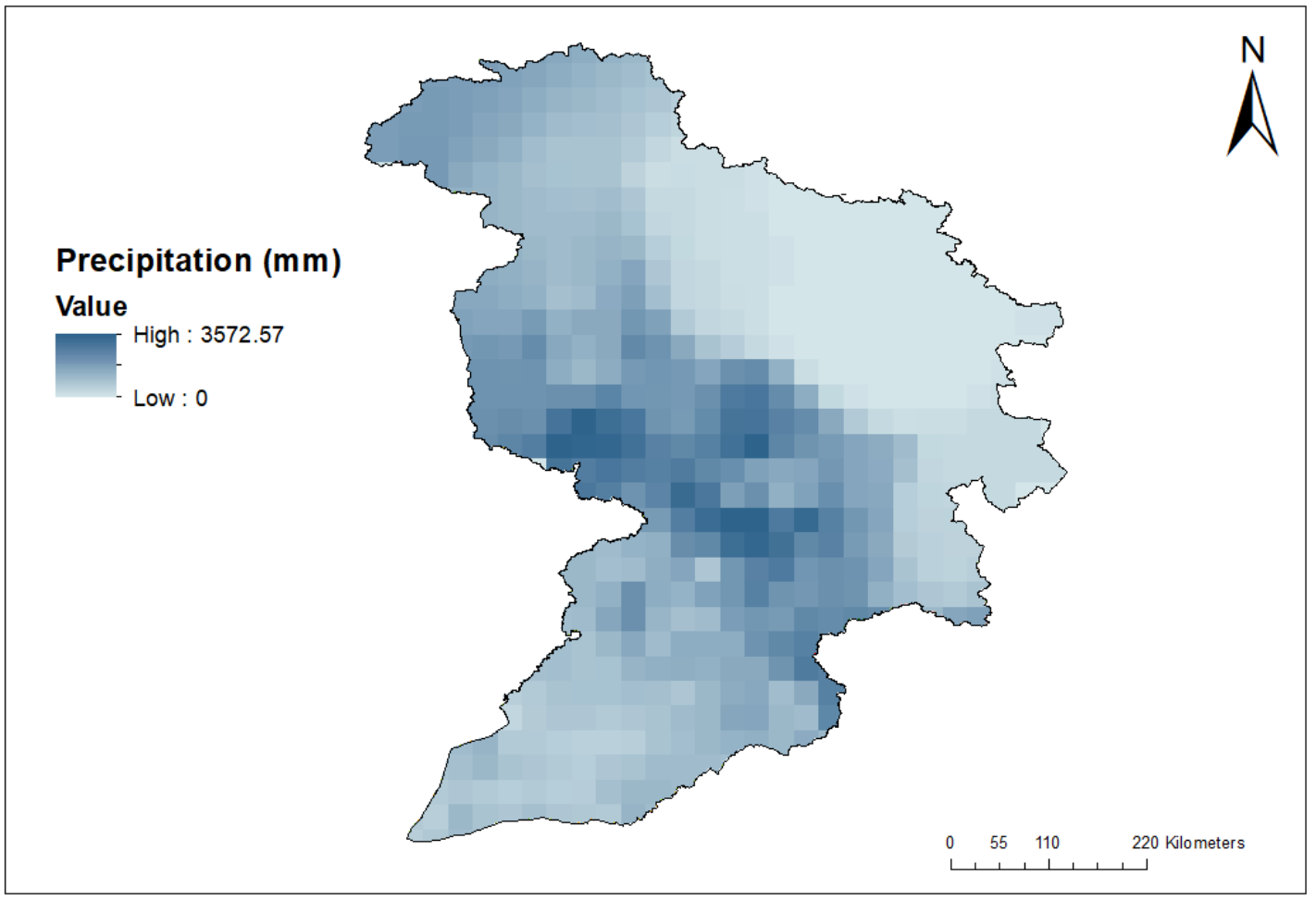


Figure 4.9.2: Precipitation map of Indus basin

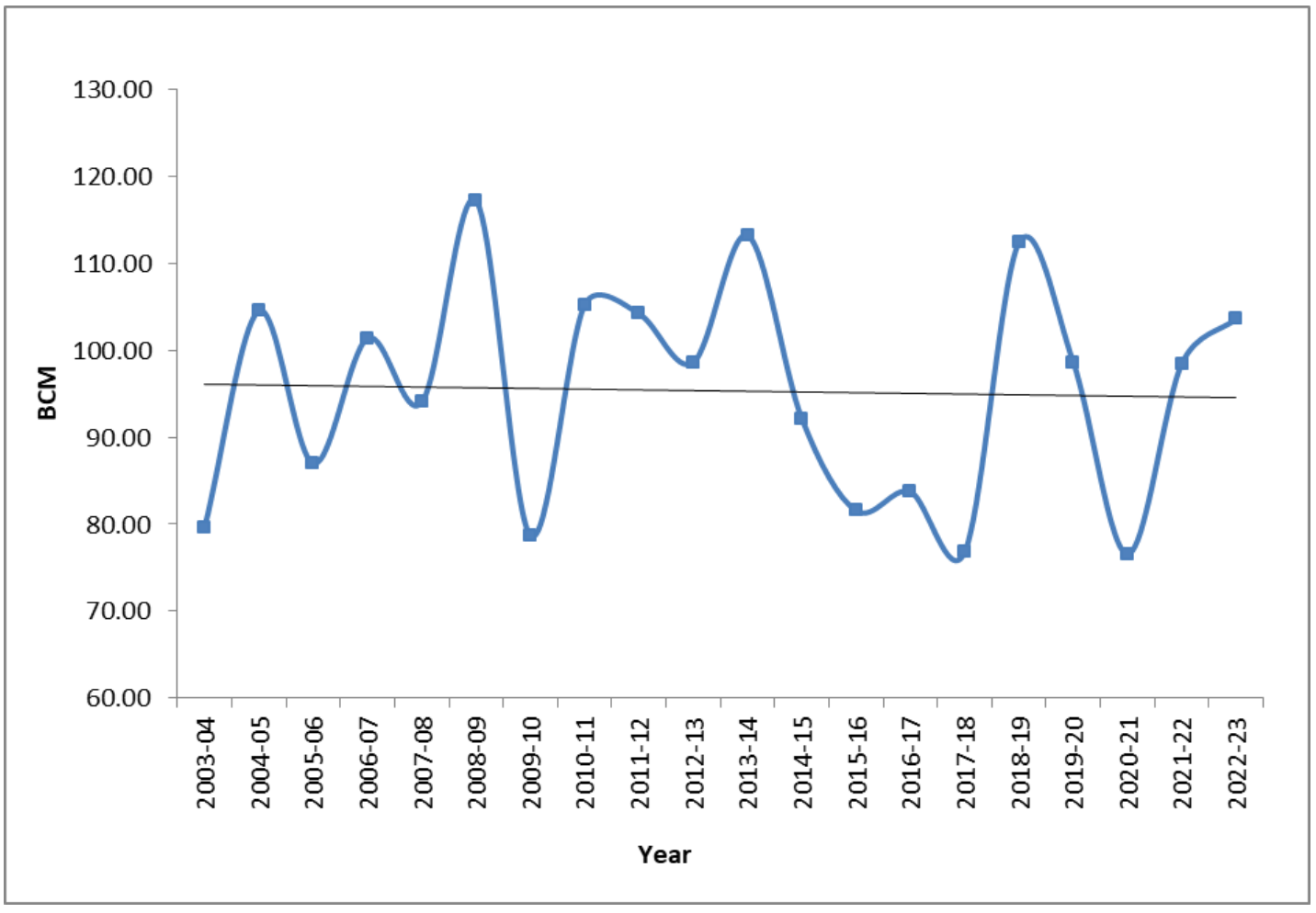


Figure 4.9.3: Annual Precipitation in Indus basin

4.9.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.9.4. The variation in the annual actual Evapotranspiration (ET) during study period of 20 years (2003-04 to 2022-23) for eastern rivers sub-basins is shown in the Figure 4.9.5. The average ET of 20 years for eastern rivers sub-basins is approximately 91.03 BCM (728 mm).

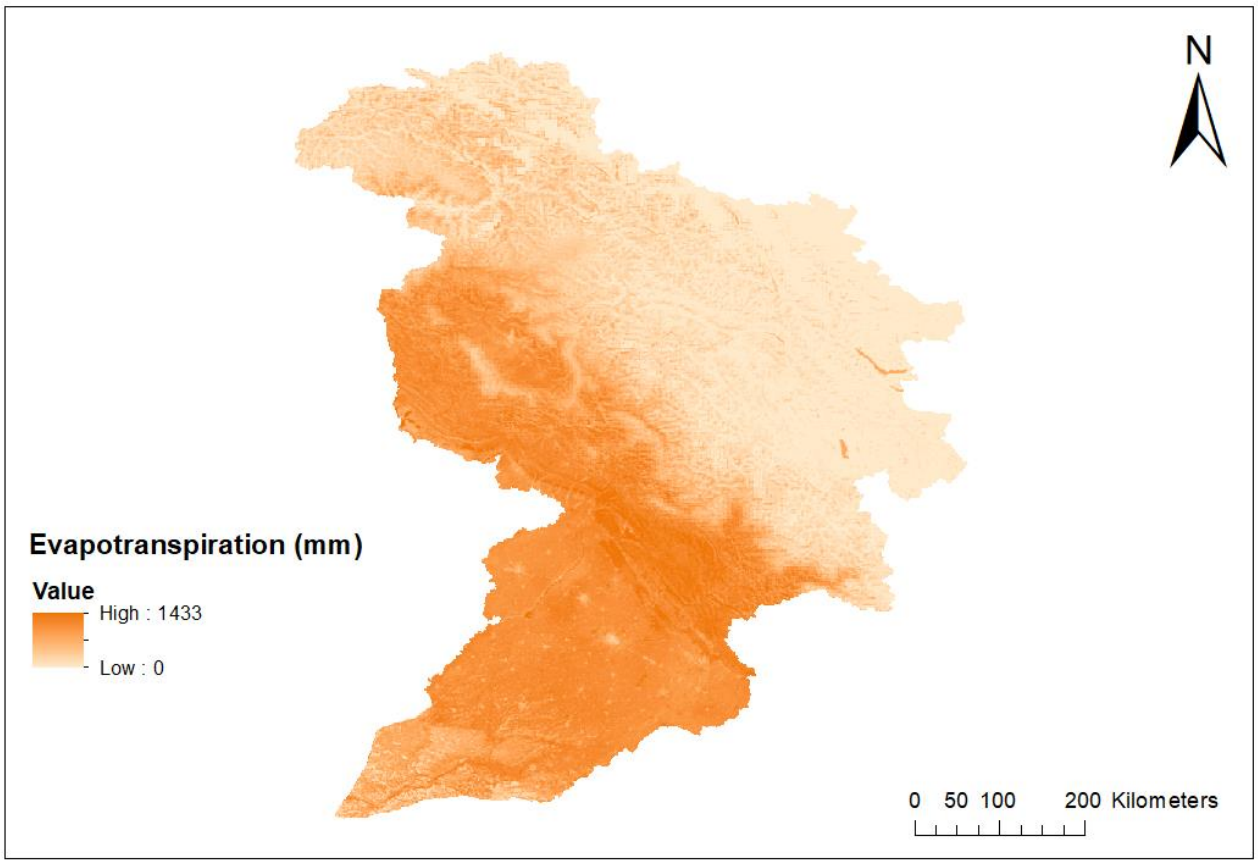


Figure 4.9.4: Evapotranspiration map of Indus basin

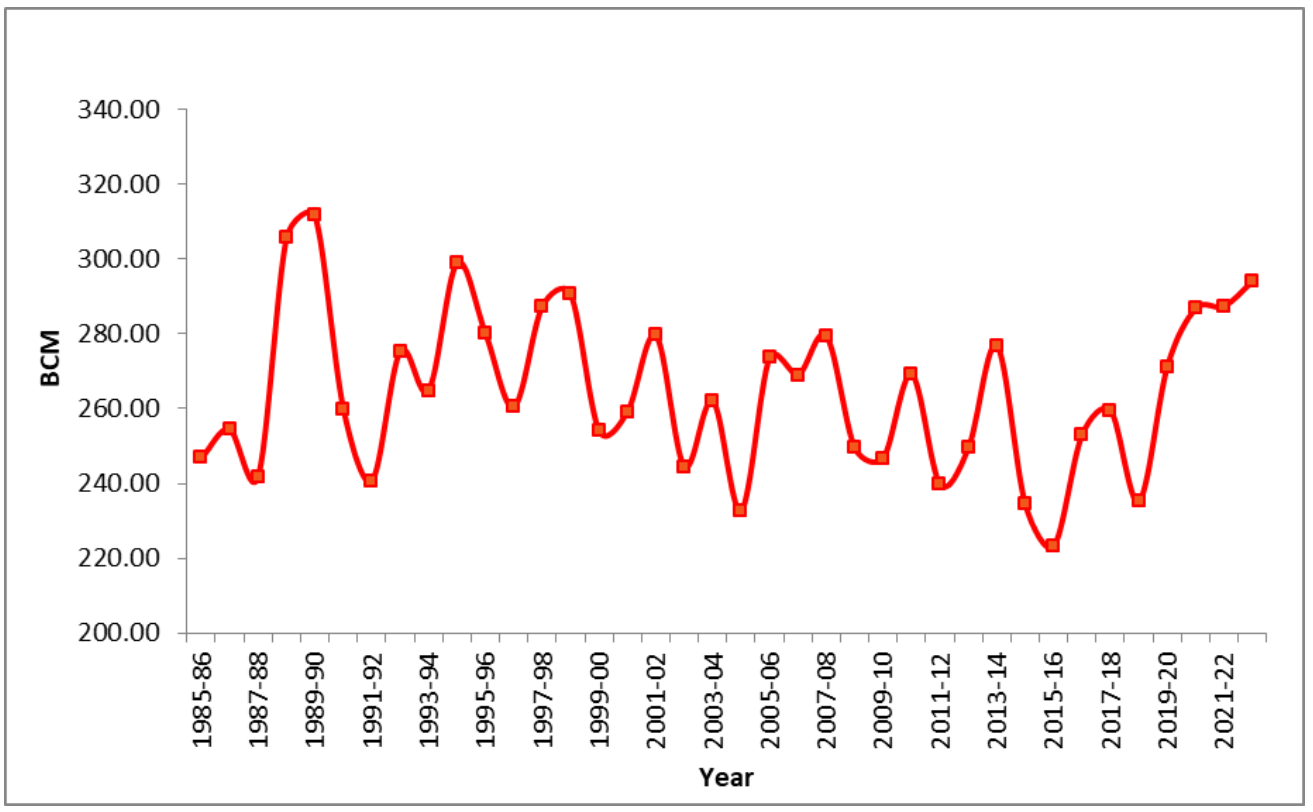


Figure 4.9.5: Annual evapotranspiration in Indus basin

4.9.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.9.6. The average annual evaporation from the reservoirs in the eastern rivers sub-basins is 0.49 BCM.

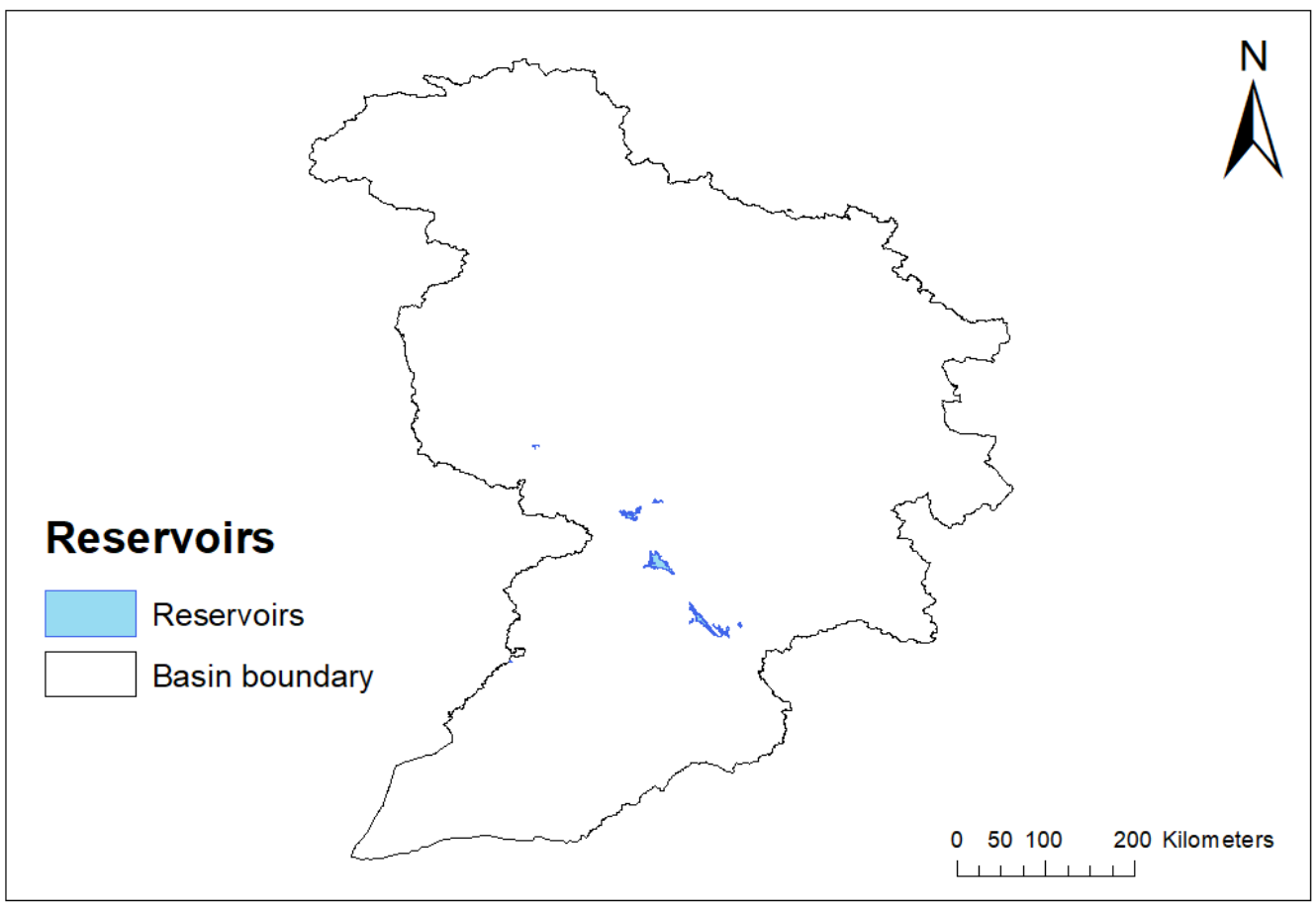


Figure 4.9.6: Reservoir map of Indus basin

4.9.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the eastern rivers sub-basins for the years 2003-2023 has been estimated as 39.05 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.9.7. The annual variation in Evapotranspiration from Irrigation Input for eastern rivers sub-basins is shown in Figure 4.9.8.

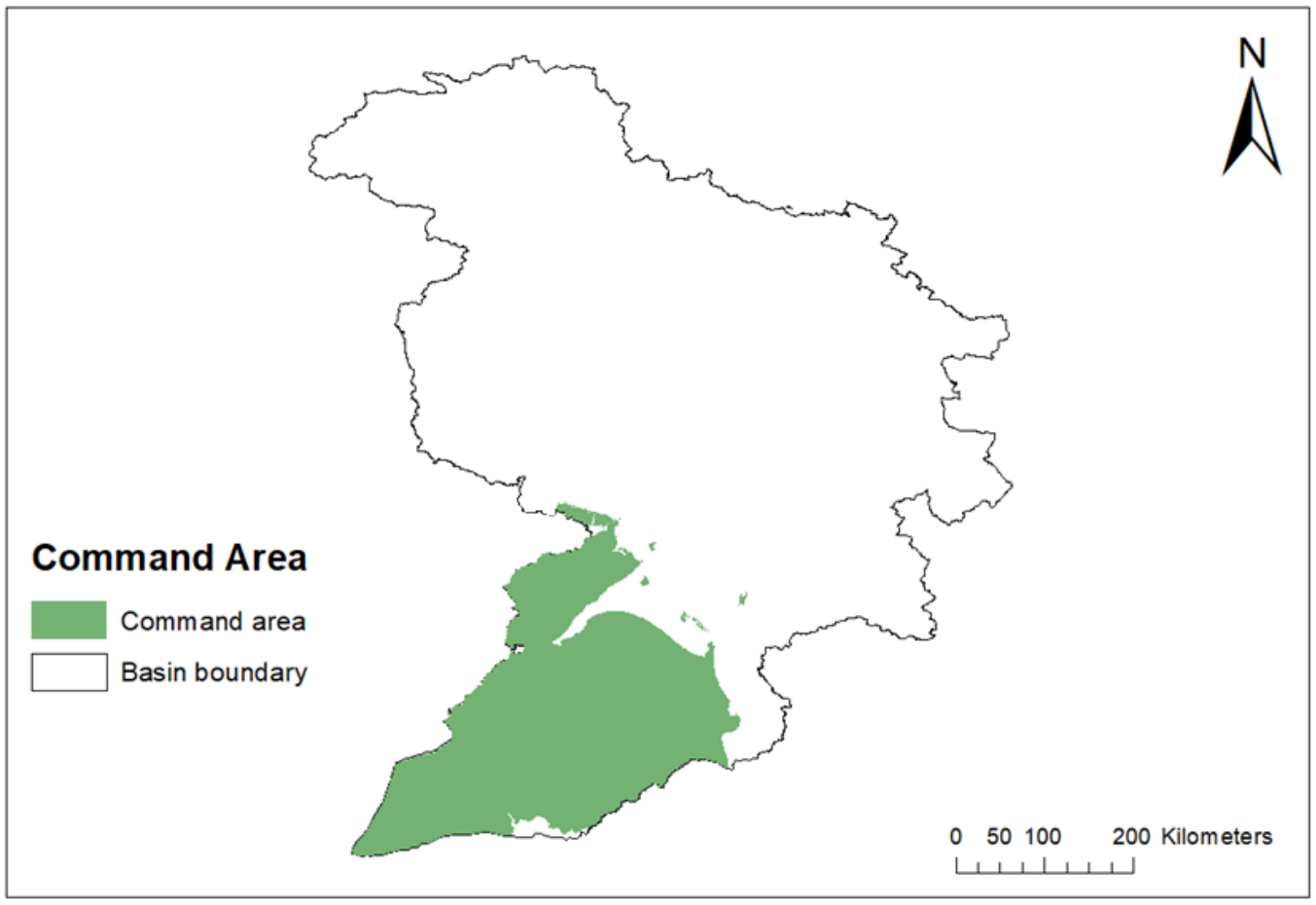


Figure 4.9.7: Command area map of Indus basin

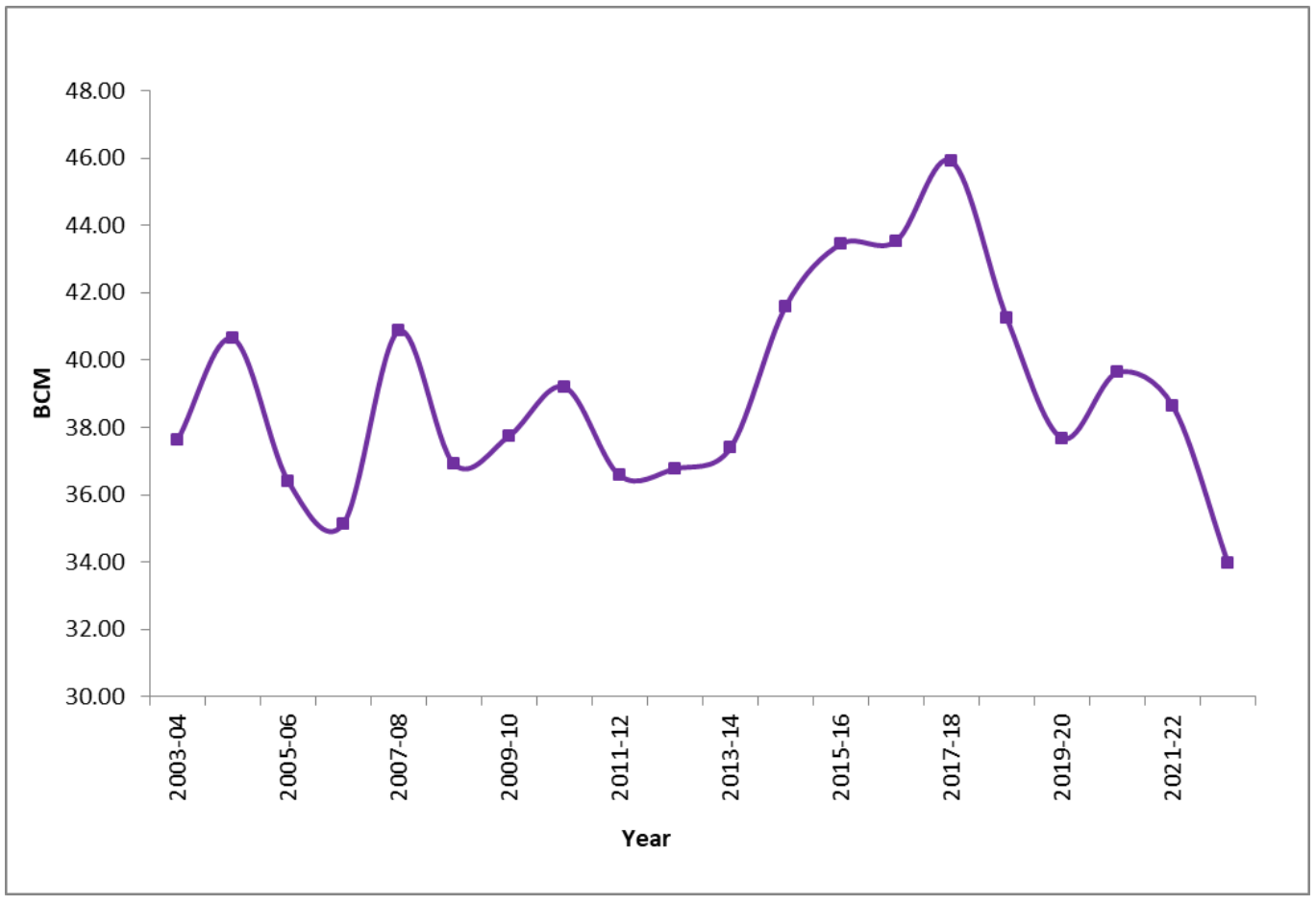


Figure 4.9.8: ET from Irrigation Input in Indus basin

4.9.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -2.11 BCM and 0.39 BCM respectively. Domestic, Industrial and Livestock consumptive use (for whole Indus basin) for 2022-23 has been estimated as 1.25 BCM.

4.9.4 Previous Estimates

Section 4.1 of CWC report on Reassessment of Water Resources Potential of India, 1993, (Basins for which reassessment was considered not necessary) mentions: "*Indus is an international river. The water resources potential of the various sub-basins of India upto the Indian border has been estimated by Indus Commission, CWC and Irrigation Commission of 1972. The water resources development in this basin is governed by the provisions of the Indus Water Treaty of 1960 between India and Pakistan. According to this treaty, the water of the Eastern Rivers, namely, Ravi, Beas and the Sutlej shall be available for the unrestricted use by India. India has also been permitted to use the waters of the Western Rivers for domestic non-consumptive purposes, for hydropower generation through run-of-the river hydroelectric plants and for specified agricultural purposes and construction of storage works. In view of the above, it is obvious that not much useful purpose will be served by reassessing the water potential of the Indian portion of the whole basin*". The water resources potential of Indus basin in 1993 report was kept as 73.30 BCM with remarks "No revision".

In 2019 study, water availability for Indus basin (Eastern Rivers only) was estimated as 45.53 BCM.

4.9.5 Annual Water Availability of Indus Basin

As mentioned earlier, for present study, the Indus basin (within India) has been divided into 07 sub-basins i.e. Ravi, Beas, Sutlej, Ghaggar, Indus, Jhelum and Chenab. There are number of canals links transferring water among Ravi, Beas, Sutlej and Ghaggar sub-basins (eastern rivers sub-basins of Indus basin) as shown in Figure 4.9.9, hence, combined water availability is estimated for all the above mentioned four sub-basins. The average annual water availability from year 2003-04 to 2022-23 for all the four sub-basins has been estimated as 47.30 BCM. The catchment areas of all the individual sub-basins within Indian border are shown in Figure 4.9.10. The results of Indus basin are shown in Table 4.9.2.

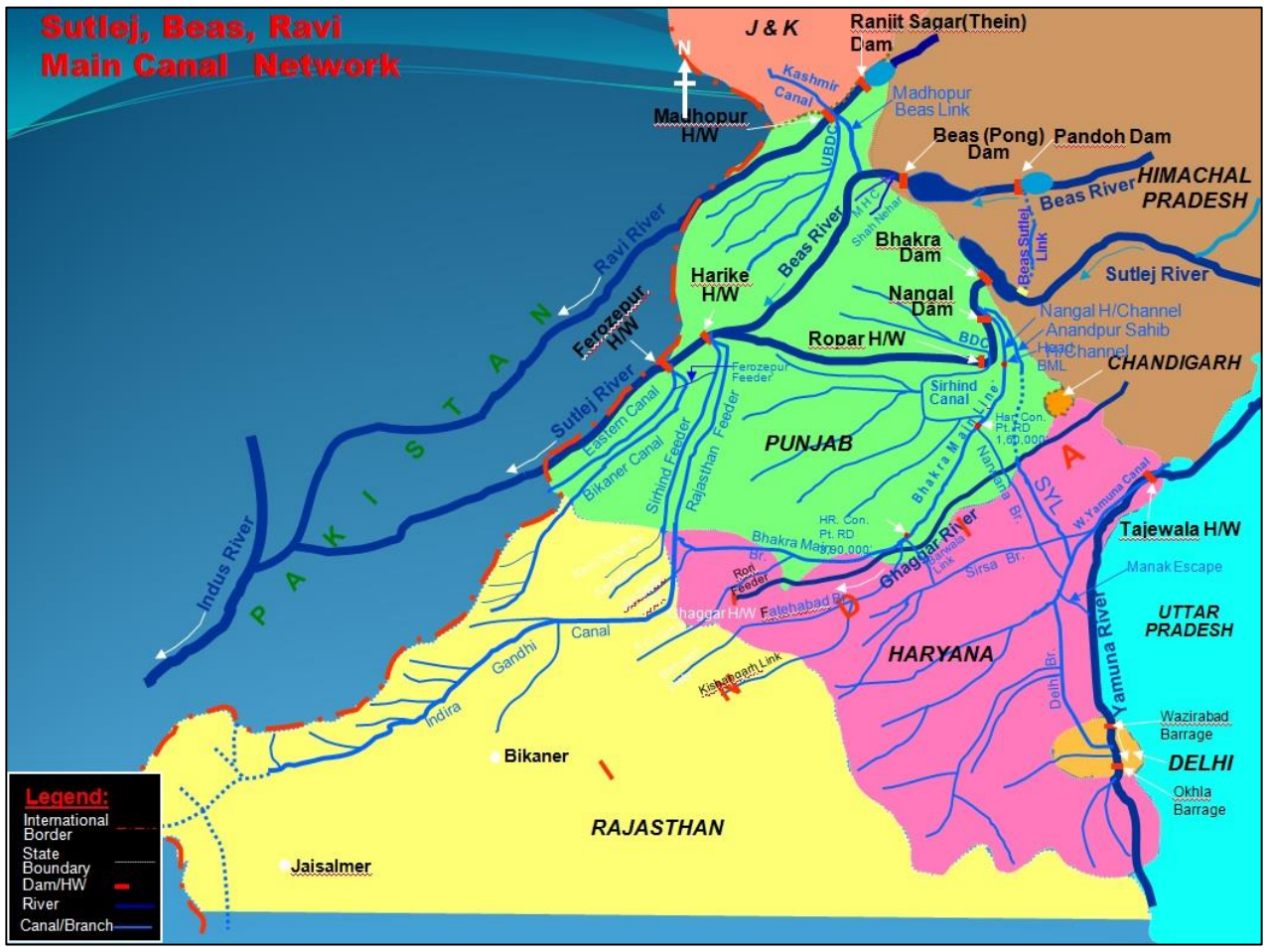


Figure 4.9.9: Canal Network in Ravi, Beas, Sutlej and Ghaggar sub-basins

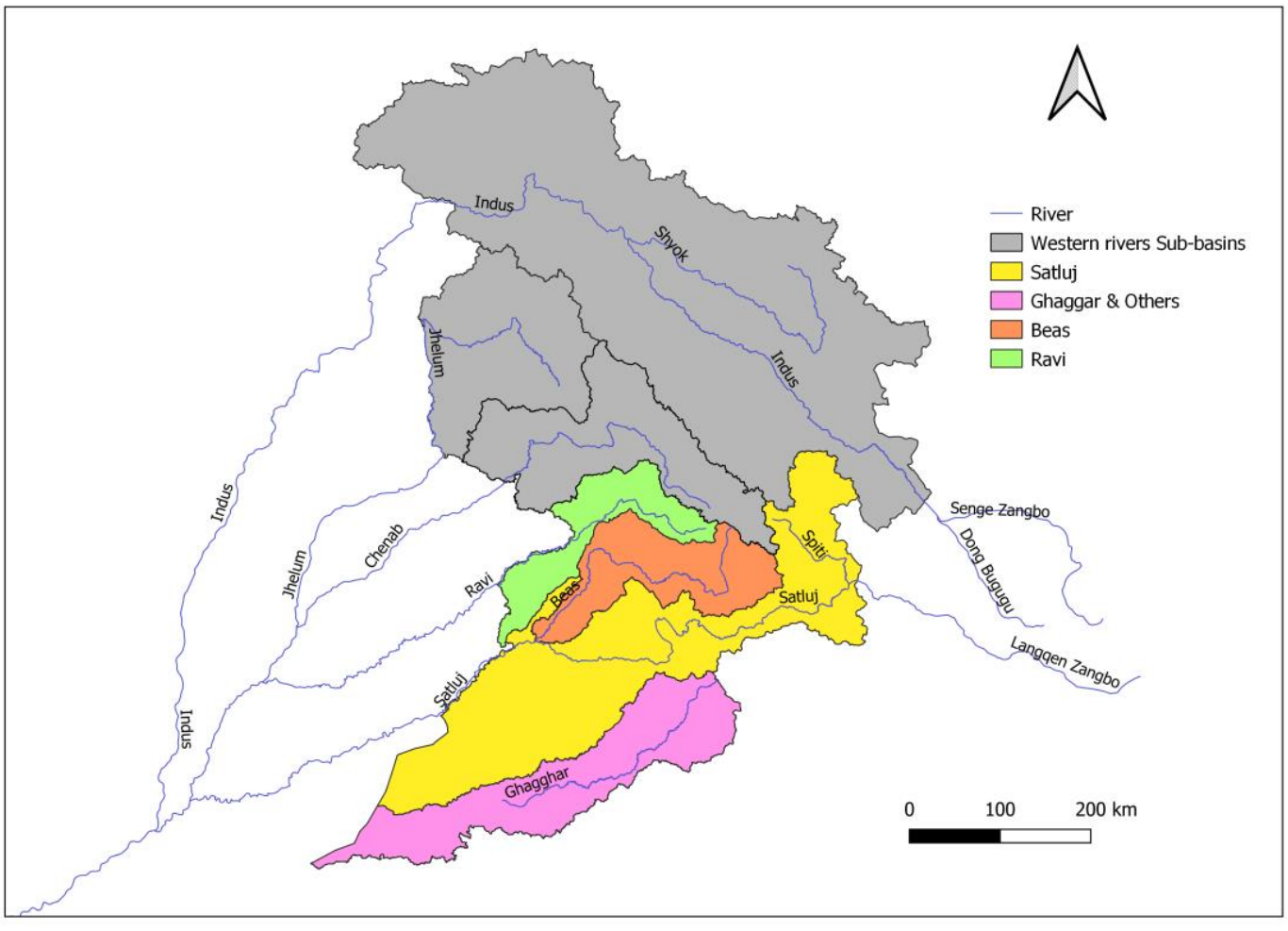


Figure 4.9.10: Sub-basins in Indus basin

The annual variations in water availability from year 2003-04 to 2022-23 for the eastern rivers sub-basins are shown in Figure 4.9.11.

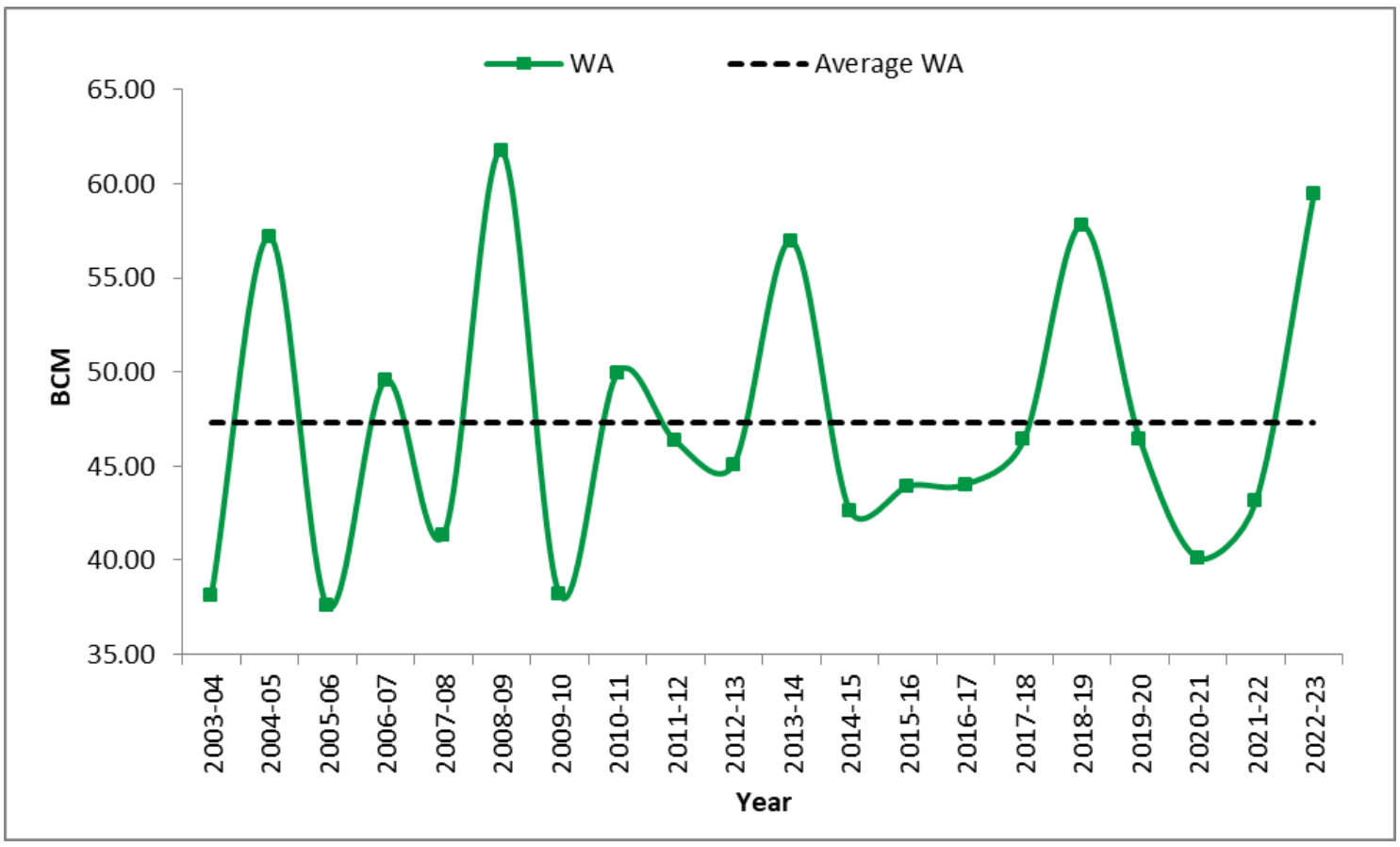


Figure 4.9.11: Water Availability of Indus Basin (eastern rivers)

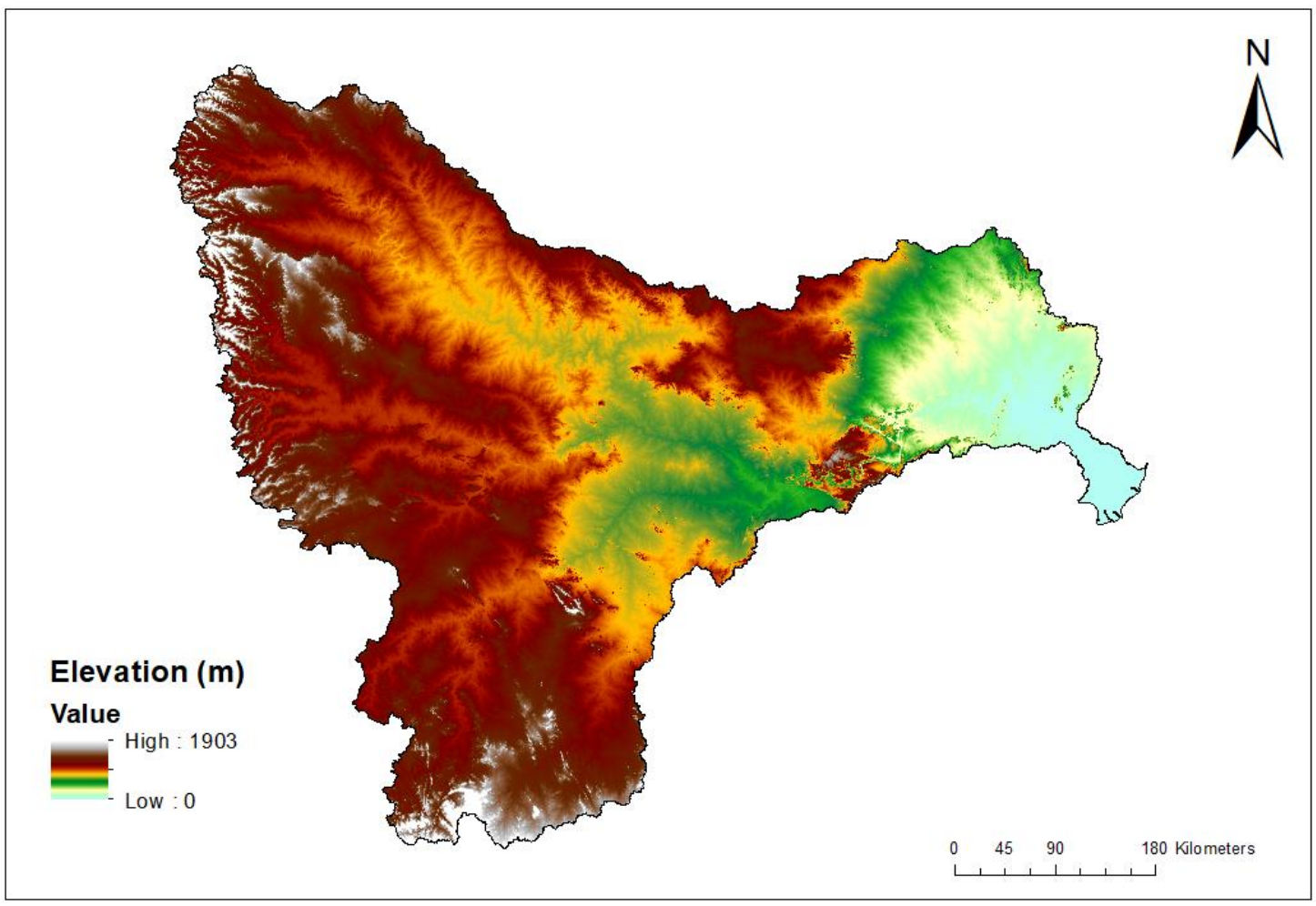
Table: 4.9.2 Water Availability for Ravi, Beas, Sutlej and Ghaggar sub-basins (Eastern Rivers)

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability*
2003-04	79.68	43.62	38.10
2004-05	104.54	49.39	57.20
2005-06	86.99	51.45	37.58
2006-07	101.40	54.68	49.56
2007-08	94.03	54.80	41.34
2008-09	117.21	57.58	61.75
2009-10	78.67	41.74	38.17
2010-11	105.26	57.50	49.95
2011-12	104.22	59.85	46.32
2012-13	98.62	55.64	45.10
2013-14	113.22	58.97	56.95
2014-15	92.12	51.45	42.65
2015-16	81.56	39.70	43.95
2016-17	83.73	41.60	44.03
2017-18	76.81	32.01	46.40
2018-19	112.40	56.06	57.79
2019-20	98.62	54.82	46.43
2020-21	76.57	38.53	40.11
2021-22	98.49	57.23	43.13
2022-23	103.63	45.94	59.47
Average	**95.39**	**50.13**	**47.30**

**Including trans-boundary contribution*

4.10 KRISHNA BASIN



HIGHLIGHTS

- *Average annual water resources availability of Krishna basin is 86.32 BCM.*
- *Maximum annual water availability is 156.47 BCM during 2005-06.*
- *Minimum annual water availability is 51.50 BCM during 2018-19.*
- *Average annual precipitation is 218.77 BCM (843.20 mm).*
- *Maximum annual precipitation is 303.46 BCM (1169.70 mm) during 2005-06.*
- *Minimum annual precipitation is 147.46 BCM (568.38 mm) during 2018-19.*

4.10.1 About Krishna Basin

The Krishna basin extends over an area of 2,59,439 sq.km, which is nearly 7.9% of the total geographical area of the country. Krishna basin lies in the states of Maharashtra (26.60%), Karnataka (43.80%), Telangana (19.80%) and Andhra Pradesh (9.80%). The river Krishna is a perennial river and second largest eastward draining interstate river in Peninsular India. The river rises from the Western Ghats near Jor village of Satara district of Maharashtra at an altitude of 1,337 m just north of Mahabaleshwar. The total length of river from origin to its outfall into the Bay of Bengal is 1400 km. Its principal tributaries joining from right are the Ghatprabha, the Malprabha, the Koyna, the Varna, the Panchganga, the Dudhganga and the Tungabhadra whereas the Bhima, the Khagna, the Musi and the Munneru are principal tributaries joining the river from left.

4.10.2 Geo-Spatial Datasets

4.10.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Krishna basin for year 2022-23 is shown in Figure 4.10.1. The major land use classes consist of Kharif only, Double/Triple and Current fallow land etc.

Table 4.10.1 shows the percentage area of each land use class in the basin for year 2022-23.

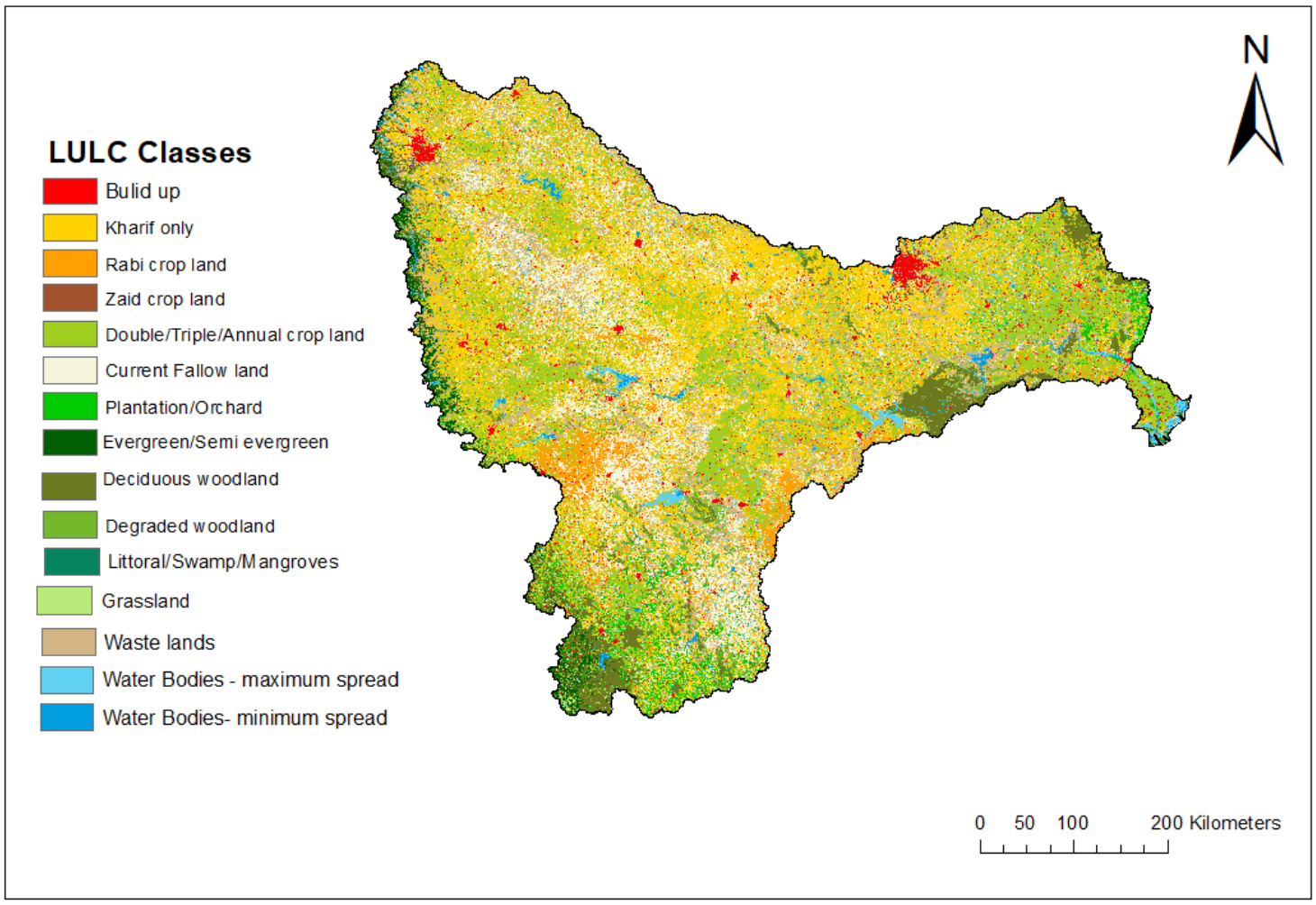


Figure 4.10.1: LULC Map of Krishna basin

Table 4.10.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	2.98
2.	Kharif only	27.56
3.	Rabi cropland	6.70
4.	Zaid cropland	0.03
5.	Double / triple cropland	21.65
6.	Current fallow land	16.64
7.	Plantation/orchard	2.45
8.	Evergreen/Semi-evergreen forest	1.50
9.	Deciduous woodland	5.70
10.	Scrub/Deg. Woodland	1.98
11.	Littoral/Swamp/Mangroves	0.04
12.	Grassland	0.04
13.	Waste lands	8.66
14.	Water Bodies - maximum spread	2.84
15.	Water Bodies - minimum spread	1.23

4.10.3 Hydro-Meteorological and other Input Data

4.10.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.10.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.10.3. The average precipitation of 38 years is approximately 218.77 BCM (843.20 mm).

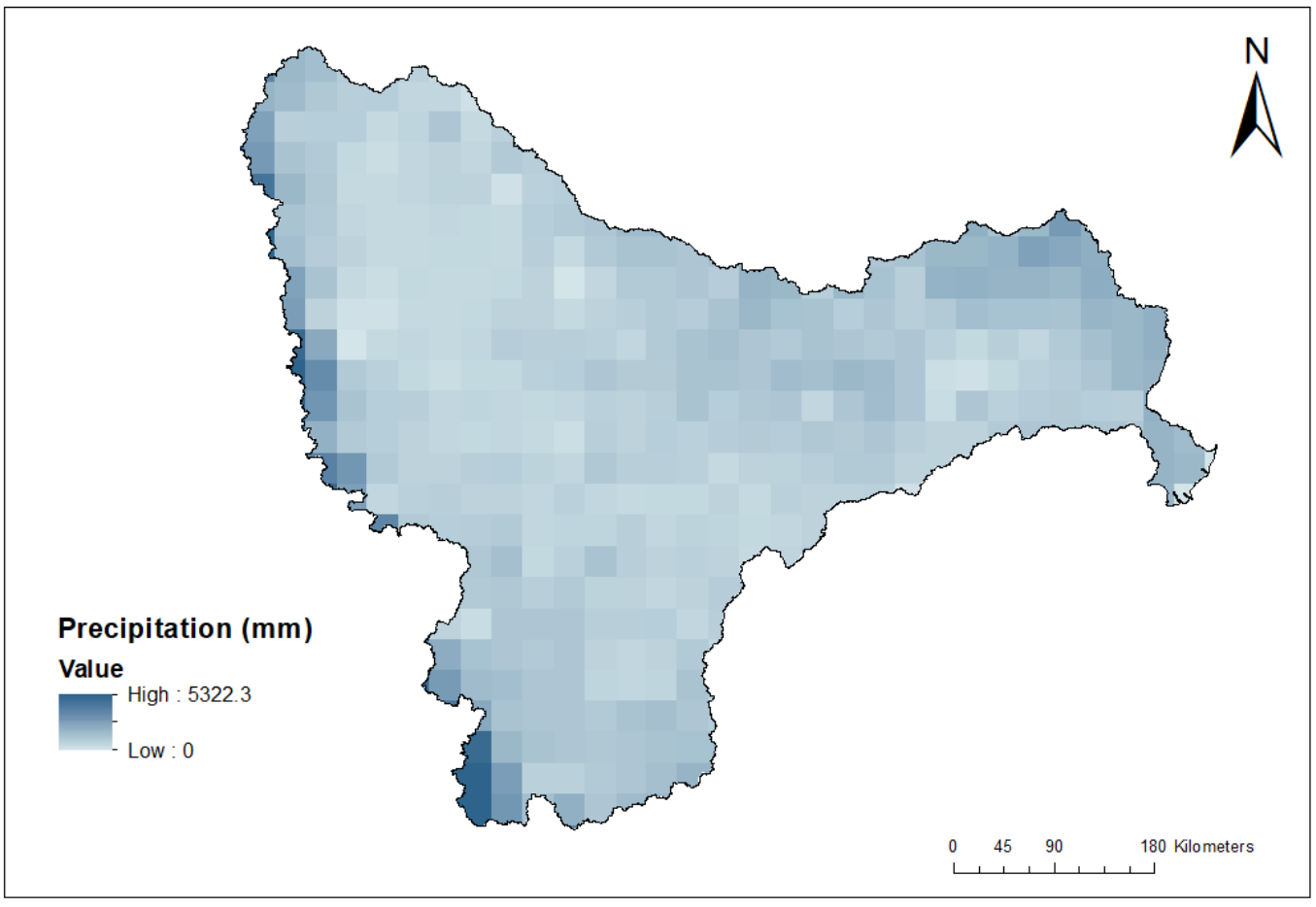


Figure 4.10.2: Precipitation map of Krishna basin

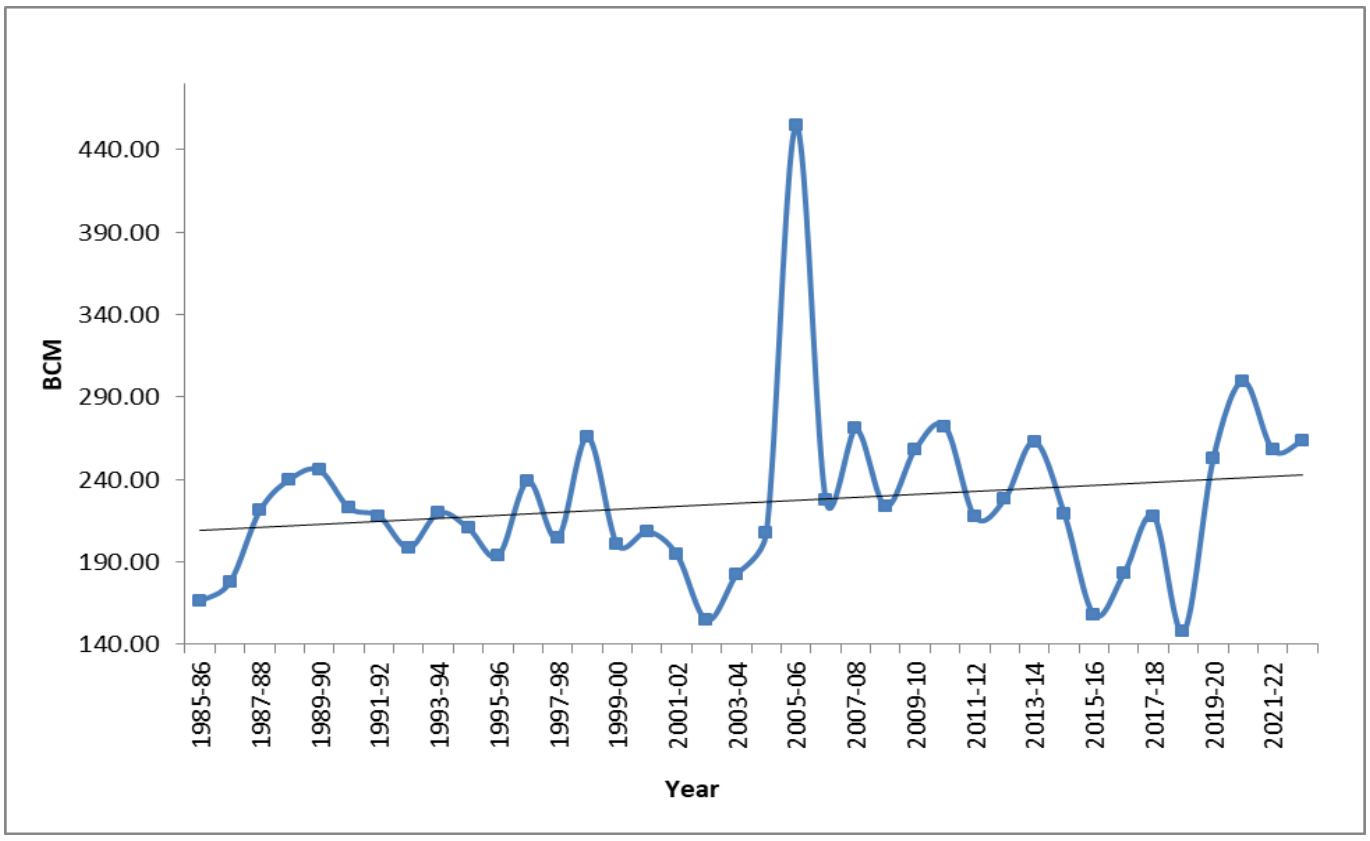


Figure 4.10.3: Annual Precipitation in Krishna basin

4.10.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.10.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.10.5. The average ET of 38 years is approx. 185.60 BCM (715.40 mm).

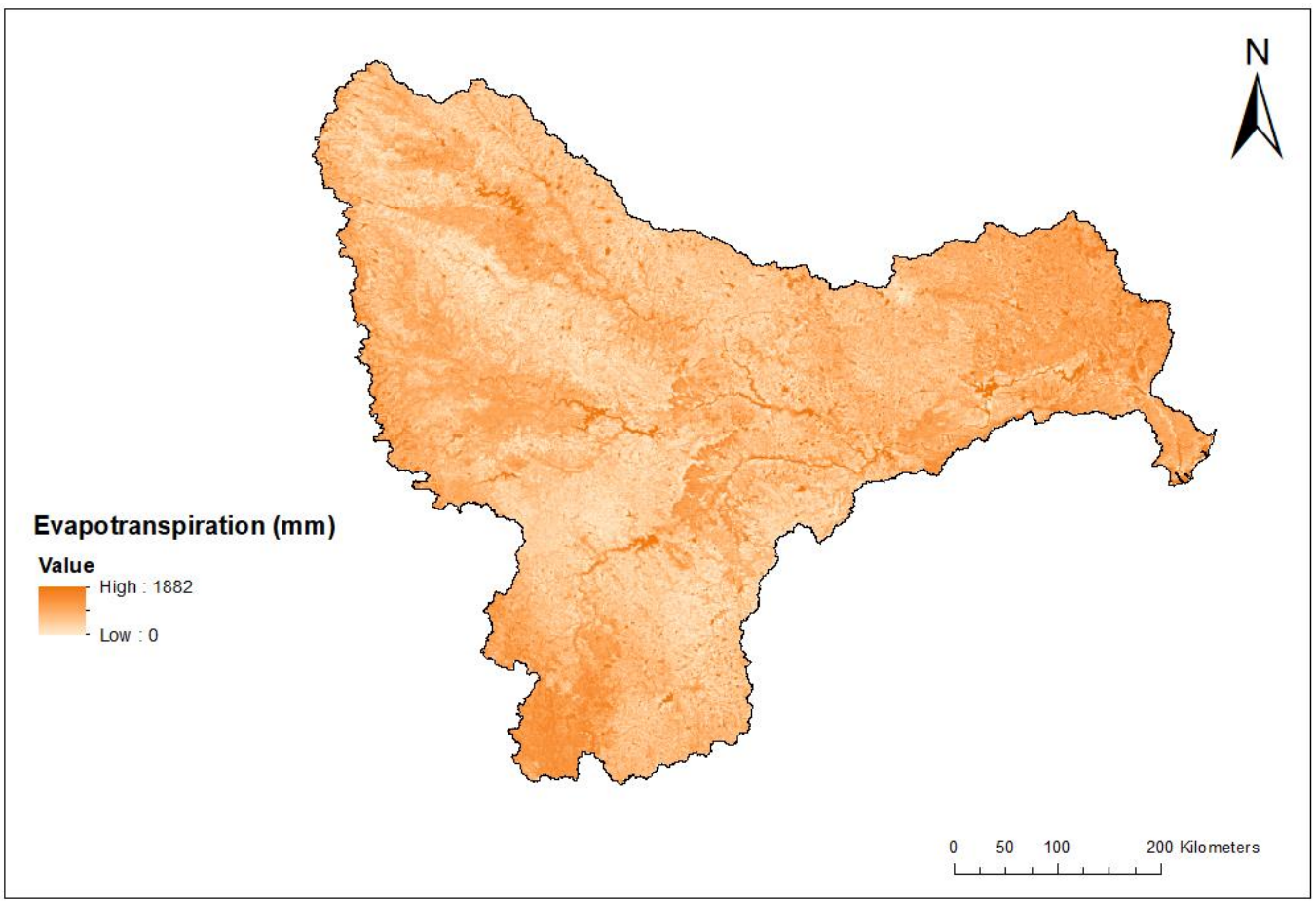


Figure 4.10.4: Evapotranspiration map of Krishna basin

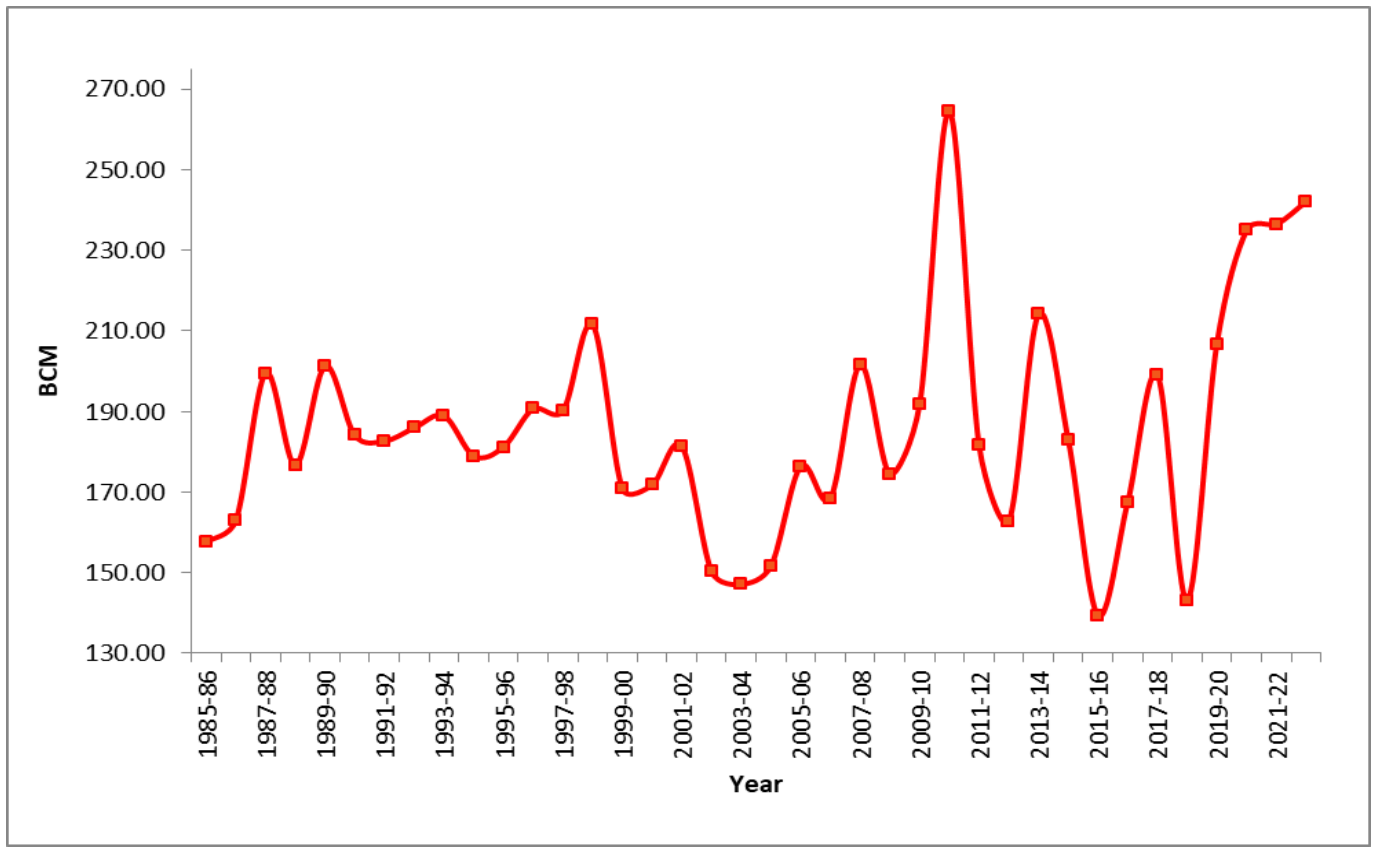


Figure 4.10.5: Annual Evapotranspiration in Krishna basin

4.10.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.10.6. The average annual evaporation from the reservoirs in the basin is 2.72 BCM.

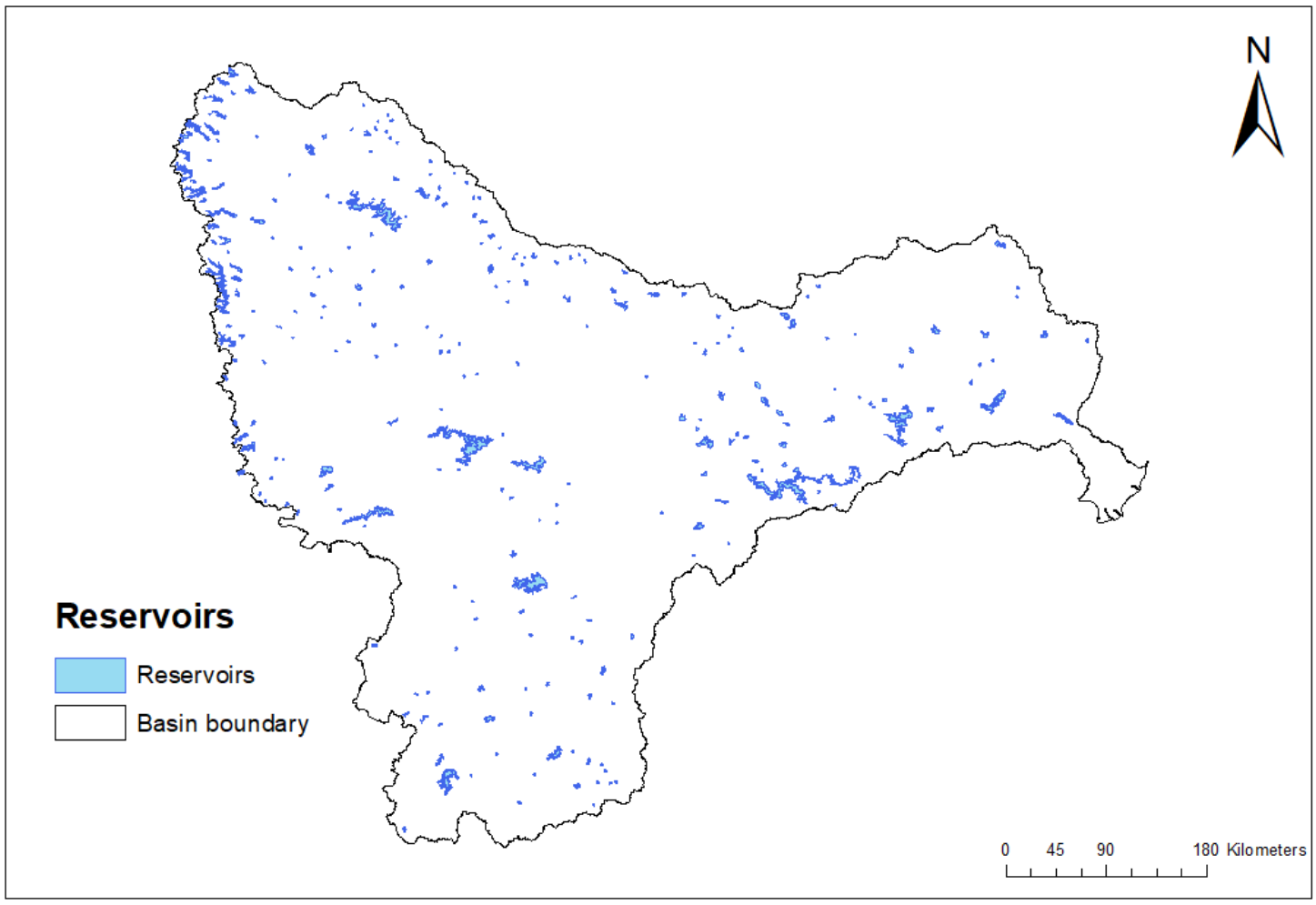


Figure 4.10.6: Reservoir map of Krishna basin

4.10.3.4 Evapotranspiration from Irrigation Input

The ET from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 50.44 BCM. The command area map for the estimation of ET_{II} is shown in Figure 4.10.7. Yearly variations in ET_{II} are shown in Figure 4.10.8.

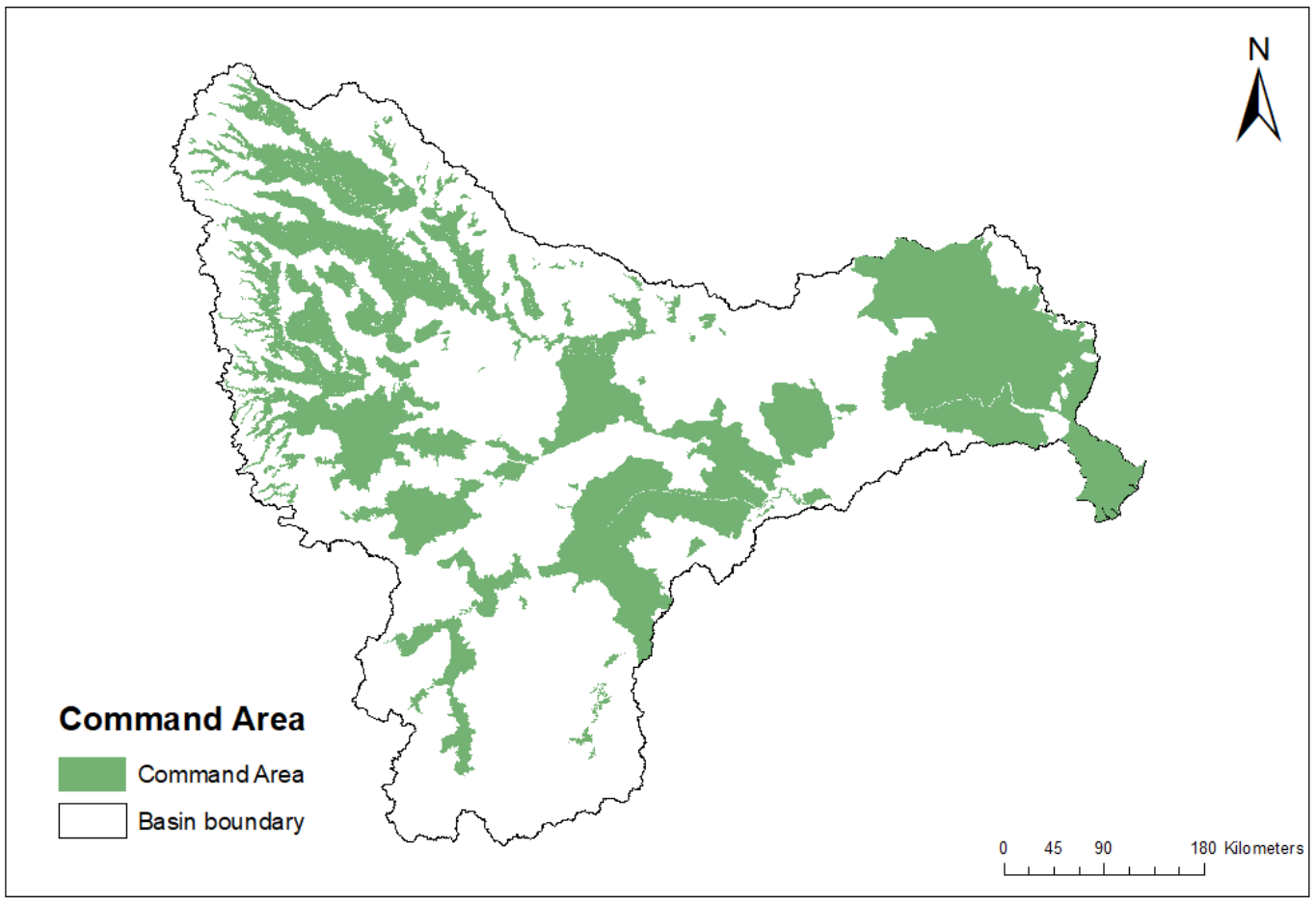


Figure 4.10.7: Command area map of Krishna basin

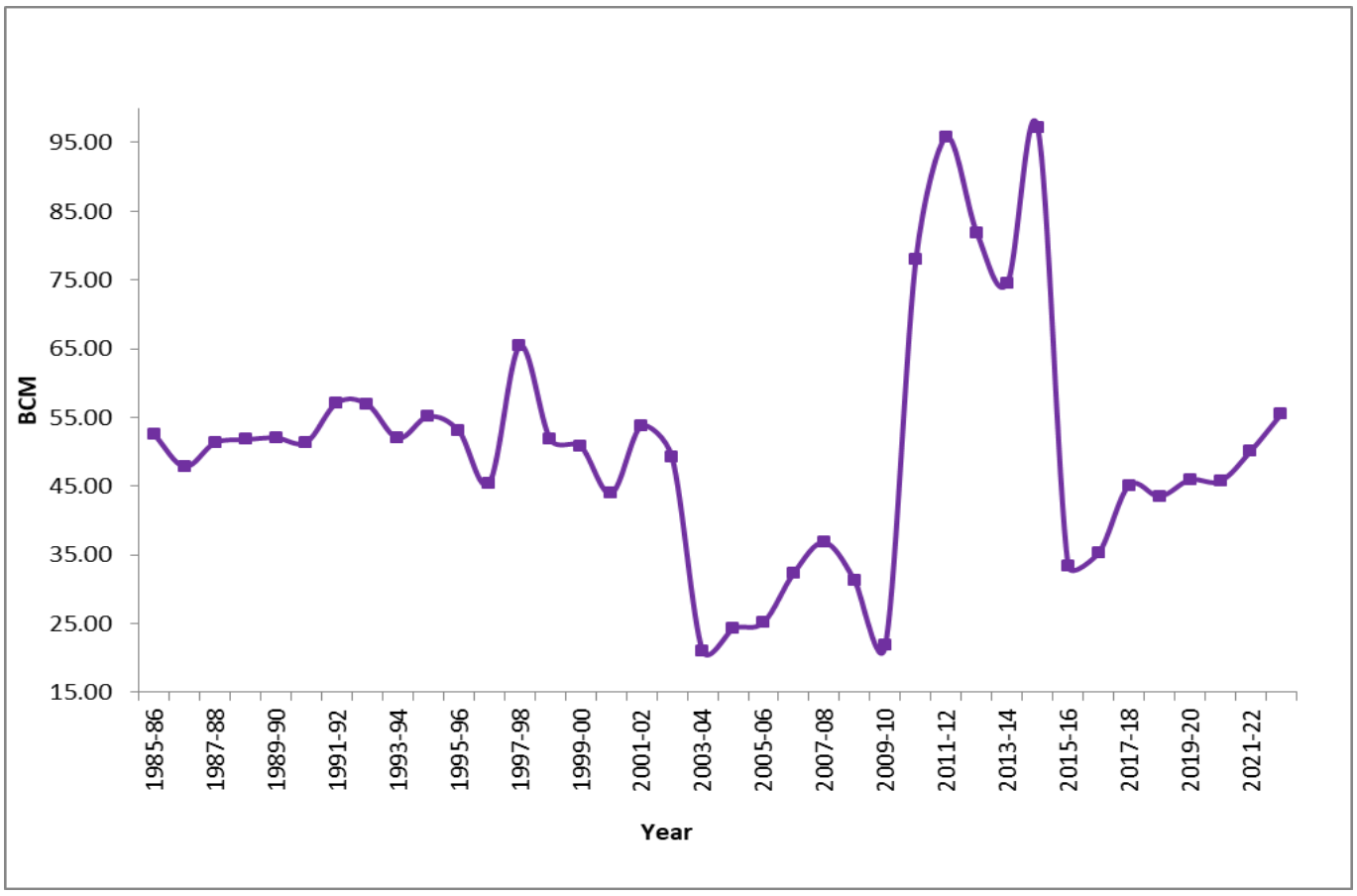


Figure 4.10.8: ET from Irrigation Input in Krishna basin

4.10.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.35 BCM and 0.02 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 2.86 BCM.

