

Project Report on

Climate Change Impacts Studies for Rajasthan (Areas of Inland Drainage and Mahi Basin)



Department of Civil Engineering

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ABBREVIATIONS USED

AET	Actual Evapotranspiration
AGRC	Fallow land
AGRR	Agriculture land
AID	Area of Inland Drainage
BF	Base flow
AOI	Area of Interest
Aq.	Aquifer
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BARR	Barren Land
CC	Climate Change
CH_K2	Channel hydraulic Conductivity
CN2	Curve Number 2
CUP	Calibration and Uncertainty Programs
CWC	Central water commission
DEM	Digital elevation Model
ESCO	Soil evaporation compensation factor
ESRI	Environmental science research institute
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FCC	False colour composite
FF	Far Future
FRSD	Forest land
GCM	General circulation Model
GIS	Geographic information system
GLUE	Generalized Likelihood Uncertainty Estimation
GW	Ground Water
GW_DELAY	Ground water delay
GW_REVAP	Ground Water Revap
GWQMN	Ground water discharge minimum
H/His	Historical
HRUs	Hydrological Response Units

HSG	Hydrologic Soils Group
IMD	Indian Meteorological Department
INCCC	Indian National Committee on Climate Change
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing
IWRM	Integrated Water Resources Management
Km	Kilometre
LH- sampling	Latin Hypercube sampling
LISS-III	Linear Imaging Self-Scanning Sensors-III
LMC	Left Main Canal
LULC	Landuse and Landcover
MBSP	Mahi Bajaj Sagar Project
MCFT	Million cubic Feet
MCMC	Markov Chain Monte Carlo
Mha	Million hectares
MK	Mann kendall
mm	MilliMeter
MME	Multi Model Ensembles
MP	Madhya Pradesh
MSS	Multi spectral scanner
NDVI	Normal differential vegetation index
NF	Near future
Nos	Number of
NRCS	Natural Resources Conservation service
NSE	Nash–Sutcliffe model efficiency coefficient
OLI	Operational Land Imager
PAN	Panchromatic
PBIAS	Percentage of bias
Perc	Percolation
PET	Potential Evapotranspiration
PPU	Percentage prediction uncertainty
Pr/Precip	Precipitation

PSO	Particle Swarm optimization
R square	Coefficient of determination
RCHRG_DP	Recharge Deep Aquifer Percolation
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
REVAPMN	Threshold depth of water in the shallow aquifer minimum
RMC	Right Main Canal
RMS	Root mean square
RNGB	Shrub Land
RS	Remote Sensing
RSR	Observations standard deviation ratio
SCS CN	Soil Conservation Service Curve Number
SDI	Standardized Discharge Index
SOI	Survey of India
SOL_AWC	Soil available water capacity of the soil layer
SPEI	Standardized Precipitation Evaporation Index
SPI	Standardized Precipitation Index
Sq.KM	Square Kilometre
SRTM	Shuttle Radar Topographic Mission
SS	Sen's slope
SUFI-2	Sequential Uncertainty Fitting-2
SURQ	Surface Runoff
SW	Soil water
SWAT	Soil water assessment tools
SWAT Model-n	Number of Hydrological SWAT Model
SWMM	Storm water management model
Tasmax	Maximum Temperature
Tasmin	Minimum Temperature
TM	Thematic mapper
UNESCO	United Nations Educational, Scientific and Cultural Organization
URHD	Settlement/Buildings
URLD	Paved area

USDA	United stat development authority
USGS	United States of Geological survey
UTM	Universal Transverse Mercator
WATR	Waterbody
WETN	Sand (River Sand/ wet Lands)
WGS	World Geological system
WRIS	Water Resource Information System
WTLD	Water Yield

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Chapter 1: Introduction

1. Introduction

The impact of Climate Change (CC) is being felt around the globe. In order to study the impact of CC on National Water Resources, the Central Water Commission (CWC) has prepared a plan for basin level study under the National Water Mission and NAPCC. The Department of Civil Engineering Malaviya National Institute of Technology (MNIT) Jaipur along with IIT Delhi and Central University of Rajasthan, Kishangarh, Ajmer proposed comprehensive research on the Areas of Inland Drainage in Rajasthan in western part of the state and Mahi Basin in the South Eastern part of the State. The primary objective of the project was to study the impact of Climate Change on various Hydrological parameters of a river basin using high resolution GCM outputs from multi model downscaling experiments. This included the analysis of extreme weather phenomenon, development of basin specific Hydrological model for quality and quantity of available water and identification of hotspots with respect to hydrological parameters. The outputs of these studies will be used for planning of Adaptation to the climate change in the form of water distribution for Municipal and Irrigation uses, Reservoir operation, crop cycling and Mitigation strategies for extreme events like flood, drought, heat wave and cold wave etc.

1.1 Objectives

The four main activities were performed viz. Surface water modelling (using SWAT), groundwater modelling (using mudflow), crop productivity modelling and reservoir/canal operation modelling. The specific objectives are as follows:

- i. Literature review: analysis of past studies and literature available to ascertain the present state of the art.
- ii. Data Collection: baseline data collection of the study area and analysis.
- iii. Trend analysis of hydrological and meteorological parameters like precipitation, temperature, stream flow, groundwater levels, sediment no. and size of water bodies, evapo-transpiration, land use land cover and extreme climate events like floods and droughts.
- iv. Hydrological modelling of the basin in a GIS environment:
 - Conceptualisation of hydrological model of basin
 - Calibration and validation of hydrological model

- v. Hydrological responses corresponding to different climate change scenarios obtained from downscaling using different GCM models.
- vi. Development of crop production functions, their calibration and validation.
- vii. Hydrological impact analysis of climate change:
 - viii. Generation of surface water responses i.e., stream flow under climate change scenarios and assessment of water availability
 - ix. Impact of hydro-meteorological changes on crop production under different climate change scenarios
 - x. Groundwater responses under different climate change scenarios and water availability
 - xi. Soil erosion responses under different climate change scenarios
- xii. Adaptation strategy under Climate Change:
 - xiii. Optimal water allocations/use involving different sources and users under Different climate change scenarios
 - xiv. Optimal reservoir/canal operations under different climate change scenarios
 - xv. Optimum agricultural practices under different climate change scenarios
 - xvi. Various water demand management options for different sectors
- xvii. Identification of possible mitigation strategies for extreme hydrological events like floods and drought.

Chapter 2: Study Area

2. Study Area

2.1 Region 1: Mahi Basin

The proposed project consists of the Mahi River Basin and area of inland drainage of Rajasthan. River Mahi originates in Dhar District and joins Gulf of Khambat. The Mahi basin extends over an area of 34,842 km² which is nearly 1.1% of the total geographical area of the country. It lies between east longitudes 72° 15' to 78° 15' and north latitudes 22° 0' to 22° 40' N respectively (Figure 2.1). The Mahi River originates in the Mahi Kanta hills in the Vindhyachal range, in the western part of Madhya Pradesh. It is bounded on the north and north-west by the Aravalli hills, on the east by the ridge separating it from the Chambal basin, on the south by the Vindhya and on the west by the Gulf of Cambay.

The basin lies in the States of Rajasthan, Gujarat and Madhya Pradesh. The upper part of the basin in Rajasthan and Madhya Pradesh comprises mostly hills and forests except the lower half in M.P., which is fairly plain. The central part lying in Gujarat consists of developed lands. The lower part of the basin lying in Gujarat is flat and fertile and well-developed alluvial tract. Important soil types in the basin are red and black soils. The culturable area of the basin is about 2.21 Mha which is 1.1% of the total culturable area of the country. The principal tributaries of the Mahi River are Som, Jakham, Moran, Anas, and the Bhadar. Major projects on the Mahi River basin are Jakham Reservoir project, Panam Dam project, Mahi Bajaj Sagar Project and Kadana Project. As per a previous study by Gosain et al. (2003) the two river basins Sabarmati and Mahi show drastic decreases in precipitation and consequent decrease in total.

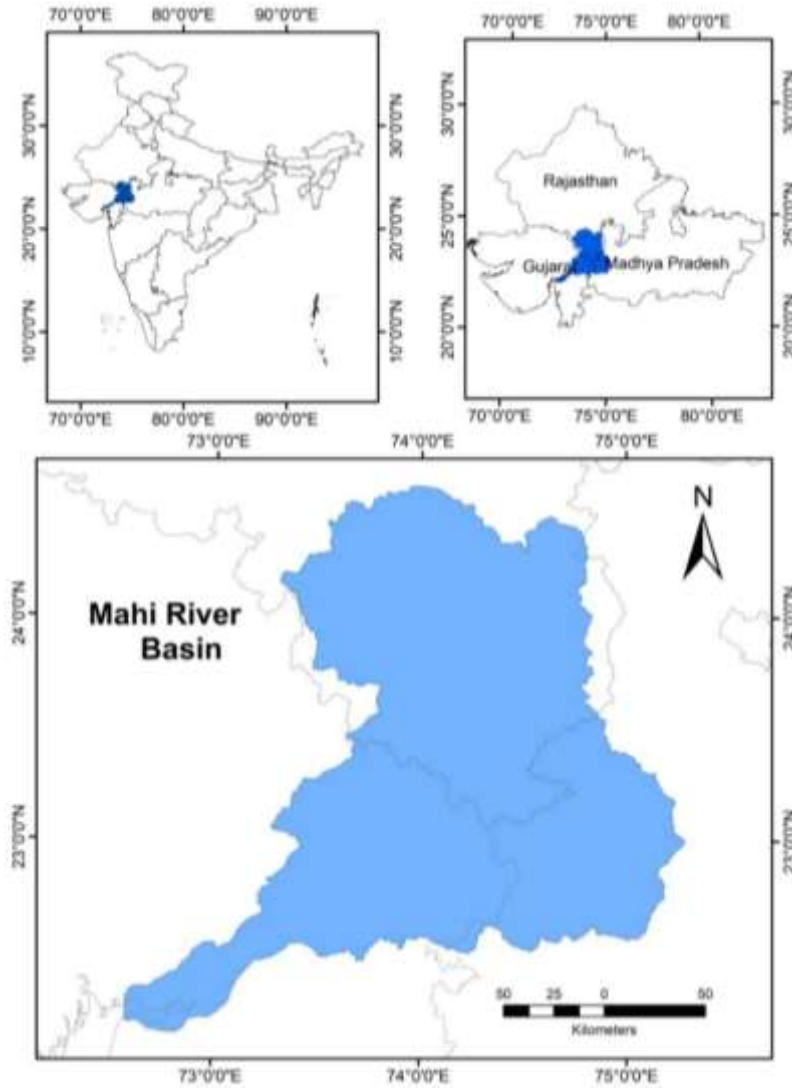


Figure 2:1 Region 1-Mahi basin

runoff to the tune of two thirds of prevailing runoff. This may lead to severe drought conditions in future in these basins. Therefore, it becomes necessary to undertake a comprehensive study of the Mahi basin for climate change impacts on hydrology of the Basin. The reservoir operation strategy under changed climate would require improved water use efficiency and conjunctive use of ground water under an Integrated water resources management approach. The outcomes from the study carried out shall be disseminated through the digital platform that will enable more effective formulation, implementation and evaluation of policies in a dynamic manner.

2.2 Region 2: Area of Inland Drainage

The proposed project consists of the Area of Inland Drainage in Rajasthan and has unique hydrological characteristics. The area has no drainage and mostly occupied by the Thar Desert (Figure 2.2). It has an Arid Climate and slopes gently towards West – Southwest

towards Indus River system. Inland drainage is surrounded by Satluj, Yamuna, Chambal and Luni River basin respectively from north, east to south. Rainfall varies between 100-400 mm annually and is received mainly during monsoon season. In addition to the monsoon rain which is very erratic and often fails, the region receives water from the Indira Gandhi canal system from which water is mainly used for drinking purpose and irrigation of Rabi crops. The soil formation consists of a thin veneer of Dune Sand of zero to few meters in thickness underlain by an impervious clay layer. The area is not investigated properly and at a few places subsurface paleochannel containing fresh water or perched aquifers have been reported. Monsoon often fails in the region and droughts are a common phenomenon followed by heat waves. In the recent past there have been few instances of flooding due to high rainfall intensity and low percolation rate. In such an environment, climate-change can have a serious impact on the effectiveness of policies as it doesn't only affect the availability of new resources, but also the efficient utilization of the existing resources. Judicious and well-thought adaptation measures will be needed. The outcomes from the studies carried out shall be disseminated through the digital platform that will enable more effective formulation, implementation and evaluation of policies in a dynamic manner.

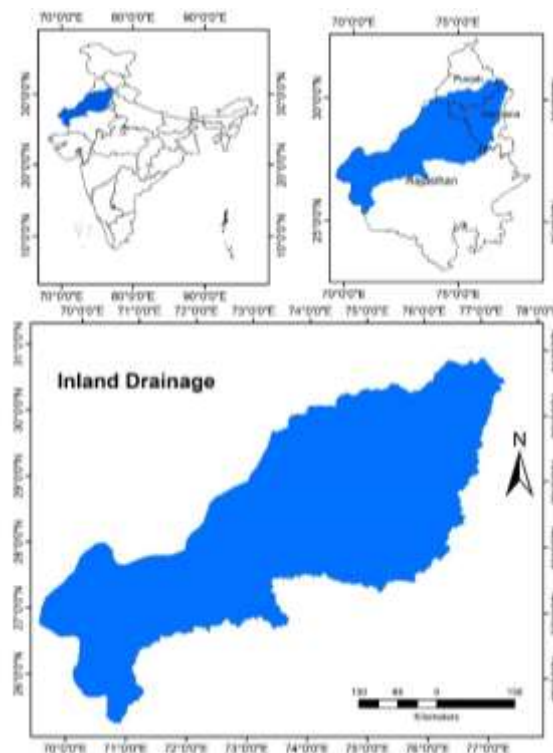


Figure 2:2 Region 2-Area of Inland drainage

Chapter 3: Data Used

3. Data used

3.1 Survey of India (SOI) Toposheet

The toposheets have been collected from <https://soinakshe.uk.gov.in/>. The Survey of India is responsible for all topographic control, surveys and mapping of India. Here, toposheets are used to check the Mahi River basin and Inland Drainage using contour line and also for checking the Digital Elevation Model (DEM) by creating an elevation point map from the toposheets. Total 89 toposheets have been downloaded from the source and used in this study. The details of the toposheets are given below (Table 3.1 & 3.2) for Mahi Basin and Inland Drainage.

Table 3.1: Details of toposheet for Mahi basin

Topographic sheet number	
G43T	4,7,8,11,12,14,15,16
G43U	2,3,4,6,7,8,11,12,15,16
F43B	5,6,7,8,9,10,11,12,13,14,15,16
F43C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
F43D	3,4,8
F43G	11,12,14,15,16
F43H	1,2,3,4,5,6,7,8,9,10,11,13,14
F43I	1,2,3,5,6,7,9,10,11,13,14,15,
F43J	1,2,5
F43M	9,10,13,14
F43N	1,5,9

Table 3.2: Details of toposheet for Inland Drainage

Topographic sheet number		
H42	W	8,12
	X	16
H43	K	8,12,16
	L	8
	M	16
	N	4,8,12,15,16
	O	3,4,7,8,11,12,15,16
	P	3,4,7,8,10,11,12,13,14,15,16
	Q	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
	R	1,2

	S	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	T	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	U	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	V	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	W	1,2,3,4,5,6,7,8,9,10,11,12
G42	D	11,12,14,15,16
	E	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	F	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	J	5,9,10,13,14
	K	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	L	1,2,3,4,5,6,7,9,10,13,14
	Q	1,5,6, 9,10,11,13,14,15,16
	R	1,2,5,6
G43	A	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	B	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	C	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
	D	1,2,3,4,5,6,7,9,10,11,13,14,15
	E	1,2,5
	G	1,2,5,6,9,10,13,14
	H	1,5,9,13
	I	1,5

3.2 Satellite Data

Satellite data is downloaded and collected from <https://earthexplorer.usgs.gov/> and NRSC. Satellite data is used for Land use and Land cover mapping. Satellite data used for Mahi Basin is in the range of year 1977 to 2018 and for Inland drainage it is from 2015 to 2018. The details of Satellite data are given in Table 3.3 & 3.4.

Folder path: Mahi basin\Final Data Mahi Basin\ Satellite data\Raw data

Table 3.3 : Salient details of satellite images for Mahi basin

Year	Satellite/Sensor	Radiometric Resolution	Spatial Resolution (m)	Spectral Resolution	season	Path	Row	Date of acquisition
1977	Landsat MSS 1-5	6 bit	80	Band 4 Band 5 Band 6 Band 7	FEB-MAR (Rabi Season)	158	43	23-03-1977
							44	23-03-1977
						159	43	10-03-1977
							44	28-03-1977
							45	28-03-1977
1990	Landsat TM	8bit	30	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7	FEB-MAR (Rabi Season)	147	43	18-03-1990
							44	14-02-1990
					OCT-NOV (Kharif Season)	148	43	09-03-1990
							44	09-03-1990
							45	09-03-1990
						147	43	31-12-1990
							44	31-12-1990
						148	43	23-01-1991

							44	23-01-1991
							45	23-01-1991
1995	Landsat TM	8bit	30	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7	FEB- MAR (Rabi Season)	147	43	12-02-1995
							44	12-02-1995
						148	43	23-03-1995
							44	23-03-1995
					OCT- NOV (Kharif Season)	147	43	02-11-1995
							44	02-11-1995
						148	43	11-11-1995
							44	11-11-1995
2000	Landsat TM	8bit	30	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7	FEB- MAR (Rabi Season)	147	43	10-02-2000
							44	10-02-2000
						148	43	16-01-2000
							44	16-01-2000
							45	16-01-2000
	Landsat ETM	9bit	30	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7 Band 8	OCT- NOV (Kharif Season)	147	43	15-10-2000
							44	15-10-2000
						148	43	22-10-2000
							44	23-11-2000
							45	22-10-2000
2005	LISS-III		23.5	Band 2 Band 3 Band 4 Band 5	FEB- MAR (Rabi Season)	93	55	
							56	
						94	55	
							56	
						95	55	
							56	
				Band 2 Band 3 Band 4 Band 5	OCT- NOV (Kharif Season)	93	55	
							56	
						94	55	
							56	
						95	55	
							56	
2010	LISS-III		23.5	Band 2 Band 3 Band 4 Band 5	OCT- NOV (Kharif Season)	93	55	
							56	
						94	54	
							55	
						95	55	
							56	
2015	Landsat OLI	12bit	30	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7 Band 8 Band 9 Band 10 Band 11	FEB- MAR (Rabi Season)	147	43	23-03-2010
							44	23-03-2010
						148	43	30-03-2015
							44	30-03-2015
					OCT- NOV (Kharif Season)	147	43	18-11-2015
							44	18-11-2015
						148	43	09-11-2015
							44	09-11-2015
2018	Landsat OLI	12bit	30	Band 1		147	43	31-03-2018

				Band 2 Band 3 Band 4 Band 5 Band 6 Band 7 Band 8 Band 9 Band 10 Band 11	FEB- MAR (Rabi Season)	148	44 43 44 45	31-03-2018 22-03-2018 22-03-2018 22-03-2018
					OCT- NOV (Kharif Season)	147 148	43 44 43 44 45	25-10-2018 25-10-2018 01-11-2018 01-11-2018 01-11-2018
2018	Sentinel		10	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7 Band 8 Band 8a Band 9 Band 10 Band 11 Band 12	FEB- MAR (Rabi Season)			31-03-2018
					OCT- NOV (Kharif Season)			25-10-2018

Table 3.4 : Salient details of satellite images for Inland drainage

Year	Satellite/ Sensor	Radiometric Resolution	Spatial Resolution (m)	Spectral Resolution	season	Path	Row	Date of acquisition
2018	Landsat OLI	12 bit	30 m	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7 Band 8 Band 9 Band 10 Band 11	Rabi Season	147	39	31-03-2018
							40	31-03-2018
							41	31-03-2018
						148	41	22-03-2018
							40	22-03-2018
						149	40	29-03-2018
							41	29-03-2018
							42	29-03-2018
						150	40	20-03-2018
							41	20-03-2018
							42	20-03-2018
						151	41	27-03-2018
							42	27-03-2018
					Kharif Season	147	39	25-10-2018
							40	25-10-2018
							41	25-10-2018
						148	41	30-09-2018
							40	30-09-2018
						149	40	07-10-2018
							41	07-10-2018
							42	07-10-2018
						150	40	12-09-2018
							41	12-09-2018

							42	14-10-2018
						151	41	21-10-2018
2010	Landsat TM	8 bit	30 m	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7	Rabi Season	147	42	21-10-2018
							39	21-02-2010
							40	21-02-2010
						148	41	21-02-2010
							40	12-02-2010
						149	40	12-02-2010
							41	19-02-2010
							42	19-02-2010
						150	40	19-02-2010
							41	26-02-2010
							42	26-02-2010
						151	40	26-02-2010
							41	17-02-2010
					Kharif Season	147	42	17-02-2010
							39	03-10-2010
							40	03-10-2010
						148	41	03-10-2010
							40	26-10-2010
						149	41	26-10-2010
							40	02-11-2010
							41	02-11-2010
						150	42	02-11-2010
							40	02-11-2010
							41	25-11-2010
						151	42	25-11-2010
							40	25-11-2010
2000	Landsat TM	8 bit	30 m	Band 1 Band 2 Band 3 Band 4 Band 5 Band 6 Band 7	Rabi Season	147	41	16-11-2010
							42	16-11-2010
						148	39	18-02-2000
							40	18-02-2000
						149	41	18-02-2000
							40	28-03-2000
						150	41	04-03-2000
							40	19-03-2000
							41	19-03-2000
						151	42	19-03-2000
							40	26-03-2000
							41	26-03-2000
						147	42	26-03-2000
							40	14-02-2000
					Kharif Season	148	41	14-02-2000
							40	15-10-2000
							41	15-10-2000
						149	41	22-10-2000
							40	22-10-2000
						149	40	21-10-2000

							41	21-10-2000
							42	21-10-2000
						150	40	28-10-2000
							41	28-10-2000
							42	28-10-2000
						151	41	19-10-2000
							42	19-10-2000

3.3 Meteorological Data

Rainfall and Temperature data have been provided by IIT Bombay for various climate models during historical (1981-2005) and future projections (2006-2100) for RCP4.5 and RCP8.5 scenarios. These climate models are BNU-ESM, CNRM-CM5, MPI-ESM-MR and MPI-ESM-LR. The multi model ensemble (MME) of these climate models was used for temperature and precipitation. This data is available at a spatial resolution of 0.25°.

3.4 RESERVOIR DATA COLLECTION

3.4.1 GENERAL

For better understanding of the multi reservoir operation, specific data on water availability at source, in the reservoir and canals and the uses of water at different sources, data collection is required. Here, the reservoir data and water utilization data for different purposes is collected for three major water resources projects on Mahi River basin named as Mahi Bajaj Sagar Dam, Kadana Water Resources Project and Panam Water Resources Project. The reservoir data is available for 1976 to 2019.

3.4.2 Mahi Bajaj Sagar Project (MBSP)

The Mahi Bajaj Sagar is a multi-purpose project which provides irrigation in Kharif and Rabi seasons, produces hydropower through canal power house and supply to other D & I demands. The inflow, rainfall, reservoir level and capacity data for MBSP is collected from MBSP circle, Banswara at daily time scale. This data is merged and prepared for monthly time scale. The releases from MBSP and Kagdi pickup weir for different purposes is collected from Kagdi pickup weir data register and it is digitized manually from 2007 to 2019 with daily time period. Table 3.5 gives the inflow and releases for different sectors for each month for period of 1977-2019.

Table 3.5 : Mahi Bajaj Sagar Project Average Monthly Inflow and Outflows in MCM (Mm³)

Month	Left Main Canal	Right Main Canal	Hydropower Utilization	Spillway Release	Total Irrigation Demand	Inflow
Jan	130.5	76.0	214.2	0.0	206.5	0.0
Feb	120.1	71.5	196.4	0.0	191.7	0.0
Mar	102.9	58.6	165.5	0.3	161.4	0.0
Apr	33.1	22.4	62.1	0.4	55.5	0.0
May	13.0	5.9	21.0	0.8	18.9	0.0
Jun	0.4	0.5	0.1	0.6	0.9	33.8
Jul	5.5	0.5	14.1	20.6	5.9	533.2
Aug	36.6	0.2	113.7	276.7	36.9	1028.0
Sep	66.5	5.1	171.7	126.6	71.6	380.2
Oct	22.5	2.1	87.2	69.8	24.6	40.7
Nov	98.3	51.6	163.4	4.7	149.9	0.0
Dec	142.0	78.6	230.0	0.0	220.6	0.0
Sum	771.5	373.0	1439.4	500.6	1144.5	2016.0

Figure 3.1 & 3.2 shows the bar diagram and pie chart of water utilization by different sectors and inflow to the reservoir for each month for the period of 1977-2019.

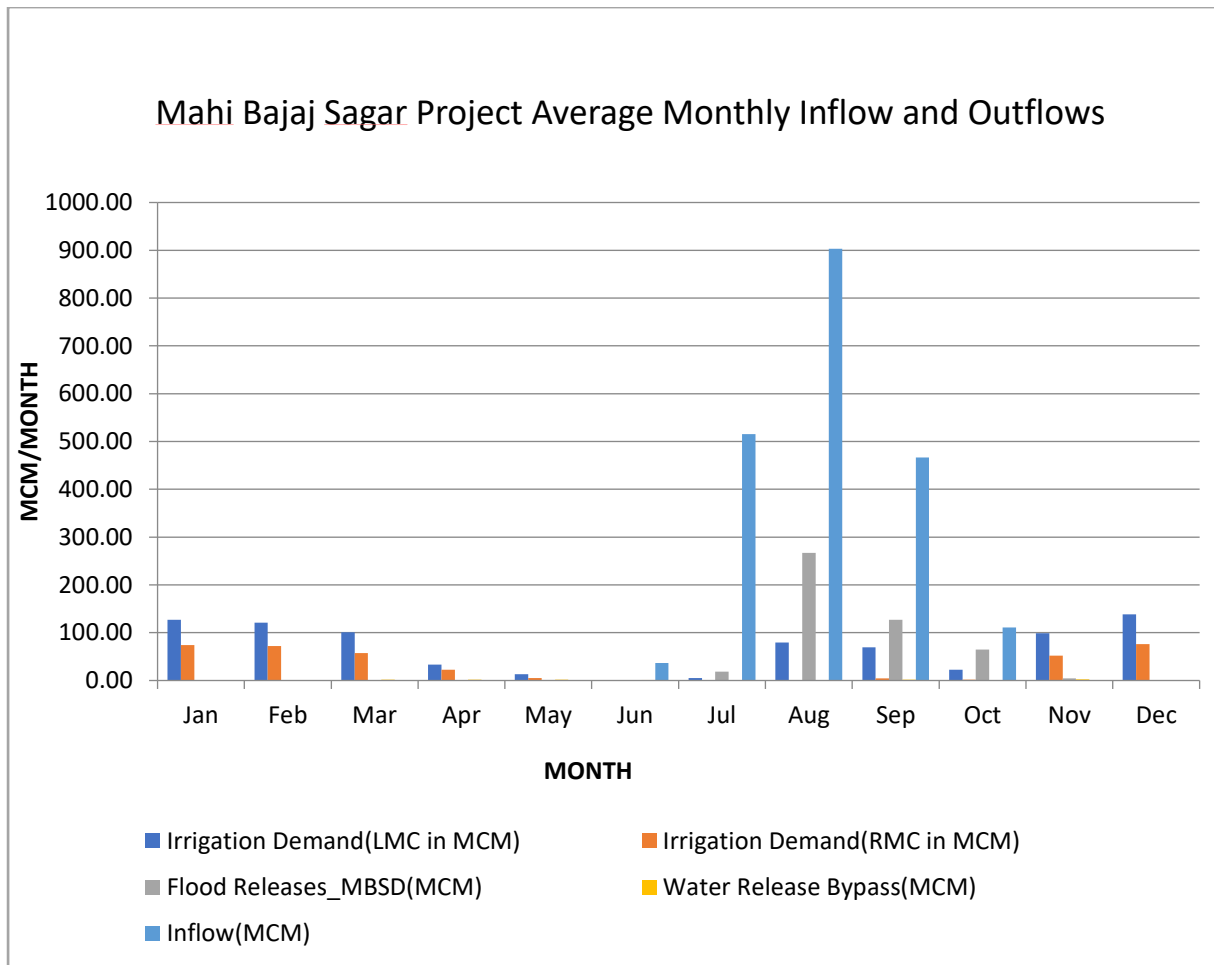


Figure 3:1 : Mahi Bajaj Sagar Project Average Monthly Inflow and Outflows (1977-2019).

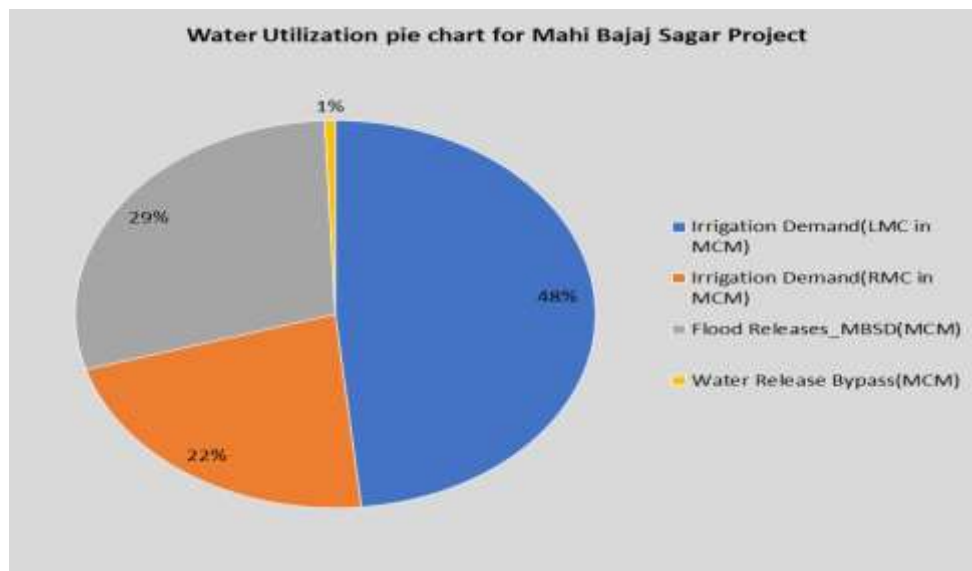


Figure 3:2 :Water Utilization pie chart for Mahi Bajaj Sagar Project (1977-2019)

3.4.3 Kadana Dam Reservoir Project

The Kadana Reservoir Project of Gujarat State is a multi-purpose project which consists of two stages viz. Stage-I & II. Stage-I Wanakbori Pickup weir with its Right Bank Canal

system in Kheda district. Stage-II : Storage Reservoir at Kadana with a direct Canal on the left Bank. For development and utilization of water from Mahi River, an agreement between the Gujarat & Rajasthan states was made in the year 1966. The main purposes of the project are Irrigation, Flood Protection, Hydropower Generation, Supply of drinking water and Fisheries. The project was commissioned in 1968 and completed in 1979 with the canal system. The canal system provides irrigation facilities to gross command area of 12795(KLBC)+315789 (MRBC)+6050(KRBC) hectares annually. The inflow, rainfall, reservoir level and capacity data for Kadana Dam Reservoir Project is collected from Kadana Dam Reservoir Project office, Kadana Project circle with daily time period and it is merged and prepared at monthly time scale. Table 3.6 gives the inflow and releases for different sectors for each month for period of 1982-2019 and 2007-2019.