4.10.4 Previous Estimates

Previous estimates of Water resources availability in Krishna basin are as given below in Table 4.10.2.

Table 4.10.2: Previous assessments on Krishna river basin

S. No.	Year	Authority/Method of estimation	Quantity (BCM)
1.	1901 - 03	First Irrigation Commission / using runoff coefficients	84.86
2.	1949	Khosla's empirical formula	44.92
3.	1953	The Technical committee for the optimum utilisation of Krishna and Godavari waters	46.87
4.	1960	CW & PC / Statistical analysis of flow data wherever available and precipitation-runoff relationships wherever data were meagre	57.76
5.	1962	The Krishna Godavari Commission-aggregation of average annual yields of all sub-basins	62.78
6.	1973	Krishna Water Disputes Tribunal	67.79
7.	1993	Central Water Commission	78.12
8.	2019	Central Water Commission	89.04

4.10.5 Annual Water Resources Availability of Krishna Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability of Krishna basin is estimated as 86.32 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.10.9. The results of Krishna basin are shown in Table 4.10.3.

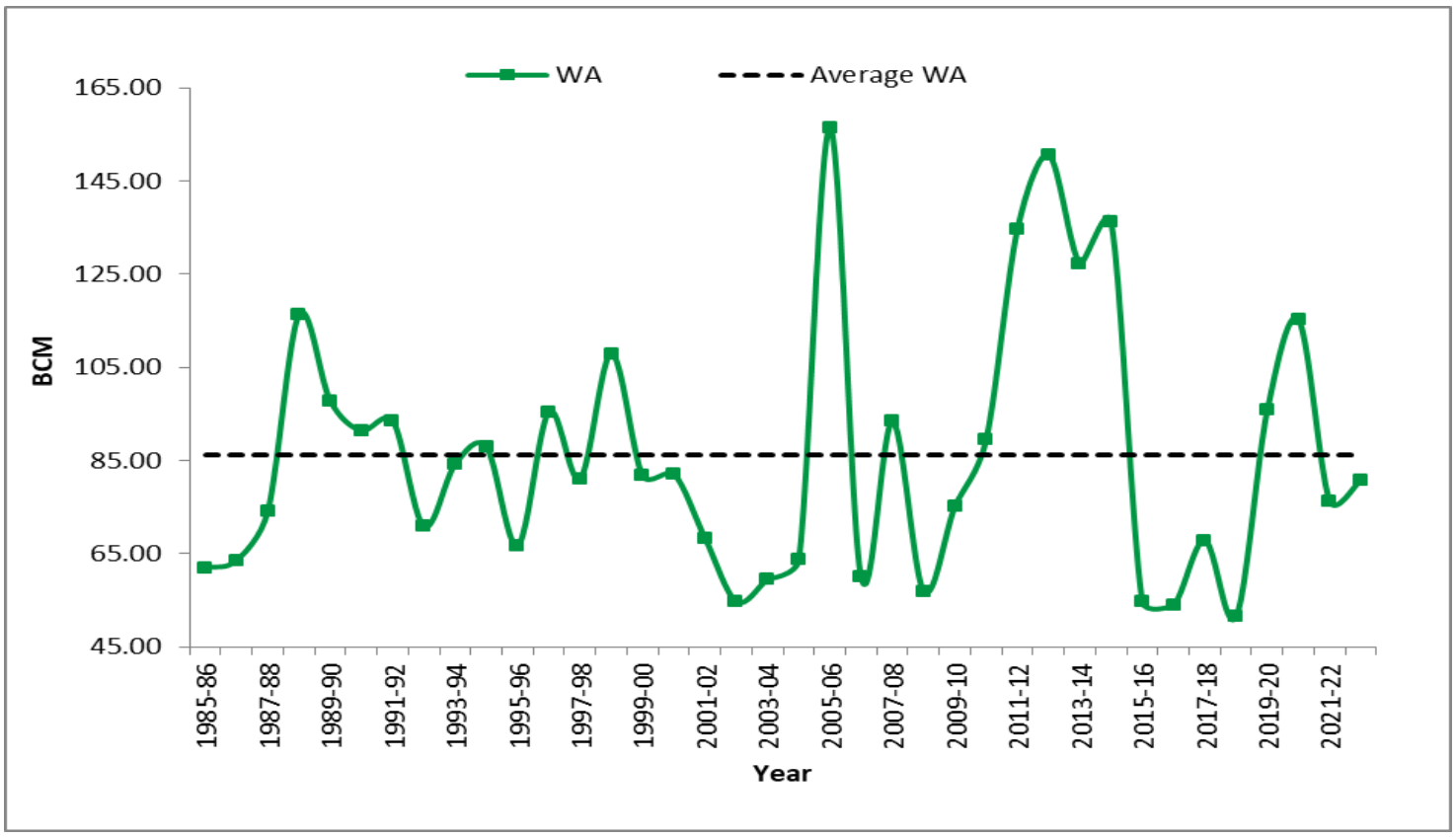


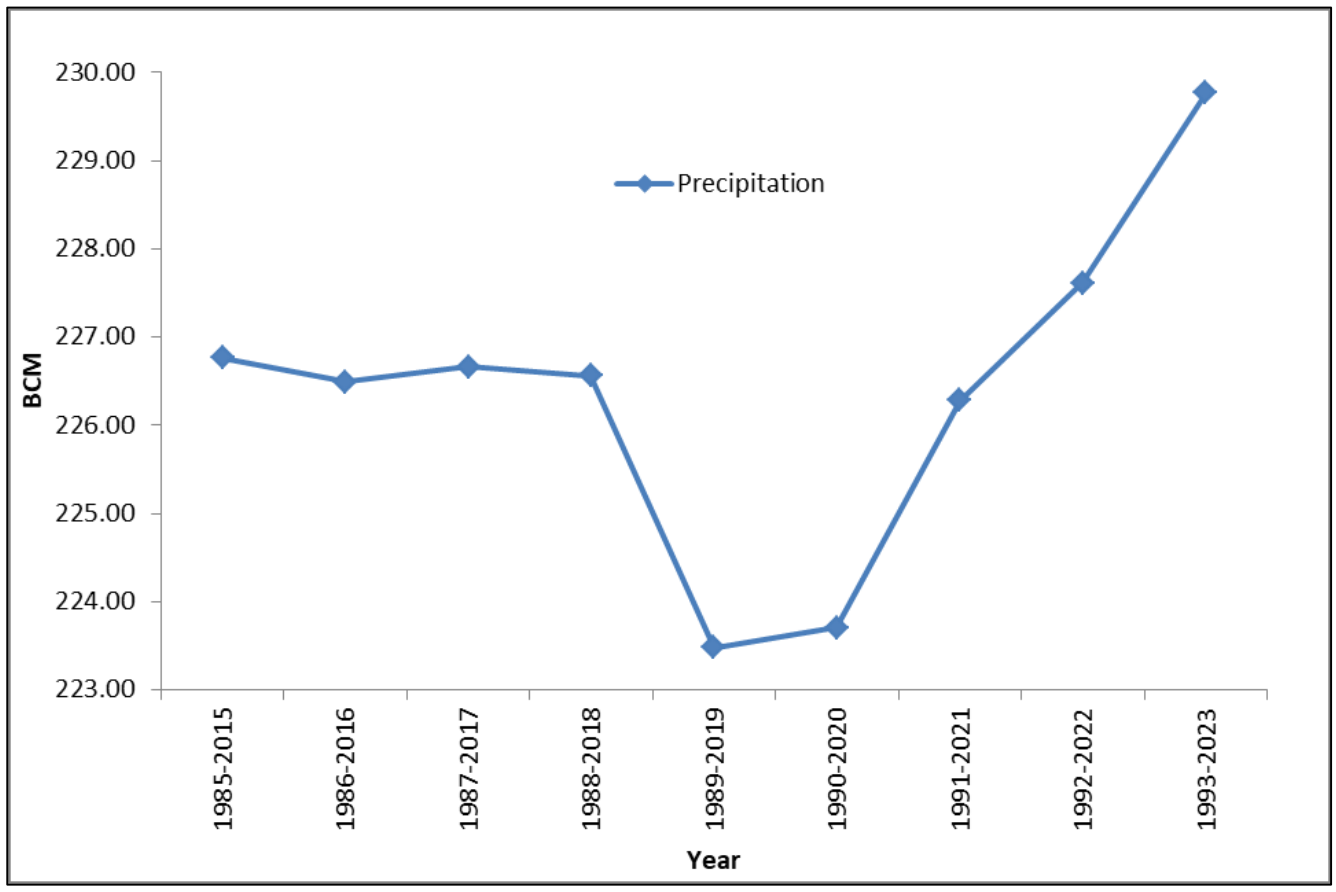
Figure 4.10.9: Water Availability of Krishna basin

4.10.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Krishna basin is given at Table 4.10.3. A line diagram of moving average of P and WA is shown in Figure 4.10.10.

Table 4.10.3: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	226.76	74.80
1986-2016	226.49	74.24
1987-2017	226.66	73.38
1988-2018	226.56	72.70
1989-2019	223.48	69.46
1990-2020	223.71	68.90
1991-2021	226.28	69.12
1992-2022	227.61	67.98
1993-2023	229.77	67.75



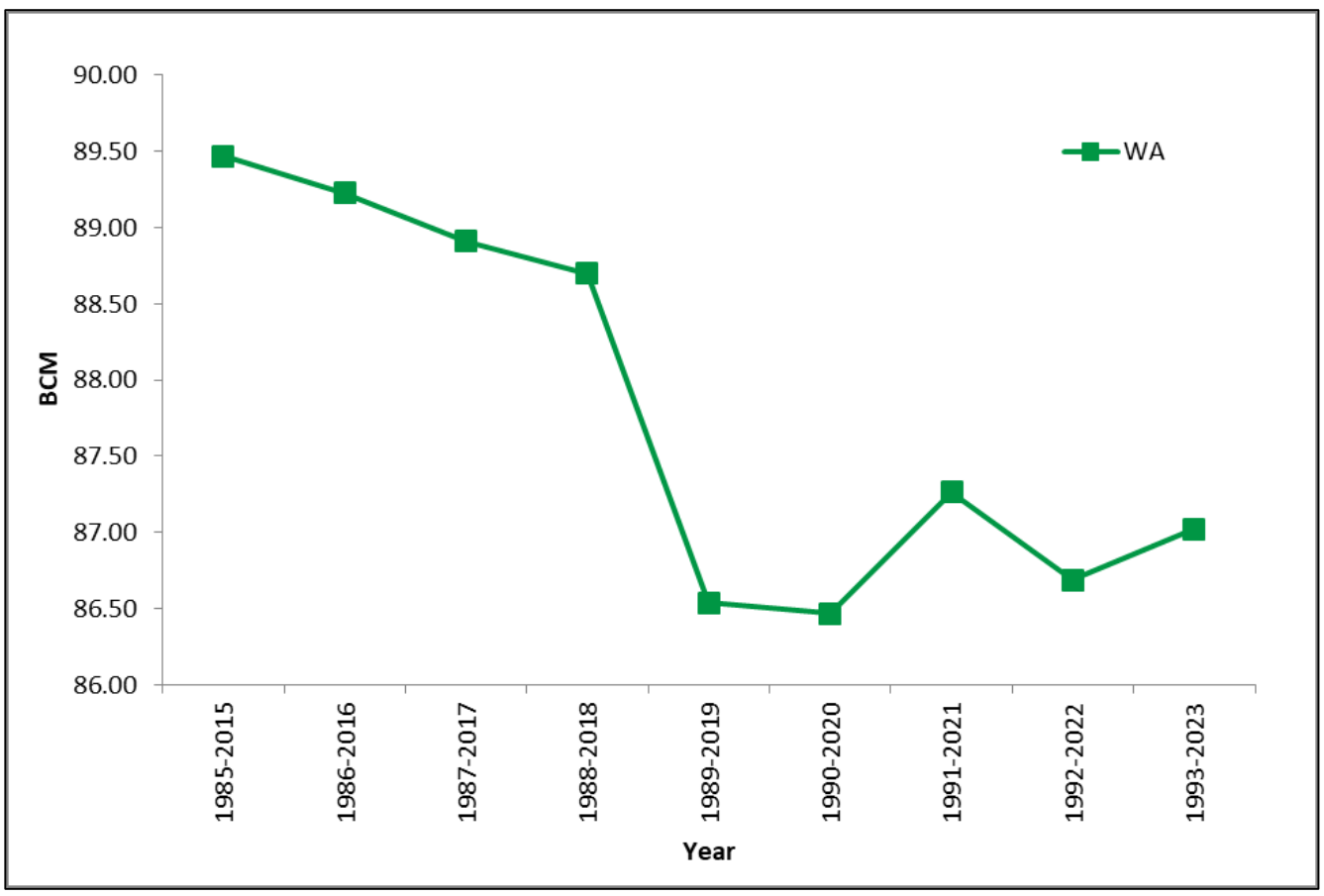


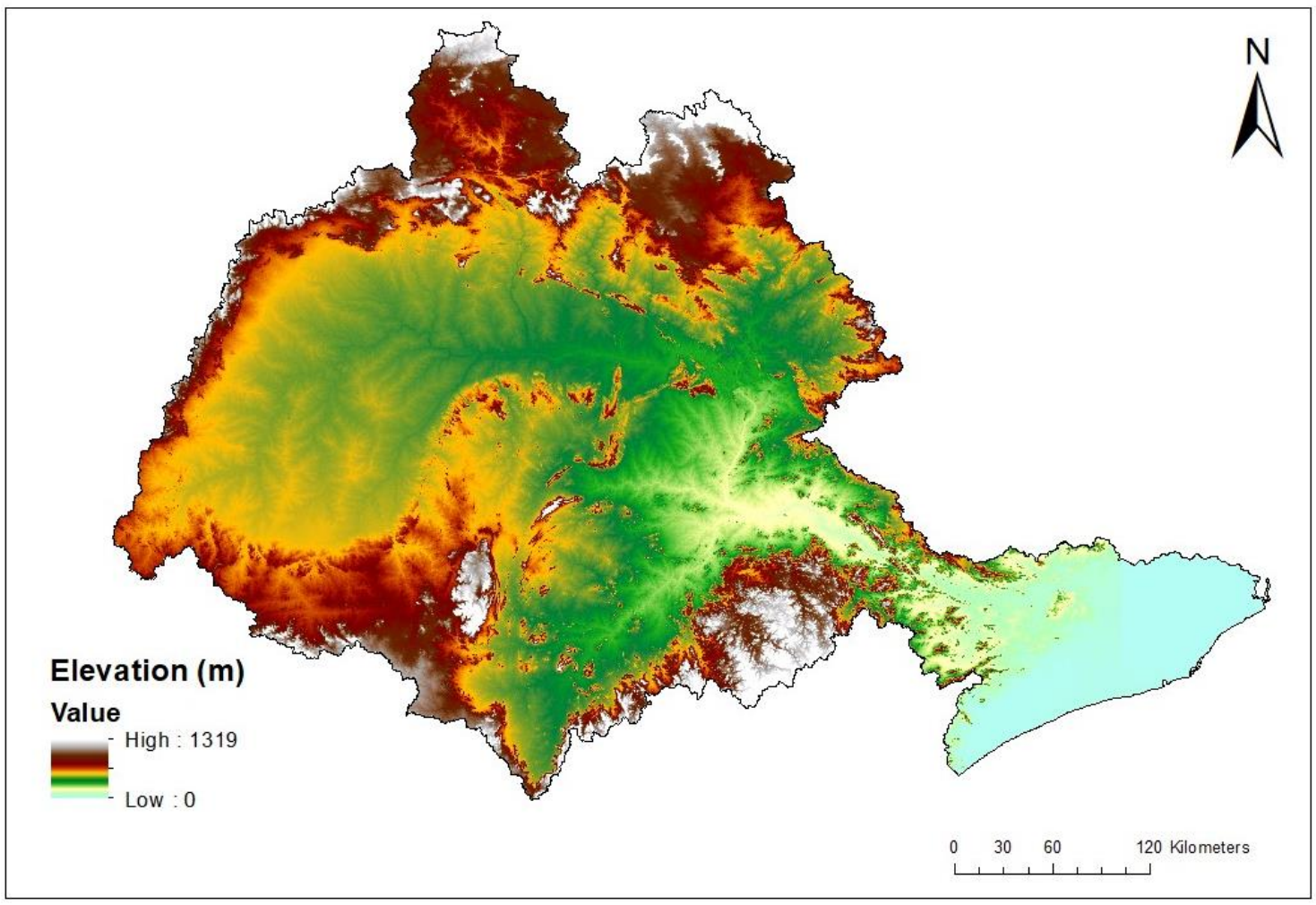
Figure 4.10.10: Moving Average of P and WA for 30 years

Table 4.10.4: Water Availability of Krishna basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	165.90	103.95	61.95
1986-87	177.63	114.03	63.60
1987-88	220.93	146.76	74.17
1988-89	239.94	123.57	116.37
1989-90	245.56	147.74	97.82
1190-91	222.61	131.24	91.37
1991-92	217.80	124.21	93.59
1992-93	198.56	127.70	70.86
1993-94	219.77	135.51	84.26
1994-95	210.43	122.55	87.88
1995-96	193.50	126.75	66.75
1996-97	238.94	143.45	95.49
1997-98	204.34	123.19	81.15
1998-99	265.75	157.79	107.96
1999-00	200.33	118.57	81.76
2000-01	208.44	126.25	82.19
2001-02	194.33	125.99	68.34
2002-03	154.59	99.80	54.79
2003-04	182.28	122.80	59.48
2004-05	187.40	123.66	63.75
2005-06	303.46	146.99	156.47
2006-07	191.92	131.92	59.99
2007-08	253.68	160.27	93.42
2008-09	196.00	139.03	56.97
2009-10	240.56	165.43	75.14
2010-11	272.10	182.51	89.59
2011-12	217.29	82.62	134.67
2012-13	227.96	77.27	150.69
2013-14	262.93	135.58	127.35
2014-15	219.34	83.09	136.25
2015-16	157.81	103.11	54.70
2016-17	182.73	128.74	54.00
2017-18	217.84	149.97	67.88
2018-19	147.46	95.96	51.50
2019-20	252.53	156.75	95.78
2020-21	299.69	184.46	115.23
2021-22	257.81	181.51	76.30
2022-23	263.27	182.41	80.86
Average	**218.77**	**132.45**	**86.32**

4.11 MAHANADI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Mahanadi basin is 72.82 BCM.*
- *Maximum annual water availability is 142.61 BCM during 1994-95.*
- *Minimum annual water availability is 31.77 BCM during 2000-01.*
- *Average annual precipitation is 194.70 BCM (1343.61 mm).*
- *Maximum annual precipitation is 292.30 BCM (2017 mm) during 1994-95.*
- *Minimum annual precipitation is 137.94 BCM (952 mm) during 2000-01.*

4.11.1 About Mahanadi Basin

The Mahanadi basin extends over states of Chhattisgarh (52.94%) and Odisha (46.33%) and comparatively smaller portions of Jharkhand (0.46%), Maharashtra (0.18%) and Madhya Pradesh (0.09%), draining an area of 1,44,905 sq.km which is nearly 4.4% of the total geographical area of the country. The geographical extent of the basin lies between 80°28’ and 86°43’ East longitudes and 19°8’ and 23°32’ North latitudes. The basin has maximum length and width of 587 km and 400 km. It is bounded by the Central India hills on the north, by the Eastern Ghats on the south and east and by the Maikala range on the west. It originates from a pool, 6 km from Farsiya village of Dhamtari district of Chhattisgarh. The total length of the river from origin to its outfall into the Bay of Bengal is 851 km. The Seonath, the Hasdeo, the Mand and the Ib joins Mahanadi from left whereas the Ong, the Tel and the Jonk joins it from right. Six other small streams between the Mahanadi and the Rushikulya draining directly into the Chilka Lake also forms the part of the basin.

4.11.2 Geo-Spatial Datasets

4.11.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Mahanadi basin for year 2022-23 is shown in Figure 4.11.1. Major land use classes consist of deciduous woodland, Kharif only, Double/Triple/Annual crop land.

Table 4.11.1 shows the distribution (in percentage) of LULC in the basin for 2022-23.

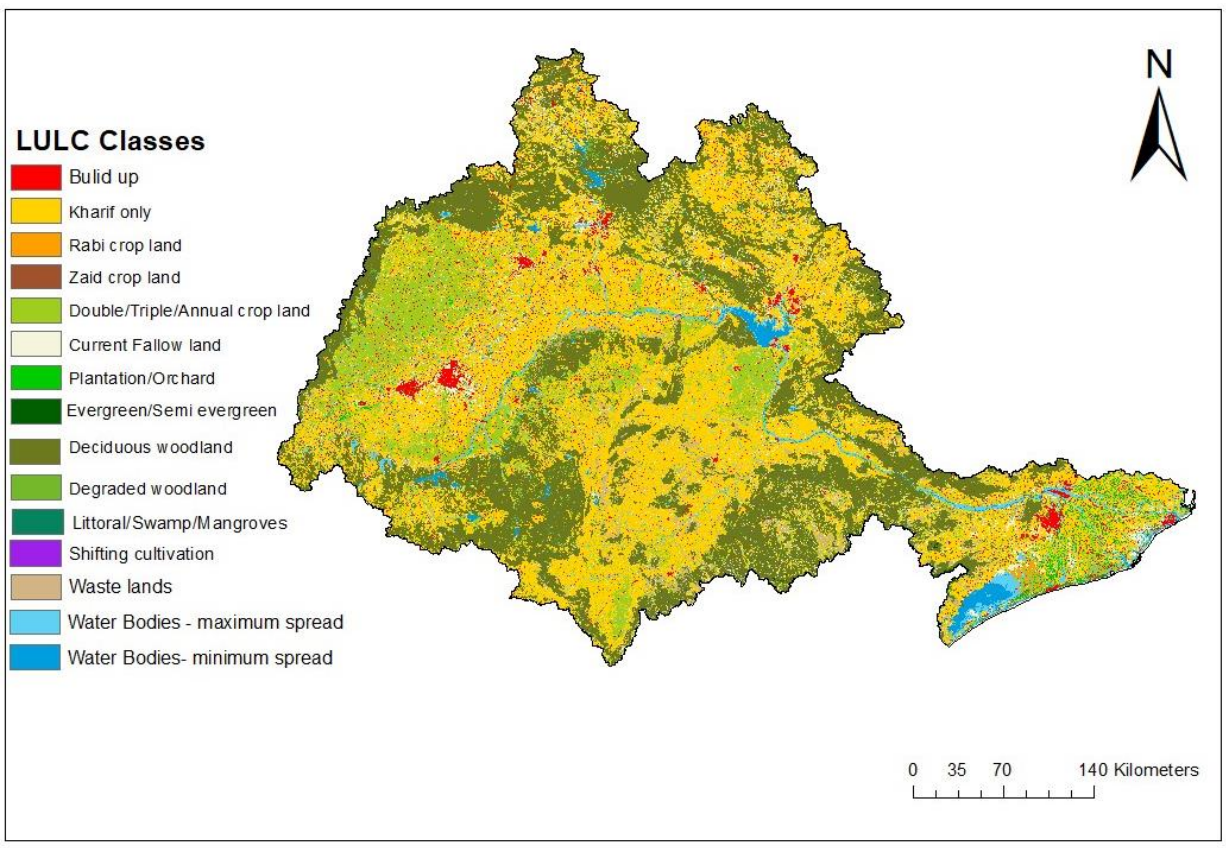


Figure 4.11.1: LULC Map of Mahanadi basin

Table 4.11.1 Percentage area of Land Use and Land Cover

S. No.	LULC Classes	Area (%) 2022-23
1.	Build up	3.57
2.	Kharif only	39.11
3.	Rabi crop land	0.46
5.	Double/Triple/Annual crop land	11.89
6.	Current Fallow land	4.19
7.	Plantation/Orchard	0.81
8.	Evergreen/Semi evergreen	0.08
9.	Deciduous woodland	29.51
10.	Degraded woodland	1.66
11.	Littoral/Swamp/Mangroves	0.02
12.	Shifting Cultivation	0.01
13.	Waste lands	4.05
14.	Water Bodies - maximum spread	3.21
15.	Water Bodies - minimum spread	1.43

4.11.3 Hydro-Meteorological and other Input Data

4.11.3.1 Precipitation

The spatial variation of Precipitation for the year 2022-23 is shown in the Figure 4.11.2 and the variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.11.3. The average precipitation of 38 years is found to be 194.70 BCM (1343.61 mm).

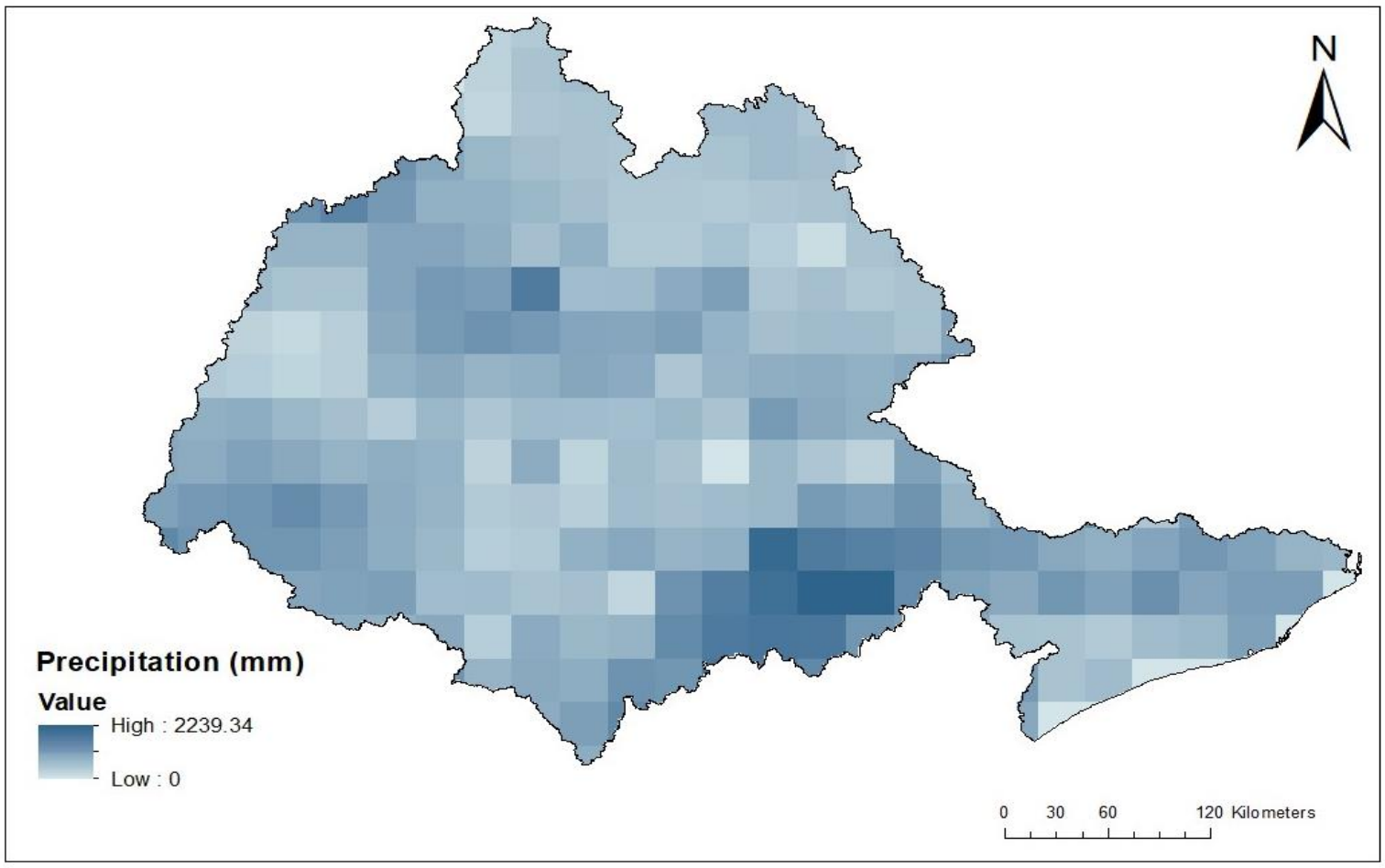


Figure 4.11.2: Precipitation map of Mahanadi basin

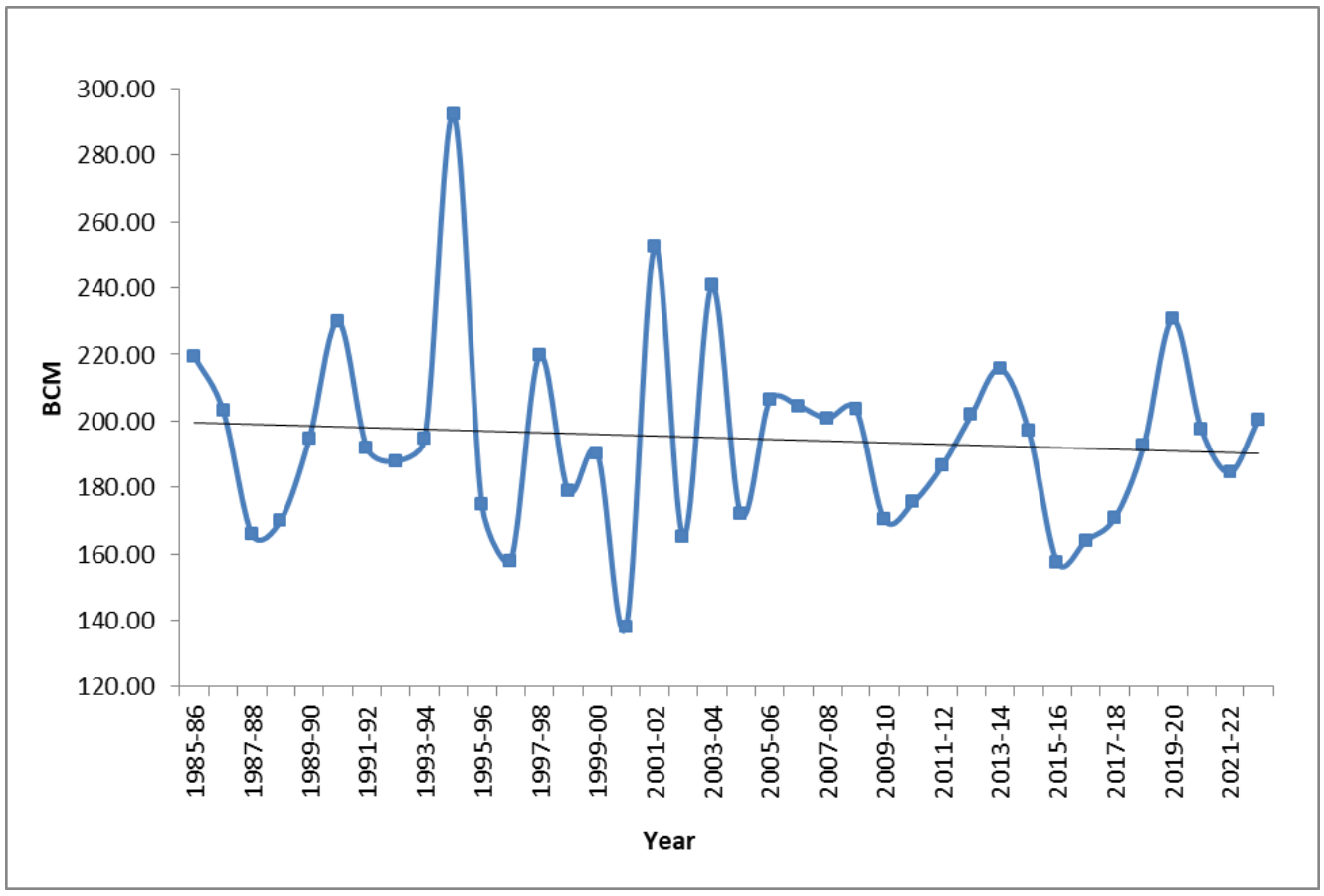


Figure 4.11.3: Annual Precipitation in Mahanadi basin

4.11.3.2 Evaporation

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.11.4. The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.11.5. The Average ET of 38 years is 136.80 BCM (944 mm).

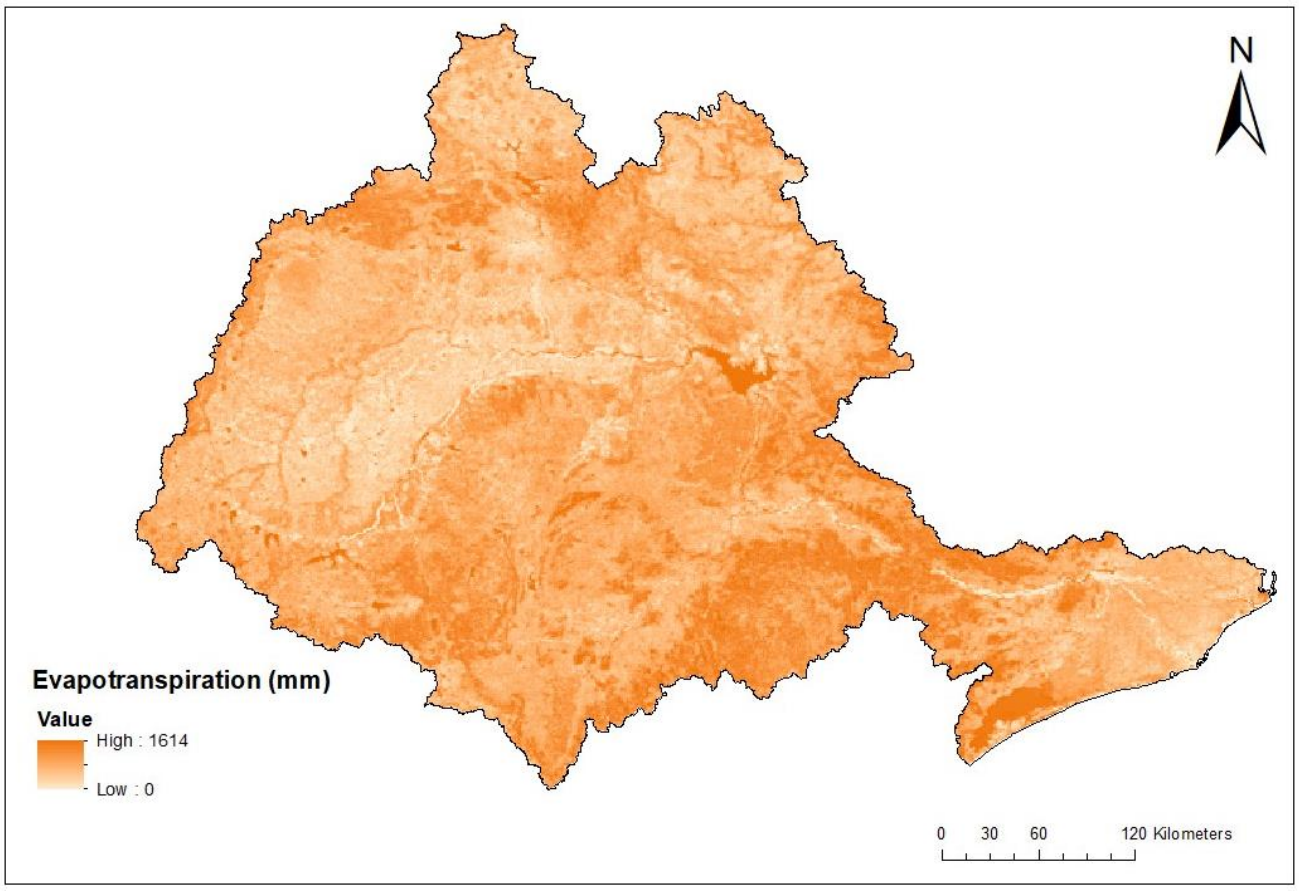


Figure 4.11.4: Evapotranspiration map of Mahanadi basin

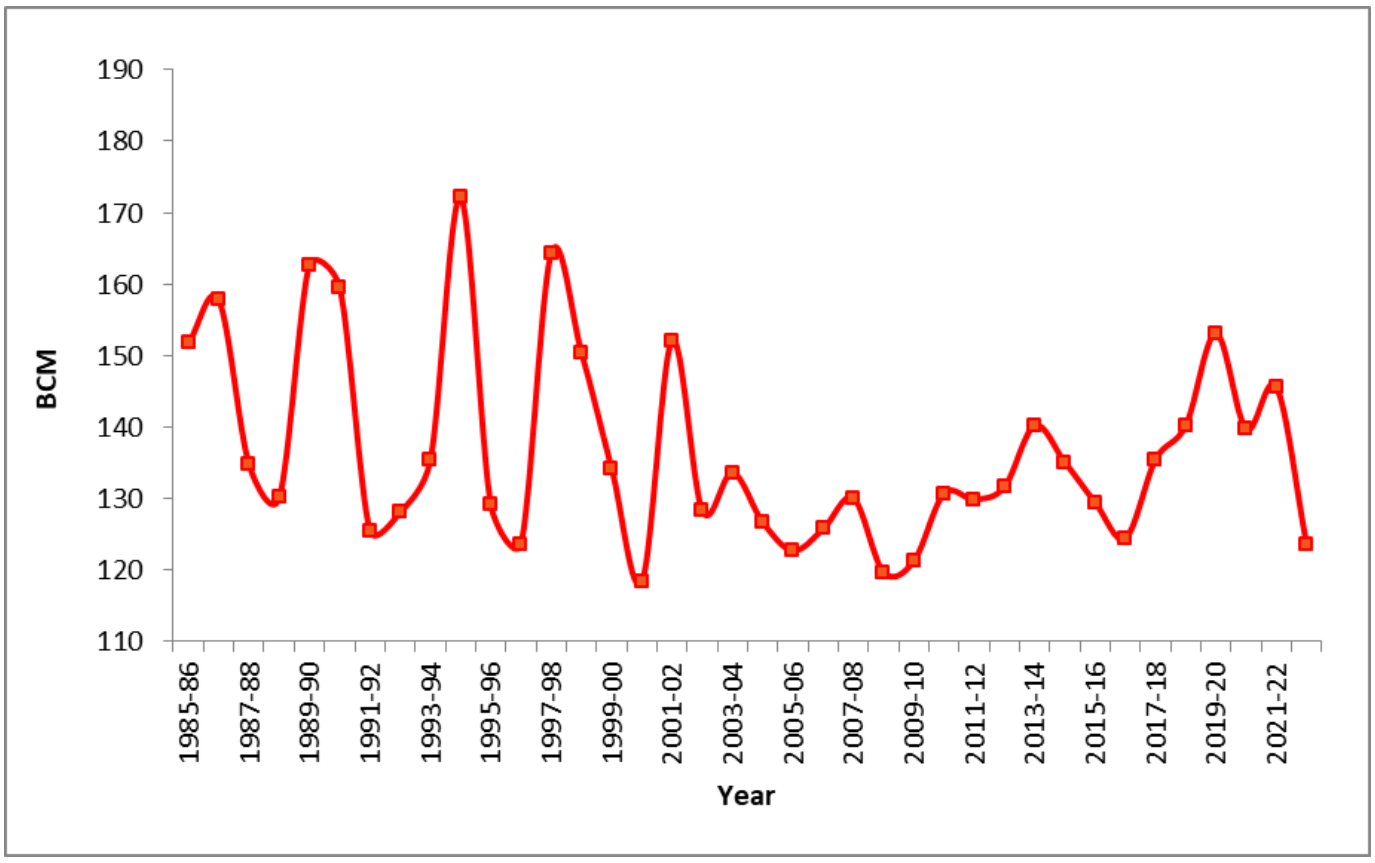


Figure 4.11.5: Annual Evapotranspiration in Mahanadi basin

4.11.3.3 Evaporation from major/medium/minor reservoirs and other water bodies

The average evaporation from the reservoirs in the basin is 1.72 BCM from the reservoirs selected are shown in Figure 4.11.6.

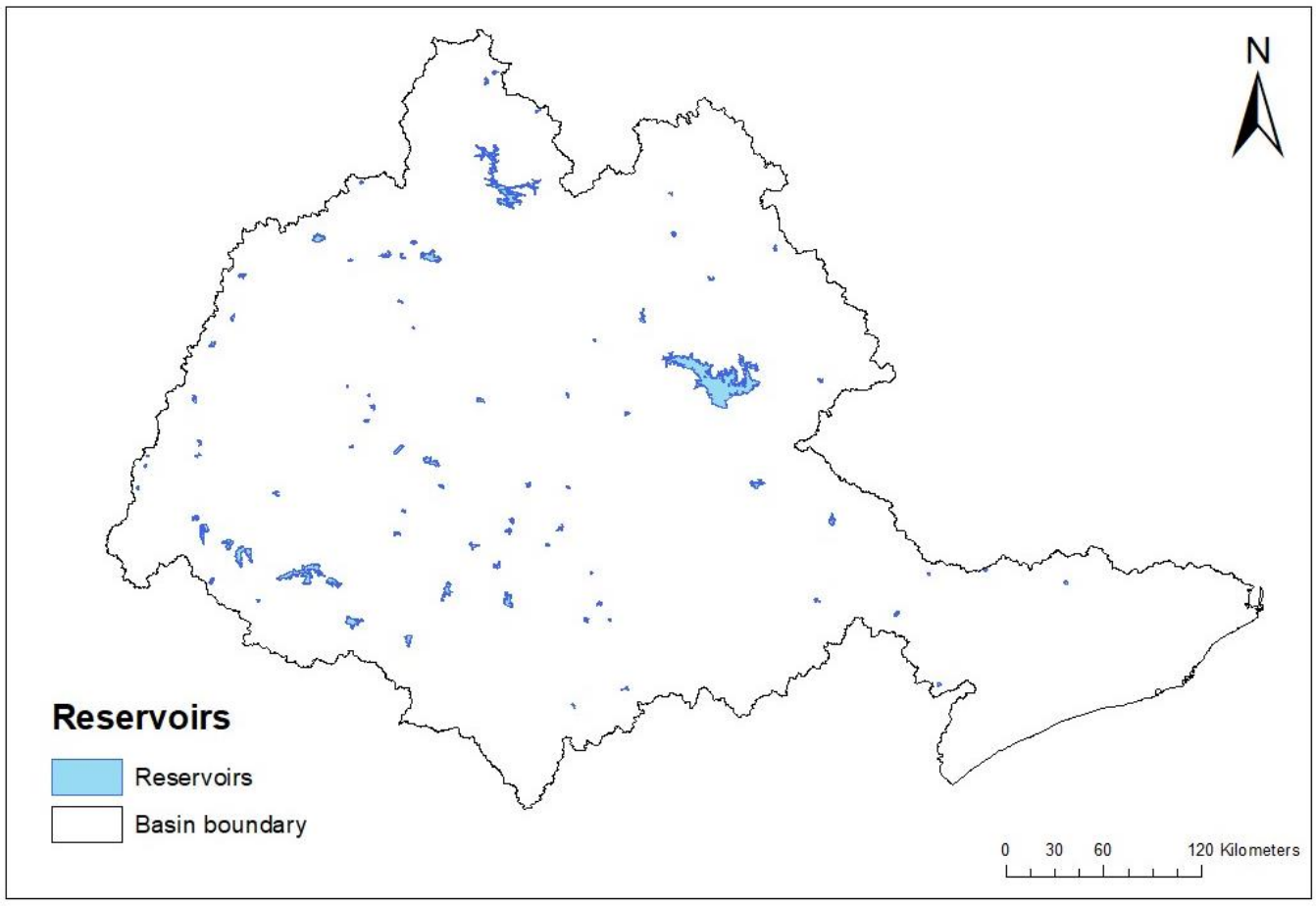


Figure 4.11.6: Reservoir map of Mahanadi basin

4.11.3.4 Evapotranspiration from Irrigation Input

The ET from Irrigation Input (ET_{II}) for the basin for the years 1986-2023 has been estimated as 14.25 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.11.7. Yearly variations in ET_{II} are shown in Figure 4.11.8.

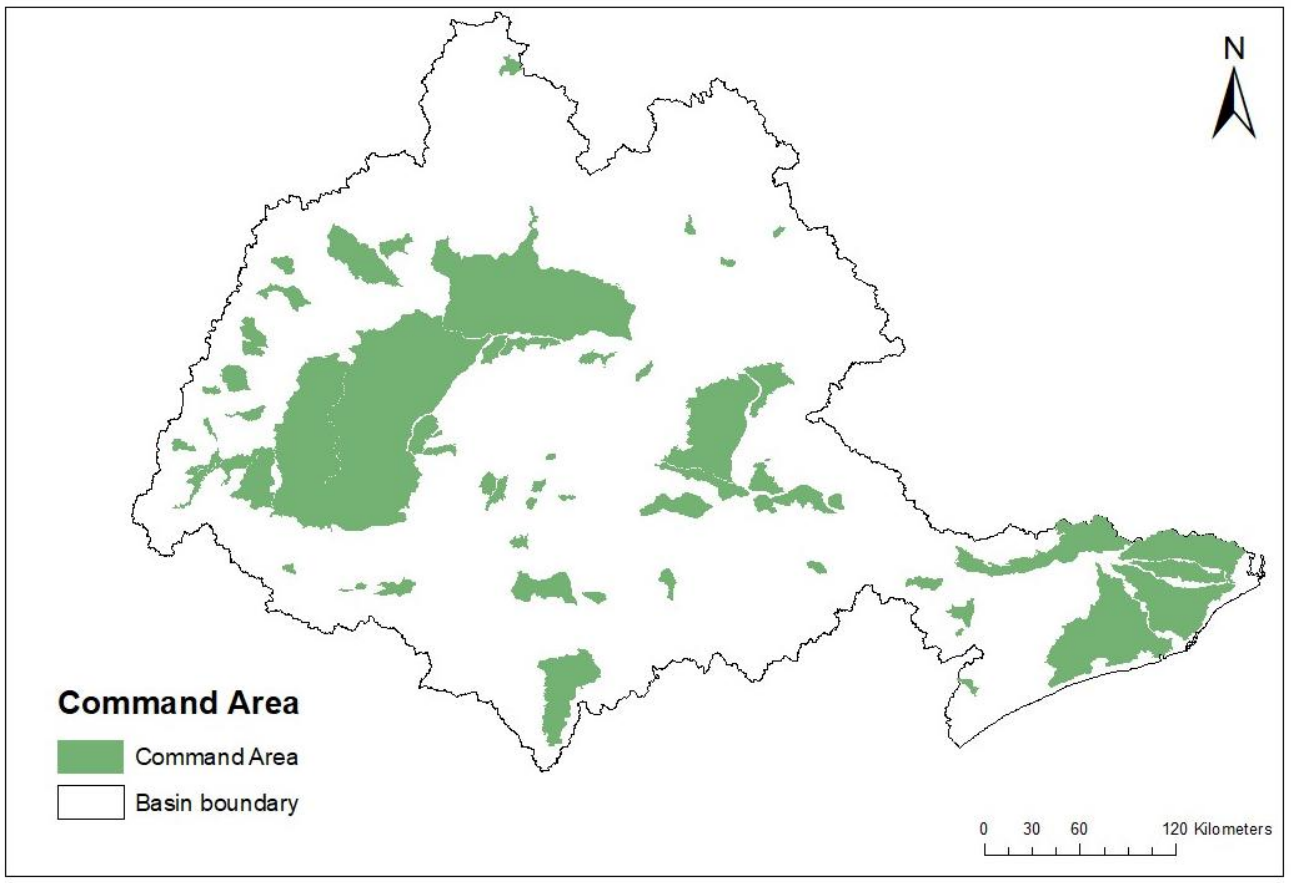


Figure 4.11.7: Command area map of Mahanadi basin

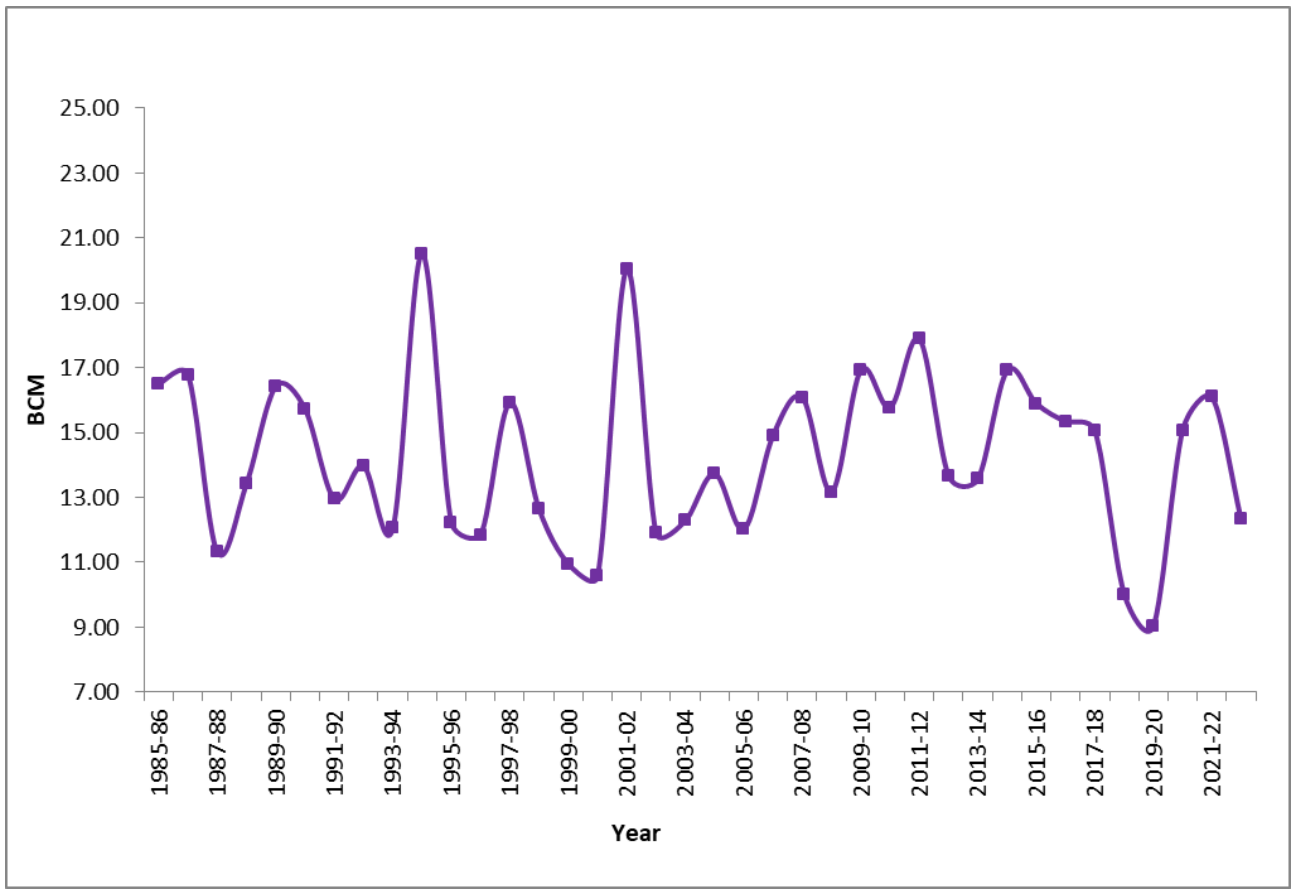


Figure 4.11.8: ET from Irrigation Input in Mahanadi basin

4.11.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is 0.01 BCM and 0.23 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.30 BCM.

4.11.4 Previous Estimates

In 2019 study by CWC, the water availability of Mahanadi basin was estimated as 73.00 BCM.

4.11.5 Annual Water Availability of Mahanadi Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated to be 72.82 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.11.9. The results of Mahanadi basin are shown in Table 4.11.3.

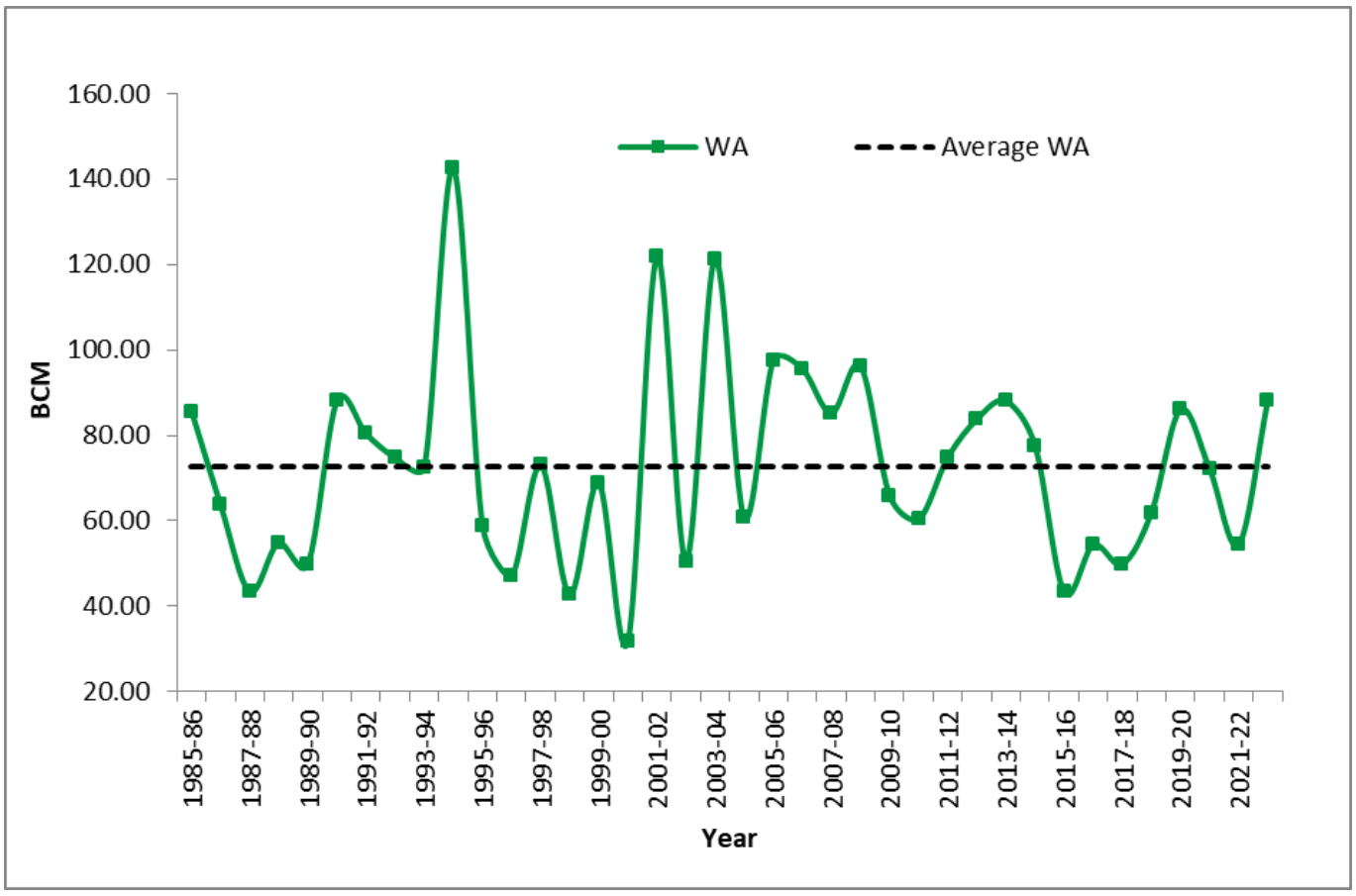


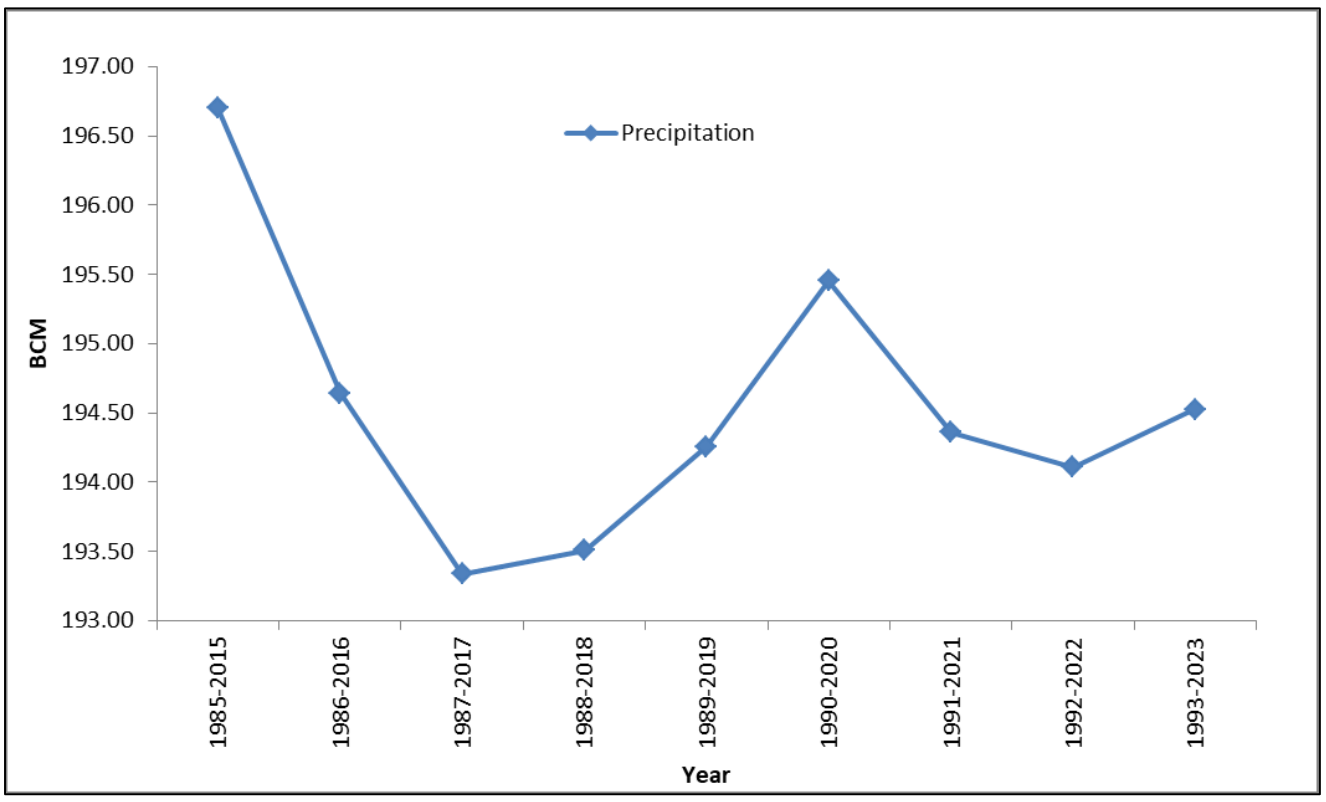
Figure 4.11.9: Water Availability of Mahanadi basin

4.11.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Mahanadi basin is given at Table 4.11.2. A line diagram of moving average of P and WA is shown in Figure 4.11.10.

Table 4.11.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	196.71	75.24
1986-2016	194.64	73.83
1987-2017	193.34	73.52
1988-2018	193.51	73.73
1989-2019	194.26	73.96
1990-2020	195.45	75.17
1991-2021	194.36	74.64
1992-2022	194.11	73.78
1993-2023	194.52	74.22



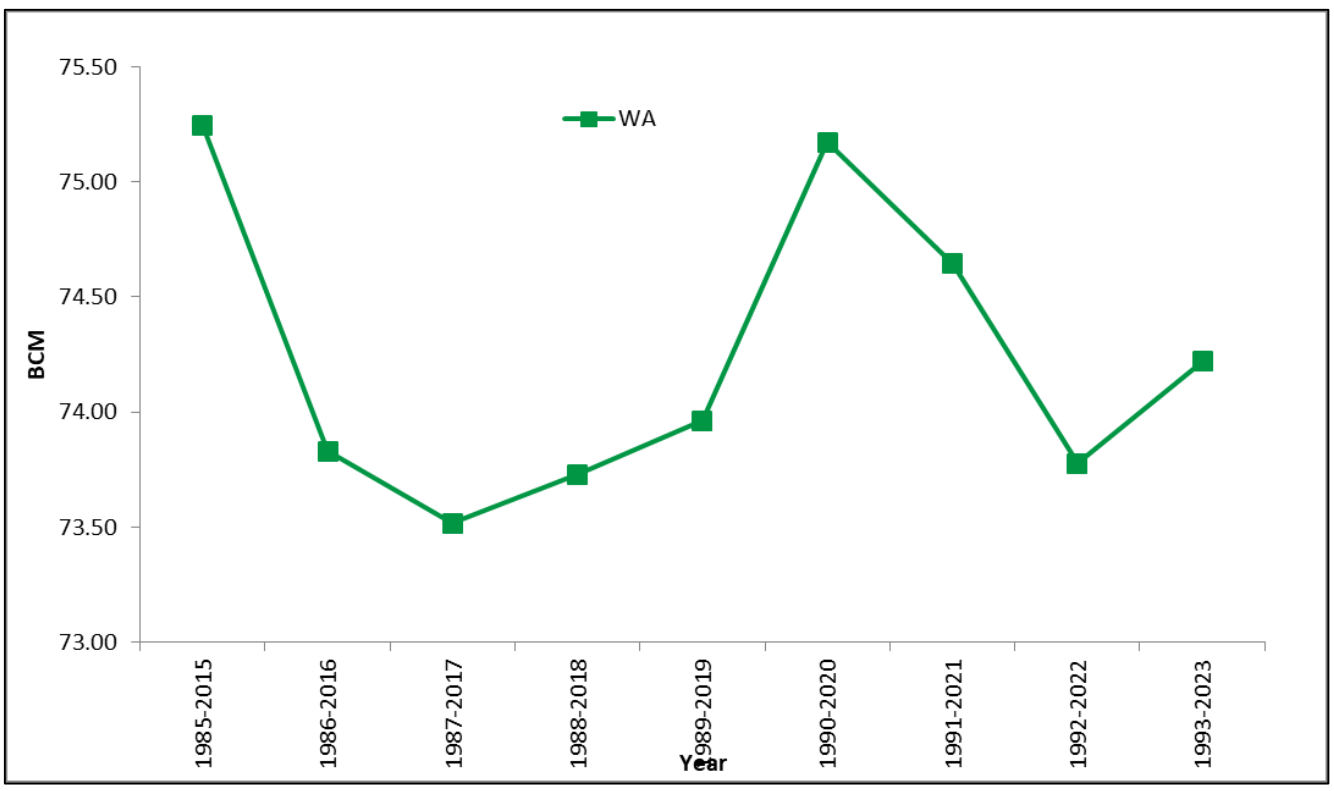


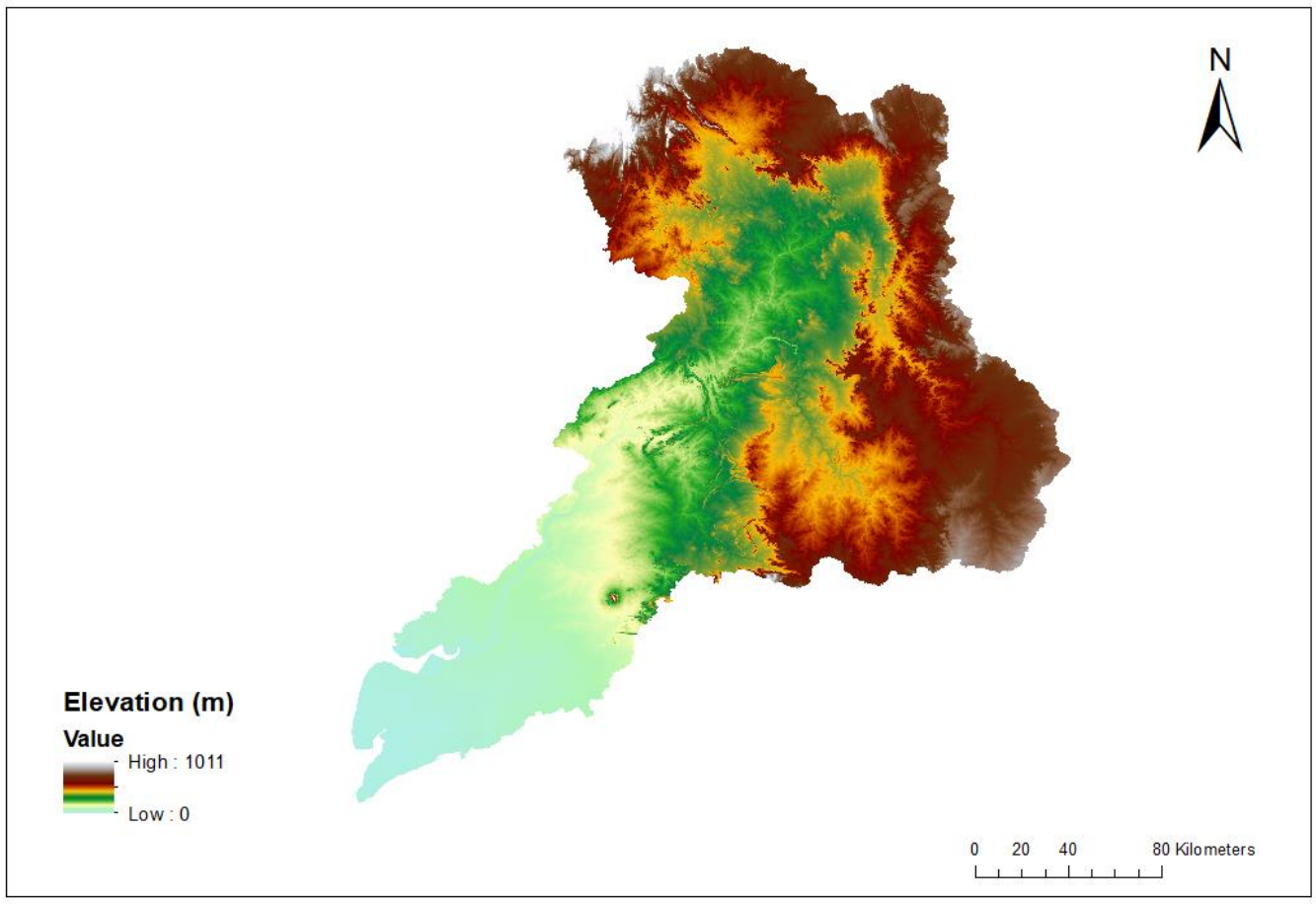
Figure 4.11.10: Moving Average of P and WA for 30 years

Table 4.11.3: Water Availability of Mahanadi basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	219.40	133.73	85.67
1986-87	203.00	139.31	63.69
1987-88	165.75	122.33	43.42
1988-89	170.00	115.10	54.90
1989-90	194.75	145.00	49.75
1990-91	230.05	141.99	88.06
1991-92	191.89	111.55	80.34
1992-93	187.85	113.07	74.78
1993-94	194.54	122.03	72.51
1994-95	292.30	149.69	142.61
1995-96	174.73	115.80	58.93
1996-97	157.73	110.68	47.05
1997-98	219.58	146.52	73.06
1998-99	178.96	136.34	42.62
1999-00	190.39	121.54	68.85
2000-01	137.94	106.17	31.77
2001-02	252.65	130.88	121.77
2002-03	165.26	114.66	50.60
2003-04	240.67	119.39	121.28
2004-05	171.82	111.06	60.76
2005-06	206.27	108.82	97.45
2006-07	204.53	108.94	95.58
2007-08	200.82	112.05	85.20
2008-09	203.73	104.74	96.23
2009-10	170.20	102.58	65.85
2010-11	175.47	113.07	60.36
2011-12	186.56	110.03	74.81
2012-13	201.76	116.02	83.78
2013-14	215.69	124.61	88.05
2014-15	196.92	116.16	77.57
2015-16	157.43	111.66	43.26
2016-17	163.94	107.15	54.29
2017-18	170.78	118.47	49.82
2018-19	192.59	128.20	61.89
2019-20	230.54	142.02	86.02
2020-21	197.29	122.59	72.21
2021-22	184.35	127.47	54.38
2022-23	200.31	109.73	88.08
Average	**194.70**	**120.82**	**72.82**

4.12 MAHI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Mahi basin is 13.03 BCM.*
- *Maximum annual water availability is 38.42 BCM during 2006-07.*
- *Minimum annual water availability is 4.01 BCM during 2000-01.*
- *Average annual precipitation is 34.77 BCM (878.72 mm).*
- *Maximum annual precipitation is 65.40 BCM (1653 mm) during 2006-07.*
- *Minimum annual precipitation is 17.57 BCM (444 mm) during 2000-01.*

4.12.1 About Mahi Basin

The Mahi basin extends over an area of 39,566 sq.km (which includes the independent Dhadhar basin having as area of 4,131 sq.km), and is nearly 1.2% of the total geographical area of the country. The basin lies in the states of Rajasthan (42.05%), Gujarat (39.91%), and Madhya Pradesh (18.04%). River Mahi is the major inter-state west flowing river of India. The river is rising from the northern slopes of the Vindhyas near the village of Sardarpur in the Dhar district of Madhya Pradesh at an elevation of about 500 m and draining in to the gulf of Khambhat. Before falling in to Arabian Sea through the Gulf of Khambhat in Kheda district of Gujarat, the river flows about 538 km through Madhya Pradesh, Rajasthan and Gujarat states. The major tributaries of river are Som, Anas and Panam.

4.12.2 Geo-Spatial Datasets

4.12.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Mahi basin for year 2022-23 is shown in Figure 4.12.1. The major land use classes consist of Kharif only, Double/Triple/Annual cropland and Deciduous woodland etc.

Table 4.12.1 shows the percentage area of each land use class in the basin for year 2022-23.

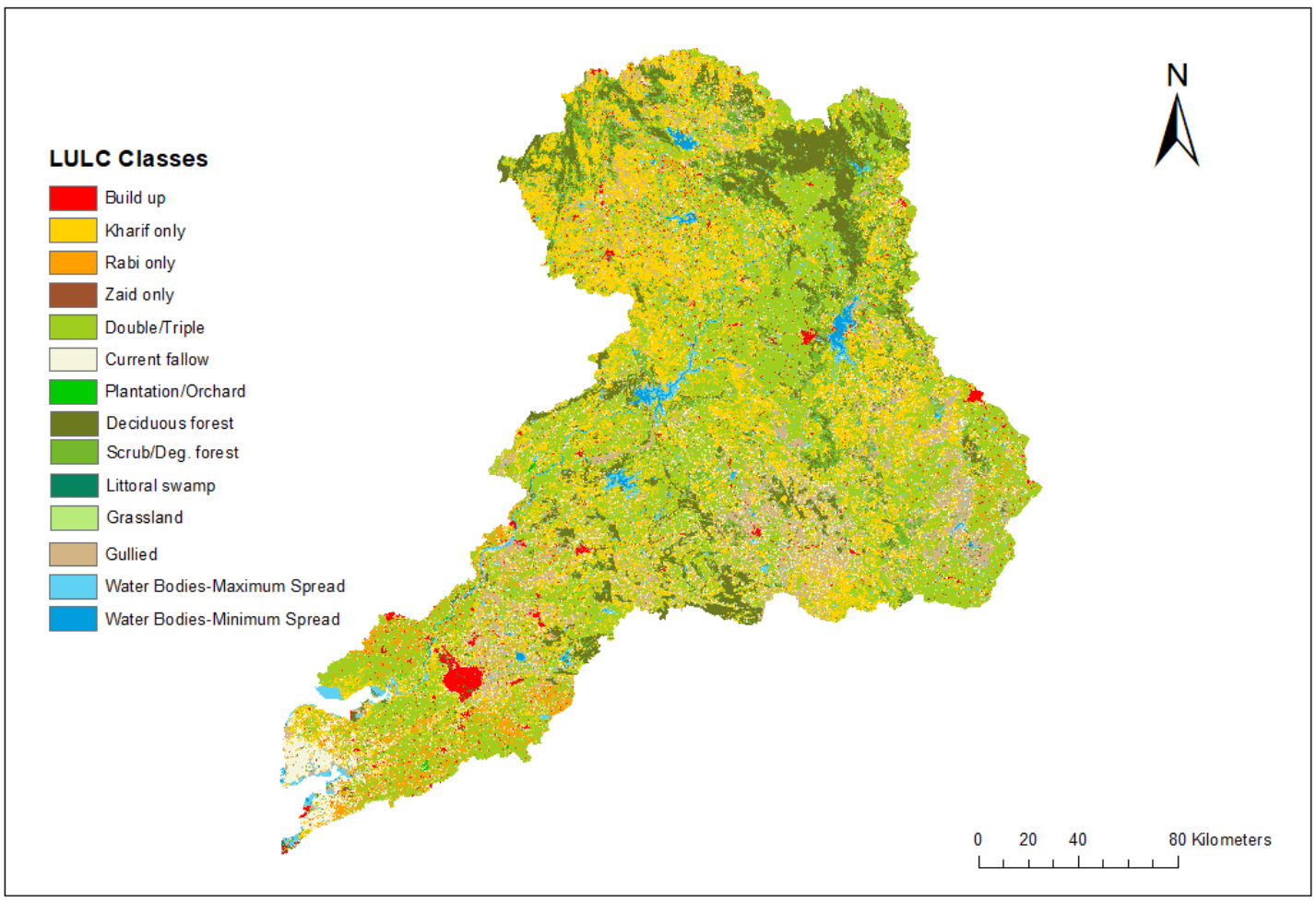


Figure 4.12.1: LULC Map of Mahi basin

Table 4.12.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	2.01
2.	Kharif only	23.51
3.	Rabi crop land	2.99
4.	Double/Triple/Annual crop land	34.42
5.	Current fallow land	7.56
6.	Plantation/orchard	0.09
7.	Deciduous woodland	8.87
8.	Degraded woodland	7.02
9.	Littoral/Swamp/Mangroves	0.01
10.	Grassland	0.12
11.	Waste lands	9.72
12.	Water bodies- maximum spread	2.90
13.	Water bodies -minimum spread	0.79

4.12.3 Hydro-Meteorological and other Input Data

4.12.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.12.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.12.3. The average precipitation of 38 years is approximately 34.77 BCM (878.72 mm).