Table 3.6 : Kadana Water Resources Project Average Monthly Inflow, Outflows and Losses

Month	Mahi Right Bank Canal	Kadana Left Bank Canal	Kadana Right Bank Canal	Evaporation	Hydropower Utilization	Spillway Release	Inflow	Mahi Right Bank Canal Demand
Jan	142.4	30.5	30.0	8.2	162.2	0.0	158.8	160.7
Feb	126.4	33.7	32.3	7.7	143.1	0.0	133.7	154.2
Mar	41.2	26.0	15.7	19.3	57.9	10.3	98.9	74.1
Apr	50.9	16.4	2.1	11.2	50.9	0.0	34.6	56.6
May	47.9	16.4	6.1	12.8	42.4	0.0	10.3	41.3
Jun	58.8	1.6	7.3	10.4	57.3	0.0	34.9	60.4
Jul	226.7	28.0	5.3	3.5	230.5	306.3	470.3	166.9
Aug	161.5	47.6	25.2	2.9	549.3	1774.8	1893.7	120.4
Sep	184.8	50.3	35.8	5.4	587.5	1649.1	1980.6	133.2

Oct	108.6	29.8	32.7	8.3	280.1	484.7	334.9	149.9
Nov	59.9	22.6	31.4	9.5	83.3	16.3	96.9	71.4
Dec	126.4	26.8	33.5	9.2	149.0	4.8	130.0	153.5
Sum	1335.6	329.7	257.3	108.3	2393.4	4246.2	5377.6	1342.7

Figure 3.3 & 3.4 shows the bar diagram and pie chart of water utilization by different sectors and inflow to the reservoir for each month for period of 1982-2019 and 2007-2019.

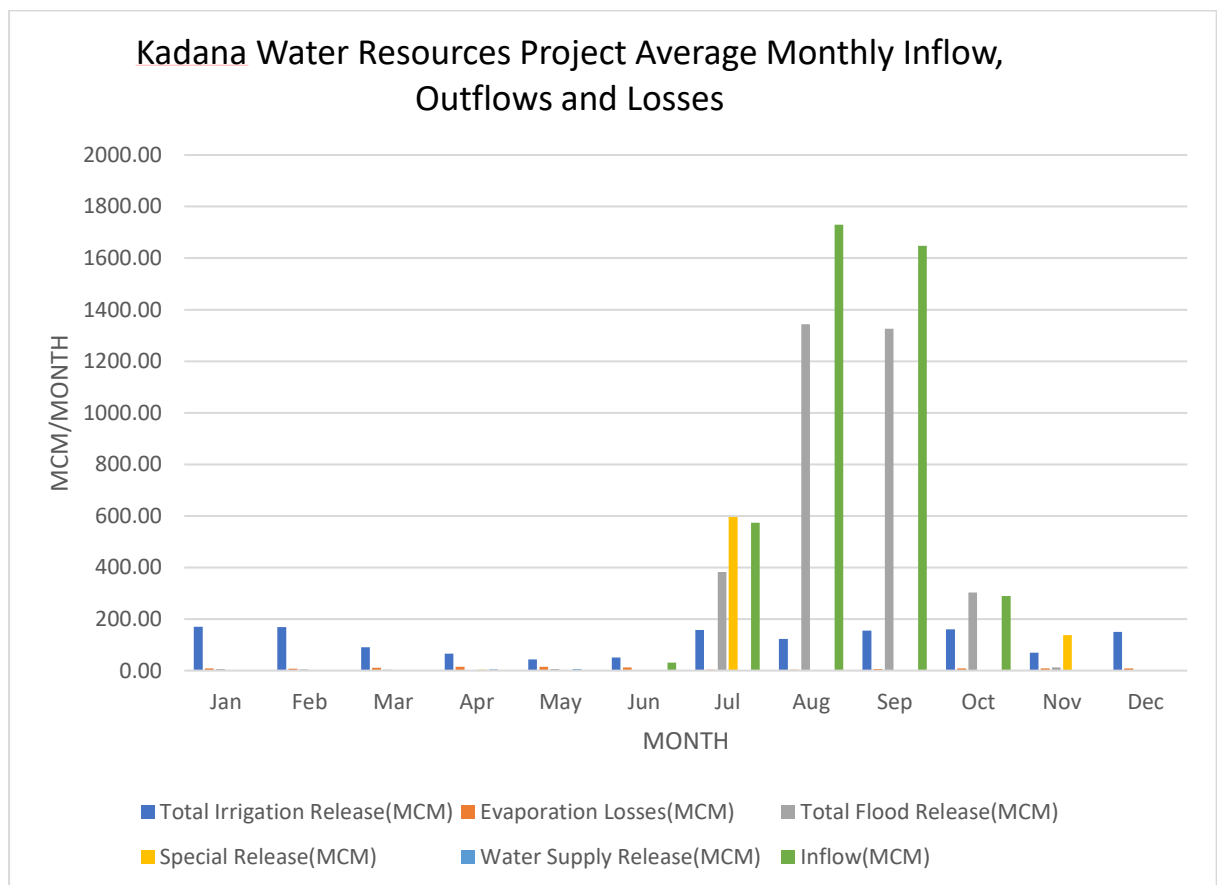


Figure 3:3 Average Monthly Inflow, Outflows and Losses for Kadana Water Resources Project

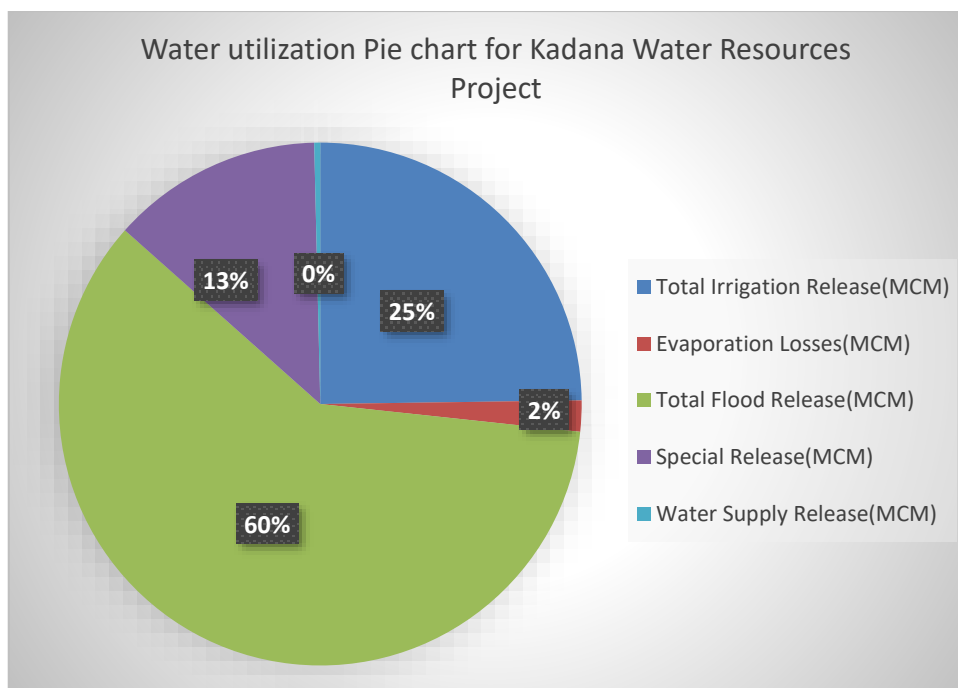


Figure 3:4 Water Utilization pie chart for Kadana Water Resources Project

3.4.4 Panam Water Resources Project

The Panam Reservoir Project of Gujarat State is a multi-purpose project. The main purposes of the project are Irrigation, Flood Protection, Hydropower Generation and Supply of drinking water. The inflow, rainfall, reservoir level and capacity data for Panam Dam Reservoir Project is collected from Panam Dam Reservoir Project office, Panam Project circle with daily time period and the data is merged and prepared for monthly time period. Table 3.7 gives the inflow and releases for different sectors for each month for period of 1976 to 2019.

Table 3.7 Panam Water Resources Project Average Monthly Inflow, Outflows and Losses

Month	Canal_release			Drinking Water Supply			Total Demand		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
Jan	41.9	31.5	5.9	0.5	0.4	0.3	42.4	31.9	6.2
Feb	50.7	38.4	7.1	0.5	0.3	0.3	51.2	38.7	7.4
Mar	52.9	37.4	6.1	0.5	0.4	0.3	53.4	37.7	6.4

Apr	49.2	21.5	0.0	0.6	0.4	0.3	49.7	21.9	0.3
May	29.0	10.2	0.0	0.5	0.4	0.3	29.5	10.6	0.3
Jun	4.5	0.4	0.0	0.5	0.4	0.3	5.1	0.7	0.3
Jul	26.8	11.0	0.0	0.5	0.3	0.3	27.3	11.4	0.3
Aug	36.9	19.6	0.0	0.5	0.3	0.3	37.4	19.9	0.3
Sep	40.9	23.1	0.2	0.5	0.3	0.3	41.3	23.5	0.5
Oct	41.8	30.7	8.5	0.5	0.3	0.3	42.3	31.1	8.8
Nov	26.4	16.1	0.3	0.5	0.4	0.3	26.9	16.4	0.6
Dec	38.9	34.2	30.0	0.5	0.3	0.0	39.4	34.5	30.0
Total	439.8	274.0	58.1	6.2	4.2	3.3	445.9	278.2	61.4

Figure 3.5 & 3.6 shows the bar diagram and pie chart of water utilization by different sectors and inflow to the reservoir for each month for the period of 1976-2019.

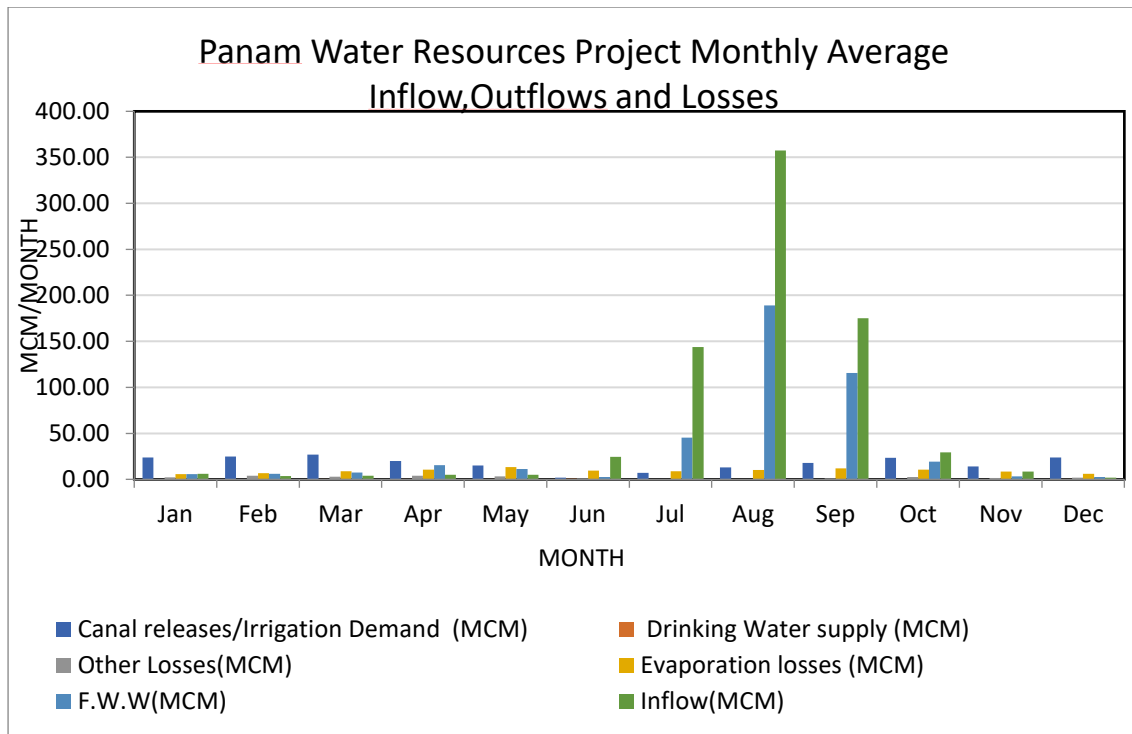


Figure 3:5 Panam Water Resources Project Average Monthly Inflow, Outflows and Losses 1976-2019

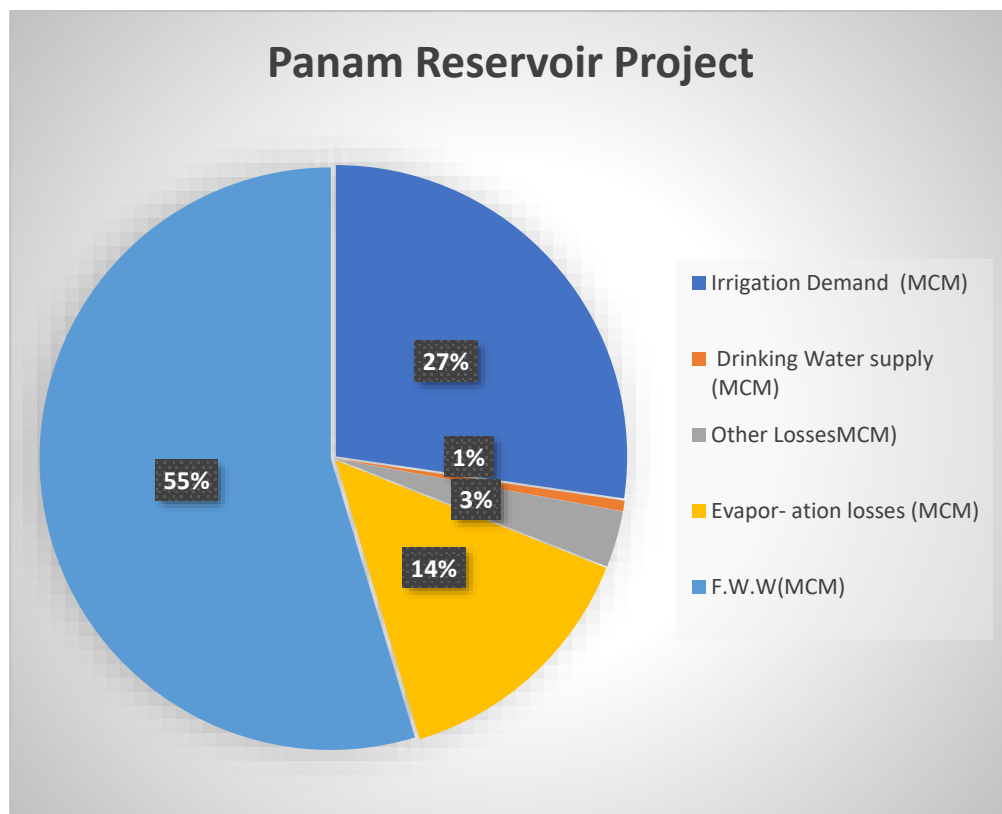


Figure 3:6 Water Utilization pie chart for Panam Water Resources Project (1976-2019)

The characteristic curves for Mahi Bajaj Sagar Reservoir are shown in Figure 3.7, which indicate the relation of water spread area and storage volume with the reservoir water levels. For example, from figure at an elevation of 259 m msl, reservoir has dead storage volume of 346.5 MCM and water spread area of 37.13km². At FRL of 281.5m msl, it has a storage capacity of 2180 MCM and the corresponding water spread area is 142.22 km².

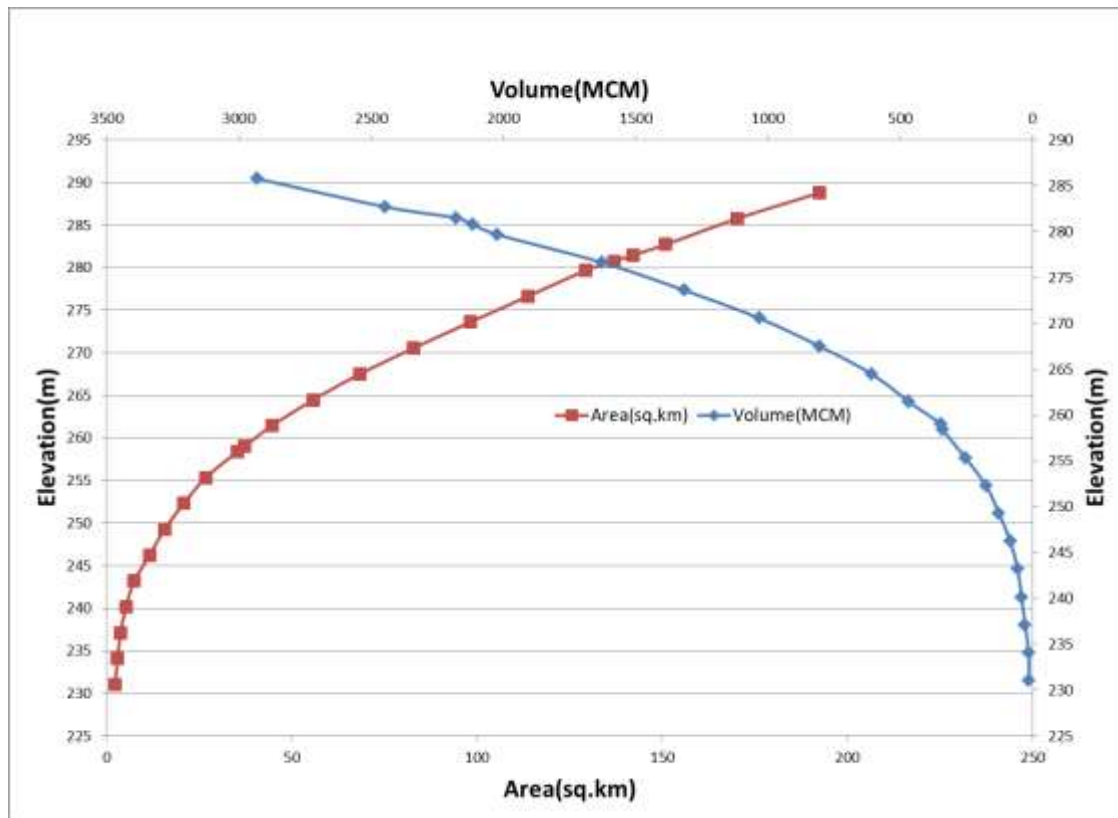


Figure 3:7 Characteristic curves for Mahi Bajaj Sagar Reservoir

The characteristic curves for Kadana Reservoir are shown in Figure 3.8, which indicate the relation of water spread area and storage volume with the reservoir water levels. For example, from figure at an elevation of 113.72m msl, reservoir has dead storage volume of 57.60 MCM and water spread area of 11.7 km². At FRL of 127.71 msl, it has a storage capacity of 1249.3 MCM and the corresponding water spread area is 38.69 km².

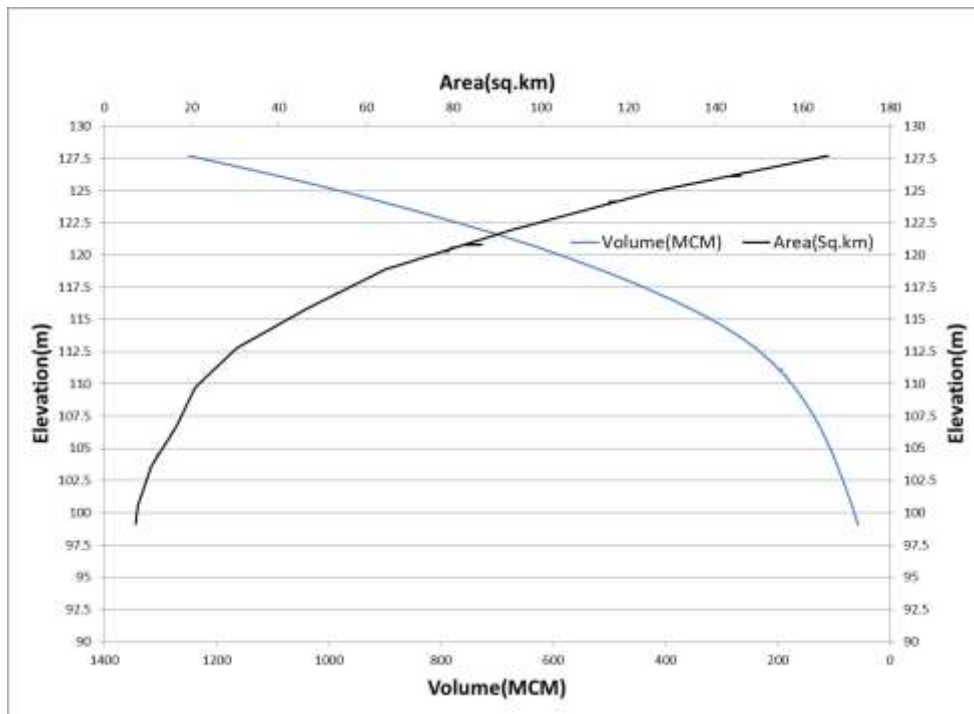


Figure 3:8 Characteristic curves for Kadana Reservoir

The characteristic curves for Panam Reservoir are shown in Figure 3.9, which indicate the relation of water spread area and storage volume with the reservoir water levels. For example, from figure at an elevation of 108.2m msl, reservoir has dead storage volume of 25.2 MCM and water spread area of 5.43 km². At FRL of 127.41 msl, it has a storage capacity of 578.185 MCM and the corresponding water spread area is 70.74 km².

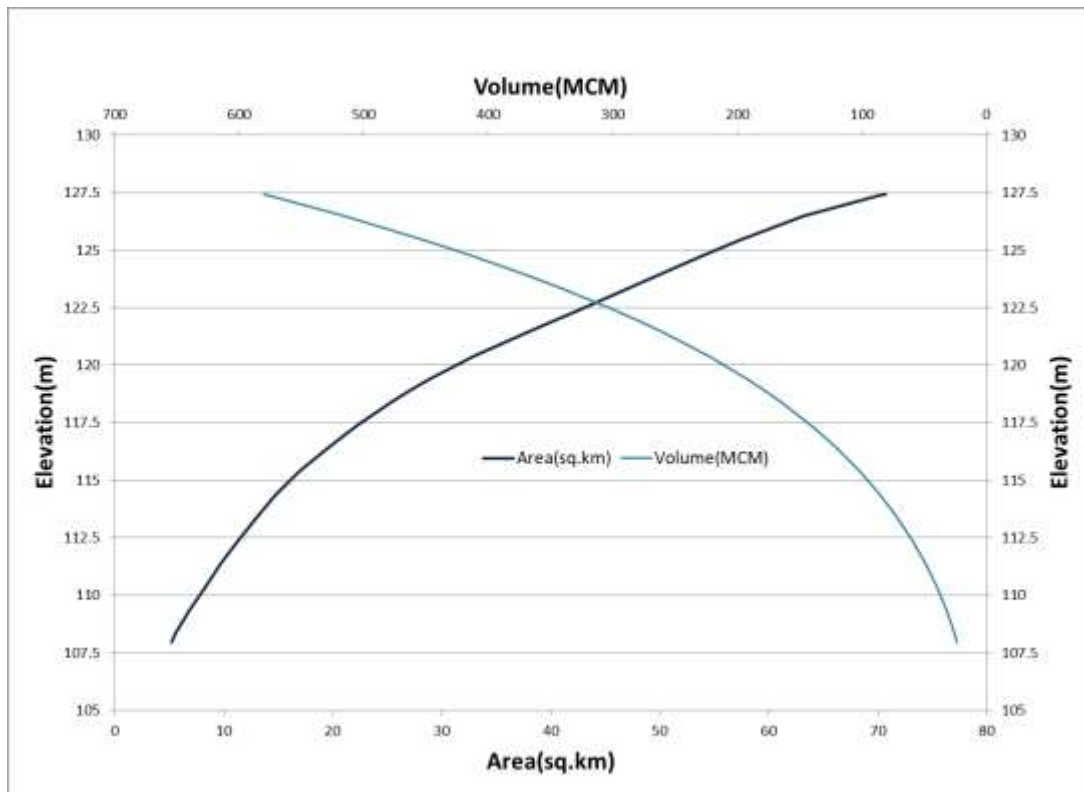


Figure 3:9 Characteristic curves for Kadana Reservoir

To determine the area of reservoir and head of the water with respect to volume are calculated on the basis of relation between area vs storage vs elevation graph. The regression equation of the three reservoirs are given below in table 3.8.

Table 3.8 : Regression equation for Mahi Bajaj Sagar reservoir, Adana reservoir and Panam reservoir

	Water spread area vs. Storage	Elevation Vs. Storage
Mahi Bajaj Sagar Reservoir	Regression: Area = $-0.000008 S^{**2} + 0.080891 S + 5.165225$	Regression: Elevation = $-0.000006 S^{**2} + 0.031820 S + 242.272032$
Kadana Reservoir	Regression: Area = $0.000005 S^{**2} + 0.125253 S + -0.074766$	Regression: Elevation = $-0.000024 S^{**2} + 0.050172 S + 100.036618$
Panam Reservoir	Regression: Area = $-0.000065 S^{**2} + 0.152905 S + 2.136686$	Regression: Elevation = $-0.000068 S^{**2} + 0.070019 S + 108.141263$

3.5 Hydropower data

Mahi Bajaj Sagar hydropower was installed in 1986 with a total capacity of 2×25(MW) named as Mahi Stage I. Mahi Bajaj Sagar reservoir has 5 saddle dams along with main dam. Power station I is situated at saddle dam no 5. Kadana hydropower project was established between year 1990-1998. Water releases for the Mahi right bank canal are used for hydropower production. Salient features for hydropower data for these two dams are given below in table 3.9.

Table 3.9 Hydropower details of Mahi Bajaj Sagar Dam and Kadana Dam

	Mahi Bajaj Sagar hydro-electric project			Kadana hydro-electric project		
Design Capacity	140 MW			240 MW		
Firm Capacity	38 MW					
Manufacturer	Mahi Stage I	2×25(MW)	BHEL Bhopal	4×60(MW) BHEL		
	Mahi Stage II	2×45(MW)	BHEL Haridwar			
Head	40(m)			Turbine	43.5(m)	
				Pump	47.0(m)	
Head	Designed head:40(m) Maximum head: 50(m) Minimum head:26(m)			Net Head	Turbine	Pumping
				Maximum	48.2(m)	51.0(m)
				Minimum	30.77(m)	35.0(m)
				Rated	43.5(m)	47.0(m)
Speed	Speed	150(rpm)		Normal Speed		142.86(rpm)
	Specific Speed	285.53(rpm)		Runway Speed		283(rpm)
Type	Vertical Francis			Deriaz Turbine (Reversible Turbines Pumped Storage)		
Discharge	At rated head & maximum Output	80.55 m³/sec		Maximum discharge:634 m³/sec		
	At rated heads & rated Output	71.1 m³/sec				
Turbine Height	235 m			70 m		

3.6 Software Used

3.6.1 ArcGIS

ArcInfo software has been used in the present study to integrate the different geo-spatial data/information required for the study and for creation of GIS database. ArcInfo is Geographic Information System (GIS) software developed by Environmental Systems Research Institute (ESRI). It is a full-featured package with tools for automation, analysis, display and management of geographic information. Typical applications include land resource management, automated mapping and facilities management, demographic analysis, forestry, environmental analysis, water resource management, mineral exploration, transportation, and telecommunication. Federal agencies such as the U.S. Geological Survey, Environmental Protection Agency, and the Natural Resource Conservation Services have adopted Arc/Info as their GIS standard. Furthermore, many universities teach GIS using ArcInfo. Consequently Arc/Info has a large established user base in the GIS community and ArcInfo -formatted spatial data is readily available from federal, regional, and state agencies as well as commercial data providers. ArcInfo includes various sub modules such as ArcScene, ArcGlobe, ArcMap, ArcCatalog, ArcToolbox etc. ArcInfo is a vector-based software and also has raster data handling capabilities.

3.6.2 ERDAS Imagine

ERDAS IMAGINE, the world's leading geospatial data authoring system, incorporates geospatial image processing and analysis, remote sensing and GIS capabilities into a powerful, convenient package. ERDAS Imagine is a broad collection of software tools developed by Leica Geosystems (USA) for digital image processing of images. ERDAS IMAGINE is a remote sensing image processing application. It allows the user to import a wide variety of remotely sensed imagery from satellite and aerial platforms and produce useful information from the data. IMAGINE is available in three levels of functionality depending upon the users' requirements: Essentials; Advantage and Professional. It also has a number of add-on modules that extend the capability of the software.

3.6.3 SWAT

In recent years, distributed watershed models are increasingly used to implement alternative management strategies in the areas of water resources allocation, flood control, impact of land use change and climate change, and finally environmental pollution control. SWAT is a well-

established physically based distributed model for analysing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds. SWAT is a continuous time, spatially distributed model designed to simulate water, sediment, nutrient and pesticide transport at a catchment scale on a daily time step. It uses hydrologic response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The model estimates relevant hydrologic components such as evapotranspiration, surface runoff and peak rate of runoff, groundwater flow and sediment yield for each HRUs unit. Within the SWAT conceptual framework, the representation of the hydrology of a basin is divided into two major parts: (a) the land phase of the hydrological cycle; and (b) the routing of runoff through the river network. The present study concerns the application of a physically based watershed model ArcSWAT to examine the influence of topographic, land use, soil and climatic condition on stream flow. For the land phase water balance, within SWAT evapotranspiration can be calculated using one of three methods: Penman-Monteith, Hargreaves or Priestley-Taylor. For surface runoff calculations, SWAT gives the user two alternatives: (a) the use of the Soil Conservation Service curve number (SCS CN) procedure, and (b) the Green and Ampt infiltration method. The model setup involved five steps: (1) data preparation; (2) sub basin discretization; (3) HRU definition; (4) parameter sensitivity analysis; (5) calibration and uncertainty analysis.

Chapter 4: Methodology

4. Methodology

To achieve the proposed objectives of this proposal following steps is taken with specific focus on local conditions:

- i. Identification of current knowledge gaps and existing issues,
- ii. Conducting applied research on Climate Change related issues/problems,

Applied research projects was conducted on different climate change-related issues using experimental and mathematical modelling procedures. Issues identified from step 1 was guiding-posts for selecting high-priority problems areas and conducting applied research.

Some of the identified issues/problems related to different aspects of climate change are presented below:

- i. Updating the basin wise water availability,
- ii. Development of GIS databases and SWAT hydrological model for Integrated Water Resources Management (IWRM),
- iii. Development of Groundwater model in Modflow and study the water quality and quantity parameters
- iv. Assessment of climate impact on crop water productivity using FAO AQUA crop model
- v. Trend analysis and identification of extreme events, hotspots and vulnerability assessment
- vi. Reservoir/canal modelling for water management, water allocation strategy for irrigation/Municipal/industrial uses.
- vii. Feasibility of linking of climate, social, and ecology data by employing integrated approaches, such as GIS
- viii. Quantifying the uncertainties in climate impact modelling
- ix. Development of strategies for cost-effective intervention in water and environmental systems and their consequences for alternative scenarios.

- x. Macroscale modelling to study basin hydrology and study the effect due to changes in land use/ land cover.
- xi. Identify suitable adaptation policies for water use, cropping patterns, calamity management, reservoir operation policies etc.

All efforts were made to propose sustainable and vulnerability-based climate change impact and adaptation strategies. IPCC (2007) defines adaptation as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. In the context of both social and natural systems, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities or to cope with the consequences). Adaptation is critical to enable societies to deal with the impacts of both natural and anthropogenic environmental change, especially in low-income countries. The adaptation strategy for a country, a basin or part thereof, refers to a general plan of action for addressing the impacts of climate change, including climate variability and extremes. It will include a mix of policies and measures with the overarching objective of reducing the country's vulnerability. Detailed methodology of the proposed research has been presented in Figure 4.1 below. Also, some of the main processes are explained in subsequent sections. The methodology used for hydrological modelling has been presented in Figure 4.2.