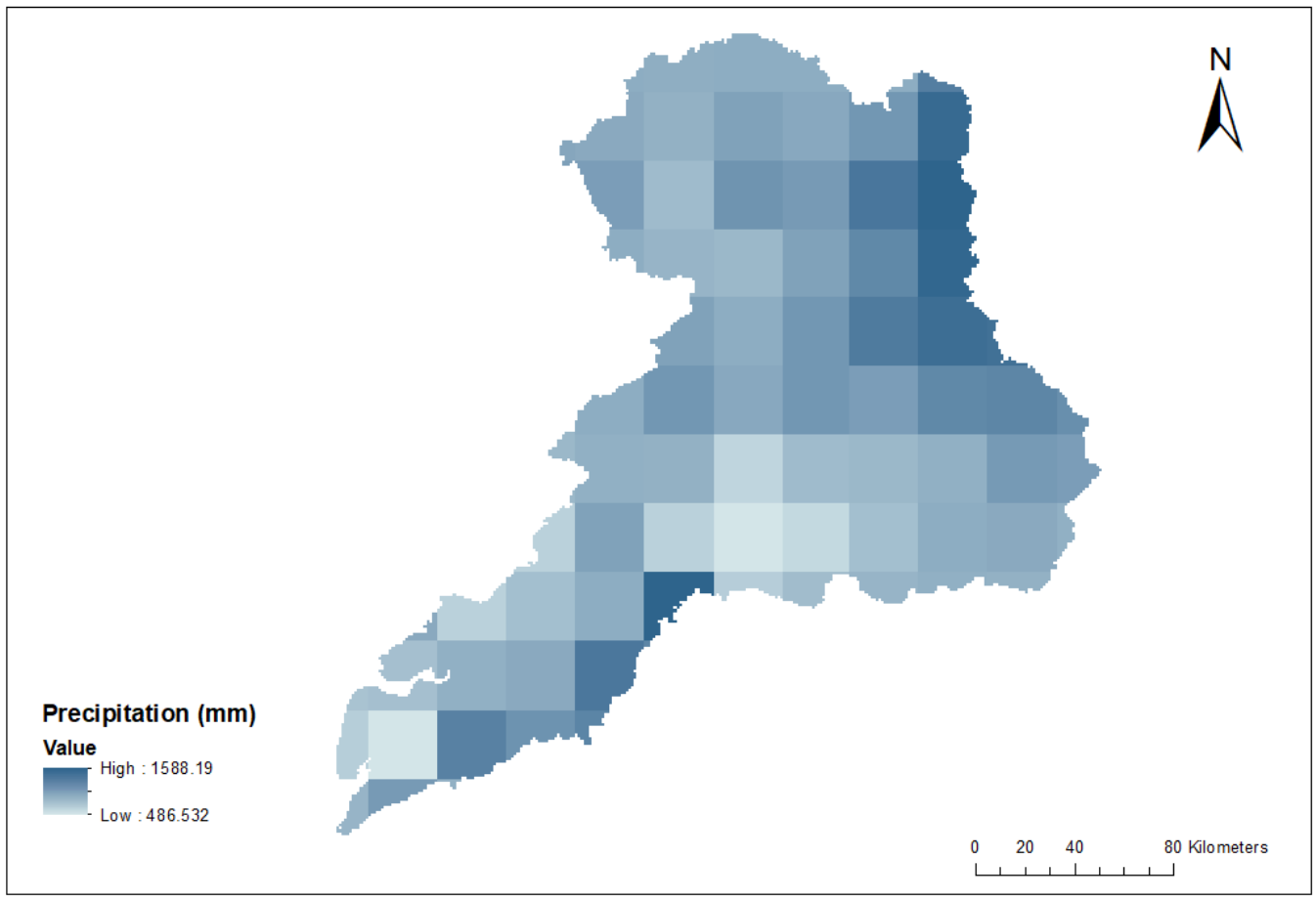


Figure 4.12.2: Precipitation map of Mahi basin

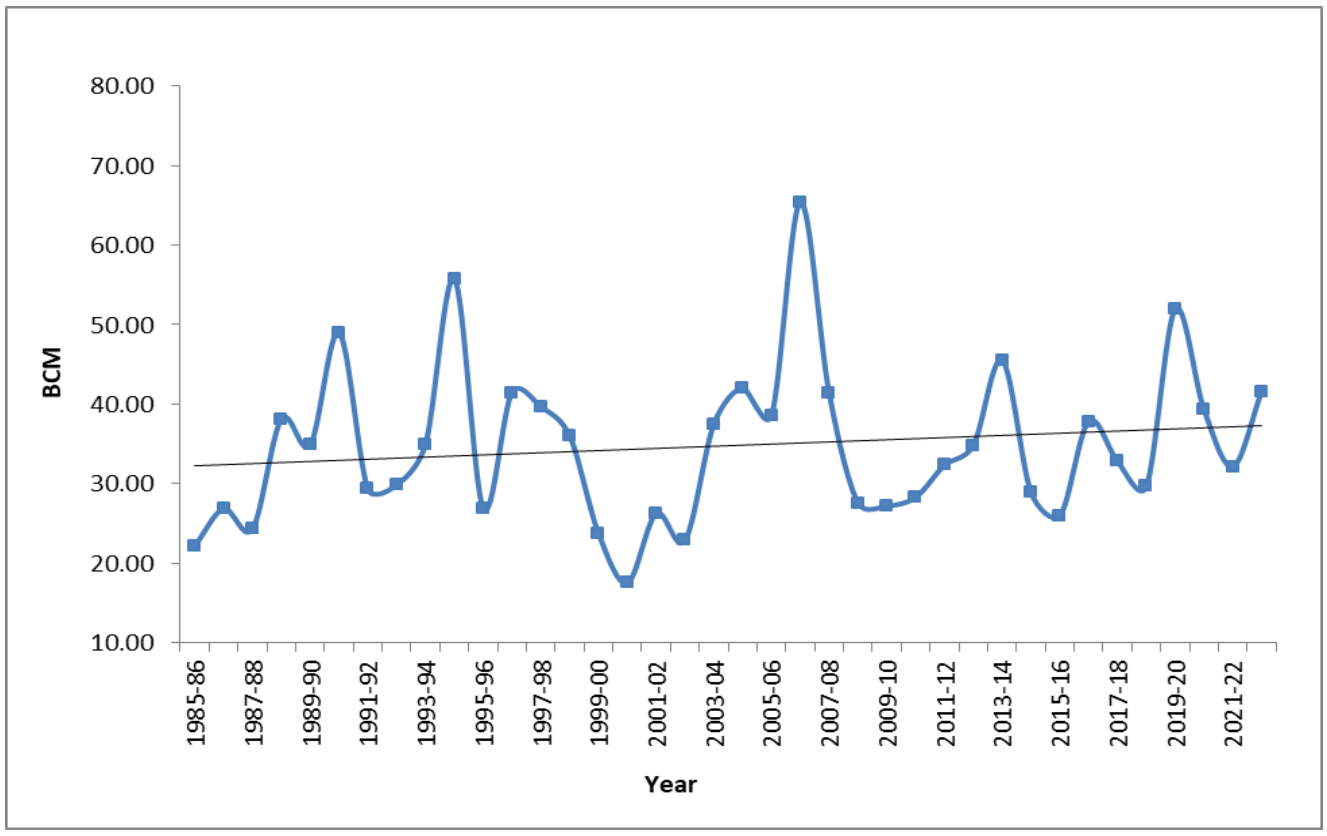


Figure 4.12.3: Annual Precipitation in Mahi basin

4.12.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.12.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.12.5. The average ET of 38 years is approximately 29.54 BCM (746.57 mm).

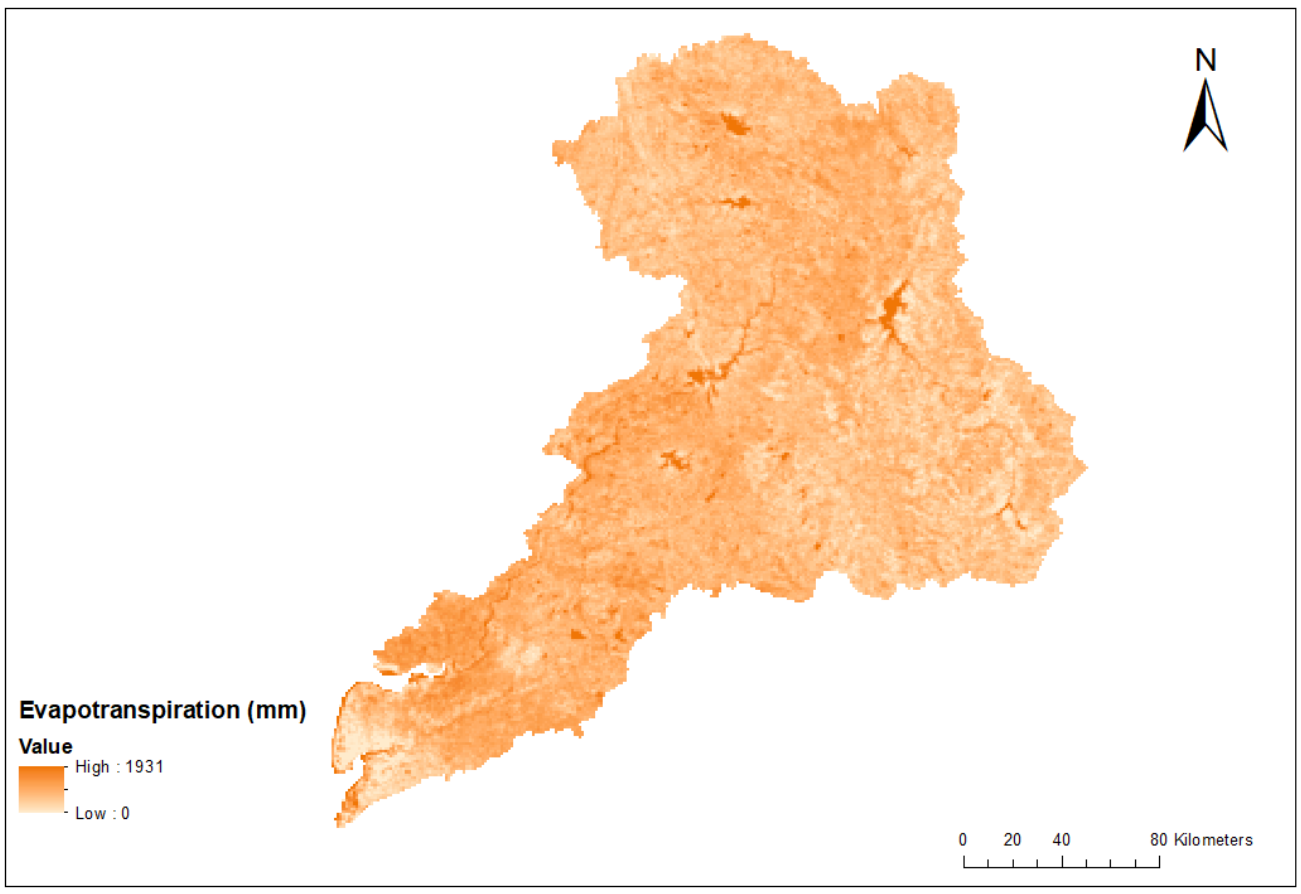


Figure 4.12.4: Evapotranspiration map of Mahi basin

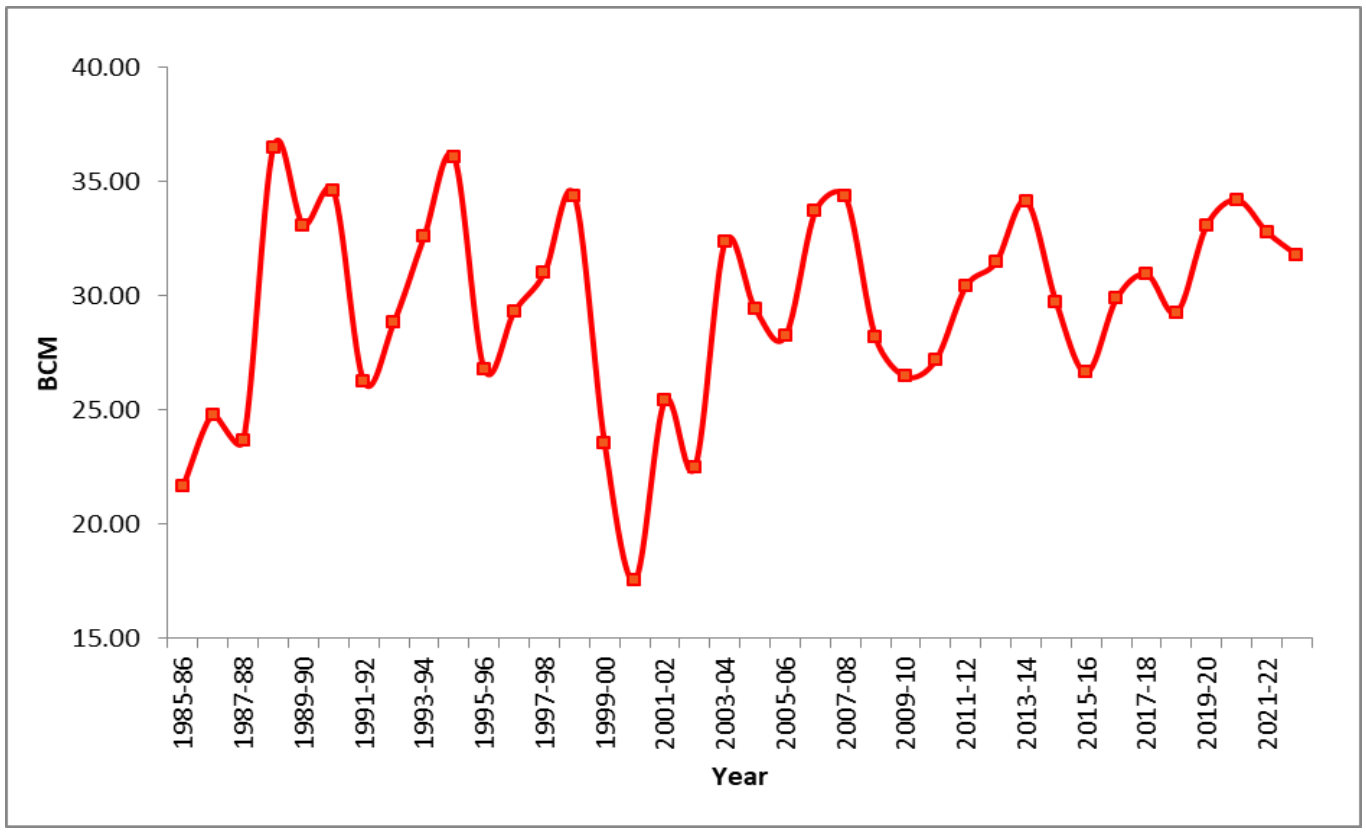


Figure 4.12.5: Annual Evapotranspiration in Mahi basin

4.12.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.12.6. The average annual evaporation from the reservoirs in the basin is 0.74 BCM.

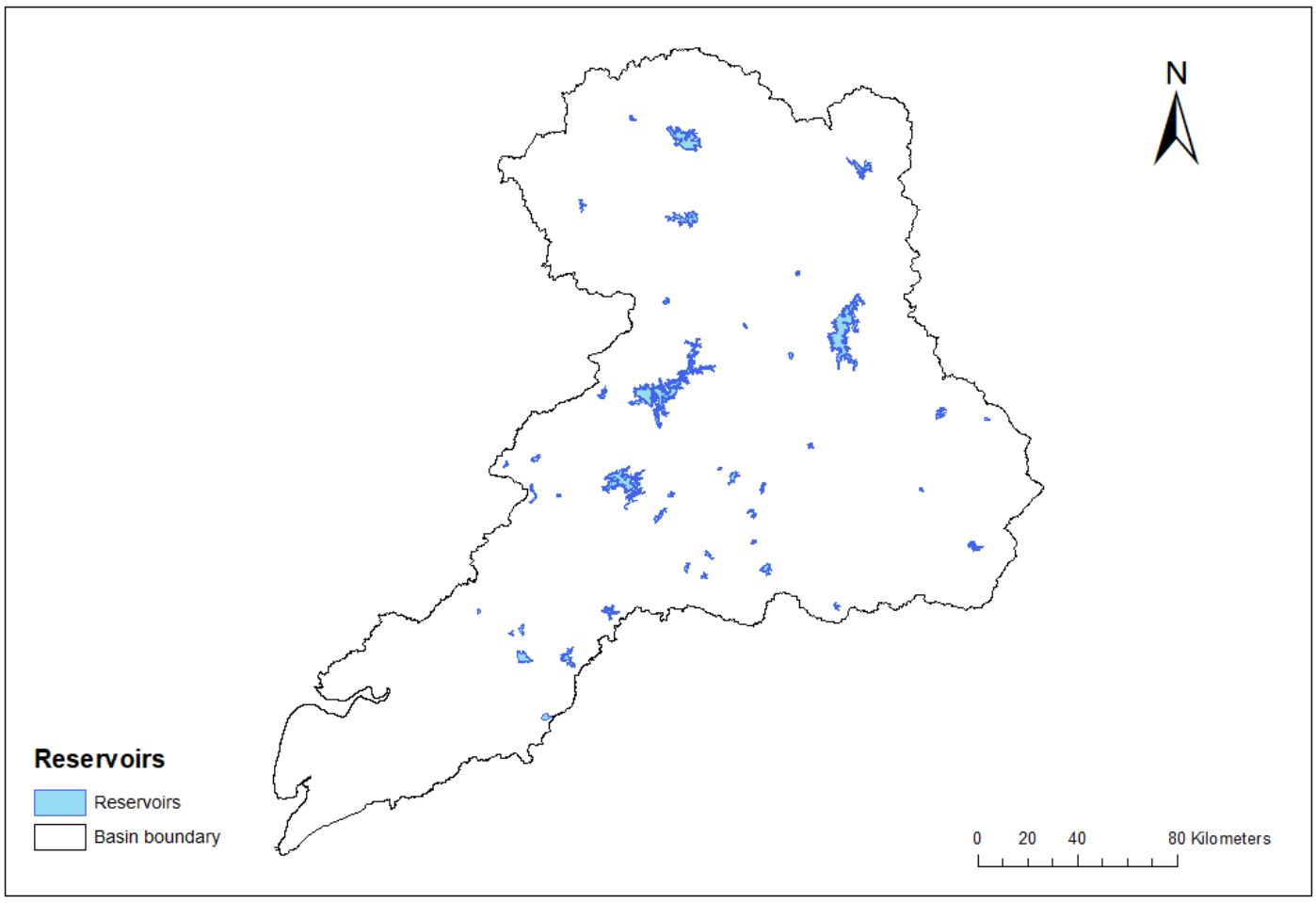


Figure 4.12.6: Reservoir map of Mahi basin

4.12.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input for the basin for the years 1985-2023 has been estimated as 7.06 BCM. The command area map used for the estimation of Evapotranspiration from Irrigation Input is shown in Figure 4.12.7. Yearly variations in Evapotranspiration from Irrigation Input are shown in Figure 4.12.8.

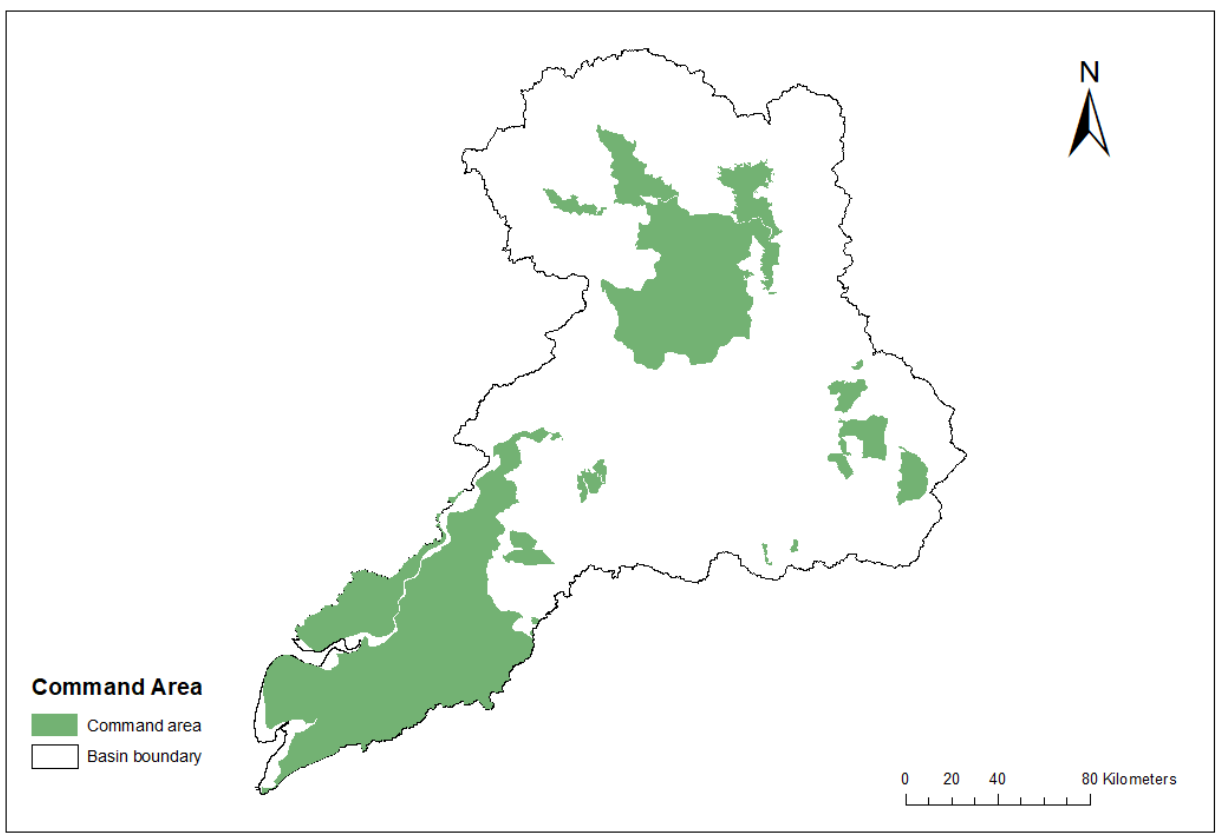


Figure 4.12.7: Command area map of Mahi basin

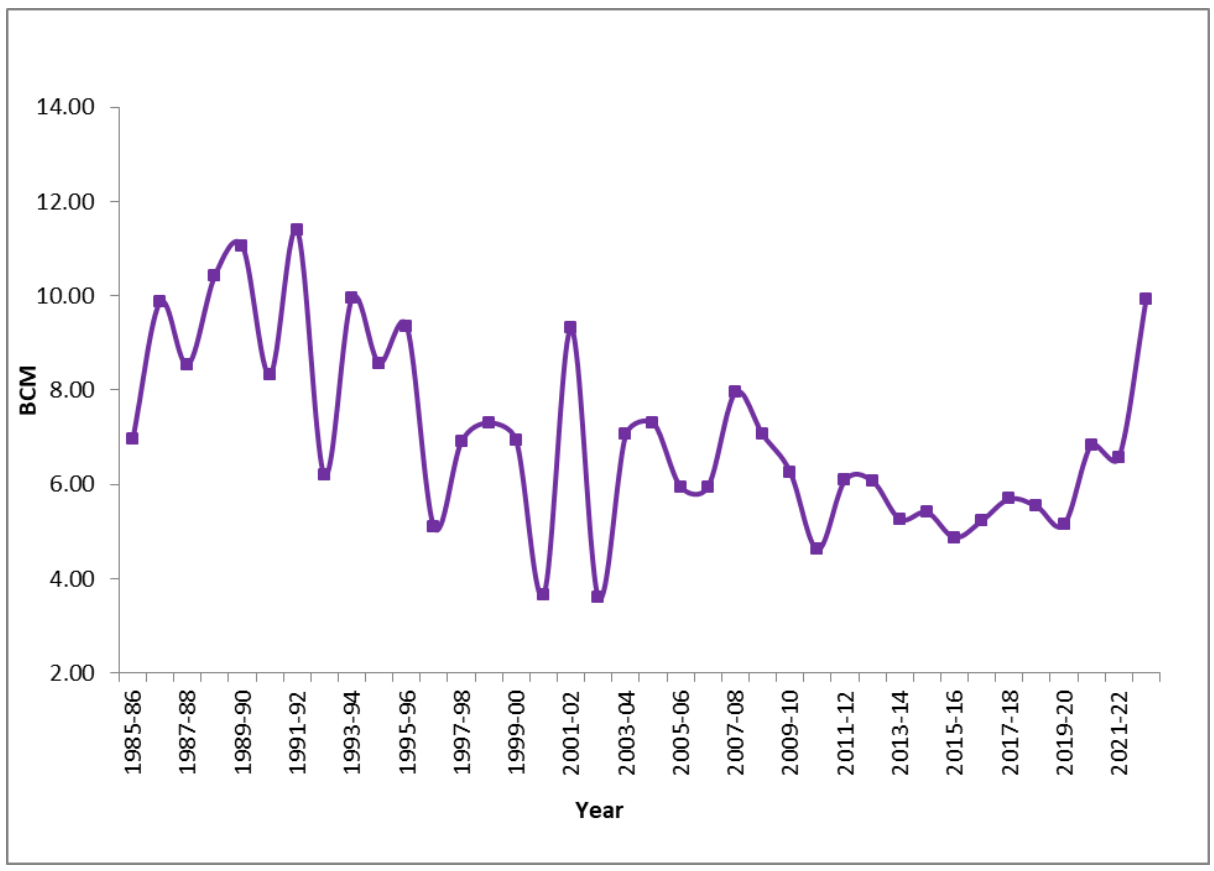


Figure 4.12.8: ET from Irrigation Input in Mahi basin

4.12.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.20 BCM and 0.07 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.34 BCM.

4.12.4 Previous Estimates

The CWC, 1993 estimate of available water resources of the total basin was estimated as 11.02 BCM while in CWC, 2019 study, available water resources of the total basin was estimated as 14.96 BCM.

4.12.5 Annual Water Availability of Mahi Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability from year 1985-86 to 2022-23 of Mahi basin is estimated as 13.03 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.12.9. The results of Mahi basin are shown in Table 4.12.3.

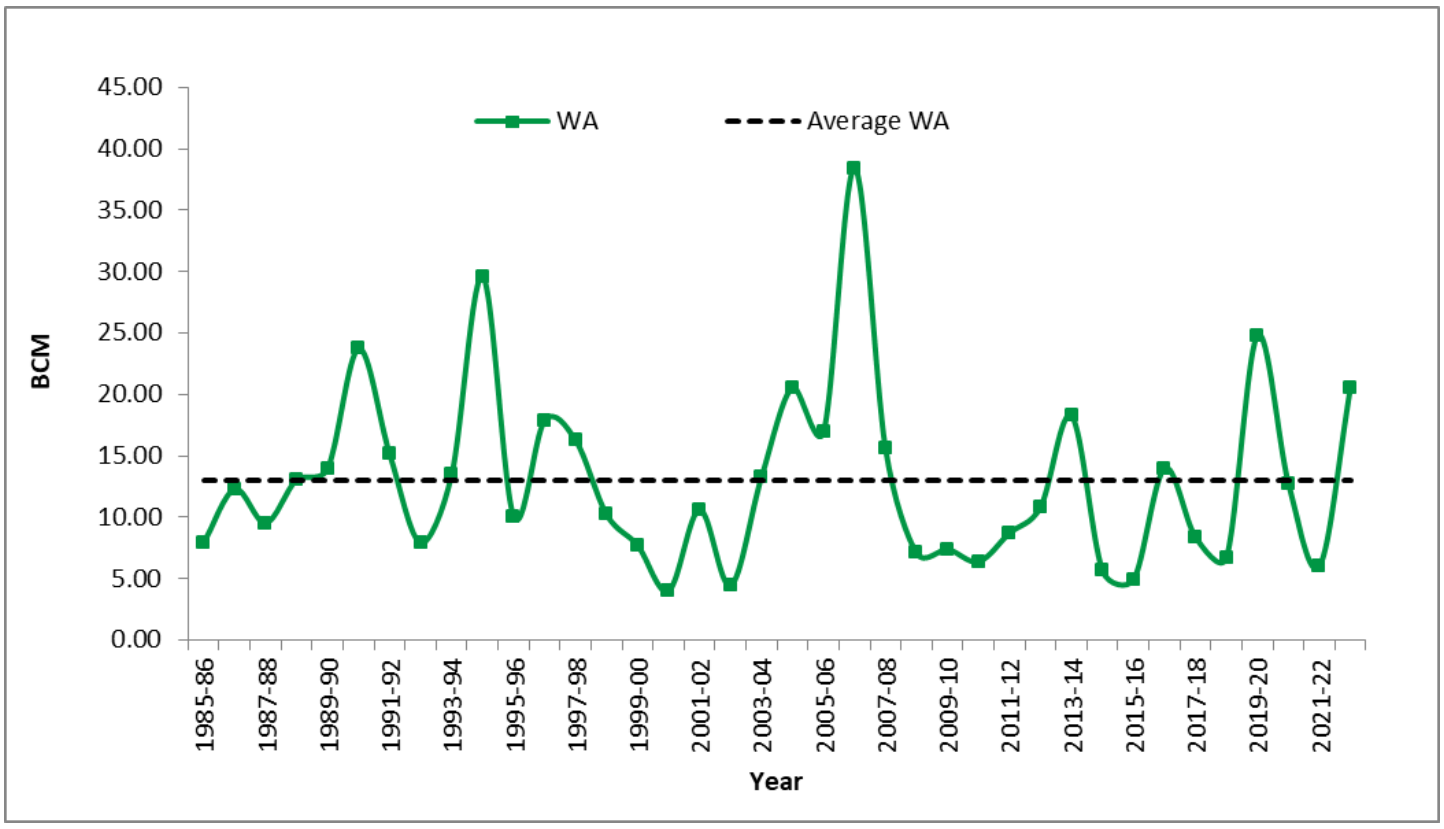


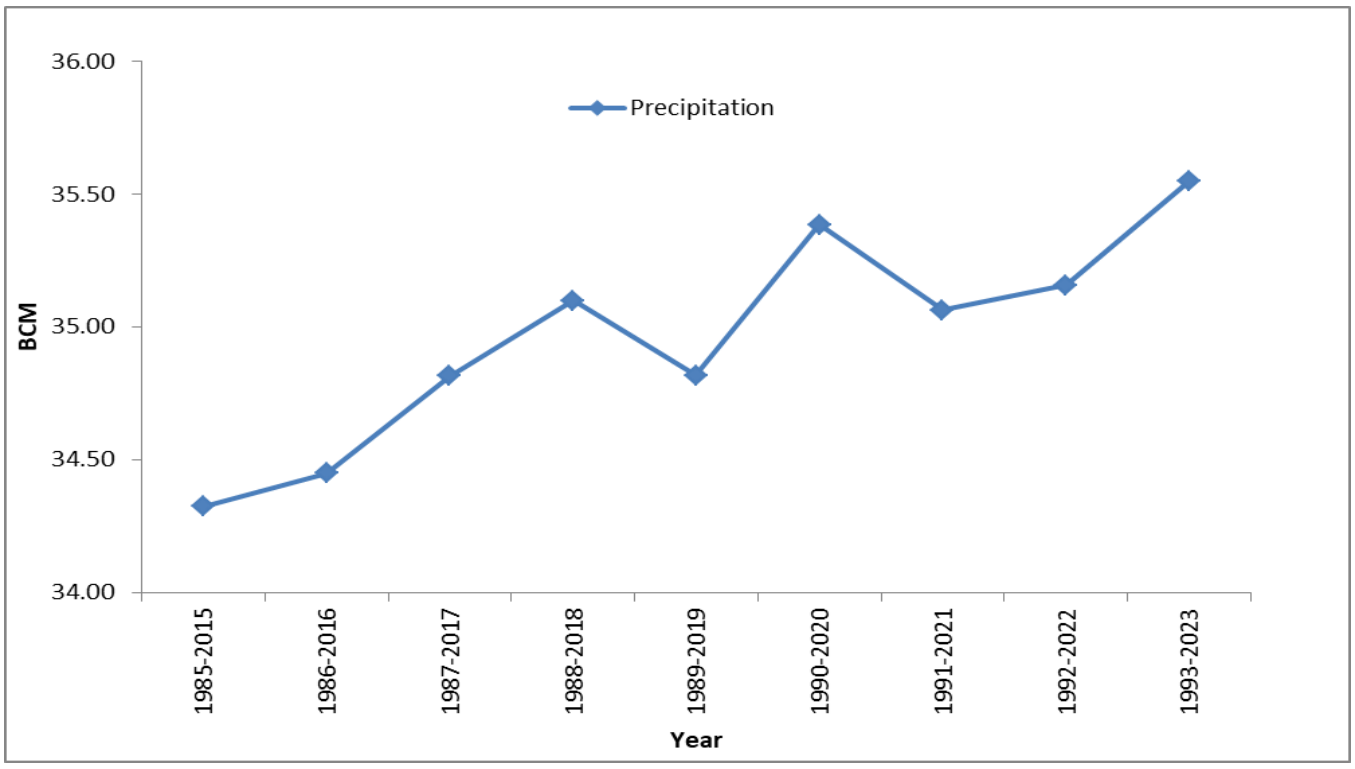
Figure 4.12.9: Water Availability of Mahi basin

4.12.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Mahi basin is given at Table 4.12.2. A line diagram of moving average of P and WA is shown in Figure 4.12.10.

Table 4.12.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	34.33	13.23
1986-2016	34.45	13.13
1987-2017	34.82	13.19
1988-2018	35.10	13.15
1989-2019	34.82	12.94
1990-2020	35.39	13.30
1991-2021	35.06	12.93
1992-2022	35.16	12.63
1993-2023	35.55	13.05



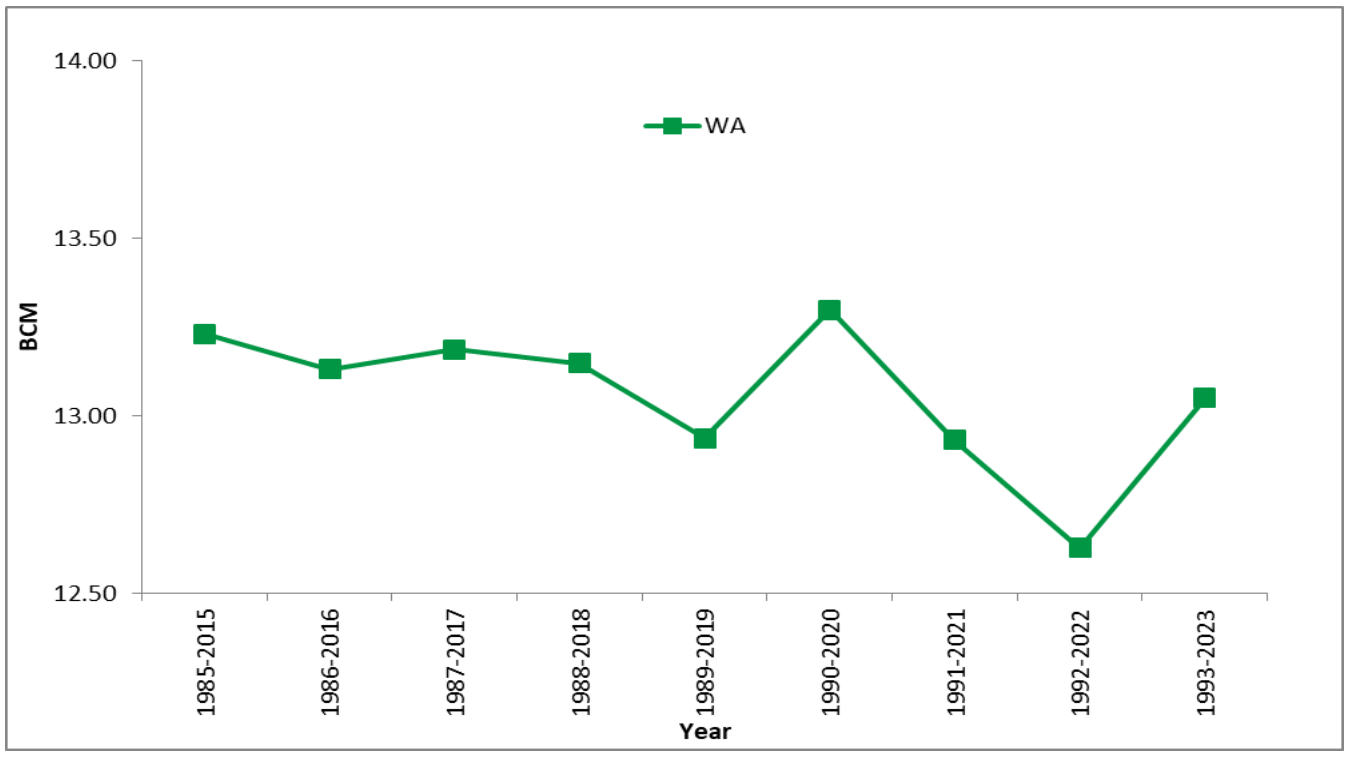


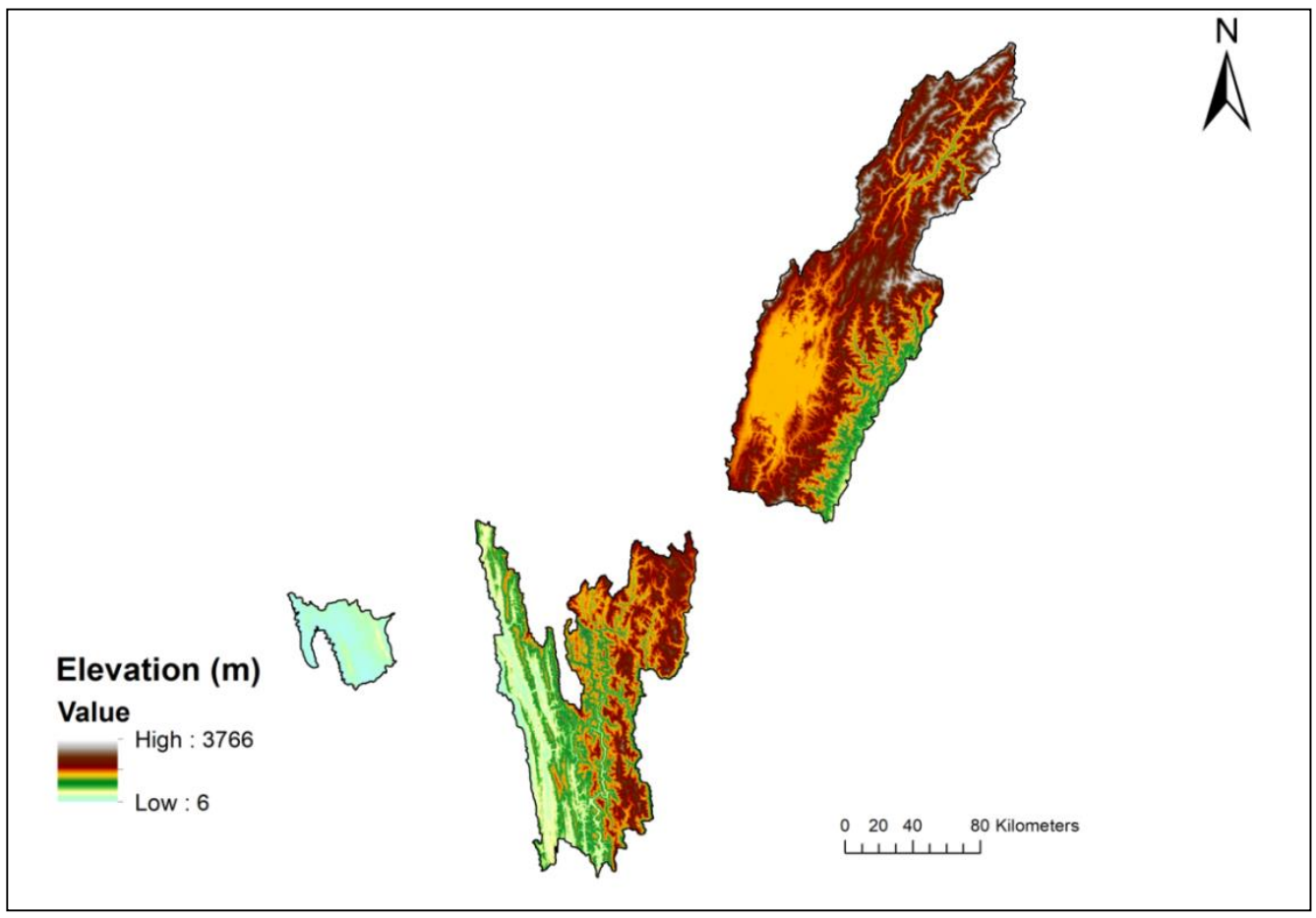
Figure 4.12.10: Moving Average of P and WA for 30 years

Table 4.12.3: Water Availability of Mahi basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	22.22	14.29	7.93
1986-87	26.86	14.58	12.28
1987-88	24.34	14.81	9.53
1988-89	38.13	25.05	13.08
1989-90	34.90	20.93	13.97
1190-91	49.01	25.28	23.73
1991-92	29.36	14.22	15.14
1992-93	29.85	21.94	7.91
1993-94	34.99	21.52	13.47
1994-95	55.74	26.14	29.60
1995-96	26.95	16.89	10.06
1996-97	41.48	23.62	17.86
1997-98	39.70	23.44	16.26
1998-99	36.04	25.83	10.21
1999-00	23.78	16.08	7.70
2000-01	17.57	13.56	4.01
2001-02	26.26	15.65	10.61
2002-03	22.90	18.47	4.43
2003-04	37.49	24.19	13.30
2004-05	42.07	21.49	20.58
2005-06	38.59	21.59	17.00
2006-07	65.40	26.98	38.42
2007-08	41.37	25.80	15.57
2008-09	27.60	20.52	7.08
2009-10	27.22	19.84	7.39
2010-11	28.32	21.93	6.39
2011-12	32.35	23.64	8.71
2012-13	34.83	24.00	10.83
2013-14	45.53	27.28	18.25
2014-15	28.91	23.28	5.63
2015-16	25.97	21.06	4.91
2016-17	37.84	23.87	13.97
2017-18	32.83	24.46	8.37
2018-19	29.68	22.95	6.73
2019-20	51.94	27.14	24.80
2020-21	39.33	26.57	12.76
2021-22	32.17	26.15	6.02
2022-23	41.62	21.08	20.54
Average	**34.77**	**21.74**	**13.03**

4.13 MINOR RIVERS DRAINING INTO MYANMAR & BANGLADESH



HIGHLIGHTS

- *Average annual water resources availability of Minor Rivers draining Myanmar & Bangladesh is 31.86 BCM.*
- *Maximum annual water availability is 60.45 BCM during 2017-18.*
- *Minimum annual water availability is 10.62 BCM during 2022-23.*
- *Average annual precipitation is 59.76 BCM (1904.30 mm).*
- *Maximum annual precipitation is 87.88 BCM (2800 mm) during 2017-18.*
- *Minimum annual precipitation is 40.13 BCM (1279 mm) during 2022-23.*

4.13.1 About Minor Rivers draining into Myanmar & Bangladesh Basin

The composite basin extends over states of Manipur (40%), Mizoram (39%), Nagaland (15%) and Tripura (6%) having a total area of nearly 31,382 sq.km and its geographical extent is between 91°33’ to 94°52’ East longitudes and 21°45’ to 26°40’ North latitudes. The basin is bounded by Purvanchal range in the north and the west and Bay of Bengal in the east and the south. The Imphal is the main river of the basin and it rises near Kangpokpi in Senapati district of Manipur and receives the Iril from the south and the Thoubal from the east. It also receives the Khuga from the south-west and is known as Manipur River below its confluence. The Chakpi River joins Imphal from the opposite direction 3 km below Shuganu and the combined water flows southward through a narrow gorge to fall into the Chindwin river of Burma.

4.13.2 Geo-Spatial Datasets

4.13.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Minor Rivers draining into Myanmar & Bangladesh Basin for year 2022-23 is shown in Figure 4.13.1. The major land use classes consist of Kharif only, Double/Triple, waste land etc.

Table 4.13.1 shows the percentage area of each land use class in the basin for year 2022-23.

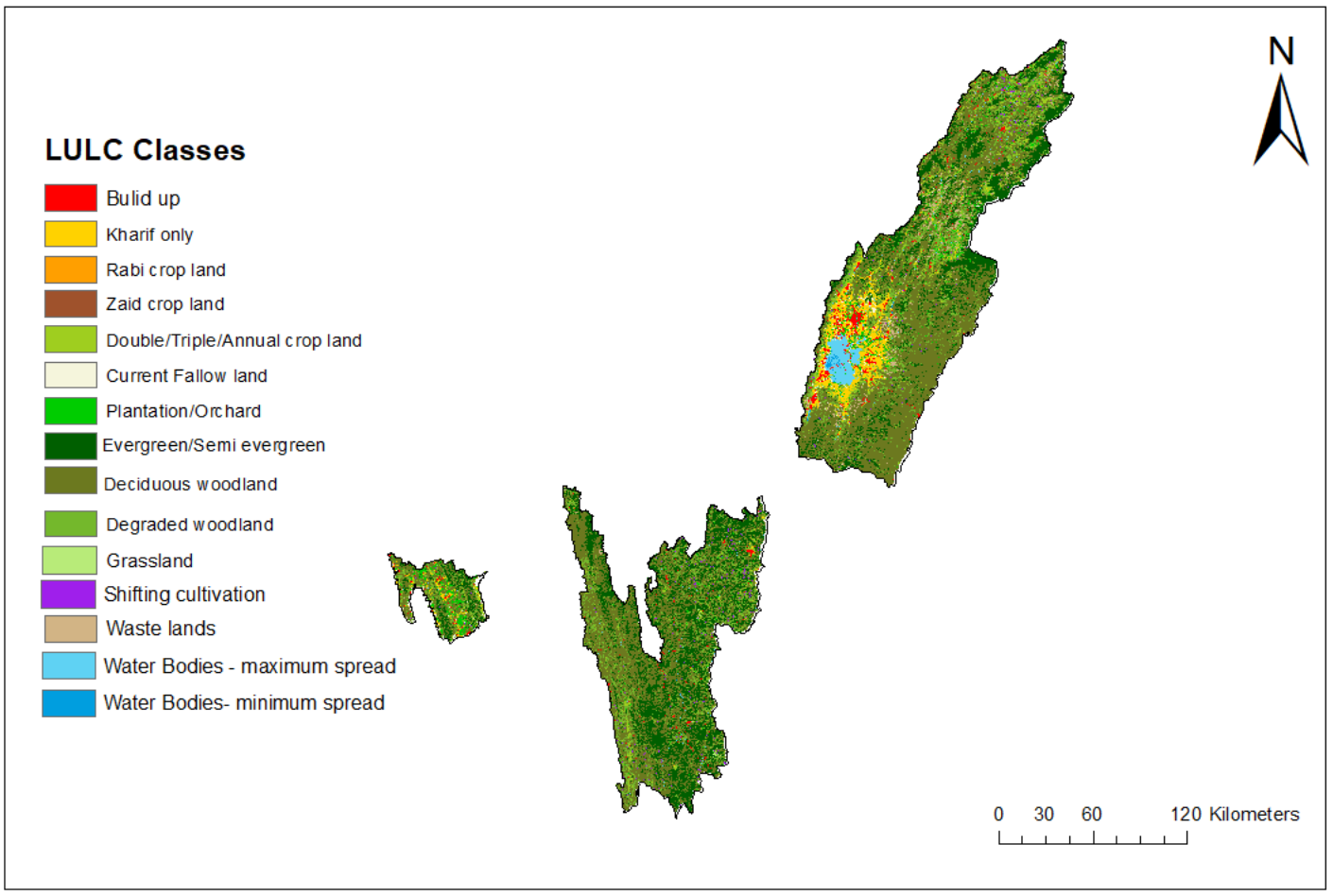


Figure 4.13.1: LULC Map of Minor Rivers draining into Myanmar & Bangladesh

Table 4.13.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	1.66
2.	Kharif only	3.42
3.	Rabi crop land	0.01
4.	Double/Triple/Annual crop land	4.16
5.	Current Fallow land	0.55
6.	Plantation/Orchard	2.10
7.	Evergreen/Semi evergreen	23.92
8.	Deciduous woodland	46.96
9.	Degraded woodland	13.32
10.	Grassland	0.03
11.	Shifting Cultivation	0.71
12.	Waste lands	1.48
13.	Water Bodies - maximum spread	1.57
14.	Water Bodies - minimum spread	0.11

4.13.3 Hydro-Meteorological and other Input Data

4.13.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.13.2. The variations in the annual Precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.13.3. The average Precipitation of 38 years is approximately 59.76 BCM (1904.30 mm).

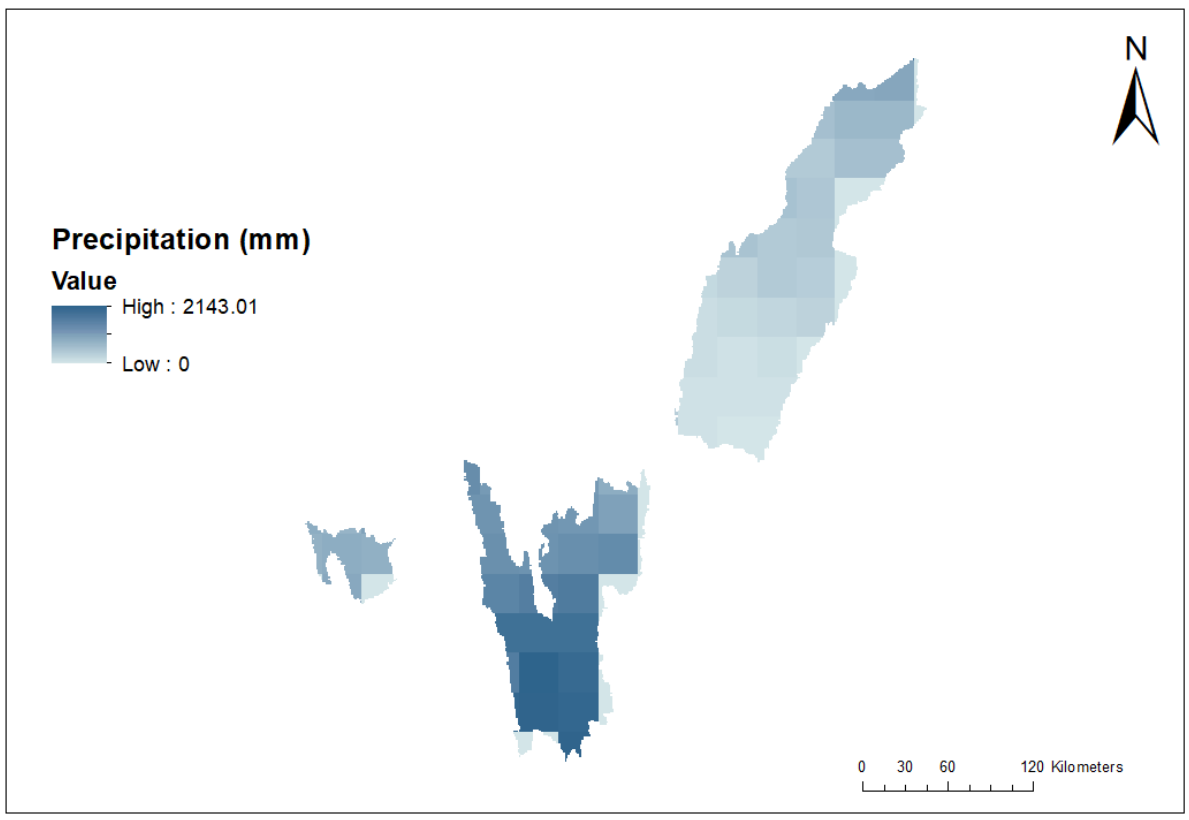


Figure 4.13.2: Precipitation map of Minor Rivers draining into Myanmar & Bangladesh

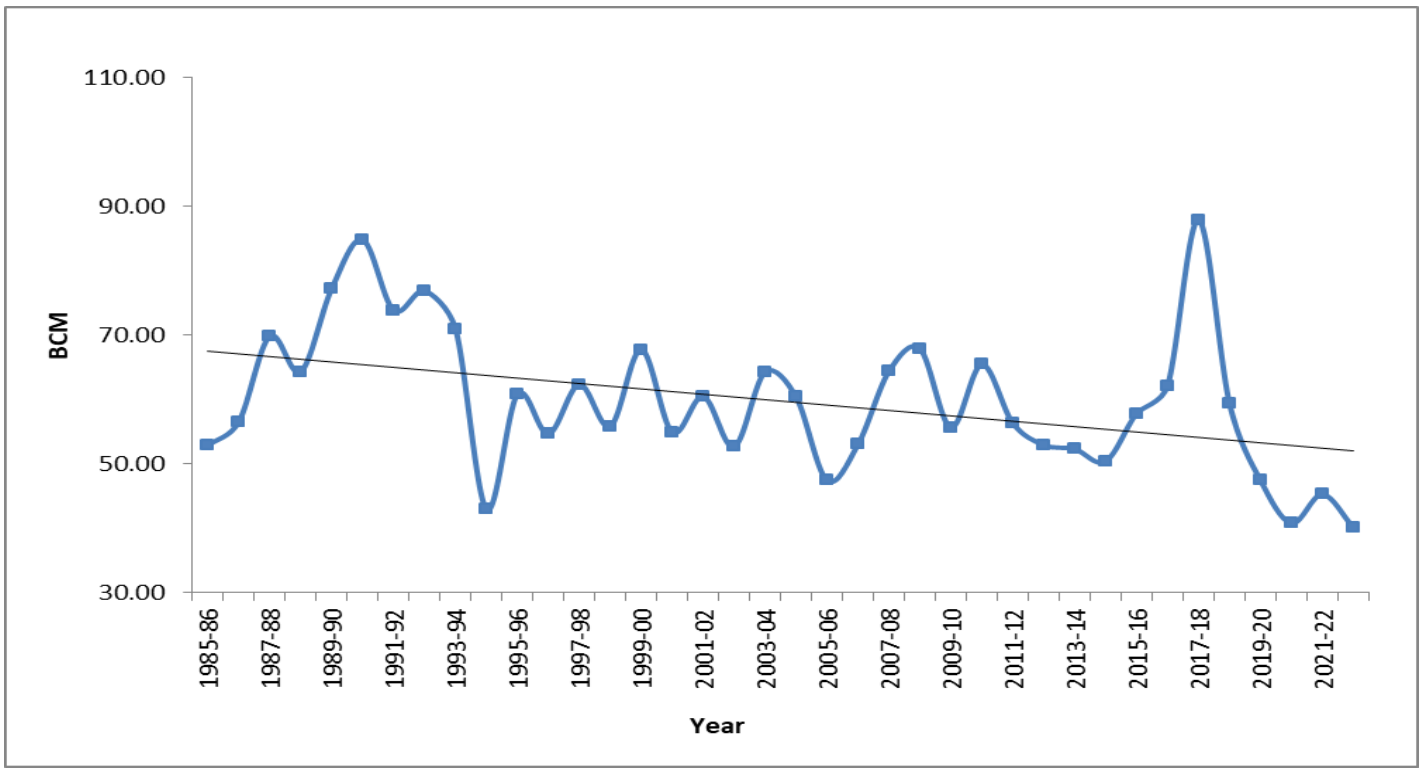


Figure 4.13.3: Annual Precipitation in Minor Rivers draining into Myanmar & Bangladesh

4.13.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.13.4. The variations in the annual actual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.13.5. The Average ET of 38 years is found to be 28.60 BCM (911.35 mm).

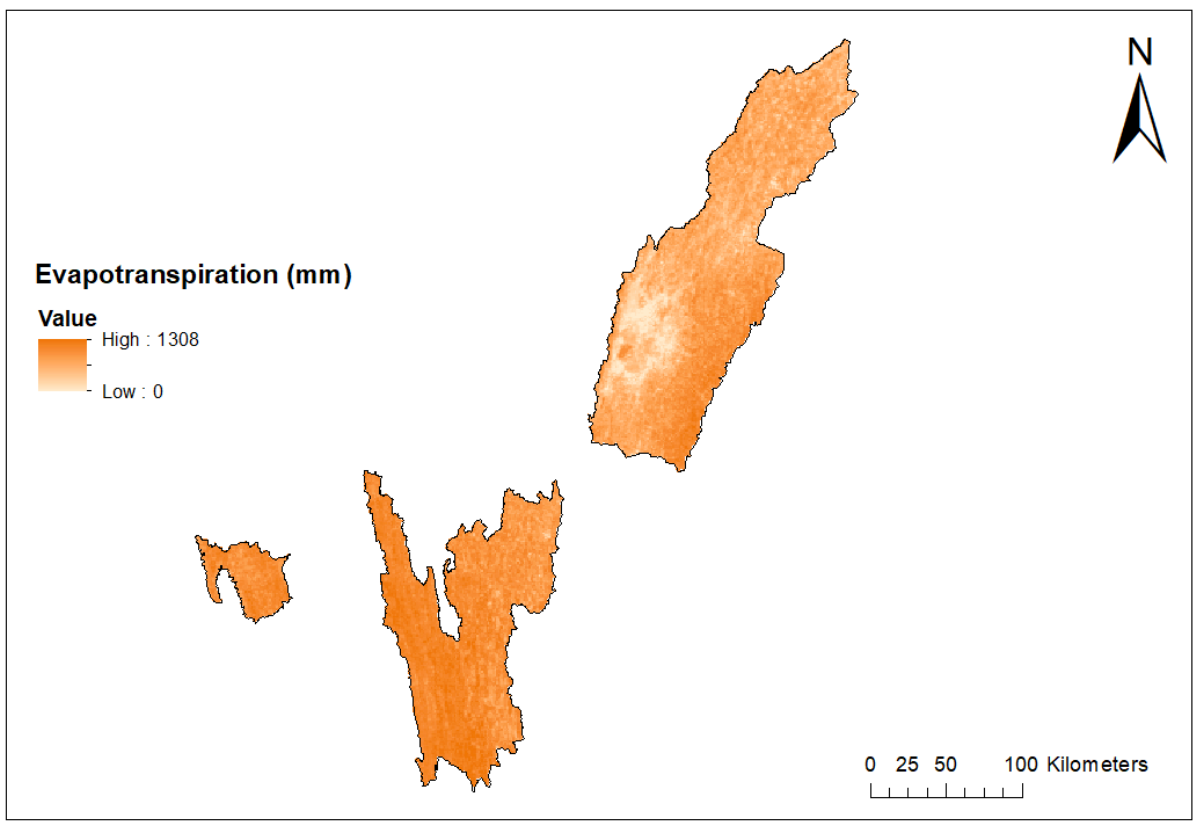


Figure 4.13.4: Evapotranspiration map of Minor Rivers draining into Myanmar & Bangladesh

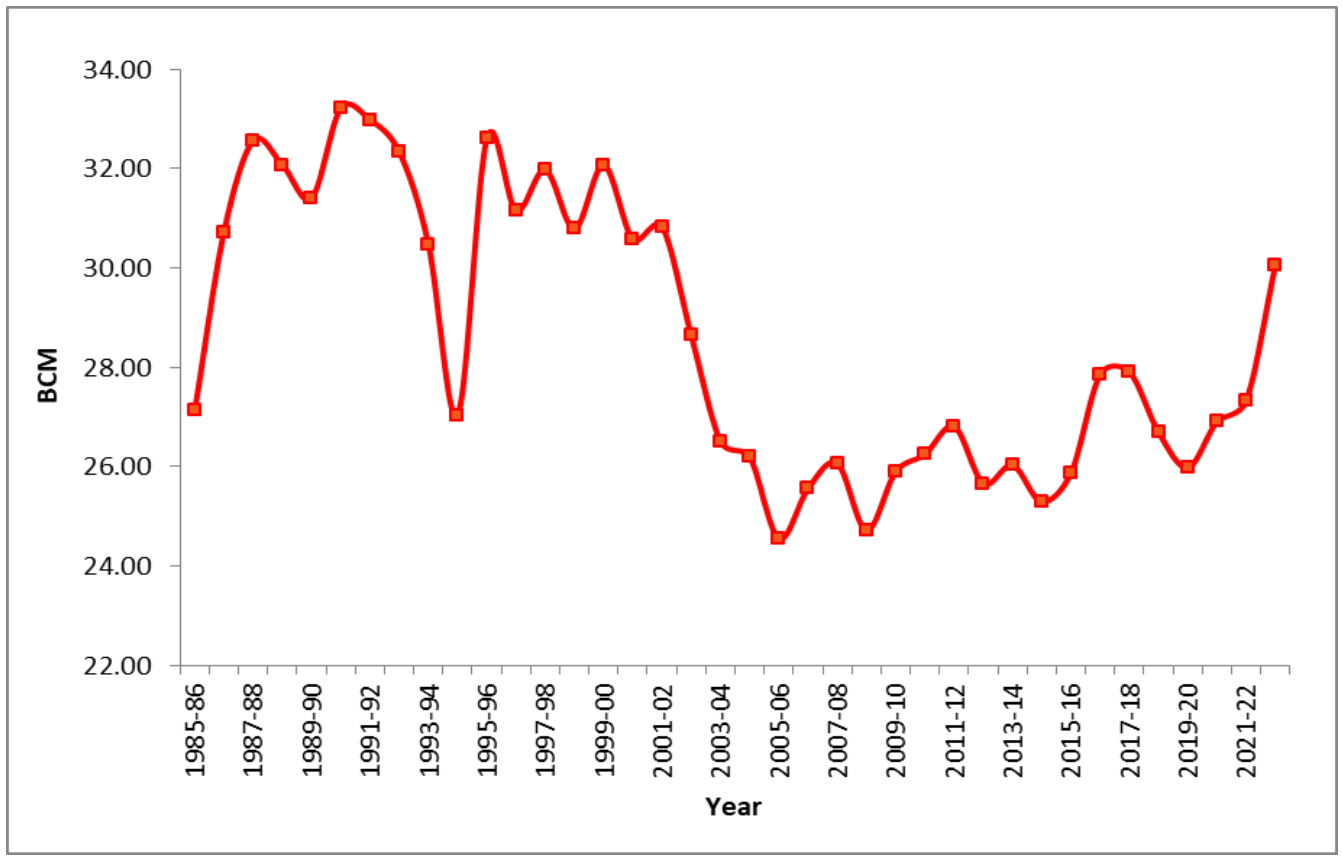


Figure 4.13.5: Annual Evapotranspiration in Minor Rivers draining into Myanmar & Bangladesh

4.13.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in figure 4.13.6. The average evaporation from the reservoirs in the basin is 0.31 BCM.

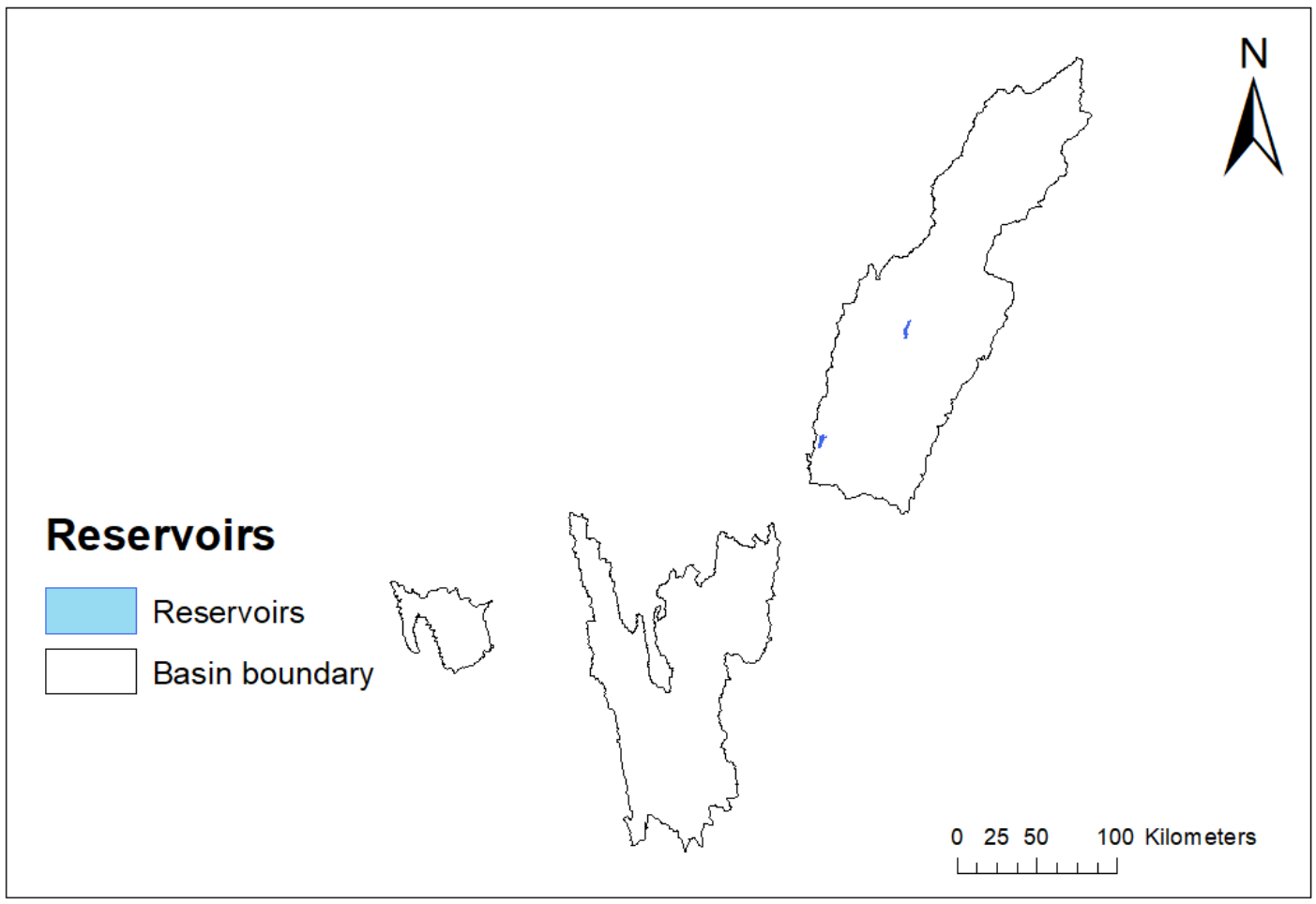


Figure 4.13.6: Reservoir map of Minor Rivers draining into Myanmar & Bangladesh

4.13.3.4 Evapotranspiration from Irrigation Input

The ET from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 0.38 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.13.7. Yearly variations in ET_{II} are shown in Figure 4.13.8.

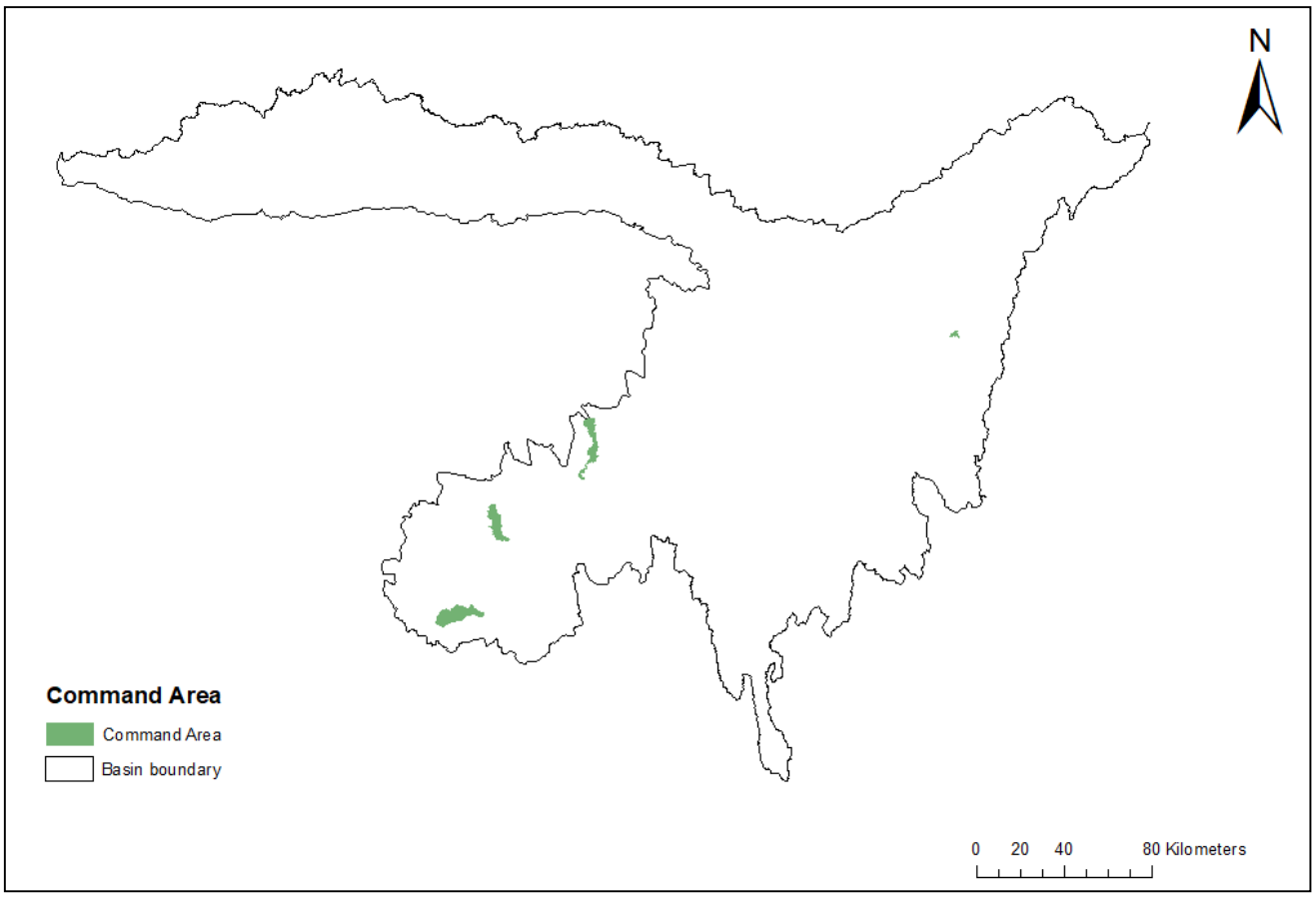


Figure 4.13.7: Command Area map of Minor Rivers draining into Myanmar & Bangladesh

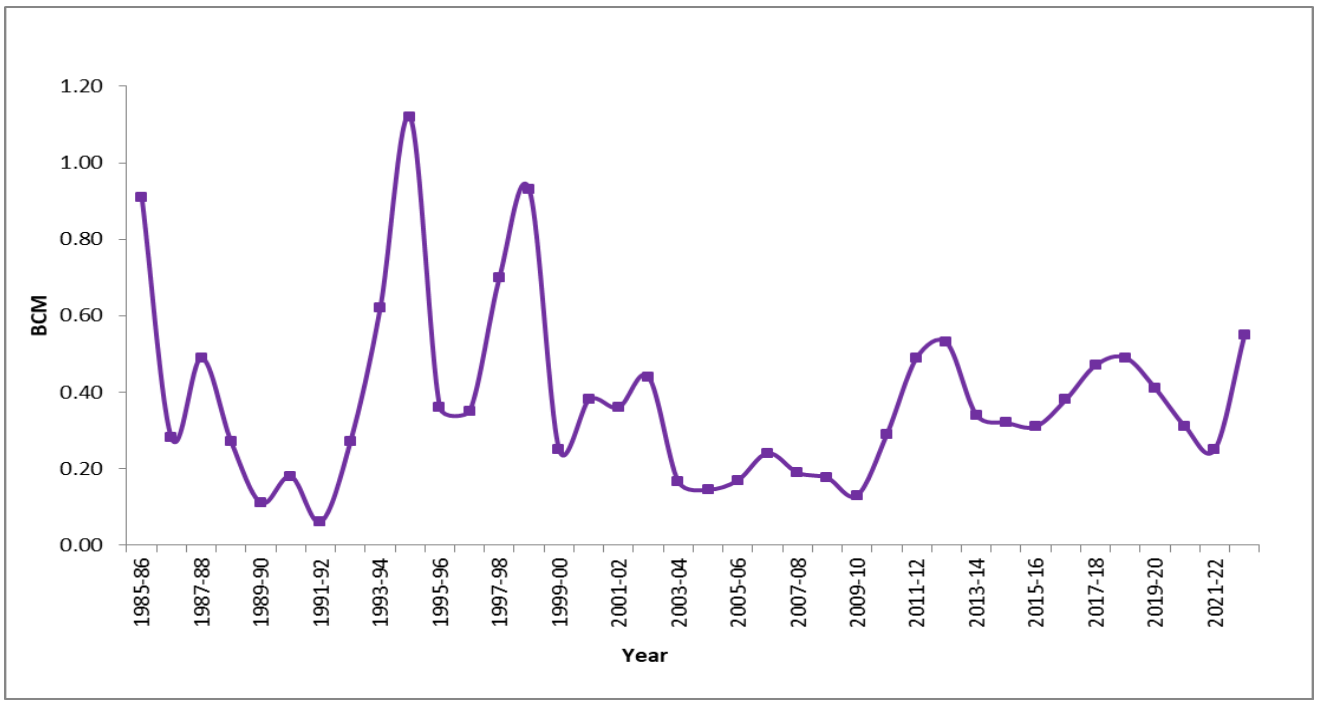


Figure 4.13.8: ET from Irrigation Input in Minor Rivers draining into Myanmar & Bangladesh

4.13.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.01 BCM and 0.00 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.16 BCM.

4.13.4 Previous Estimates

The CWC 1993 study estimate of available water resources of the Minor Rivers draining into Myanmar & Bangladesh basin is 31.00 BCM, whereas in 2019 study, it was 31.17 BCM.

4.13.5 Annual Water Availability of Minor Rivers draining into Myanmar & Bangladesh basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the Average water resource availability from year 1985-86 to 2022-23 is estimated to be 31.86 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.13.9. The results of Minor Rivers draining into Myanmar & Bangladesh basin are shown in Table 4.13.3.

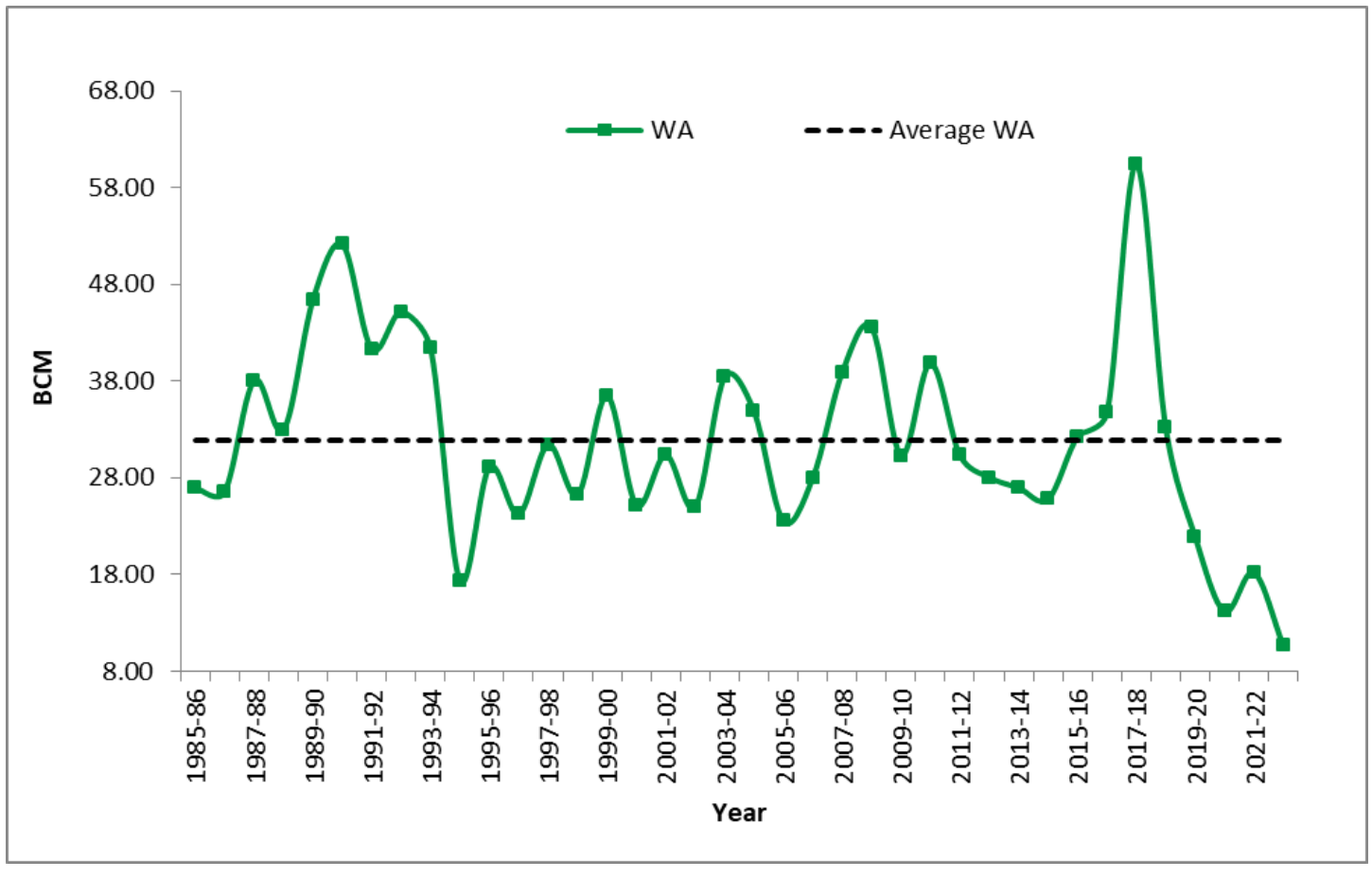


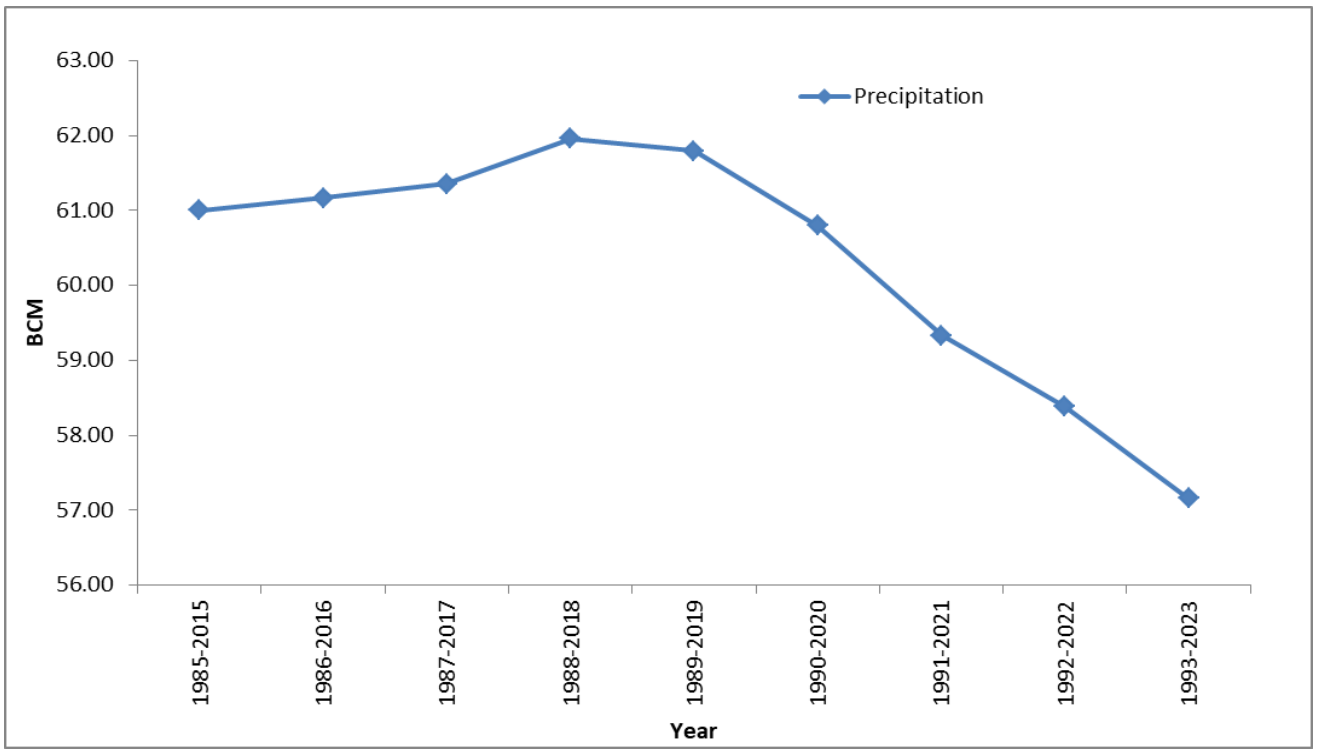
Figure 4.13.9: Water availability of Minor Rivers draining into Myanmar & Bangladesh

4.13.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Minor Rivers draining into Myanmar & Bangladesh is given at Table 14.2. A line diagram of moving average of P and WA is shown in Figure 4.13.10.

Table 4.13.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	61.00	32.83
1986-2016	61.17	33.01
1987-2017	61.35	33.28
1988-2018	61.96	34.03
1989-2019	61.79	34.04
1990-2020	60.80	33.22
1991-2021	59.33	31.95
1992-2022	58.38	31.18
1993-2023	57.15	30.03



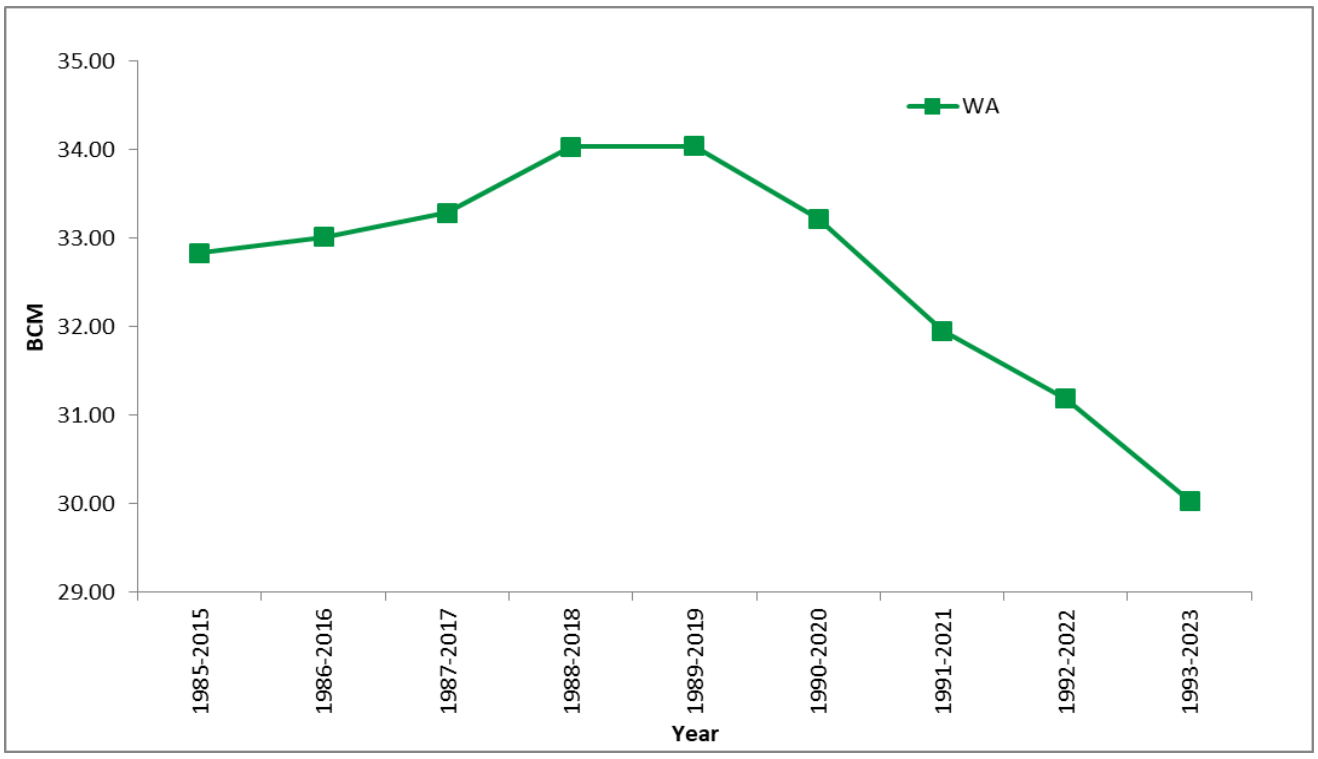


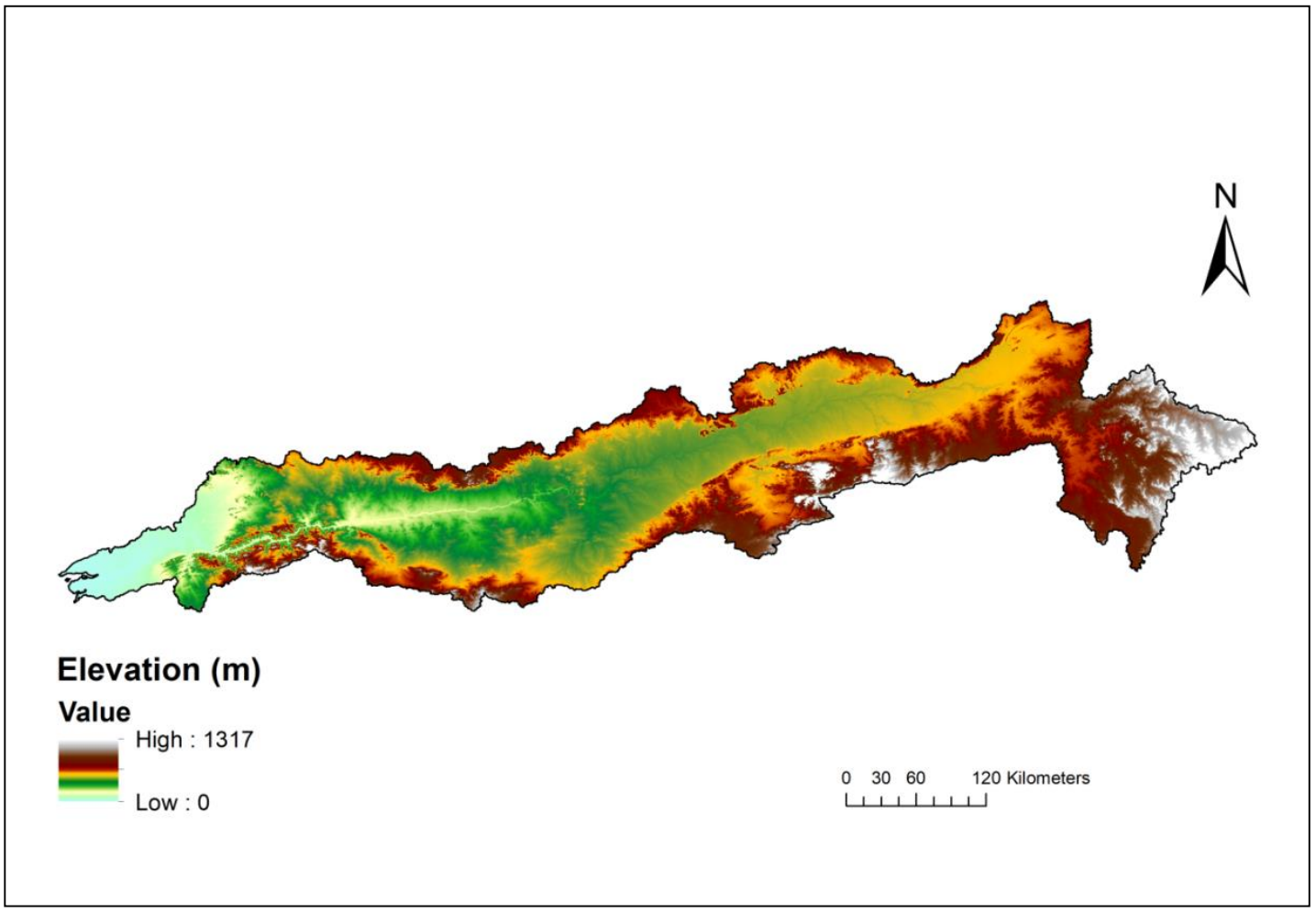
Figure 4.13.10: Moving Average of P and WA for 30 years

Table 4.13.3: Water Availability of Minor Rivers draining into Myanmar & Bangladesh basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	52.85	25.91	26.94
1986-87	56.53	29.97	26.56
1987-88	69.83	31.75	38.08
1988-89	64.30	31.35	32.95
1989-90	77.21	30.79	46.42
1990-91	84.82	32.67	52.15
1991-92	73.85	32.54	41.31
1992-93	76.89	31.70	45.19
1993-94	70.96	29.57	41.39
1994-95	42.95	25.56	17.39
1995-96	60.81	31.71	29.10
1996-97	54.65	30.42	24.23
1997-98	62.33	30.90	31.43
1998-99	55.81	29.60	26.21
1999-00	67.77	31.28	36.49
2000-01	54.89	29.71	25.18
2001-02	60.47	30.09	30.38
2002-03	52.65	27.67	24.98
2003-04	64.26	25.84	38.42
2004-05	60.41	25.55	34.86
2005-06	47.44	23.92	23.52
2006-07	53.02	25.02	28.00
2007-08	64.38	25.47	38.91
2008-09	67.89	24.34	43.55
2009-10	55.64	25.35	30.29
2010-11	65.44	25.57	39.87
2011-12	56.33	25.99	30.34
2012-13	52.92	24.87	28.05
2013-14	52.30	25.34	26.96
2014-15	50.39	24.58	25.81
2015-16	57.84	25.55	32.29
2016-17	62.18	27.47	34.71
2017-18	87.88	27.43	60.45
2018-19	59.37	26.19	33.18
2019-20	47.45	25.56	21.89
2020-21	40.78	26.59	14.19
2021-22	45.28	27.07	18.21
2022-23	40.13	29.51	10.62
Average	**59.76**	**27.91**	**31.86**

4.14 NARMADA BASIN



HIGHLIGHTS

- *Average annual water resources availability of Narmada basin is 49.95 BCM.*
- *Maximum annual water availability is 105.76 BCM during 1994-95.*
- *Minimum annual water availability is 22.52 BCM during 2017-18.*
- *Average annual precipitation is 107.89 BCM (1116.16 mm).*
- *Maximum annual precipitation 157.51 BCM (1630.00 mm) during 2013-14.*
- *Minimum annual precipitation 73.63 BCM (762.00 mm) during 2000-01.*

4.14.1 About Narmada Basin

The Narmada basin extends over an area of 96,659.79 sq. km, which is nearly 2.9% of the total geographical area of the country. The basin lies in the states of Madhya Pradesh (86.9%), Gujarat (11.60%) and Maharashtra (1.50%). The Narmada originates from a Kund (spring) at an elevation of 1,057m at Amarkantak in the Maikal hill in Shahdol district of Madhya Pradesh and flows through Madhya Pradesh, Maharashtra and Gujarat between Vindhya and Satpura hill ranges before falling into the Gulf of Cambay in the Arabian Sea, about 10 km north of Bharuch, Gujarat. The total length of this west flowing river from its origin to its outfall into the Arabian Sea is 1,312 km. For the first 1,079 km, it flows in Madhya Pradesh and thereafter forms the common boundary between Madhya Pradesh and Maharashtra for 35 km, and Maharashtra and Gujarat for 39 km. In Gujarat State it stretches for 159 km. There are 41 important tributaries to the Narmada. Significant among them are Burhner, Banjar, Hiran, Tawa, ChhotaTawa, Orsang and Kundi.

4.14.2 Geo-Spatial Datasets

4.14.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Narmada basin for year 2022-23 is shown in Figure 4.14.1. The major land use classes consist of Kharif only, Double/Triple, waste land etc.

Table 4.14.1 shows the percentage area of each land use class in the basin for 2022-23.

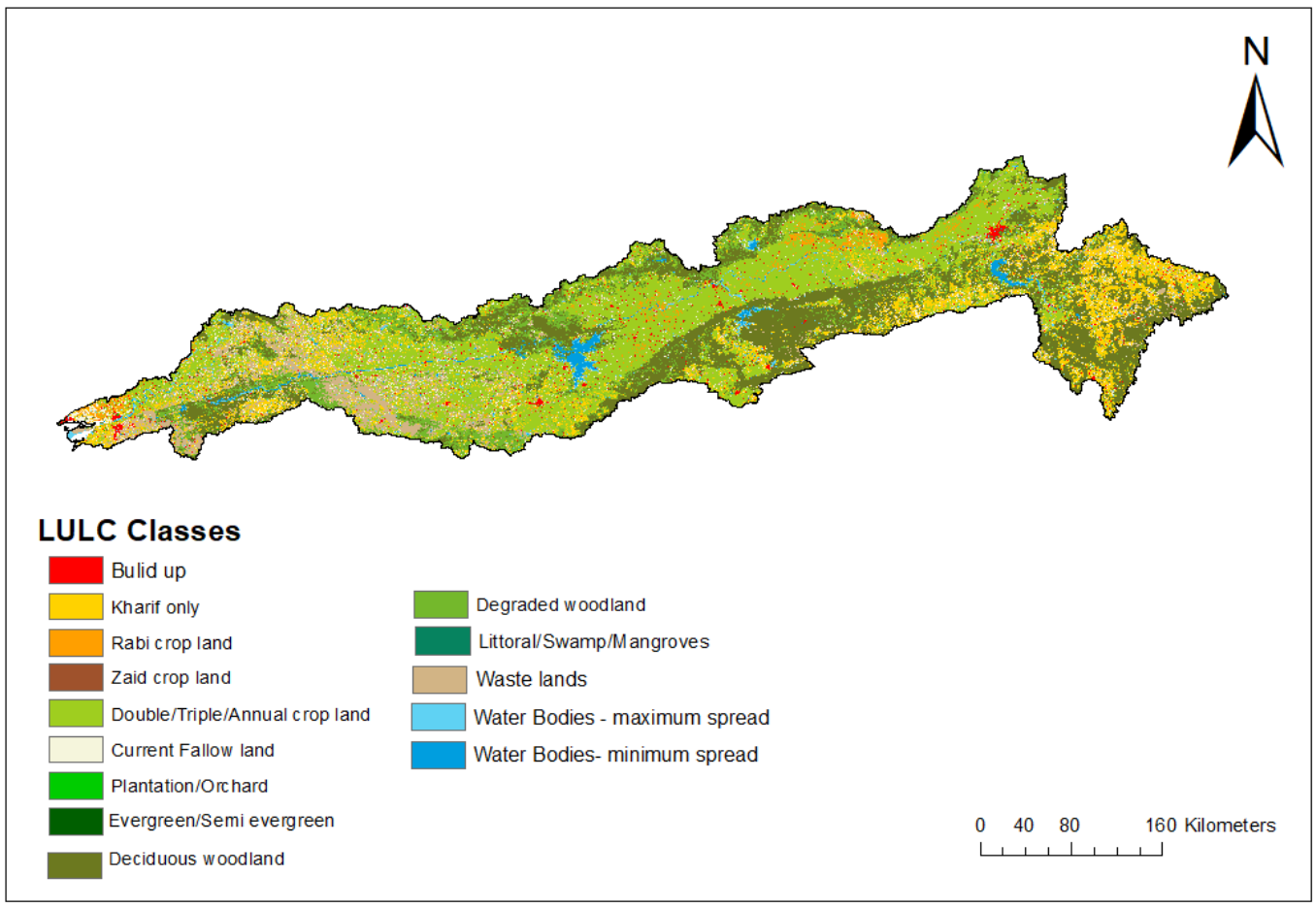


Figure 4.14.1: LULC Map of Narmada basin

Table 4.14.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	1.44
2.	Kharif only	13.37
3.	Rabi crop land	1.91
4.	Double/Triple/Annual crop land	33.21
5.	Current Fallow land	4.66
6.	Plantation/Orchard	0.05
7.	Evergreen/Semi evergreen	0.01
8.	Deciduous woodland	25.50
9.	Degraded woodland	8.81
10.	Waste lands	7.98
11.	Water Bodies - maximum spread	1.76
12.	Water Bodies - minimum spread	1.29

4.14.3 Hydro-Meteorological and other Input Data

4.14.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.14.2. The variations in the annual Precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.14.3. The average precipitation of 38 years is approximately 107.89 BCM (1116.16 mm).

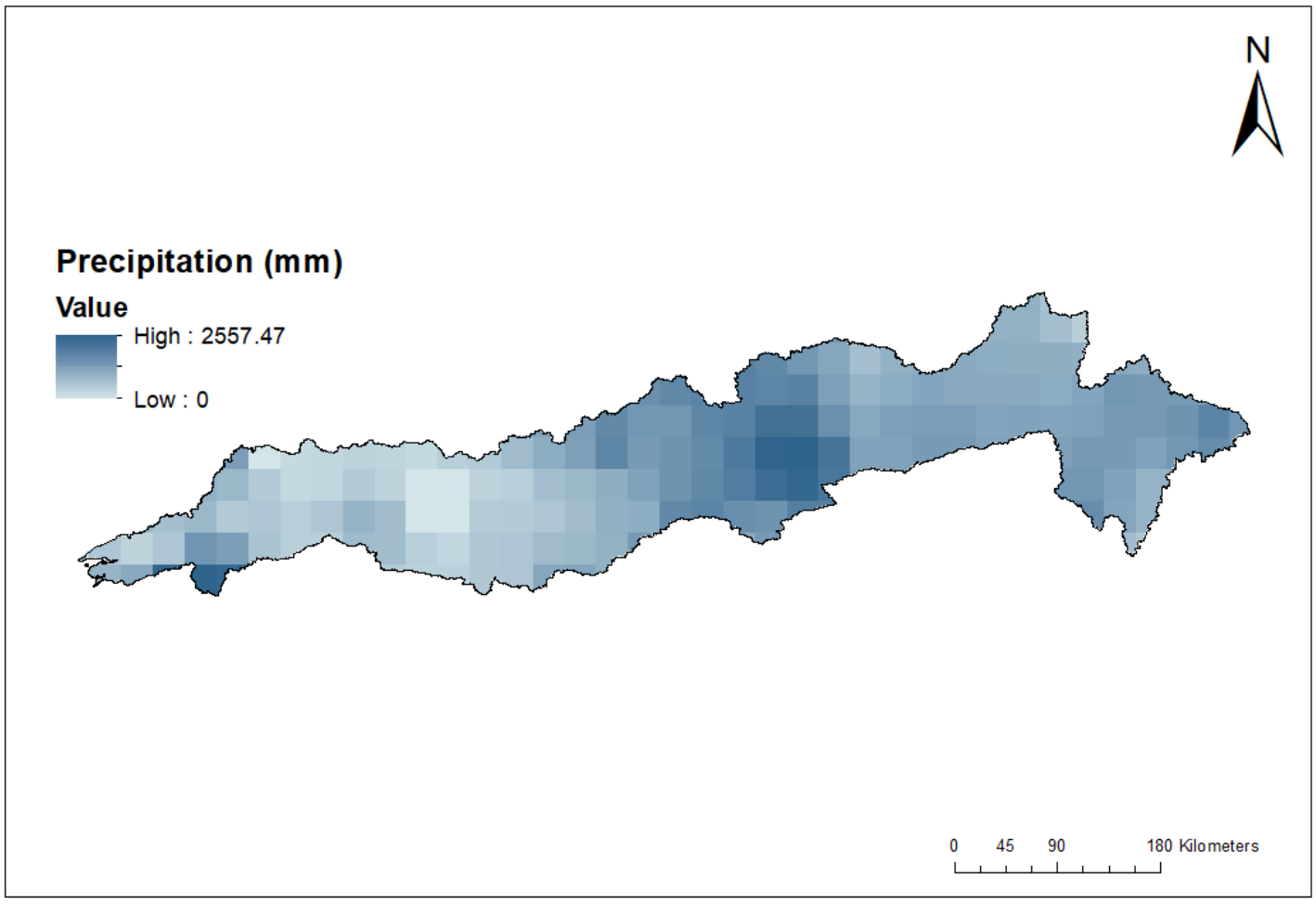


Figure 4.14.2: Precipitation map of Narmada basin

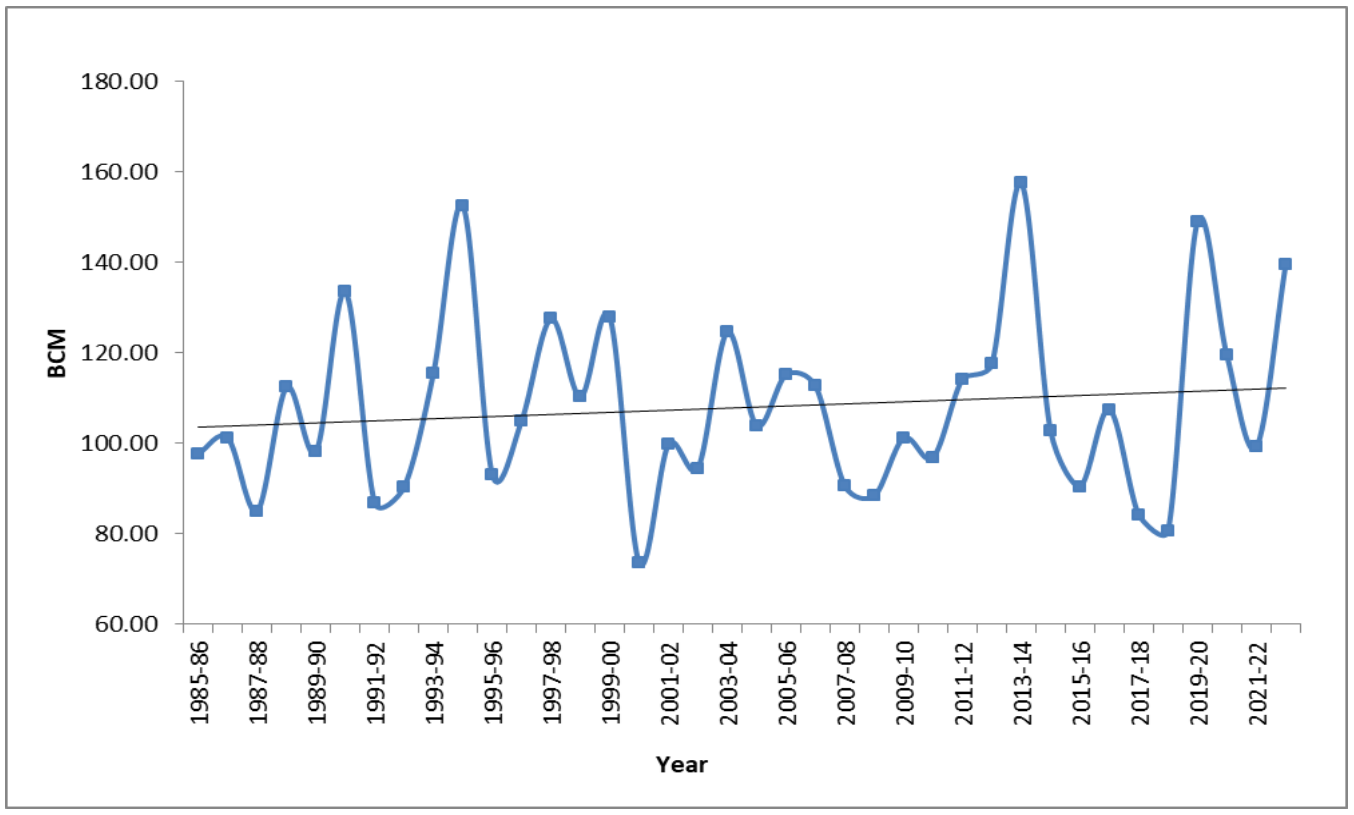


Figure 4.14.3: Annual Precipitation in Narmada basin

4.14.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.14.4. The variations in the annual actual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.14.5. The average ET of 38 years is approx. 73.56 BCM (761.02 mm).

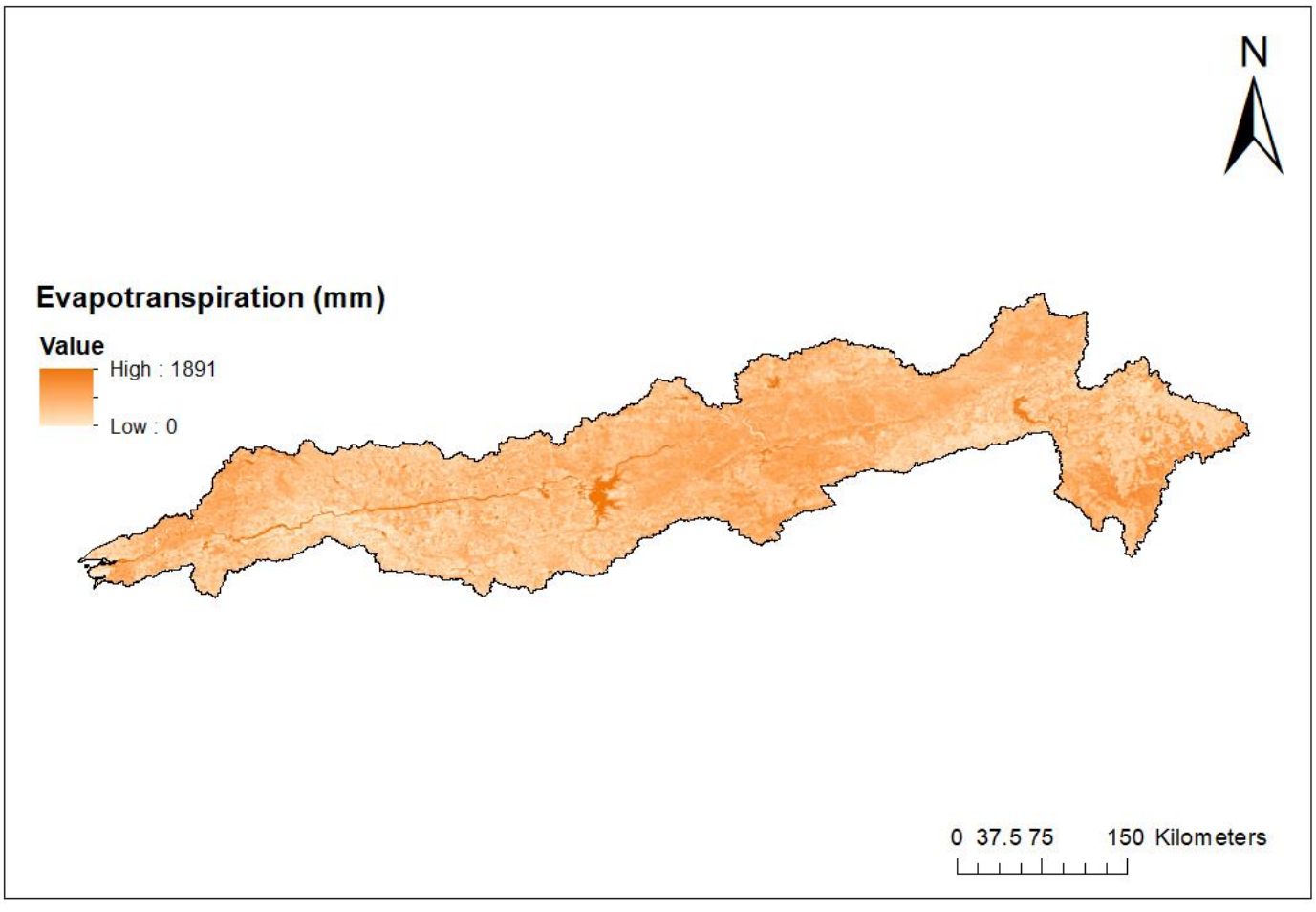


Figure 4.14.4: Evapotranspiration map of Narmada basin

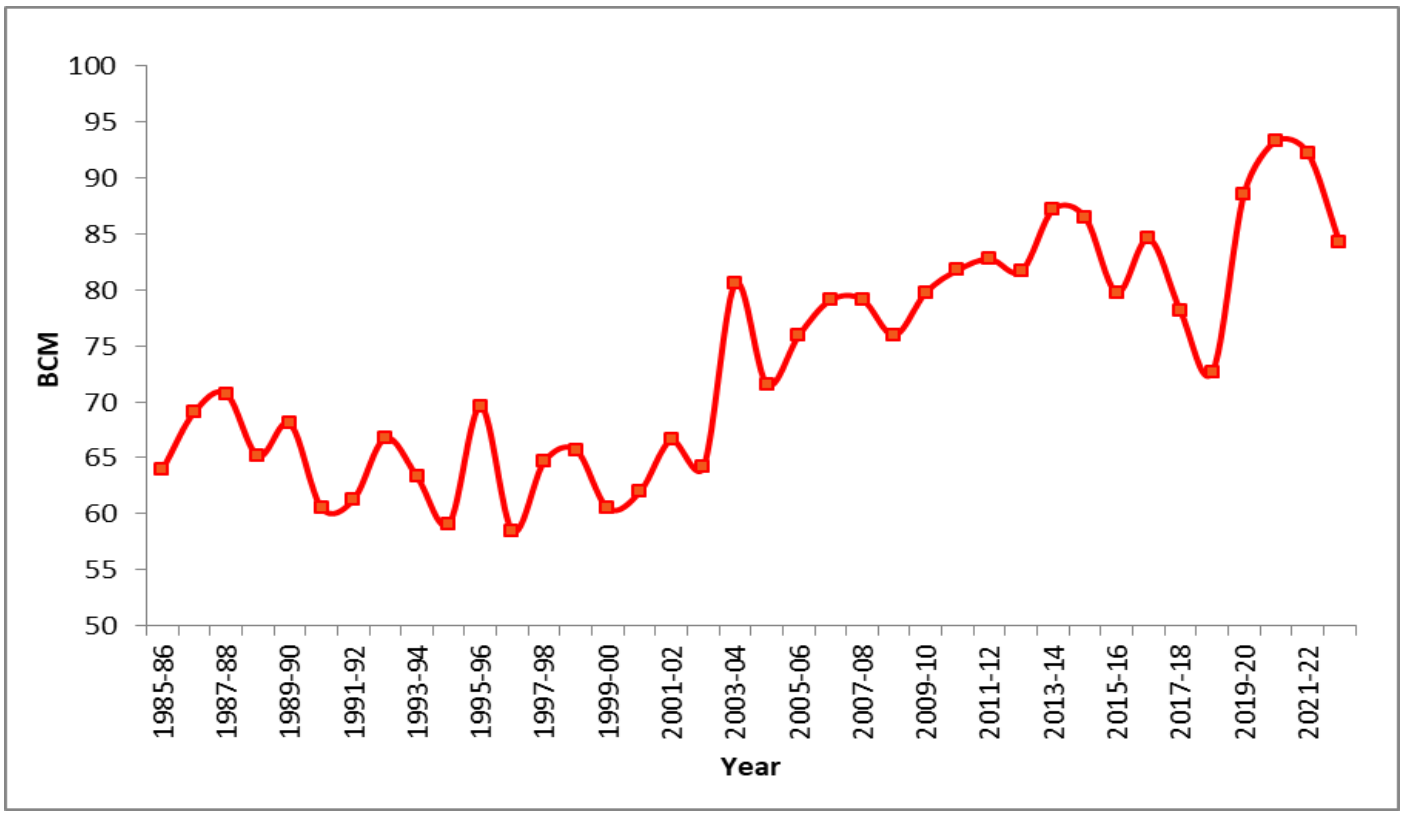


Figure 4.14.5: Annual Evapotranspiration in Narmada basin

4.14.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectare has been used for the estimation of reservoir evaporation as shown in Figure 4.14.6. The average evaporation from the reservoirs in the basin is 1.44 BCM.

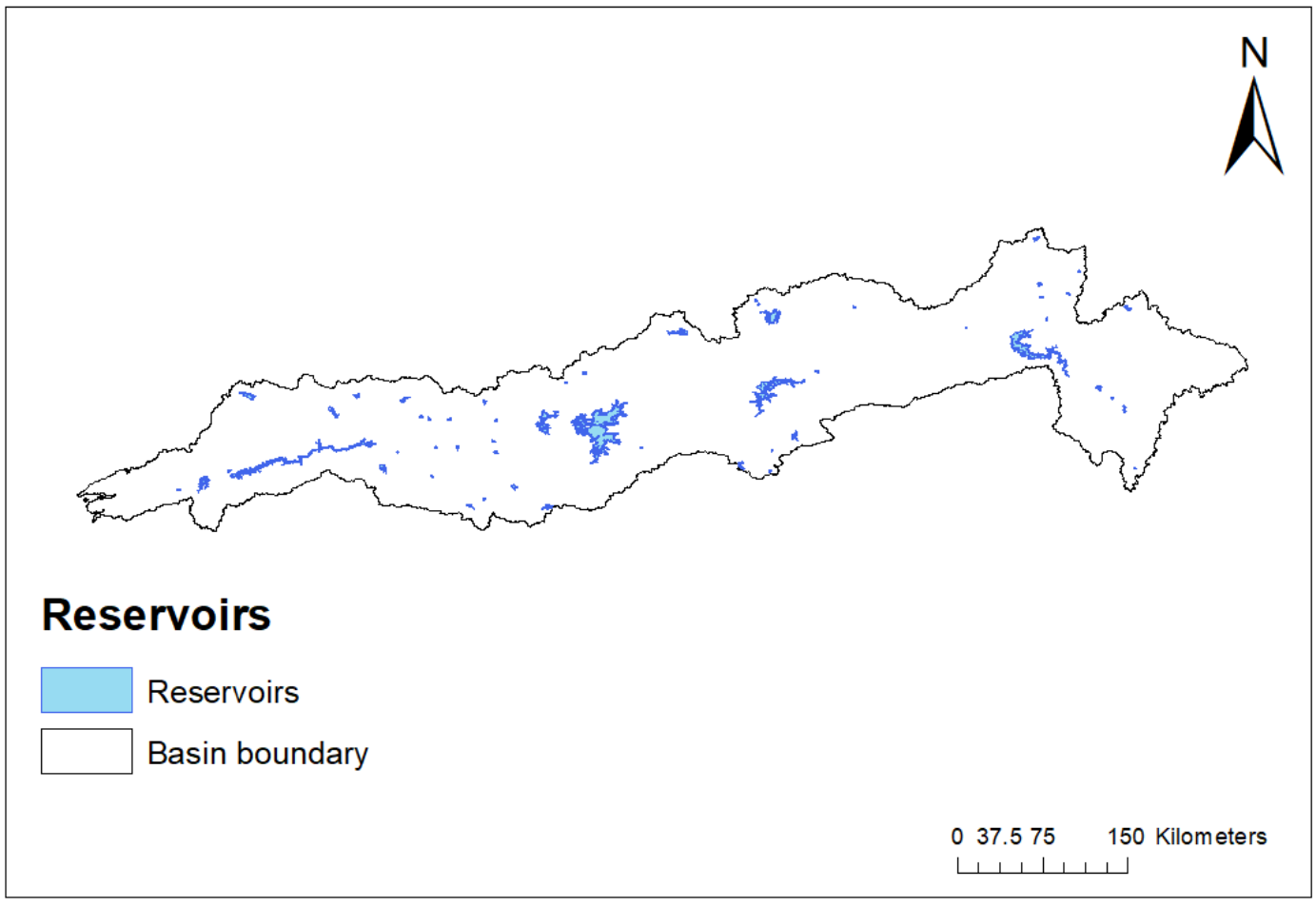


Figure 4.14.6: Reservoir map of Narmada Basin

4.14.3.4 Evapotranspiration from Irrigation Input

The ET from Irrigation Input for the basin for the years 1985-2023 has been estimated as 14.19 BCM. The command area map used for the estimation of ET from Irrigation Input is shown in Figure 4.14.7. Yearly variations in Evapotranspiration from Irrigation Input are shown in Figure 4.14.8.

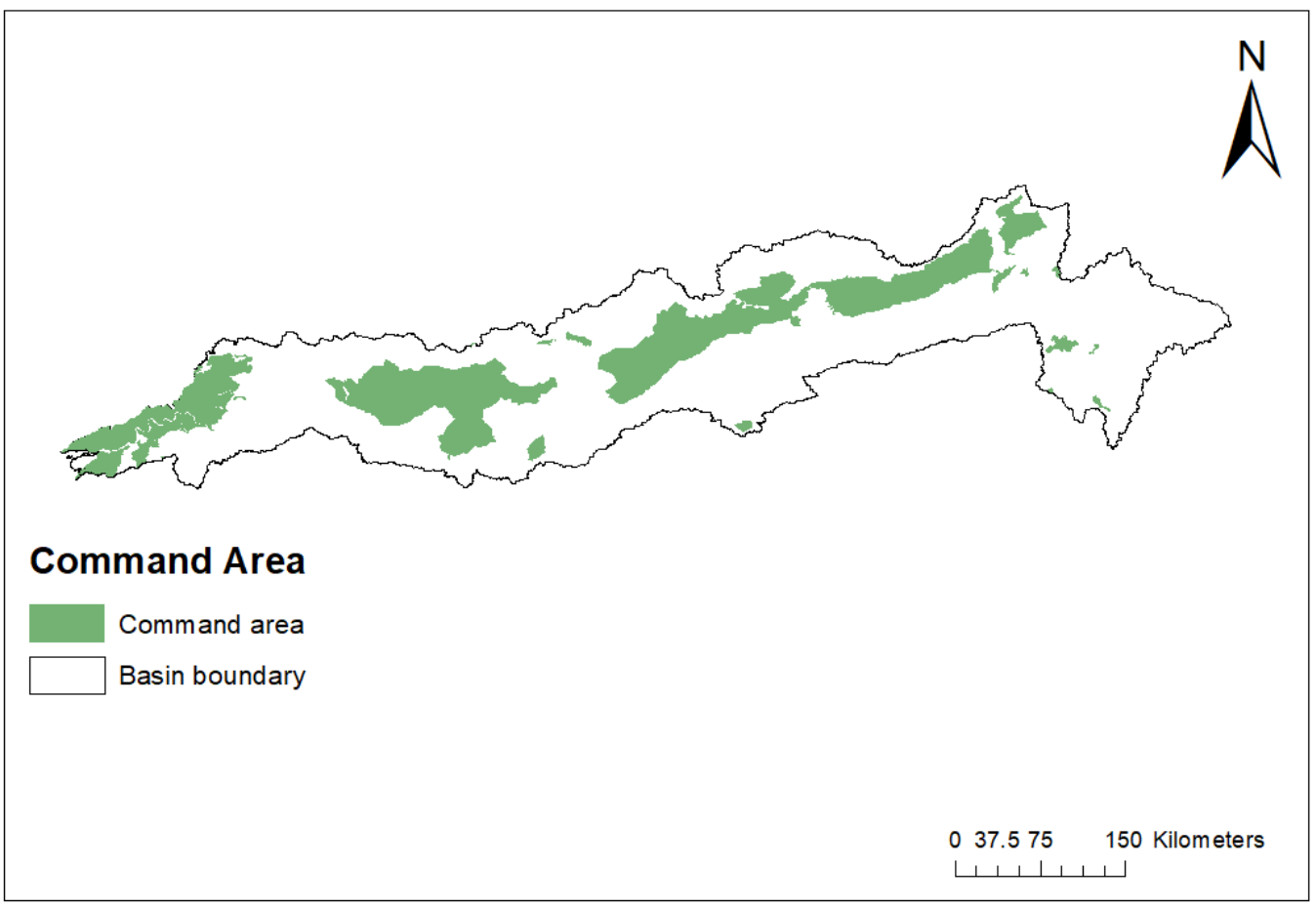


Figure 4.14.7: Command area map of Narmada basin

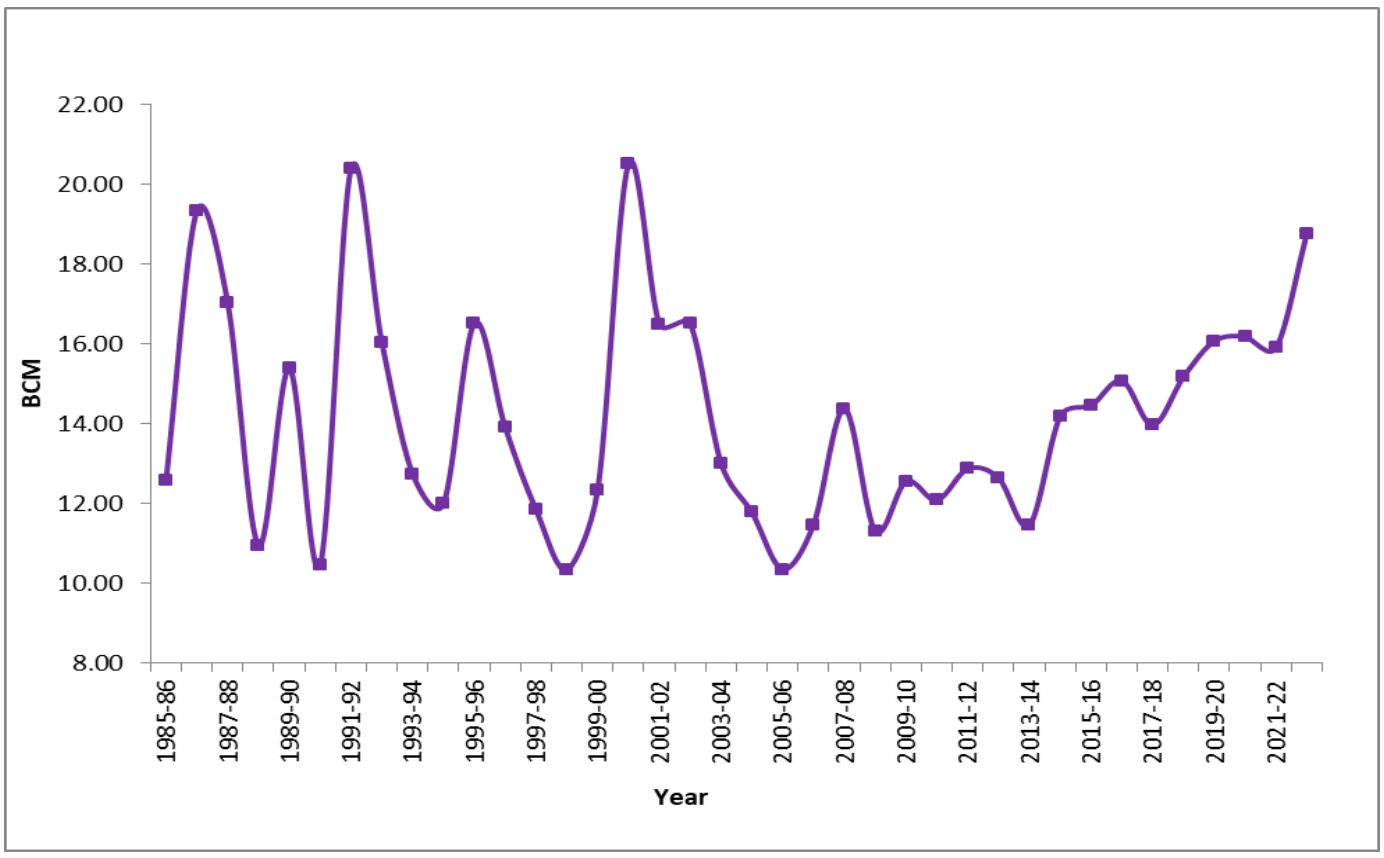


Figure 4.14.8: ET from Irrigation Input in Narmada basin

4.14.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.27 BCM and 0.16 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.46 BCM.

4.14.4 Previous Estimates

During 1993 study, no separate assessment was made for estimating water resources of the Narmada basin. The potential of Narmada basin was worked out on the basis of catchment area proportion from the potential assessed at Garudeswar (catchment area = 89,345 sq.km) as given in the report with its decision, 1979 of Narmada Water Disputes Tribunal. The water resources potential was estimated as 45.64 BCM.

The CWC (2019) estimate of Water Availability using space inputs of the Narmada basin was 58.21 BCM.

4.14.5 Annual Water Availability of Narmada Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated as 49.95 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.14.9. The results of Narmada basin are shown in Table 4.14.3.

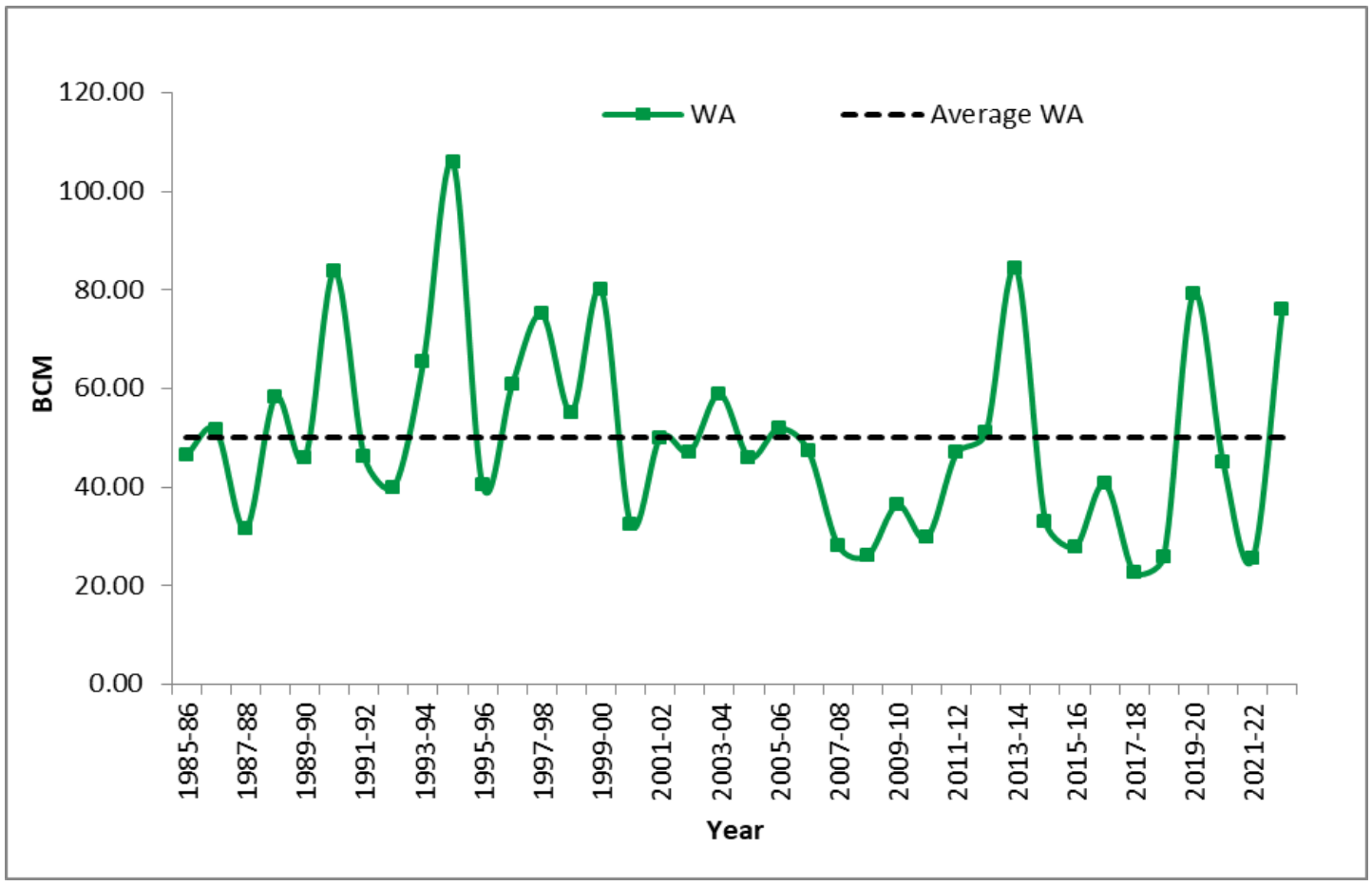


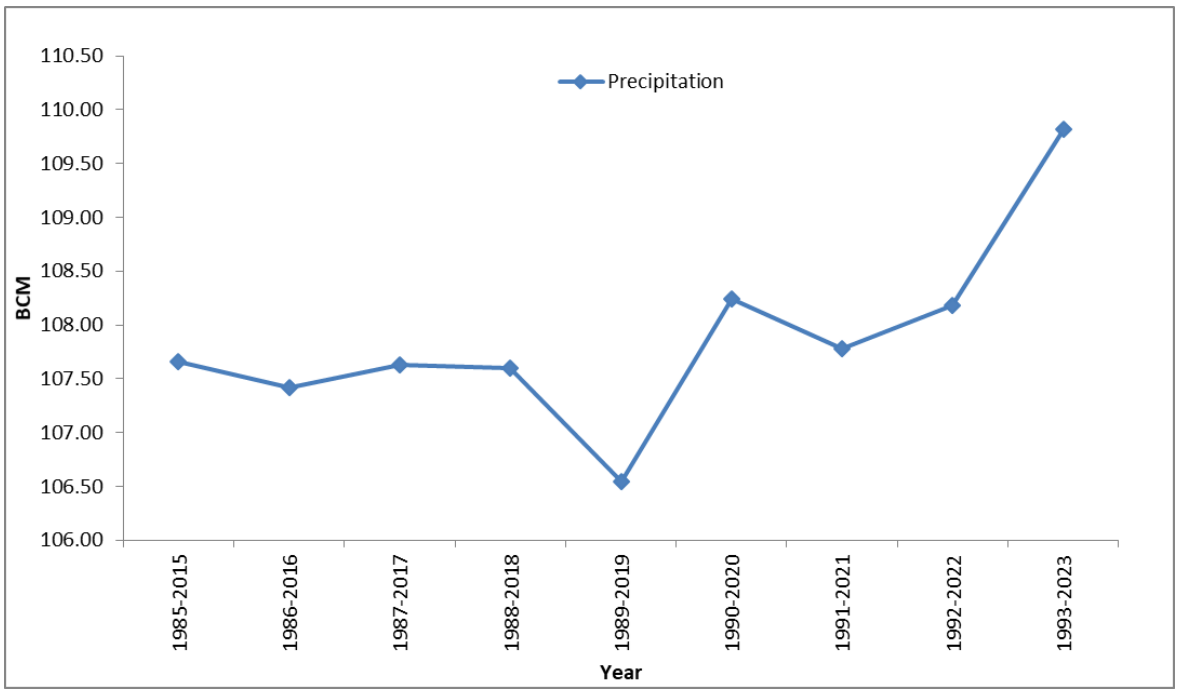
Figure 4.14.9: Water Availability of Narmada basin

4.14.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water resources availability of Narmada basin is given at Table 4.14.2. A line diagram of moving average of P and WA is shown in Figure 4.14.10.

Table 4.14.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	107.66	51.51
1986-2016	107.42	50.88
1987-2017	107.63	50.52
1988-2018	107.60	50.11
1989-2019	106.55	48.71
1990-2020	108.24	49.82
1991-2021	107.78	48.53
1992-2022	108.18	47.84
1993-2023	109.82	49.06



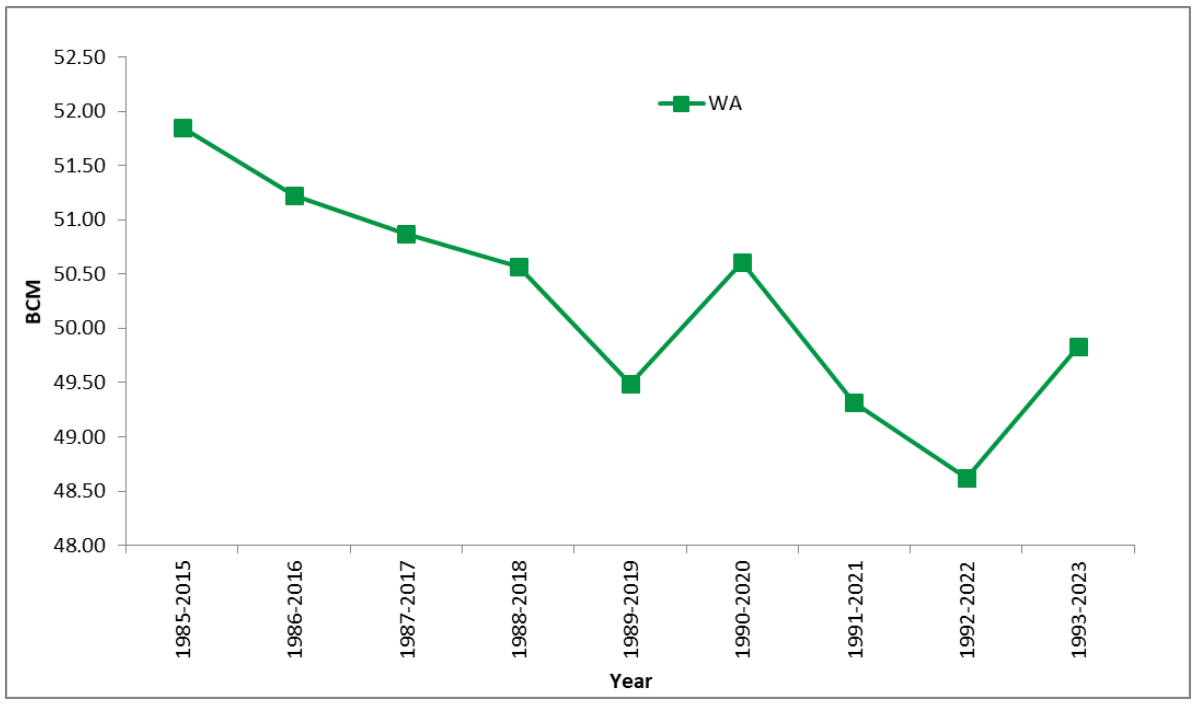


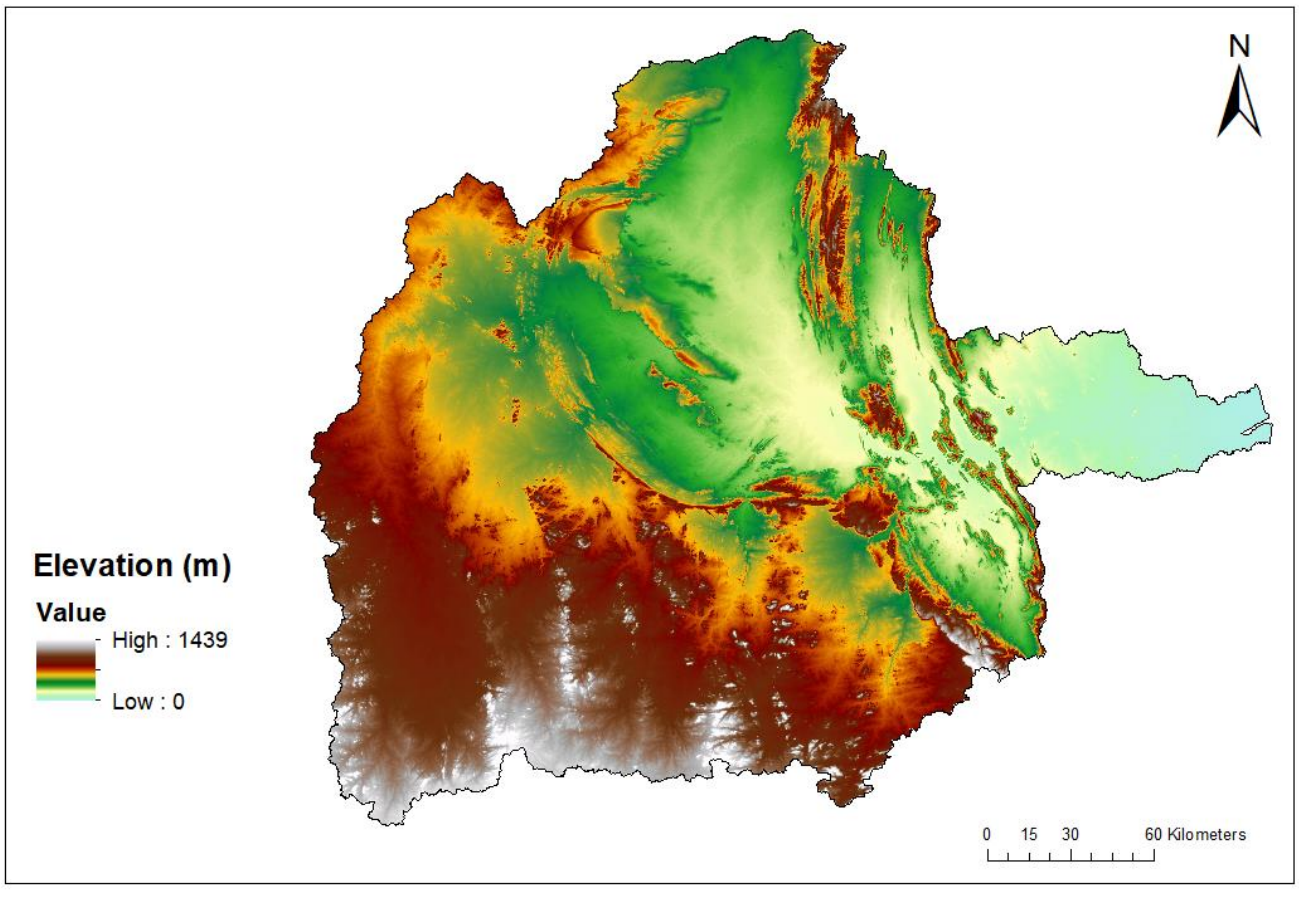
Figure 4.14.10: Moving Average of P and WA for 30 years

Table 4.14.3: Water Availability of Narmada basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	97.74	51.29	46.45
1986-87	101.13	49.63	51.50
1987-88	85.02	53.56	31.46
1988-89	112.35	54.09	58.26
1989-90	98.16	52.36	45.80
1990-91	133.46	49.68	83.78
1991-92	86.87	40.62	46.25
1992-93	90.34	50.43	39.91
1993-94	115.56	50.21	65.35
1994-95	152.47	46.71	105.76
1995-96	93.09	52.75	40.34
1996-97	105.00	44.23	60.77
1997-98	127.49	52.45	75.04
1998-99	110.25	55.02	55.23
1999-00	127.80	47.79	80.01
2000-01	73.63	41.15	32.48
2001-02	99.84	49.78	50.06
2002-03	94.48	47.30	47.18
2003-04	124.56	65.68	58.88
2004-05	103.90	57.86	46.04
2005-06	115.21	63.30	51.91
2006-07	112.63	65.27	47.36
2007-08	90.56	62.38	28.18
2008-09	88.35	62.30	26.05
2009-10	101.12	64.75	36.37
2010-11	96.88	67.17	29.71
2011-12	114.21	67.29	46.92
2012-13	117.54	66.47	51.07
2013-14	157.51	73.09	84.42
2014-15	102.75	69.69	33.06
2015-16	90.45	62.75	27.70
2016-17	107.47	66.82	40.65
2017-18	84.18	61.66	22.52
2018-19	80.71	54.77	25.94
2019-20	148.99	69.75	79.24
2020-21	119.41	74.32	45.09
2021-22	99.15	73.70	25.45
2022-23	139.46	63.41	76.05
Average	**107.89**	**57.93**	**49.95**

4.15 PENNAR BASIN



HIGHLIGHTS

- *Average annual water resources availability of Pennar basin is 10.42 BCM.*
- *Maximum annual water availability is 30.23 BCM during 1996-97.*
- *Minimum annual water availability is 2.67 BCM during 2011-12.*
- *Average annual precipitation is 41.33 BCM (752.72 mm).*
- *Maximum annual precipitation is 69.46 BCM (1265 mm) during 2020-21.*
- *Minimum annual precipitation is 21.67 BCM (395 mm) during 2018-19.*

4.15.1 About Pennar Basin

Located in peninsular India, the Pennar basin extends over states of Andhra Pradesh (87%) and Karnataka (13%) having an area of 54,905 sq.km, which is nearly 1.67% of the total geographical area of the country with maximum length and width of 433 km and 266 km. The Pennar River (also known as Uttara Pinakini) is one of the major East Flowing Rivers in southern India with length of 697 km. It rises in the Chenna Kasava hill of the Nandidurg range in Karnataka, flows in the North Westerly direction through Kolar and Tumkur districts of Karnataka and enters Andhra Pradesh in the Hindupur taluk of Anantapur district, runs eastwards before draining into the Bay of Bengal near Nellore. The principal tributaries of the river joining from left are the Jayamangali, the Kunderu and the Sagileru whereas the Chitravathi, the Papagni and the Cheyyeru join it from right.

4.15.2 Geo-Spatial Datasets

4.15.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Pennar basin for year 2022-23 is shown in Figure 4.15.1. The major land use classes consist of Kharif only, Double/Triple, waste land etc.

Table 4.15.1 shows the percentage area of each land use class in the basin for year 2022-23.

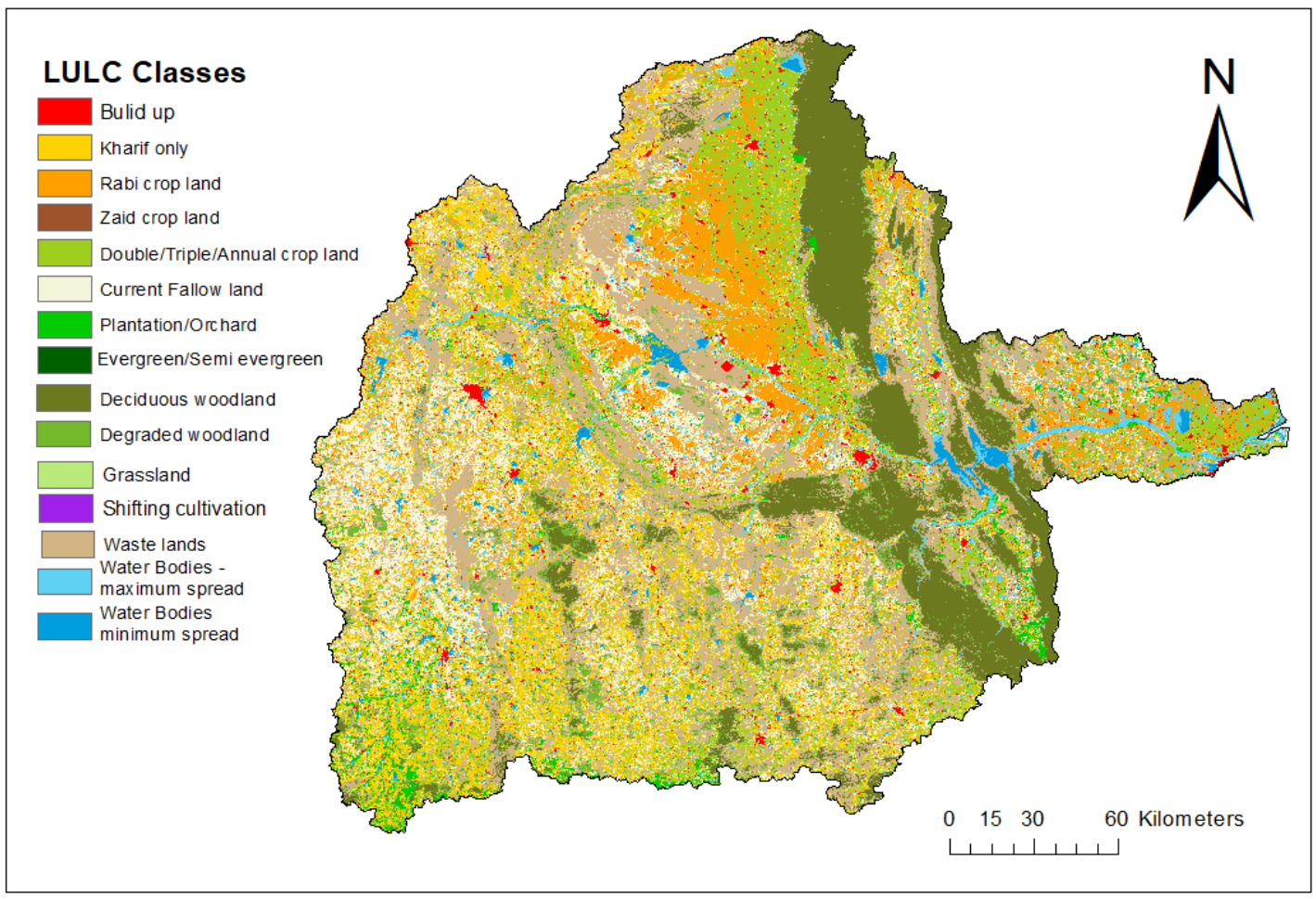


Figure 4.15.1: LULC Map of Pennar basin

Table 4.15.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	1.89
2.	Kharif only	14.12
3.	Rabi crop land	10.19
4.	Zaid crop land	0.04
5.	Double/Triple/Annual crop land	13.22
6.	Current Fallow land	16.24
7.	Plantation/Orchard	1.83
8.	Deciduous woodland	12.70
9.	Degraded woodland	3.00
10.	Waste lands	21.60
11.	Water Bodies - maximum spread	3.74
12.	Water Bodies - minimum spread	1.43

4.15.3 Hydro-Meteorological and other Input Data

4.15.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.15.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.15.3. The average precipitation of 38 years is approximately 41.33 BCM (752.72 mm).

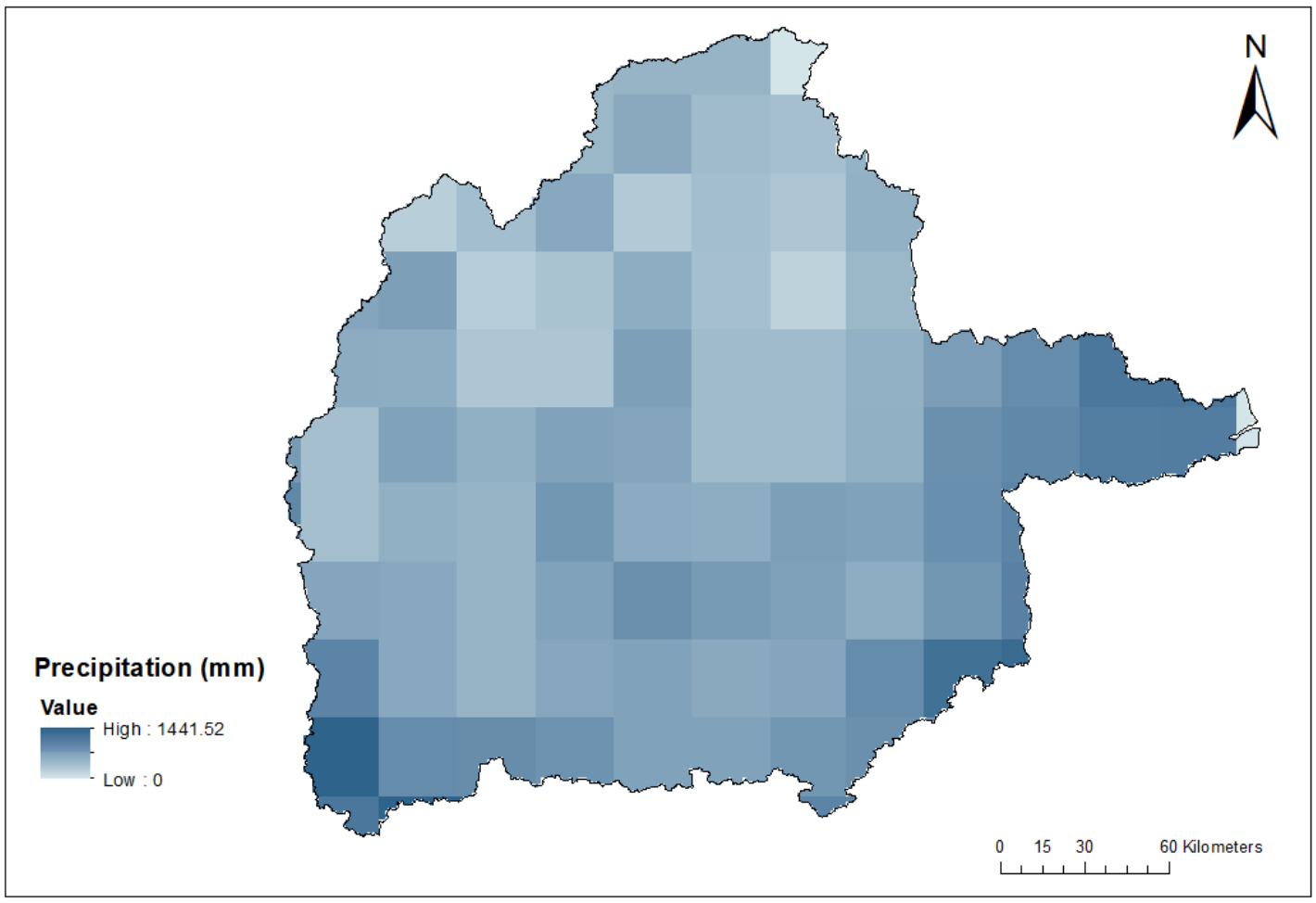


Figure 4.15.2: Precipitation map of Pennar basin

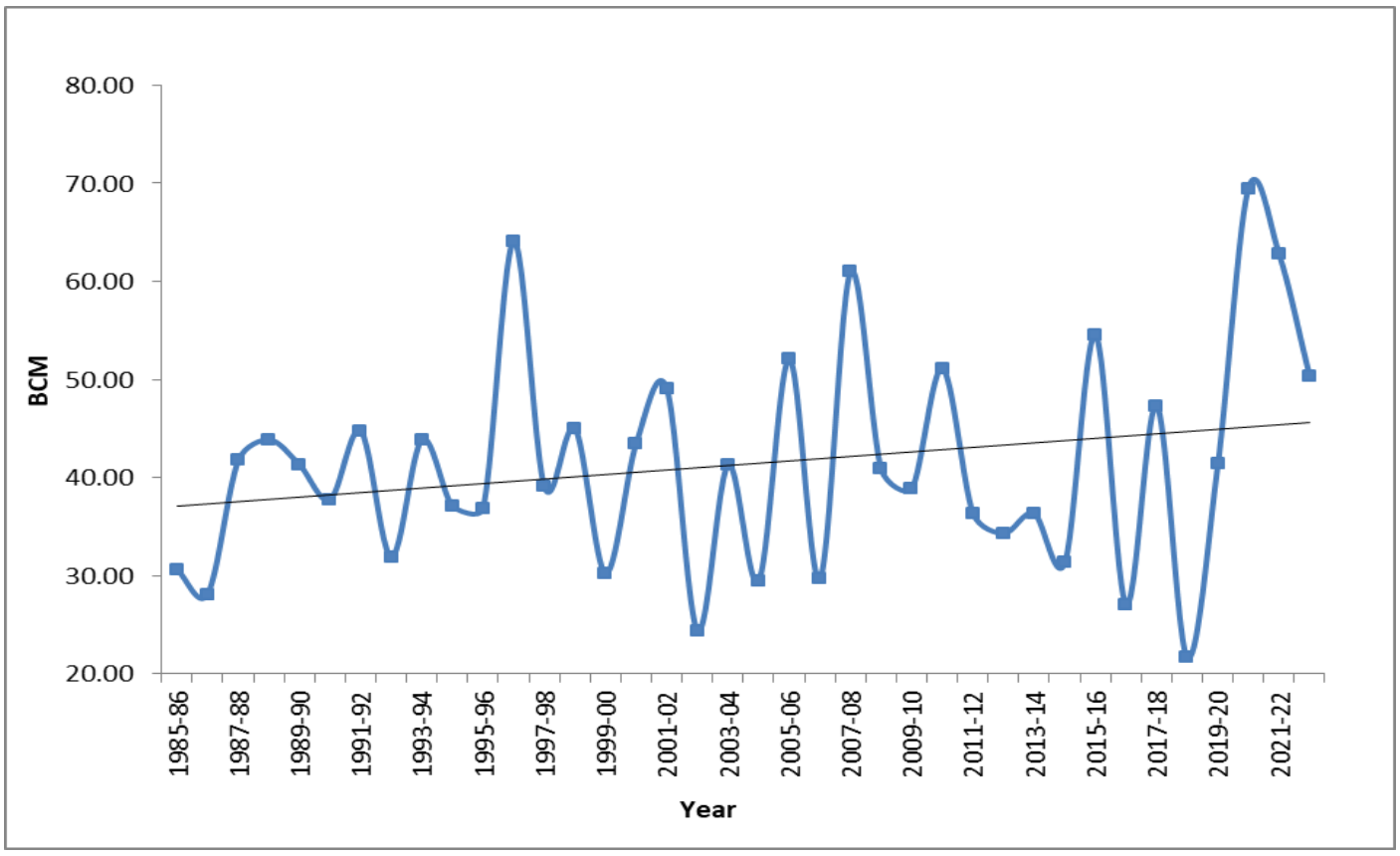


Figure 4.15.3: Annual Precipitation in Pennar basin

4.15.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.15.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.15.5. The average ET of 38 years is approximately 36.75 BCM (669.32 mm).

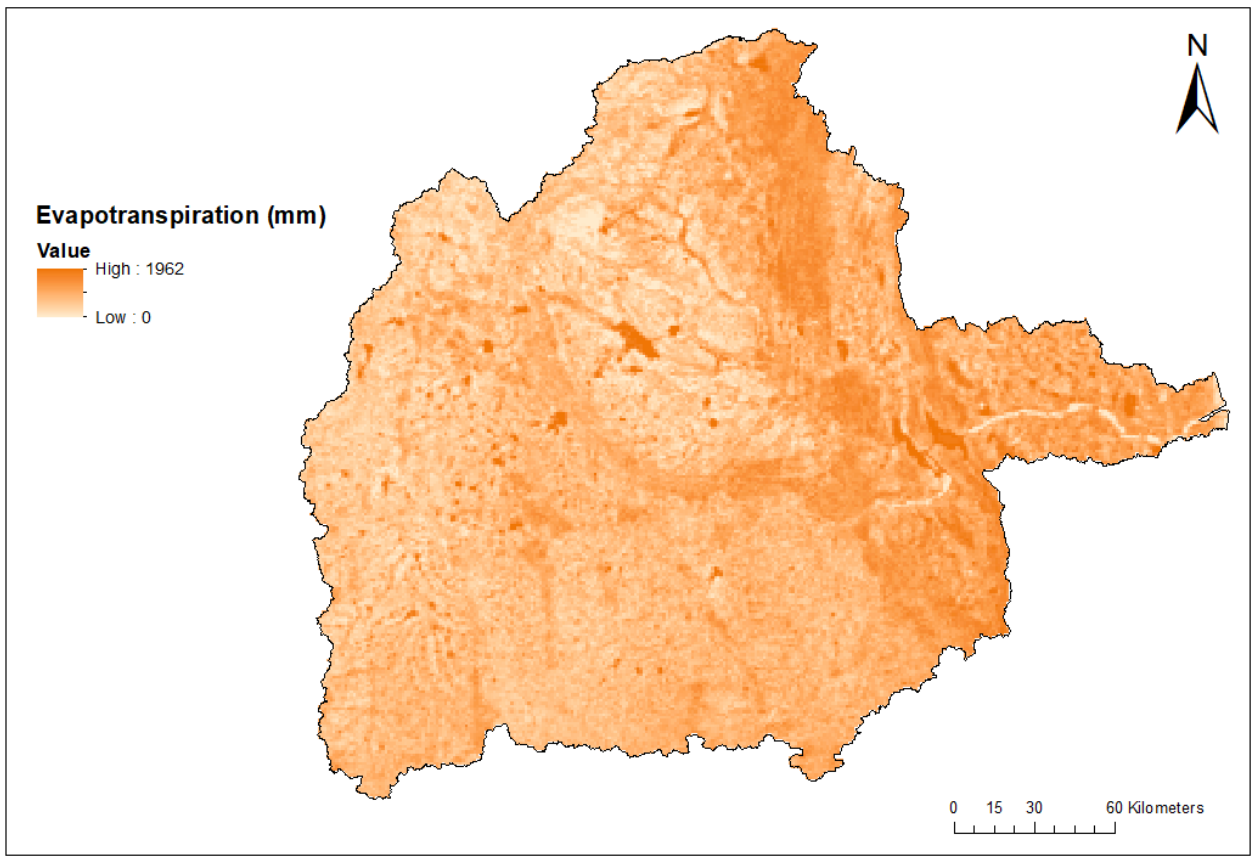


Figure 4.15.4: Evapotranspiration map of Pennar basin

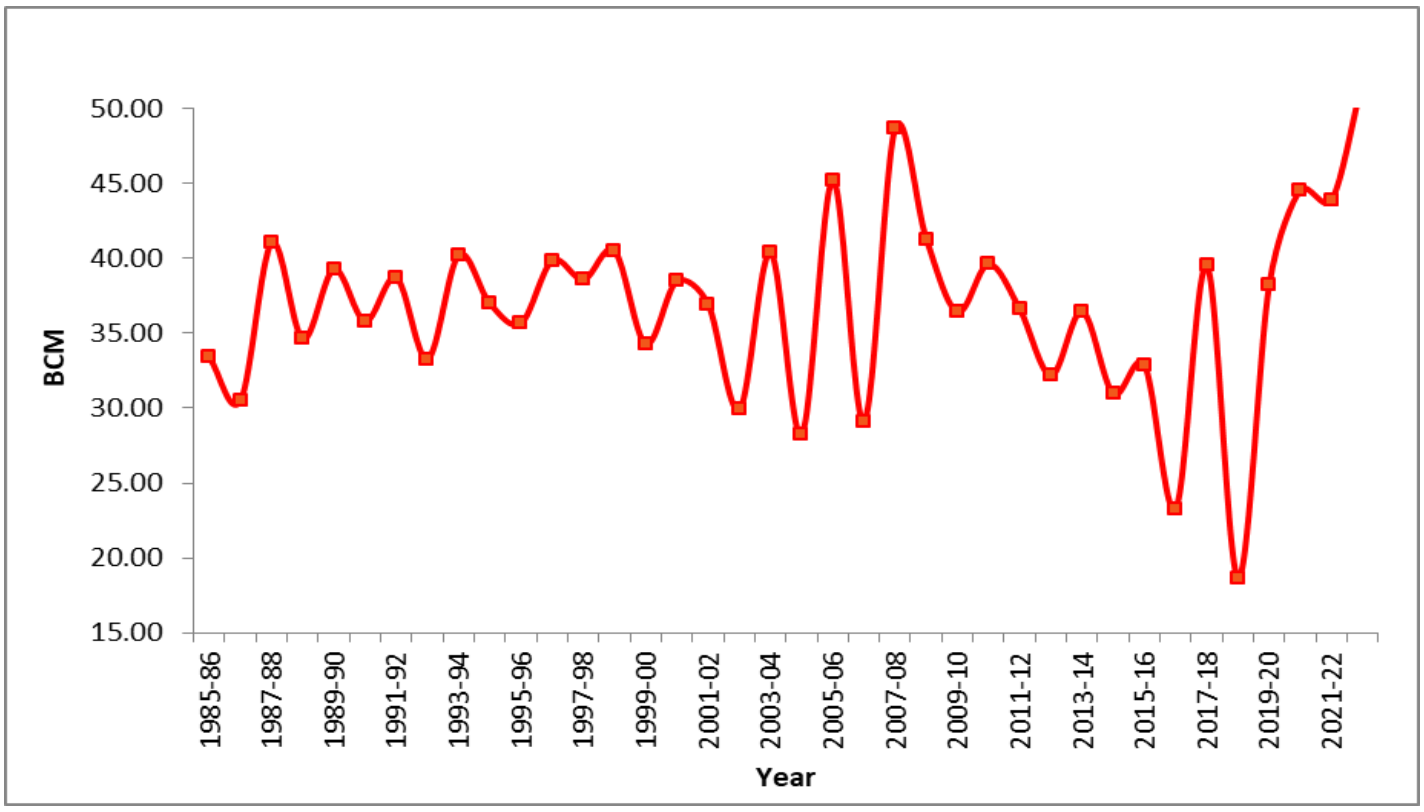


Figure 4.15.5: Annual Evapotranspiration in Pennar basin

4.15.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.15.6. The average annual evaporation from the reservoirs in the basin is 0.50 BCM.