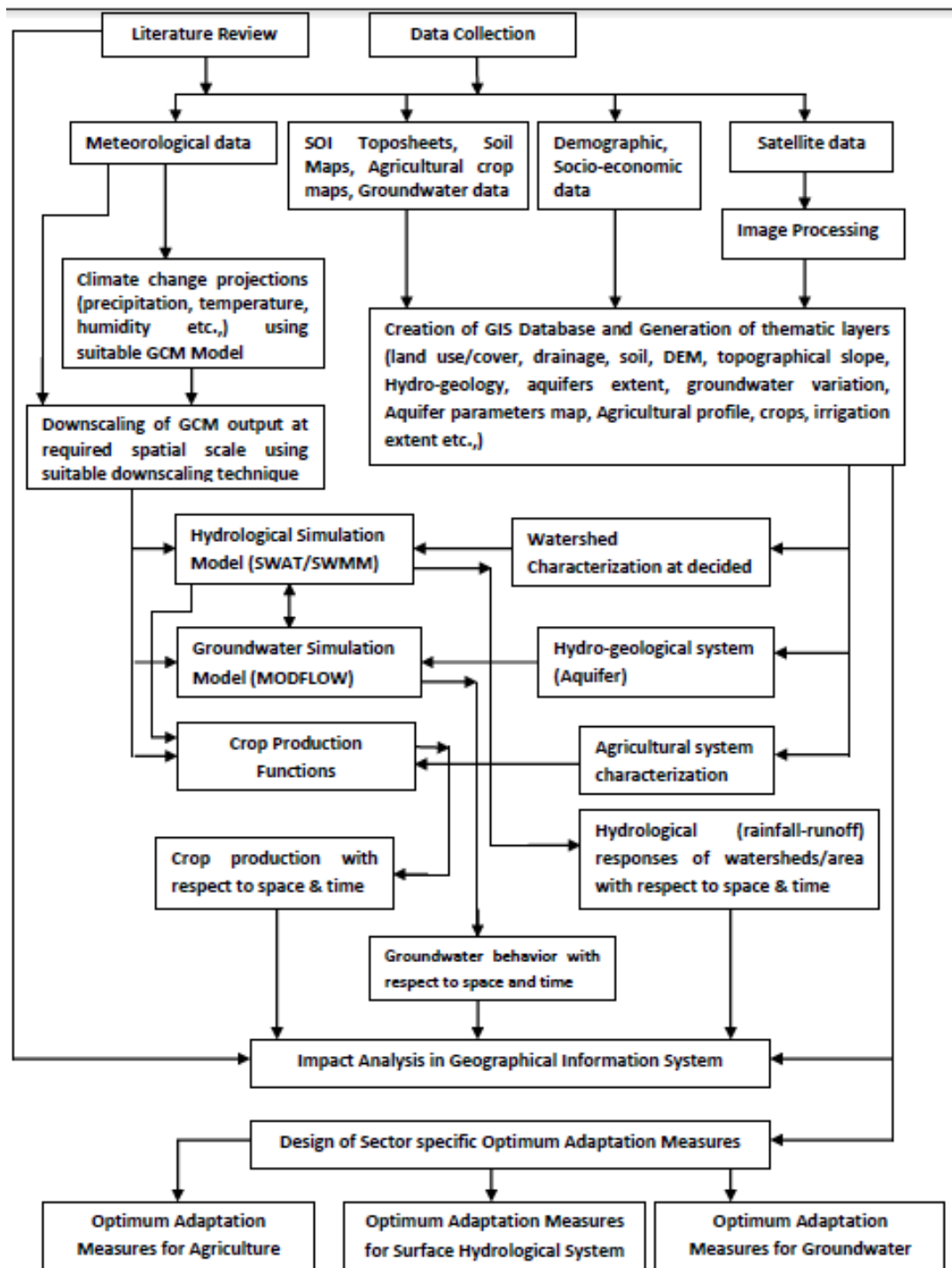


Figure 4:1 Overall methodology

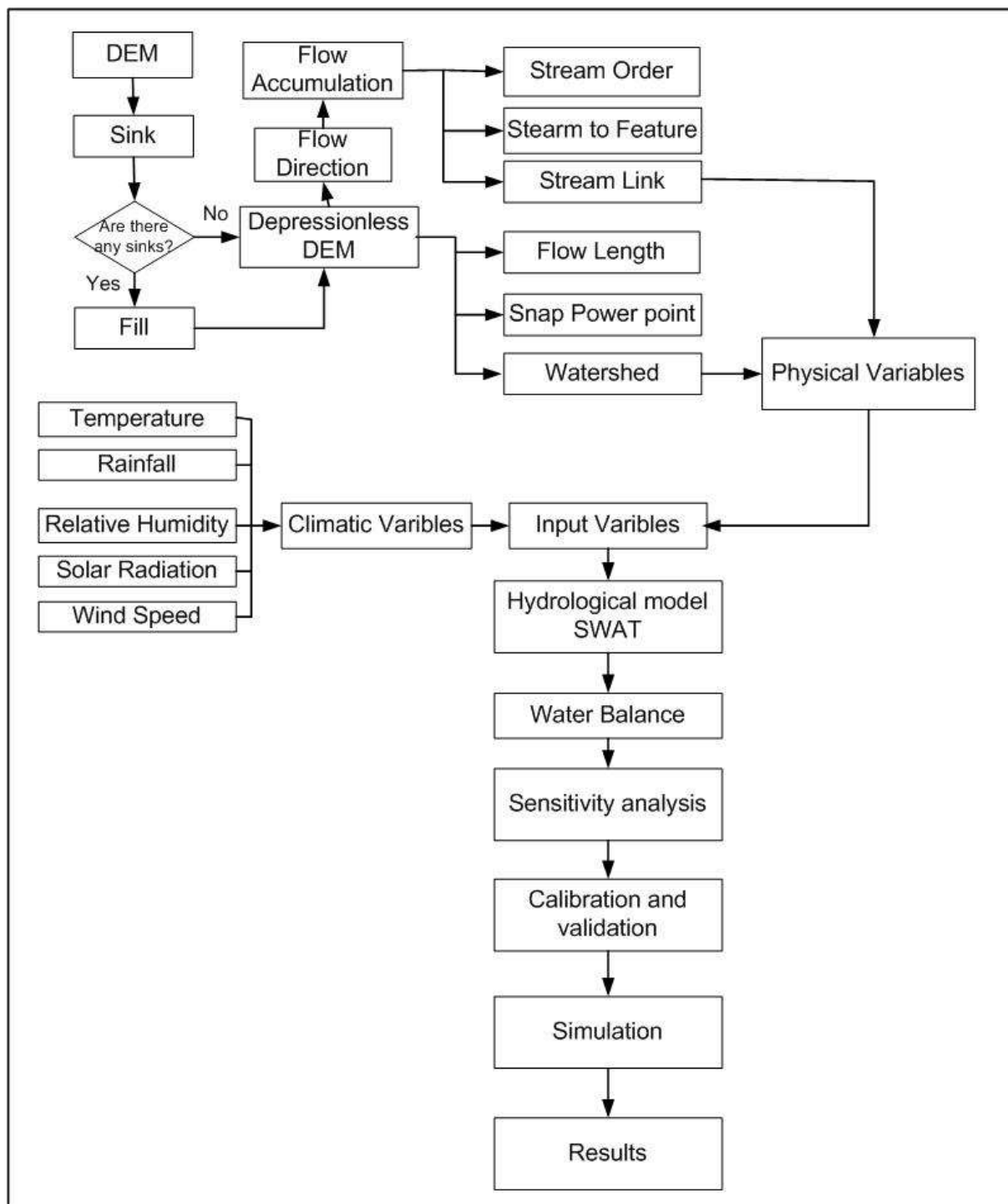


Figure 4:2 Methodology for hydrological modelling

Chapter 5: GIS Database Creation

5. GIS Database

5.1 Mahi Basin

5.1.1 Image Analysis and LULC Map Preparation

LULC classification is one of the most widely used applications in remote sensing. The most commonly used approaches include unsupervised classification, supervised classification, image segmentation and NDVI. Each of these methods has their own restrictions and advantages. However, none of them individually can create an acceptable level of accuracy in producing LULC maps. Using the technique of object-based image segmentation, detailed information in the study area can be gathered effectively from the analysis of satellite images and certain ancillary data. In response to this, a new protocol was proposed in this research study as a way to combine the advantages of these methods and enhance the quality of LULC maps. The research methodology and proposed protocol have been shaped using a multidisciplinary and hierarchical approach.

5.1.2 Pre-processing of the images

For pre-processing of the images, the preliminary task of image analysis is to perform radiometric corrections over satellite images. It is required to remove or reduce atmospheric noise or speckle noise from the data. Geometric corrections are required for satellite data with the help of image rectification or geo-referencing to rectify the image.

5.1.3 False Colour Composite (FCC)

After that layer stacking is done in Erdas Imagine to combine all bands information into single image to prepare False Colour Composite (FCC). To get the study area we perform subsetting and masking. The coordinate system used in the topographic maps was the Universal Transverse Mercator (UTM) zone 43N with spheroid and datum WGS 1984. Figure 5.1 & 5.2 are showing the FCCs prepared for both the Rabi and the Kharif season.

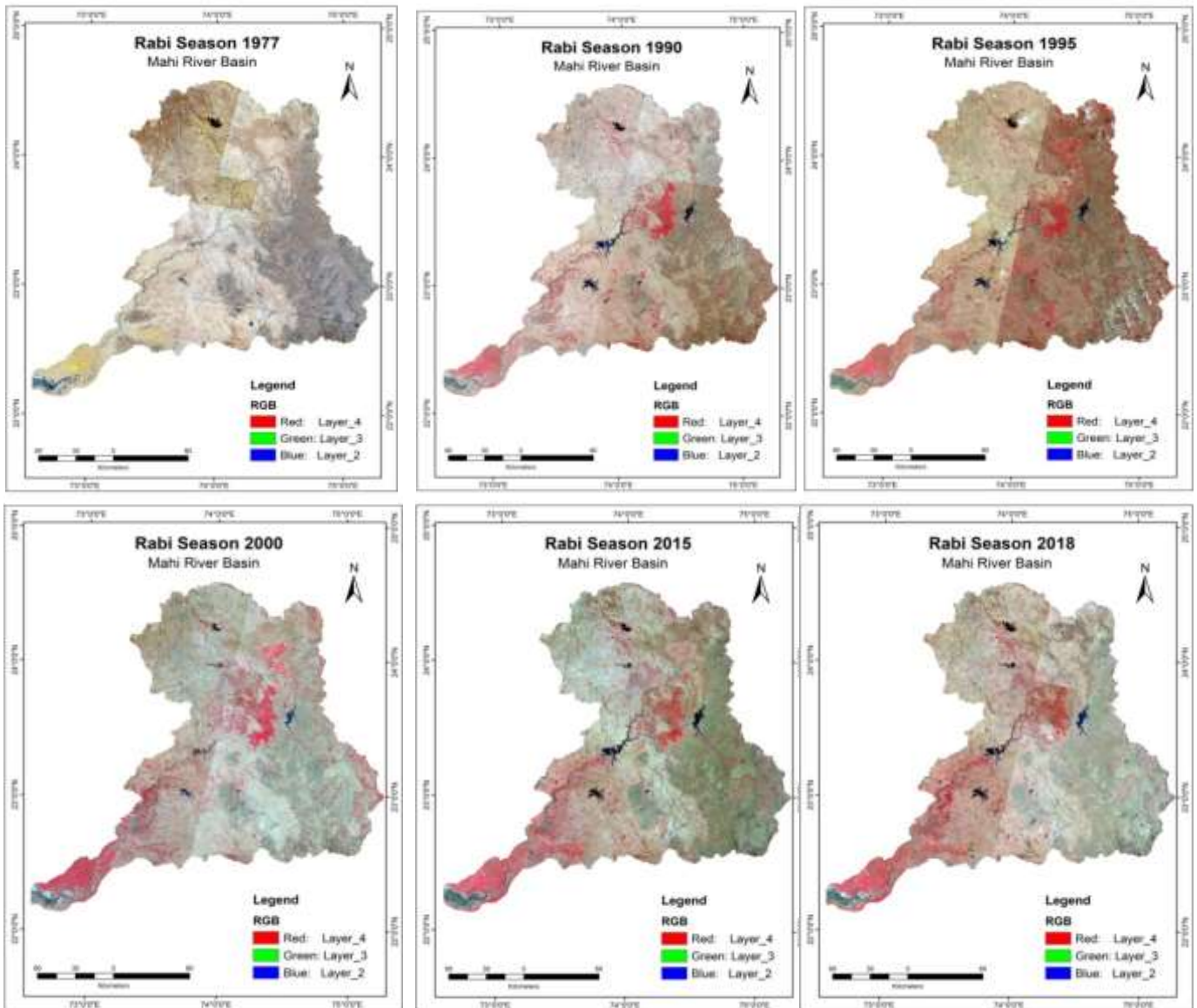


Figure 5.1 FCCs prepared of Rabi season for Mahi basin

5.1.4 Signature Selection

Training sampling locations were chosen to encompass a full variety of potential LULC classes across the entire study area. This study encompassed a relatively large watershed with different climatic zones and a complex combination of hills, plains and dessert. Images have been examined visually and by drawing spectral and spatial profiles to have an idea about separable LULC classes. The total ten possible LULC classes which can be extracted from the satellite images are given bellow.

1. Water Bodies 2. Built-up Settlement 3. Built-up paved 4. Shrubs land 5. River Sand 6. Rocky Barren 7. Barren land 8. Agriculture Fallow 9. Agriculture Land and 10. Forest

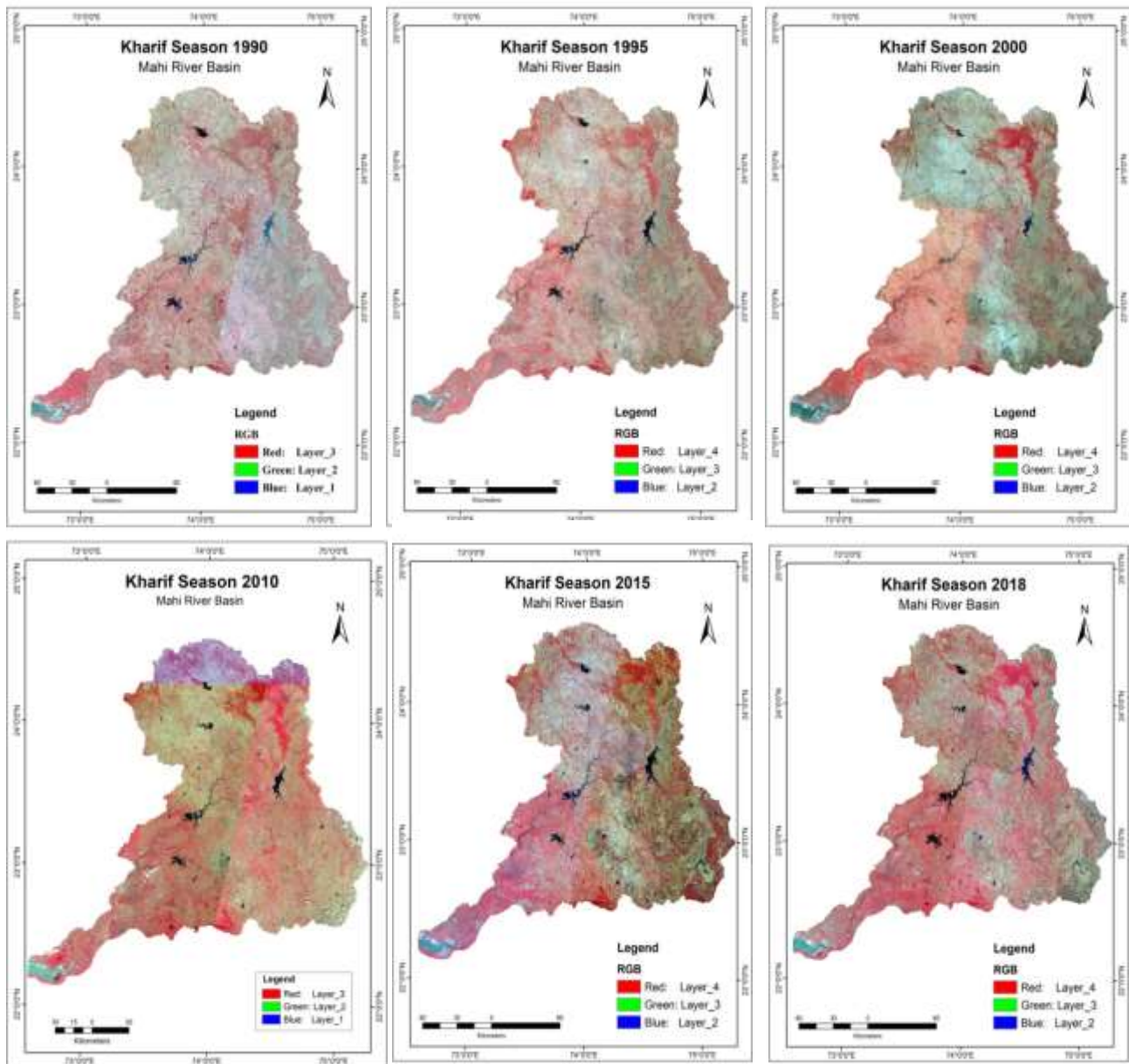


Figure 5.2 FCCs prepared of Kharif season for Mahi basin

5.1.5 Supervised Classification

In the present study, a supervised classification method has been used for classification of satellite images. Supervised classification requires training of algorithm. Based on the prior knowledge suitable cluster of pixels have been selected from respective FCC, as training samples for different LULC classes, through AOI tools in ERDAS Imagine. Such collected pixels are called signatures and process is called signature selection. Signatures have been

selected for ten LULC classes (as discussed above). The classified outputs are presented in Figure 5.3 & 5.4 for Rabi and Kharif season respectively.

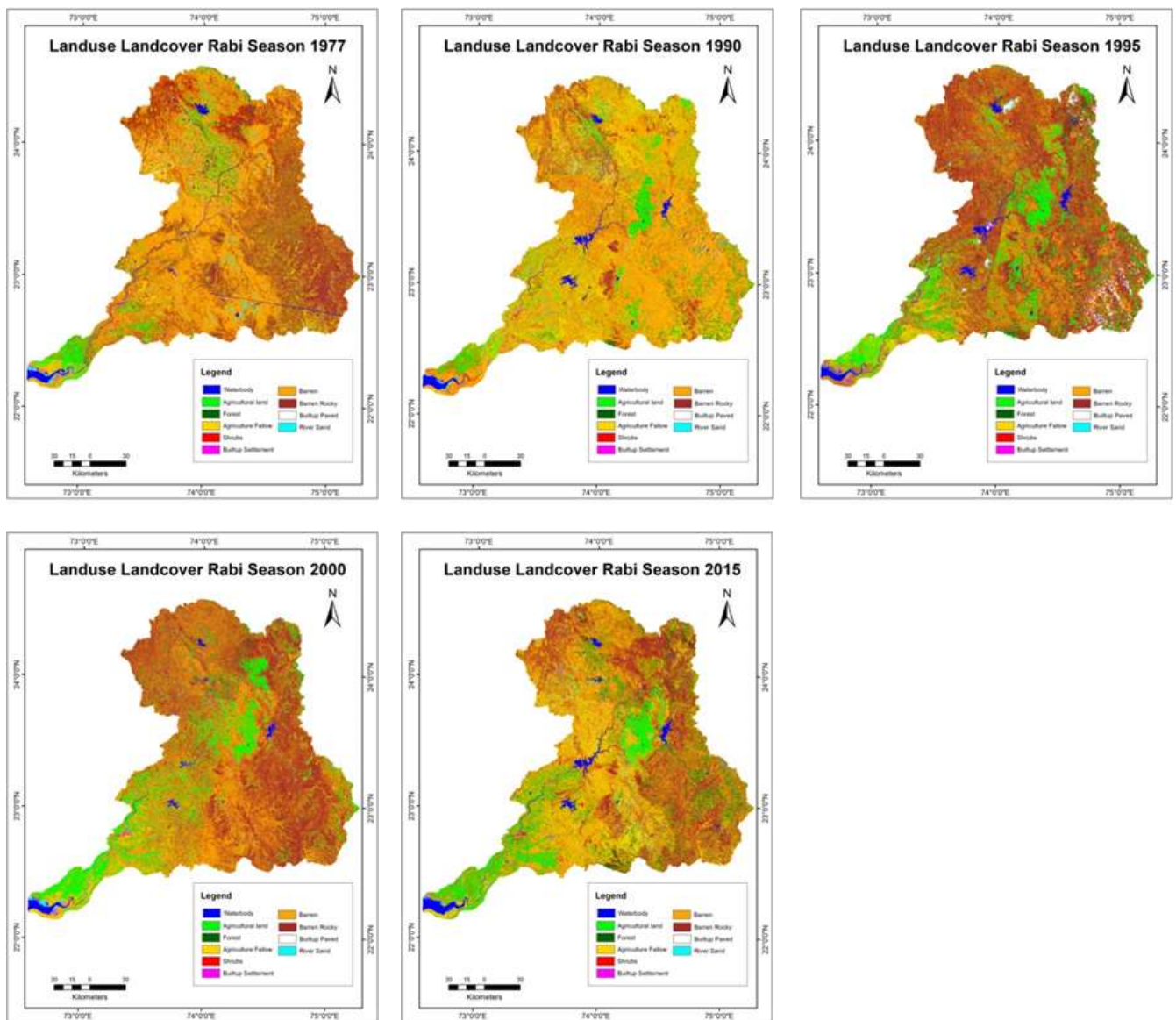


Figure 5.3 FCCs prepared of Rabi season for Mahi basin

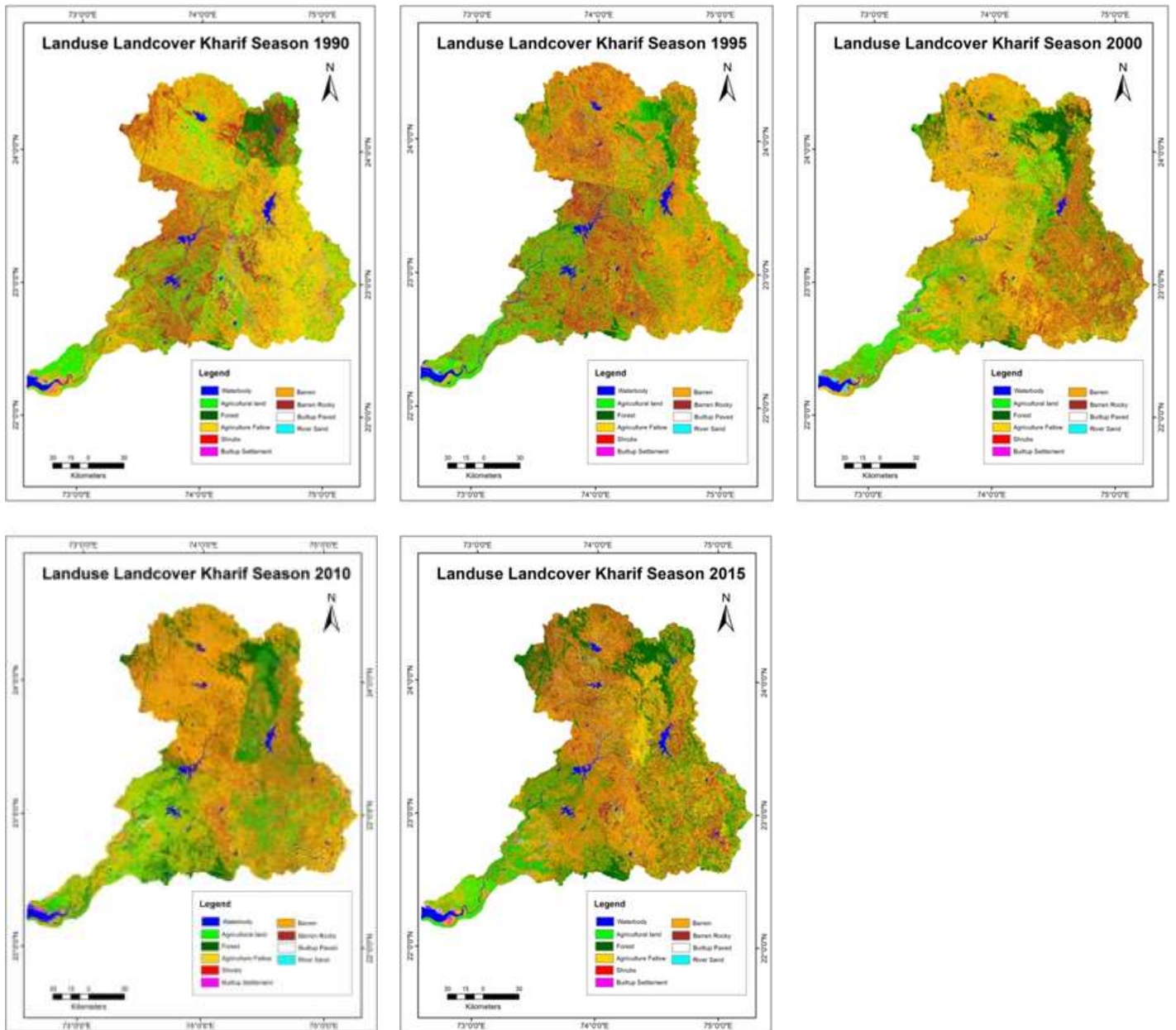


Figure 5.4 FCCs prepared of kharif season for Mahi basin

5.1.6 Mahi River Basin Boundary

Mahi river basin boundary (Figure 5.5) has been delineated using DEM and validated with topographic maps. ASTER DEM is downloaded from USGS(<https://earthexplorer.usgs.gov>). Using Arc-Hydro Tool the basin boundary has been delineated. Then it is checked and validated by checking the ridge line in topographic maps. The spatial resolution of ASTER DEM is 30m.

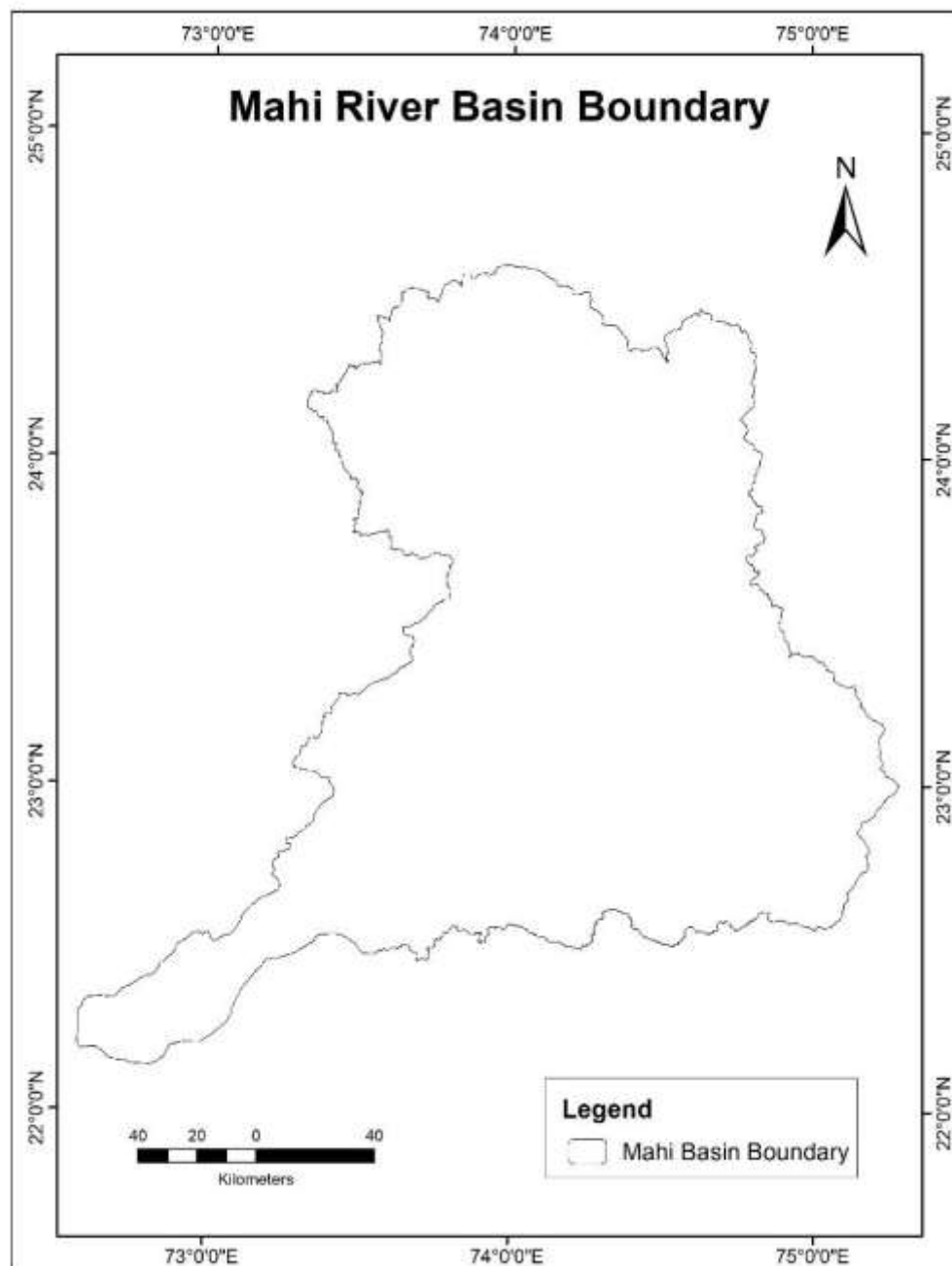


Figure 5.5 Mahi River basin boundary

5.1.7 Drainage Network

Drainage Line has been digitized using Landsat-OLI Satellite Image. Image of the kharif season were used for better identification of water flow line (Figure 5.6).

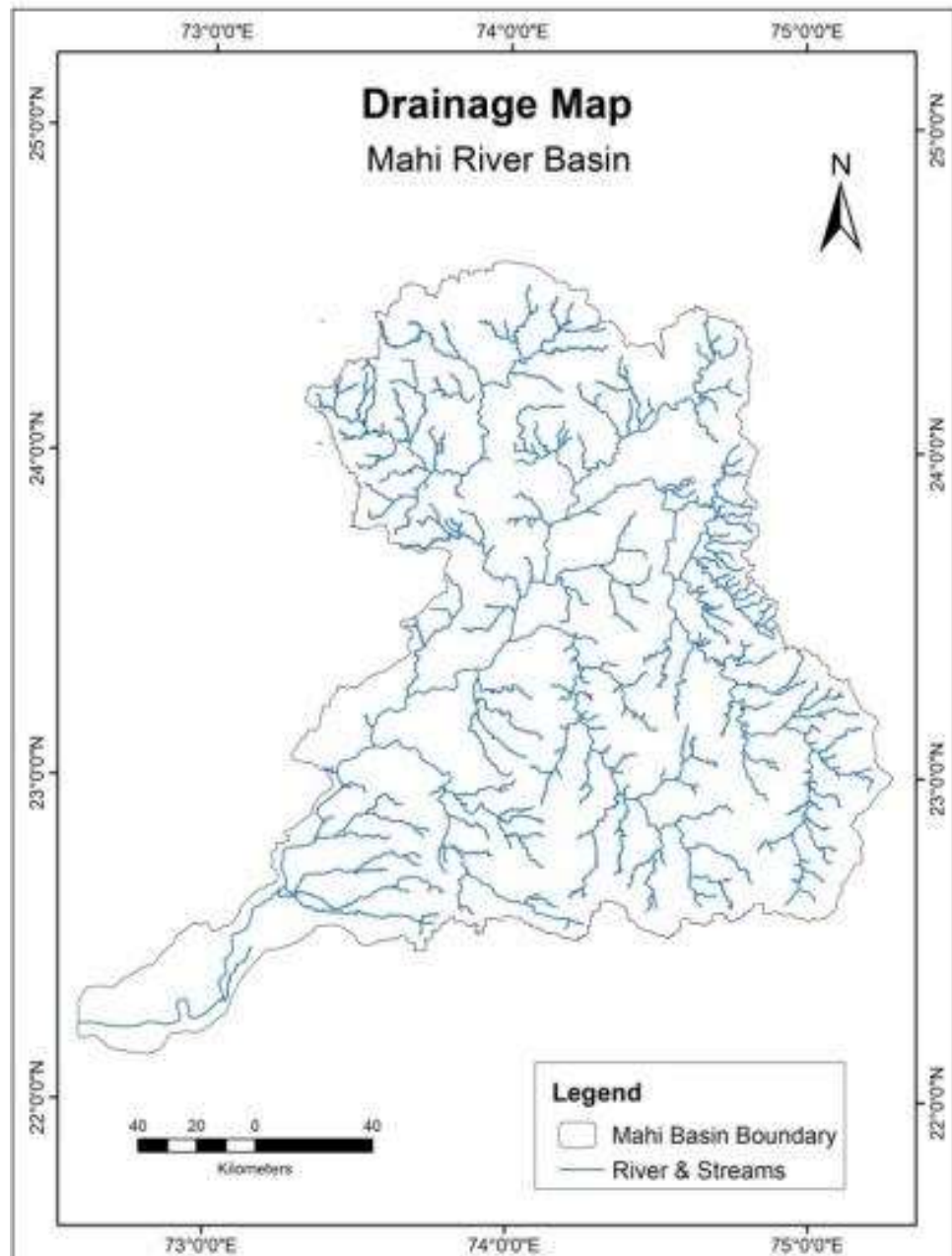


Figure 5.6 Drainage network for Mahi basin

5.1.8 Survey of India (SOI) Toposheet

All the toposheet are geo-referenced in UTM WGS84 43N projection and coordinate system with an acceptable range of RMS error (Figure 5.7).