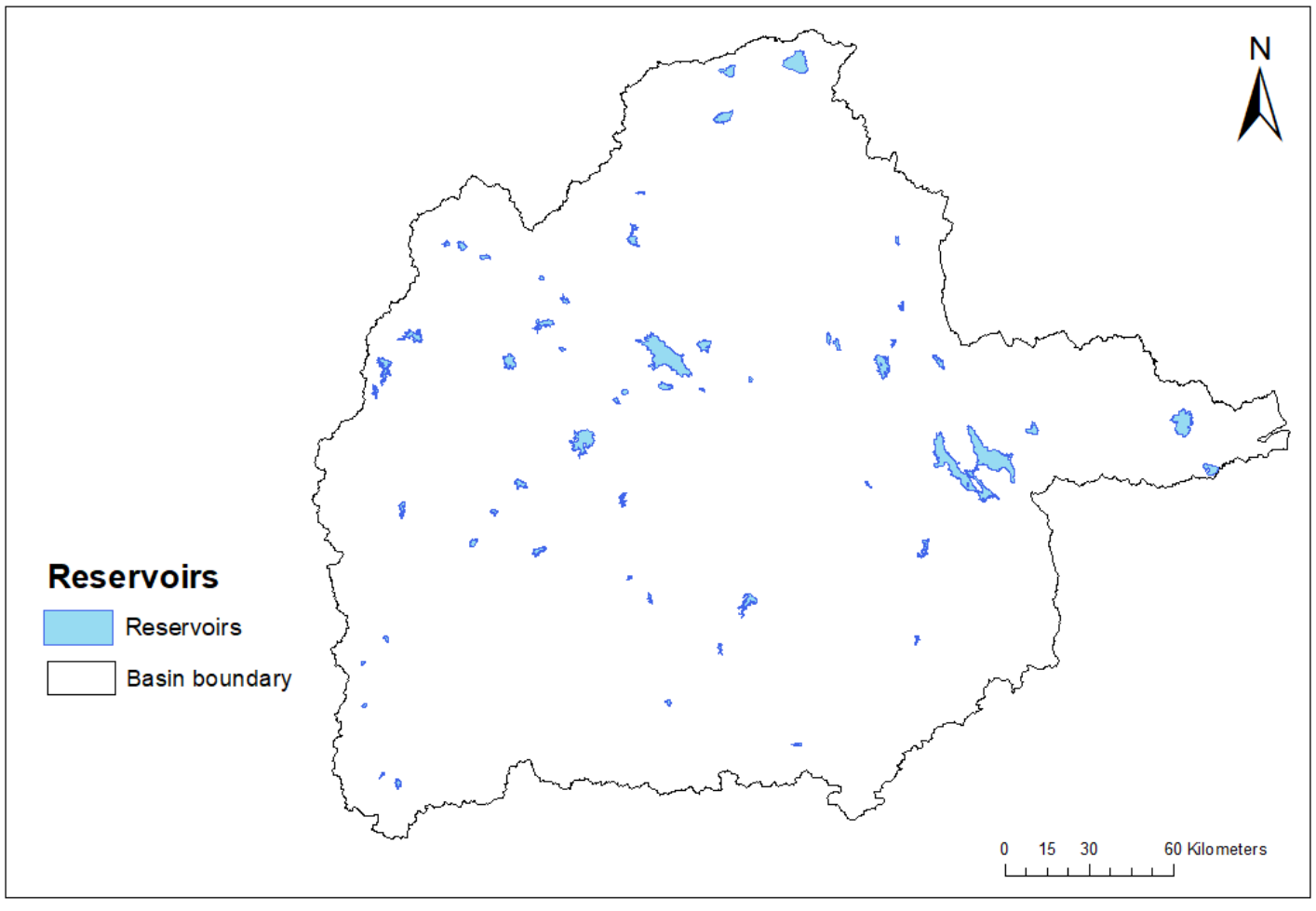


Figure 4.15.6: Reservoir map of Pennar basin

4.15.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 6.02 BCM. The command area map used for the estimation of ET_{II} is shown in figure 4.15.7. Yearly variations in ET_{II} are shown in Figure 4.15.8.

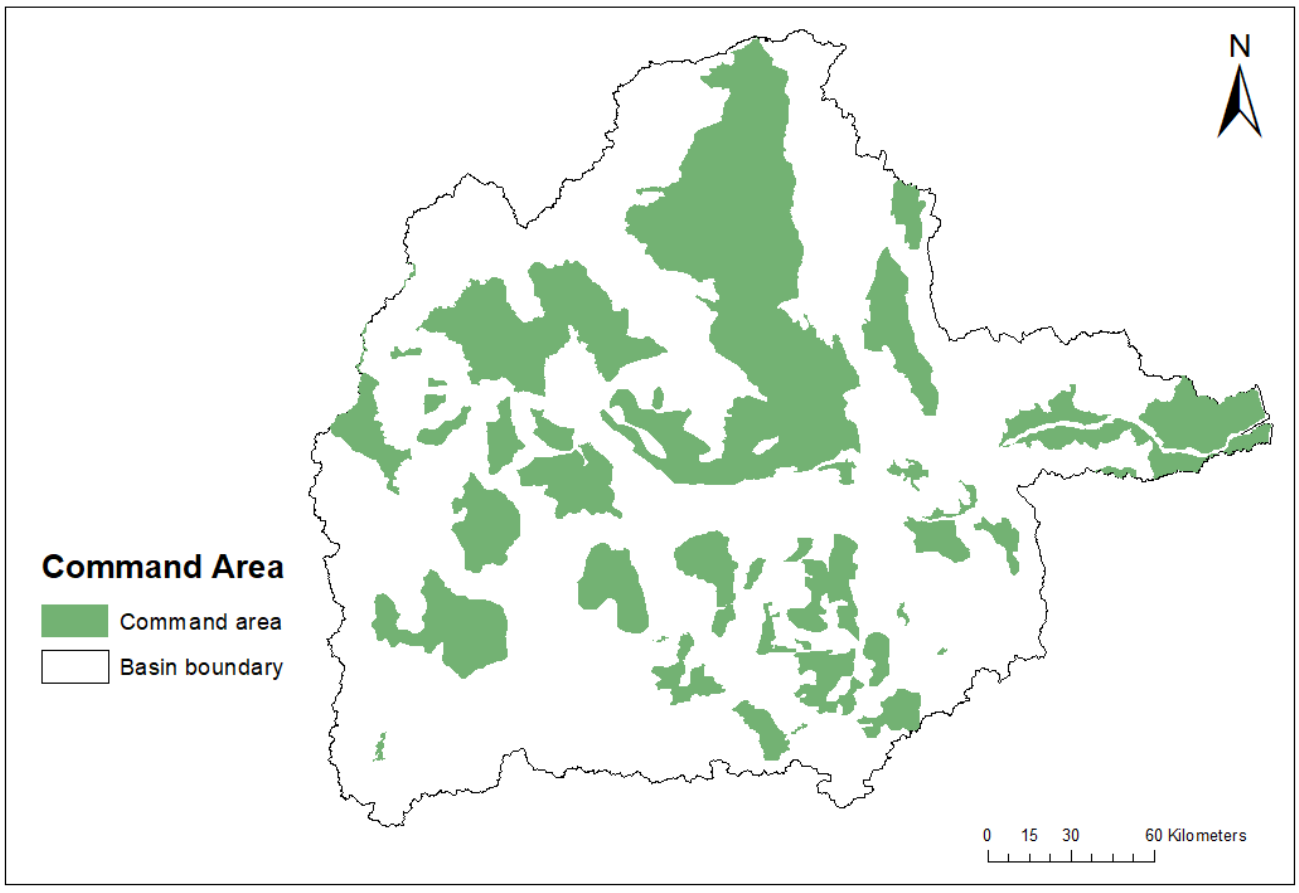


Figure 4.15.7: Command area map of Pennar basin

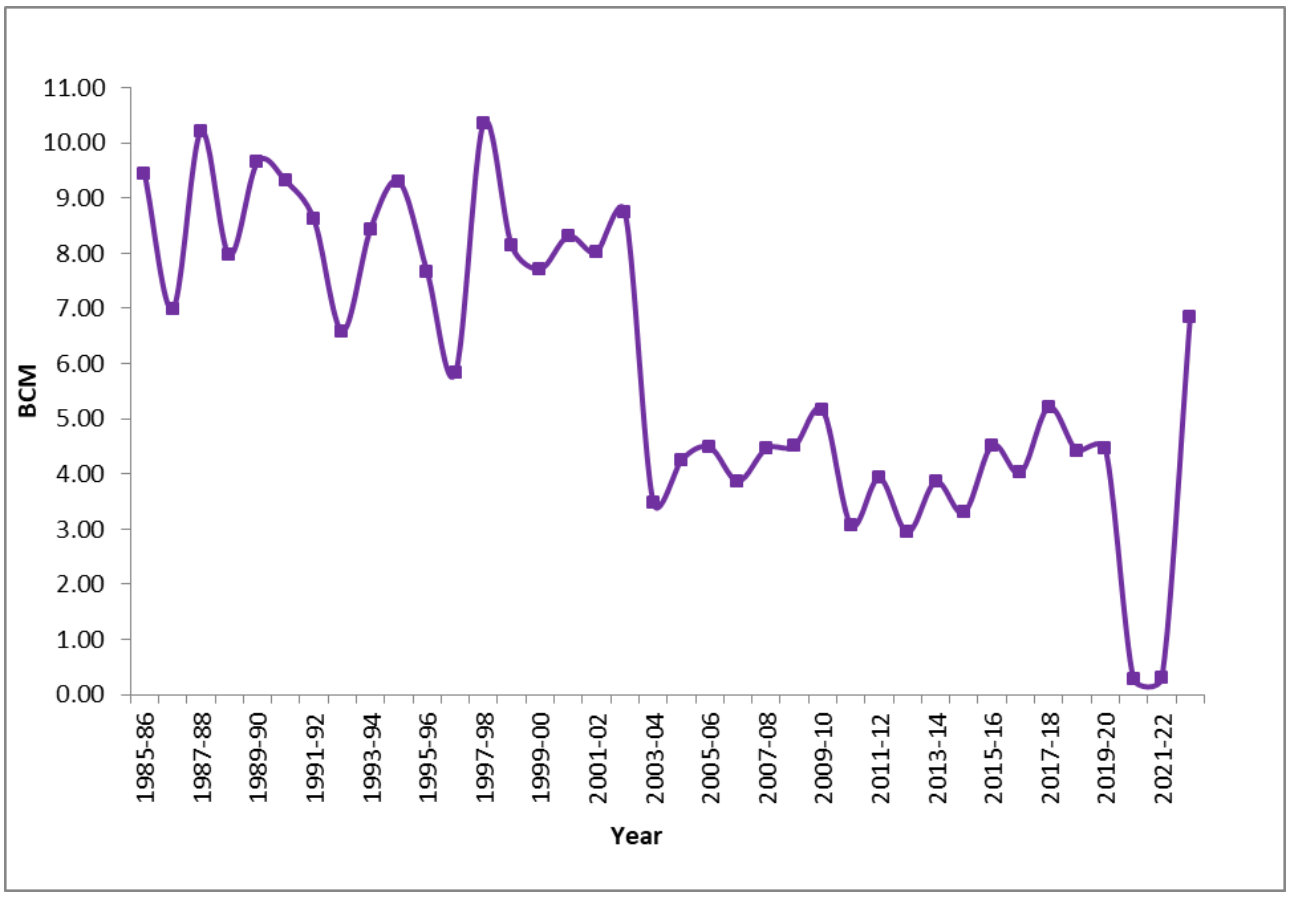


Figure 4.15.8: Evapotranspiration from Irrigation Input in Pennar basin

4.15.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.42 BCM and 0.05 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.49 BCM.

4.15.4 Previous Estimates

In 1949 when the basin wise assessment of the water resources of the country was made on the basis of Khosla's empirical formula, the annual runoff of Pennar river system was estimated as practically nil. In 1960, CW&PC assessed the total annual runoff of Pennar river as 6.86 BCM which is also reported in CWC's Publication No. 30/88 "Water Resources of India", April 1988.

In the 1993 study done by CWC, the estimated water availability of Pennar basin was 6.32 BCM. As per 2019 study of CWC, the water availability of Pennar basin was estimated as 11.20 BCM.

4.15.5 Annual Water Availability of Pennar Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average annual water availability from year 1985-86 to 2022-23 of Pennar basin is estimated as 10.42 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.15.9. The results of Pennar basin are shown in Table 4.15.3.

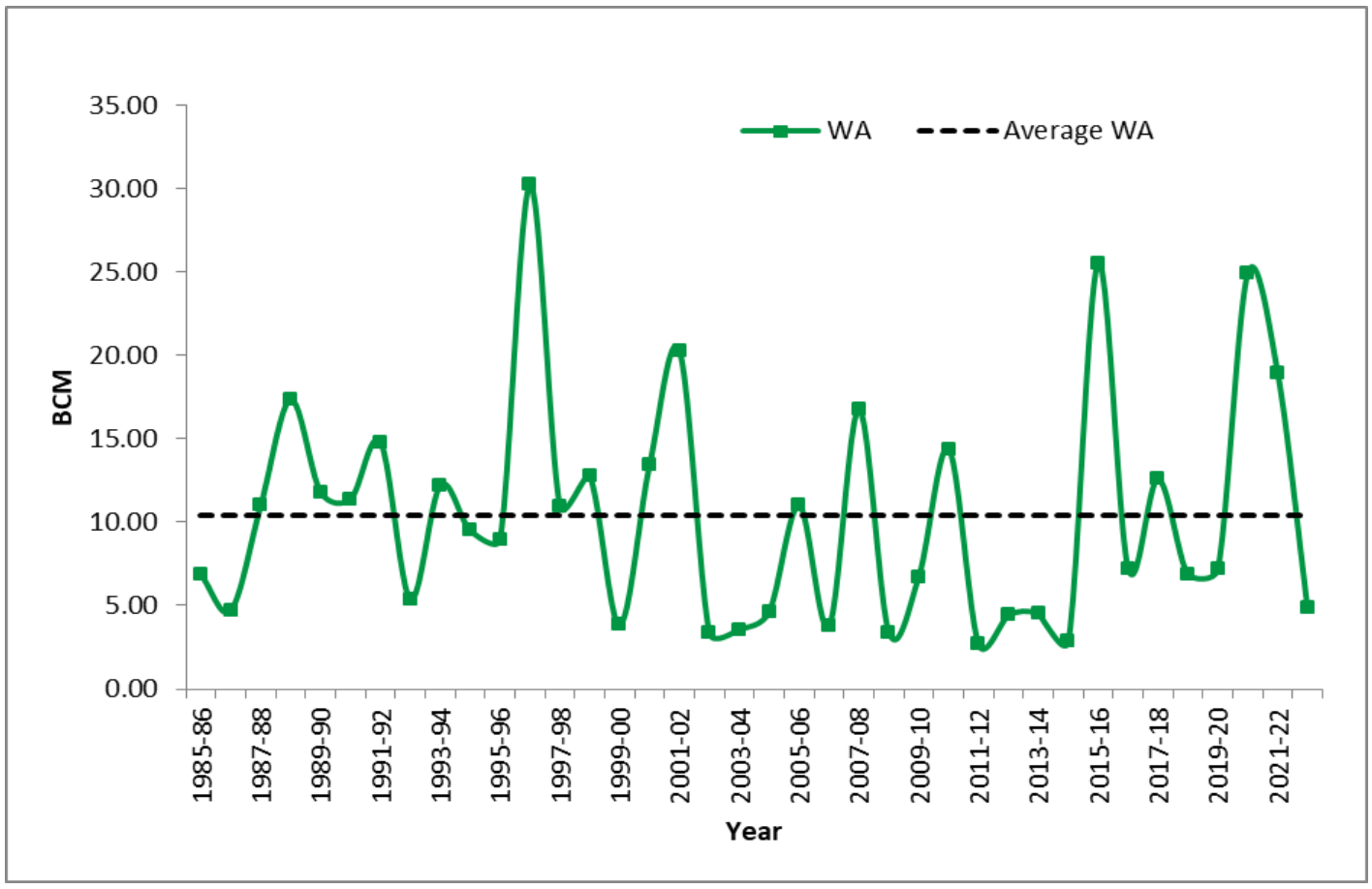


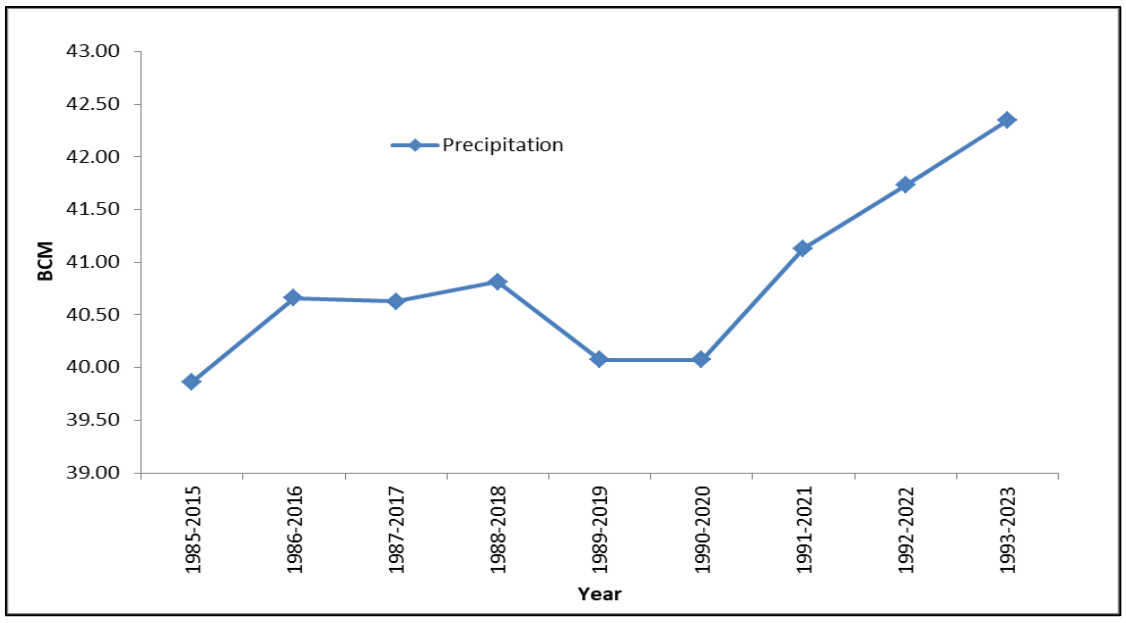
Figure 4.15.9: Water Availability of Pennar basin

4.15.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Pennar basin is given at Table 4.15.2. A line diagram of moving average of P and WA is shown in Figure 4.15.10.

Table 4.15.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	39.86	9.59
1986-2016	40.66	10.21
1987-2017	40.63	10.29
1988-2018	40.81	10.35
1989-2019	40.07	10.00
1990-2020	40.07	9.84
1991-2021	41.13	10.30
1992-2022	41.73	10.43
1993-2023	42.35	10.42



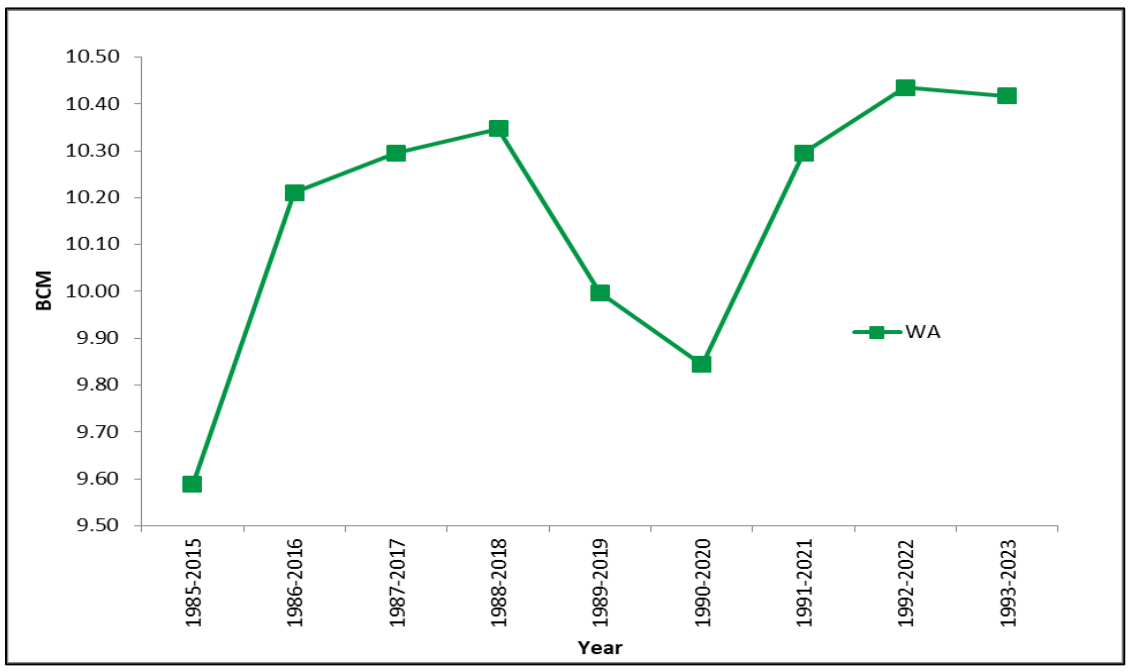


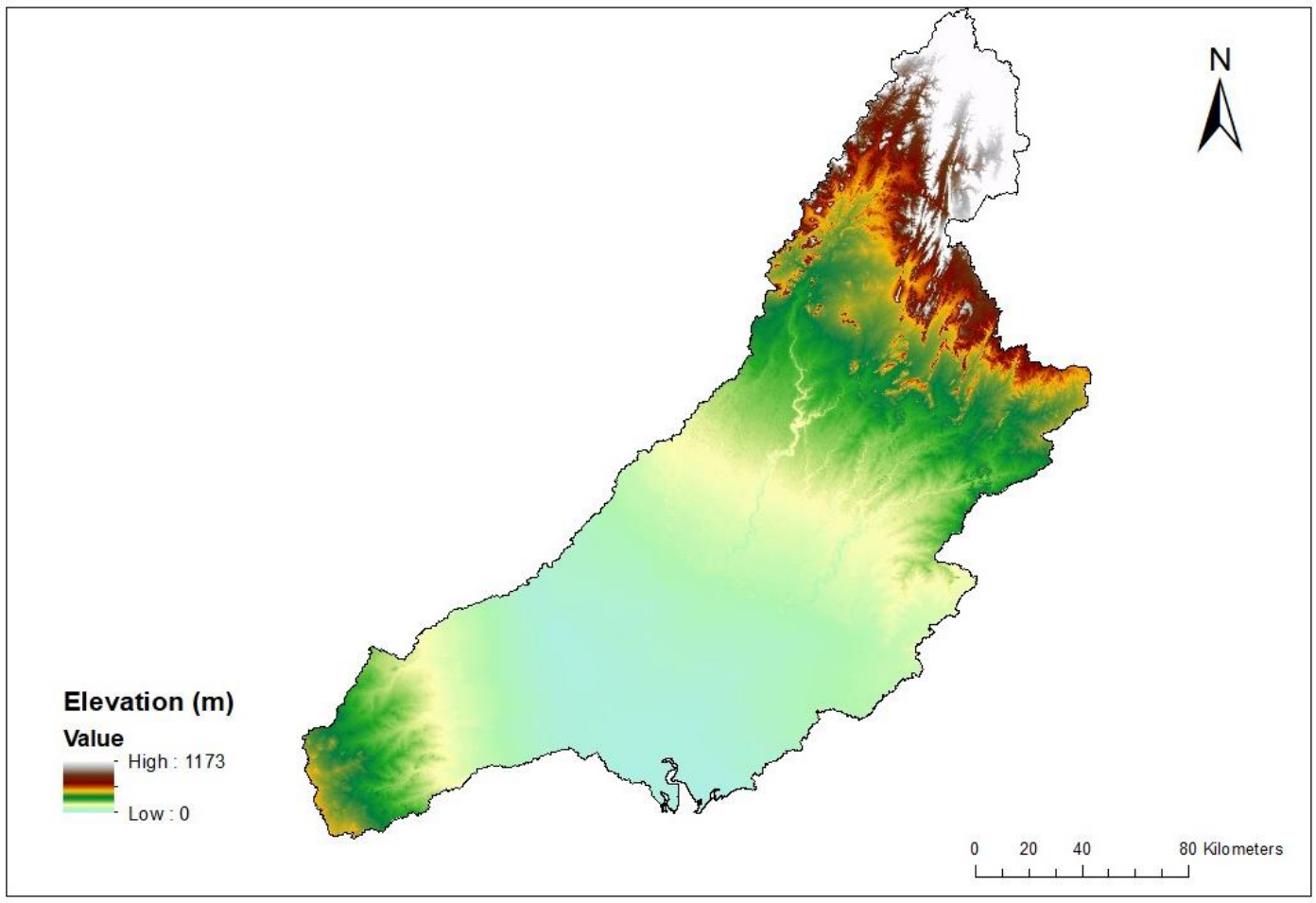
Figure 4.15.10: Moving Average of P and WA for 30 years

Table 4.15.3 Water Availability of Pennar basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	30.64	23.80	6.84
1986-87	28.11	23.39	4.72
1987-88	41.73	30.71	11.02
1988-89	43.88	26.53	17.35
1989-90	41.31	29.50	11.81
1190-91	37.77	26.39	11.38
1991-92	44.76	29.96	14.80
1992-93	31.91	26.52	5.39
1993-94	43.87	31.66	12.21
1994-95	37.08	27.57	9.51
1995-96	36.89	27.90	8.99
1996-97	64.08	33.85	30.23
1997-98	39.08	28.10	10.98
1998-99	44.98	32.23	12.75
1999-00	30.25	26.41	3.84
2000-01	43.48	30.04	13.44
2001-02	49.06	28.80	20.26
2002-03	24.41	21.05	3.36
2003-04	41.27	36.31	3.58
2004-05	29.49	23.43	4.64
2005-06	52.09	39.92	11.00
2006-07	29.68	24.49	3.76
2007-08	60.95	43.30	16.77
2008-09	40.87	35.94	3.40
2009-10	38.84	30.43	6.72
2010-11	51.10	35.66	14.40
2011-12	36.37	31.80	2.67
2012-13	34.29	28.54	4.42
2013-14	36.35	30.66	3.42
2014-15	31.33	26.95	2.88
2015-16	54.52	27.66	25.53
2016-17	27.09	18.51	7.24
2017-18	47.32	33.40	12.59
2018-19	21.67	13.49	6.85
2019-20	41.38	32.85	7.21
2020-21	69.46	43.20	24.93
2021-22	62.78	42.48	18.97
2022-23	50.32	44.15	4.84
Average	**41.33**	**30.20**	**10.42**

4.16 SABARMATI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Sabarmati basin is 9.87 BCM.*
- *Maximum annual water availability is 25.51 BCM during 1994-95.*
- *Minimum annual water availability is 1.33 BCM during 2018-19.*
- *Average annual precipitation is 24.20 BCM (758.62 mm).*
- *Maximum annual precipitation is 41.73 BCM (1308 mm) during 2006-07.*
- *Minimum annual precipitation is 8.74 BCM (274 mm) during 1987-88.*

4.16.1 About Sabarmati Basin

The Sabarmati River is one of the major west flowing inter-state rivers in India draining into the Gulf of Khambhat. The basin lies in the states of Rajasthan and Gujarat and have a drainage area of 4,126.2 sq.km (12.93%) and 27,775 sq.km (87.07%) respectively in these States. The Sabarmati river originates in the Aravalli hills in the State of Rajasthan at an elevation of 762 m above MSL. The basin is bounded by Aravalli hills in the North and north-east, ridge separating it from Minor streams which are flowing into the Rann of Kutch in the west and Gulf of Khambhat in the south. The total catchment area of the Sabarmati basin extends over an area of 31,901 sq. km. The major tributaries of the Sabarmati are Sei, Wakal, Harnav, Hathmati and Watrak.

4.16.2 Geo-Spatial Datasets

4.16.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Sabarmati basin for year 2022-23 is shown in Figure 4.16.1. Major land use classes consist of Double/Triple/Annual crop land, Current Fallow land, Kharif only etc.

Table 4.16.1 shows the percentage area of each land use class for year 2022-23.

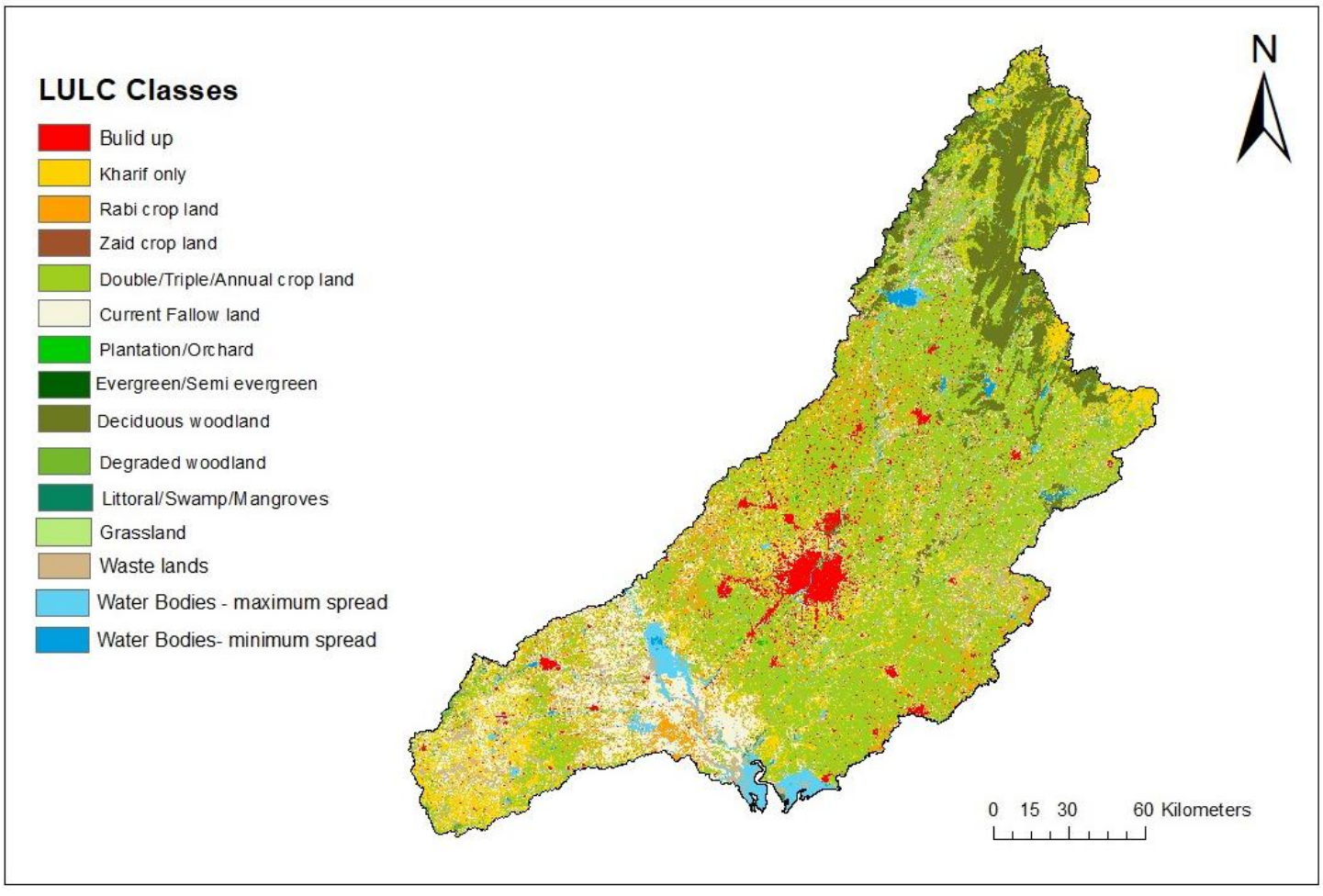


Figure 4.16.1: LULC Map of Sabarmati basin

Table 4.16.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) 2022-23
1.	Built-up land	4.32
2.	Kharif only	12.67
3.	Rabi crop land	6.56
4.	Double/Triple/Annual crop land	41.57
5.	Current Fallow land	12.35
6.	Plantation/Orchard	0.12
7.	Deciduous woodland	9.42
8.	Degraded woodland	2.51
9.	Grassland	0.01
10.	Waste lands	6.12
11.	Water Bodies - maximum spread	3.81
12.	Water Bodies- minimum spread	0.52

4.16.3 Hydro-Meteorological and other Input Data

4.16.3.1 Precipitation

The spatial variation of Precipitation for the year 2022-23 is shown in the Figure 4.16.2 and the variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.16.3. The average precipitation of 38 years is found to be 24.20 BCM (758.62 mm).

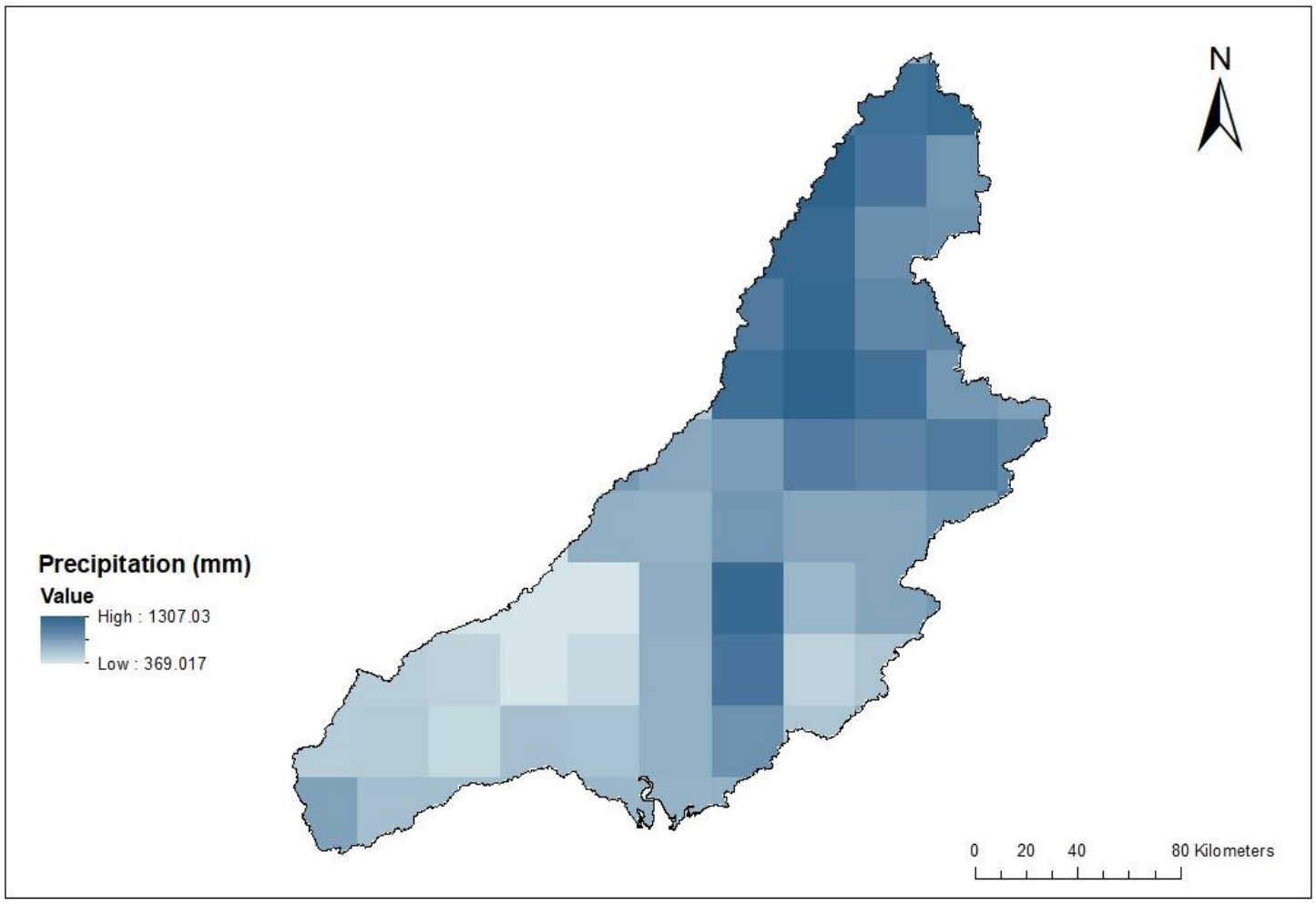


Figure 4.16.2: Precipitation map of Sabarmati basin

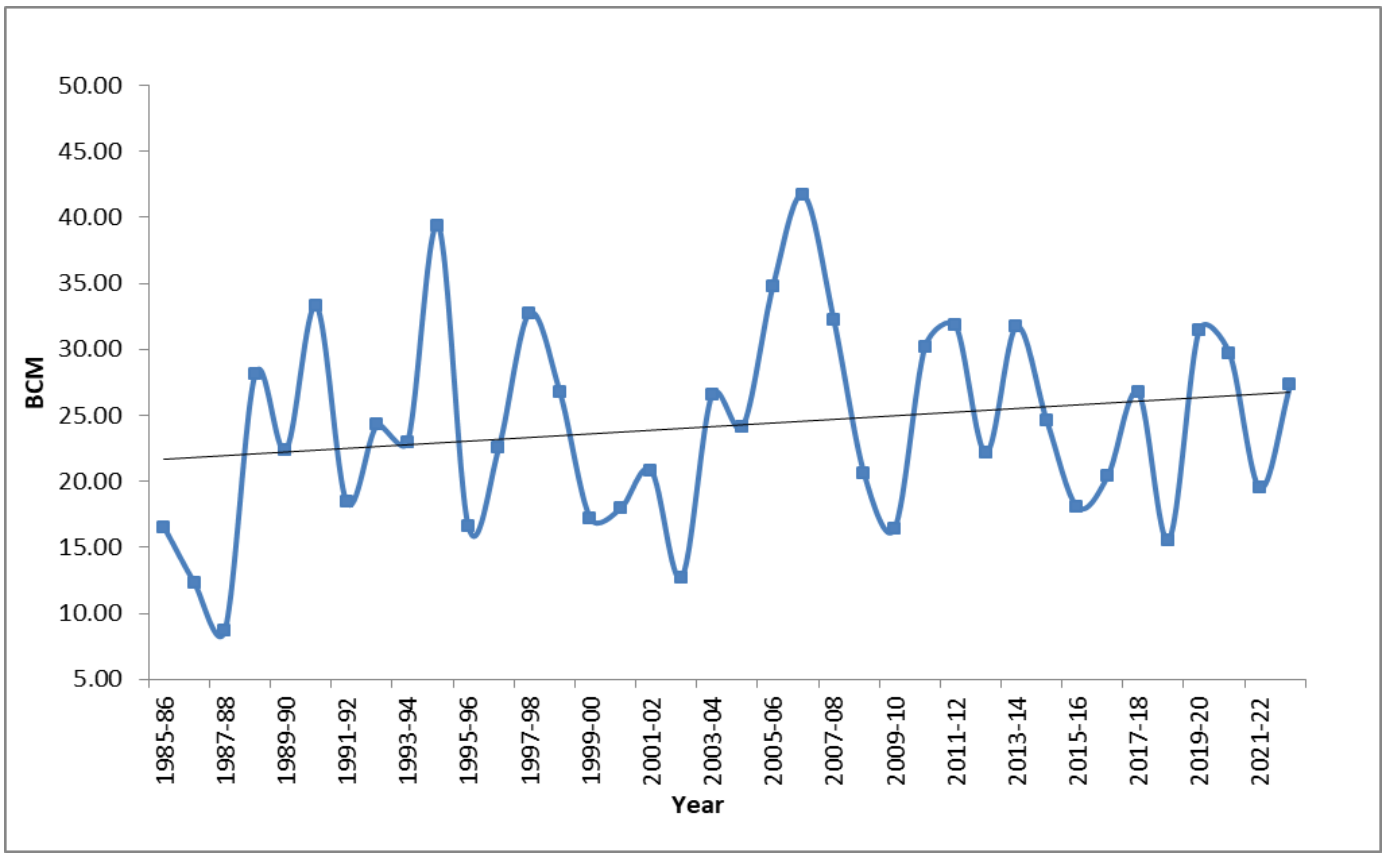


Figure 4.16.3: Annual Precipitation in Sabarmati basin

4.16.3.2 Evaporation

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.16.4. The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.16.5. The Average ET of 38 years is found to be 21.76 BCM (682.06 mm).

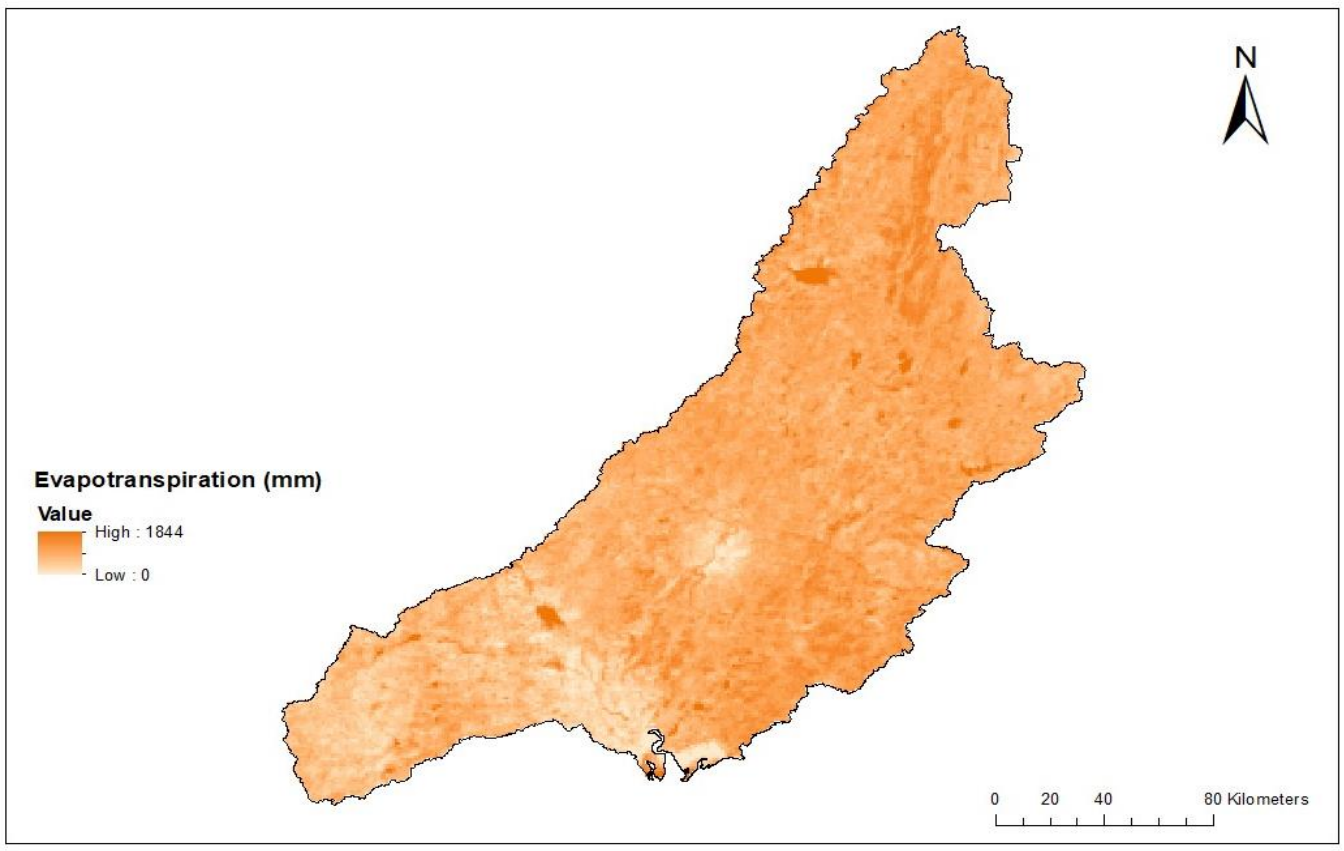


Figure 4.16.4: Evapotranspiration map of Sabarmati basin

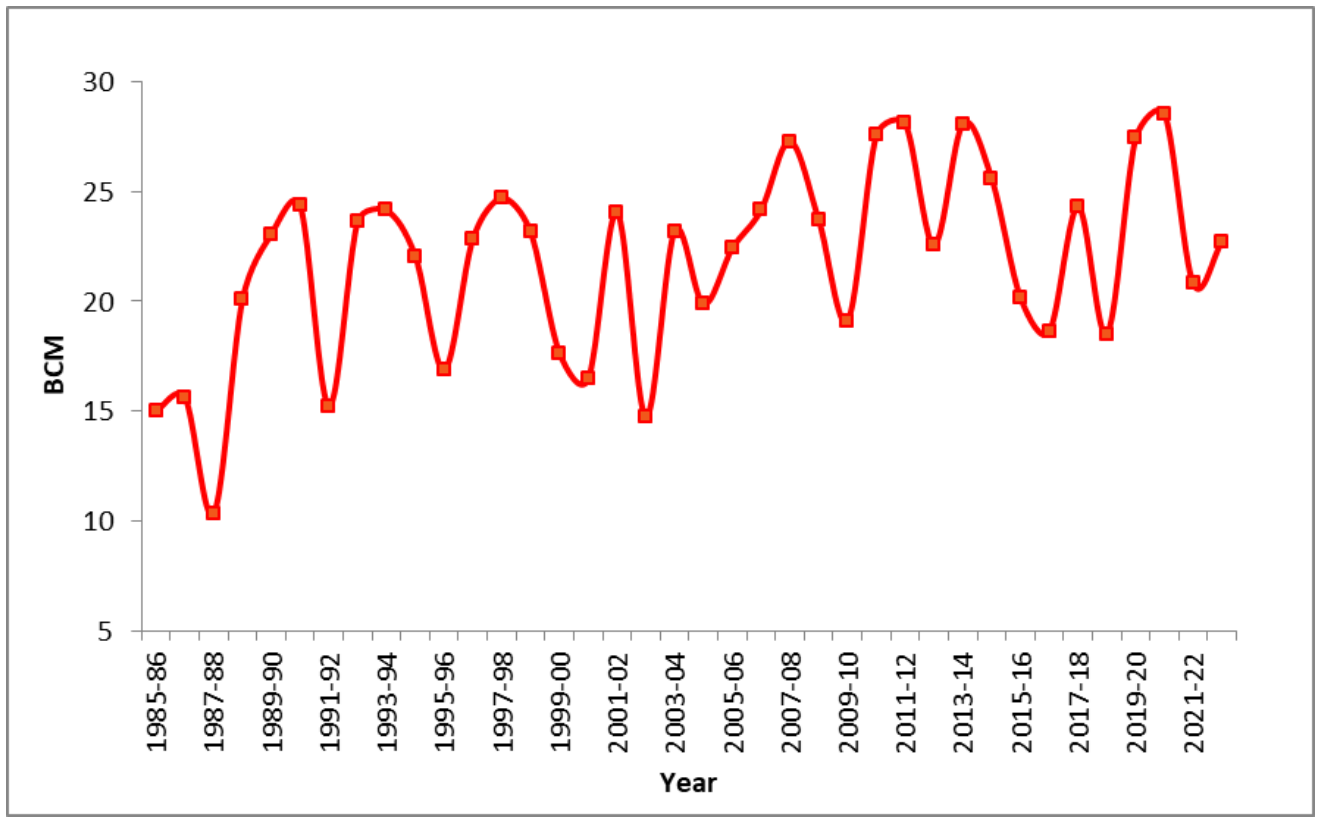


Figure 4.16.5: Annual Evapotranspiration in Sabarmati basin

4.16.3.3 Evaporation from major/medium/minor reservoirs and other water bodies

The average evaporation from the reservoirs in the basin is 0.40 BCM from the reservoirs selected are shown in Figure 4.16.6.

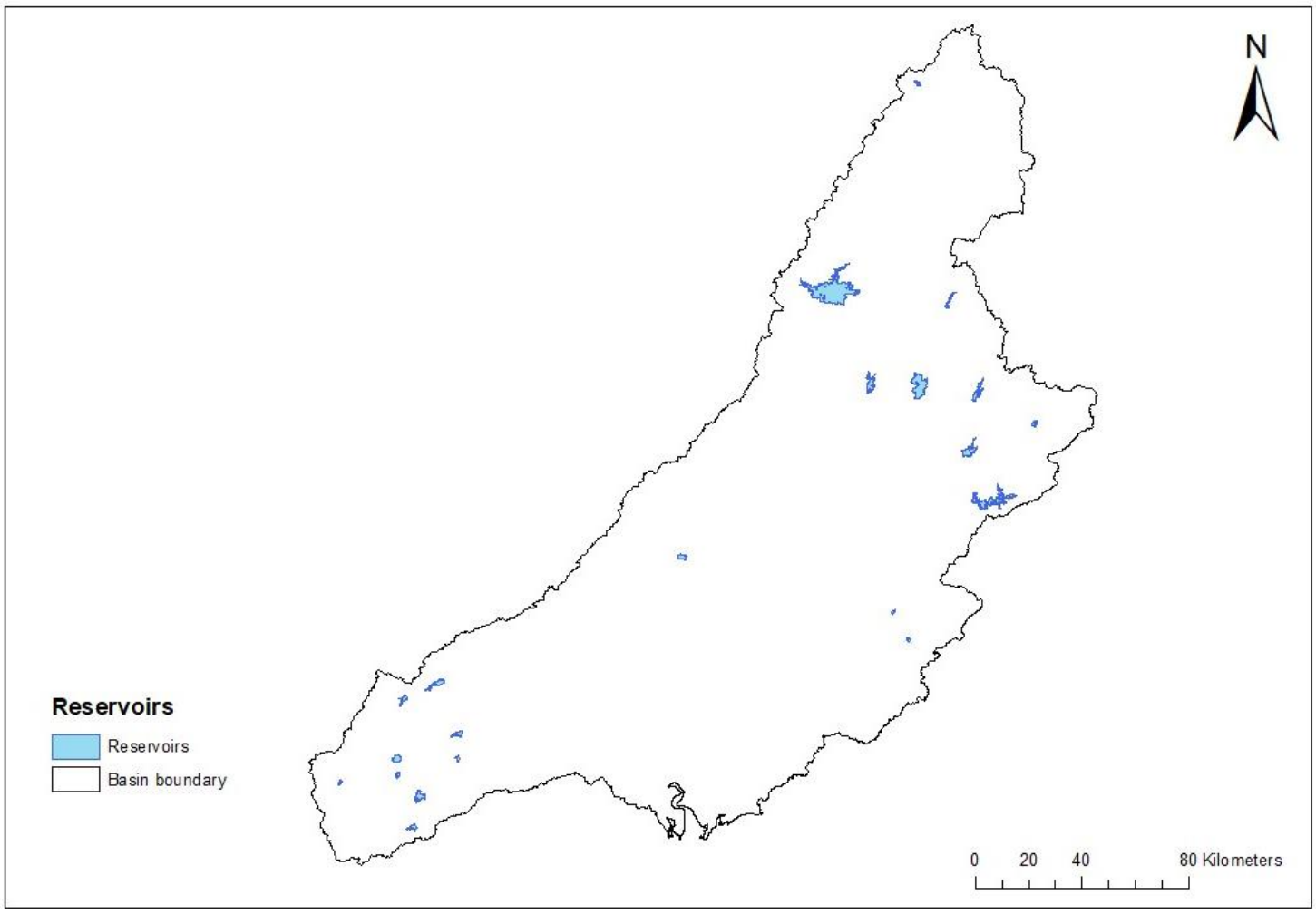


Figure 4.16.6: Reservoir map of Sabarmati basin

4.16.3.4: Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input for the basin for the years 1986-2023 has been estimated as 7.03 BCM. The command area map used for the estimation of consumptive irrigation support is shown in Figure 4.16.7. Yearly variations in ET from Irrigation Input are shown in Figure 4.16.8.

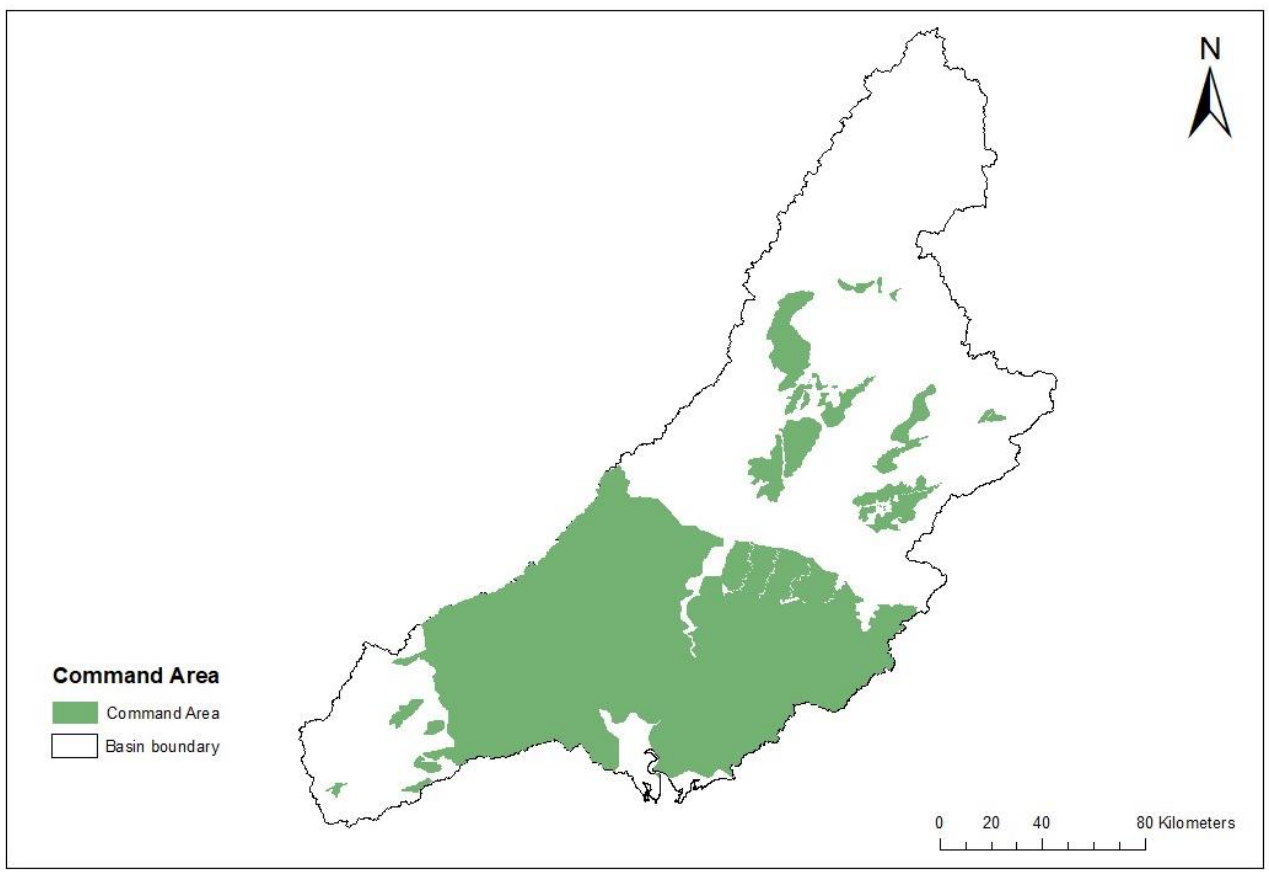


Figure 4.16.7: Command area map of Sabarmati basin

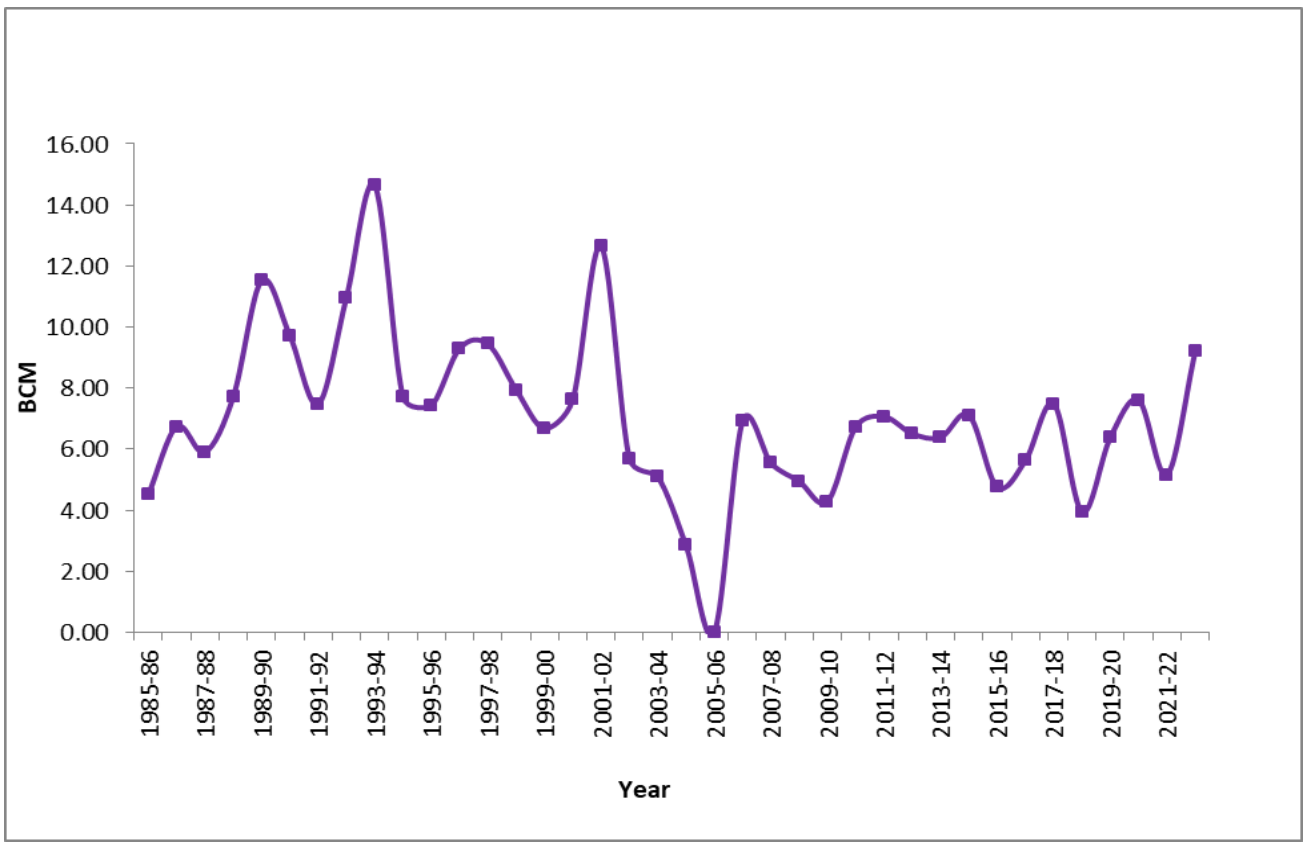


Figure 4.16.8: ET from Irrigation Input in Sabarmati Basin

4.16.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.36 BCM and 0.01 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.47 BCM.

4.16.4 Previous Estimates

In 1949, on the basis of Khosla's empirical formula, the annual runoff of Sabarmati basin had been assessed as 4.663 BCM. In 1960, the Central Water & Power Commission, while conducting irrigation potential studies, assessed the average annual runoff of Sabarmati as 3.663 BCM, which was subsequently revised to 4.079 BCM in CWC's Publication No. 30/88 "Water Resources of India", April 1988.

The CWC (1993) estimate of available water resources of the total basin was 3.81 BCM. Observed discharges were taken into account for arriving at the natural flow at Ahmedabad study after accounting all other abstractions.

The CWC (2019) study estimated the water availability of the Sabarmati basin as 12.96 BCM.

4.16.5 Annual Water Availability of Sabarmati Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated to be 9.87 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.16.9. The results of Sabarmati basin are shown in Table 4.16.3.

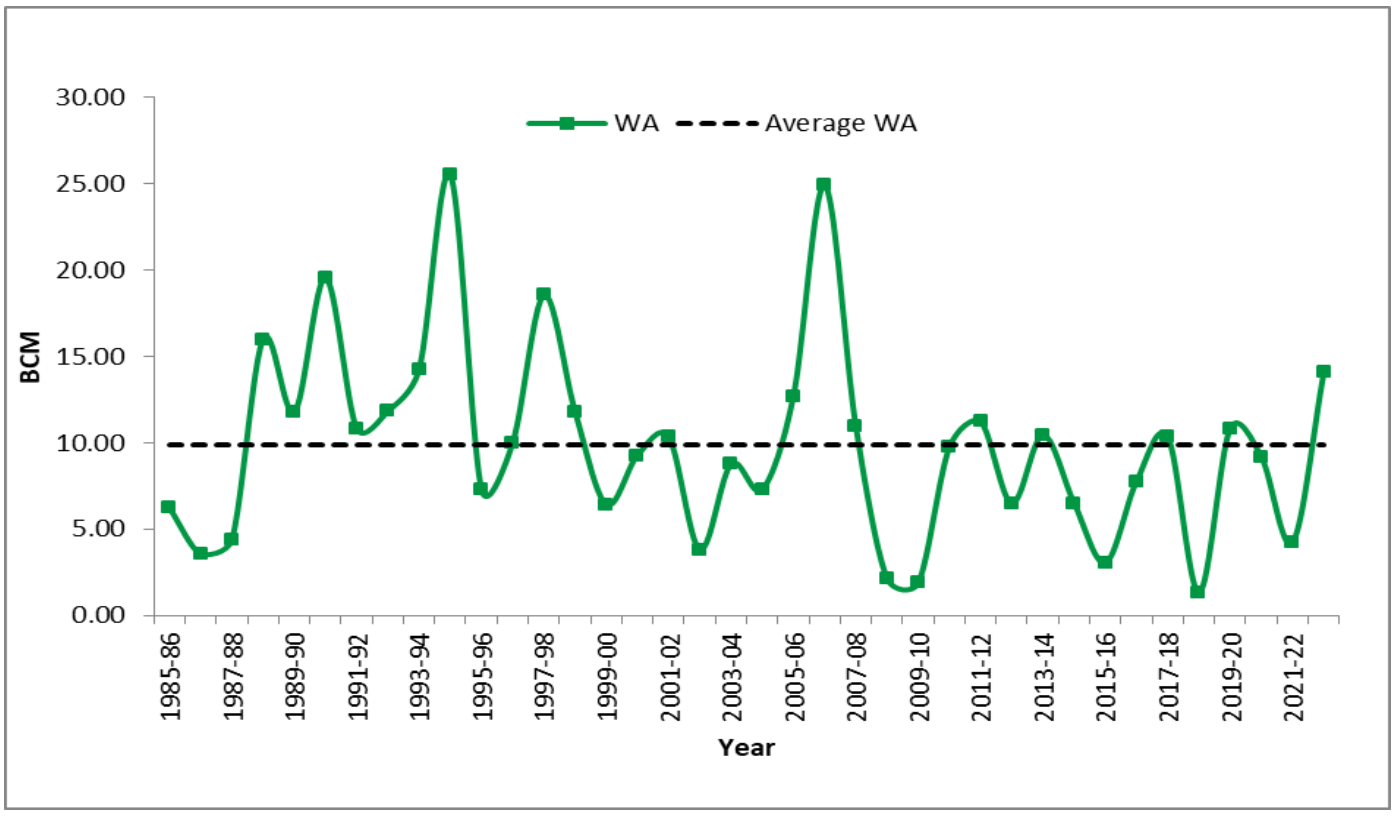


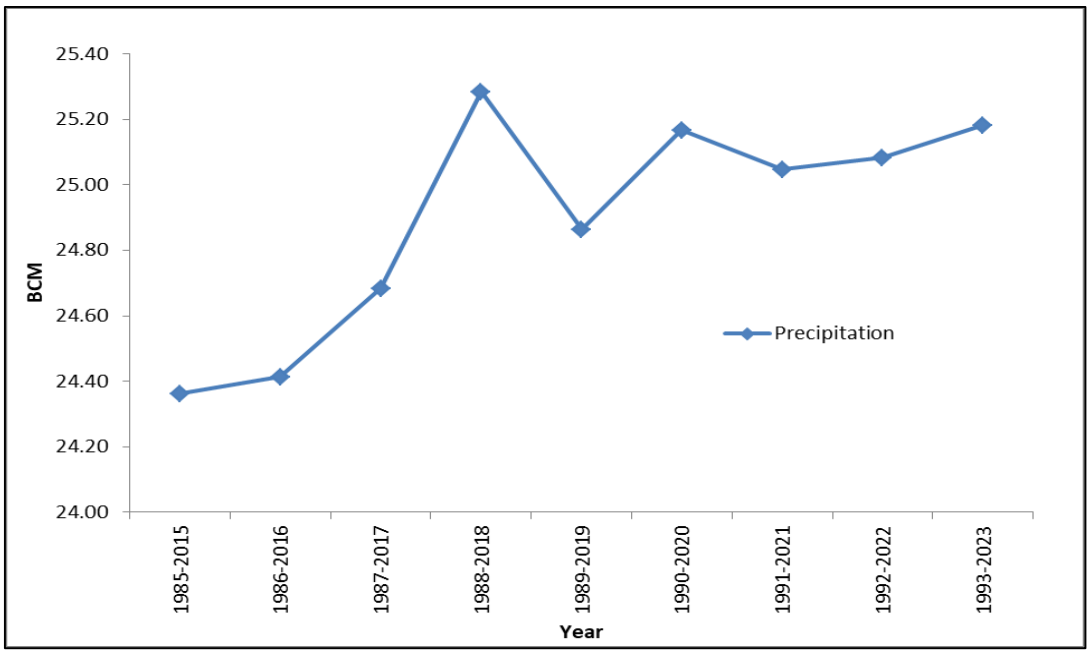
Figure 4.16.9: Water Availability of Sabarmati basin

4.16.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Sabarmati basin is given at Table 4.16.2. A line diagram of moving average of P and WA is shown in Figure 4.16.10.

Table 4.16.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	24.36	10.48
1986-2016	24.41	10.37
1987-2017	24.68	10.52
1988-2018	25.28	10.71
1989-2019	24.86	10.22
1990-2020	25.17	10.19
1991-2021	25.05	9.85
1992-2022	25.08	9.63
1993-2023	25.18	9.70



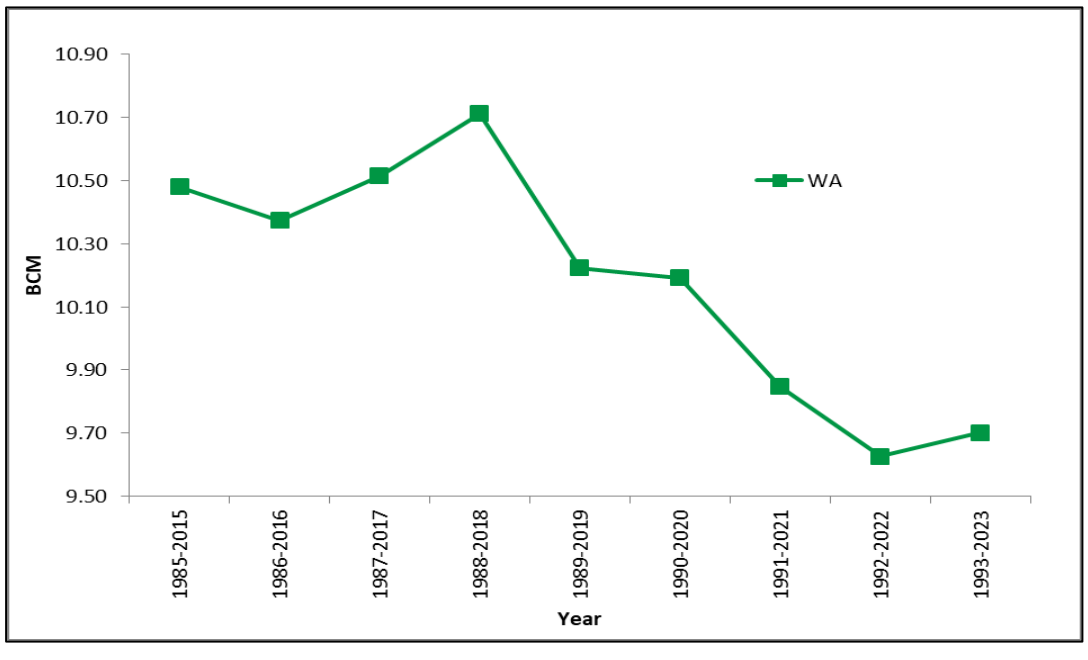


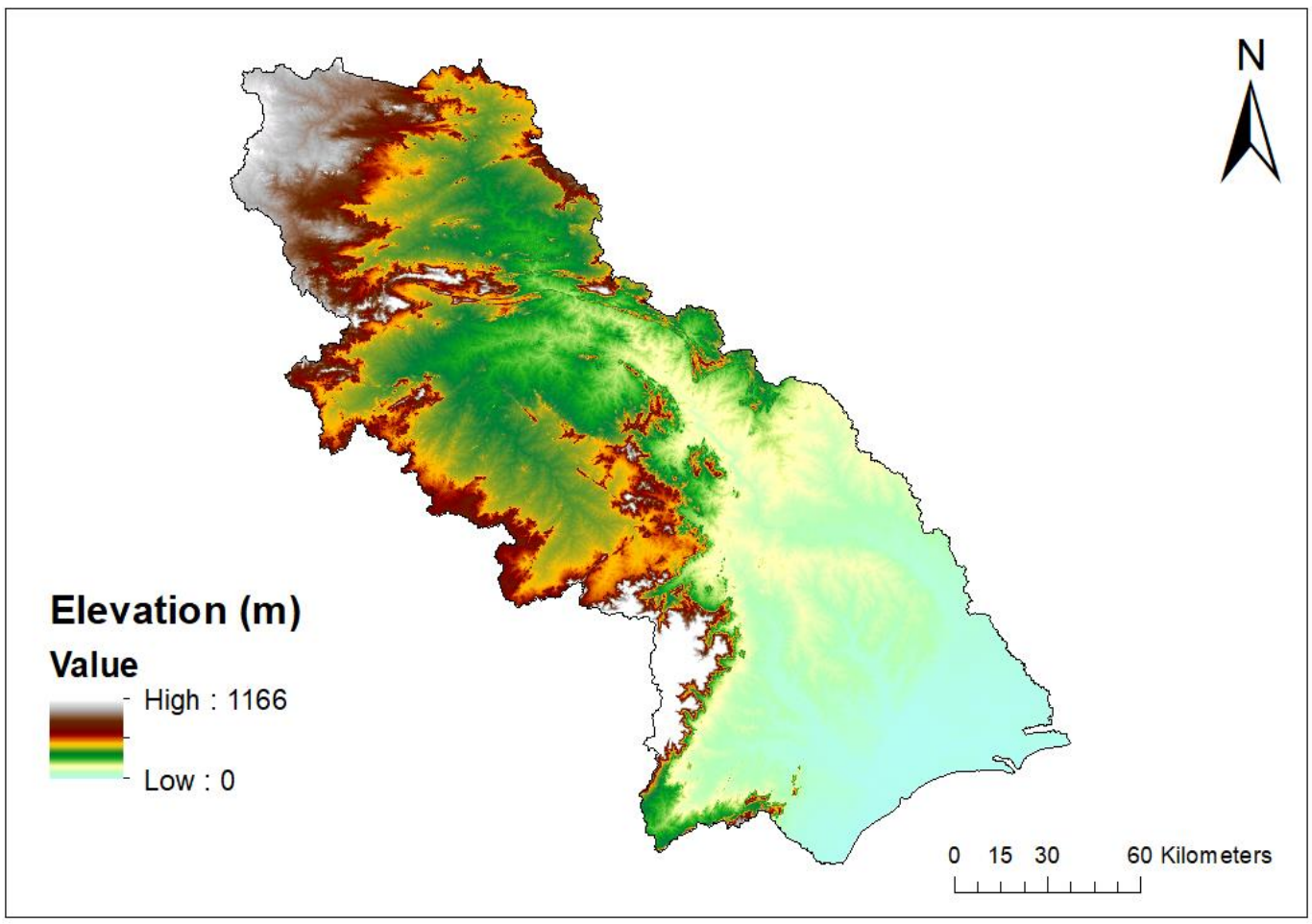
Figure 4.16.10: Moving Average of P and WA for 30 years

Table 4.16.3 Water Availability of Sabarmati basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	16.55	10.33	6.22
1986-87	12.31	8.75	3.56
1987-88	8.74	4.33	4.41
1988-89	28.15	12.16	15.99
1989-90	22.37	10.61	11.76
1990-91	33.29	13.74	19.55
1991-92	18.43	7.61	10.82
1992-93	24.29	12.46	11.83
1993-94	22.98	8.74	14.24
1994-95	39.4	13.89	25.51
1995-96	16.56	9.26	7.30
1996-97	22.57	12.57	10.00
1997-98	32.74	14.2	18.54
1998-99	26.79	14.99	11.8
1999-00	17.23	10.8	6.43
2000-01	17.96	8.69	9.27
2001-02	20.85	10.52	10.33
2002-03	12.72	8.91	3.81
2003-04	26.57	17.81	8.76
2004-05	24.11	16.81	7.29
2005-06	34.75	22.06	12.70
2006-07	41.73	16.83	24.90
2007-08	32.26	21.31	10.95
2008-09	20.56	18.42	2.14
2009-10	16.42	14.54	1.88
2010-11	30.22	20.46	9.76
2011-12	31.84	20.62	11.22
2012-13	22.16	15.67	6.49
2013-14	31.73	21.28	10.45
2014-15	24.60	18.11	6.49
2015-16	18.08	15.03	3.05
2016-17	20.41	12.63	7.78
2017-18	26.74	16.42	10.32
2018-19	15.56	14.23	1.33
2019-20	31.45	20.62	10.83
2020-21	29.71	20.52	9.18
2021-22	19.49	15.27	4.22
2022-23	27.30	13.23	14.07
Average	**24.20**	**14.33**	**9.87**

4.17 SUBERNAREKHA BASIN



HIGHLIGHTS

- *Average annual water resources availability of Subernarekha basin is 14.48 BCM.*
- *Maximum annual water availability is 26.83 BCM during 2007-08.*
- *Minimum annual water availability is 4.72 BCM during 2010-11.*
- *Average annual precipitation is 39.43 BCM (1471 mm).*
- *Maximum annual precipitation is 48.94 BCM (1826 mm) during 2013-14.*
- *Minimum annual precipitation is 26.61 BCM (993 mm) during 2010-11.*

4.17.1 About Subernarekha Basin

The Subernarekha (Including Burhabalang) basin extends over an area of 26,804 sq. km, which is nearly 0.82% of the total geographical area of the country. The basin covers the states of Jharkhand (48.87%), Odisha (37.31%) and West Bengal (13.82%). The river Subernarekha is one of the longest east flowing interstate rivers. It originates near Nagri village in Ranchi district of Jharkhand at an elevation of 600 m. The total length of river is about 395 km. The principal tributaries of the river are Kanchi, Kharkai and Karkai. Subernarekha river is situated in the North-East corner of peninsular India. It is bounded on the North-West by the Chhotanagpur Plateau, in the South-West by Brahmani basin, in the South by Burhabalang basin and in the South-East by the Bay of Bengal.