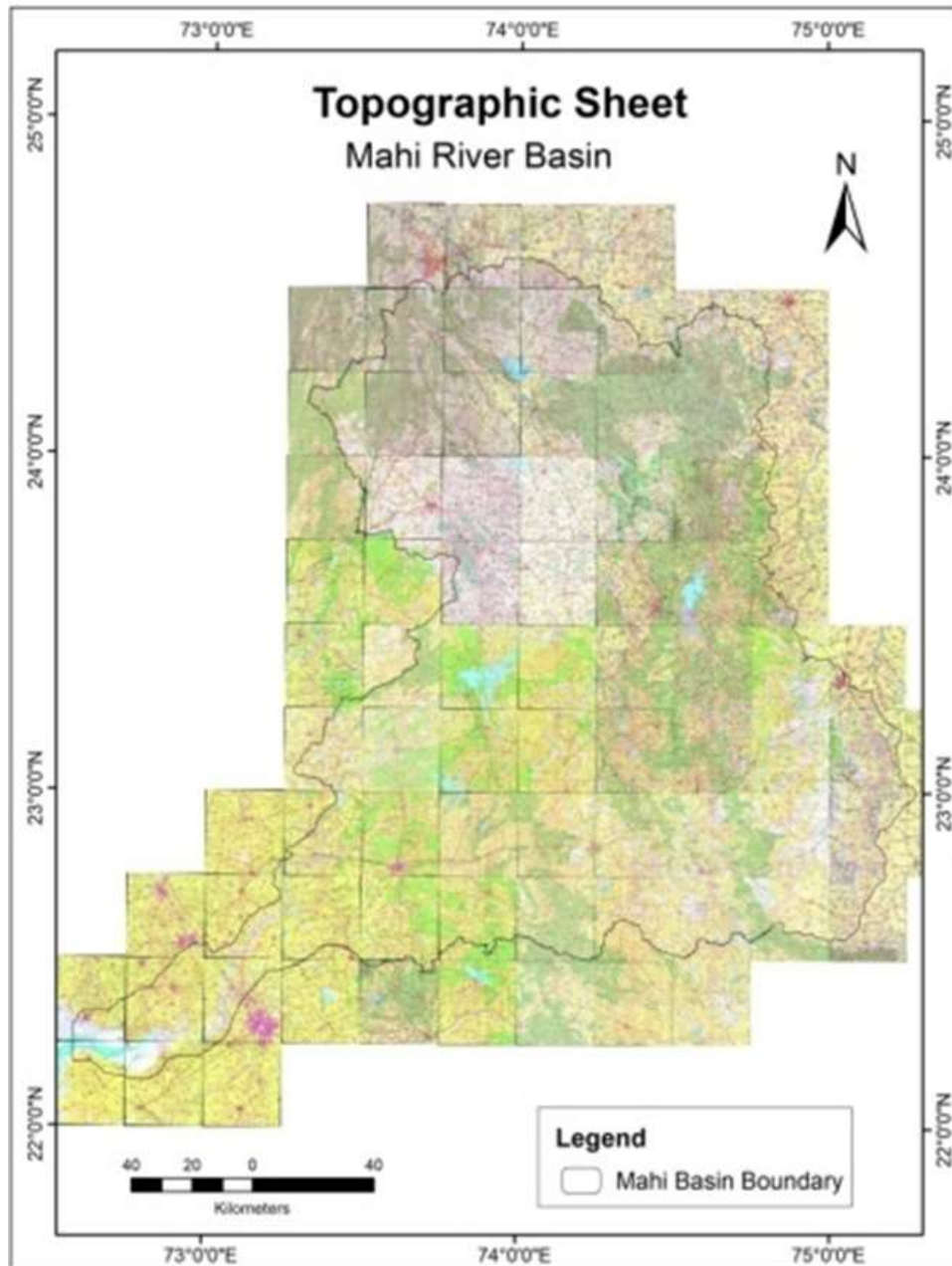


Figure 5.7 Geo-referenced toposheet for Mahi basin

5.1.9 Soil Map

The soil map has been downloaded from FAO (Food and Agriculture Organization of the United Nations). Then it is characterized with the help of FAO to USDA soil types. The soil types defined here are clay, loam, sandy clay loam, sandy loam and waterbody. The important waterbodies contributing to the catchment of Mahi River basin has been collected from google earth (Figure 5.8).

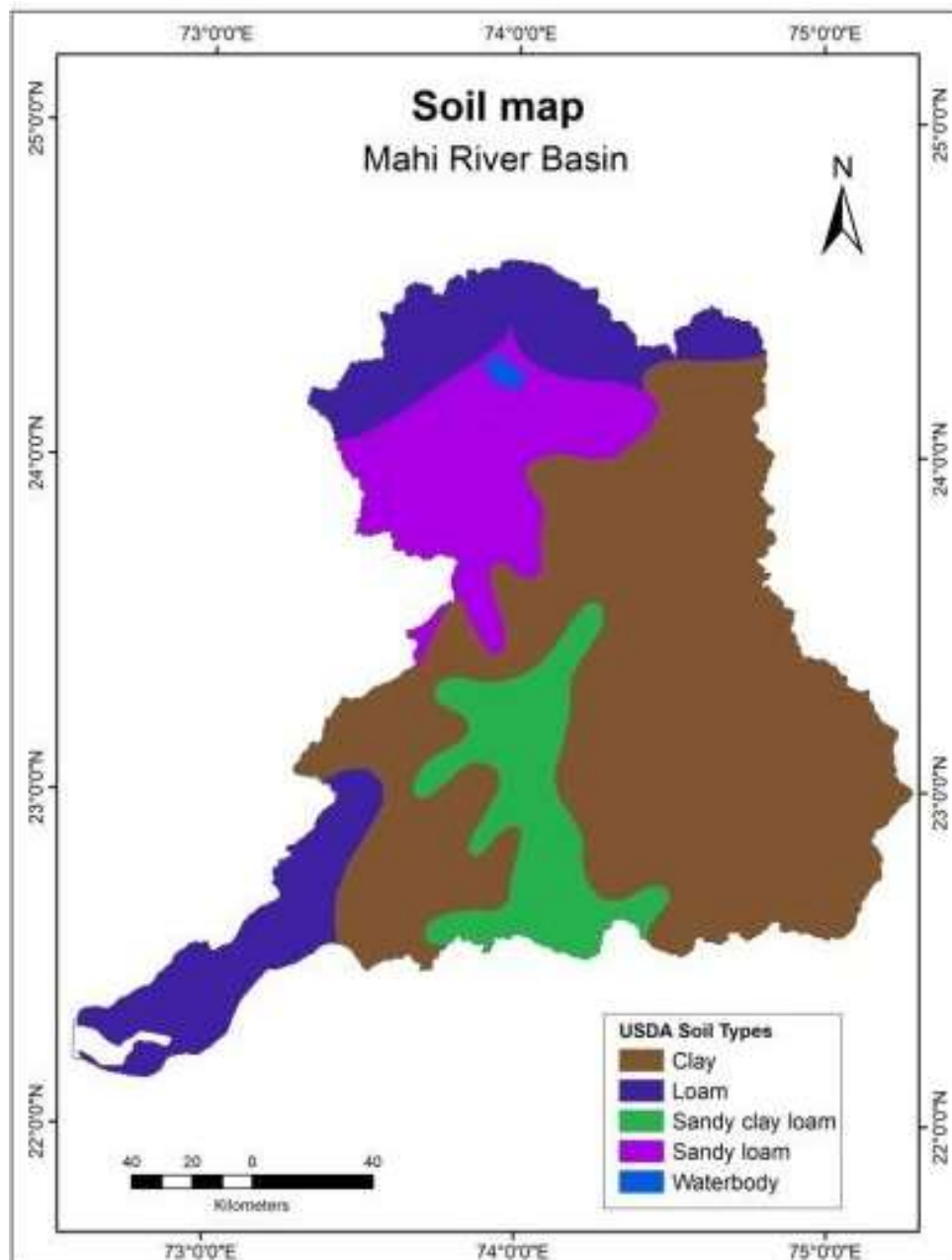


Figure 5.8 Soil map for Mahi basin

5.2 Waterbodies

The important water bodies contributing to the catchment of Mahi River basin has been collected from google earth. Total 745 numbers of water bodies are there in the Mahi Basin area (Figure 5.9).

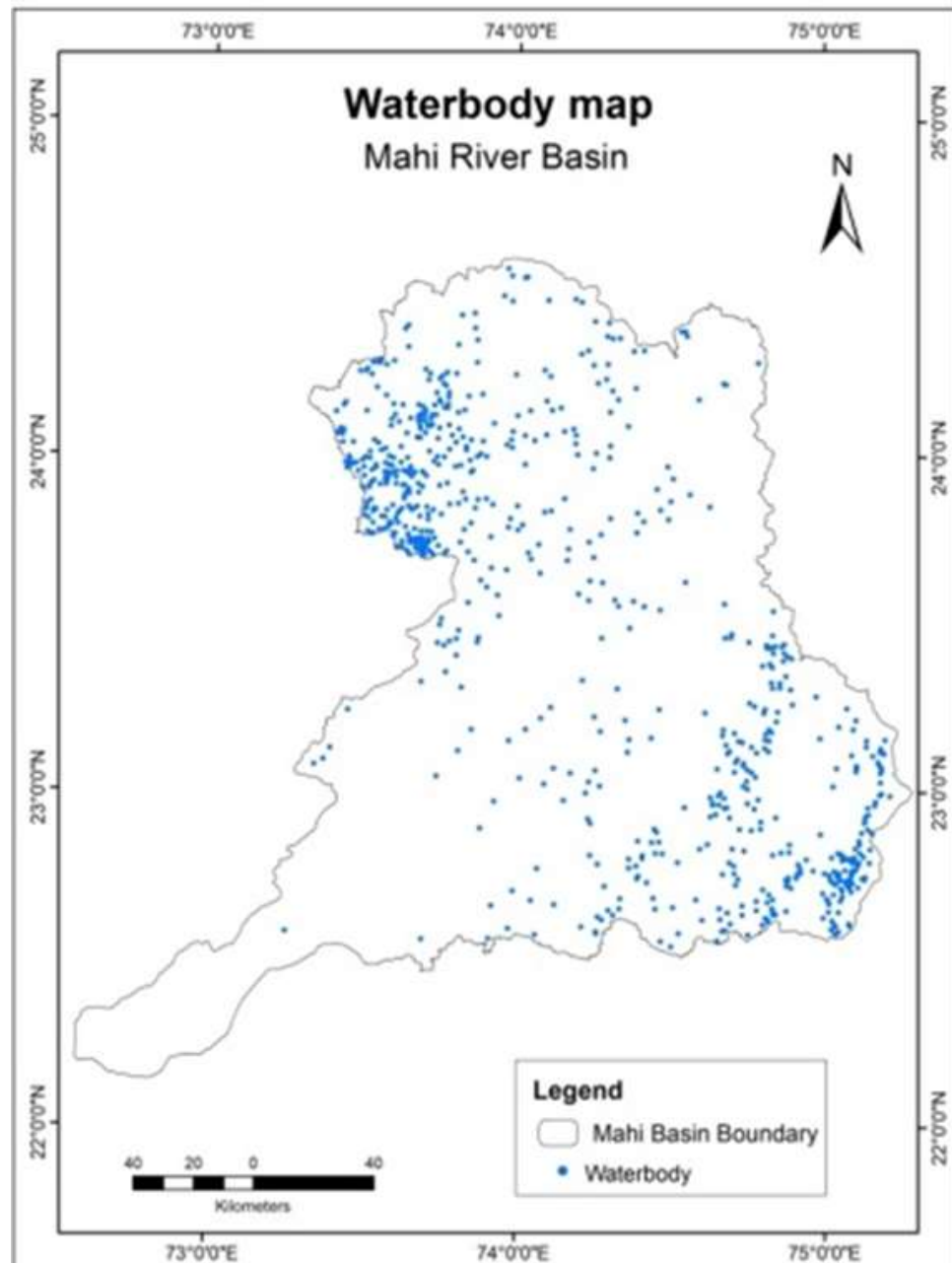


Figure 5.9 Waterbody for Mahi basin

5.2.1 Digital Elevation Model (DEM)

The DEM (Digital Elevation Model) has been prepared for Mahi River basin. Here ASTER DEM is used for delineation and the spatial resolution was 30m. The range of elevation is 1-1032(m) (Figure 5.10).

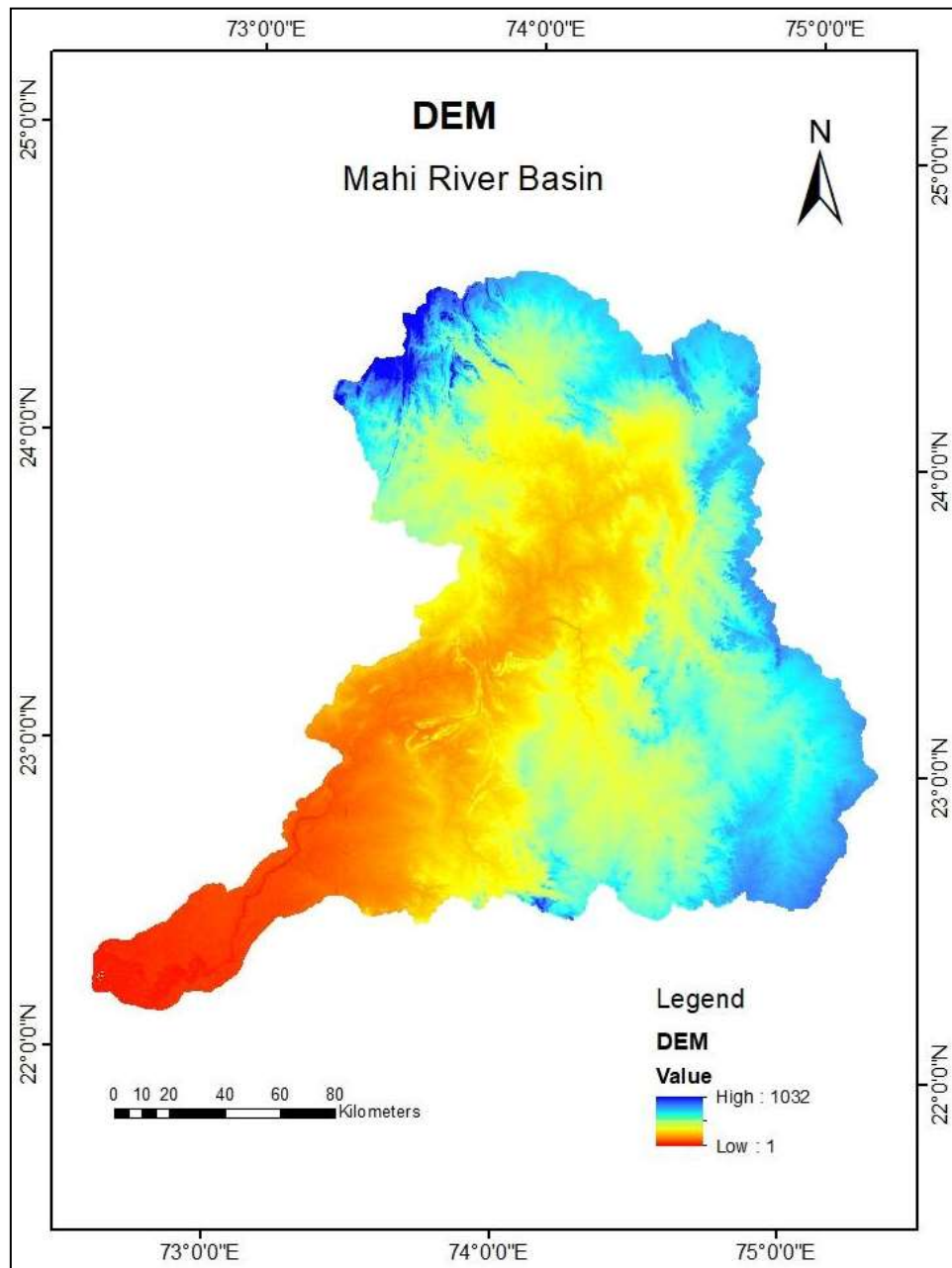


Figure 5.10 DEM for Mahi basin

5.2.2 Contour Map

The contour map (30m resolution) has been prepared for Mahi River basin. Contour interval of 30m has been used. ASTER DEM is used for contour map generation (Figure 5.11).

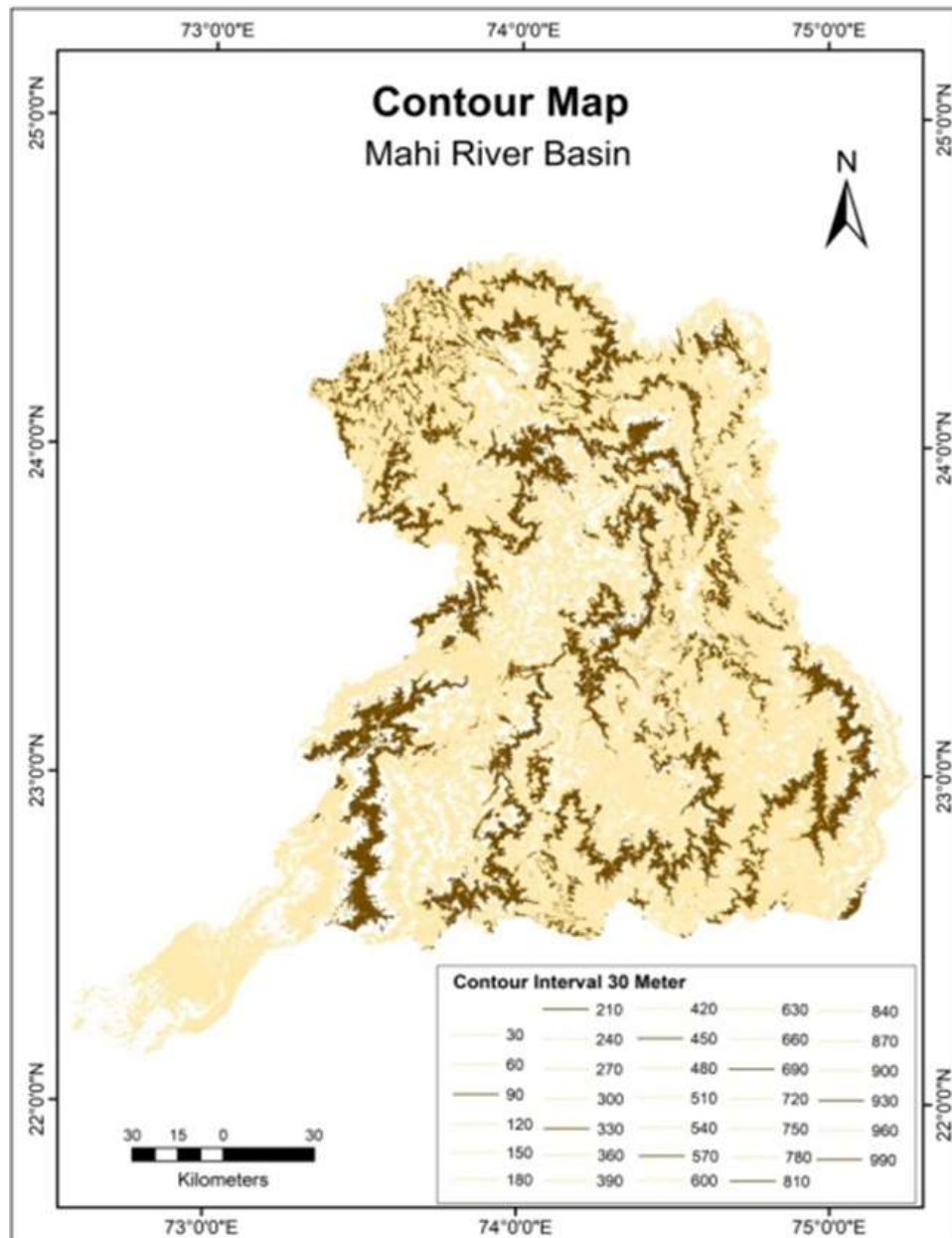


Figure 5.11 Contour map for Mahi basin

5.2.3 Raingauge Stations

The rain gauge stations have been digitized for the Mahi River basin. The observed rainfall data has been collected from IMD Pune. The rain gauge station point map has been digitized with the help of latitude and longitude data given in the IMD data source (Figure 5.12).

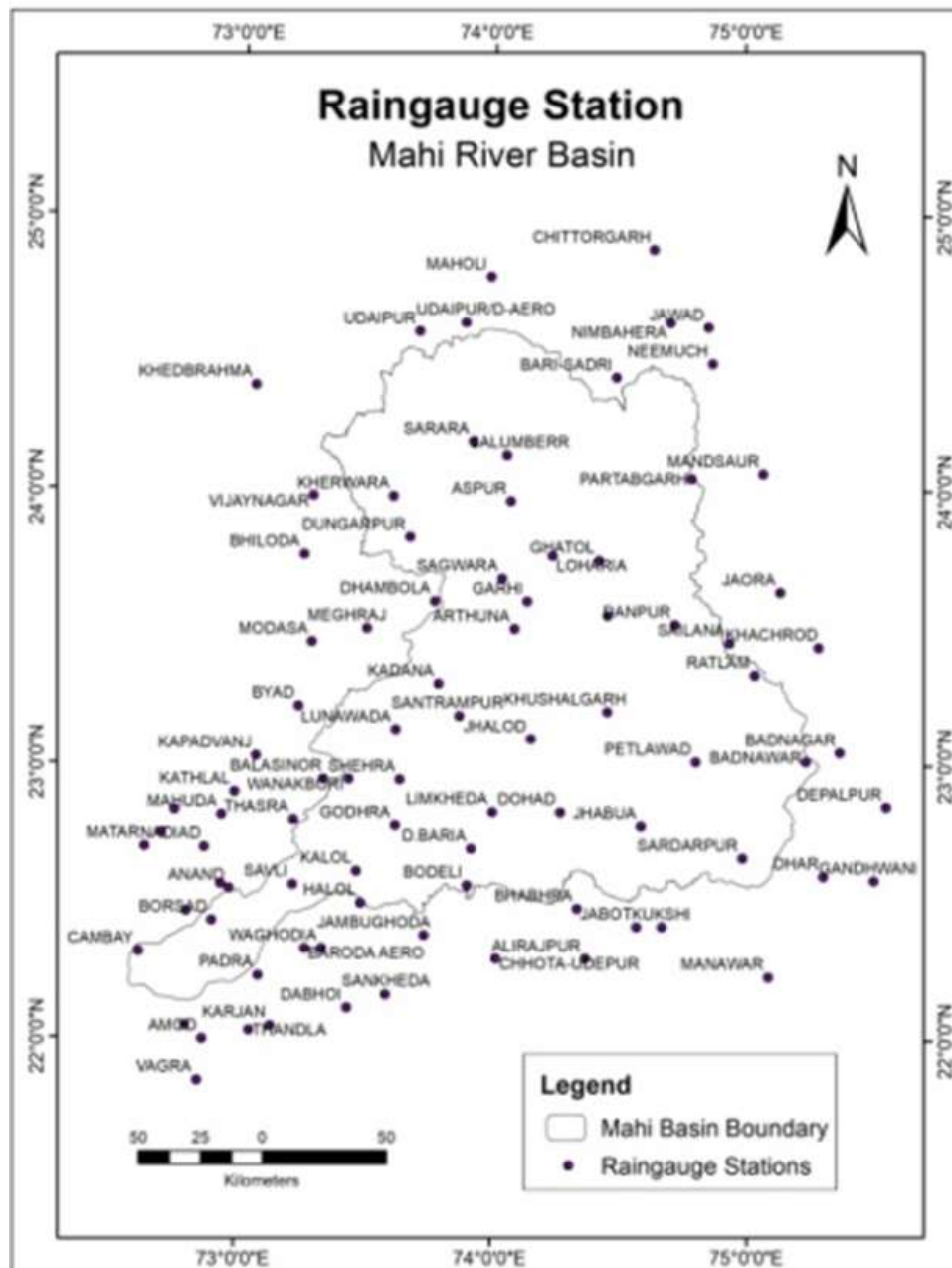


Figure 5.12 Rain gauge stations for Mahi basin

5.2.4 Slope Map

The slope map has been prepared for Mahi River basin (Figure 5.13). It has been classified into six categories i.e. Very gentle, Gentle, Moderate, Moderately steep, Steep and Very steep (Table 5.1).

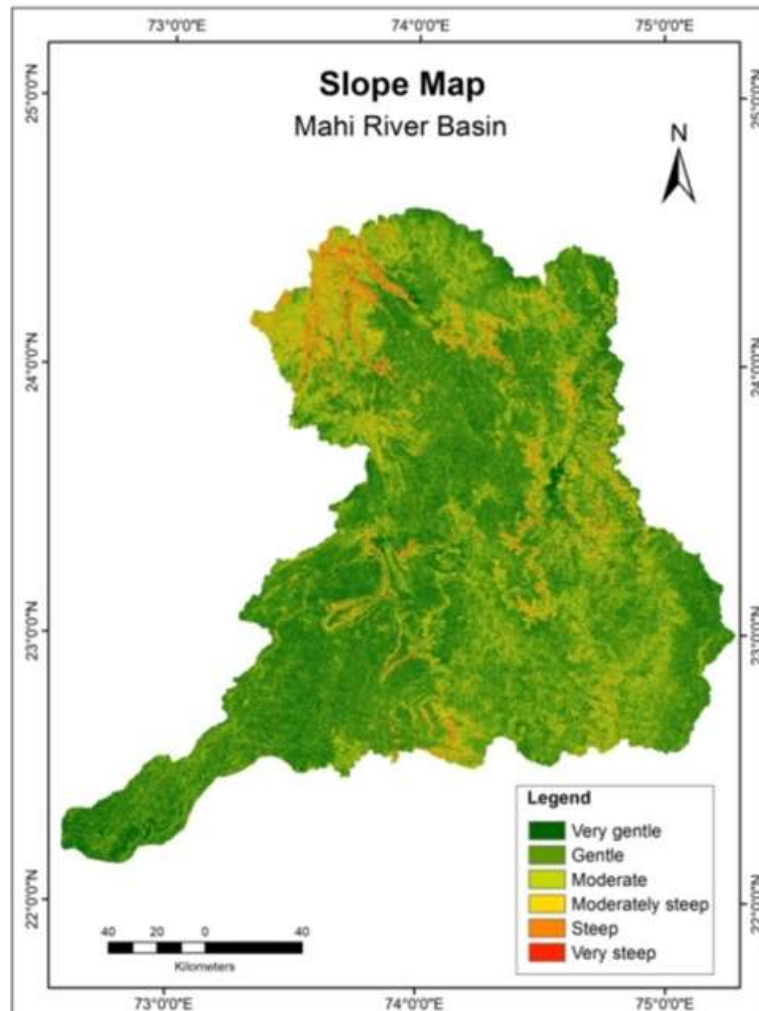


Figure 5.13 Slope map for Mahi basin

Table 5.1 Slope classification

S.no.	Range (in degrees)	Category
1	0 to 5	Very Gentle
2	5 to 10	Gentle
3	10 to 15	Moderate
4	15 to 25	Moderately Steep
5	25 to 35	Steep
6	>35	Very Steep

5.2.5 Drainage Details

The drainage with stream details has been prepared which contains the information of first, second, third, fourth, fifth and sixth order drains for Mahi River basin (Figure 5.14) (Table 5.2).

Table 5.2 Details of streams

Stream order	Number of streams	Total Length (m)
1	1092	4973647.92
2	511	2408743.91
3	268	1201301.14
4	138	492358.74
5	70	220549.21
6	90	316703.39

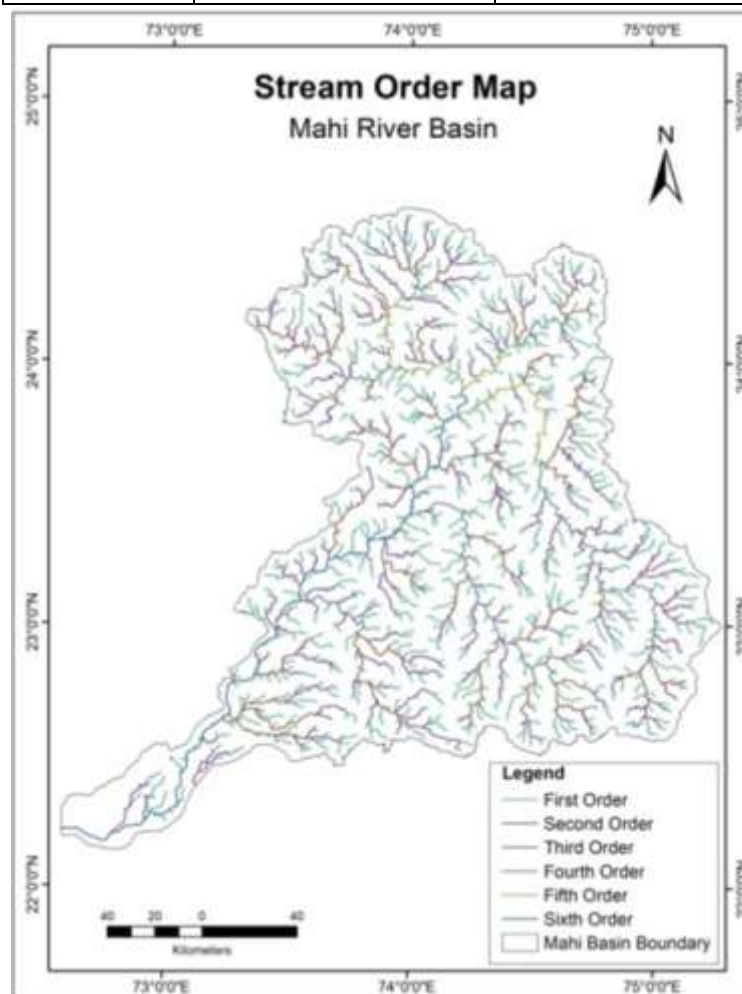


Figure 5.14 Stream order map for Mahi basin

Table 5.3 Land use/ Land Cover change over the years

	Area (Hectare)									
	1977	1990		1995		2000		2010	2015	
Class Name	Rabi	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Kharif	Rabi	Kharif
Agricultural Land	234758	343081	987794	505391	934155	639489	1026107	1118757	847775	1089151
Agricultural Fallow Land	684072	924054	326014	997546	600478	1021928	631129	670836	1034118	817124
Barren Land	816428	639489	549626	465684	432943	441651	405427	316261	340991	300936
Barren Rocky Area	718206	632174	633916	625905	608141	574007	557637	463594	434337	430505
Built up Settlement	6966	10101	10101	10449	10797	12539	13236	14977	17764	18460
Built up Paved	12539	16022	17067	17764	18460	21247	21943	45280	65133	66178
Shrub Land	279689	287004	222567	291183	258443	304071	272375	325317	347260	312778
River Sand	36224	32741	32741	21943	27168	23336	29258	23685	18808	17067
Water body	71054	60953	81155	78717	92998	51549	76975	114592	85683	103795
Forest	623118	537435	622073	468471	499470	393237	448966	389754	291183	327059

5.3 Area of Inland Drainage (AID)

5.3.1 Area of Inland Drainage Boundary

Area of Inland Drainage boundary (Figure 5.15) has been delineated using DEM and validated with topographic maps. ASTERDEM is downloaded from USGS (<https://earthexplorer.usgs.gov>). Using Arc-Hydro Tool the basin boundary has been delineated. Then it is checked and validated by checking the ridge line in topographic maps. The spatial resolution of ASTER DEM is 30m.