4.17.2 Geo-Spatial Datasets

4.17.2.1 Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Subarnarekha basin for year 2022-23 is shown in Figure 4.17.1. Major land use classes consist of Kharif only, Deciduous woodland, Current fallow land etc.

Table 4.17.1 shows the percentage area of each land use class for year 2022-23.

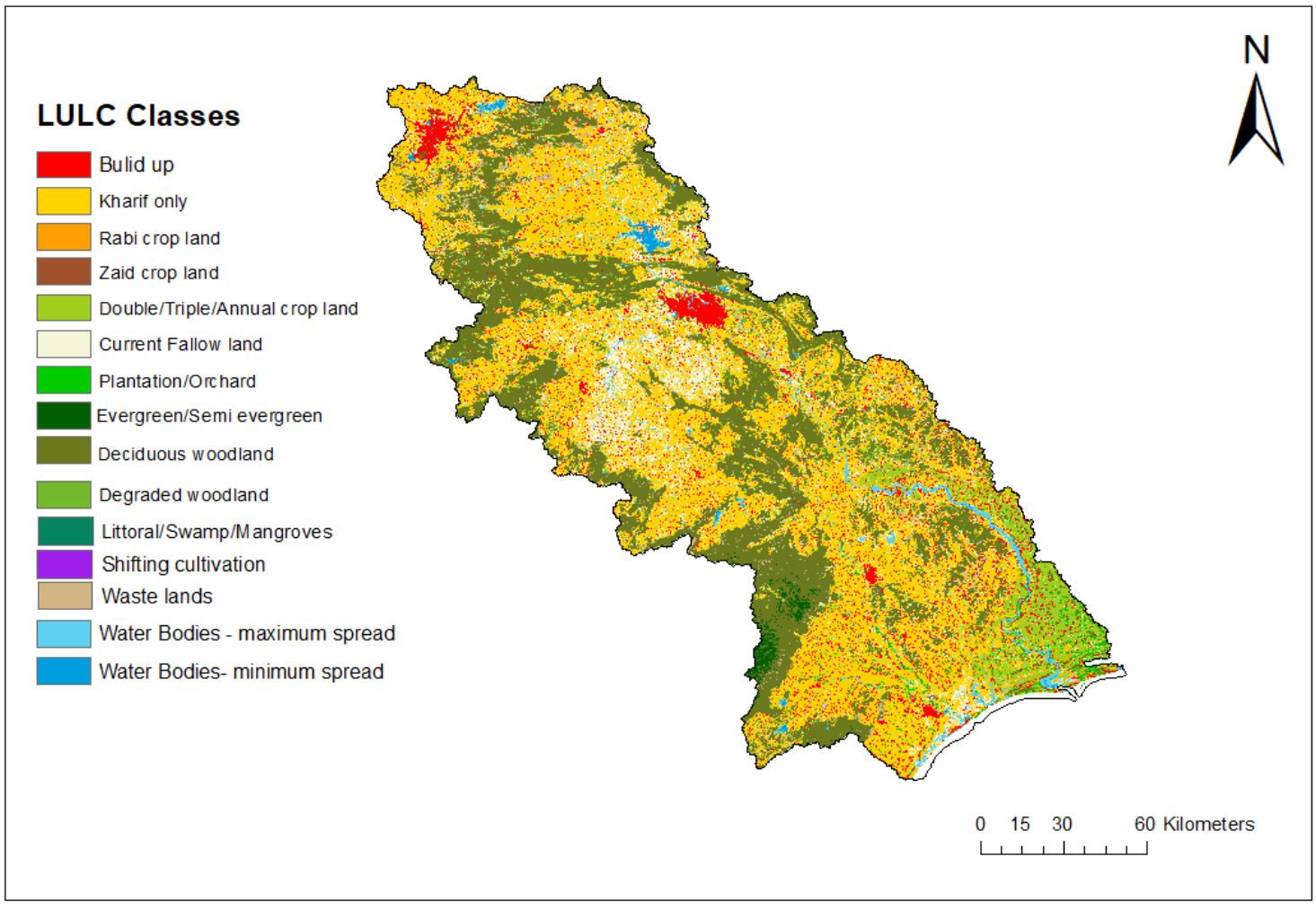


Figure 4.17.1: LULC Map of Subernarekha basin

Table 4.17.1: Percentage area of Land Use and Land Cover

S. No.	LULC class	Area (%) in 2022-23
1.	Built-up land	7.07
2.	Kharif only	41.41
3.	Rabi crop land	0.19
4.	Double/Triple/Annual crop land	6.51
5.	Current fallow land	9.36
6.	Plantation/Orchid	1.03
7.	Evergreen/Semi-evergreen woodland	0.57
8.	Deciduous woodland	26.89
9.	Degraded woodland	1.67
10.	Waste lands	2.73
11.	Water Bodies - maximum spread	2.08
12.	Water Bodies - minimum spread	0.48

4.17.3 Hydro-Meteorological and other Input Data

4.17.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.17.2. The variation in the annual precipitation during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.17.3. The average precipitation of 38 years is approximately 39.43 BCM (1471 mm).

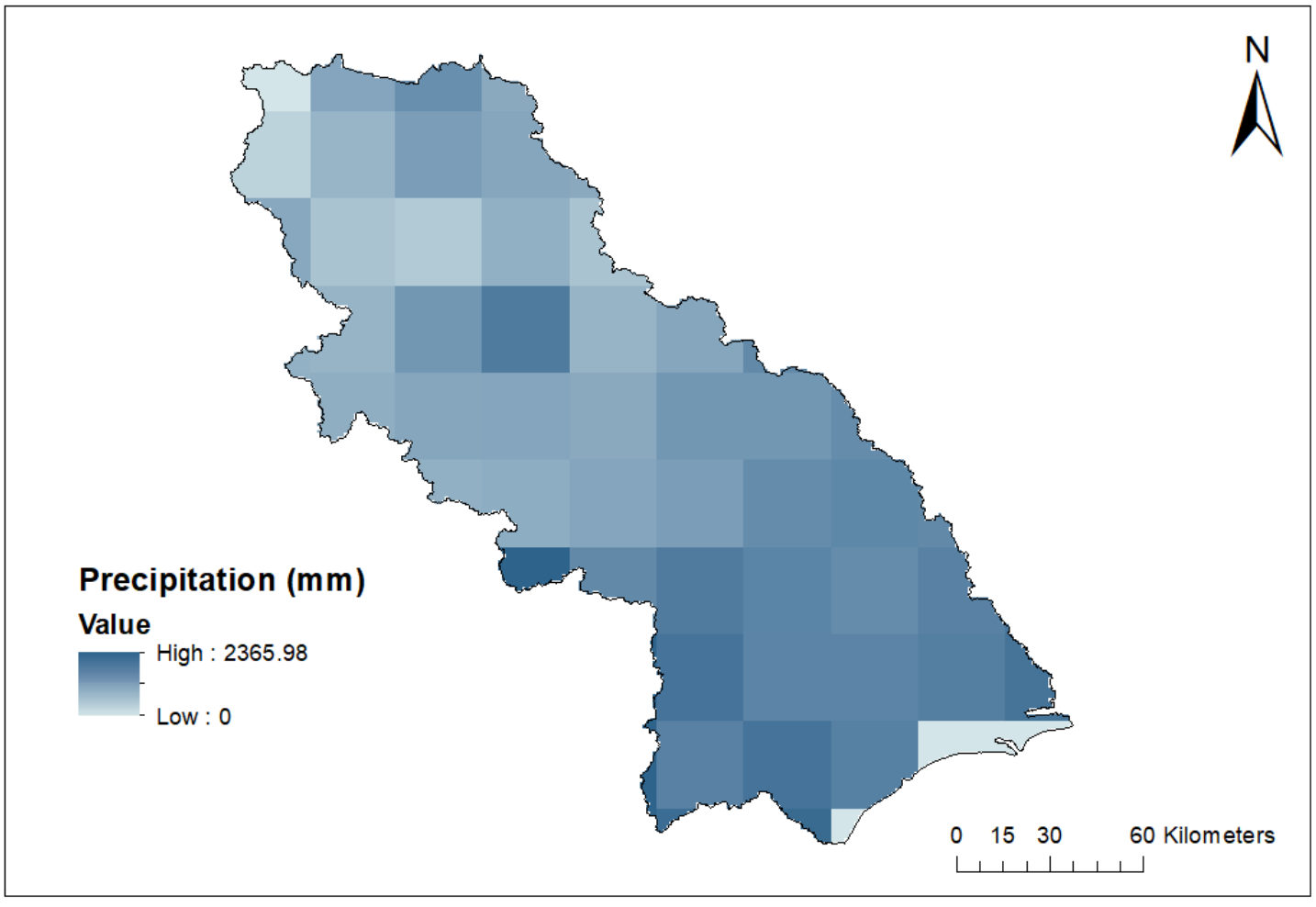


Figure 4.17.2: Precipitation map of Subarnarekha basin

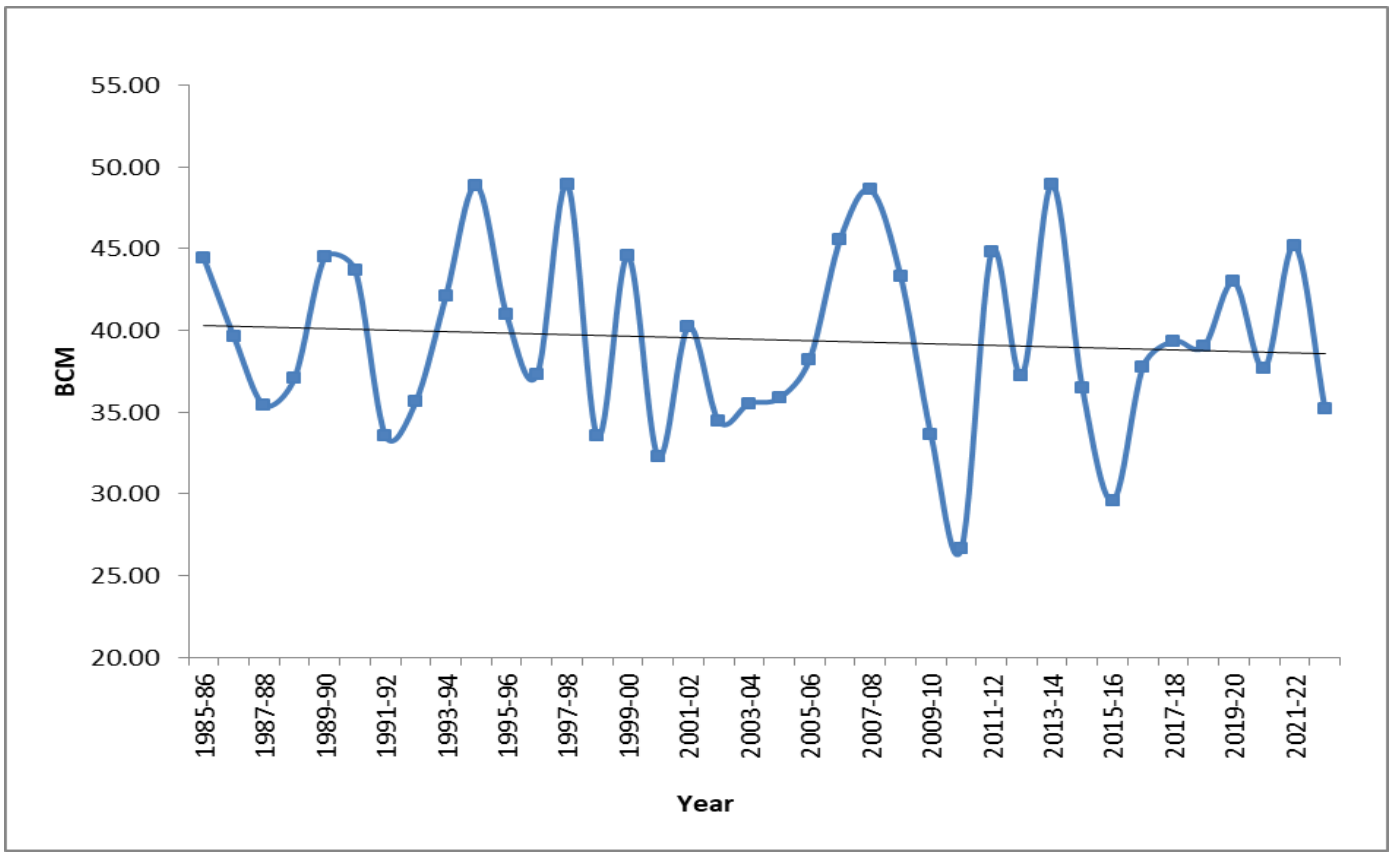


Figure 4.17.3: Annual Precipitation in Subarnarekha basin

4.17.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.17.4. The variation in the annual actual Evapotranspiration (ET) during study period of 38 years (1985-86 to 2022-23) is shown in the Figure 4.17.5. The average ET of 38 years is approximately 26.78 BCM (999 mm).

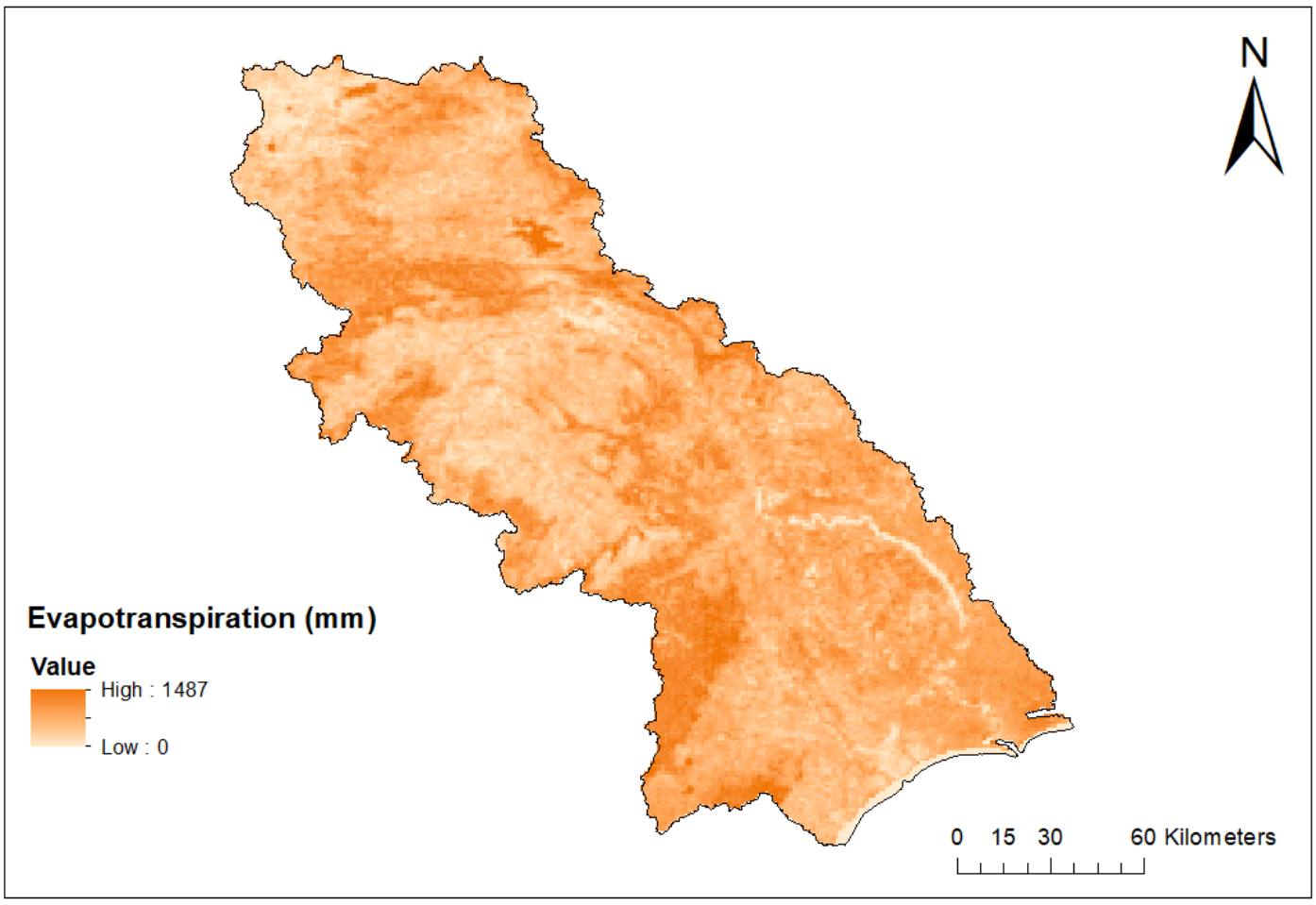


Figure 4.17.4: Evapotranspiration map of Subarnarekha basin

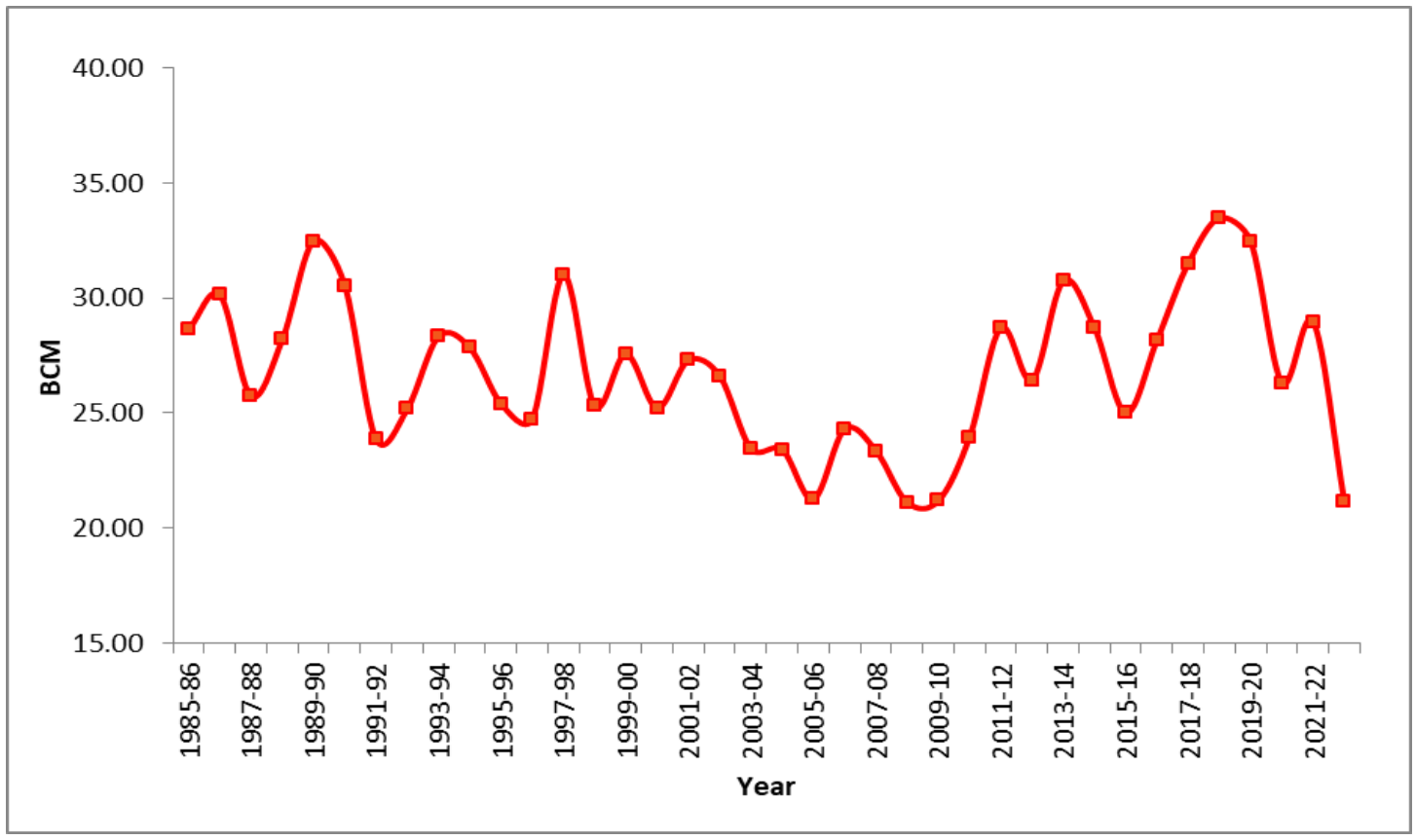


Figure 4.17.5: Annual evapotranspiration in Subarnarekha basin

4.17.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.17.6. The average annual evaporation from the reservoirs in the basin is 0.38 BCM.

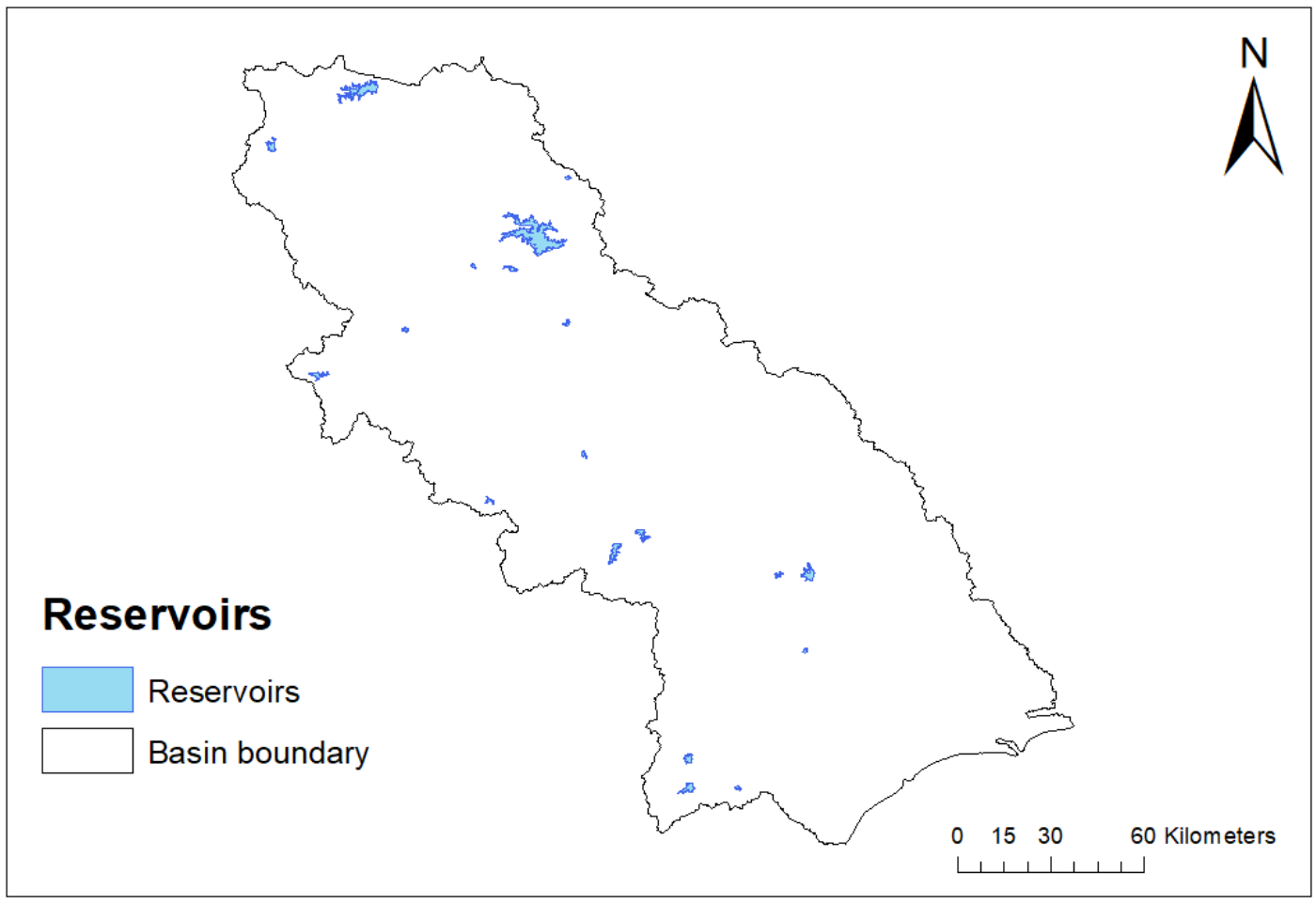


Figure 4.17.6: Reservoir map of Subarnarekha basin

4.17.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 1.45 BCM. The command area map used for the estimation of ETII is shown in Figure 4.17.7. The annual variation in ET_{II} is shown in Figure 4.17.8.

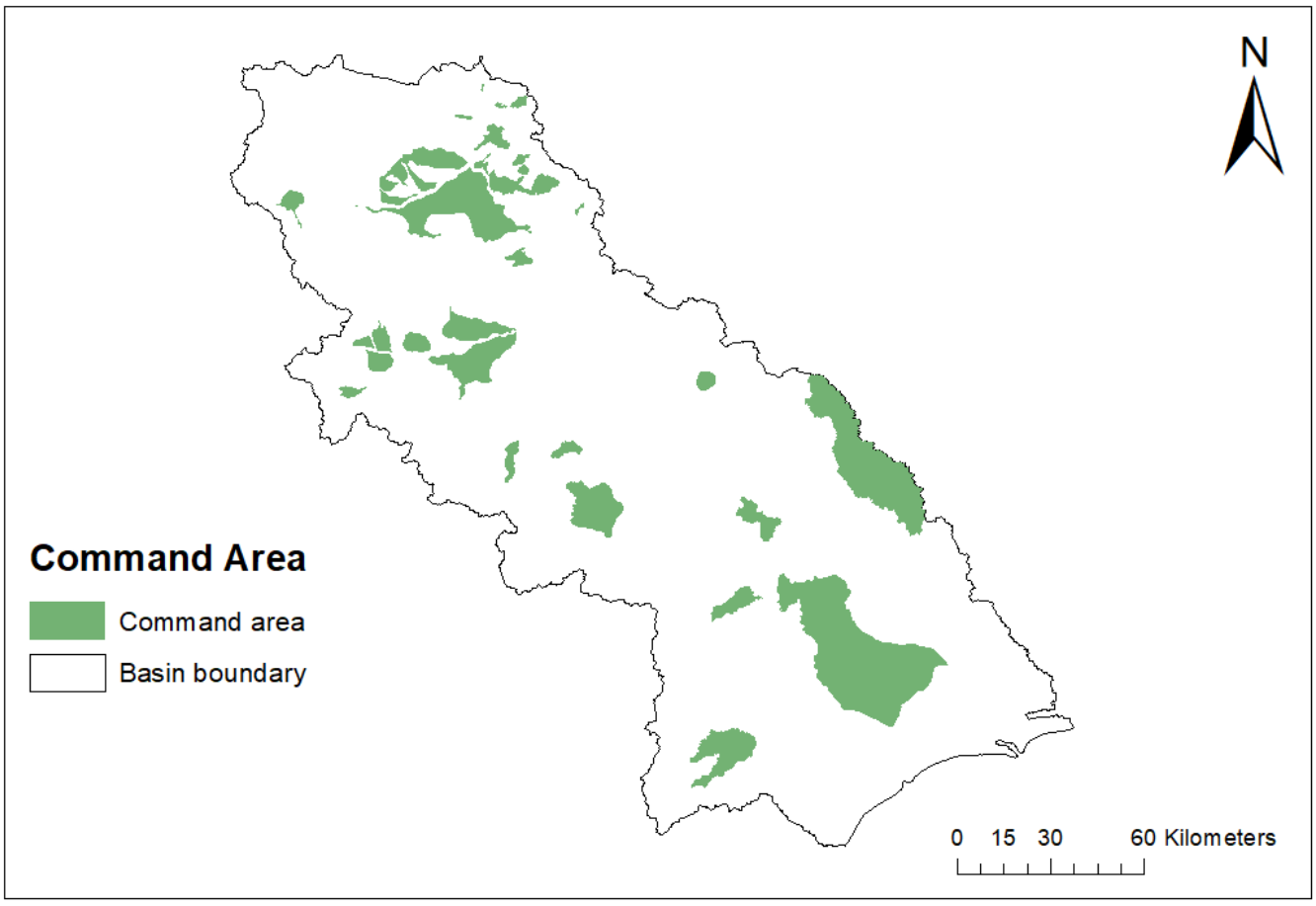


Figure 4.17.7: Command area map of Subarnarekha basin

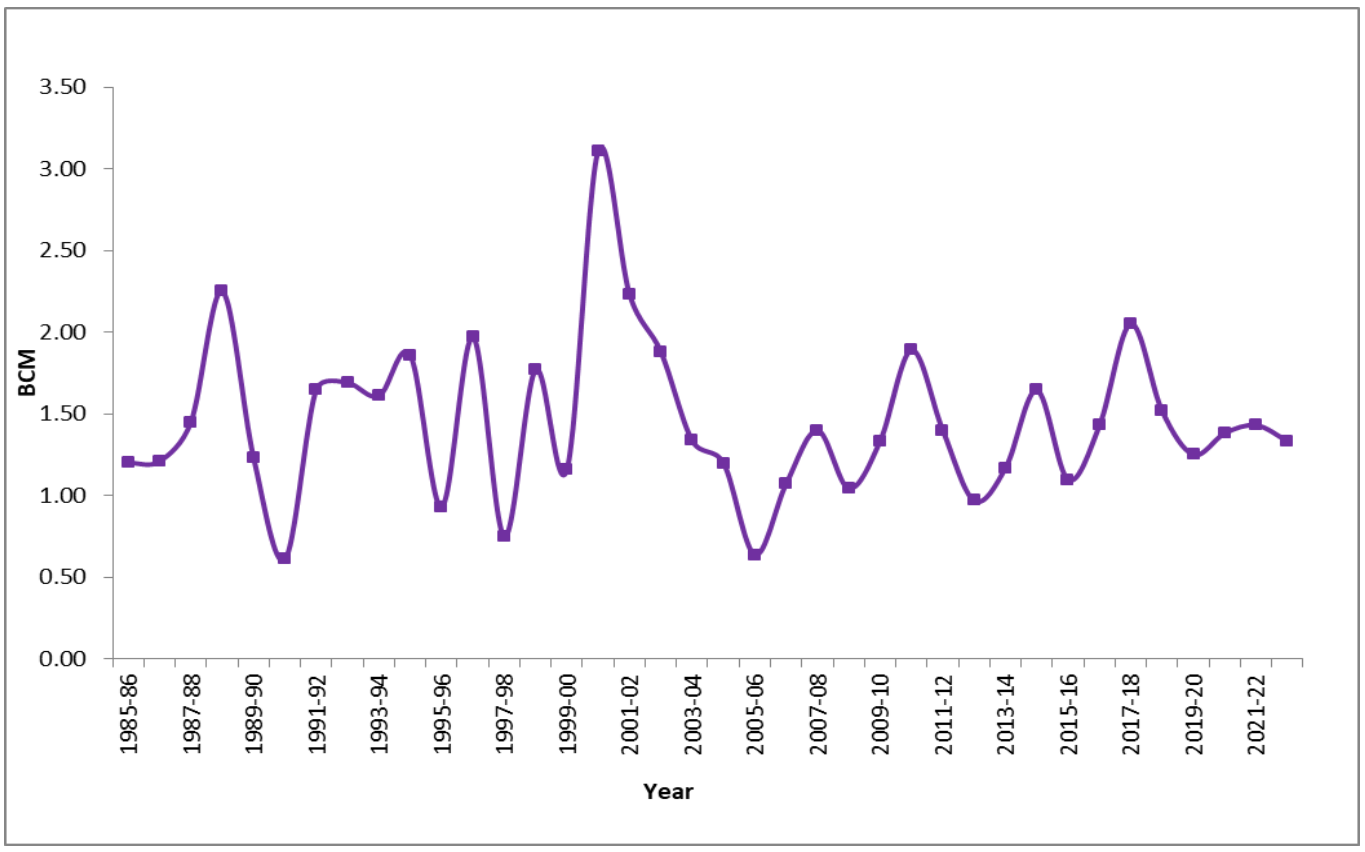


Figure 4.17.8: ET from Irrigation Input in Subarnarekha basin

4.17.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is 0.04 BCM and 0.01 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.21 BCM.

4.17.4 Previous Estimates

In 1949, on the basis of Khosla's formula, the total annual runoff of the river systems in the basin was estimated to be 20.33 BCM. In 1960, the Central Water and Power Commission, while conducting irrigation potential studies, assessed the total annual runoff of the river systems in the basin to be 14.81 BCM on the basis of Strange's precipitation-runoff coefficients for average catchments. This figure has been revised to 10.79 BCM in CWC's Publication No.30/88 "Water Resources of India", April 1988 (based on precipitation-runoff relationship). In 1993, CWC estimated water availability of Subarnarekha basin as 12.37 BCM.

In 2019 study, the water availability of Subarnarekha basin was estimated as 15.05 BCM.

4.17.5 Annual Water Availability of Subarnarekha Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated to be 14.48 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.17.9. The results of Subarnarekha basin are shown in Table 4.17.3.

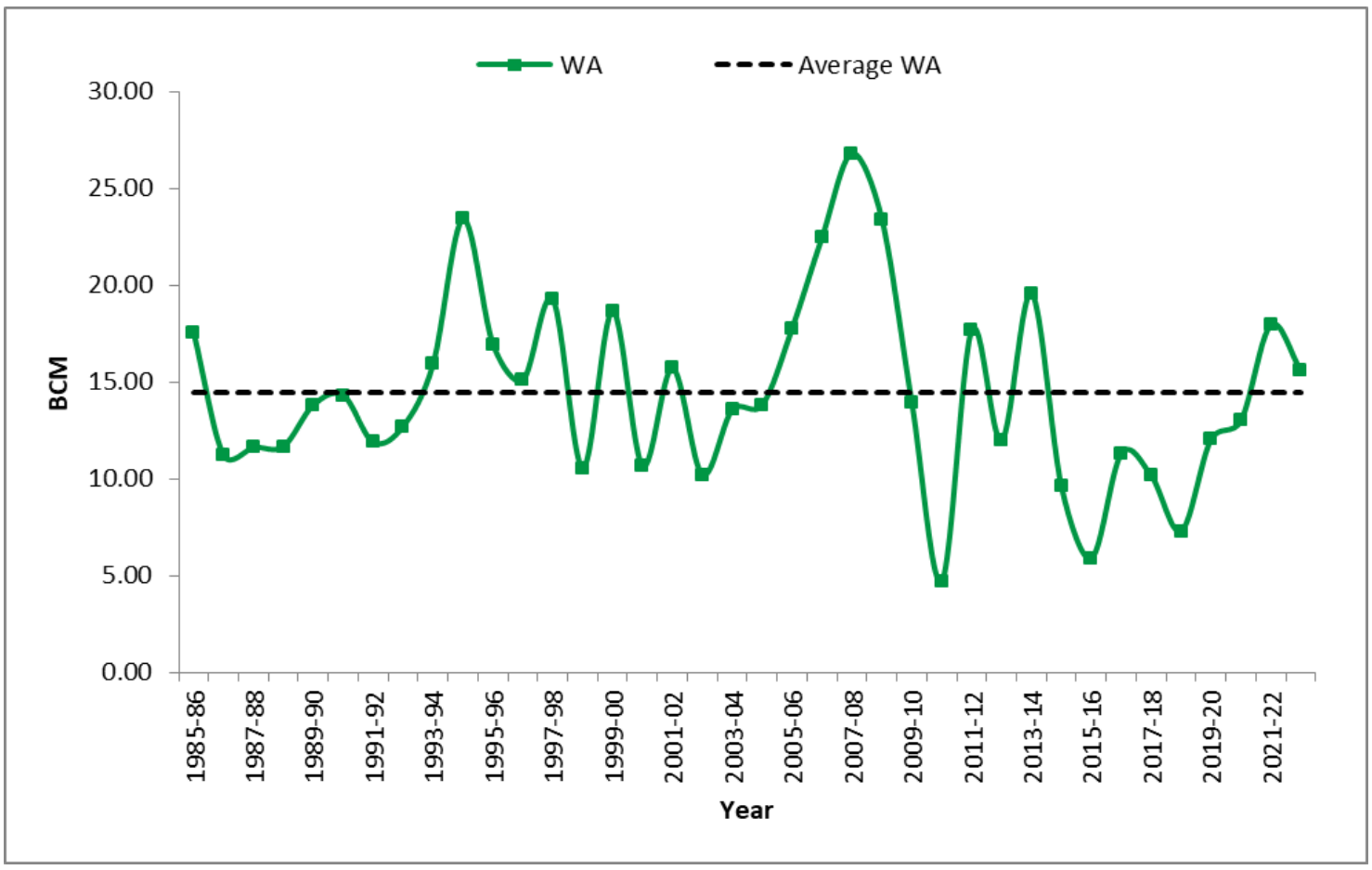


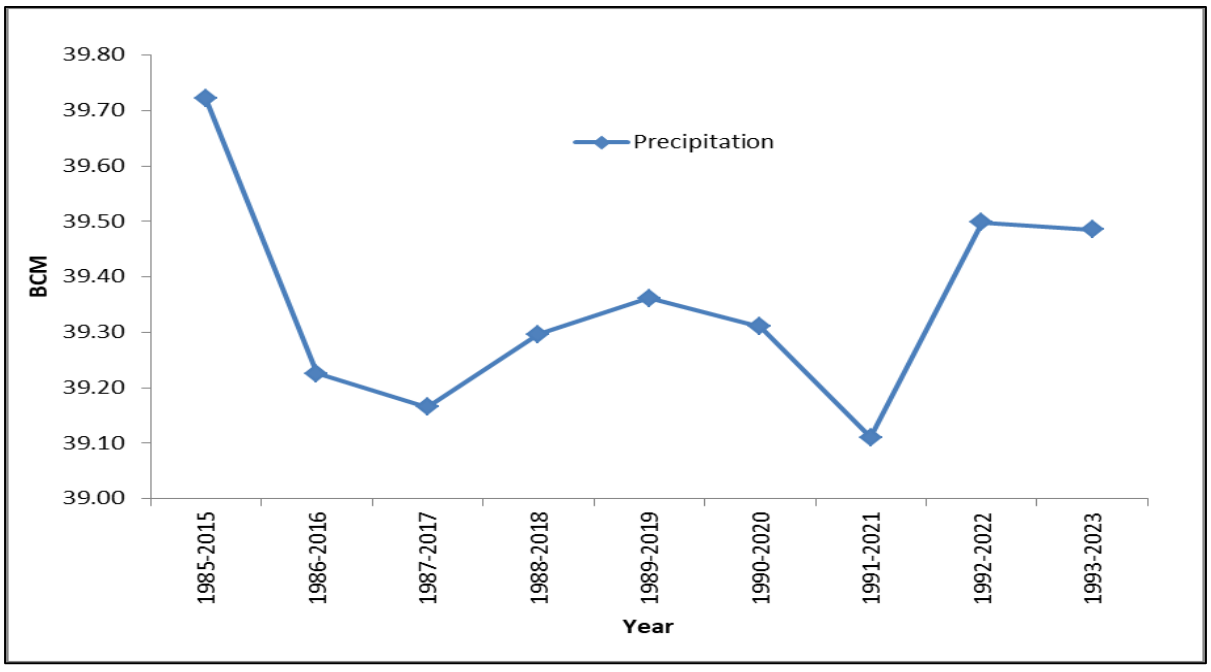
Figure 4.17.9: Water availability of Subernarekha basin

4.17.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Subarnarekha basin is given at Table 4.17.2. A line diagram of moving average of P and WA is shown in Figure 4.17.10.

Table 4.17.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	40.05	15.23
1986-2016	39.55	14.84
1987-2017	39.49	14.84
1988-2018	39.62	14.79
1989-2019	39.69	14.65
1990-2020	39.64	14.59
1991-2021	39.44	14.54
1992-2022	39.83	14.75
1993-2023	39.81	14.84



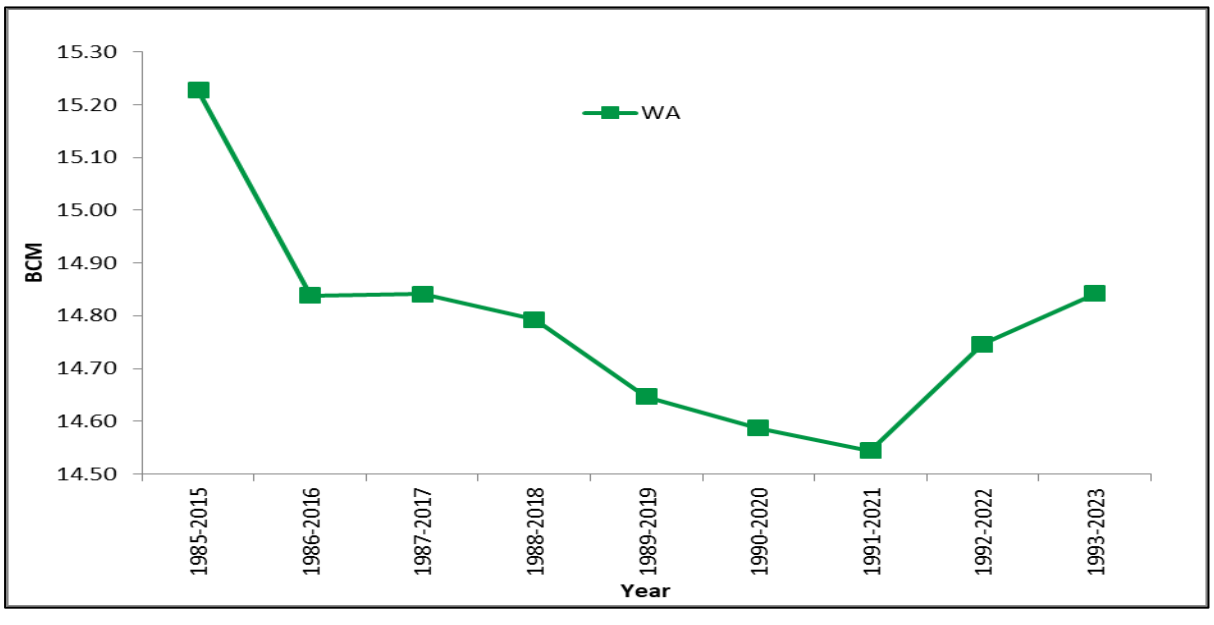


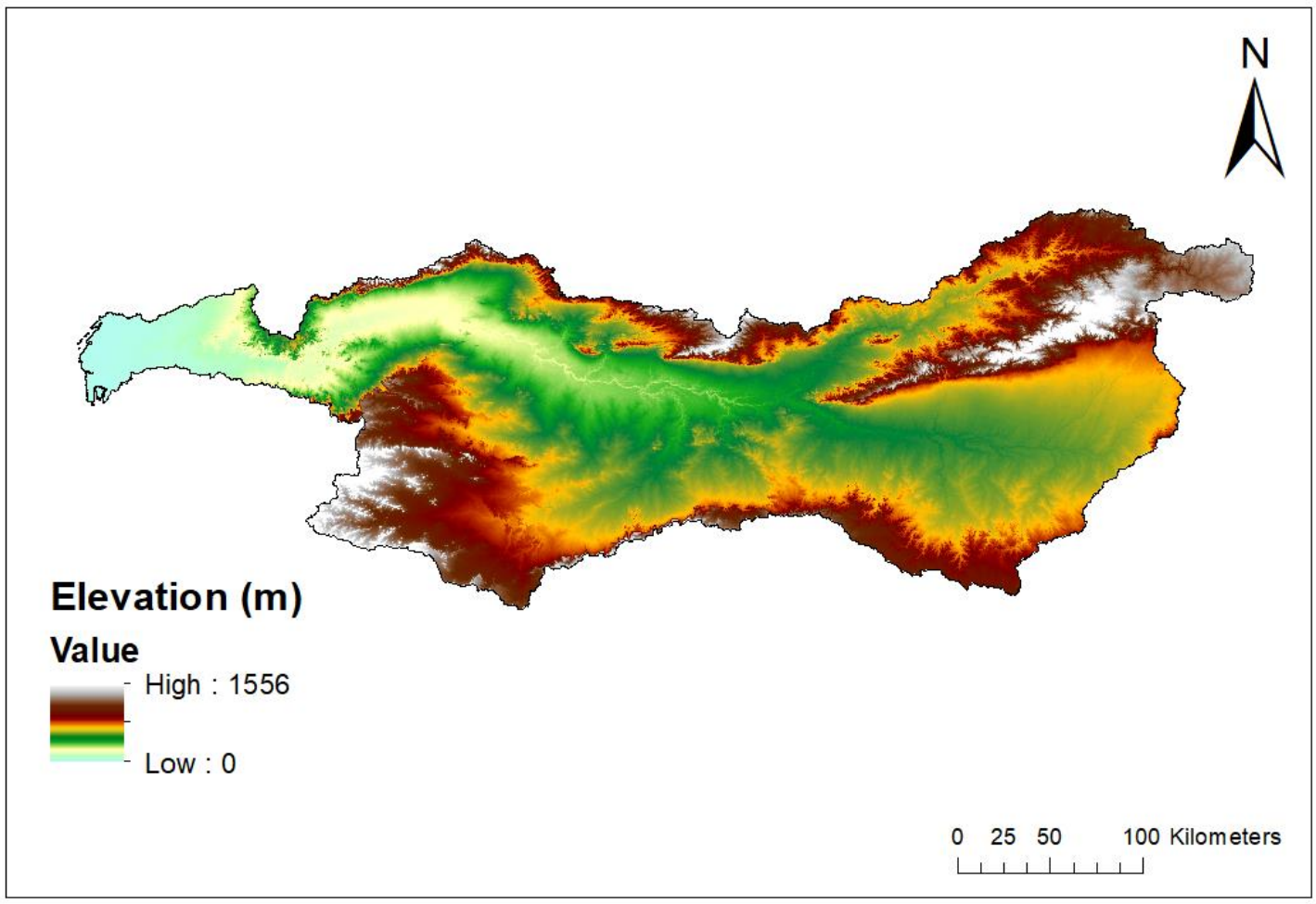
Figure 4.17.10: Moving Average of P and WA for 30 yearsTable

4.17.3: Water Availability of Subarnarekha basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	44.46	26.90	17.56
1986-87	39.62	28.40	11.22
1987-88	35.39	23.76	11.63
1988-89	37.06	25.38	11.68
1989-90	44.48	30.66	13.82
1990-91	43.69	29.37	14.32
1991-92	33.56	21.66	11.90
1992-93	35.62	22.90	12.72
1993-94	42.13	26.20	15.93
1994-95	48.88	25.45	23.43
1995-96	40.95	23.99	16.96
1996-97	37.27	22.17	15.10
1997-98	48.93	29.66	19.27
1998-99	33.51	22.95	10.56
1999-00	44.55	25.87	18.68
2000-01	32.28	21.60	10.68
2001-02	40.22	24.49	15.73
2002-03	34.43	24.21	10.22
2003-04	35.52	21.93	13.58
2004-05	35.85	22.03	13.81
2005-06	38.22	20.44	17.78
2006-07	45.52	23.04	22.48
2007-08	48.61	21.78	26.83
2008-09	43.31	19.90	23.41
2009-10	33.62	19.67	13.94
2010-11	26.61	21.89	4.72
2011-12	44.77	27.09	17.68
2012-13	37.24	25.26	11.98
2013-14	48.94	29.36	19.58
2014-15	36.45	26.85	9.60
2015-16	29.56	23.67	5.89
2016-17	37.78	26.48	11.30
2017-18	39.35	29.18	10.17
2018-19	38.99	31.69	7.30
2019-20	42.97	30.93	12.04
2020-21	37.67	24.65	13.02
2021-22	45.20	27.23	17.97
2022-23	35.22	19.63	15.59
Average	**39.43**	**24.96**	**14.48**

4.18 TAPI BASIN



HIGHLIGHTS

- *Average annual water resources availability of Tapi basin is 20.98 BCM.*
- *Maximum annual water availability is 40.64 BCM during 1994-95.*
- *Minimum annual water availability is 4.27 BCM during 2018-19.*
- *Average annual precipitation is 58.52 BCM (889.31 mm).*
- *Maximum annual precipitation is 82.08 BCM (1247.00 mm) during 2013-14.*
- *Minimum annual precipitation is 39.45 BCM (618.00 mm) during 2000-01.*

4.18.1 About Tapi Basin

The Tapi basin extends over states of Maharashtra (77.38%), Madhya Pradesh (14.21%) and Gujarat (8.41%) having an area of 65,805.80 sq. km which is nearly 2% of the total geographical area of the country, with a maximum length and width of 534 and 196 km. Situated in the Deccan plateau, the basin is bounded by the Satpura range on the north, the Mahadev hills on the east, the Ajanta Range and the Satmala hills on the south and the Arabian Sea on the west. The hilly region of the basin is well forested while the plains are broad and fertile areas suitable for cultivation. The Tapi is the second largest westward draining river of the Peninsula. It originates near Multai reserve forest in Betul district of Madhya Pradesh at an elevation of 752 m. The total length of the river from origin to outfall into the Arabian Sea is 724 km and its important tributaries are the Suki, the Gomai, the Arunavati and the Aner which joins it from right, and those joining from left are the Vaghur, the Amravati, the Buray, the Panjhra, the Bori, the Girna, the Purna, the Mona and the Sipna.

4.18.2 Geo-Spatial Datasets

4.18.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of Tapi basin for year 2022-23 is shown in Figure 4.18.1. The major land use classes consist of Kharif only, Double/Triple/Annual crop land, waste land etc.

Table 4.18.1 shows the percentage area of each land use class in the basin for year 2022-23.

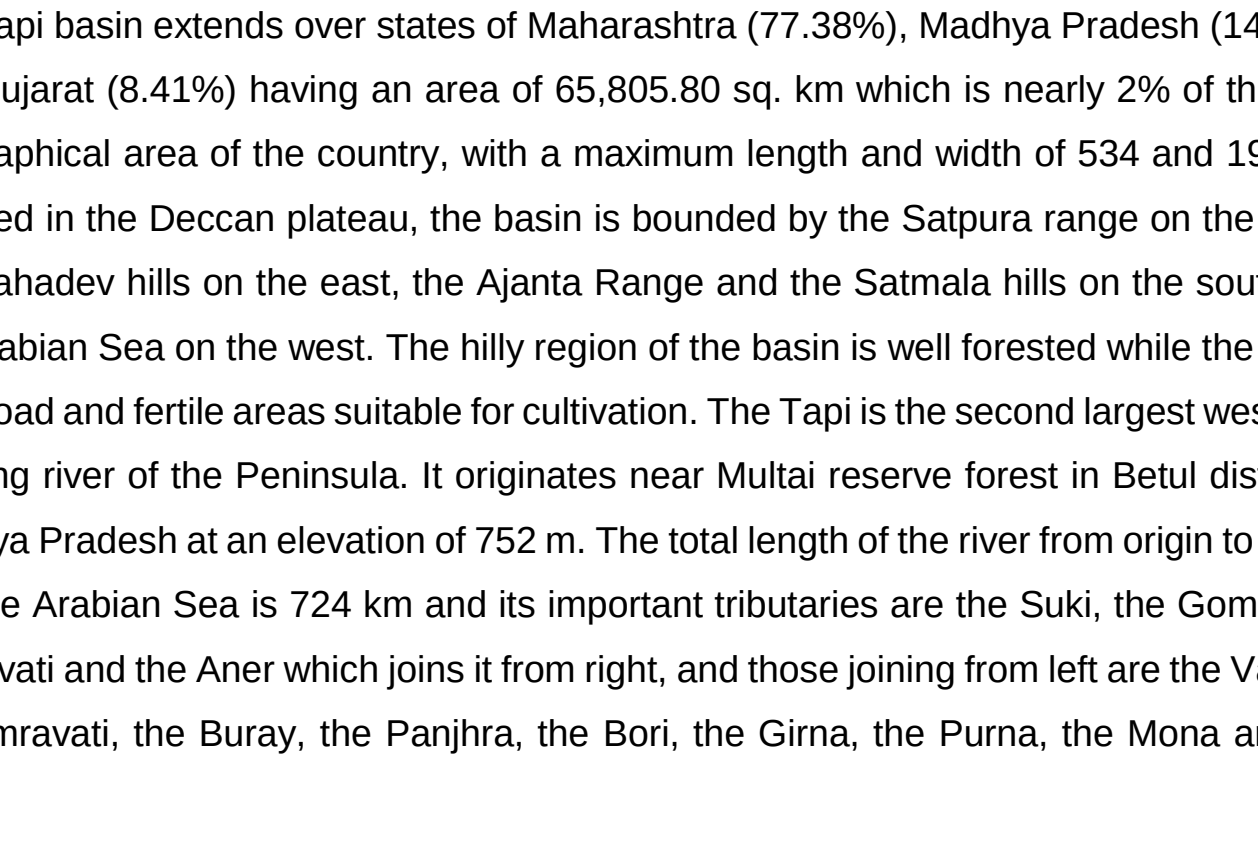


Figure 4.18.1: LULC Map of Tapi basin

Table 4.18.1: Percentage change in Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	1.95
2.	Kharif only	26.43
3.	Rabi crop land	1.67
4.	Zaid crop land	0.01
5.	Double/Triple/Annual crop land	30.41
6.	Current Fallow land	6.65
7.	Plantation/Orchard	1.20
8.	Evergreen/Semi evergreen	0.04
9.	Deciduous woodland	15.04
10.	Degraded woodland	7.68
11.	Littoral/Swamp/Mangroves	0.03
12.	Waste lands	5.81
13.	Water Bodies - maximum spread	1.94
14.	Water Bodies - minimum spread	1.15

4.18.3 Hydro-Meteorological and other Input Data

4.18.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.18.2. The variations in the annual Precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.18.3. The average precipitation of 38 years is approximately 58.52 BCM (889.31 mm).

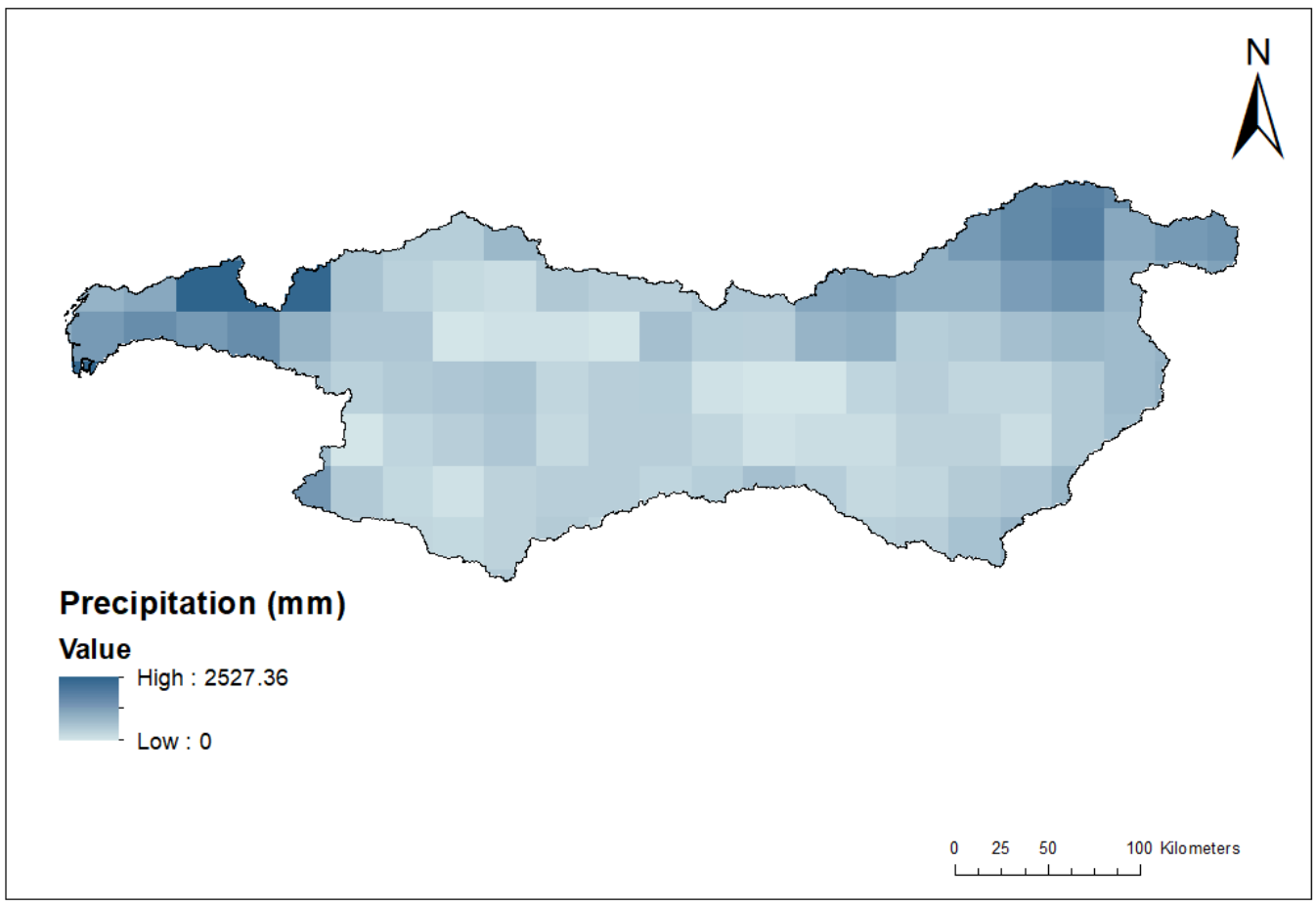


Figure 4.18.2: Precipitation map of Tapi basin

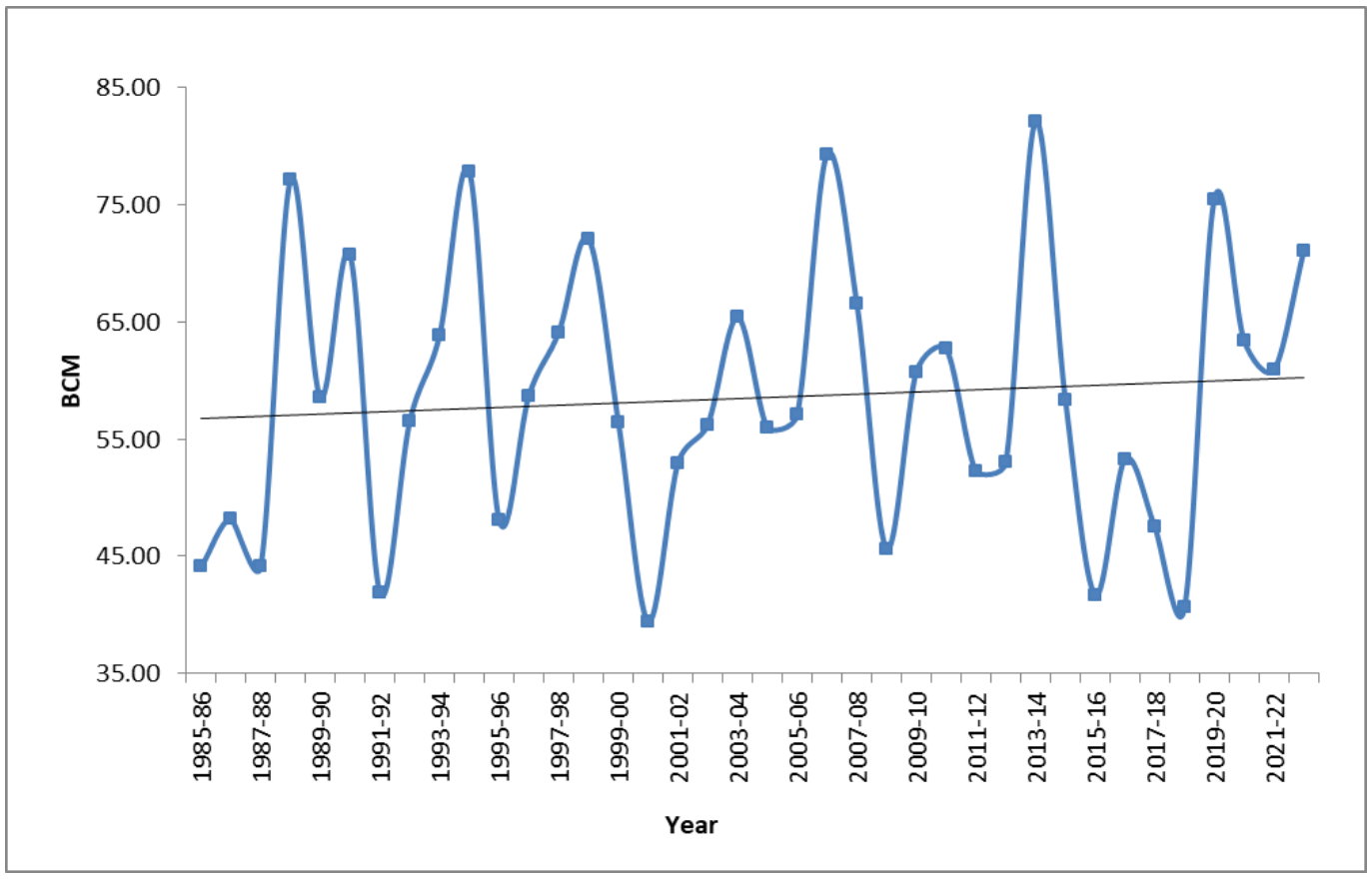


Figure 4.18.3: Annual Precipitation in Tapi basin

4.18.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.18.4.The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.18.5. The average ET of 38 years is found to be 49.45 BCM (751.51 mm).

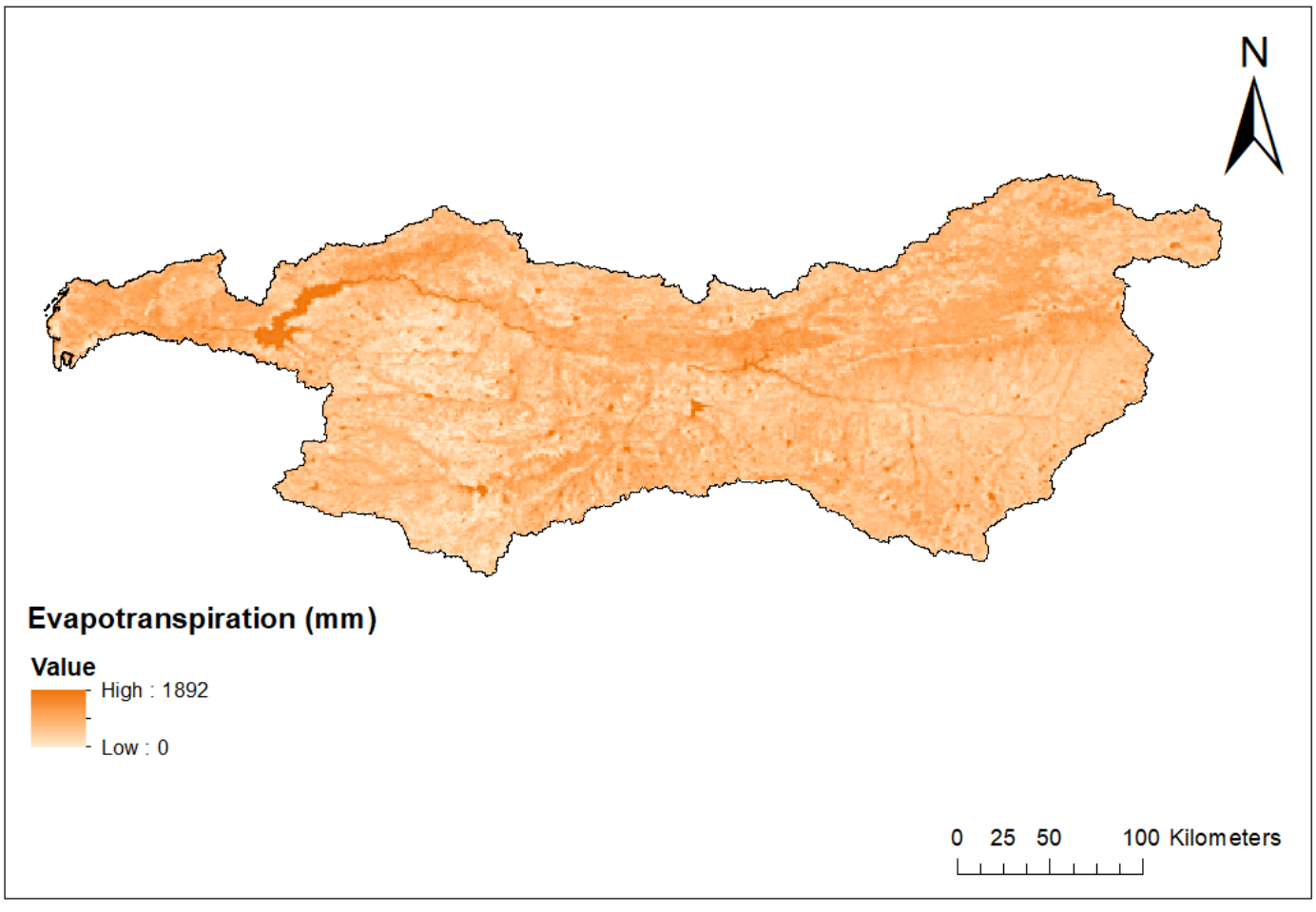


Figure 4.18.4: Evapotranspiration map of Tapi basin

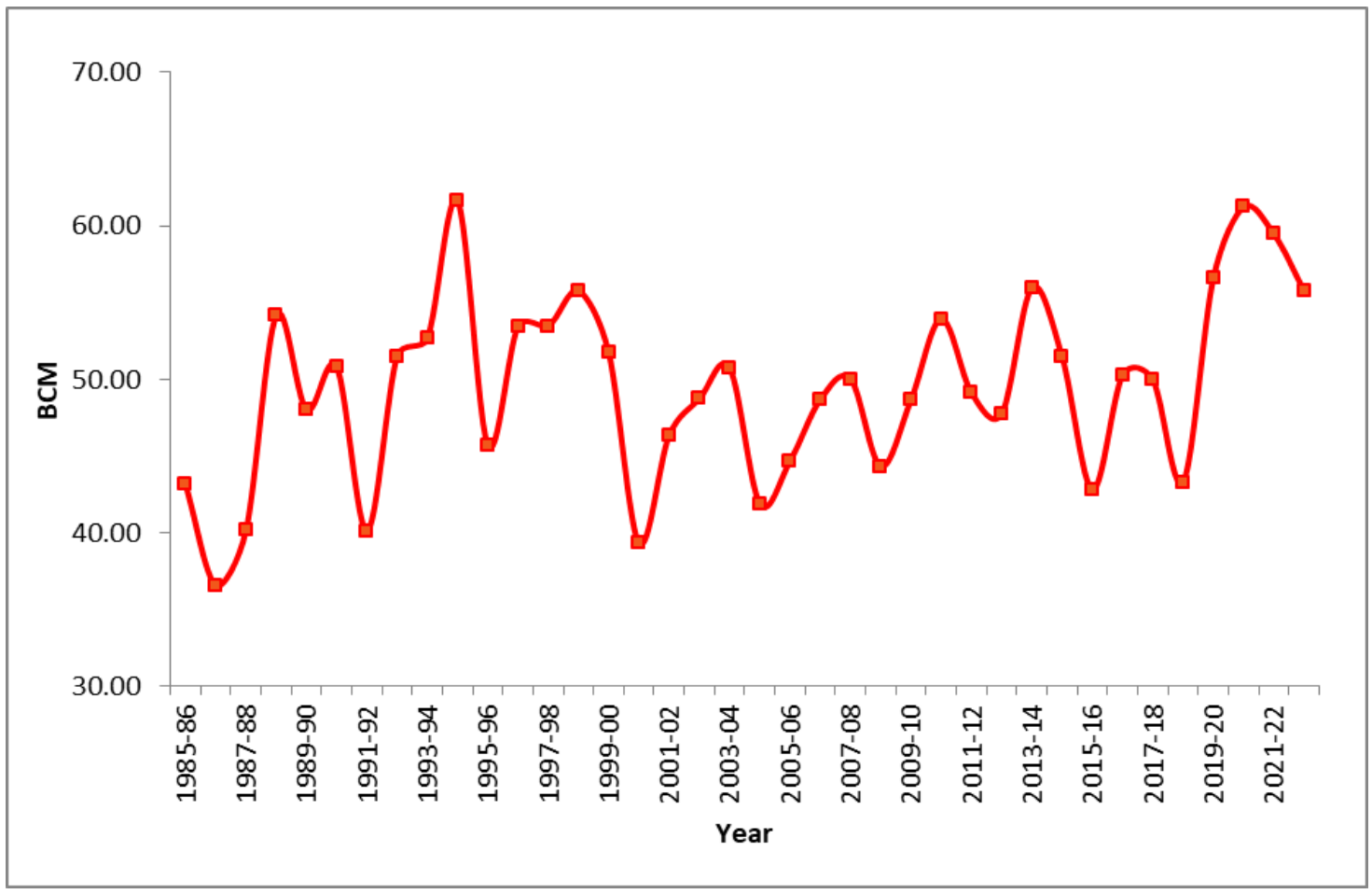


Figure 4.18.5: Annual Evapotranspiration in Tapi basin

4.18.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.18.6. The average evaporation from the reservoirs in the basin is 1.00 BCM.

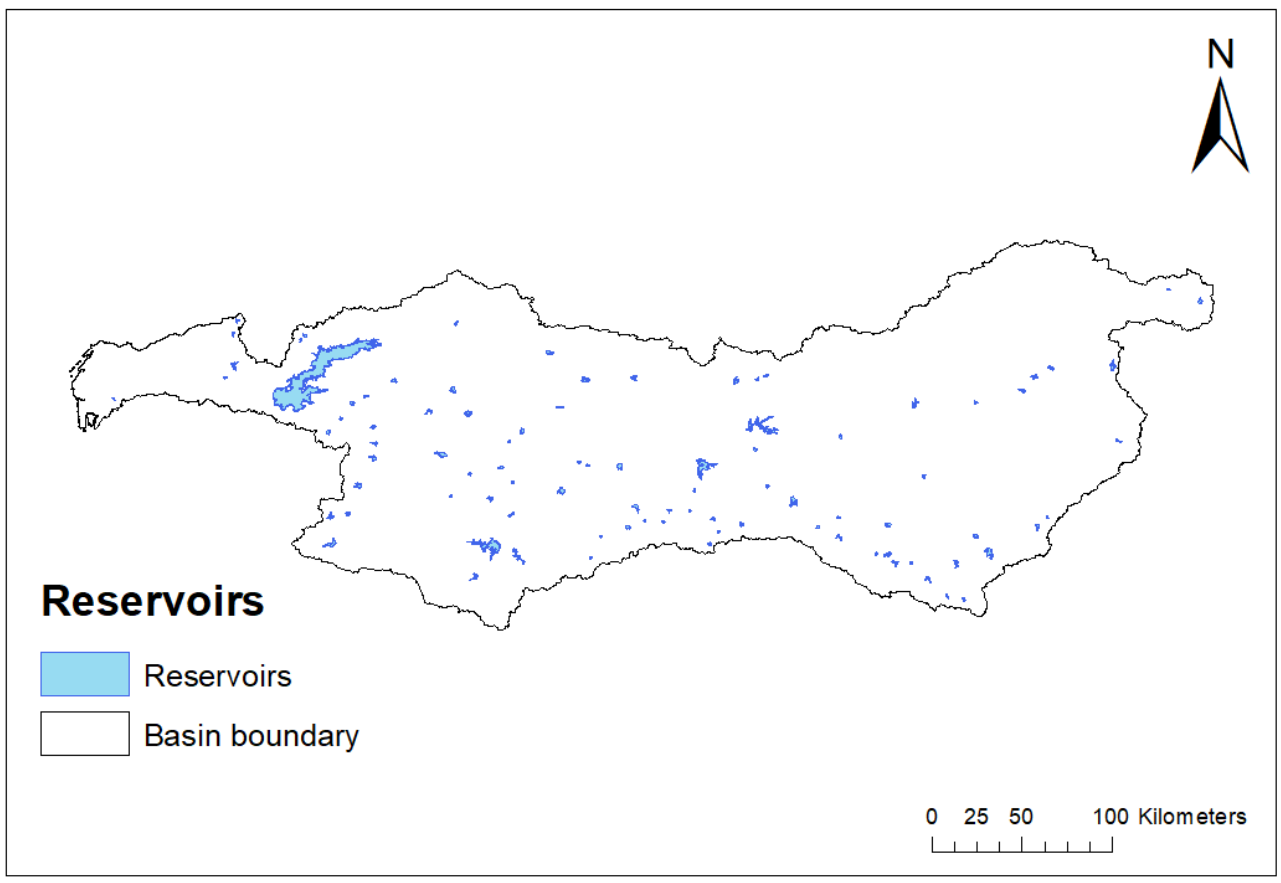


Figure 4.18.6: Reservoir map of Tapi Basin

4.18.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1985-2023 has been estimated as 10.92 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.18.7. Yearly variations in ET_{II} are shown in Figure 4.18.8.

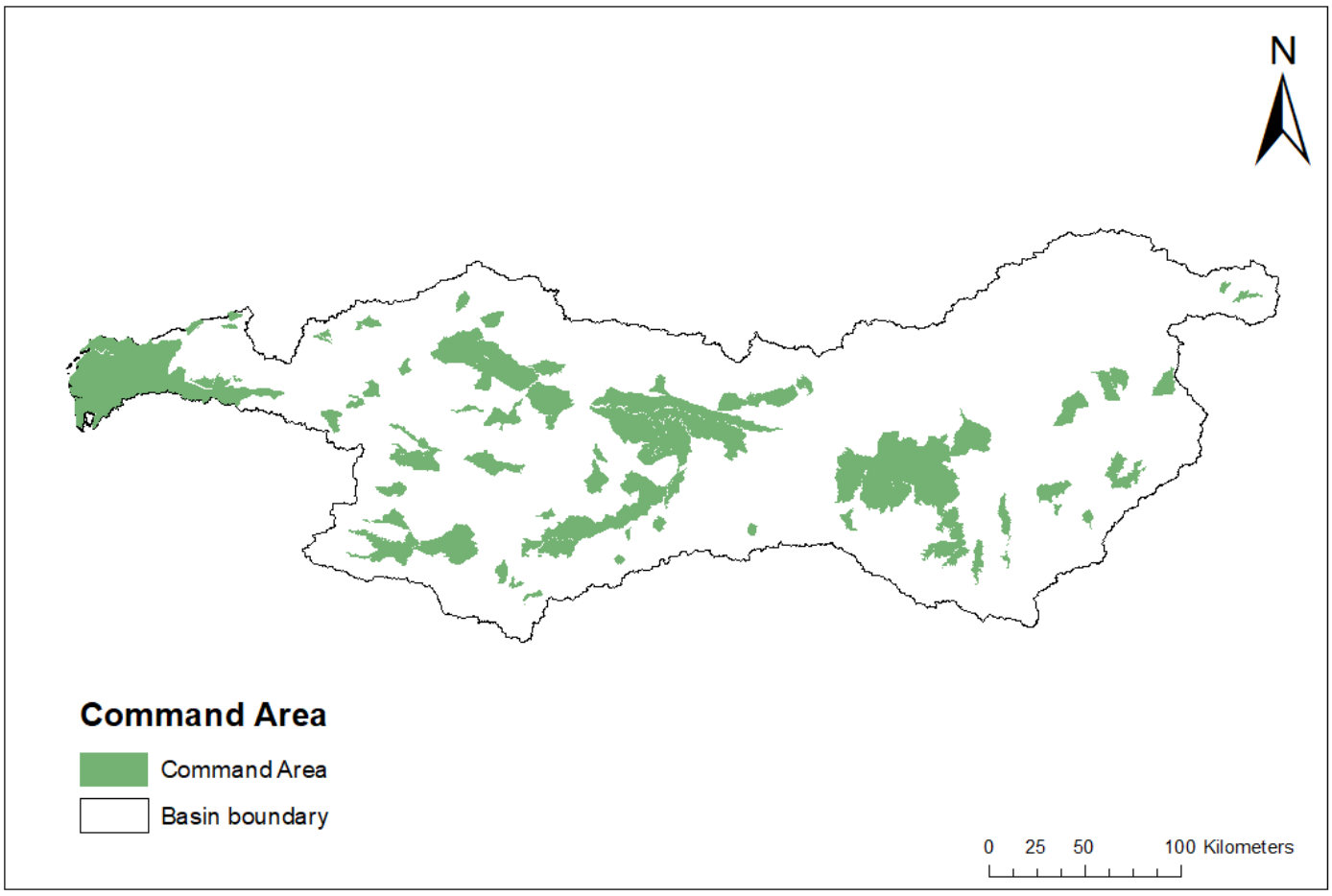


Figure 4.18.7: Command Area map of Tapi basin

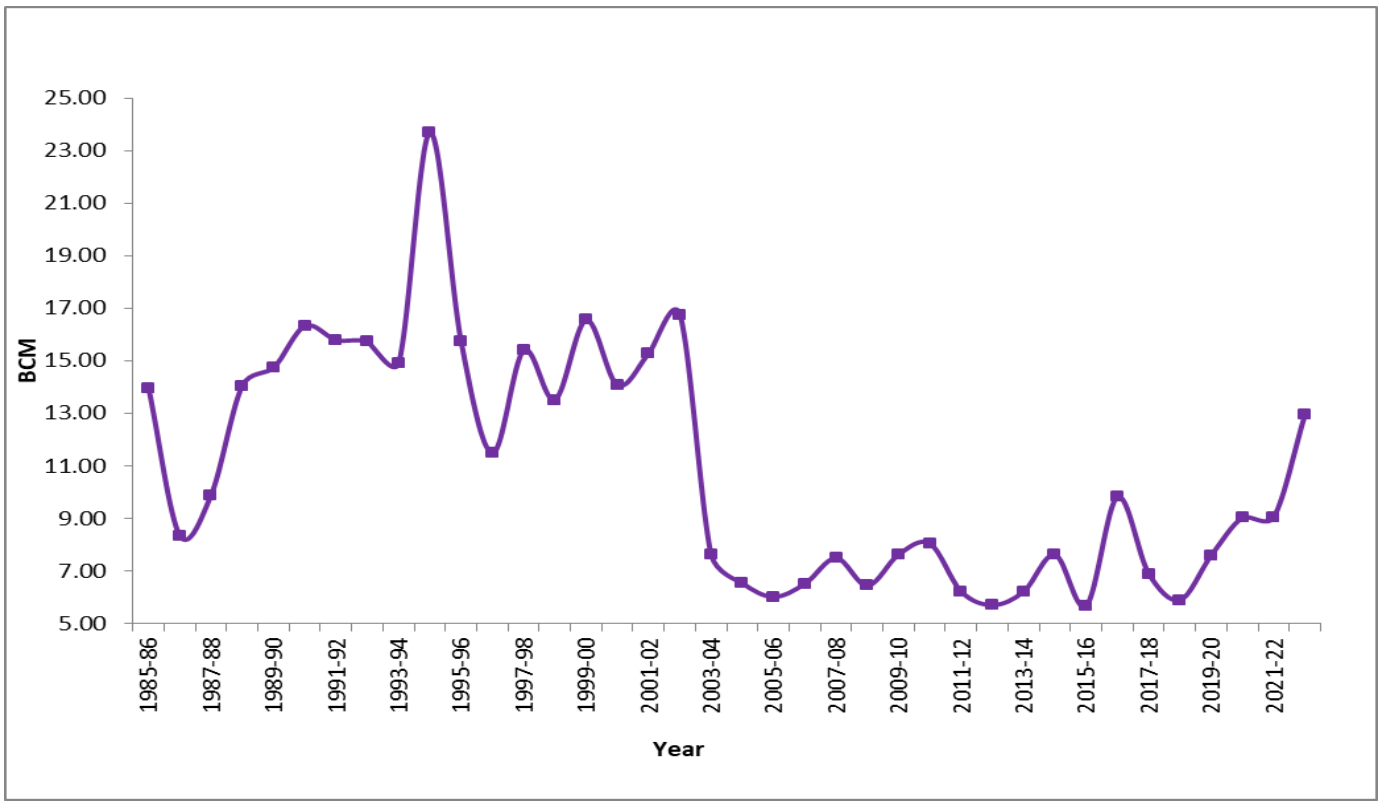


Figure 4.18.8: ET from Irrigation Input in Tapi basin

4.18.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.30 BCM and 0.10 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 1.36 BCM.