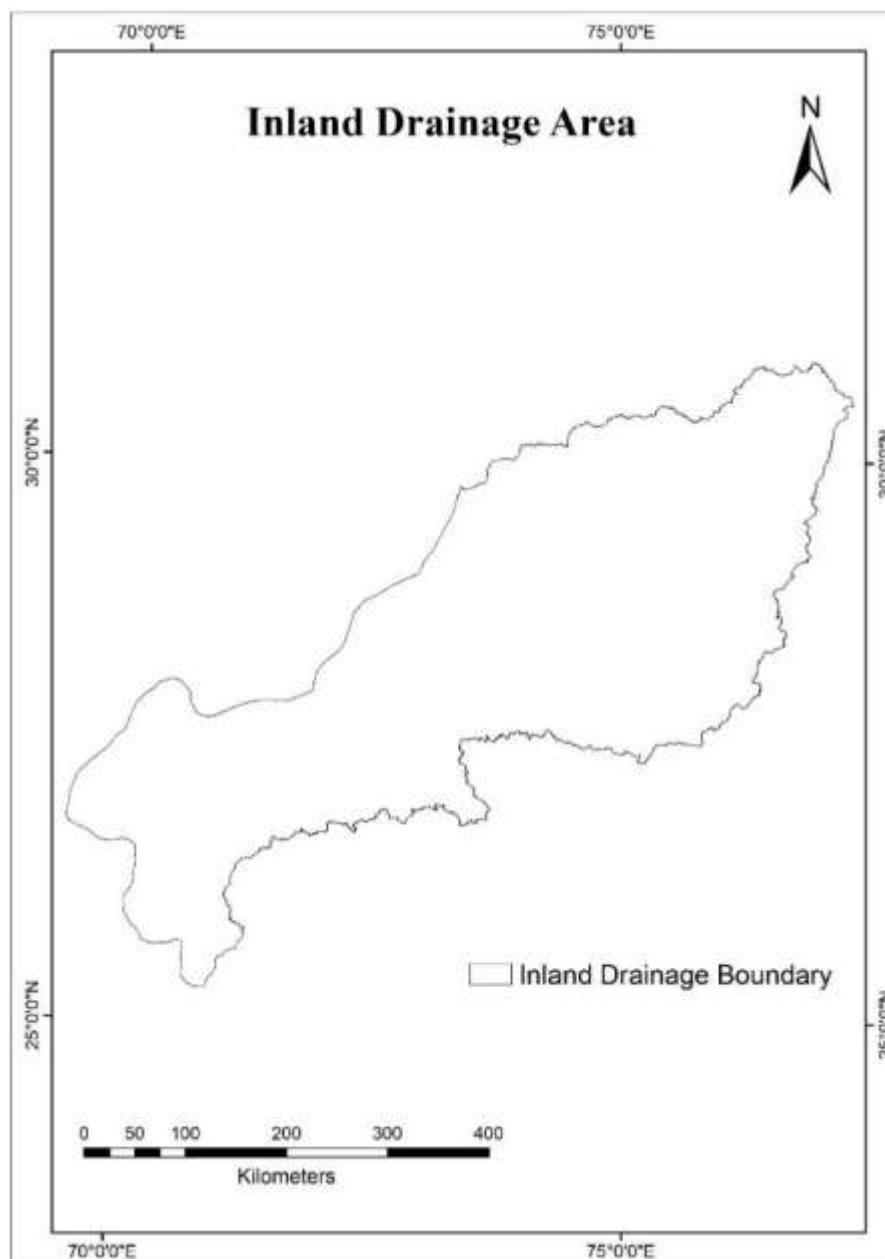


Figure 5.15 Area of Inland Drainage boundary

5.3.2 Drainage Network of AID

Drainage network of AID as shown in Figure 5.16. It is generated by the DEM 30m.

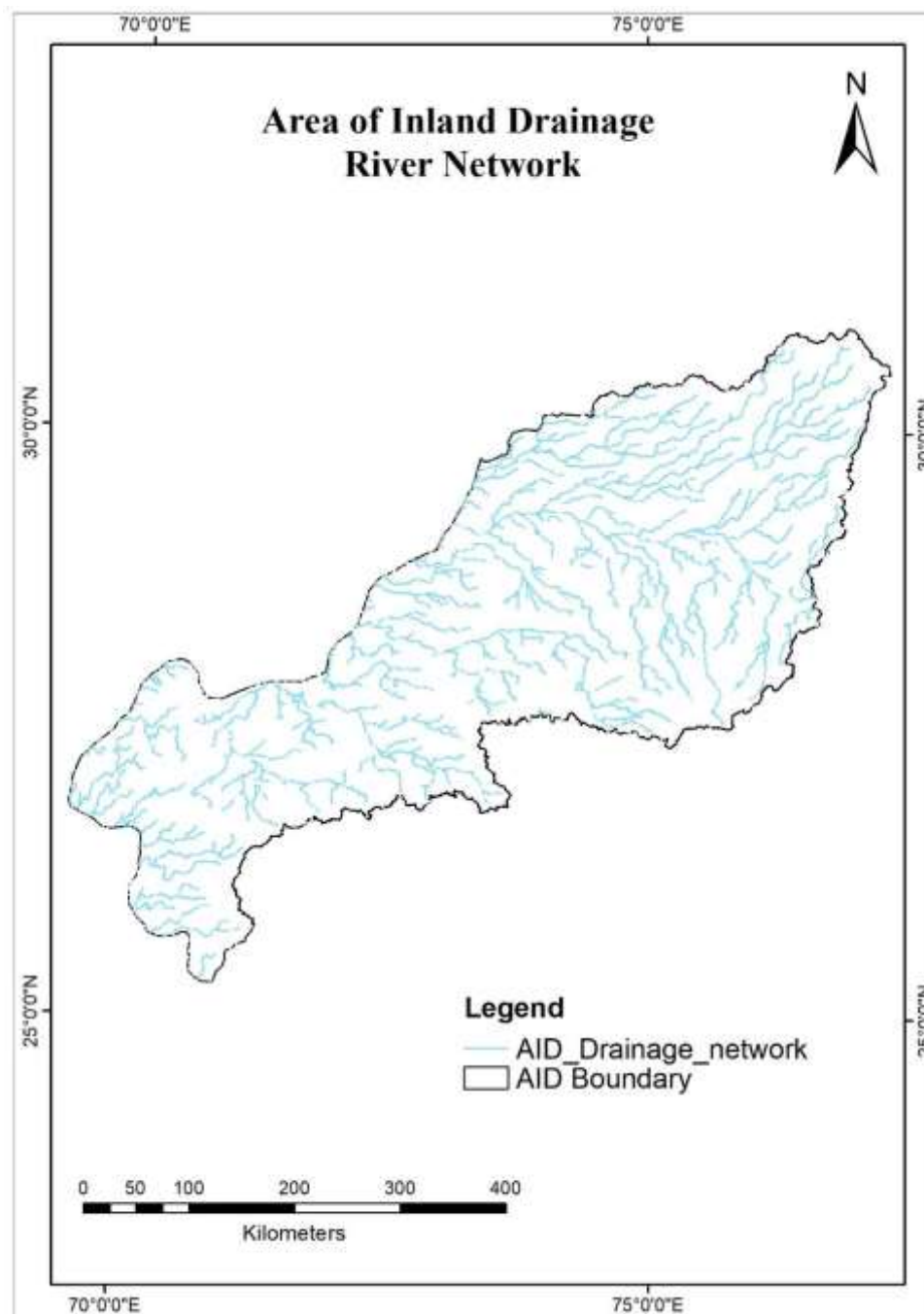


Figure 5.16 Drainage Network of AID

5.3.3 Digital Elevation Map

Digital elevation model obtained from the USGS. It has Maximum value of elevation 1915meter and minimum value of elevation 11 meter (Figure 5.17).

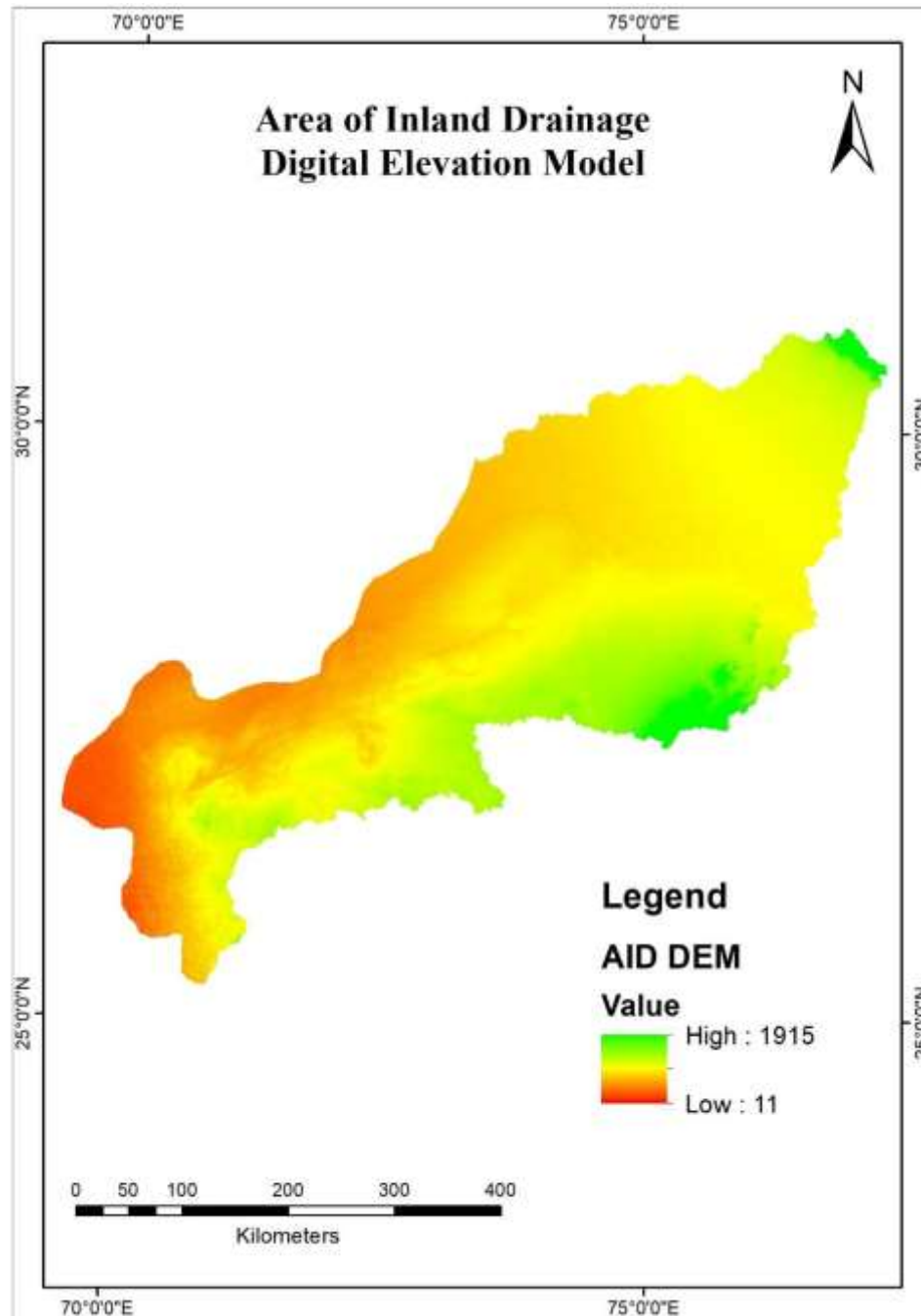


Figure 5.17 Digital elevation Map of AID

5.3.4 Sub basin map of AID

Sub basin map generated by SWAT Model and divided sub basin according to their size.

There are 18 sub basins generated. Sub basin map shown in Figure 5.18

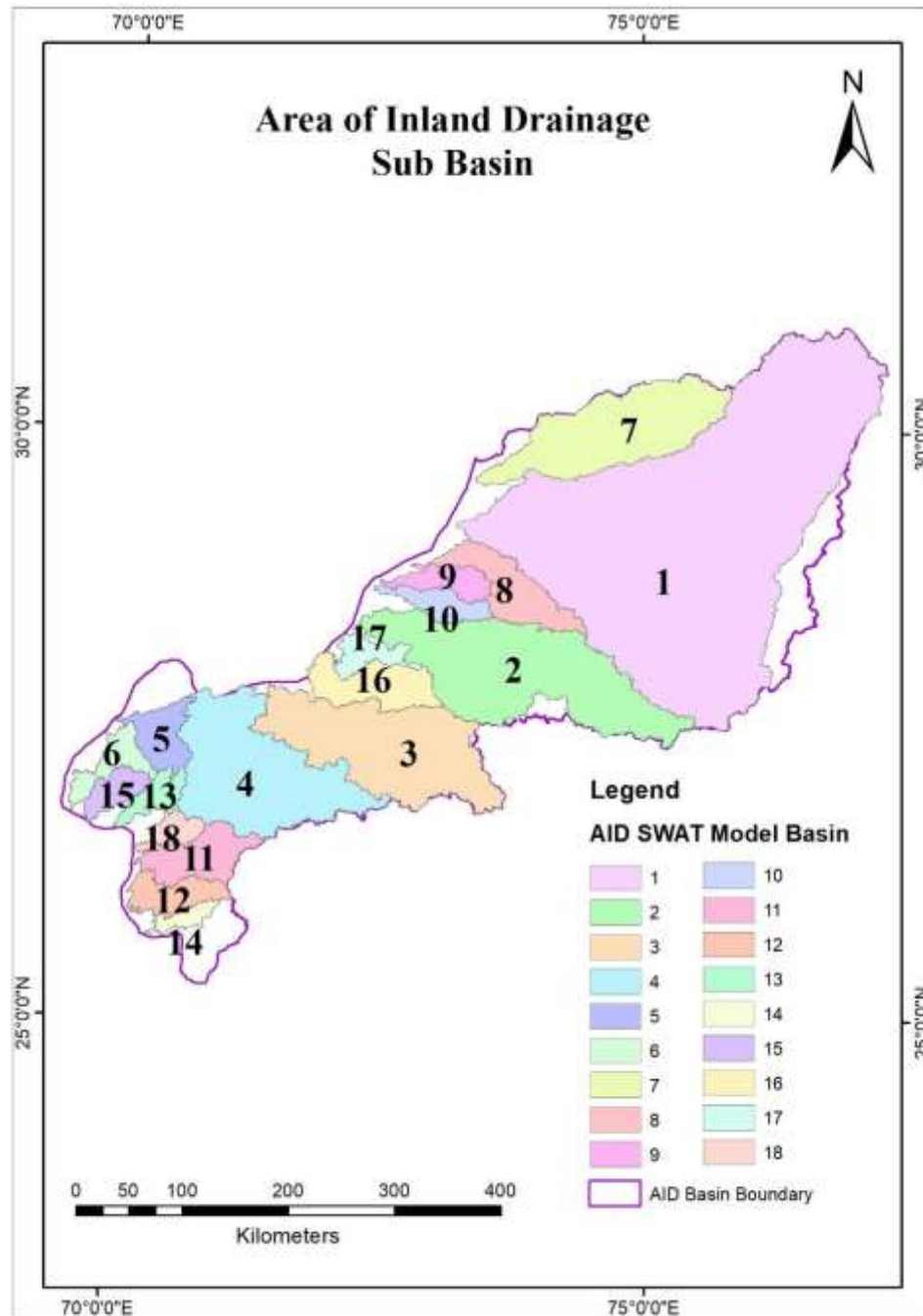


Figure 5.18 Sub basin location map of AID

5.3.5 Slope Map of AID

Slope Map generated using 30-meter DEM. Slope map shown in Figure 5.19. There are 5 classes according to their elevation. It is generated by the percentage rise method.

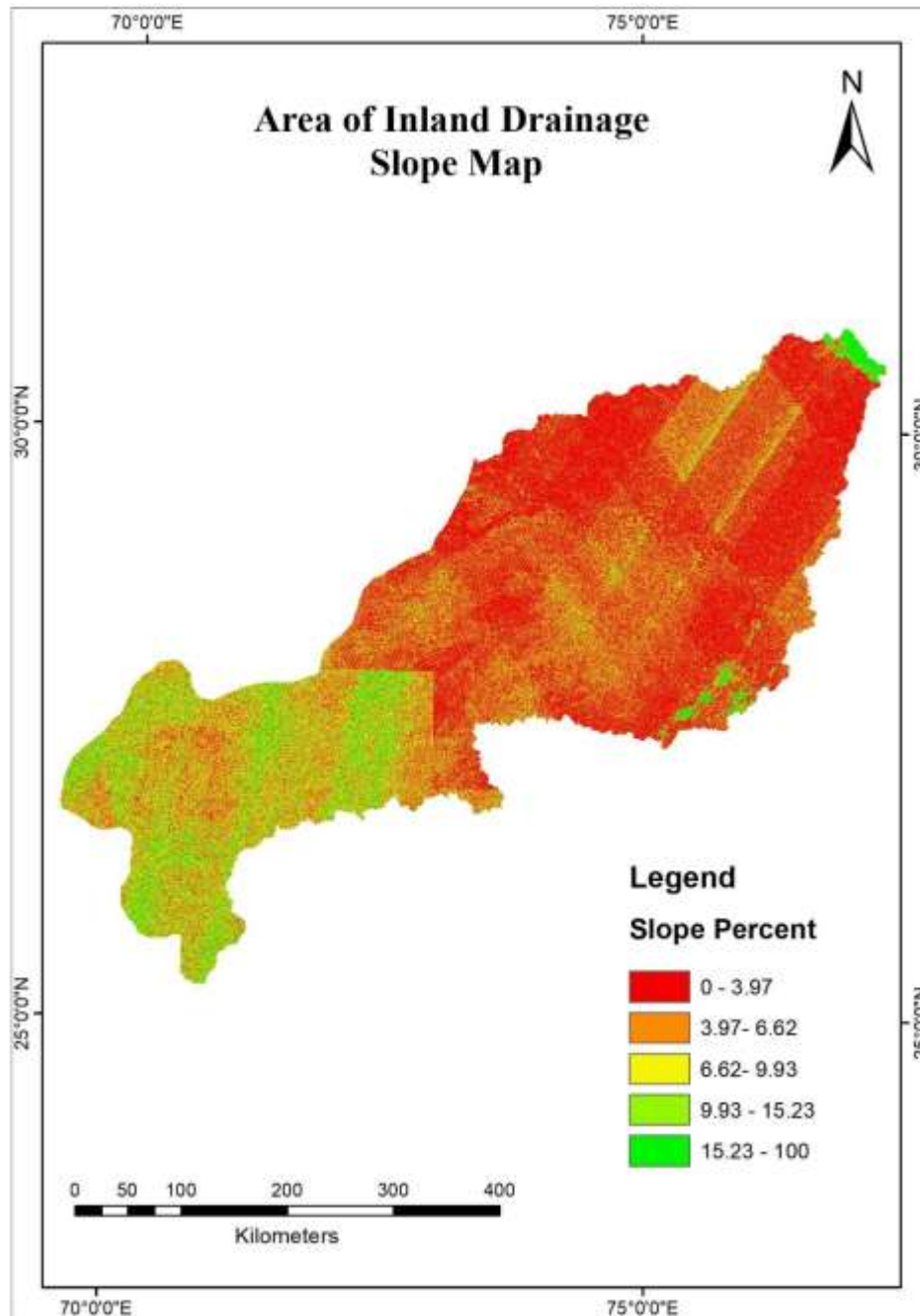


Figure 5.19 Slope map of AID

5.3.6 Soil Map of AID

Soil map generated by FAO Data. It has 20 classes of soil. Soil map shown in Figure 5.20

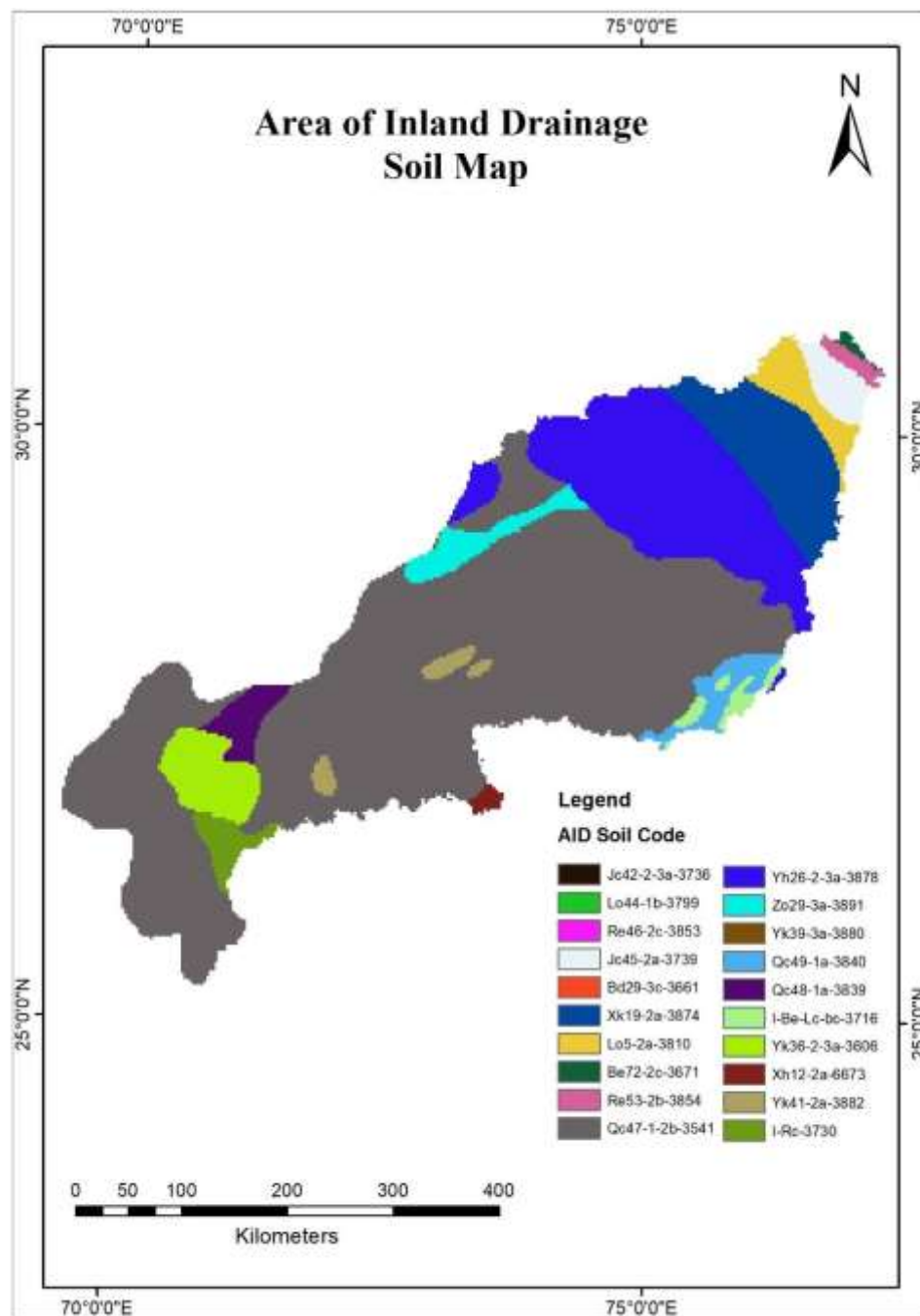


Figure 5.20 Soil Map of AID

5.3.7 LULC of AID

Landuse and landcover map shown in Figure 5.21. It has eight classes which are well distributed in the AID area. The Table 5.4 represents the land use land cover area during 2000 and 2018 for AID area.

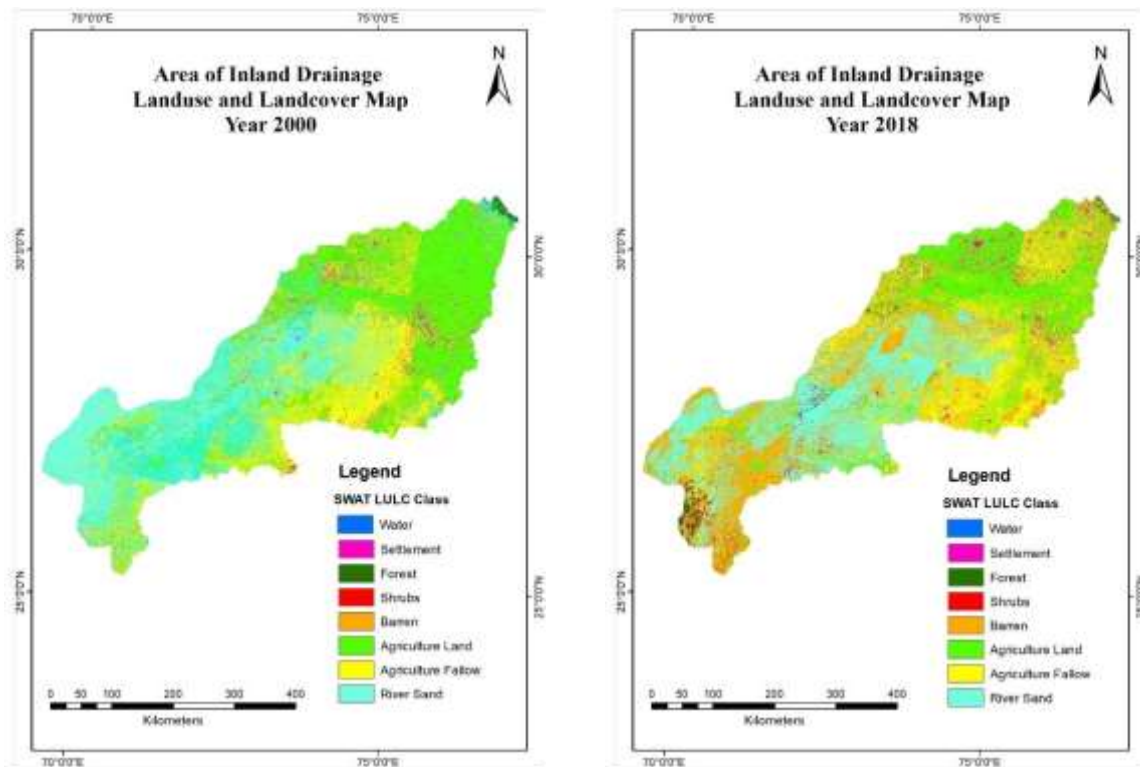


Figure 5.21 Land use and landcover map

Table 5.4 Land use and landcover Area distribution in Year 2000 and Year 2018

SWAT Classes	LULC 2000 Area (Sq.KM)	Area LULC 2018(Sq.KM)
Water	457.28	328.98
Built- up High	3009.33	882.79
Built- up Low	1229.65	3335.72
Forest	2249.52	913.34
Shrub	3509.27	992.25
Barren Land	43465.30	32796.15
Agriculture	38601.69	51531.99
Agriculture fallow land	38959.75	46398.90
River sand	48443.75	42745.71

Table 5.5 Soil Classification of AID Area

S. N O	SOIL Code	SOIL Name	Texture	HSG	Clay (%)	SILT (%)	Sand (%)	Rock (%)
1	3736	Qc47-1-2b-3541	LOAMY_SAND	C	9	12	79	0
2	3799	Yk36-2-3a-3606	CLAY_LOAM	D	30	35	35	0
3	3853	Bd29-3c-3661	CLAY_LOAM	C	37	33	30	0
4	3739	Be72-2c-3671	LOAM	D	22	36	42	0
5	3661	I-Be-Lc-b-3716	LOAM	C	23	32	45	0
6	3874	I-Rc-3730	LOAM	D	25	40	35	0
7	3810	Jc42-2-3a-3736	CLAY_LOAM	D	29	44	27	0
8	3671	Jc45-2a-3739	LOAM	D	19	44	37	0
9	3854	Lo44-1b-3799	SANDY_LOAM	C	13	9	78	0
10	3541	Lo5-2a-3810	LOAM	D	21	36	43	0
11	3878	Qc48-1a-3839	SANDY_LOAM	C	12	15	73	0
12	3891	Qc49-1a-3840	SANDY_LOAM	C	14	32	54	0
13	3880	Re46-2c-3853	LOAM	C	21	34	45	0
14	3840	Re53-2b-3854	LOAM	C	21	32	47	0
15	3839	Xk19-2a-3874	LOAM	D	26	44	30	0
16	3716	Yh26-2-3a-3878	LOAM	D	26	30	44	0

17	3606	Yk39-3a-3880	SANDY_CLAY_LOAM	D	28	22	51	0
18	6673	Yk41-2a-3882	LOAM	D	27	39	34	0
19	3882	Zo29-3a-3891	CLAY_LOAM	D	35	39	26	0
20	3730	Xh12-2a-6673	SILT_LOAM	D	21	55	25	0

(Source: Harmonized world soil Database v1.2, FAO UNESCO soil map of the world (FAO 1971-1981))

Area of inland drainage is covered by 20 types of soils which is obtained from the FAO database. In the AID area database mainly clay loam, sandy clay loam, loam soil, silt loam, sandy loam and loam sand soil are distributed over the basin of AID. In the Table no.5.4 composition of different components of soil are provided and associated code of soil listed which is used in SWAT Modeling of the AID area. Most dominant soil type is Qc47-1-2b-3541 which covered 56.81% of the total area. Soil type Yh26-2-3a-3878 is spread by 15.94% of the total area and the rest of all other types of soil distributed well in the AID area.

Chapter 6: Time Series Analysis

Spatial and temporal time series analysis

6.1 Mahi River Basin

Spatial Distribution of Annual Mean Precipitation, maximum temperature and minimum temperature projected by MME during Historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under RCP4.5 and RCP8.5 scenarios is analysed.

6.1.1 Spatial distribution of Annual mean Precipitation

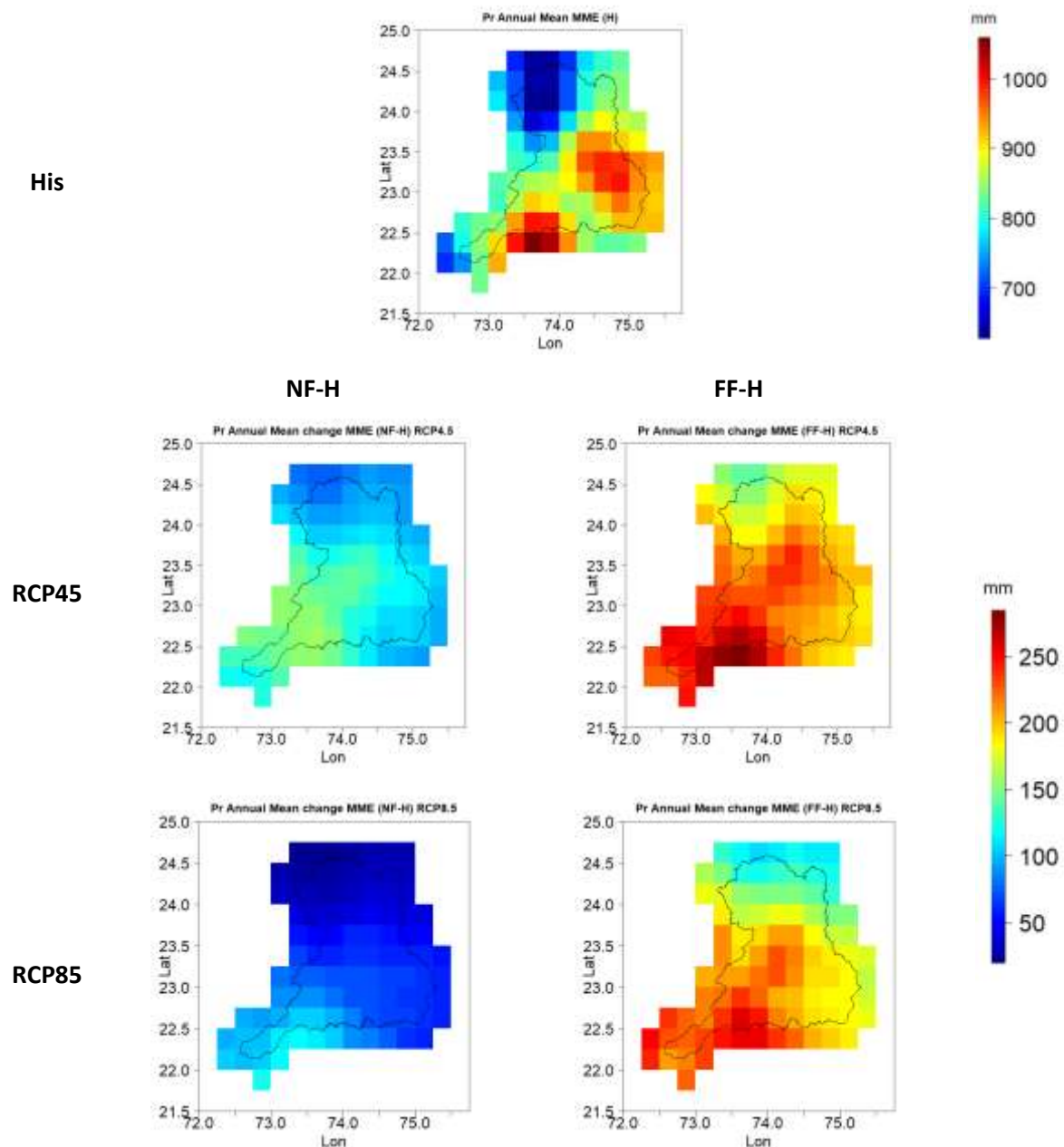


Figure 6.1 Spatial distribution of annual mean precipitation projected by MME during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

Table 6.1 Annual mean precipitation during Historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) of RCP4.5 and RCP8.5 scenarios.

Precipitation (mm)			
		NF	FF
His	843.23(631.85,1056.2)		
RCP4.5		117.33(74.05,160.24)	211.59(142.96,282.73)
RCP8.5		63.23(21.89,120.07)	188.50(109.53,256.55)

Figure 6.1 shows the mean annual precipitation during the historical period (1981-2005) and the relative changes during Near Future (NF) (2021-2045) and Far Future (FF) (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual precipitation during the historical period was 843.23mm which is projected to increase by 117.33 and 211.59mm during NF and FF period of RCP4.5 scenarios (Table 6.1). While it is projected to increase by 63.23mm (NF) and 188.50mm (FF) under RCP8.5. It is projected to increase less in RCP8.5 scenario as compared to RCP4.5 scenario in both NF and FF period. The lower sub-basin area is projected to have large changes as compared to other areas of the basin. The area of high rainfall during the historical period is projected to impact more as compared to other areas of Mahi River Basin.

6.1.2 Spatial distribution of Annual mean of Maximum Temperature (Tasmax)

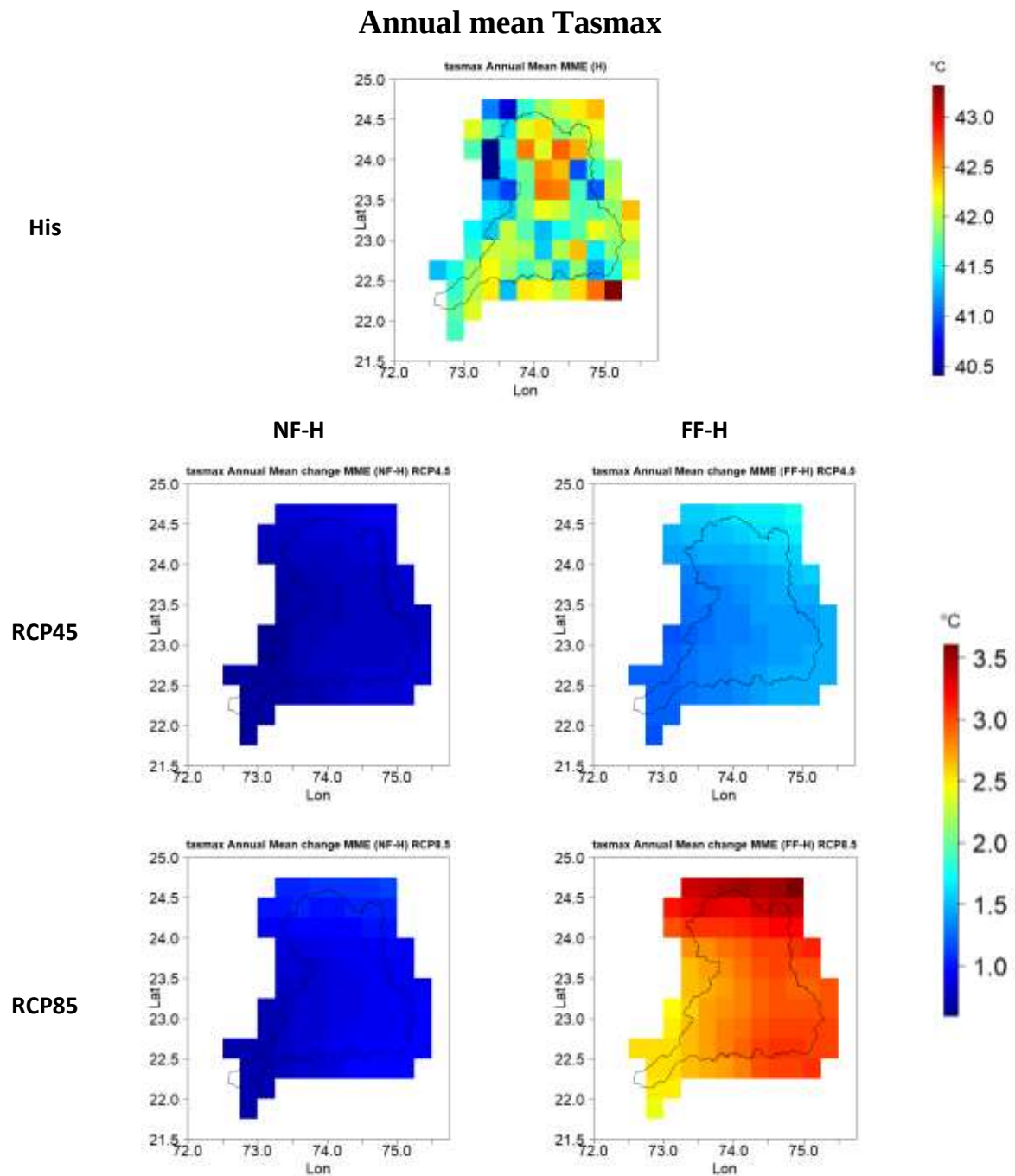


Figure 6.2 Spatial distribution of mean annual maximum temperature projected by MME over Mahi River Basin during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

Table 6.2 Spatial variation range and mean of annual maximum temperature during Historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) of RCP4.5 and RCP8.5 scenario.

Annual mean Maximum Temperature (Tasmax) (°C)			
		NF	FF
His	41.82(40.42,43.29)		
RCP45		0.75(0.62,0.92)	1.41(1.18,1.72)
RCP85		0.88(0.70,1.13)	2.94(2.40,3.58)

Figure 6.2 shows the mean annual maximum temperature (tasmax) during the historical period (1981-2005) and the relative changes during the Near Future (NF) (2021-2045) and Far Future (FF) (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual maximum temperature during the historical period was 41.82°C which is projected to increase by 0.75°C and 1.41°C during NF and FF period of RCP4.5 scenarios (Table 6.2). While it is projected to increase by 0.88°C and (NF) and 2.94°C (FF) under RCP8.5. It is projected to increase more in RCP8.5 scenario as compared to RCP4.5 scenario in both NF and FF period. The warming in FF of RCP8.5 scenario will be more than two times of FF of RCP4.5 scenario. The temperature is projected to increase more in the upper Mahi River Basin as compared to other area.

6.1.3 Spatial distribution of Annual mean of Minimum Temperature

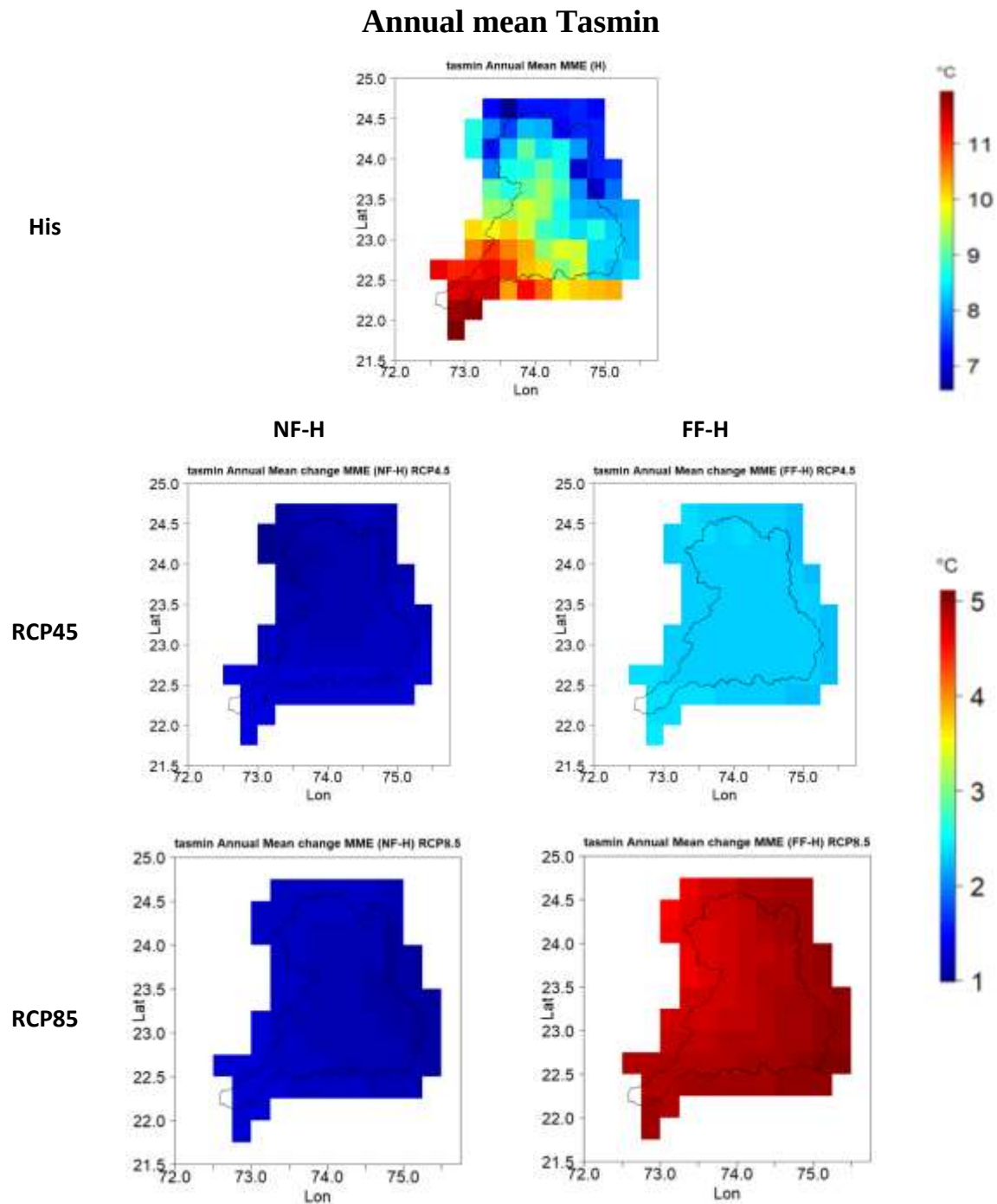


Figure 6.3 Spatial distribution of mean annual minimum temperature projected by MME over Mahi River Basin during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

Table 6.3 Spatial variation range and mean of Annual minimum temperature during historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099).

Annual mean Minimum TemperatureTasmin (°C)			
		NF	FF
His	9.02 (6.60,11.90)		
RCP45		1.13 (1.02,1.24)	2.30 (2.22,2.41)
RCP5		1.11 (1.04,1.18)	4.87 (4.58,5.08)

The Figure 6.3 shows the mean annual minimum temperature (tasmin) during historical period (1981-2005) and the relative changes during Near Future (2021-2045) and Far Future (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual maximum temperature during historical period was 9.02°C which is projected to increase by 1.13°C and 2.30°C during NF and FF period of RCP4.5 scenarios (Table 6.3). While it is projected to increase by 1.11°C and (NF) and 4.87°C (FF) under RCP8.5. It is projected to increase more in RCP8.5 scenario as compared to RCP4.5 scenario in FF period due to high warming rate in this scenario. The warming in NF of both scenario is almost equal but during FF of RCP8.5 scenario it will be more than two times of FF of RCP4.5 scenario. It is found to increase more as compared to mean annual maximum temperature under both scenarios.

6.2 Time Series Analysis

Annual time series were analysed using different non-parametric statistical techniques Mann–Kendall (MK) test, modified Mann-Kendall (MMK) test, Theil–Sen slope estimator test and Pettitt-t test for Mahi River basin. The MK test is used to detect trends in time series (Mann 1945; Kendall 1975) when the autocorrelation is non-significant. The MMK test was used to identify the trend in the presence of autocorrelation in the series. The MK (and MMK) test statistic ‘Z (and Zc)’ represents the trend. A positive value of Z (and Zc) indicates an increasing trend and negative value of ‘Z (and Zc)’ indicates decreasing trend. The annual magnitude of the trend is determined by Theil–Sen slope estimator test (Sen 1968). The Pettitt-t test gives the major change point in the given time series.

6.2.1 Trend Analysis of mean annual Precipitation

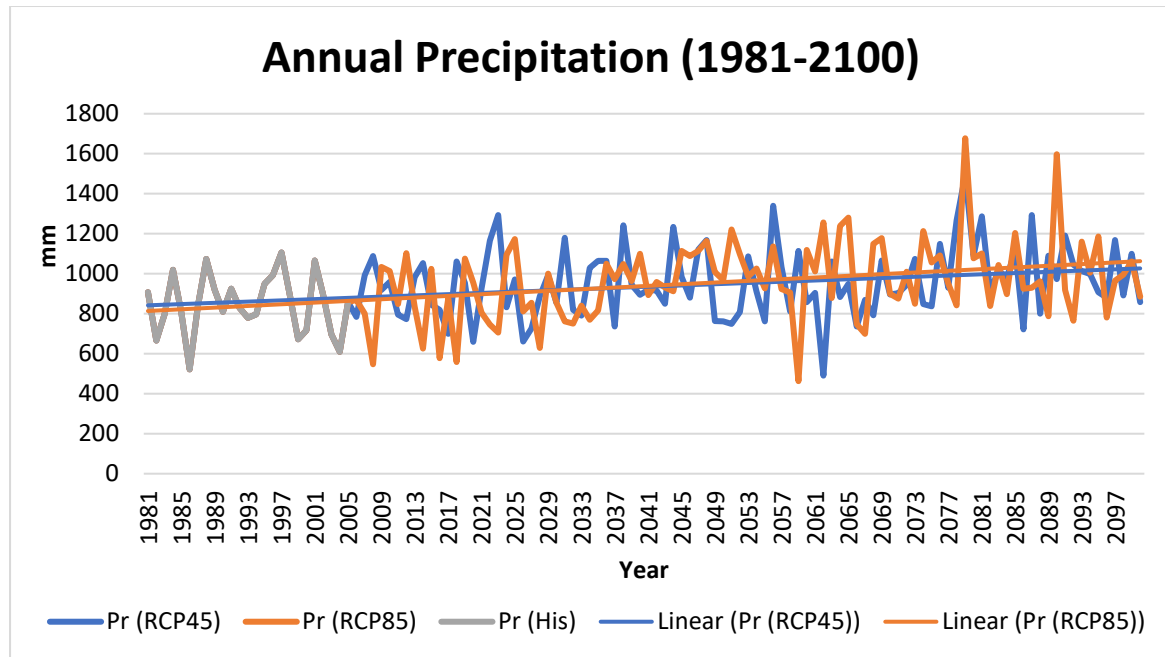


Figure 6.4 Time series of annual precipitation over Mahi River Basin during Historical (1981-2005) and long-term future (2006-2100)

Table 6.4 Trend analysis statistics for annual precipitation in Mahi River Basin during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenarios.

Annual Precipitation Trend Statistics					
		Z/Zc	P/Pc	SS/Dec (mm)	t
His	His	-0.29	0.77	-7.72	1998
RCP4.5	ALL (H+RCP4.5)	11.13	0.00	14.50	2033
	NF45	1.08	0.28	24.68	2033
	FF45	-2.68	0.00	-57.67	2081
RCP8.5	ALL (H+RCP8.5)	8.09	0.00	18.50	2035
	NF85	8.09	0.00	18.50	2035
	FF85	-1.71	0.09	-23.29	2081

Figure 6.4 shows the time series of mean annual precipitation in Mahi River basin during the Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenarios. Table 6.4 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Z_c ; P/P_c , for trend detection), Sen's slope estimator test (SS/Decade, for trend magnitude) and Pettit-t test (t , change point) in the time series. The historical period shows a non-significant decreasing trend but the future projection of long-term shows a significant increasing trend under both RCPs. It will increase with a rate of 14.50mm/decade (RCP4.5) and 18.50mm/decade (RCP8.5).

6.2.2 Trend Analysis of mean annual Maximum Temperature (Tmax)

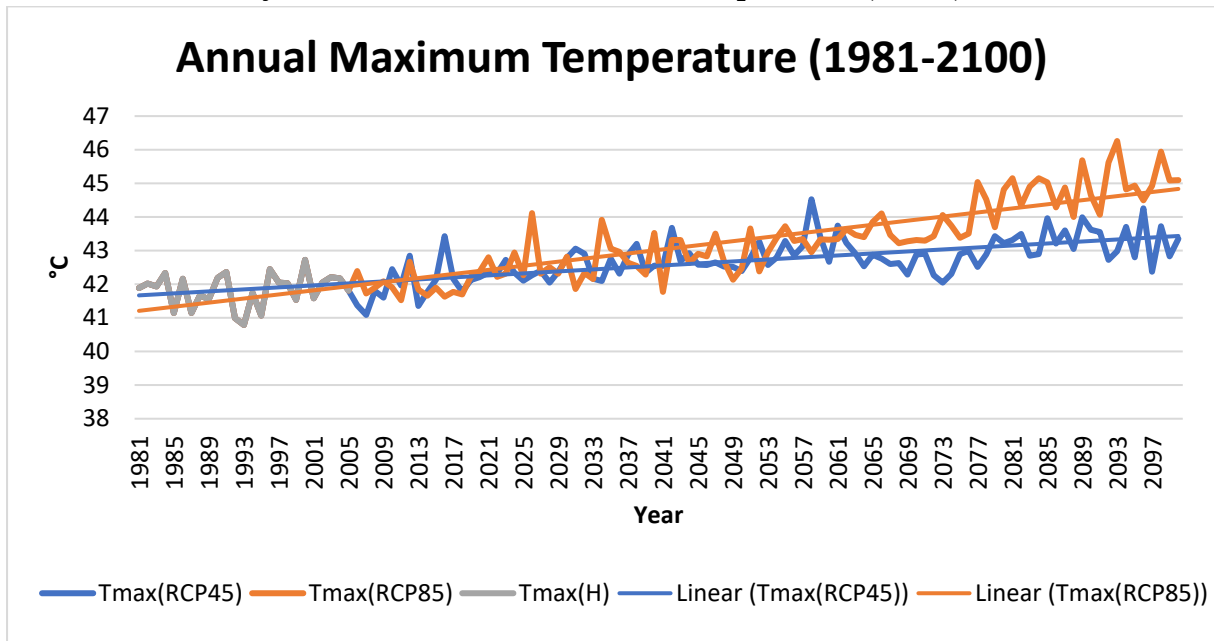


Figure 6.5 Time series of mean annual maximum temperature over Mahi River Basin during Historical (1981-2005) and long-term future (2006-2100)

Table 6.5 Trend analysis statistics for mean annual maximum temperature in Mahi River Basin during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenario

Annual Tmax Trend Statistics					
		Z/Zc	P/Pc	SS/Dec (°C)	t
His	His	1.83	0.07	0.08	1995
RCP45	ALL (H+RCP45)	17.15	0.00	0.14	2029
	NF45	5.38	0.00	0.18	2029
	FF45	2.12	0.03	0.15	2084
RCP85	ALL (H+RCP85)	10.44	0.00	0.30	2041
	NF85	3.60	0.00	0.15	2033
	FF85	6.88	0.00	0.48	2091

The figure 6.5 shows the time series of mean annual maximum temperature in Mahi River basin during the Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenarios. The Table 6.5 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Z_c ; P/P_c , for trend detection), Sen's slope estimator test ($SS/Decade$, for trend magnitude) and Pettit-t test (t , change point) in the time series. The historical period shows a non-significant increasing trend and the future projection of long-term shows significant increasing trend under both RCPs. It is projected to increase by $0.14^{\circ}\text{C}/\text{dec}$ and $0.30^{\circ}\text{C}/\text{dec}$ during the long term period of RCP4.5 and RCP8.5 scenarios, respectively. The change point in RCP4.5 will be 2029 while it will be 2091 for RCP8.5 scenario for long-term period.

6.2.3 Trend Analysis of mean annual minimum Temperature

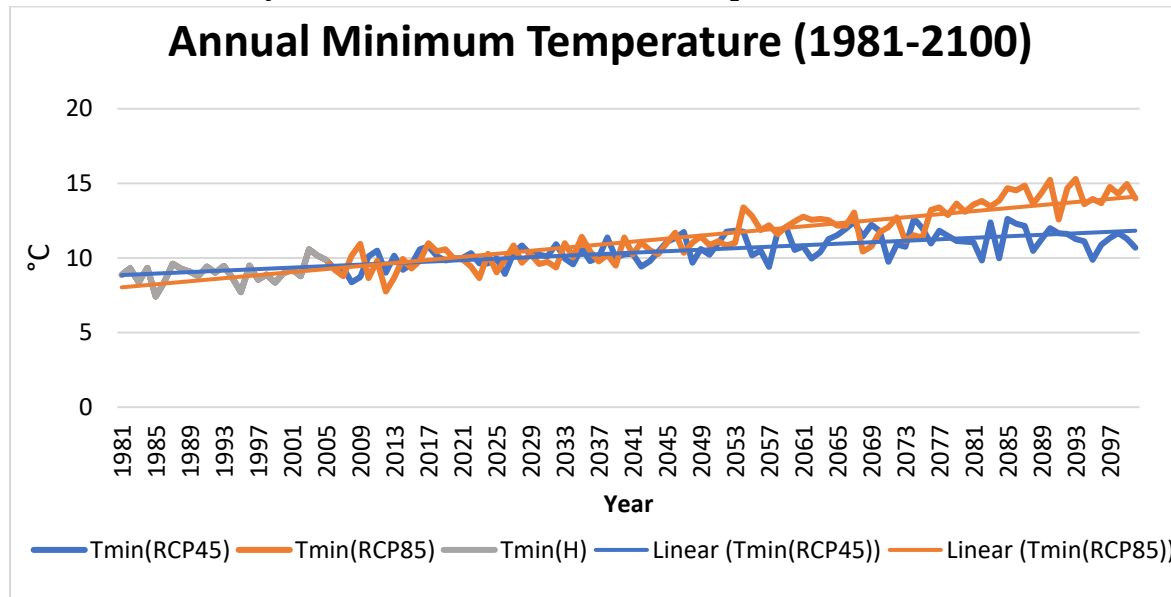


Figure 6.6 Time series of mean annual minimum temperature over Mahi River Basin during Historical (1981-2005) and long-term future (2006-2100)

Table 6.6 Trend analysis statistics for mean annual minimum (Tmin) temperature in Mahi River Basin during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenario

Annual Tmin Trend Statistics					
		Z/Zc	P/Pc	SS/Dec (°C)	t
His	His	2.41	0.02	0.25	2002
RCP45	ALL (H+RCP45)	14.47	0.00	0.25	2043
	NF45	2.77	0.01	0.14	2026
	FF45	-1.61	0.11	-0.15	2092
RCP85	ALL (H+RCP85)	11.41	0.00	0.51	2044
	NF85	10.16	0.00	0.51	2032
	FF85	6.34	0.00	0.76	2083

Figure 6.6 shows the time series of mean annual minimum temperature in Mahi River basin during the Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenario. Table 6.6 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Zc; P/Pc, for trend detection), Sen's slope estimator test (SS/Decade, for trend magnitude) and Pettit-t test (t, change point) in the time series. The historical period and future projection of long-term period both shows a significant increasing trend under both RCPs. It is projected to increase by 0.25°C/dec and 0.51°C/dec during long term period of RCP4.5 and RCP8.5 scenarios, respectively. The change point in RCP4.5 will be 2043 while it will be 2083 for RCP8.5 scenario for long-term period. The warming rate is found two times in RCP8.5 as compared to RCP4.5 scenario

6.3 Area of Inland Drainage

Spatial Distribution of Annual Mean Precipitation, maximum temperature and minimum temperature projected by MME during Historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under RCP4.5 and RCP8.5 scenarios is analysed for Area of Inland drainage.

6.3.1 Spatial distribution of Annual mean Precipitation

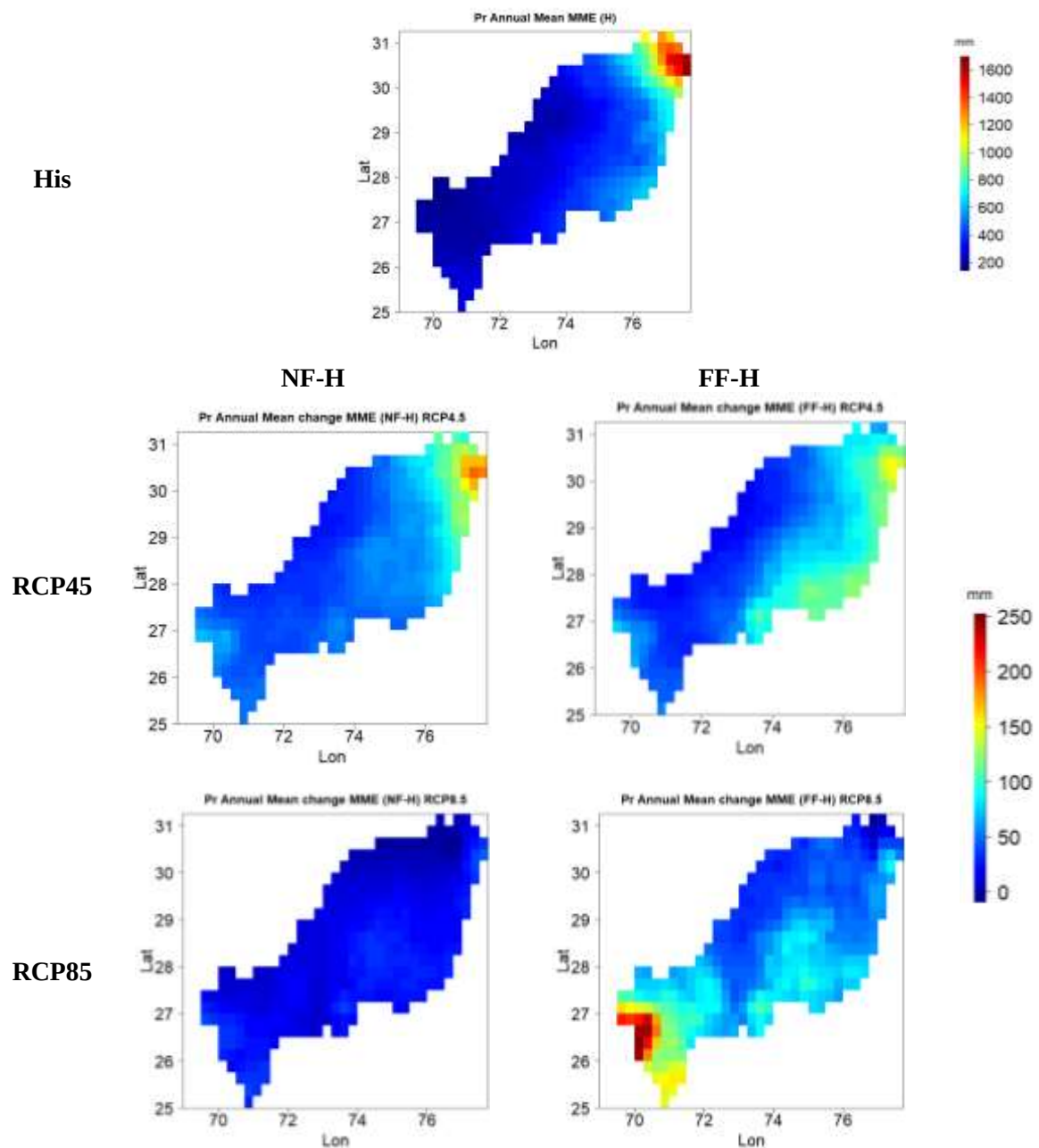


Figure 6.7 Spatial distribution of annual mean precipitation projected by MME over AID during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

The figure 6.7 shows the mean annual precipitation during historical period (1981-2005) and the relative changes during Near Future (2021-2045) and Far Future (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual precipitation during historical period was 399.35 mm which is projected to increase by 57.05 mm and 61.55 mm during NF and FF period of RCP4.5 scenarios (Table 6.7). While it is projected to increase by 18.19 mm (NF) and 69.97 mm (FF) under RCP8.5. It is projected to increase less in RCP8.5 scenario as compared to RCP4.5 scenario in NF period. The lower area is projected to have large changes as compared to other area of AID.

Table 6.7 Spatial variation range and mean of annual precipitation during historical period and relative changes in NF and FF of RCP4.5/8.5.

Precipitation (mm)			
		NF	FF
His	399.35(151.75,1682.9)		
RCP4.5		57.05(24.64,191.56)	61.55(18.56,152.51)
RCP8.5		18.19(-6.92,44.03)	69.97(7.22,250.38)

6.3.2 Spatial distribution of Annual mean of Maximum Temperature

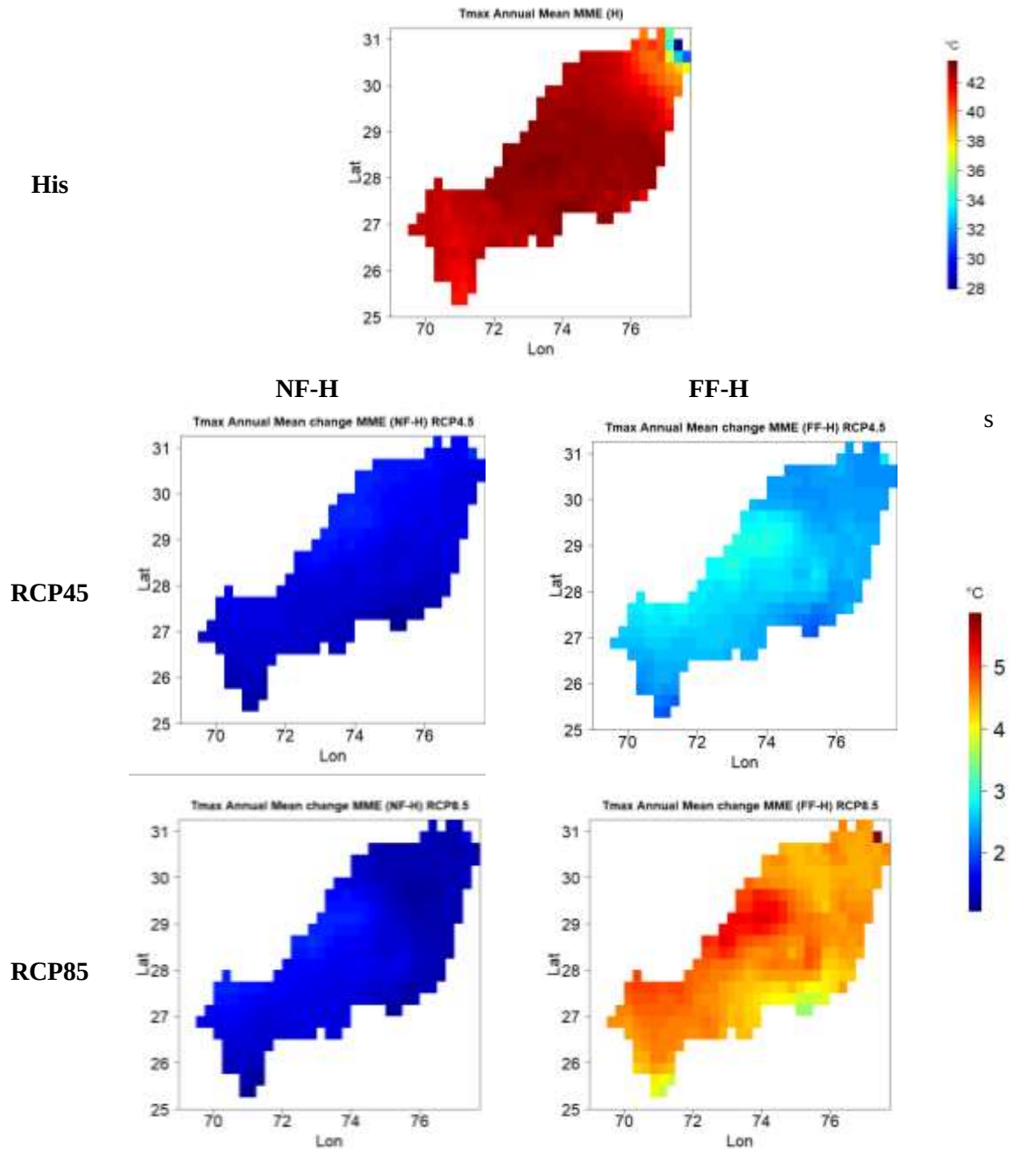


Figure 6.8 Spatial distribution of mean annual maximum temperature projected by MME over AID during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

The figure 6.8 shows the mean annual maximum temperature (tasmax) during historical period (1981-2005) and the relative changes during Near Future (NF) (2021-2045) and Far Future (FF) (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual maximum temperature during the historical period was 42.26°C which is projected to increase by 1.23°C and 2.34°C during the NF and FF period of RCP4.5 scenarios (Table 6.8). While it is projected to increase

by 1.41°C (NF) and 4.56°C (FF) under RCP8.5. It is projected to increase more in RCP8.5 scenario as compared to RCP4.5 scenario in both NF and FF period. The warming in FF of RCP8.5 scenario will be around two times of FF of RCP4.5 scenario.