4.18.4 Previous Estimates

The previous CWC (1993) estimate of available water resources of the Tapi basin was 14.88 BCM while in 2019 study (1985 to 2015) available water resources of the Tapi basin was 26.24 BCM

4.18.5 Annual Water Availability of Tapi Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability of Tapi Basin from year 1985-86 to 2022-23 is estimated as 20.98 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.18.9. The results of Tapi basin are shown in Table 4.18.3.

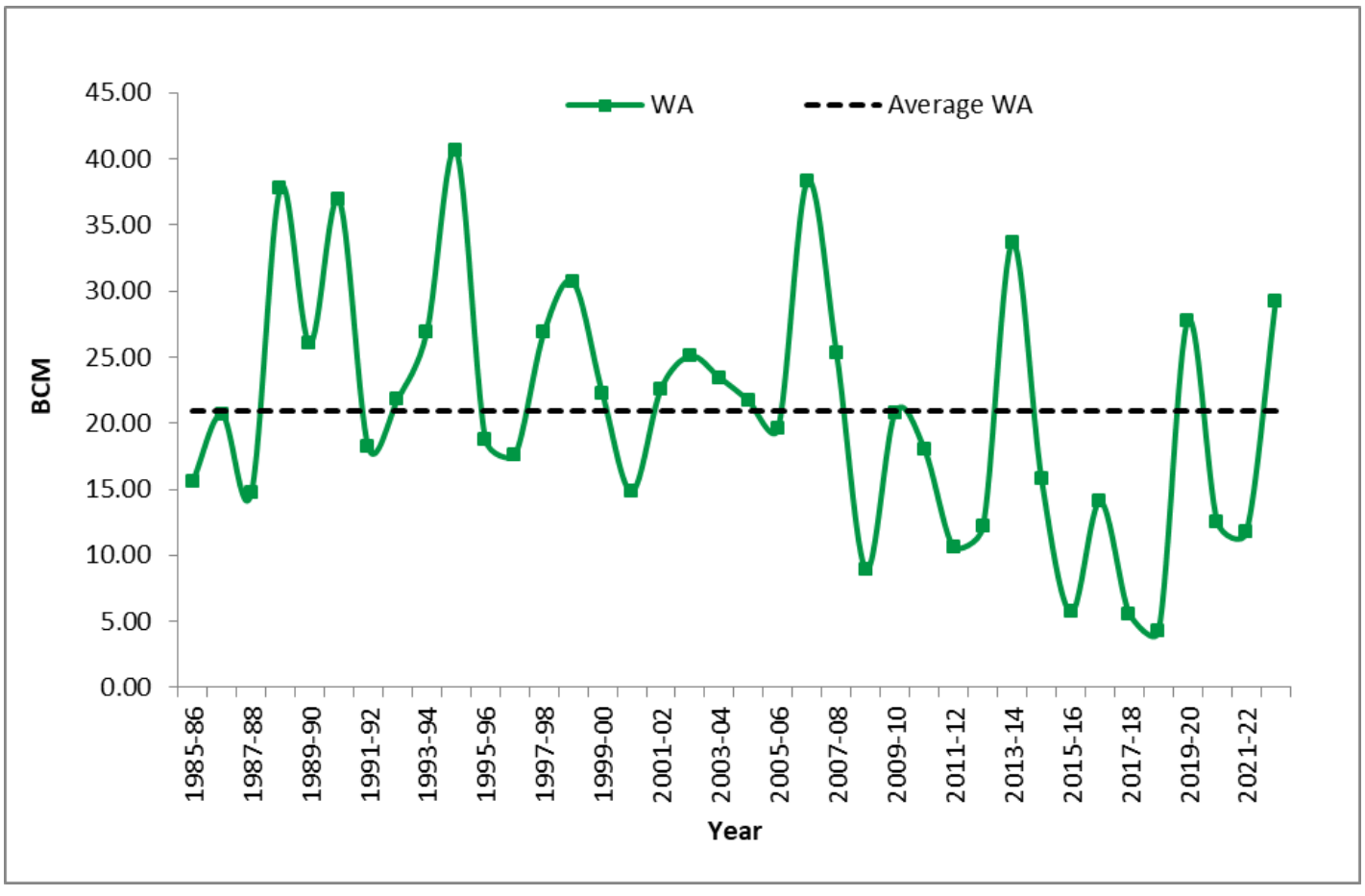


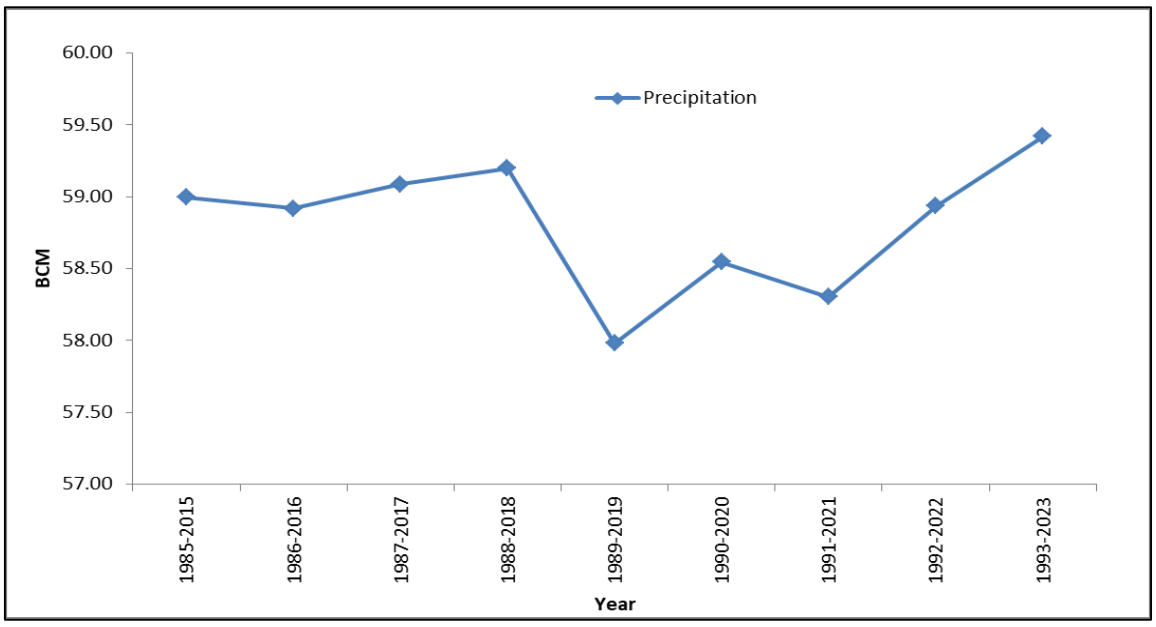
Figure 4.18.9: Water Availability of Tapi basin

4.18.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of Tapi basin is given at Table 4.18.2. A line diagram of moving average of P and WA is shown in Figure 4.18.10.

Table 4.18.2: Moving Average of 30 years from 1985-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	59.00	22.74
1986-2016	58.92	22.45
1987-2017	59.09	22.15
1988-2018	59.20	21.93
1989-2019	57.98	20.90
1990-2020	58.55	20.97
1991-2021	58.30	20.16
1992-2022	58.94	19.95
1993-2023	59.42	20.21



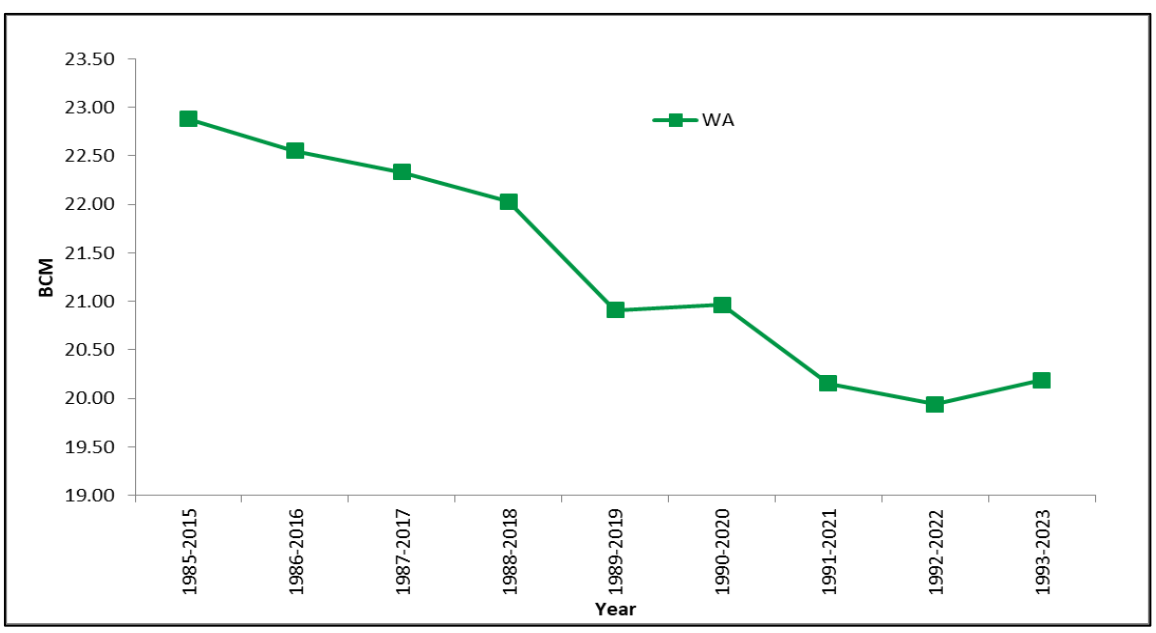


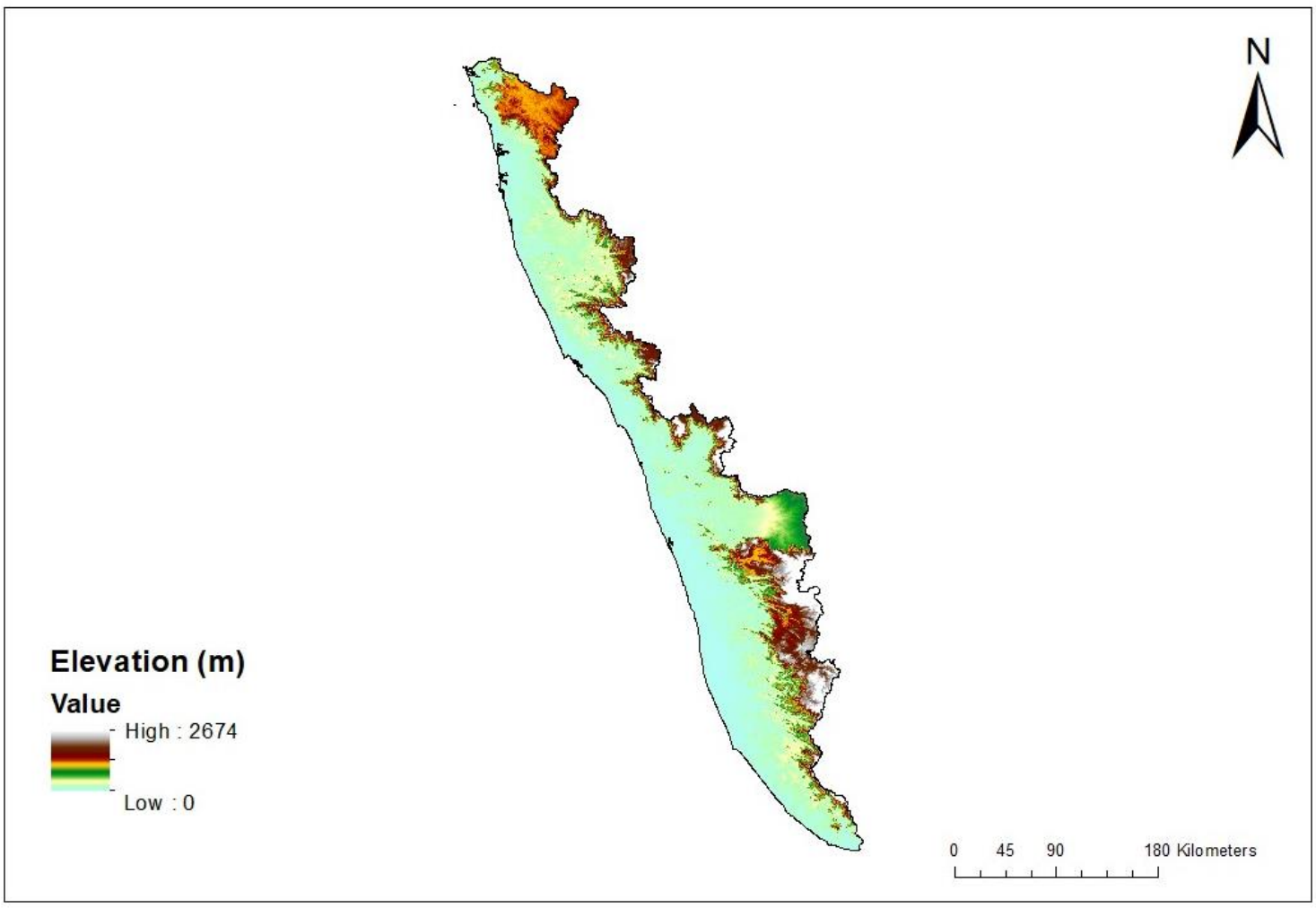
Figure 4.18.10: Moving Average of P and WA for 30 years

Table 4.18.3: Water Availability of Tapi basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	44.09	28.53	15.56
1986-87	48.17	27.49	20.68
1987-88	44.19	29.49	14.70
1988-89	77.13	39.30	37.83
1989-90	58.54	32.50	26.04
1990-91	70.67	33.75	36.92
1991-92	41.90	23.71	18.19
1992-93	56.49	34.70	21.79
1993-94	63.86	36.97	26.89
1994-95	77.78	37.14	40.64
1995-96	48.07	29.27	18.80
1996-97	58.70	41.15	17.55
1997-98	64.11	37.25	26.86
1998-99	72.06	41.36	30.70
1999-00	56.42	34.16	22.26
2000-01	39.45	24.60	14.85
2001-02	52.95	30.34	22.61
2002-03	56.23	31.13	25.10
2003-04	65.38	41.91	23.47
2004-05	55.97	34.25	21.72
2005-06	57.09	37.49	19.60
2006-07	79.27	40.95	38.32
2007-08	66.56	41.28	25.28
2008-09	45.66	36.71	8.95
2009-10	60.74	39.93	20.81
2010-11	62.70	44.65	18.05
2011-12	52.23	41.63	10.60
2012-13	53.02	40.85	12.17
2013-14	82.08	48.41	33.67
2014-15	58.38	42.59	15.79
2015-16	41.70	36.00	5.70
2016-17	53.26	39.17	14.09
2017-18	47.51	41.92	5.59
2018-19	40.67	36.40	4.27
2019-20	75.47	47.69	27.78
2020-21	63.39	50.84	12.55
2021-22	60.88	49.10	11.78
2022-23	71.03	41.78	29.25
Average	**58.52**	**37.54**	**20.98**

4.19 WEST FLOWING RIVERS FROM TADRI TO KANYAKUMARI



HIGHLIGHTS

- *Average annual water resources availability of WFR from Tadri to Kanyakumari is 116.47 BCM.*
- *Maximum annual water availability is 154.96 BCM during 1998-99.*
- *Minimum annual water availability is 79.35 BCM during 2016-17.*
- *Average annual precipitation is 149.57 BCM (2758.03 mm).*
- *Maximum annual precipitation is 193.63 BCM (3750 mm) during 1994-95.*
- *Minimum annual precipitation is 102.10 BCM (1883 mm) during 2016-17.*

4.19.1 About WFR from Tadri to Kanyakumari

The West Flowing Rivers from Tadri to Kanyakumari is a composite basin, which extends over the states of Kerala (63%), Karnataka (28%), Tamil Nadu (8%), and Union Territory of Puducherry (1%). It has an area of 54,231 sq.km, which is 1.66% of total geographical area of the country with a maximum length and width of 777 km and 135 km respectively. There are 54-river systems in the basin. The total river length is about 98,395 km. The major independent rivers (directly draining into Arabian Sea) in the basin having length more than 150 km are Bharathapuzha, Periyar, and Pamba. The basin is bounded by Sahyadri hills on the north, the Western Ghats on the east, Indian Ocean on the south, and the Arabian Sea on the west.

4.19.2 Geo-Spatial Datasets

4.19.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of WFR Tadri to Kanyakumari basin for year 2022-23 is shown in Figure 4.19.1. Major land use classes consist of Plantation/Orchard, Deciduous woodland, Evergreen/Semi evergreen woodland etc.

Table 4.19.1 shows the percentage area of each land use class in the basin for year 2022-23.

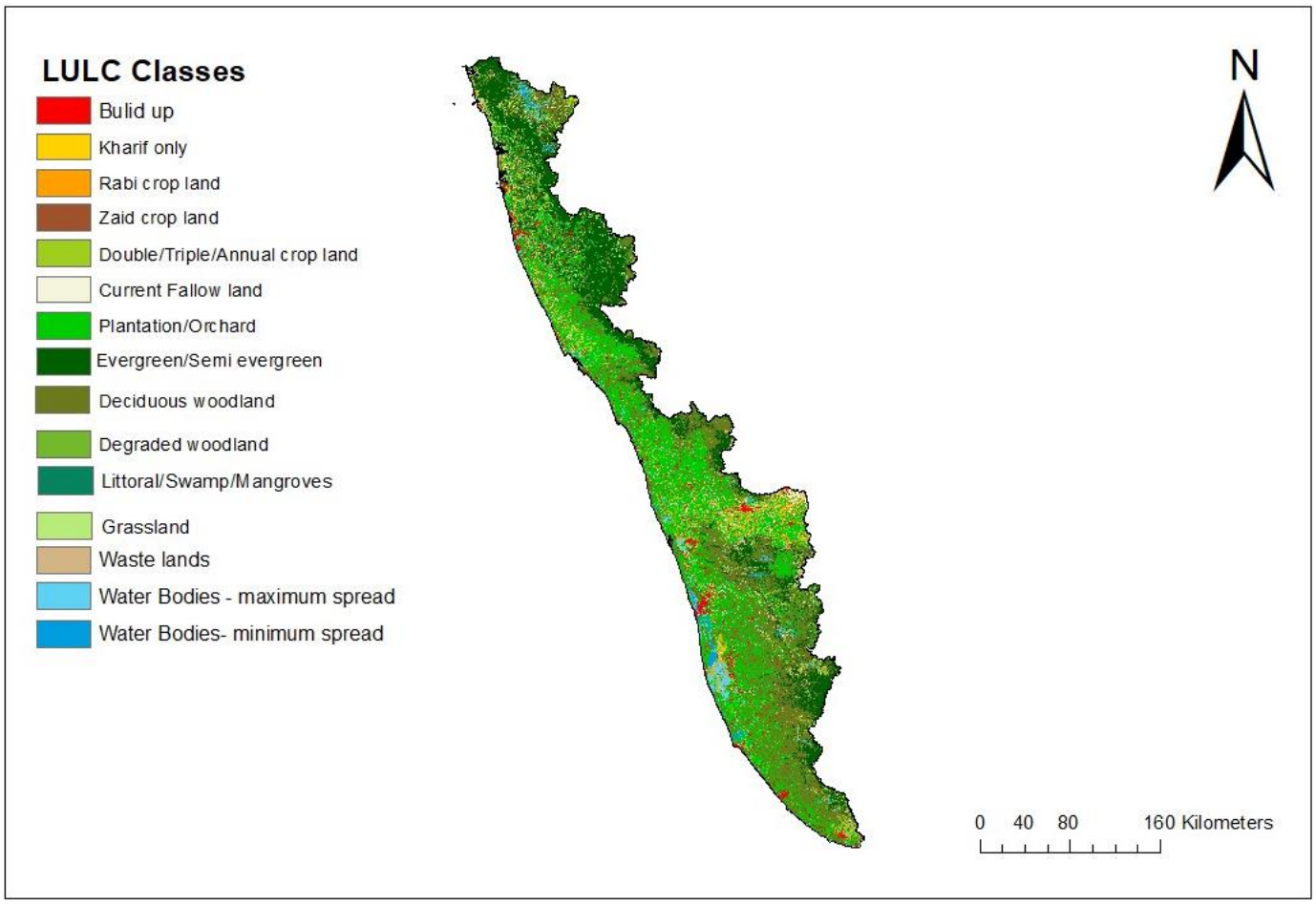


Figure 4.19.1: LULC Map of WFR from Tadri to Kanyakumari basin

Table 4.19.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) 2022-23
1.	Build up	3.67
2.	Kharif only	0.42
3.	Rabi crop land	1.58
4.	Double/Triple/Annual crop land	7.41
5.	Current Fallow land	2.68
6.	Plantation/Orchard	29.76
7.	Evergreen/Semi evergreen woodland	20.01
8.	Deciduous woodland	29.05
9.	Degraded woodland	0.32
10.	Grassland	0.19
11.	Waste lands	1.37
12.	Water Bodies - maximum spread	2.42
13.	Water Bodies - minimum spread	1.12

4.19.3 Hydro-Meteorological and other Input Data

4.19.3.1 Precipitation

The spatial variation of Precipitation for the year 2022-23 is shown in the Figure 4.19.2 and the variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.19.3. The average precipitation of 38 years is estimated as 149.57 BCM (2758.03 mm).

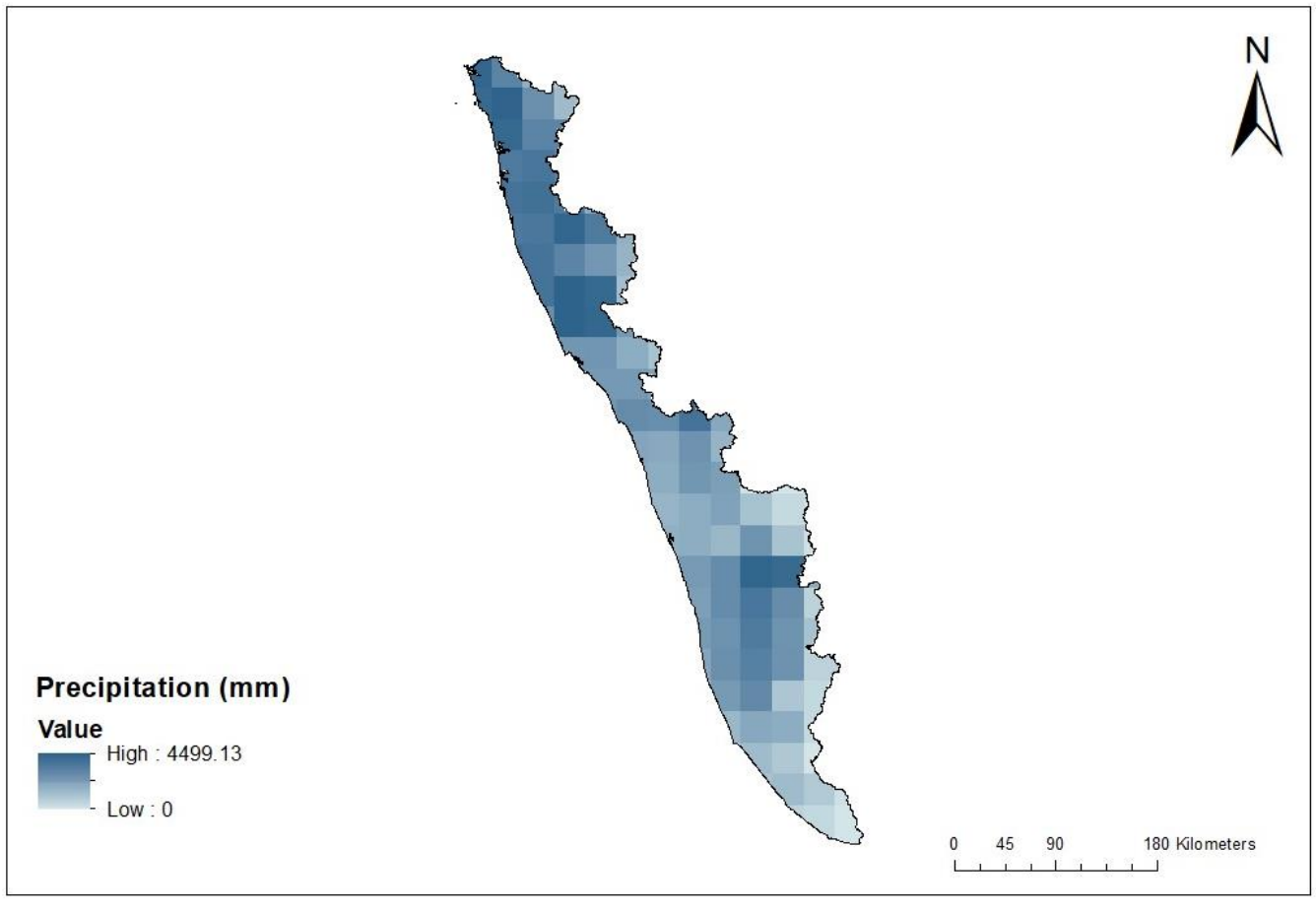


Figure 4.19.2: Precipitation map of WFR from Tadri to Kanyakumari basin

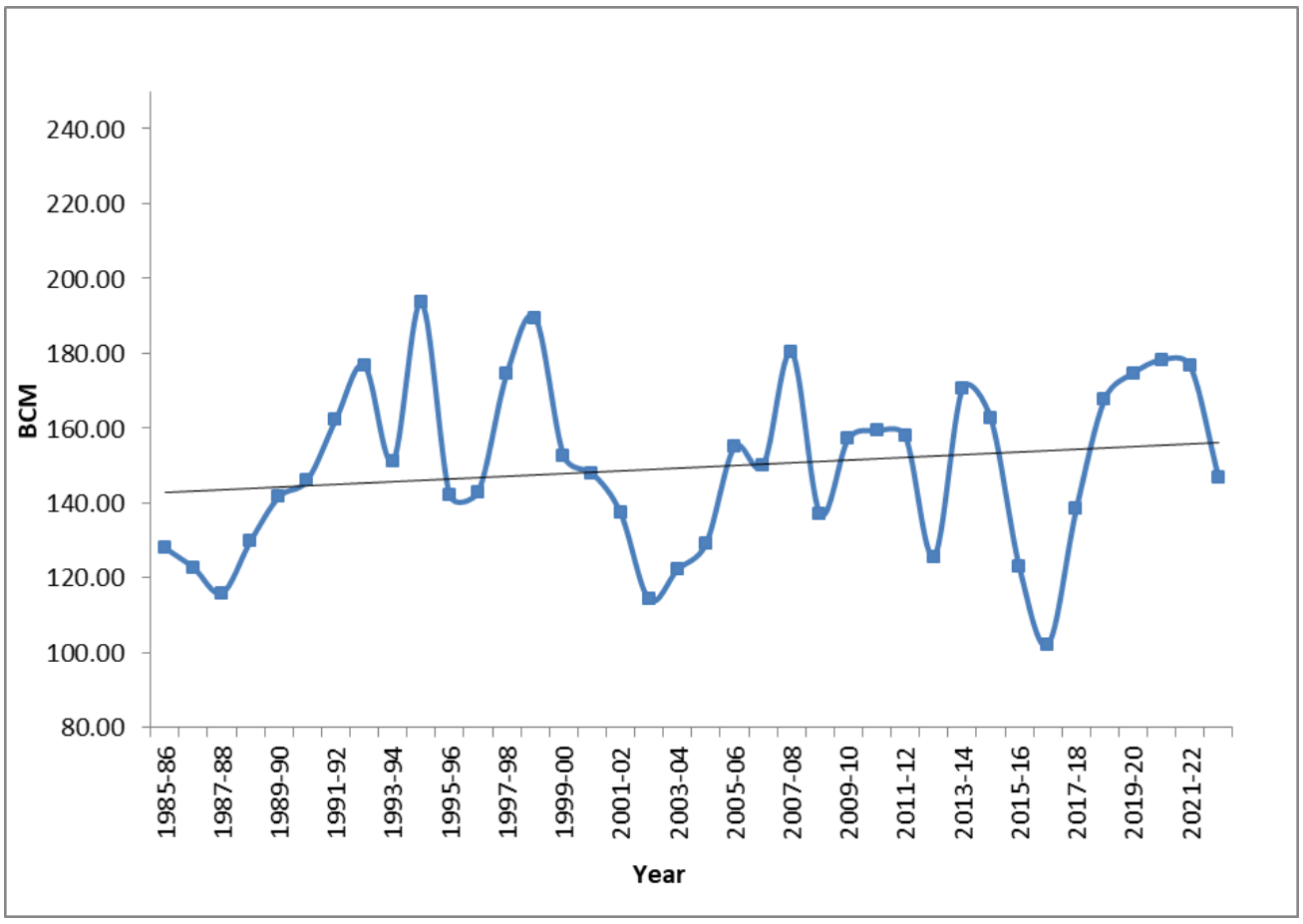


Figure 4.19.3: Annual Precipitation in WFR from Tadri to Kanyakumari basin

4.19.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.19.4. The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.19.5. The Average ET of 38 years is 37.52 BCM (692 mm).

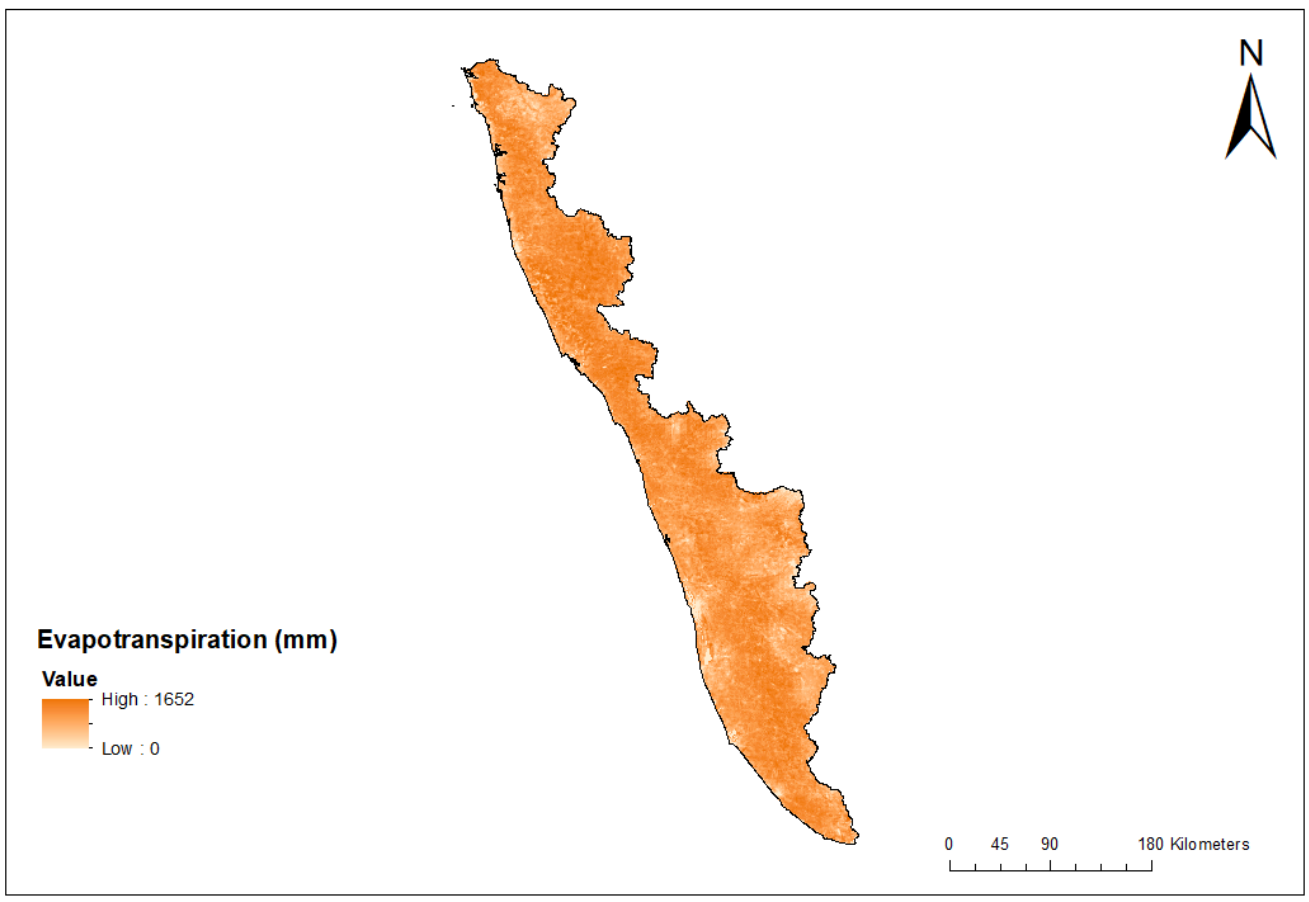


Figure 4.19.4: Evapotranspiration map of WFR from Tadri to Kanyakumari basin

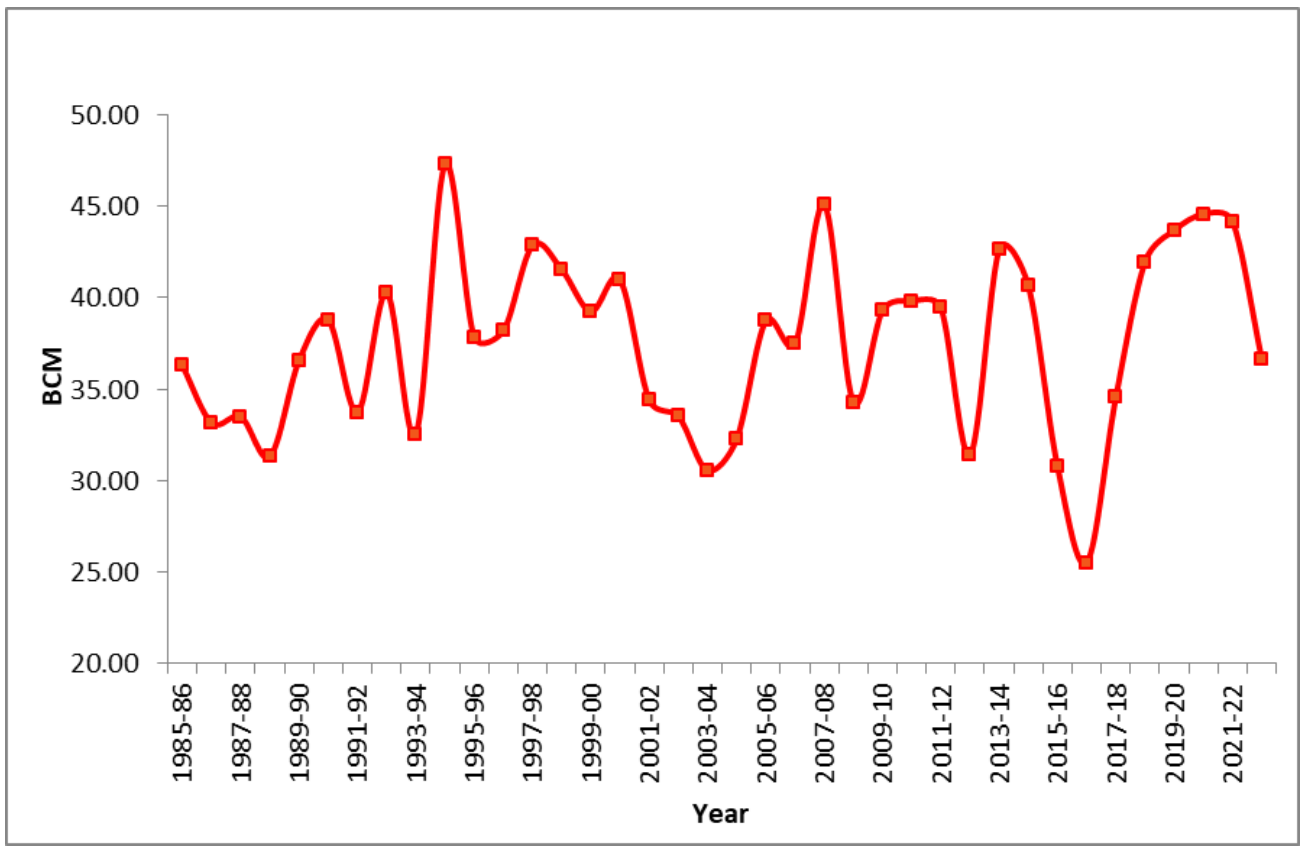


Figure 4.19.5: Annual Evapotranspiration in WFR from Tadri to Kanyakumari basin

4.19.3.3 Reservoir Evaporation

The average evaporation from the reservoirs in the basin is 1.07 BCM from the reservoirs selected are shown in Figure 4.19.6.

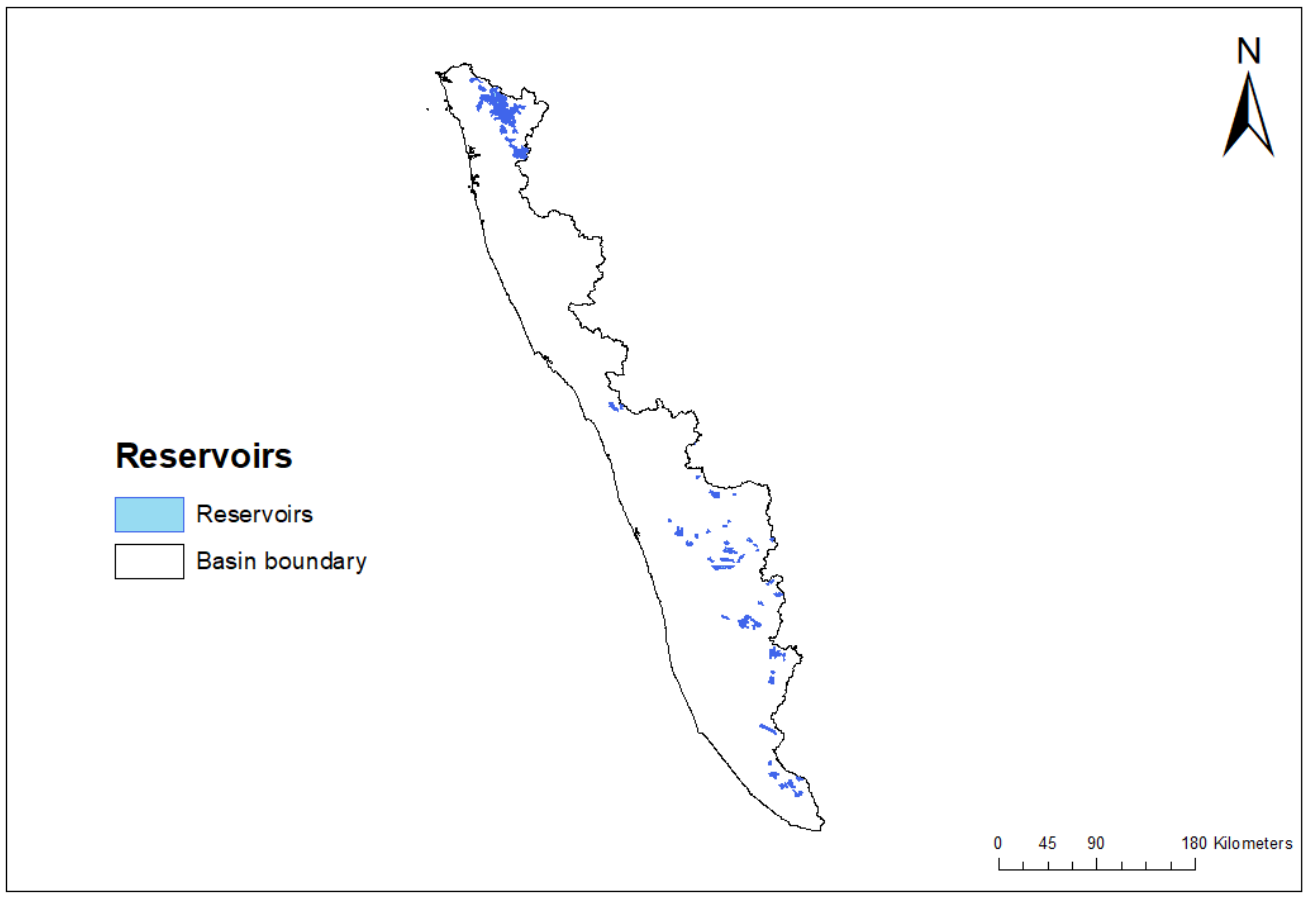


Figure 4.19.6: Reservoir map of WFR from Tadri to Kanyakumari basin

4.19.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1986-2023 has been estimated as 3.35 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.19.7. Yearly variations in ET_{II} are shown in Figure 4.19.8.

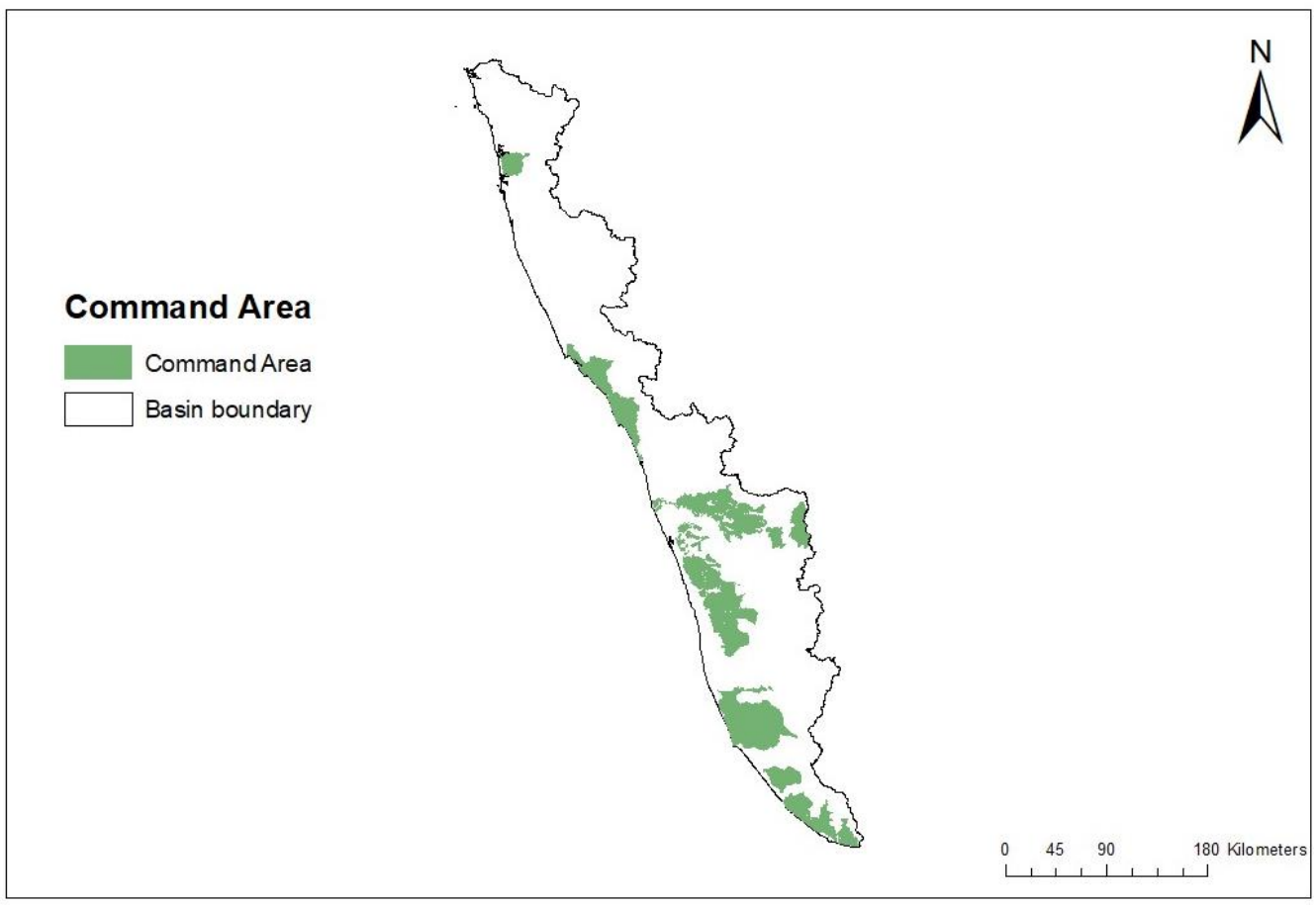


Figure 4.19.7: Command area map of WFR from Tadri to Kanyakumari basin

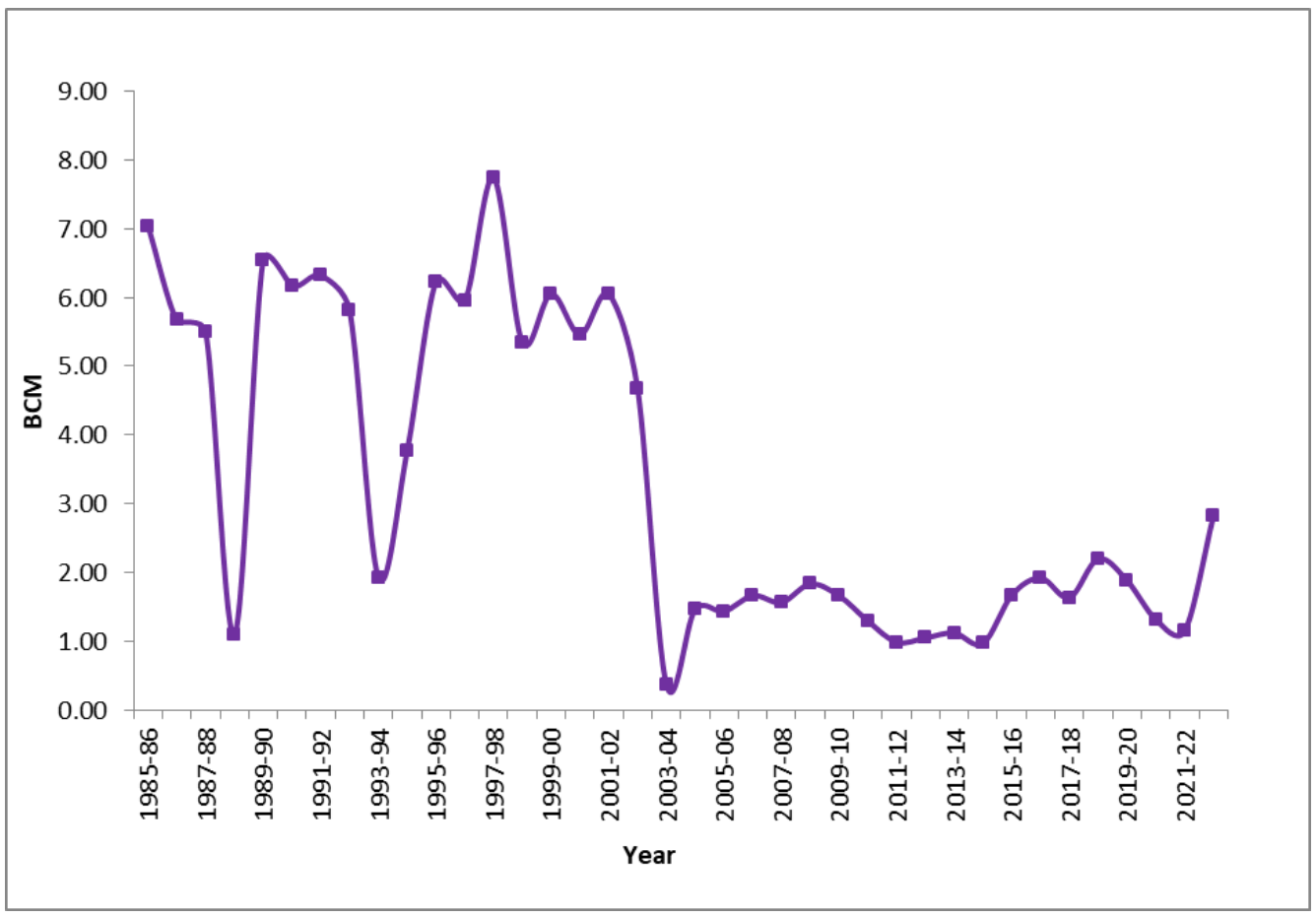


Figure 4.19.8: ET from Irrigation Input in WFR from Tadri to Kanyakumari basin

4.19.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.18 BCM and 0.02 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.90 BCM.

4.19.4 Previous Estimates

As per 1993 report of CWC, this basin has 54 minor river systems of which five rivers had observed flow records for 12 to 16 years. The methodology involved developing a relationship between average annual catchment precipitation and runoff. This study estimated available water resources as 113.5 BCM.

The CWC (2019) estimate of water availability using space inputs of the total basin was 119.06 BCM.

4.19.5 Annual Water Availability of WFR Tadri to Kanyakumari Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated as 116.47 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.19.9. The results of WFR Tadri to Kanyakumari basin are shown in Table 4.19.3.

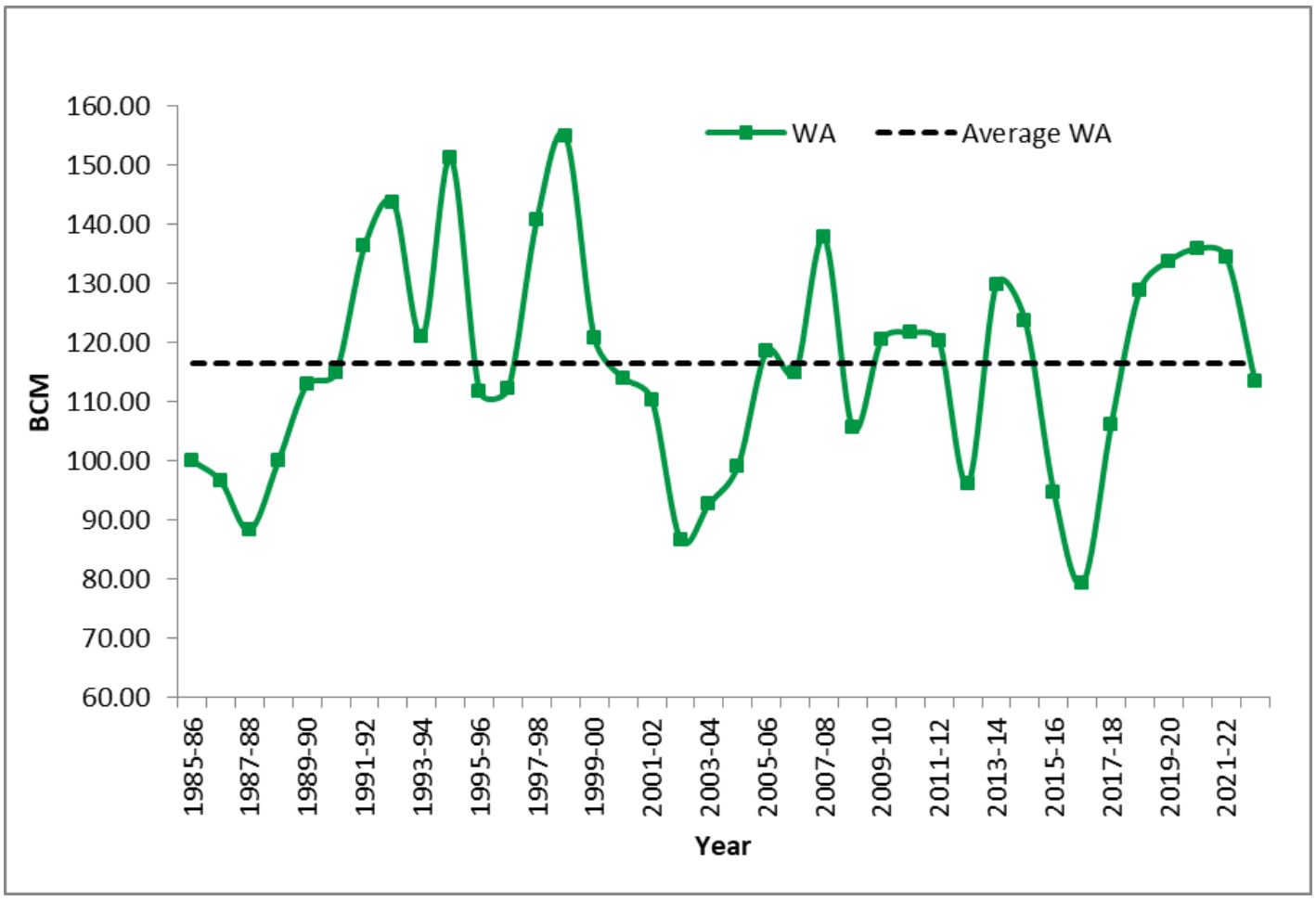


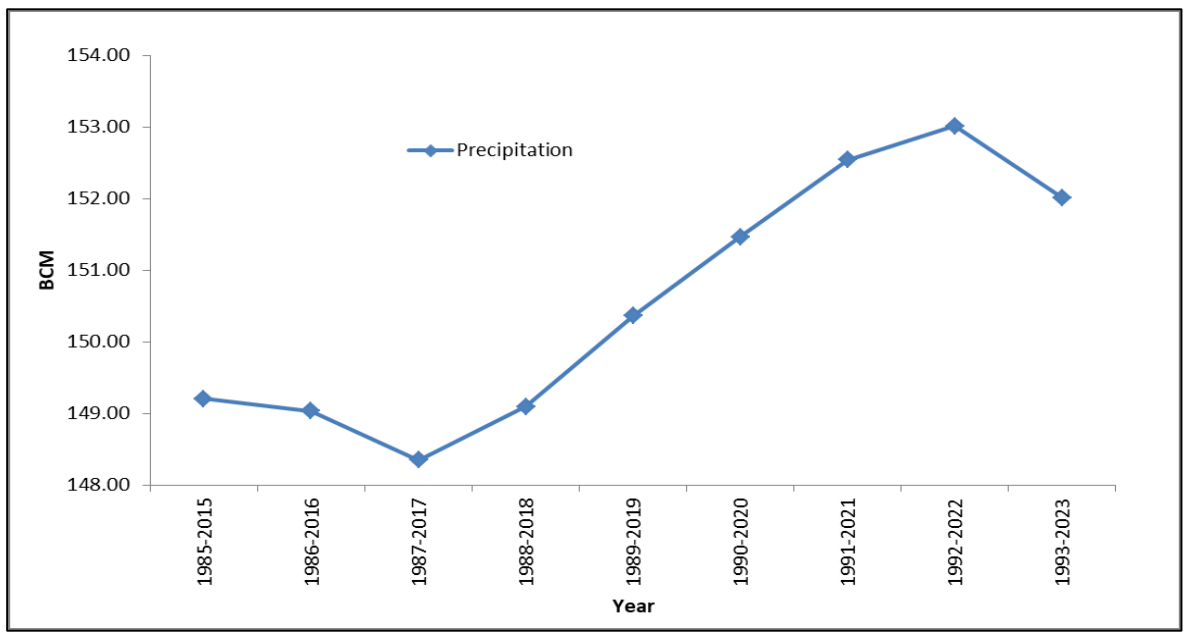
Figure 4.19.9: Water Availability of WFR from Tadri to Kanyakumari basin

4.19.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water availability of WFR from Tadri to Kanyakumari basin is given at Table 4.19.2. A line diagram of moving average of P and WA is shown in Figure 4.19.10.

Table 4.19.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	149.20	116.62
1986-2016	149.04	116.44
1987-2017	148.35	115.87
1988-2018	149.09	116.47
1989-2019	150.36	117.43
1990-2020	151.47	118.13
1991-2021	152.54	118.83
1992-2022	153.02	118.77
1993-2023	152.01	117.76



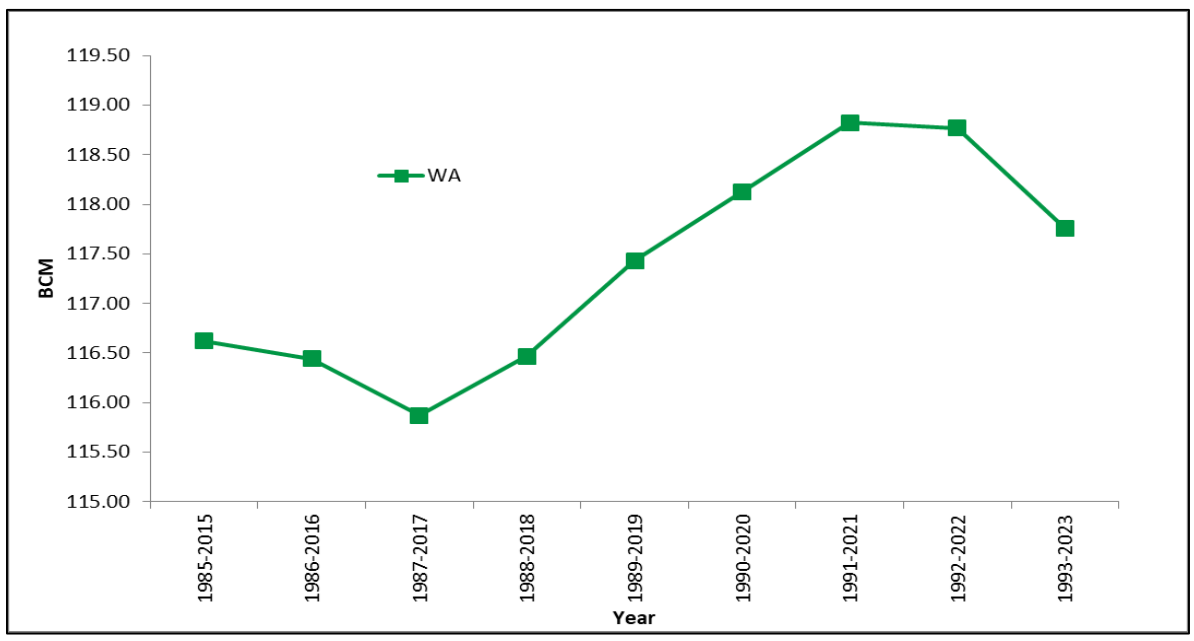


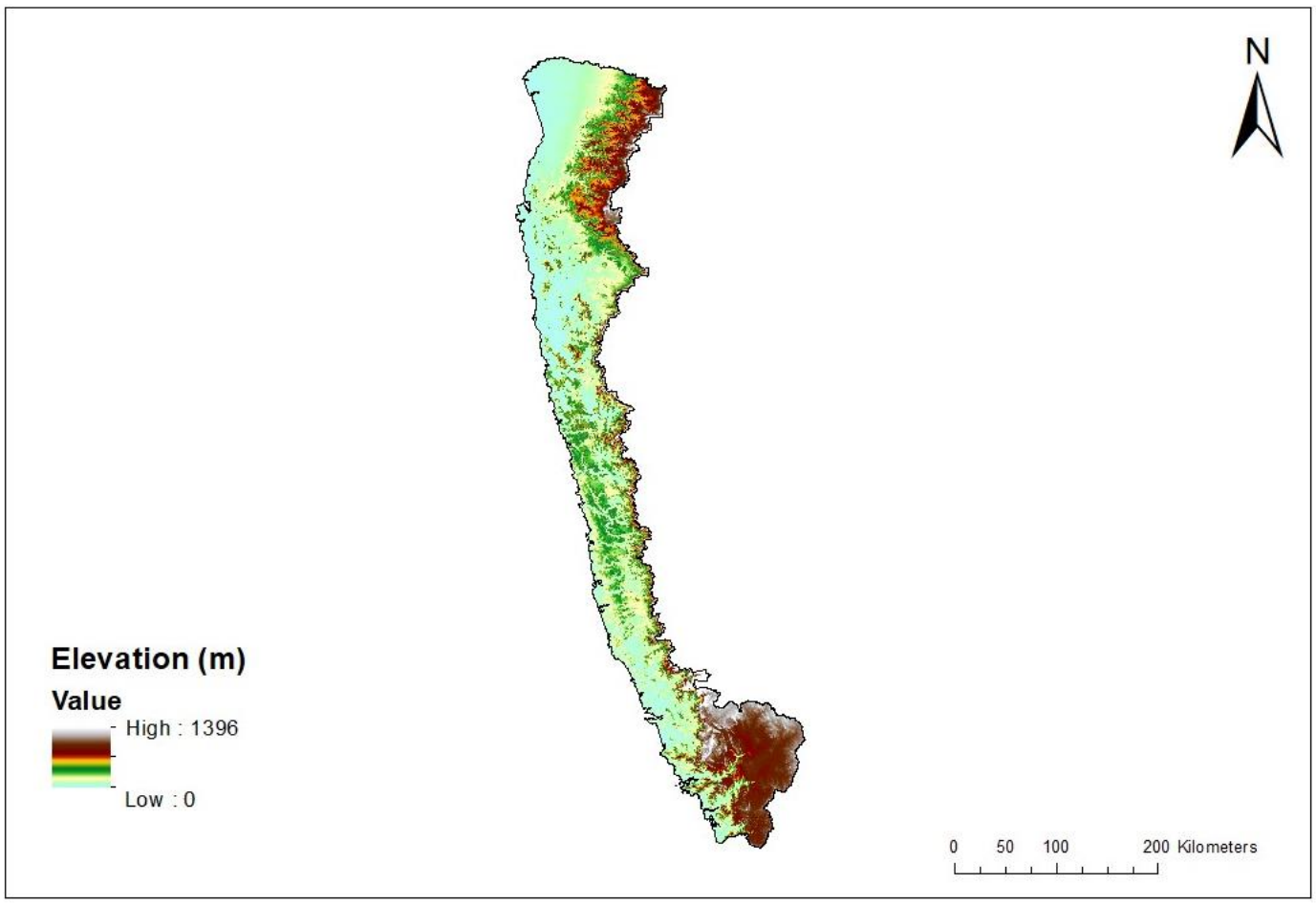
Figure 4.19.10: Moving Average of P and WA for 30 years

Table 4.19.3: Water Availability of WFR Tadri to Kanyakumari basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	128.00	27.91	100.09
1986-87	122.75	26.17	96.58
1987-88	115.95	27.57	88.38
1988-89	129.73	29.74	99.99
1989-90	141.63	28.63	113.00
1990-91	146.10	31.17	114.93
1991-92	162.31	26.00	136.31
1992-93	176.79	32.98	143.81
1993-94	151.13	30.16	120.97
1994-95	193.63	42.42	151.21
1995-96	142.15	30.27	111.88
1996-97	143.00	30.81	112.19
1997-98	174.44	33.66	140.78
1998-99	189.50	34.54	154.96
1999-00	152.62	31.72	120.90
2000-01	147.99	33.90	114.09
2001-02	137.37	26.93	110.44
2002-03	114.23	27.46	86.77
2003-04	122.21	29.40	92.82
2004-05	129.14	29.94	99.20
2005-06	155.00	36.38	118.62
2006-07	149.92	34.89	115.03
2007-08	180.37	42.59	137.78
2008-09	137.17	31.58	105.59
2009-10	157.19	36.72	120.48
2010-11	159.26	37.59	121.67
2011-12	157.81	37.53	120.28
2012-13	125.62	29.49	96.13
2013-14	170.52	40.57	129.95
2014-15	162.56	38.78	123.78
2015-16	122.98	28.21	94.77
2016-17	102.10	22.75	79.35
2017-18	138.35	32.08	106.27
2018-19	167.83	38.86	128.97
2019-20	174.73	40.88	133.85
2020-21	178.28	42.31	135.96
2021-22	176.65	42.07	134.57
2022-23	146.67	33.11	113.56
Average	**149.57**	**33.10**	**116.47**

4.20 WEST FLOWING RIVERS FROM TAPI TO TADRI



HIGHLIGHTS

- *Average annual water resources availability of WFR Tapi to Tadri basin is 110.44 BCM.*
- *Maximum annual water availability is 173.86 BCM during 2019-20.*
- *Minimum annual water availability is 44.51 BCM during 2015-16.*
- *Average annual precipitation is 159.69 BCM (2736.36 mm).*
- *Maximum annual precipitation is 233.20 BCM (3996 mm) during 2019-20.*
- *Minimum annual precipitation is 101.24 BCM (1735 mm) during 2015-16.*

4.20.1 About WFR from Tapi to Tadri

The West Flowing Rivers from Tapi to Tadri is a composite basin, extending over an area of 58,360 sq.km, which is nearly 1.77 % of the total geographical area of the country. The basin lies in the states of Maharashtra (57.01%), Karnataka (18.99%), Gujarat (16.94%), Dadra & Nagar Haveli (0.84%) and Goa (6.22%). Being a coastal basin, the various rivers of basin do not meet into one major stream; rather they flow independently and drain directly into the Arabian Sea. The independent rivers in the basin are Purna, Ambika, Damanganga, Vaitarna, Ulhas, Amba, Savitri, Vashishti, Kajvi, Vaghotan, Gad, Mandavi, Kalinadi, Gangavali (Bedti) and Tadri.

4.20.2 Geo-Spatial Datasets

4.20.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover (LULC) map of WFR Tapi to Tadri basin for year 2022-23 is shown in Figure 4.20.1. Major land use classes consist of deciduous woodland, Evergreen/Semi evergreen woodland, Kharif only etc.

Table 4.20.1 shows the distribution of LULC in the basin for 2022-23.

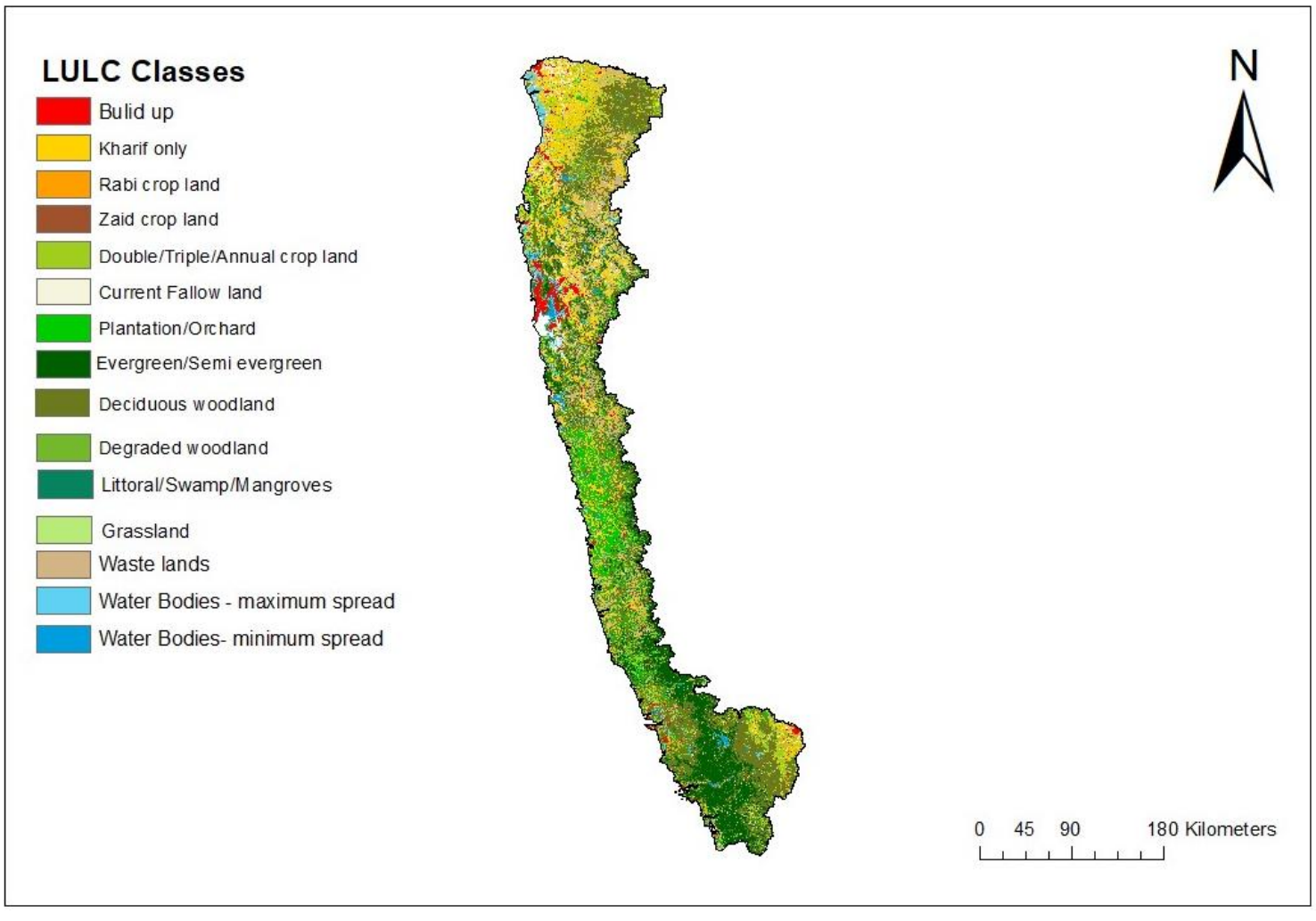


Figure 4.20.1: LULC Map of WFR from Tapi to Tadri basin

Table 4.20.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) 2022-23
1.	Build up	3.41
2.	Kharif only	16.25
3.	Rabi crop land	0.41
4.	Zaid crop land	0.01
5.	Double/Triple/Annual crop land	6.64
6.	Current Fallow land	3.81
7.	Plantation/Orchard	8.62
8.	Evergreen/Semi evergreen woodland	15.04
9.	Deciduous woodland	29.48
10.	Degraded woodland	2.44
11.	Littoral/Swamp/Mangroves	0.43
12.	Waste lands	9.48
13.	Water Bodies - maximum spread	2.78
14.	Water Bodies - minimum spread	1.19

4.20.3 Hydro-Meteorological and other Input Data

4.20.3.1 Precipitation

The spatial variation of Precipitation for the year 2022-23 is shown in the Figure 4.20.2 and the variations in the annual precipitation during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.20.3. Precipitation varies both spatially and temporally in WFR Tapi to Tadri basin. The average precipitation of 38 years is 159.69 BCM (2736.36 mm).

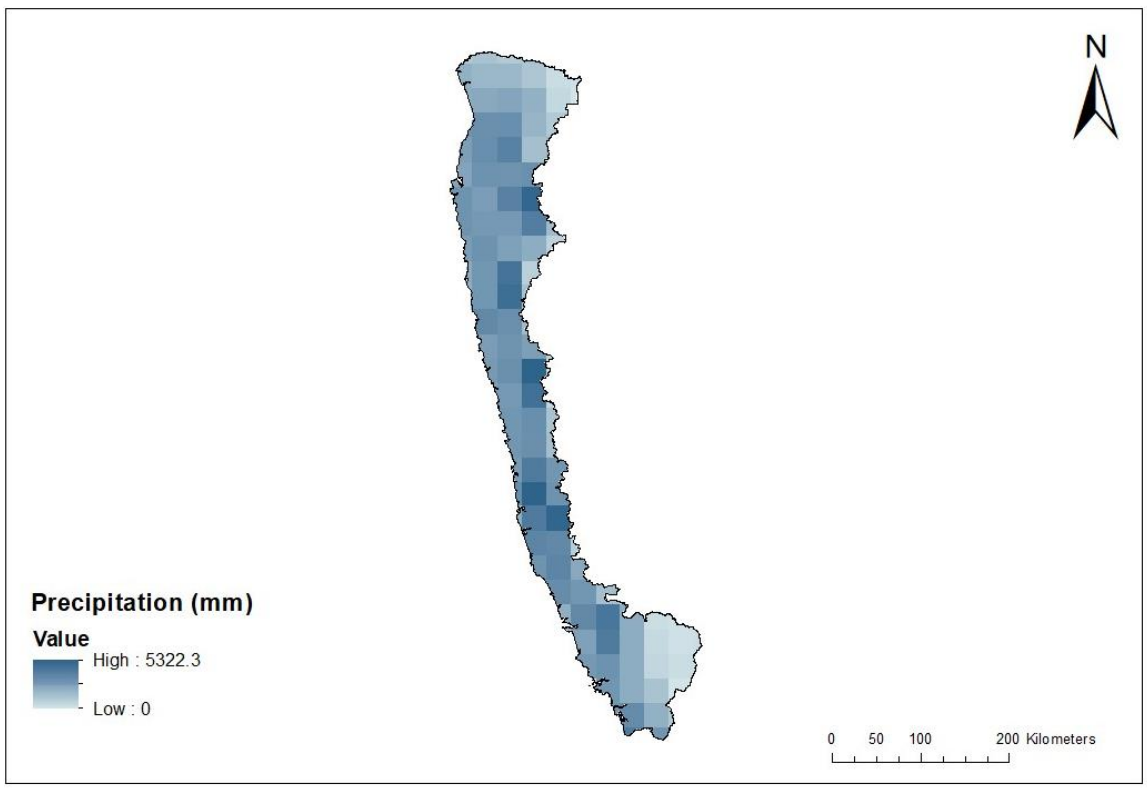


Figure 4.20.2: Precipitation in WFR from Tapi to Tadri basin

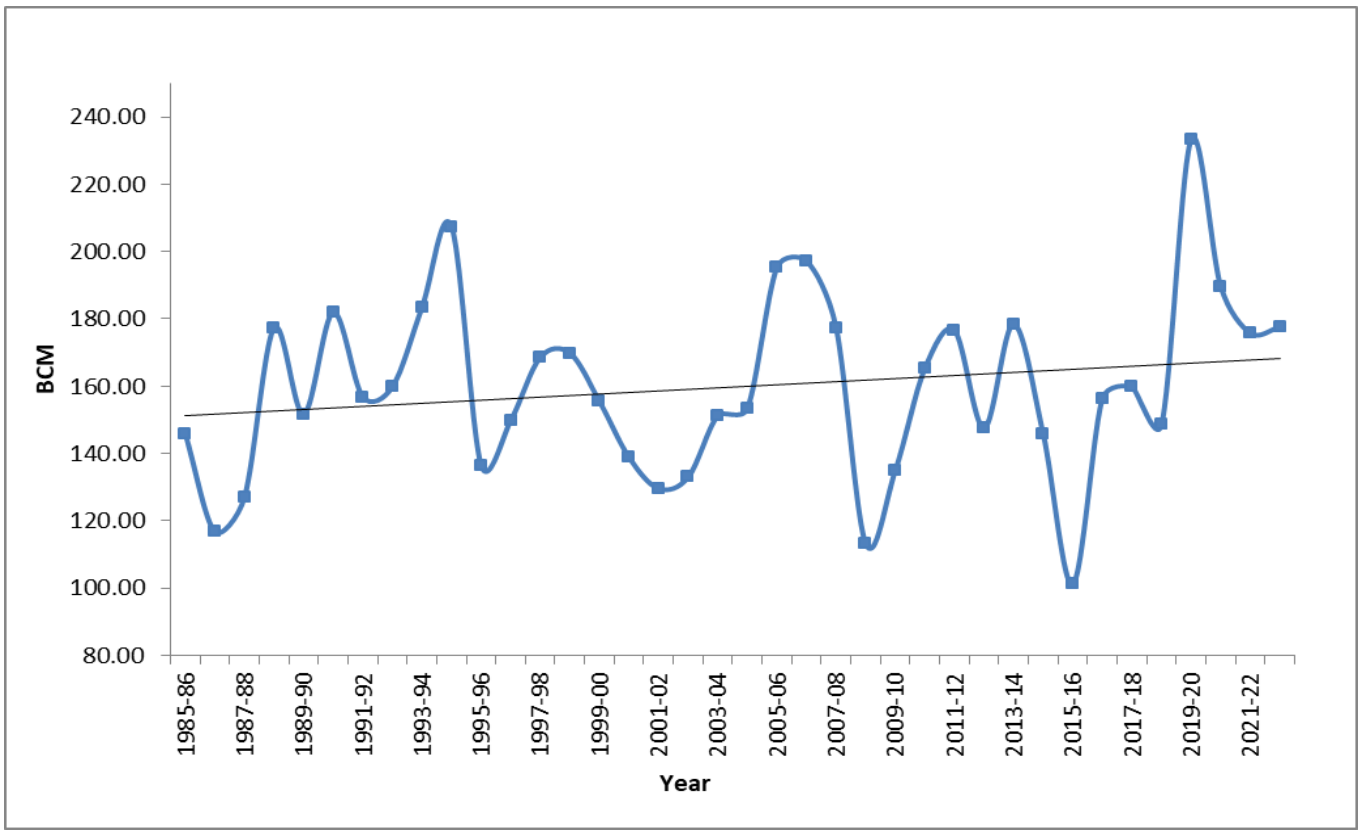


Figure 4.20.3: Annual Precipitation in WFR from Tapi to Tadri basin

4.20.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.20.4. The variations in the annual ET during study period of 38 years (1985-86 to 2022-23) are shown in the Figure 4.20.5. The Average ET of 38 years is 55.47 BCM (951 mm).