Table 6.8 Spatial variation range and mean of annual maximum temperature during historical period and relative changes in NF and FF of RCP4.5/8.5.

Tasmax (°C)			
		NF	FF
His	42.26(28.05,43.32)		
RCP45		1.23(0.83,1.60)	2.34(1.77,2.84)
RCP85		1.41(1.09,1.83)	4.56(3.51,5.83)

6.3.3 Spatial distribution of Annual mean of Minimum Temperature

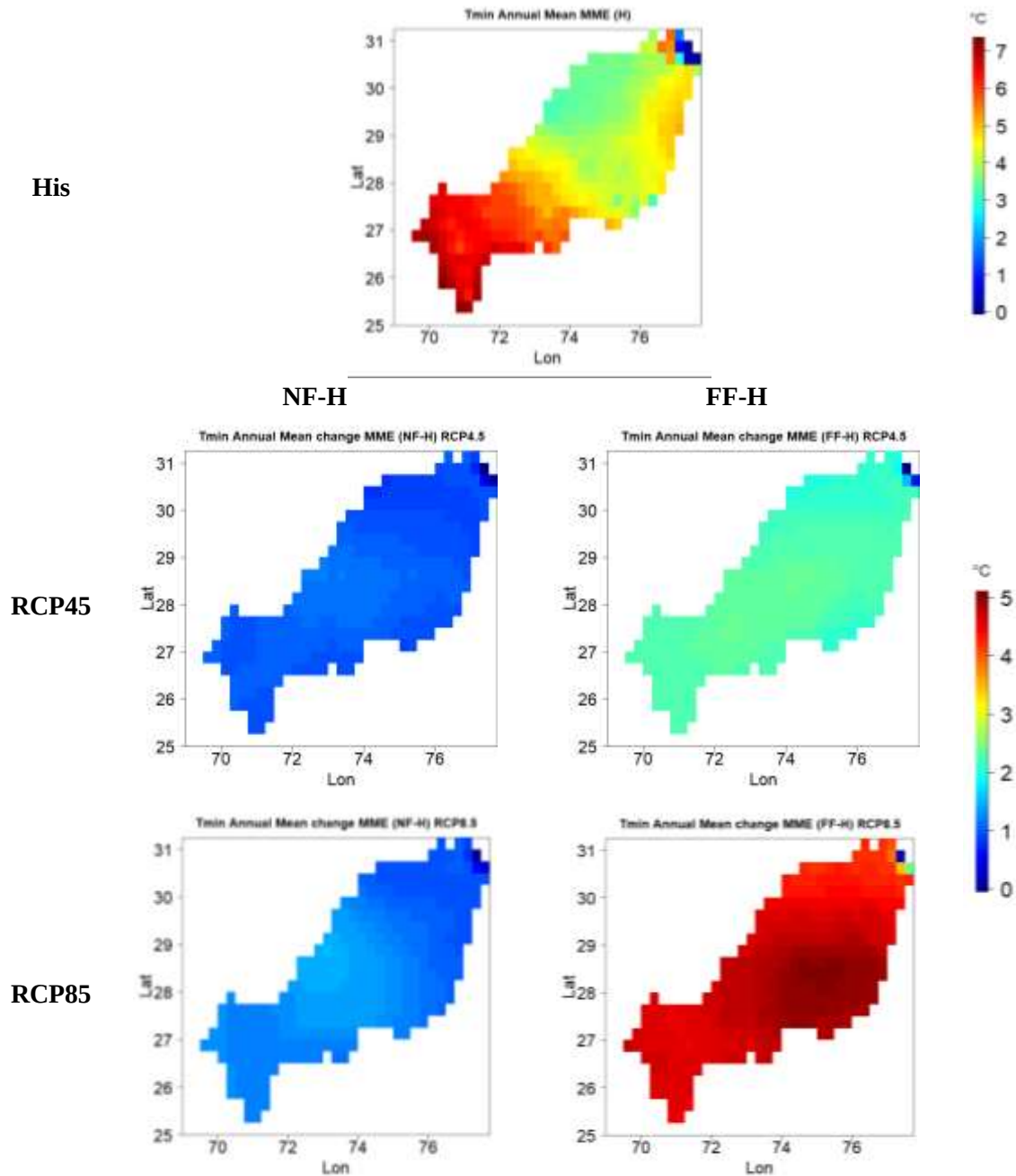


Figure 6.9 Spatial distribution of mean annual minimum temperature projected by MME over AID during the historical period (1981-2005) and relative changes during NF (2021-2045) and FF (2075-2099) under the RCP4.5 and RCP8.5 scenarios.

The figure 6.9 shows the mean annual maximum temperature (tasmin) during historical period (1981-2005) and the relative changes during Near Future (NF) (2021-2045) and Far Future (FF) (2075-2099) of RCP4.5 and RCP8.5 scenarios. The mean annual maximum temperature during historical period was 4.77°C which is projected to increase by 1.00°C and 2.21°C during NF and FF period of RCP4.5 scenarios (Table 6.9). While it is projected to increase by 1.19°C

(NF) and 4.64°C (FF) under RCP8.5. It is projected to increase more in RCP8.5 scenario as compared to RCP4.5 scenario in FF period. The warming in NF of both scenario is similar but during FF of RCP8.5 scenario it will be more than two times of FF of RCP4.5 scenario.

Table 6.9 Spatial variation range and mean of annual minimum temperature during historical period and relative changes in NF and FF of RCP4.5/8.5.

Tasmin (°C)			
		NF	FF
His	4.77(0,7.31)		
RCP4.5		1.00(0,1.19)	2.21(0,2.37)
RCP8.5		1.19(0,1.496)	4.64(0.21,5.078)

6.4 Time Series Analysis

The time series of precipitation and temperature were analysed using different non-parametric statistical techniques: Mann–Kendall (MK) test, modified Mann-Kendall (MMK) test, Theil–Sen slope estimator test and Pettitt-t test. The MK test is used to detect trends in time series (Mann 1945; Kendall 1975) when the autocorrelation is non-significant. The MMK test was used to identify the trend in the presence of autocorrelation in the series. The MK (and MMK) test statistic ‘Z (and Zc)’ represents the trend. A positive value of Z (and Zc) indicates an increasing trend and negative value of ‘Z (and Zc)’ indicates decreasing trend. The annual magnitude of the trend is determined by Theil–Sen slope estimator test (Sen 1968). The Pettitt-t test gives the major change point in the given time series.

6.4.1 Trend Analysis of mean annual Precipitation

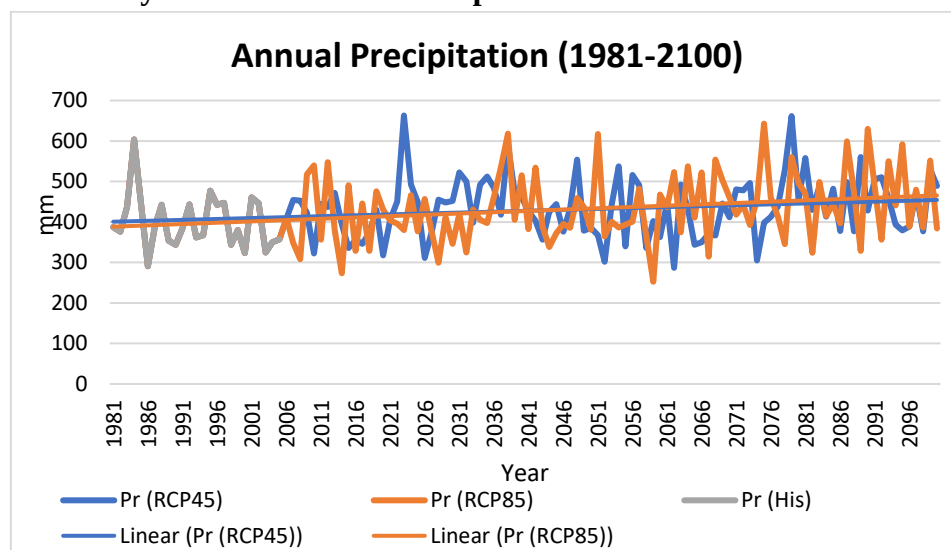


Figure 6.10 Time series of annual precipitation over AID during Historical (1981-2005) and long-term future (2006-2100).

Table 6.10 Trend analysis statistics for annual precipitation in AID during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenario.

Annual Precipitation Trend Statistics					
		Z/Zc	P/Pc	SS/Dec (mm)	t
His	His	-2.31	0.02	-11.66	1997
RCP45	ALL (H+RCP45)	6.39	0.00	4.59	2021
	NF45	-1.53	0.13	-12.10	2040
	FF45	-1.70	0.09	-14.14	2093
RCP85	ALL (H+RCP85)	10.70	0.00	6.17	2059
	NF85	0.59	0.55	6.24	2032
	FF85	-0.08	0.94	-4.23	2075

The figure 6.10 shows the time series of mean annual precipitation in AID during Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenario. The Table 6.10 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Z_c ; P/P_c , for trend detection), Sen's slope estimator test (SS/Decade, for trend magnitude) and Pettit-t test (t , change point) in the time series. The historical period shows a non-significant decreasing trend but the future projection of long-term shows significant increasing trend under both RCPs. It will increase with a rate of 4.59mm/decade (RCP4.5) and 6.17mm/decade (RCP8.5).

6.4.2 Trend Analysis of mean annul Maximum Temperature

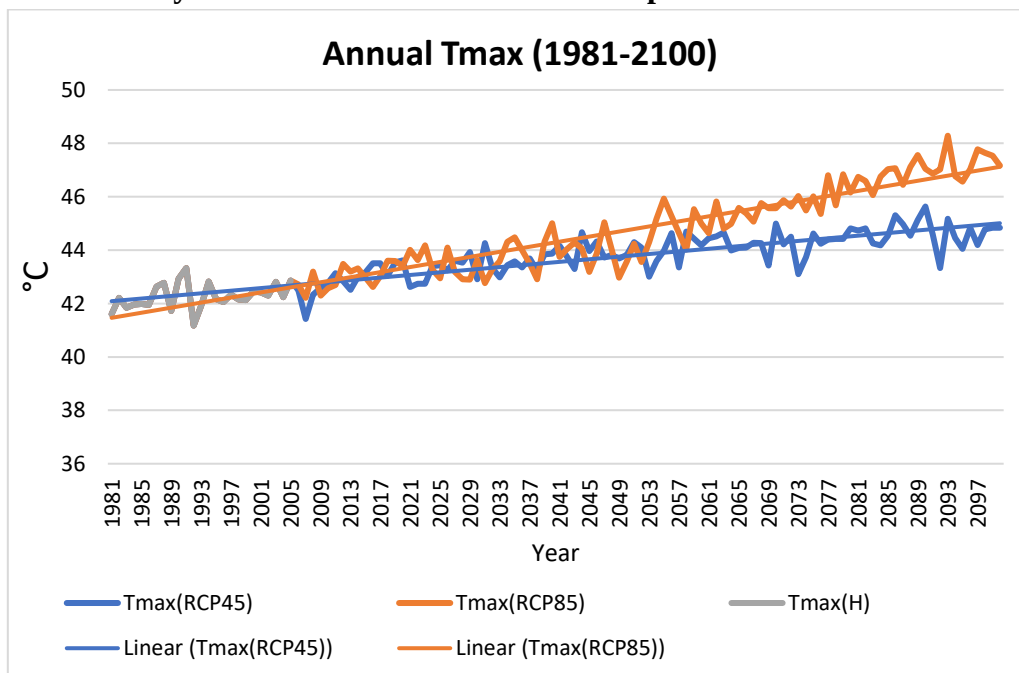


Figure 6.11 Time series of mean annual maximum temperature over AID during Historical (1981-2005) and long-term future (2006-2100).

Table 6.11 Trend analysis statistics for mean annual maximum temperature in AID during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenario.

Annual Tmax Trend Statistics					
		Z/Zc	P/Pc	SS/Dec (°C)	t
His	His	5.17	0.00	0.27	1986
RCP45	ALL (H+RCP45)	15.18	0.00	0.25	2038
	NF45	7.44	0.00	0.45	2038
	FF45	1.91	0.06	0.12	2085
RCP85	ALL (H+RCP85)	10.63	0.00	0.48	2052
	NF85	2.07	0.04	0.20	2033
	FF85	11.69	0.00	0.63	2084

The figure 6.11 shows the time series of mean annual maximum temperature in AID during Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenario. The Table 6.11 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Zc; P/Pc, for trend detection), Sen's slope estimator test (SS/Decade, for trend magnitude) and Pettit-t test (t, change point) in the time series. The historical period and the future projection of long-term, both shows significant increasing trend under both RCPs. It is projected to increase by 0.25°C/dec and 0.48°C/dec during long term period of RCP4.5 and RCP8.5 scenarios, respectively. The change point in RCP4.5 will be 2038 while it will be 2052 for RCP8.5 scenario for long-term period.

6.4.3 Trend Analysis of mean annul minimum Temperature

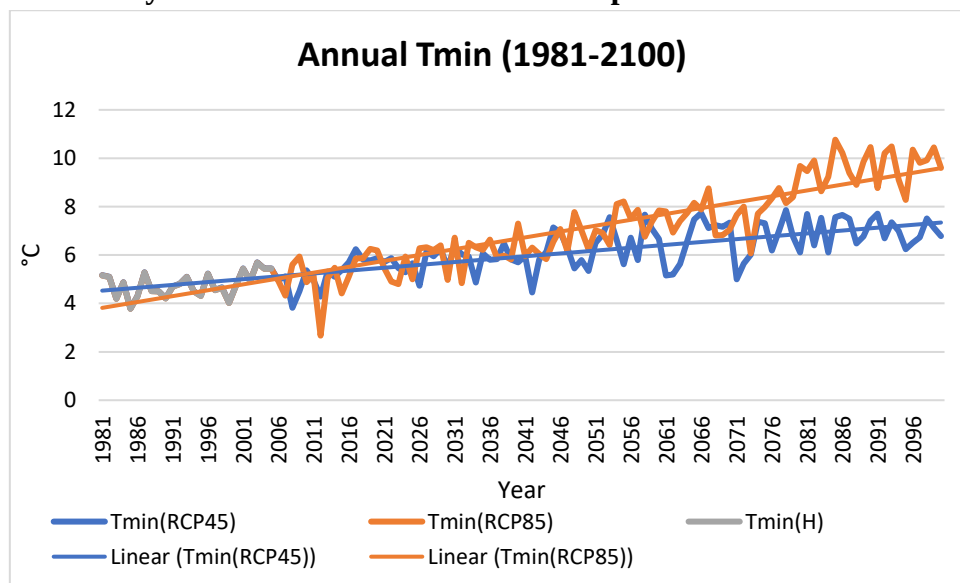


Figure 6.12 Time series of mean annual minimum temperature over AID during Historical (1981-2005) and long-term future (2006-2100).

Table 6.12 Trend analysis statistics for mean annual minimum (Tmin) temperature in AID during historical and Long-term future, Near Future (NF) and Far Future (FF) of RCP4.5 and RCP8.5 scenario.

Annual Tmin Trend Statistics					
		Z/Zc	P/Pc	SS/Dec	t
	His	3.74	0.00	0.29	1999
RCP45	ALL (H+RCP45)	24.38	0.00	0.24	2043
	NF45	3.84	0.00	0.17	2026
	FF45	-0.40	0.69	-0.03	2084
RCP85	ALL (H+RCP85)	11.46	0.00	0.48	2044
	NF85	3.81	0.00	0.32	2025
	FF85	5.33	0.00	0.66	2084

The figure 6.12 shows the time series of mean annual minimum temperature in AID during the Historical (1981-2005) and long-term period (1981-2100) of RCP4.5 and RCP8.5 scenarios. The Table 6.12 shows the trend statistics obtained from Mann-Kendall or Modified Mann-Kendall test (Z/Zc; P/Pc, for trend detection), Sen's slope estimator test (SS/Decade, for trend magnitude) and Pettit-t test (t, change point) in the time series. The historical period and future projection of the long-term period both show a significant increasing trend under both RCPs. It is projected to increase by 0.24°C/dec and 0.48°C/dec during the long-term period of RCP4.5 and RCP8.5 scenarios, respectively. The change point in RCP4.5 will be 2043 while it will be 2044 for RCP8.5 scenario for long-term period. The warming rate is found two times in RCP8.5 as compared to RCP4.5 scenario.

Chapter 7: Hydrological Modelling

7.1 Mahi River Basin

Mahi River basin extends over an area of 34,842 km² which accounts for nearly 1.1% of the total geographical area of the country it is situated between east longitude 72°15' to 78°15' and north latitude 22°0' to 22° 40' respectively. The upper part of the basin in Rajasthan and Madhya Pradesh comprises mostly hills and forests except for the lower half in M.P., which is fairly plain. The central part lying in Gujarat consists of developed lands. The lower part of the basin lying in Gujarat is a flat and fertile and well-developed alluvial tract. Important soil types in the basin are red and black soils. The culturable area of the basin is about 2.21 Mha which is 1.1 percent of the total culturable area of the country.

The Mahi River originates in the northern slope of the Vindhya ranges in MP at an elevation of nearly 500 m. It flows for about 583 km before outfalling into the Arabian Sea. It flows southwards for about 120 km in MP before entering the Banswara District of Rajasthan. The river makes a 'U' shaped loop in Rajasthan before entering Gujarat and finally discharges into the Gulf of Cambay. Being a monsoonal river, it is found that the inflow from seven dry months is less than 5% of the total inflow. The principal tributaries of the Mahi River are Som, Jakham, Moran, Anas, and the Bhadra. It is surrounded by north and northwest by Aravalli hills, on the east by the ridge separating it from the Chambal basin, on the south by the Vindhya and on the west by the Gulf of Khambhat. The basin shares its boundary with Rajasthan, Madhya Pradesh and Gujarat State. The state-wise drainage area for Rajasthan, Gujarat and Madhya Pradesh are nearly 16,453 km², 11,694 km² and 6,695 km² respectively. The mean annual rainfall over the Mahi basin is around 700 mm, of which 94% falls during four monsoon months. As per the 2001 census of India, the total human population in the basin area is about 1,27,70,704 spread in 15 districts [*Central Water Commission of India report on Mahi Basin*]. The major tributaries of Mahi River are Som, Panam, Jakham, Moran, Anas and Bhadar. Major projects on the River Mahi are Jakham Reservoir, Panam Dam, Mahi Bajaj Sagar Project and Kadana Project. As per a previous study by Gosain et al. (2003) the two river basins Sabarmati and Mahi show drastic decreases in precipitation and consequent decrease in total runoff to the tune of two thirds of prevailing runoff. This may lead to severe drought conditions in future in these basins. Therefore, it becomes necessary to undertake a comprehensive study of the Mahi basin for climate change impacts on hydrology of the Basin.

The objective of the proposed project is to study the impact of Climate change on the hydrology of the Mahi Basin and suggest strategic adaptation and mitigation options. There are four main activities to be performed viz. Surface water modelling (using SWAT), groundwater modelling, crop productivity modelling and reservoir/canal operation modelling. The outcomes from the studies carried out shall be disseminated through the digital platform that will enable more effective formulation, implementation and evaluation of policies in a dynamic manner.

DEM is the raster data consisting of an array of cells or pixels containing elevation values. DEM is used to delineate the networks of river streams, sub-basins, and parameters like slopes for HRUs. Aster DEM 30 m spatial resolution is used for the SWAT model.

Slope of the area is calculated in the percentage of rising. Then the area is classified based on types of slope of the area. Five types of the slope have been considered for the model. Slope has been classified on equal area perspective (Le et al., 2014).

For creating LULC maps, the whole basin area is classified into nine land use land cover classes. These classes are shown in table 7.1

Table 7.1 : LULC classes used in Study

S. No.	LULC classes	Description
1	Water bodies	This category comprises areas with surface water either impoundment in the form of pond lakes and reservoirs or flowing as stream river canals etc.
2	Paved	It is an area of land to cover or lay (a road, walk, etc.) with concrete, stones, bricks, tiles, wood, or the like, so as to make a firm, level surface.
3	Built Up Land/Settlement	It is an area of human habitation developed due to non-agriculture use and that has a cover of buildings transport and communication utilities in associations with water vegetation and vacant lands
4	Forest	These are the areas that consist of thick and dense canopy of tall trees which predominantly remains green throughout the year. It includes both coniferous and tropical broad leaves evergreen and deciduous species with former dominant canopy cover

5	Shrub Land	This a land which is generally prone to deteriorate due to erosion with scrub dominating the landscape they have a tendency for intermixing with cropped area
6	Barren	Barren land/waste Land is described as degraded land which can be brought under reasonable effort and which currently under civilized and land which is deteriorating for out of appropriate water and soil management or account of natural causes
7	Agriculture land	These are the areas synonyms with the cropping season extending between June /July to Sept/October. The season coincides with the southwest monsoon season. It is associated with rain-fed crops under dry land farming, limited or no irrigation and areas of rainfed paddy and other dry crops.
8	Fallow land	These are the lands which are taken up for cultivate but are temporarily allowed to rest uncropped for one or more season but not less than one year
9	River Sand	It includes the all-other categories of wasteland (like Sandy areas, salt affected areas and barren rocky waste land).

Soil map is collected from the Food and Agricultural Organisation of the United Nations. Three types of soils are found in the area i.e. loamy, clayey and sandy. Most of the area is covered with loamy soil. Hydrologic soil group of each type of soil data is considered from the US Natural Resources Conservation service (NRCS) report. NRCS classifies the soil into four hydrologic soil groups. After considering the infiltration capacity and percentage of clay, sand and silt, each soil type has been grouped into respective classes of the NRCS class (A, B, C, D) as shown in table 7.2. “A” type of soil has a high infiltration rate. Soil having less than 10 % of clay and more than 90 % of sand, gravel is considered in this group. Soil having moderate infiltration rate with moderately fine to moderately coarse texture is considered in soil class “B”. Clay percentage of the “B” category of soil is 10% to 20%. “C” type soil group has moderately high runoff potential. There is 20 to 40 percentage of clay in this soil type. Soil type having more than 40 % of clay and less than 50 % of sand are classified

into “**D**” soil group. This type of soil has very high runoff potential. (SWAT Manual, Version 2012, US NRCS soil handbook 1996)

Table 7.2 : Classification of Soil

SNAM	HYDGR P	TEXTURE	CLAY %	SILT %	SAND %	ROCK %
Ao81-2b-3652	B	LOAM	22	28	50	0
Be75-2a-3676	B	LOAM	23	37	40	0
Be76-2b-3677	B	LOAM	25	36	39	0
Bv12-3b-3696	C	CLAY_LOAM	37	29	34	0
I-Be-Lc-b-3716	B	LOAM	23	32	45	0
Jc51-2a-3744	B	LOAM	23	37	40	0
Lc70-1-2b- 3774	C	SANDY_CLAY_LOA M	27	20	53	0
Vc13-2-3b- 3858	D	CLAY	45	26	29	0
Vc21-3a-3859	D	CLAY	49	27	24	0
Vc43-3ab-3861	D	CLAY	51	30	19	0
Vc45-3a-3864	D	CLAY	52	31	17	0
WATER-6997	D	No-Soil	0	0	0	0

(Source: Harmonized world soil Database v1.2, FAO UNESCO soil map of the world (FAO 1971-1981)

7.1 Climate overview:

The tropic of cancer passes through the southern tips in the Banswara district in the west Rajasthan is relatively dry and infertile the area includes some of the Thar desert also known as Great Indian desert in the south eastern part of the state the land is wetter, hilly and more fertile the climate varies throughout Rajasthan on an average winter temperature ranges

from 8⁰ to 28⁰ C and summer temperature ranges for 25⁰ to 46⁰C. The average annual rainfall over the Mahi Basin is about 700 mm, and most of the rainfall occurs during the four monsoon months (June-September) [Rajasthan irrigation department].

7.2 Input Data

For creating the slope maps, stream network, watershed, LULC maps and soil map using Arc map and ERDAS Imagine following data as shown in table 7.3 is used

Table 7.3: Different data details

Data type	Description	Resolution/scale	Remarks
Topography	Digital Elevation model	30 m*30 m	Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model
Landuse landcover map	Satellite image classification	30 m*30 m	Landsat TM data for the year 1990, 1995 and 2000
Soil	Soil types and texture	1:5000000	Food and Agriculture Organisation of United Nations
Weather	Daily precipitation, Max and Min Temp	0.25*0.25 degree	Downscaled weather data

7.3 Elevation Profile

Elevation profile of the major rivers in the watershed area are drawn using Aster DEM. Longitudinal elevation profile are drawn for three main river channel Mahi, Som, Jakham, Anas and Panam(Figure 7.1-7.5).

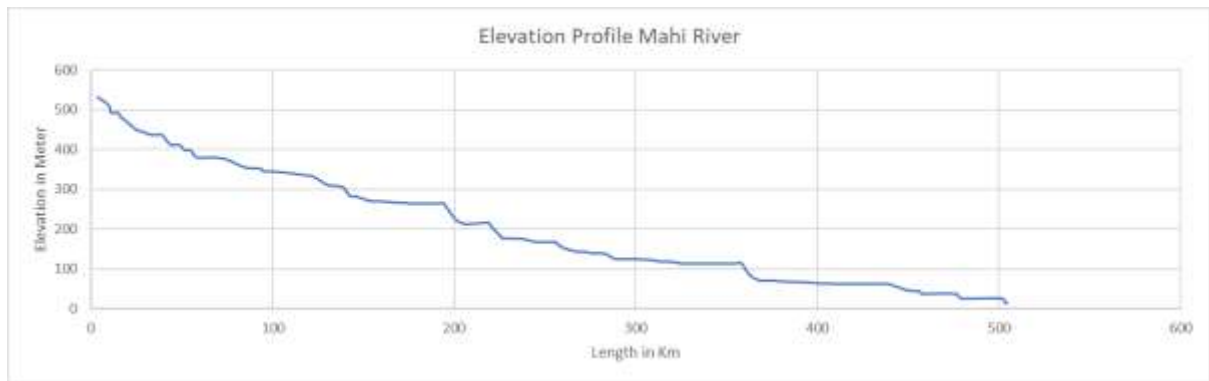


Figure 7.1: Elevation profile for Mahi River

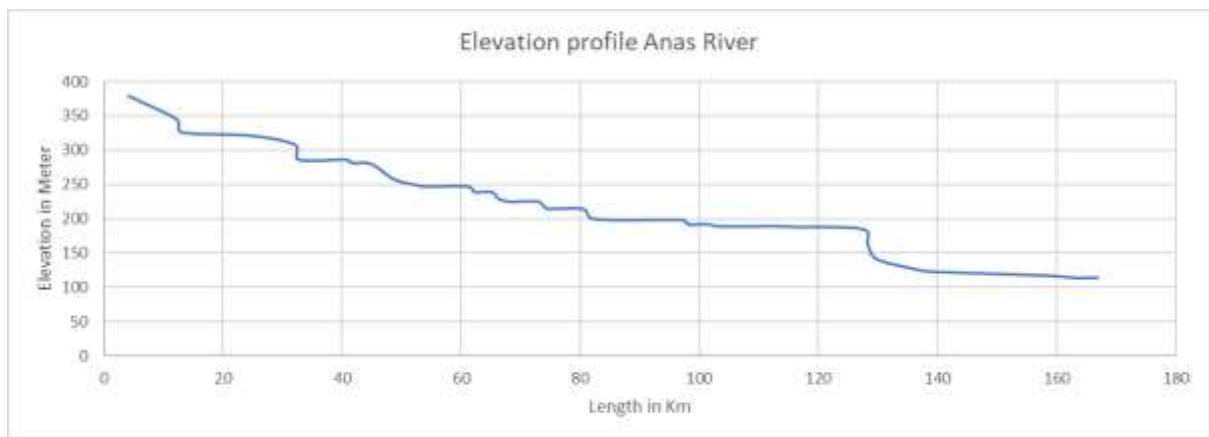


Figure 7.2: Elevation profile for Anas River



Figure 7.3: Elevation profile for Jakham River

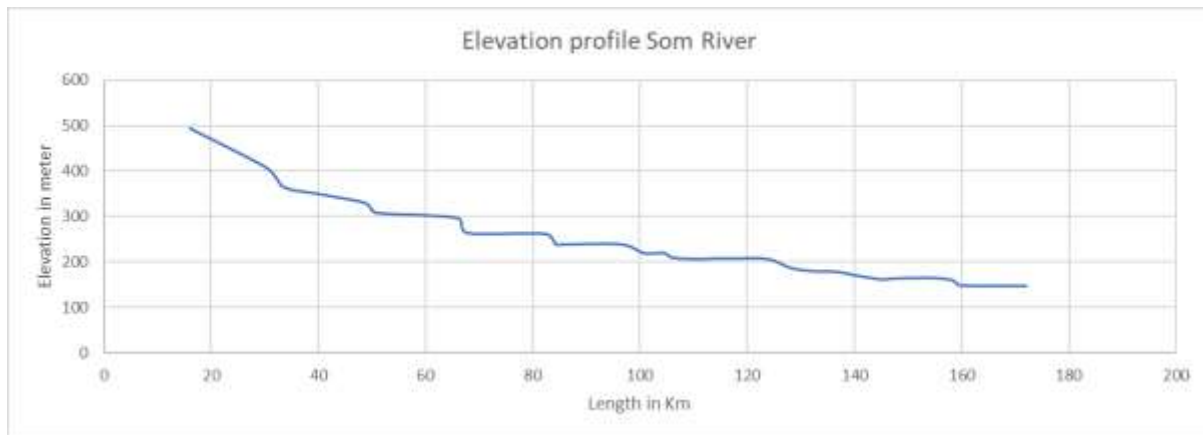


Figure 7.4: Elevation profile for Som River

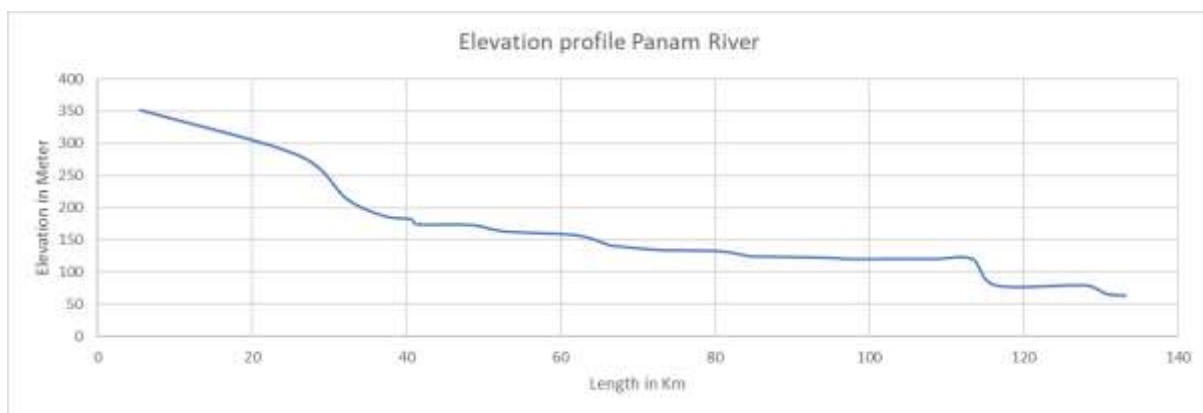


Figure 7.5: Elevation profile for Panam River

7.4 Various Observation Sites

7.4.1 Khanpur Observation site

Khanpur station is situated 52 km from the mouth of Mahi River in Anand district, Gujarat. The station is placed at 22°32'05" N 73°08'27" E (Figure 7.6). Khanpur station observes Gauge, Discharge, Sediment and Water quality. The discharge observation at the station was started in 1978. According to the data of Khanpur station, the maximum discharge of 31,062 m³/s was obtained on 12 August 2006. The average in the period is calculated as 140 m³/s. Total watershed area for the khanpur observation sites is 32,954 Sq km. The SWAT model for Khanpur is simulated for 25 years from 1981 to 2005 with 4 years of warm up period.