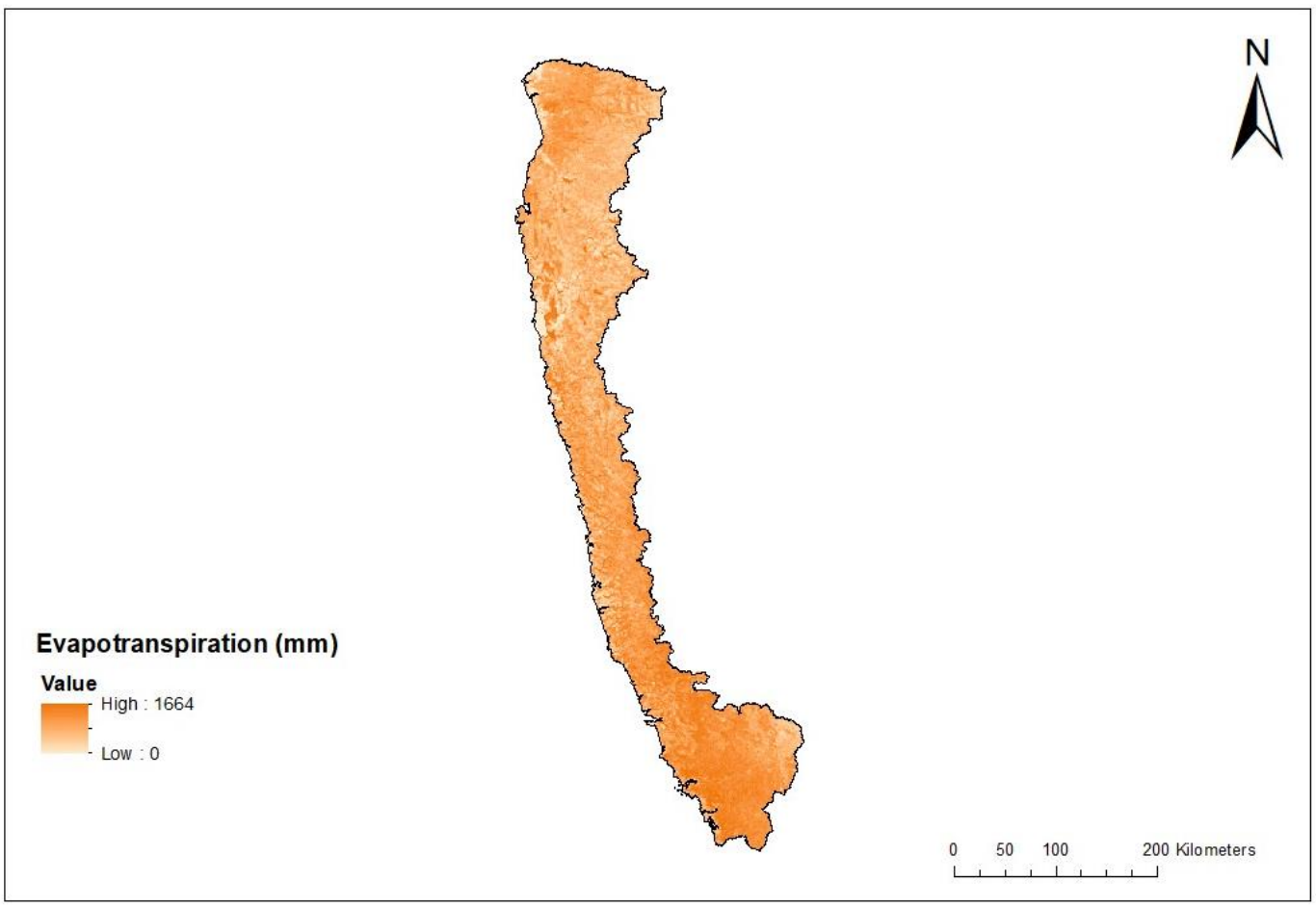


Figure 4.20.4: Evapotranspiration map of WFR from Tapi to Tadri basin

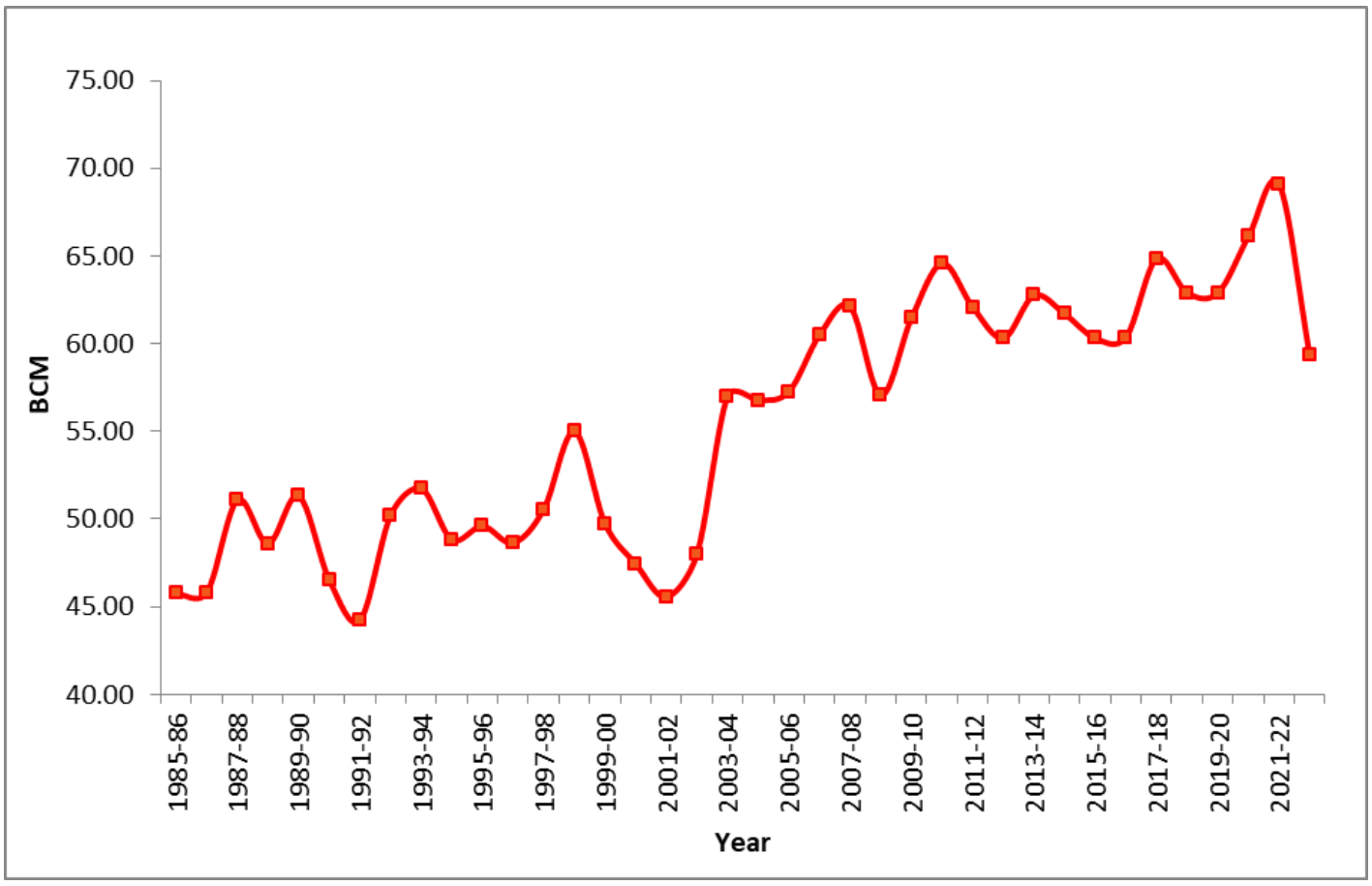


Figure 4.20.5: Annual Evapotranspiration in WFR from Tapi to Tadri basin

4.20.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in Figure 4.20.6. The average annual evaporation from the reservoirs in the basin is 0.92 BCM.

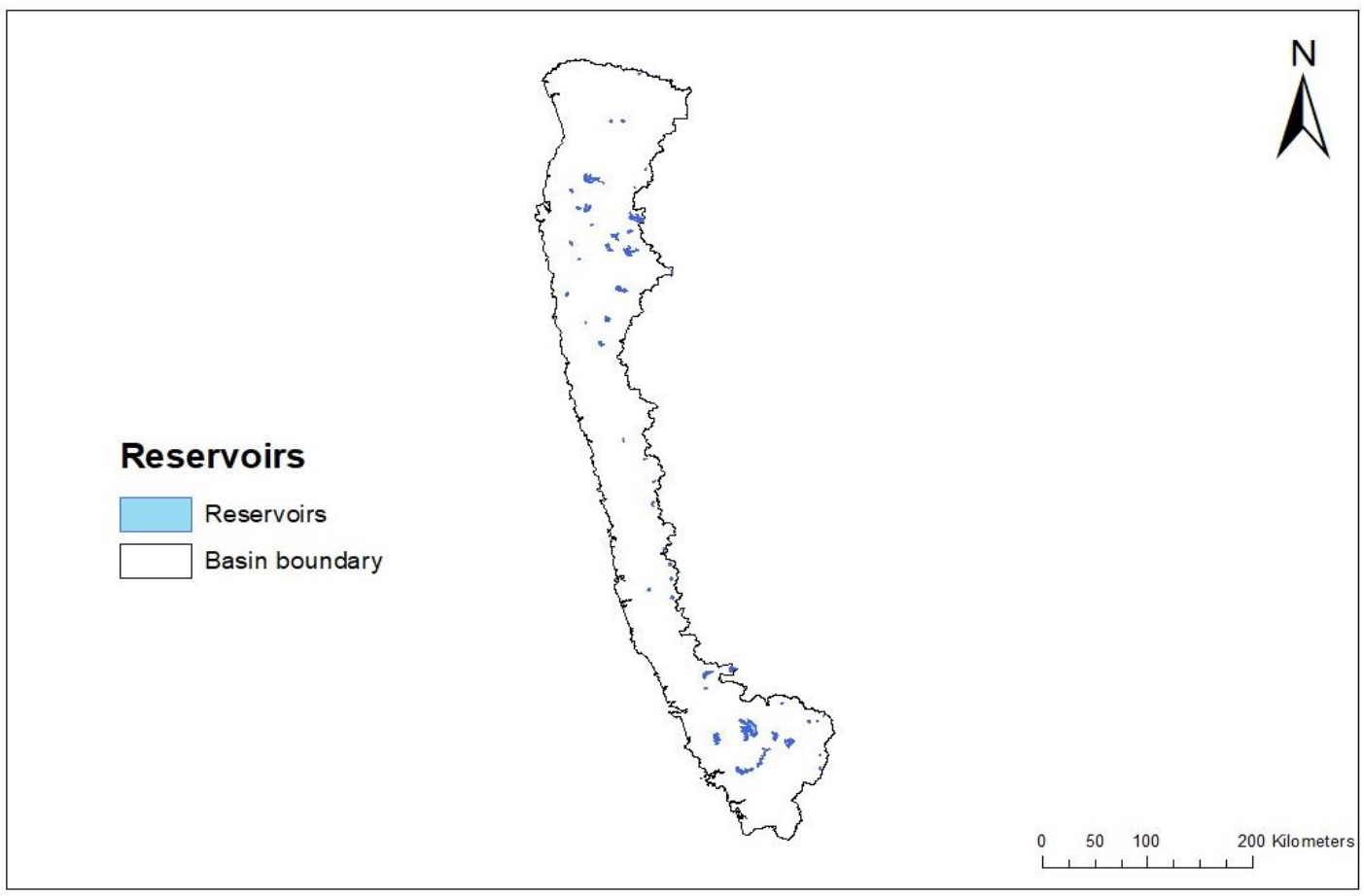


Figure 4.20.6: Reservoir map of WFR from Tapi to Tadri basin

4.20.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input (ET_{II}) for the basin for the years 1986-2023 has been estimated as 5.30 BCM. The command area map used for the estimation of ET_{II} is shown in Figure 4.20.7. Yearly variations in ET_{II} are shown in Figure 4.20.8.

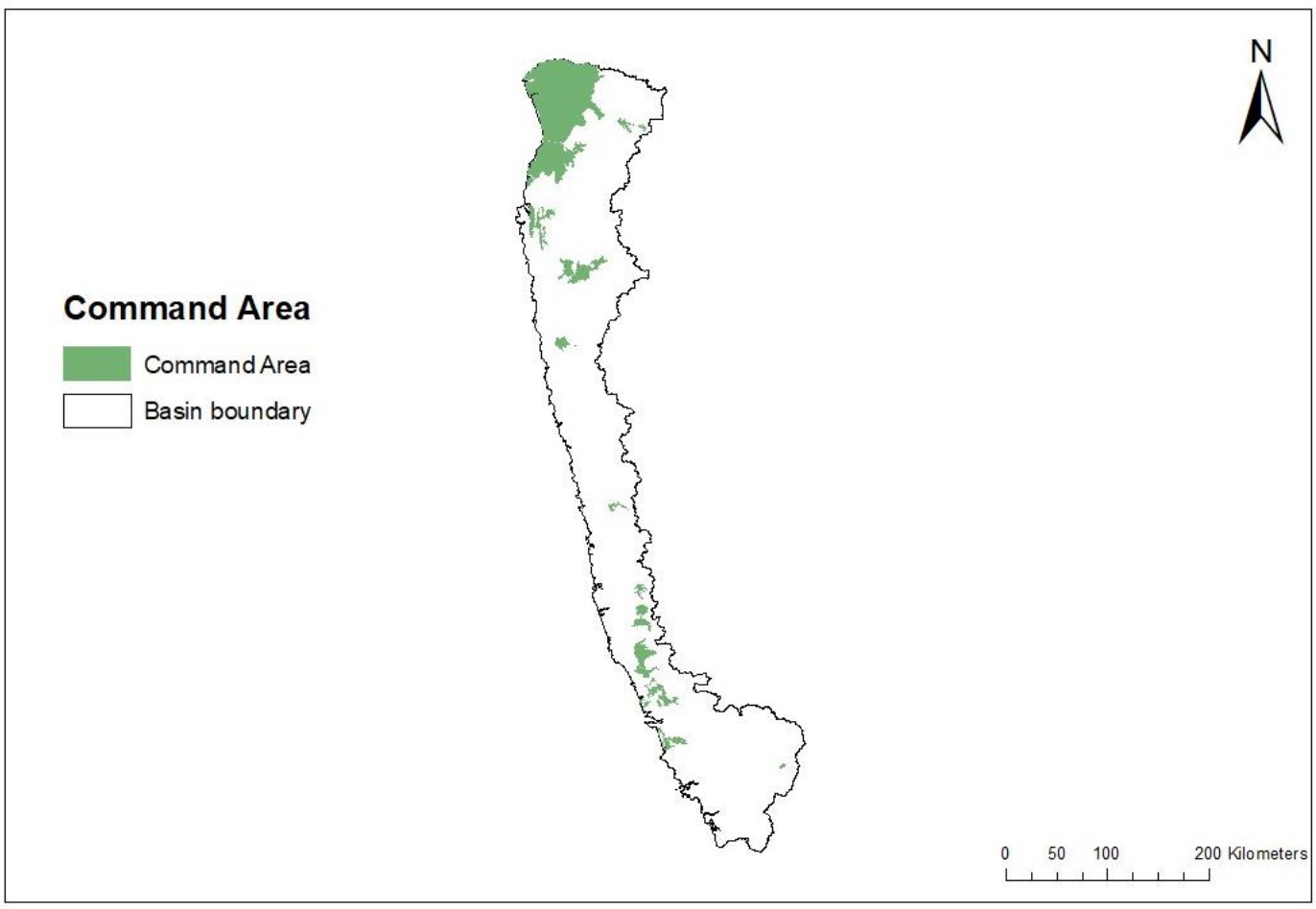


Figure 4.20.7: Command area map of WFR from Tapi to Tadri basin

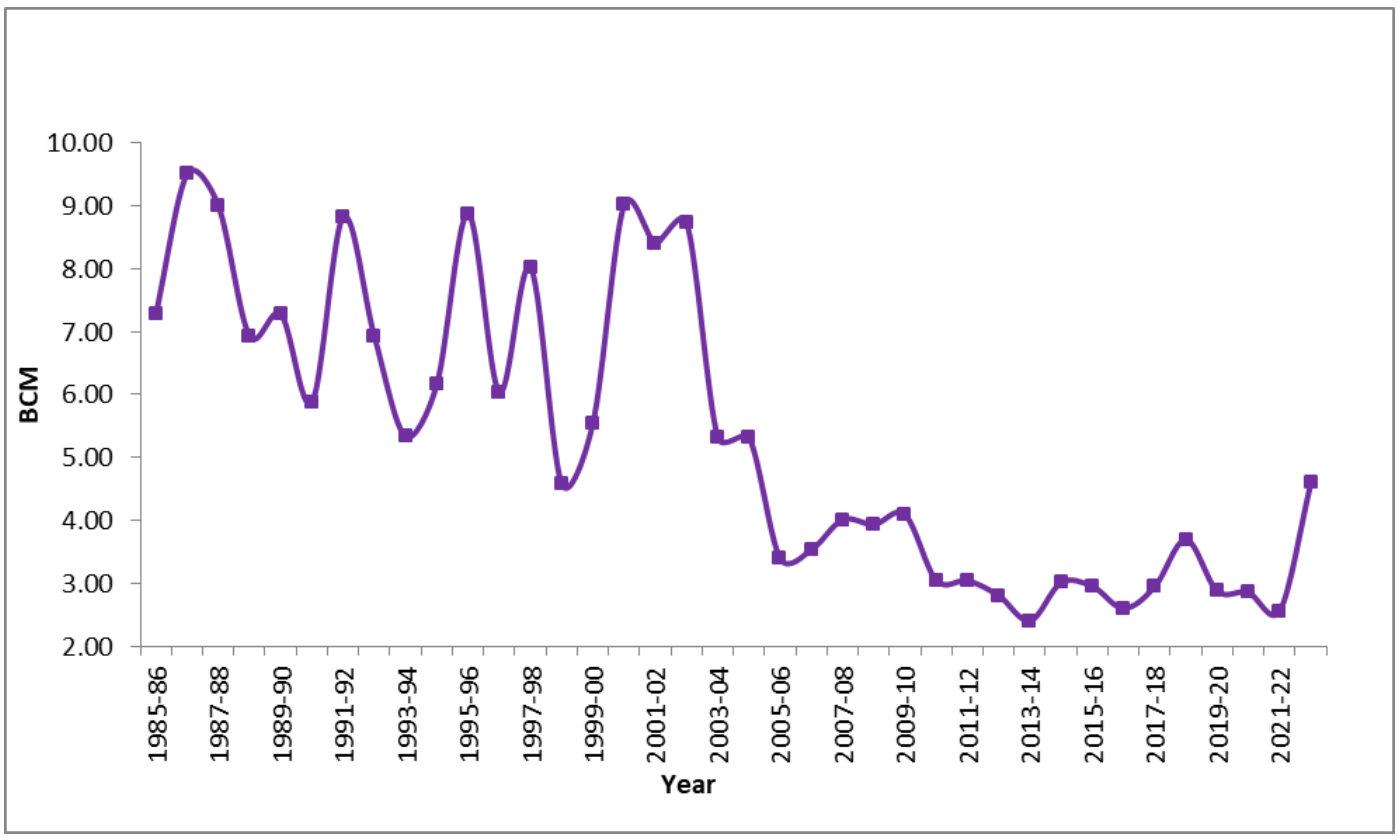


Figure 4.20.8: ET from Irrigation Input in WFR from Tapi to Tadri basin

4.20.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -0.05 BCM and 0.01 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.90 BCM.

4.20.4 Previous Estimates

The first assessment of the water resources potential was made by the Irrigation Commission (1901-03) which estimated the annual runoff of this basin as 230.78 BCM for a catchment area of 93,805 sq. km. In 1949, on the basis of the Khosla's empirical formula, the annual runoff of the west flowing rivers basin was estimated at 229.02 BCM. In 1960, the CW&PC while conducting irrigation potential studies assessed the total annual runoff of the basin as 217.89 BCM based on the available observed data and Strange's Coefficients of precipitation and runoff. Later in 1982 the committee for assessment of water resources of rivers flowing into Arabian Sea and its utilisation assessed the potential of the basin as 198.854 BCM. In 1993, first time separate assessment was made for Tapi to Tadri basin. The total water resource was estimated as 87.411 BCM in the basin.

The CWC (2019) estimate of Water Availability using space inputs of the total basin was 118.35 BCM.

4.20.5 Annual Water Availability of WFR Tapi to Tadri Basin

Using the Geospatial Datasets, Hydro-Meteorological and other inputs the average annual water availability from year 1985-86 to 2022-23 is estimated to be 110.44 BCM. The annual variations from year 1985-86 to 2022-23 are shown in Figure 4.20.9. The results of WFR Tapi to Tadri basin are shown in Table 4.20.3.

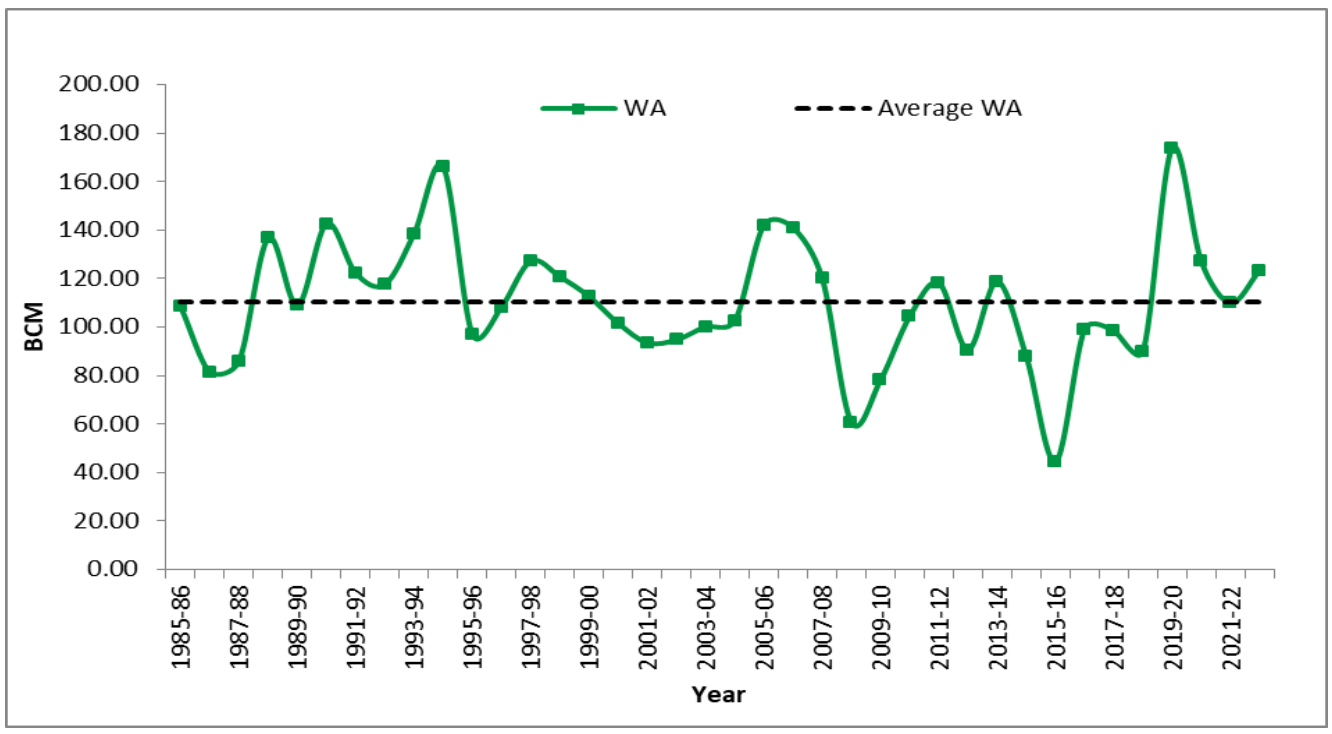


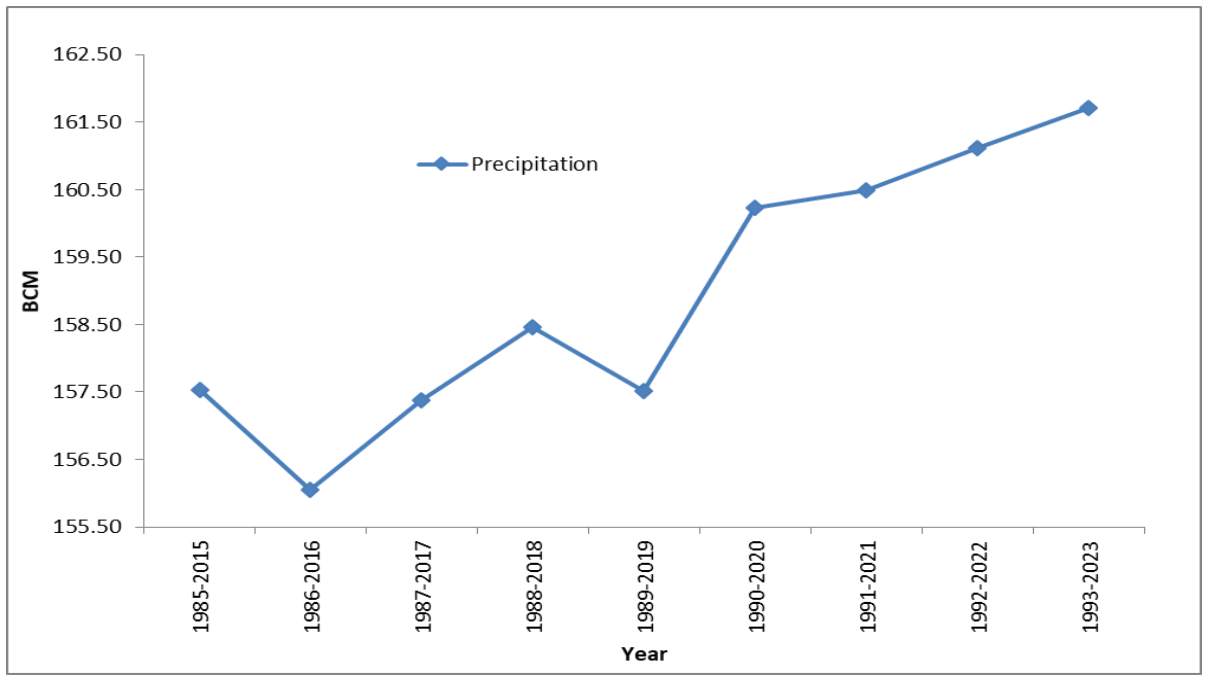
Figure 4.20.9: Water Availability of WFR from Tapi to Tadri basin

4.20.6 Moving Average of 30 years from 1985-2015 to 1993-2023

Moving average of precipitation and water resources availability for the basin is given at Table 4.20.2. A line diagram of moving average of P and WA is shown in Figure 4.20.10.

Table 4.20.2: Moving Average of 30 years from 1986-2015 to 1993-2023

Years	P (BCM)	WA (BCM)
1985-2015	157.54	110.99
1986-2016	156.05	108.86
1987-2017	157.37	109.46
1988-2018	158.46	109.88
1989-2019	157.51	108.32
1990-2020	160.23	110.49
1991-2021	160.48	109.96
1992-2022	161.12	109.55
1993-2023	161.71	109.74



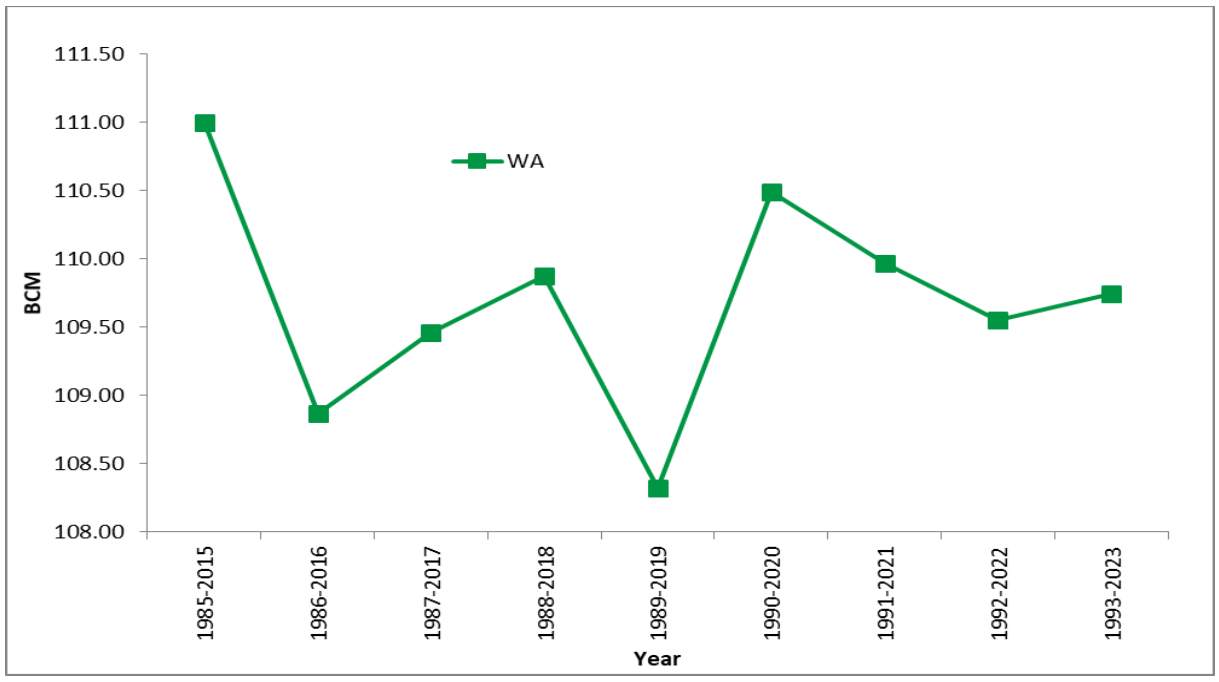


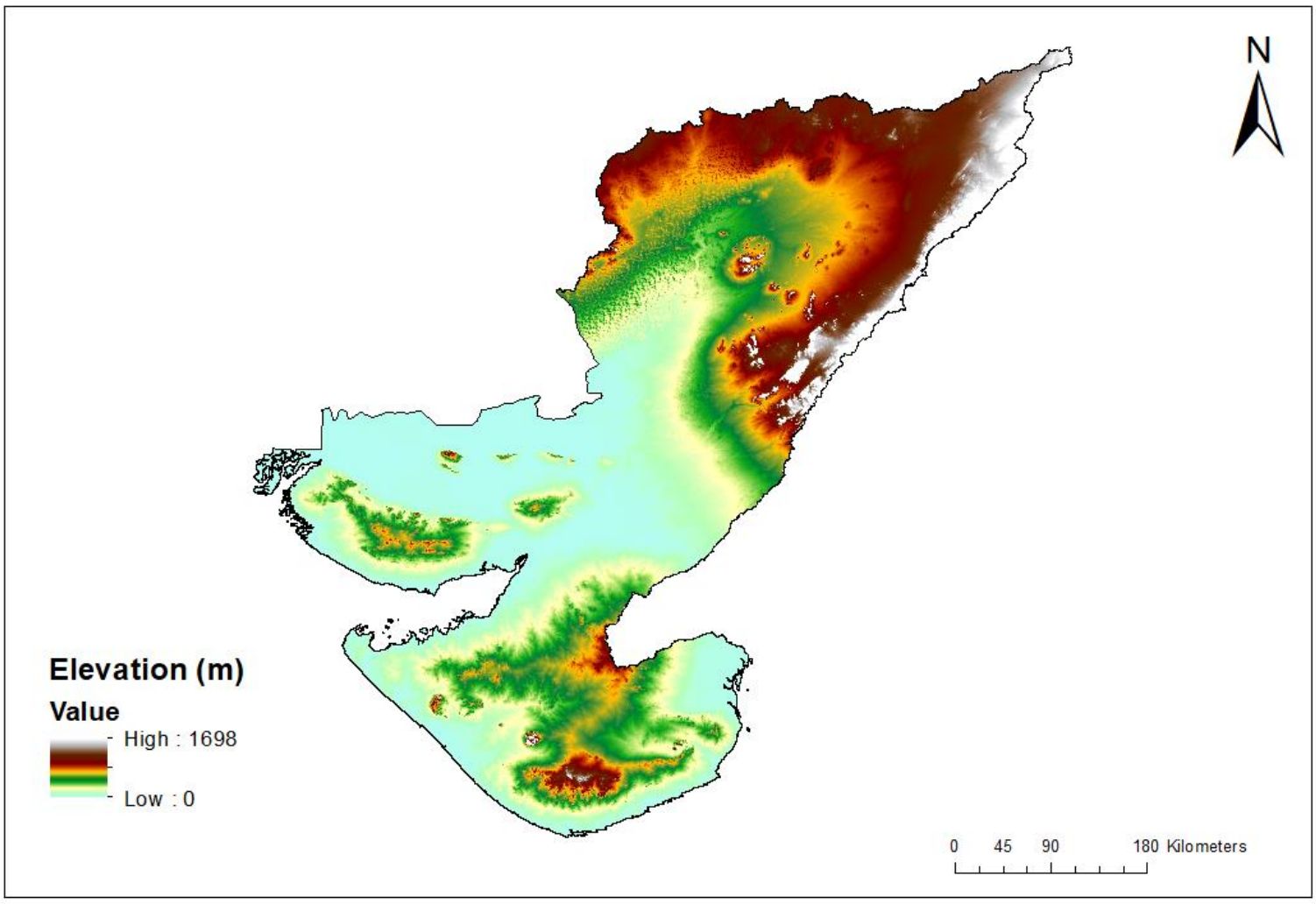
Figure 4.20.10: Moving Average of P and WA for 30 years

Table 4.20.3: Water Availability of WFR from Tapi to Tadri basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-86	145.80	37.39	108.41
1986-87	116.74	35.32	81.42
1987-88	127.05	40.94	86.11
1988-89	177.27	40.50	136.77
1989-90	151.67	42.77	108.90
1990-91	181.94	39.26	142.68
1991-92	156.82	34.49	122.33
1992-93	159.79	42.11	117.68
1993-94	183.39	44.86	138.53
1994-95	207.44	41.34	166.10
1995-96	136.52	39.48	97.04
1996-97	149.74	41.40	108.34
1997-98	168.59	41.35	127.24
1998-99	169.86	49.01	120.85
1999-00	155.49	42.82	112.67
2000-01	138.85	37.22	101.63
2001-02	129.62	36.05	93.57
2002-03	132.98	38.21	94.77
2003-04	151.28	51.10	100.18
2004-05	153.43	50.83	102.60
2005-06	195.31	53.20	142.11
2006-07	197.27	56.29	140.99
2007-08	177.41	57.41	119.99
2008-09	113.23	52.48	60.75
2009-10	134.91	56.71	78.20
2010-11	165.30	60.86	104.44
2011-12	176.62	58.36	118.26
2012-13	147.54	56.86	90.68
2013-14	178.45	59.65	118.80
2014-15	145.79	58.02	87.76
2015-16	101.24	56.73	44.51
2016-17	156.35	57.10	99.25
2017-18	159.83	61.21	98.61
2018-19	148.66	58.54	90.11
2019-20	233.20	59.35	173.86
2020-21	189.63	62.57	127.06
2021-22	175.78	65.82	109.96
2022-23	177.59	54.19	123.40
Average	**159.69**	**49.26**	**110.44**

4.21 WEST FLOWING RIVERS OF KUTCH & SAURASHTRA INCLUDING LUNI



HIGHLIGHTS

- *Average annual water resources availability of West Flowing Rivers of Kutch & Saurashtra including Luni basin is 26.95 BCM.*
- *Maximum annual water availability is 69.26 BCM during 2010-11.*
- *Minimum annual water availability is 9.08 BCM during 2018-19.*
- *Average annual precipitation is 111 BCM (577.81 mm).*
- *Maximum annual precipitation is 173.45 BCM (903 mm) during 2010-11.*
- *Minimum annual precipitation is 53.42 BCM (278 mm) during 2018-19.*

4.21.1 About West Flowing Rivers of Kutch & Saurashtra including Luni Basin

The West Flowing Rivers of Kutch & Saurashtra including Luni is a composite basin extending over large areas in Rajasthan (39%) and Gujarat (61%) and covers whole of Diu having an area of 1,92,112 sq.km with maximum length and width of 865 km and 445 km. The basin is bounded by Aravalli range and Gujarat plains on the east, Rajasthan desert on north, and the Arabian Sea on the south and the west. Luni is the major river system of the basin with length of the 511 km and it drains a total area of 32,879 sq. km. The main tributaries of Luni joining from left are the Lilri, the Guhiya, the Bandi (Hemawas), the Sukri, the Jawai, the Khari Bandi, the Sukri Bandi and the Sagi whereas the Jojri joins it from right. Other independent rivers of the basin are the Shetrunji, the Bhadar, the Machhu, the Rupen, the Saraswati and the Banas. The Shetrunji drains into the Gulf of Khambhat, the Bhadar outfalls into Arabian Sea, and the Machhu, the Rupen, the Saraswati and the Banas drains into Little Rann of Kutch.

4.21.2 Geo-Spatial Datasets

4.21.2.1: Land Use and Land Cover Classification

The Land Use and Land Cover map of West Flowing Rivers of Kutch & Saurashtra including Luni basin for year 2022-23 is shown in Figure 4.21.1. The major land use classes consist of Kharif only, Double/Triple/Annual crop land, current fallow land and wastelands etc.

Table 4.21.1 shows the percentage area of each land use class in the basin for year 2022-23.

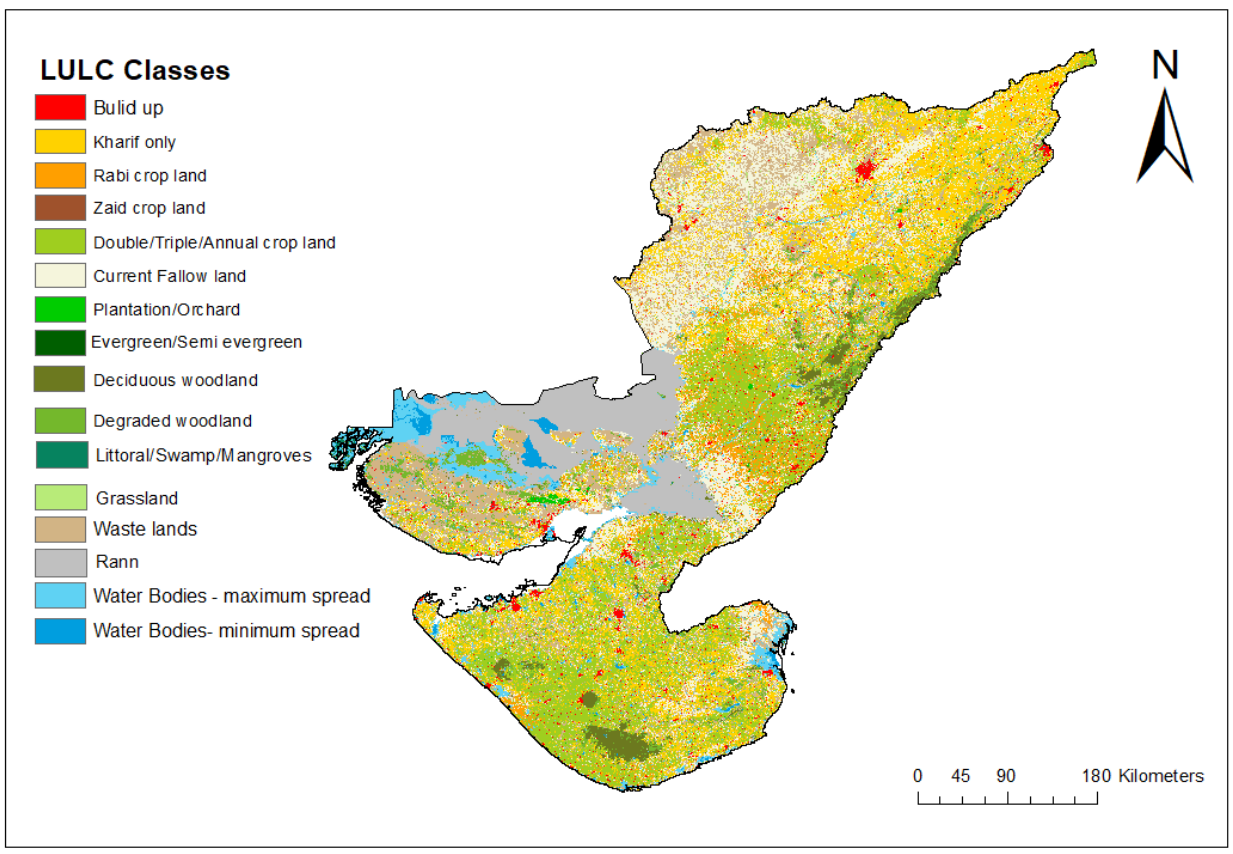


Figure 4.21.1: LULC Map of WFR of Kutch & Saurashtra including Luni basin

Table 4.21.1: Percentage area of Land Use and Land Cover

S. No.	LULC Class	Area (%) in 2022-23
1.	Build up	1.97
2.	Kharif only	19.87
3.	Rabi crop land	4.40
4.	Double/Triple/Annual crop land	18.46
5.	Current fallow land	20.40
6.	Plantation/orchard	0.18
7.	Deciduous woodland	2.68
8.	Degraded woodland	2.78
9.	Littoral/Swamp/Mangroves	0.16
10.	Grassland	0.94
11.	Waste lands	13.75
12.	Rann	8.68
13.	Water Bodies - maximum spread	4.73
14.	Water Bodies - minimum spread	1.00

4.21.3 Hydro-Meteorological and other Input Data

4.21.3.1 Precipitation

The spatial variation of precipitation in the basin for the year 2022-23 has been shown in Figure 4.21.2. The variation in the annual precipitation during study period of 20 years (2003-04 to 2022-23) is shown in the Figure 4.21.3. The average precipitation of 20 years is approximately 110 BCM (629.36 mm).

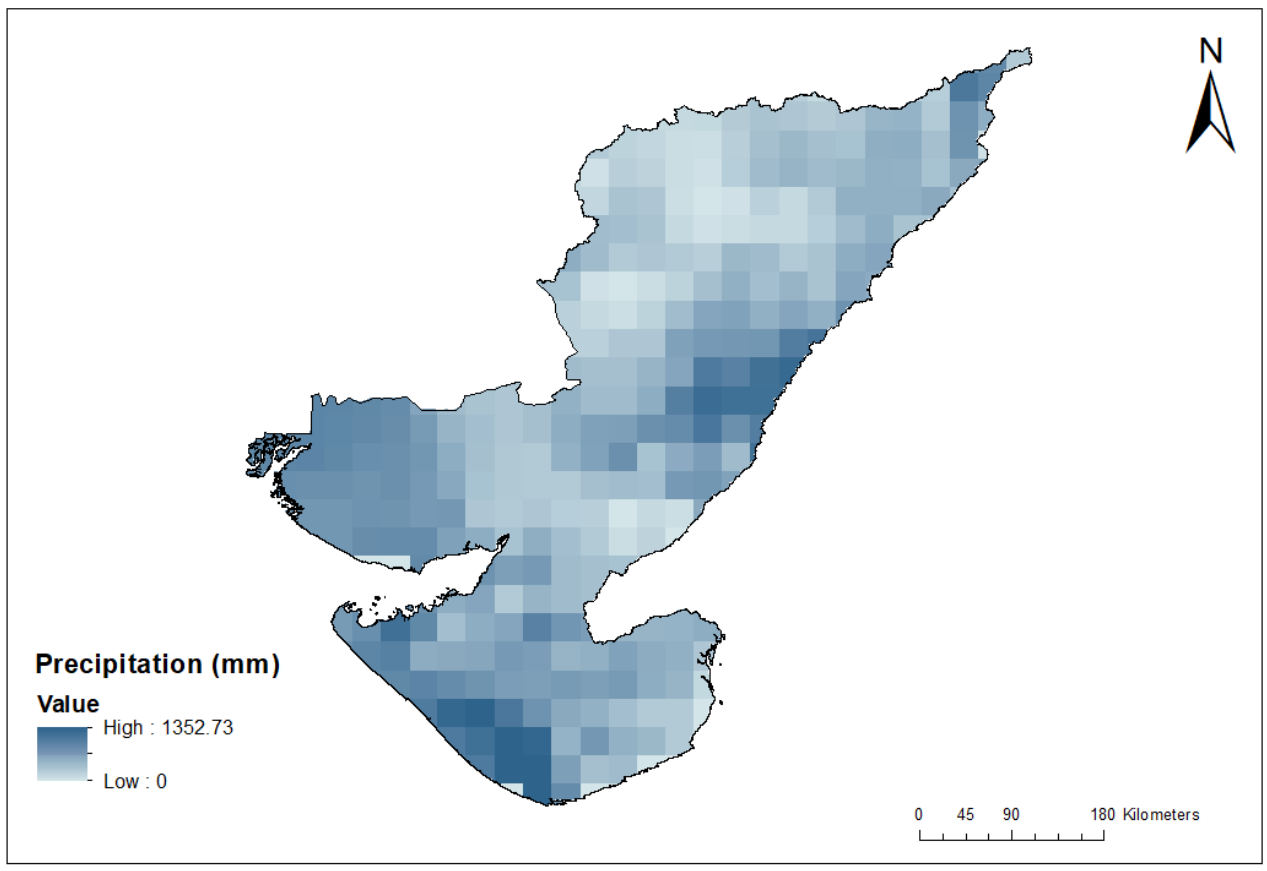


Figure 4.21.2: Precipitation map of WFR of Kutch & Saurashtra including Luni basin

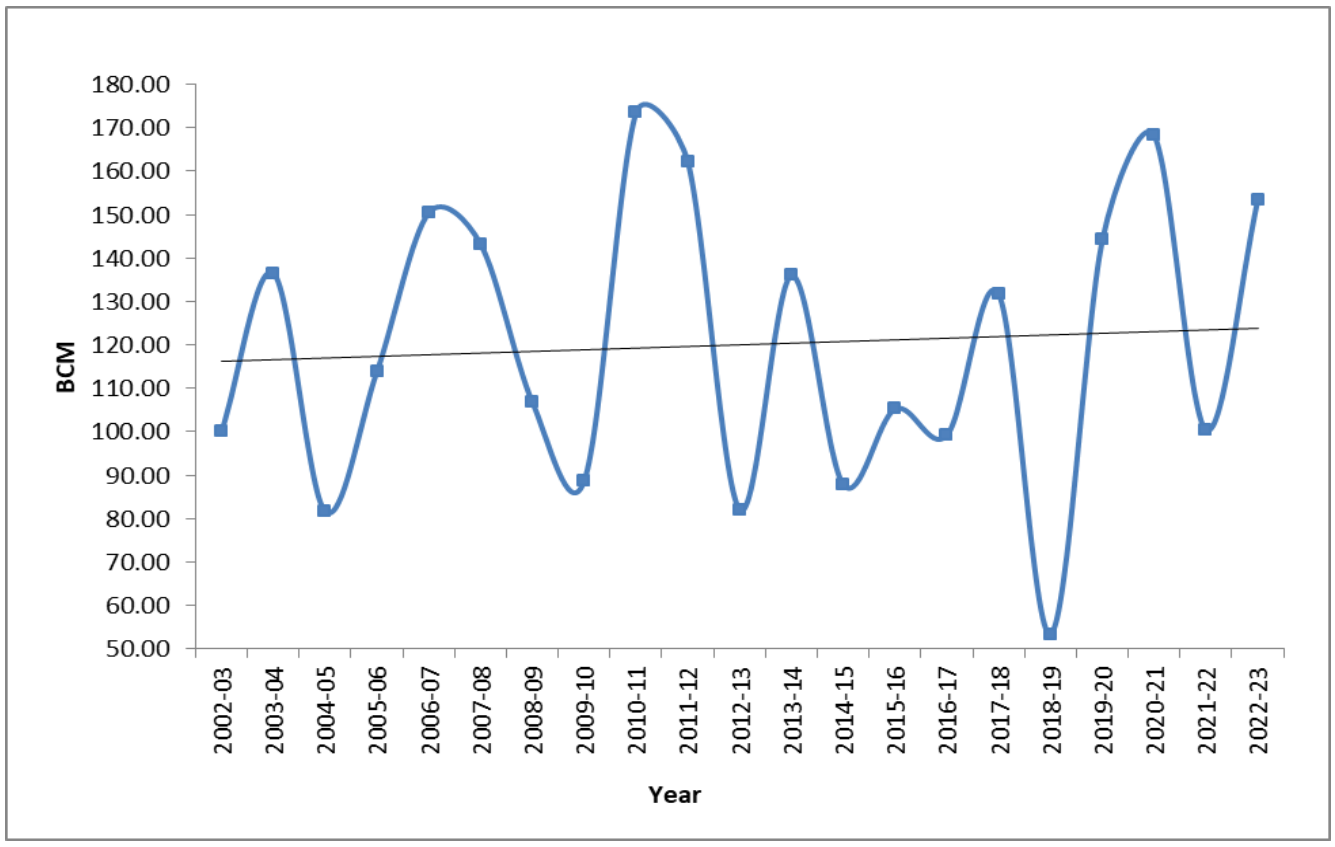


Figure 4.21.3: Annual Precipitation in WFR Kutch & Saurashtra including Luni basin

4.21.3.2 Actual Evapotranspiration

The spatial variation of actual Evapotranspiration (ET) in the basin for the year 2022-23 has been shown in Figure 4.21.4. The variation in the annual actual Evapotranspiration (ET) during study period of 20 years (2003-04 to 2022-23) is shown in the Figure 4.21.5. The average ET of 20 years is approx. 115.17 BCM (599.47 mm).

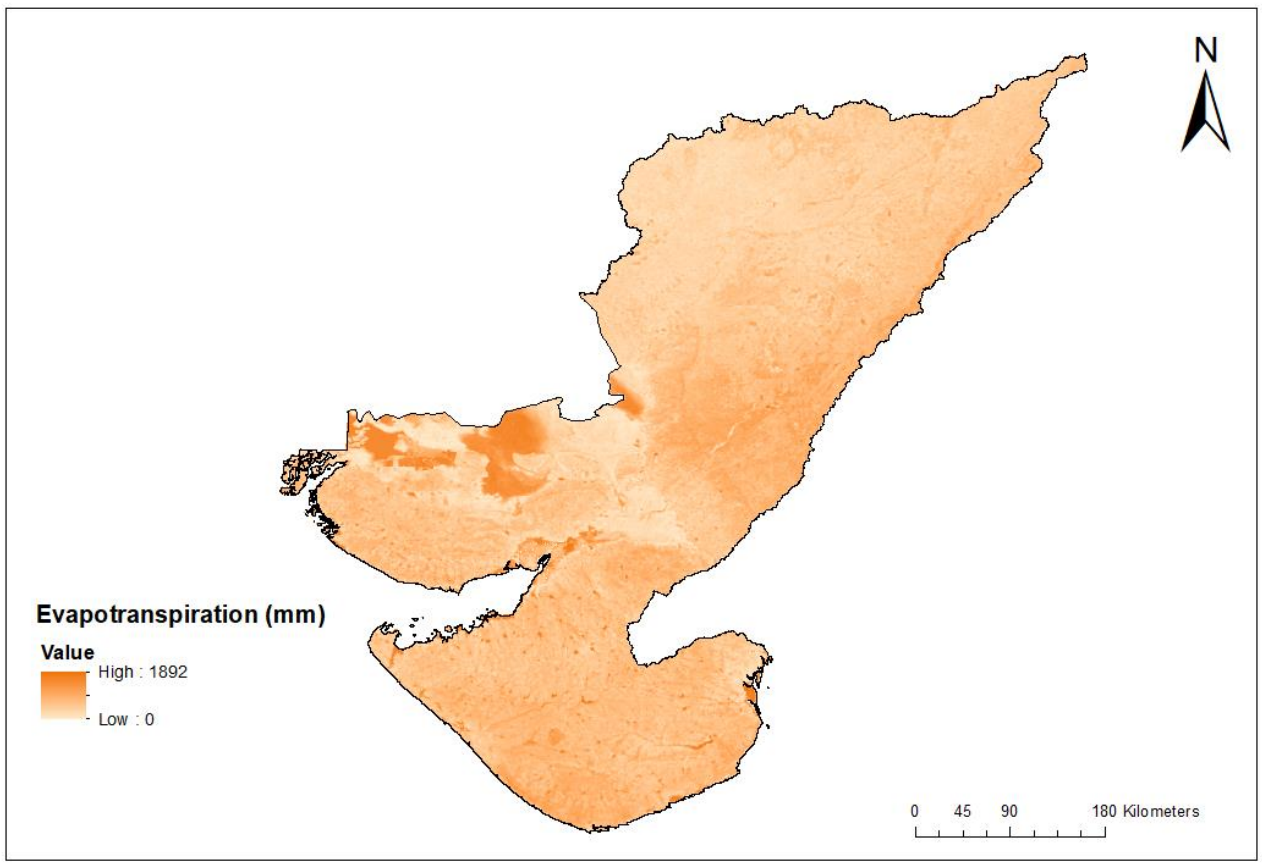


Figure 4.21.4: Evapotranspiration map of WFR Kutch & Saurashtra including Luni basin

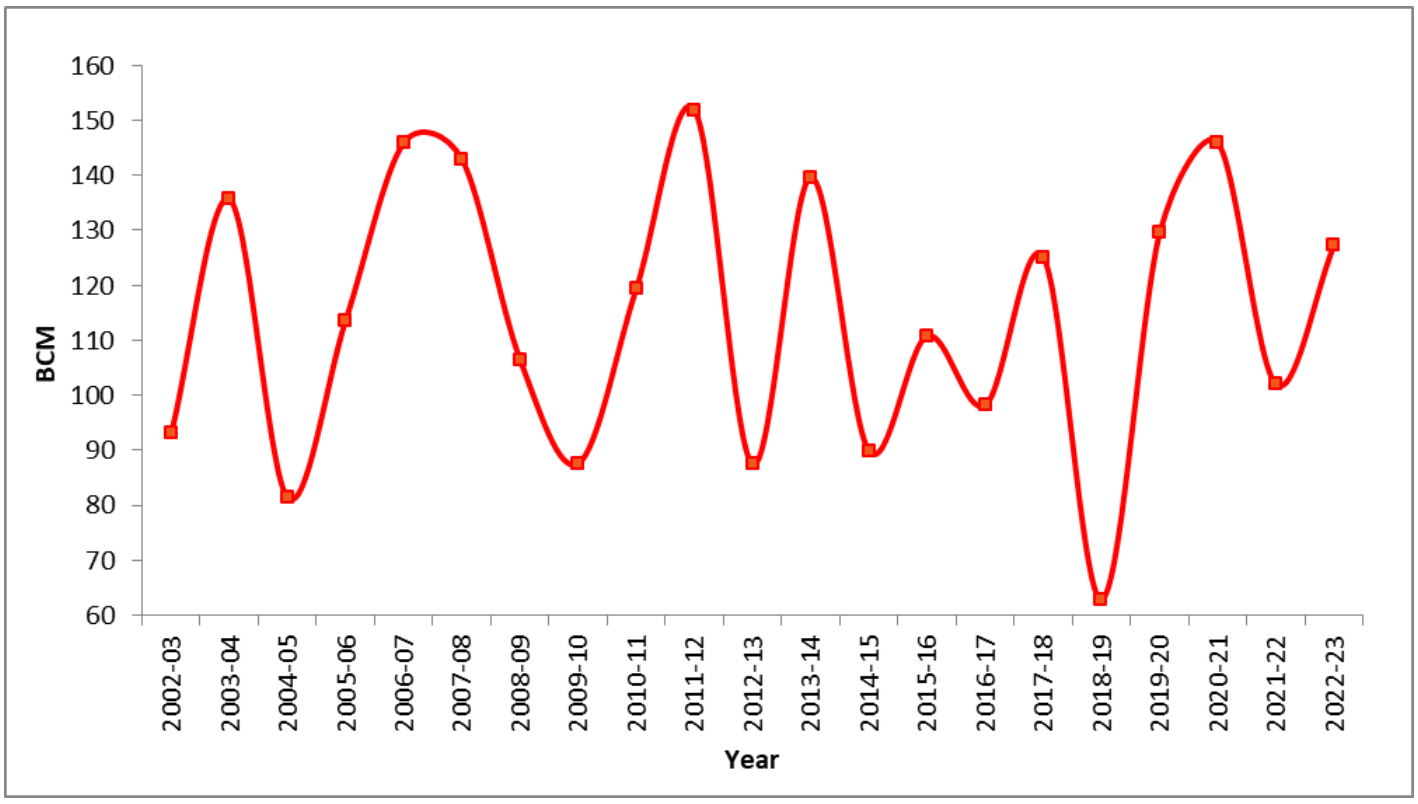


Figure 4.21.5: Annual ET in WFR of Kutch & Saurashtra including Luni basin

4.21.3.3 Reservoir Evaporation

The reservoirs having area greater than 100 hectares has been used for the estimation of reservoir evaporation as shown in figure 4.21.6. The average annual evaporation from the reservoirs in the basin is 1.01 BCM.

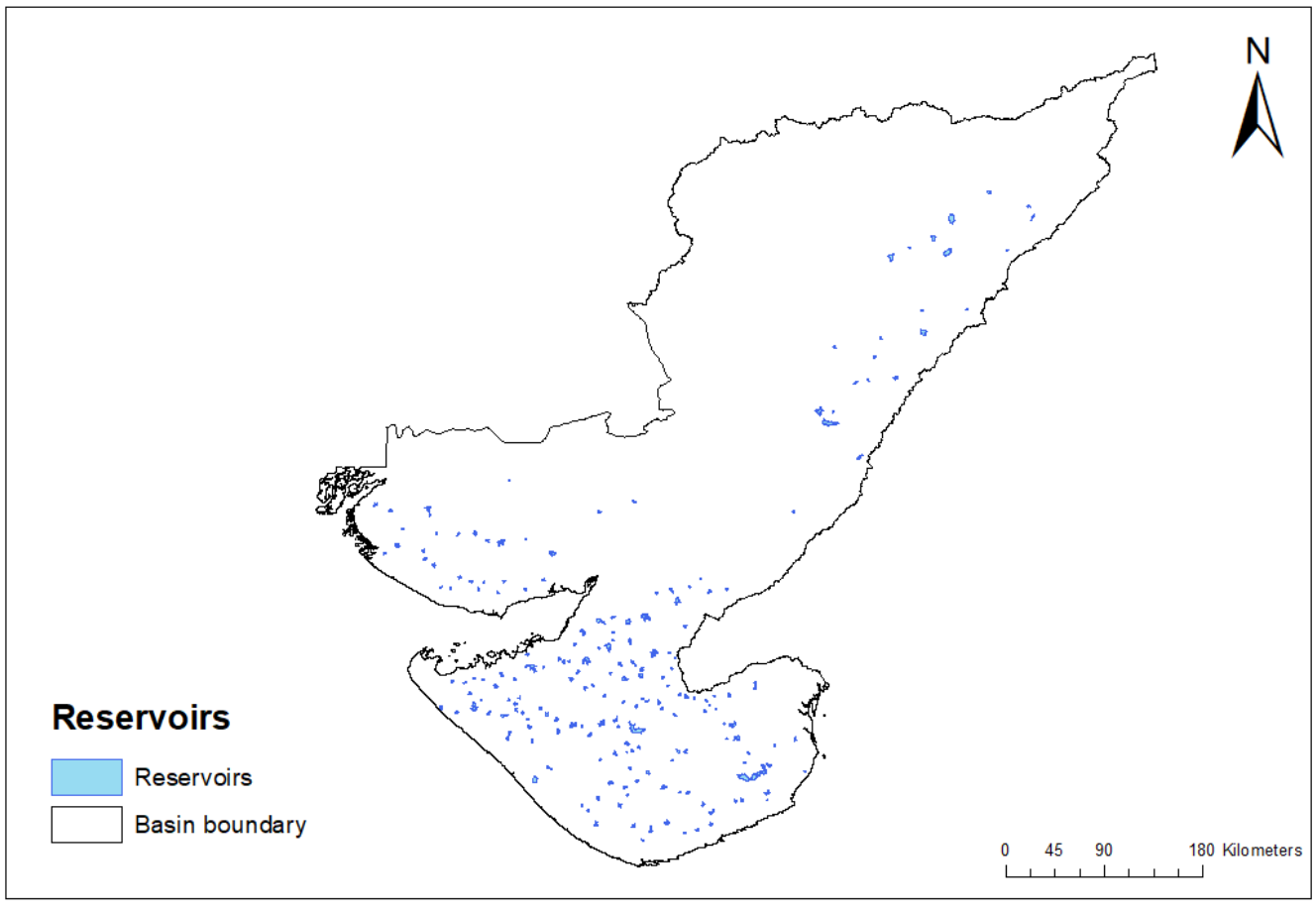


Figure 4.21.6: Reservoir map of WFR of Kutch & Saurashtra including Luni basin

4.21.3.4 Evapotranspiration from Irrigation Input

The Evapotranspiration from Irrigation Input for the basin for the years 2003-2023 has been estimated as 20.19 BCM. The command area map used for the estimation of Evapotranspiration from Irrigation Input is shown in Figure 4.21.7. Yearly variations in Evapotranspiration from Irrigation Input are shown in Figure 4.21.8.

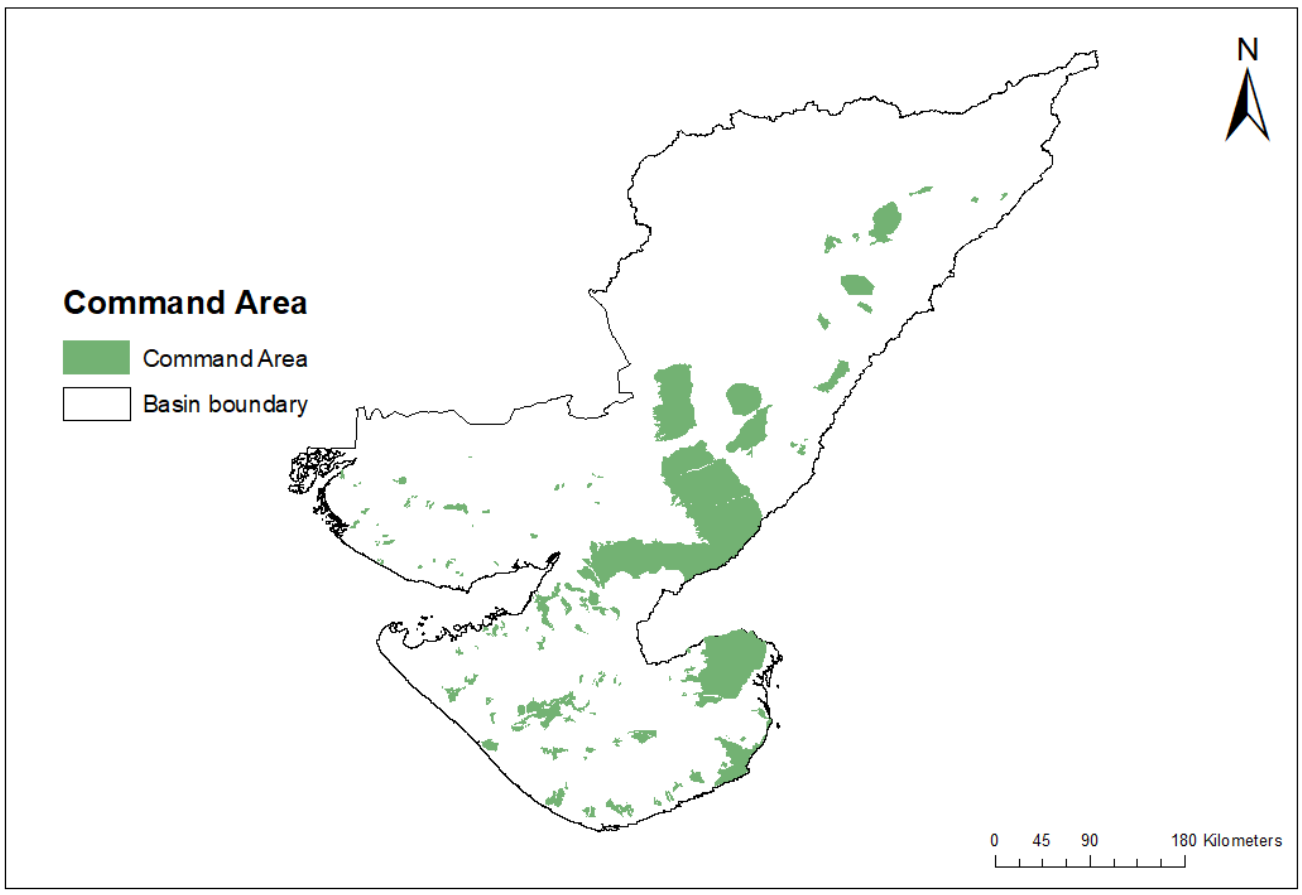


Figure 4.21.7: Command area map of WFR of Kutch & Saurashtra including Luni basin

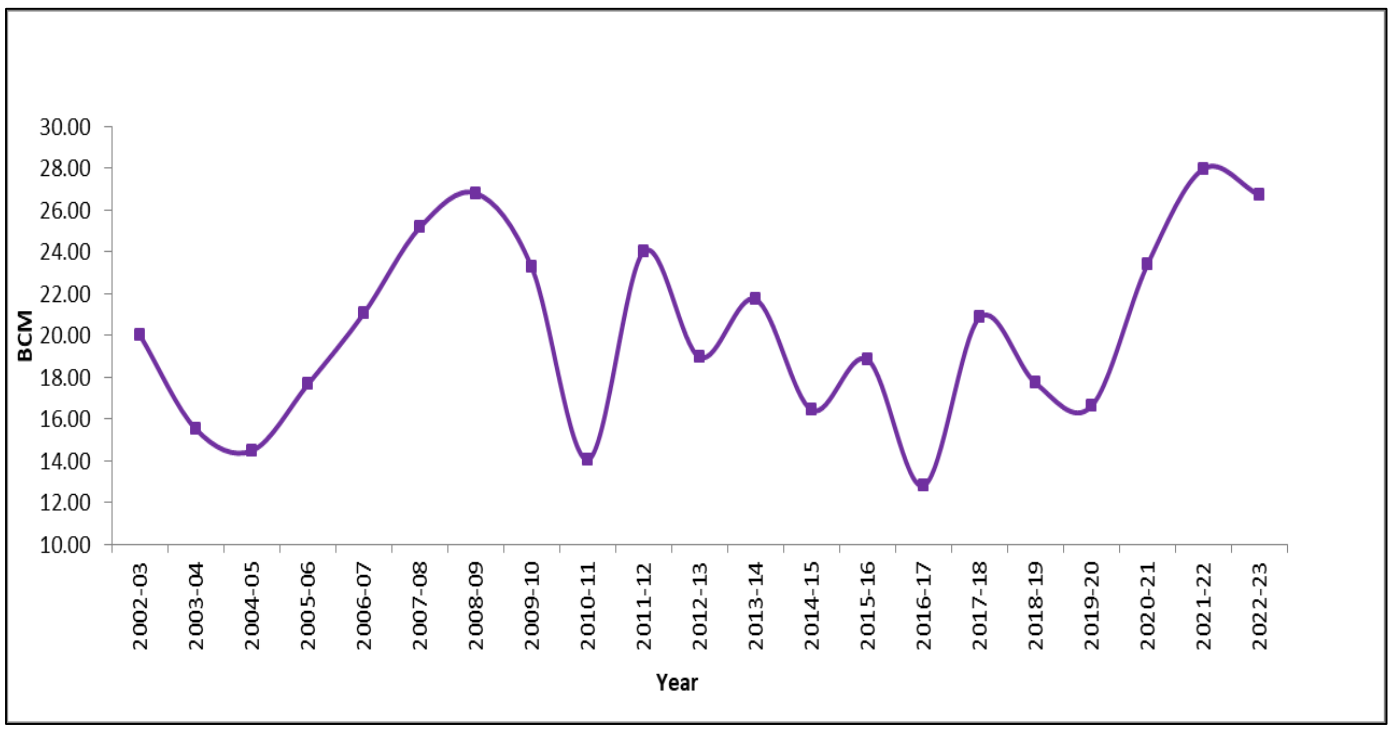


Figure 4.21.8: ET from Irrigation Input in WFR of Kutch & Saurashtra including Luni basin

4.21.3.5 Groundwater flux, Reservoir flux and Domestic, Industrial and Livestock consumptive use

The average annual Groundwater flux (GW flux), Reservoir flux for the basin for 1985-86 to 2022-23 is -1.05 BCM and 0.02 BCM respectively. Domestic, Industrial and Livestock consumptive use for 2022-23 has been estimated as 0.28 BCM.

4.21.4 Previous Estimates

The reassessment study of this composite basin was not performed in 1993. The results from the CWC Publication No. 30/88 “Water Resources of India”, 1988 were reproduced in the 1993 report.

Further, in CWC, 2019 study it was found that there has been increase in the precipitation in the basin in last 30 years (1985-2015). The basin area considered for the 2019 study was 1,92,112 sq. km as compared to 321, 851 sq.km taken in 1993 study. The water availability of major sub-basins was calculated based on the precipitation and area proportions of the nearby sub-basins. The Average available annual water resources potential for composite basin of WFR of Kutch & Saurashtra including Luni was 26.93 BCM.

4.21.5 Annual Water Availability of WFR of Kutch & Saurashtra including Luni Basin

Using the Geospatial Datasets, Hydro-Meteorological and other input data, the average water availability of West Flowing Rivers of Kutch & Saurashtra including Luni basin from 2003-04 to 2022-23 is estimated as 26.95 BCM. The annual variations from year 2003-04 to 2022-23 are shown in Figure 4.21.9. The results of WFR Kutch & Saurashtra including Luni basin are shown in Table 4.21.2.

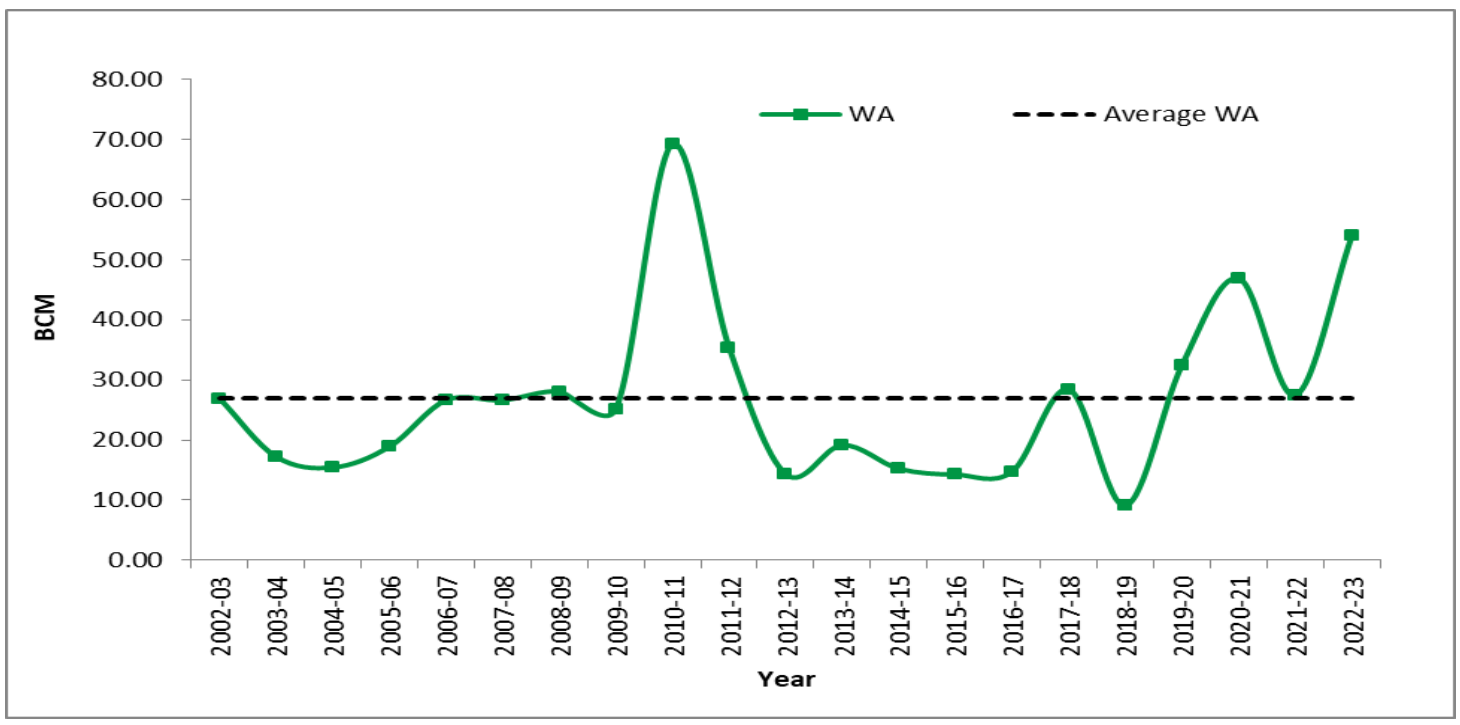


Figure 4.21.9: WA of WFR of Kutch & Saurashtra including Luni basin

Table 4.21.2: Water Availability in West Flowing Rivers of Kutch & Saurashtra including Luni basin

(All values in BCM)

Year	Precipitation	Evapotranspiration (Natural)	Water Availability
1985-2003*	100.00	73.07	26.93
2003-04	136.49	119.25	17.24
2004-05	81.64	66.21	15.43
2005-06	113.87	94.99	18.88
2006-07	150.43	123.80	26.63
2007-08	143.22	116.58	26.64
2008-09	106.77	78.67	28.10
2009-10	88.71	63.55	25.16
2010-11	173.45	104.19	69.26
2011-12	162.07	126.66	35.42
2012-13	82.08	67.74	14.34
2013-14	135.98	116.82	19.16
2014-15	87.81	72.59	15.22
2015-16	105.26	91.00	14.26
2016-17	99.19	84.42	14.77
2017-18	131.60	103.16	28.43
2018-19	53.42	44.34	9.08
2019-20	144.22	111.69	32.53
2020-21	168.21	121.29	46.92
2021-22	100.37	72.90	27.47
2022-23	153.38	99.34	54.04
Average**	**111.00**	**84.06**	**26.95**

**In 2019 study, water availability of West Flowing Rivers of Kutch & Saurashtra including Luni Basin was calculated based on the precipitation and area proportions.*

Annexure-I

Multi-Disciplinary Consultative Committee

S. No.	Designation	Role in Project Steering Committee
1.	Chief Engineer (BPMO), CWC	Chairman
2.	Superintending Engineers (Coord.) of CWC Regional Offices	Member
3.	Director (Hydrology-South), CWC, New Delhi	Member
4.	Director (Remote Sensing), CWC, New Delhi	Member
5.	Director (RDC-II), CWC, New Delhi	Member
6.	Representative from National Remote Sensing Centre (NRSC)	Member
7.	Representative from Central Ground Water Board (CGWB)	Member
8.	Representative from India Meteorological Department (IMD)	Member
9.	Representative from National Institute of Hydrology (NIH)	Member
10.	Director (P&P), CWC, New Delhi	Special - Invitee
11.	Director (BP-I), CWC, New Delhi	Member Secretary

Central Water Commission

August, 2024