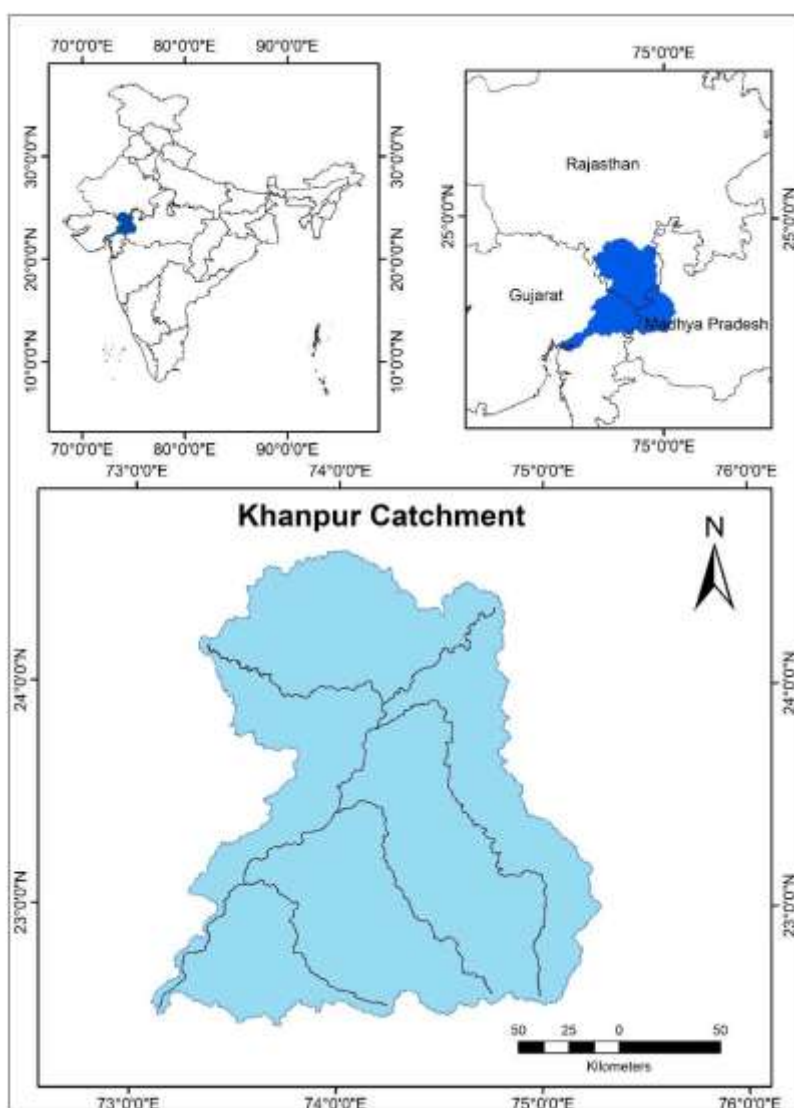


Figure 7.6: Khanpur station

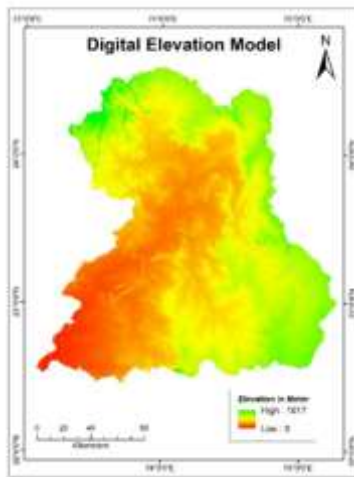
- **Watershed Characteristics-**

Digital Elevation Model

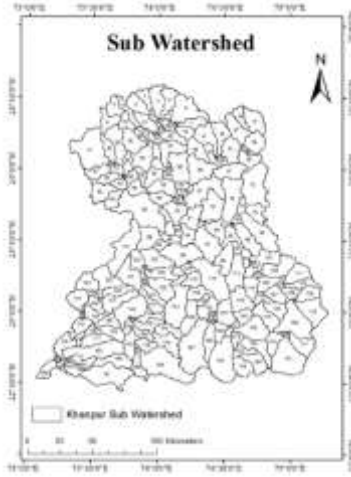
Figure 7.7(a) shows the DEM of Khanpur observation site. DEM varies from 5m to 1017 m above the mean sea level.

Table 7.4 Details of Elevation Khanpur observation site

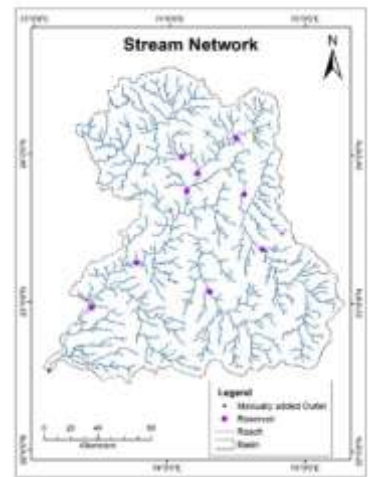
Minimum Elevation	5m
Maximum Elevation	1017m
Mean Elevation	509.50m
Standard Elevation	291.57m



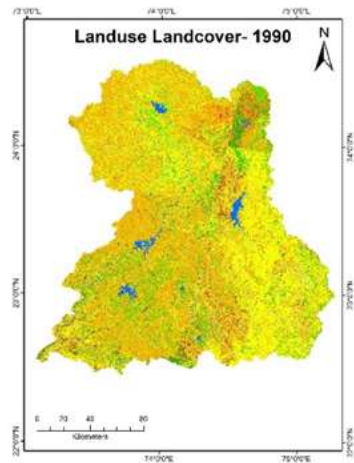
a



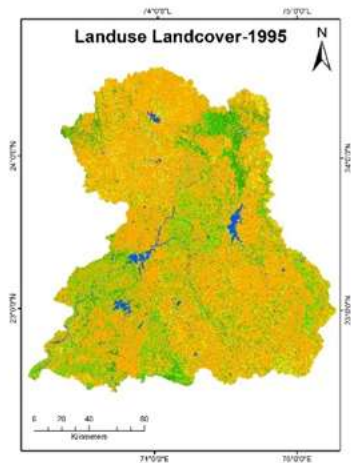
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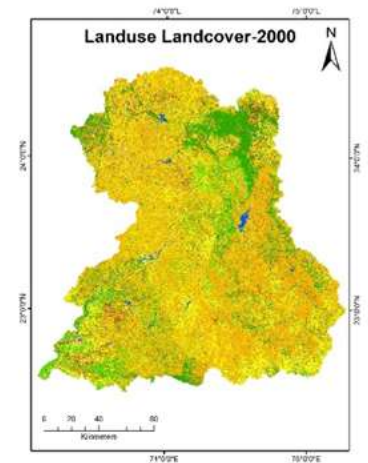
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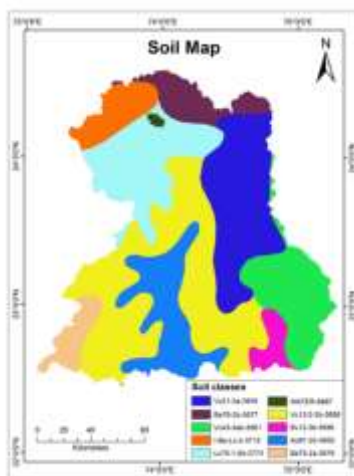
d



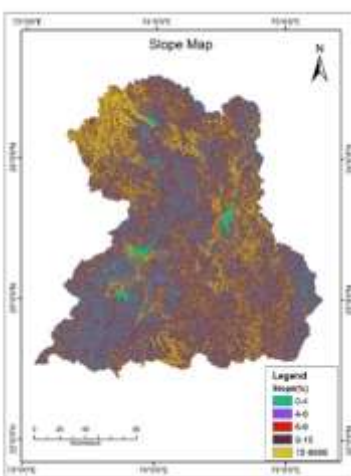
e



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g



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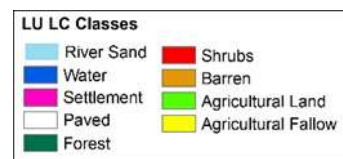


Figure 7.7 Watershed characteristics for Khanpur observation site

Sub Basin

Total 198 nos of subbasin has been generated (Figure 7.7(b)). Final outlet at 198th no subbasin outlet. Reservoirs are placed at 77, 103, and 148 subbasin for Bajajsagar, Kadana and Panam respectively.

Table 7.5 Details of subbasins of Khanpur observation site

Number of Subbasins	198
Maximum Area	697 Km ²
Minimum Area	0.16 Km ²
Average Area	168.41 Km ²

Table 7.6 Details of river network of Khanpur observation site

Number of Streams	198
MaximumLength of streams	33.52 Km
Minimum length of streams	0.044 Km
Average Length of streams	5.7 Km

Stream Order

The Figure 7.7(c) shows the number of stream order in main river of Khanpur station. Details are given in Table 7.3.

Table 7.7 Stream order and its length

Stream order	Length (km)
1 st	6629.86
2 nd	3264.21
3 rd	1738.83
4 th	626.12

5 th	559.23
6 th	245.75

Landuse Landcover

The land use land cover change from 1990 to 2000 is shown in Table 7.5 and Figure 7.7(d-f).

The distribution of LULC classes are given in Table 7.4.

Table 7.5 LULC classes distribution and area statistics.

Land use classes	LU_SWAT code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	629.45	1.91	735.22	2.23	555.39	1.69
Paved	URLD	37.68	0.11	10.38	0.03	29.11	0.09
Settlement	URHD	197.62	0.60	100.08	0.3	75.83	0.23
Forest	FRSD	686.38	2.08	2064.17	6.26	3170.03	9.62
Shrub	RNGB	1034.42	3.14	193.09	0.59	1187.73	3.60
Barren	BARR	12403.57	37.64	21281.55	64.58	14765.81	44.81
Agriculture land	AGRR	4442.86	13.48	5495.17	16.68	4387.25	13.31
Fallow land	AGRC	13104.59	39.77	2917.53	8.85	8567.38	26
Sand	WETN	417.91	1.27	157.28	0.48	215.95	0.66

Soil Data

Classification of various soil classes are shown in figure 7.7 (g) and area of specific class is given in Table 7.5.

Table 7.6 Various soil types and its area distribution

Soil type	Area in km ²	Soil type	Area in km ²
Be76-2b-3677	1792.58	Vc-13-2-3b-3858	9750.96
I-Be-Lc-b-3715	1654.79	Vc43-3ab-3861	3732.66
Lc70-1-2b-3774	4675.62	Ao81-2b-3652	3572.25
Vc21-3a-3859	5712.95	Be75-2a-3676	1136.46
WATER-6997	93.27	Bv12-3b-3696	832.92

Slope

Maximum and minimum percentage of slopes area 189% and 9% respectively (Figure 7.7 (h)). Standard deviation of the slope is 8.9%.

Simulation Details

Table 7.7 Details of simulation for Khanpur observation site

Simulation Details	Values
Simulation Length	25 years
Warm up Period	4 years
Number of HRUs	7655
Number of Subbasins	198
Simulation time step	Monthly
Basin Area	32984.00Km ²

Water Balance

Table 7.8: Average Annual Basin Values at the time of simulation

Description	Values in mm
Precip	1009.9
Surface runoff Q	315.66
Lateral soil Q	14.43
Tile Q	0.00

Groundwater Q	220
Revap (shal aq => soil/plants)	48.15
Deep aq recharge	13.42
Total water yield	550.09
Percolation out of soil	268.67
ET	425.6
PET	2470.8

Table 7.9 Details of water balance components ratios for Khanpur observation site

Water balance components	Ratio
Streamflow/Precipitation	0.53
Baseflow/Total flow	0.41
Surface Runoff/Total Flow	0.59
Percolation/Precipitation	0.27
Deep Recharge /Precipitation	0.01
Evapotranspiration/Precipitation	0.42

Continuity error

Total flow = surface runoff + base flow = 535.01mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $1009.9 + 48.15 = 1058.05$ mm

Total outflow = $315.66 + 14.43 + 220 + 425.6 + 13.42 = 989.11$ mm

Continuity error= 6.5 %

Water Balance at Outlet

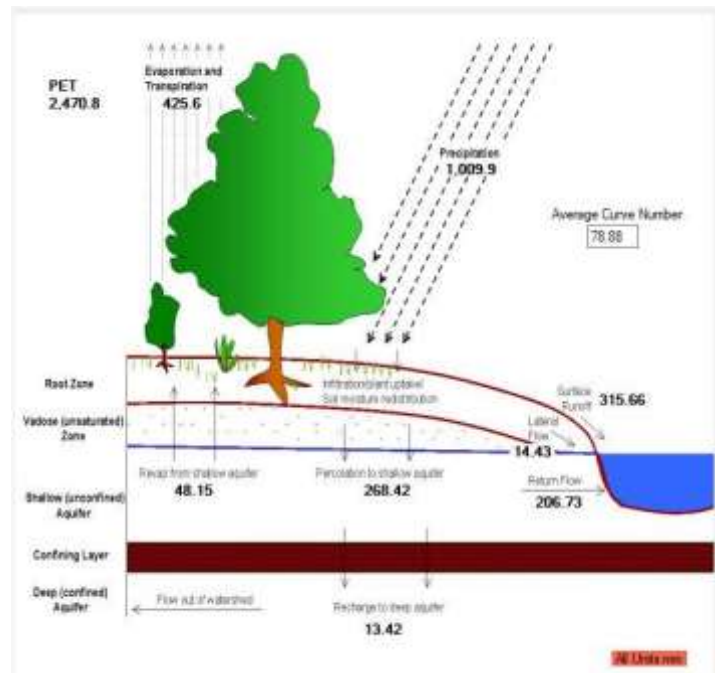


Figure 7.8: Water Balance Components at outlet of Khanpur station

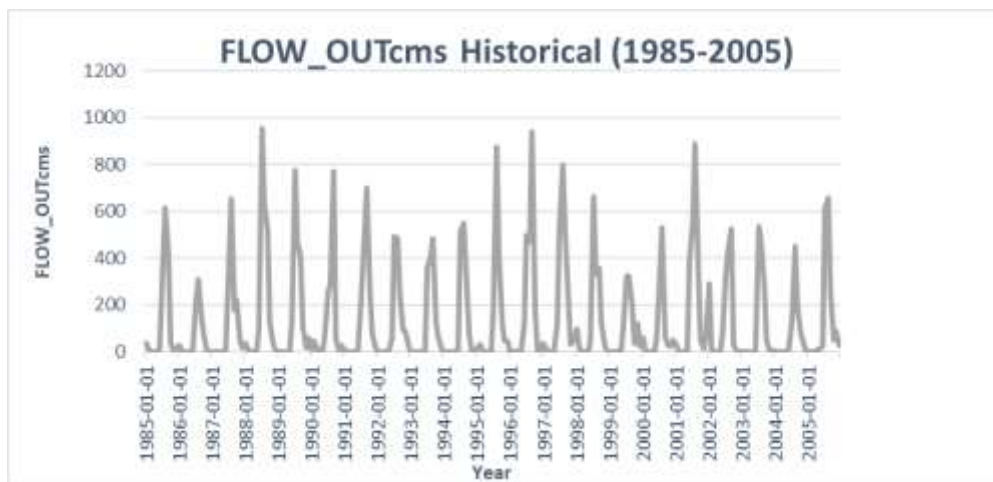


Figure 7.9: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.2. Chakaliya Observation site

Chakaliya station is situated in Panchmahal district of Gujarat on Anas River. The station is placed at 23°02'58" N and 74°19'14" E. Chakaliya station has an observation gauge and discharge from 1991. According to the data of Chakaliya station, the peak gauge level, 226.9m was observed on 11/08/2006. Total watershed area for the chakaliya observation sites is

3547.16 Sq km. The SWAT model for Chakaliya is simulated for 25 years from 1981 to 2005 with 4 years of warm up period.

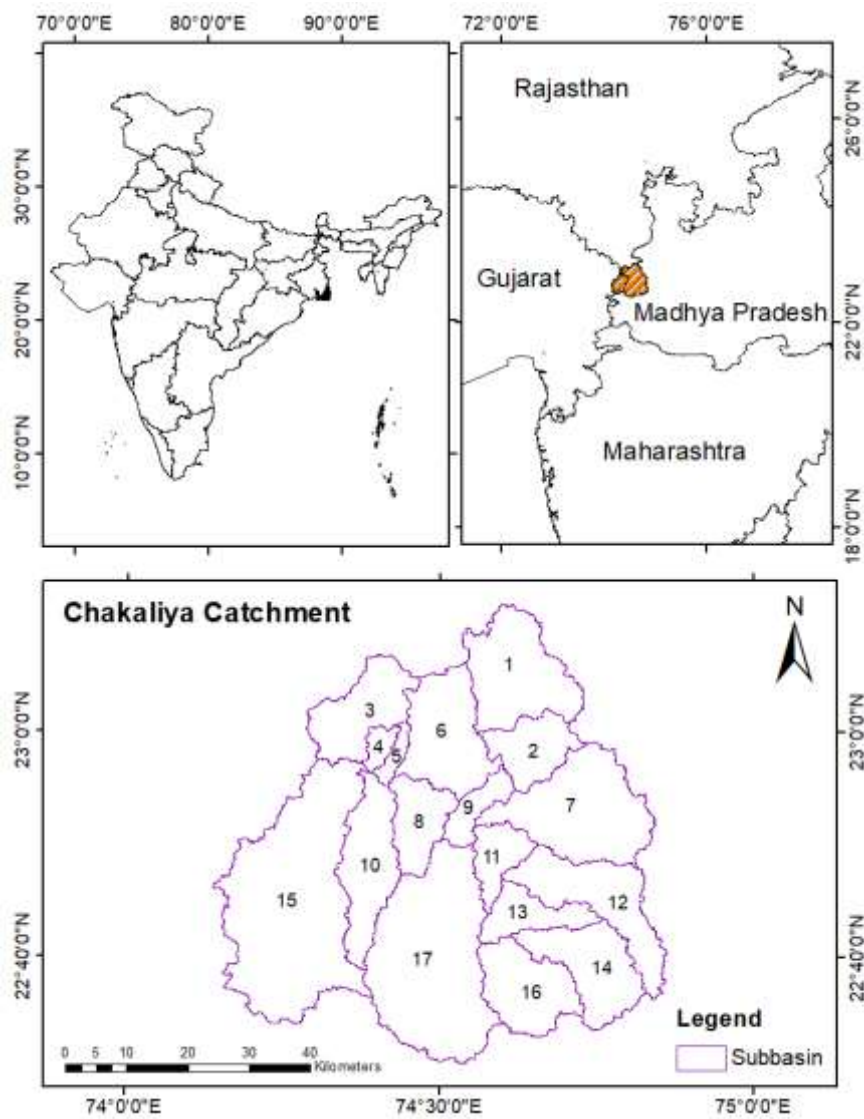


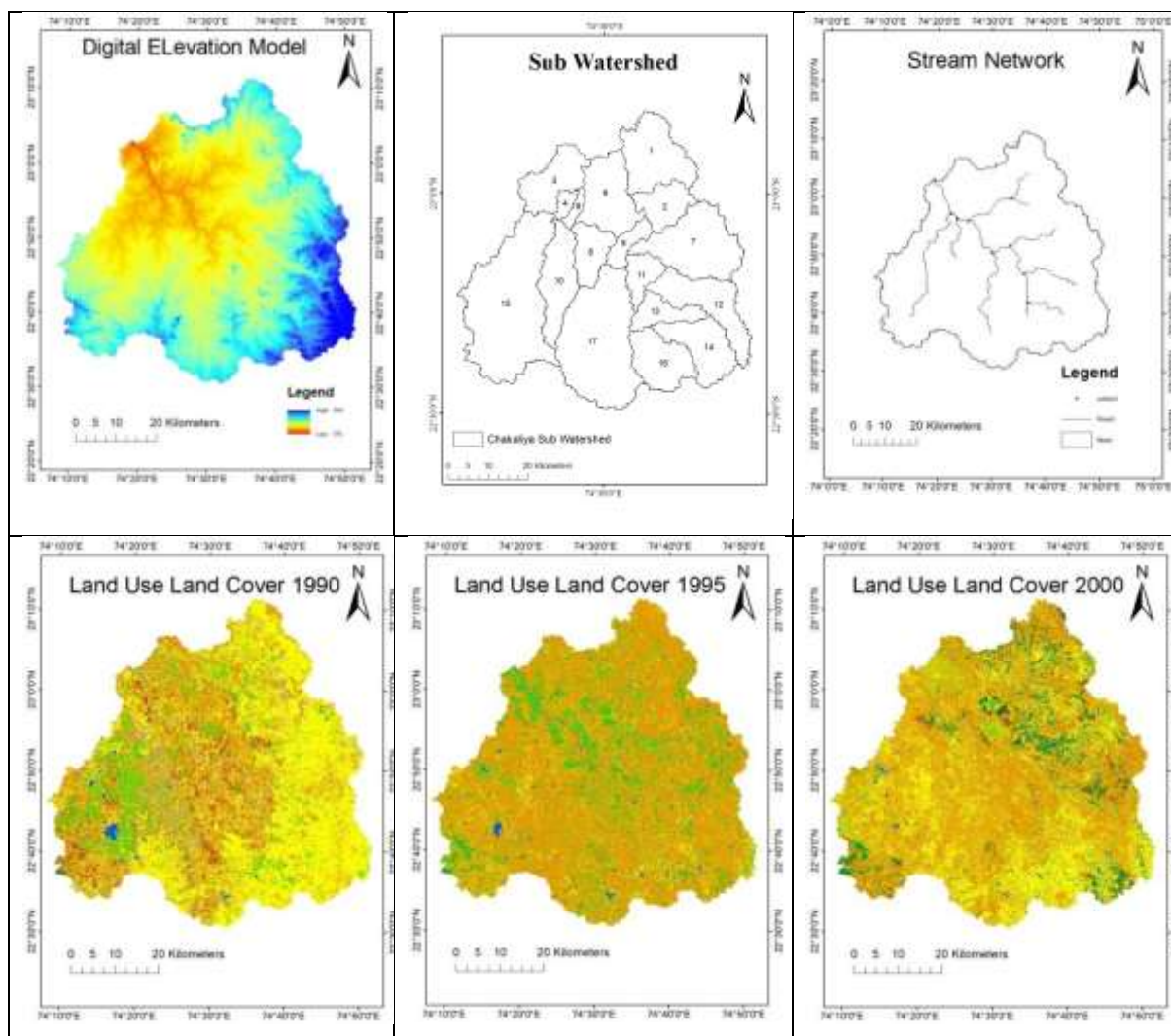
Figure 7.10: Chakaliya station

Digital elevation Model

Figure shows DEM profile of the Chakaliya station covering 3547.16 Sq km area.

Table 7.10 Digital Elevation Model values for Chakaliya observation sites

Minimum Elevation	176meters
Maximum Elevation	595 meters
Mean Elevation	384.5meters
Standard Deviation	119.58meters



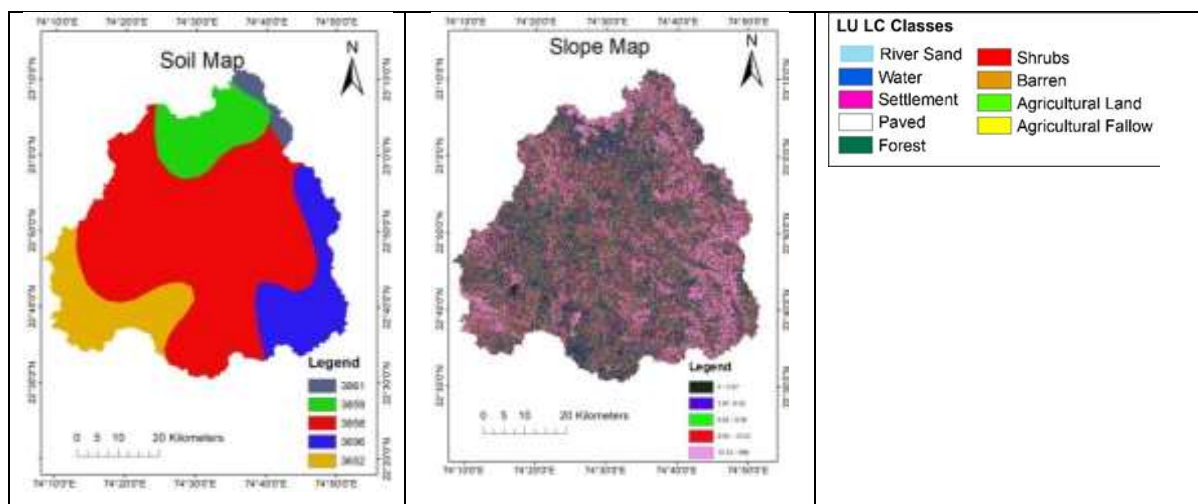


Figure 7.11: Watershed characteristics for Chakaliya observation site

Sub Basin

Total 17 number of subbasin has been generated for Chakaliya station site. Final outlet is at 3rd order stream. There is no reservoir subbasin.

Table 7.11 Details of subbasins of Chakaliya observation site

Number of Subbasins	17
Maximum Area in all subbasin	670 km ²
Minimum Area in all subbasin	24 km ²
Average area of all subbasins	223 km ²

Landuse Landcover

Table and figure shows the LULC details from 1990 to 2000.

Table 7.12 Landuse and landcover class distribution for Chakaliya observation site

Land use Classes	LU_SWAT Code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	37.47	1.05	42.61	1.20	31.7	0.89
Paved	URLD	7.51	0.21	0.48	0.014	1.04	0.029
Settlement	URHD	35.21	0.99	6.39	0.18	4.9	0.13
Forest	FRSD	3.16	0.089	130.65	3.68	236.69	6.67
Shrub	RNGB	182.88	5.15	20.75	0.58	41.58	1.17
Barren	BARR	1127.14	31.77	2453.68	69.17	1926.99	54.32
Agriculture land	AGRR	403.34	11.37	498.69	14.05	168.73	4.75
Fallow land	AGRC	1645.08	46.37	389.96	10.99	1130.41	31.86
Sand	WETN	105.37	2.97	3.95	0.11	5.1	0.14

(Chow; Applied hydrology, 1988)

Soil Data

Chakaliya station area has 6 types of soil as shown in figure 7.11.

Table 7.13 Details of Soil classes of Chakaliya observation site

Soil type	Area in sq km
Vc43-3ab-3861	74.7648
Vc21-3a-3859	377.73
Vc-13-2-3b-3858	2155.4928
Bv12-3b-3696	483.921
Ao81-2b-3652	455.2461
Vc43-3ab-3861	74.7648

Slope

There are lots of hilly area in the study area. Five types of slope has been considered for the model as shown in figure . variation of slope is observed from 0 to 105.63% having standard deviation of the slope is 7.18%.

Table 7.14 Details of Slope classes of Chakaliya observation site

Slope in percentage of rise	Area in Sq km
0 - 3.97	572.031
3.97 - 6.62	717.6708
6.62 - 9.93	810.1062
9.93 - 15.23	819.5148
15.23 - 999	653.6187

Simulation details

Table 7.15 Details of simulation by SWAT Model of Chakaliya observation site

Simulation Length	25 years
Number of HRUs	4 years
Number of Subbasin	17
Time step of simulation	Monthly
Chakaliya Basin Area	3547.34 km ²

Water Balance

Average Annual Basin Values at the time of simulation

Table 7.16 Details of average annual basin values at chakaliya observation site

Description	Values in mm
Precip	887.5
Surface runoff Q	306.88
Lateral soil Q	9.91
Tile Q	0.00
Groundwater Q	142.65
Revap (shal aq => soil/plants)	46.31
Deep aq recharge	9.45
Total water yield	460
Percolation out of soil	188.96
ET	393.5
PET	2374.2
Transmission losses	0.00
Septic inflow	0.00
Tile from impounded water	0.00
Evaporation from impounded water	0.00
Seepage into soil from impounded water	0.00
Overflow from impounded water	0.00

Table 7.17 Water balance components ratio at chakaliya observation sites

Water Balance Components	Ratio Values
Steam flow / Precipitation	0.51
Surface runoff / total flow	0.32
Percolation / Precipitation	0.68
Percolation / Precipitation	0.21
Deap recharge / Precipitation	0.01
ET / Precipitation	0.44

Continuity error

Total flow = 450mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $887.5 + 46.31 = 933.81$ mm

Total outflow = $306.88 + 9.91 + 142.65 + 393.5 + 9.45 = 862.39$ mm

Continuity error = 7.65 %

Water Balance at Outlet

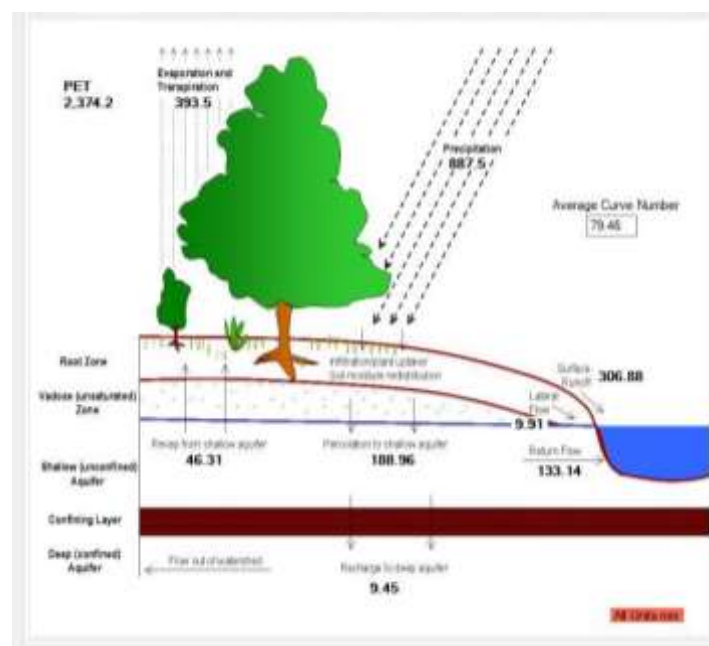


Figure 7.12: Water Balance Components at outlet of Chakaliya station

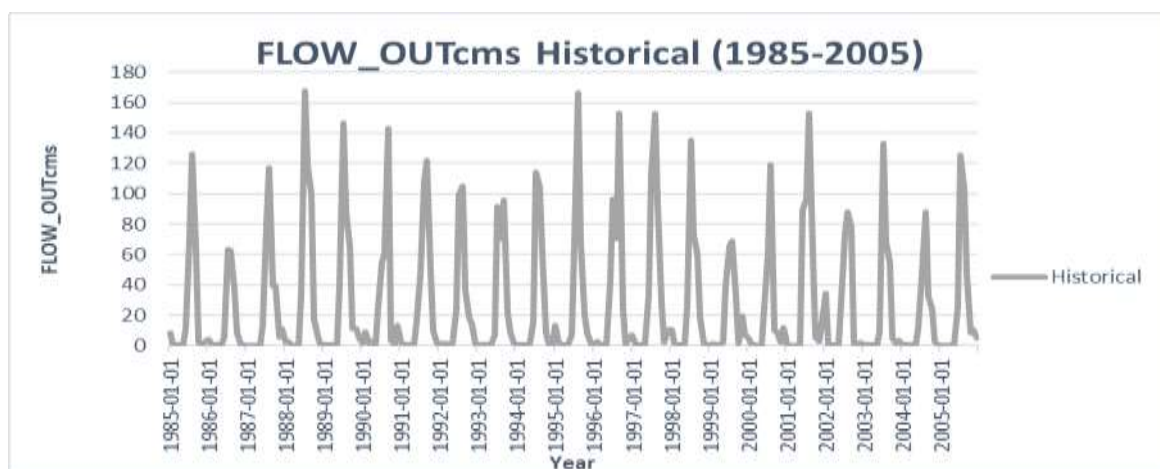


Figure 7.13: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.3. Dhariyawad Observation Site

Dhariyabad station is situated in Udaipur district, Rajasthan. The station is placed at 24°04'43"N and 74°28'02" E. Dhariyabad station observes Gauge and Discharge from 01.06.1988. According to the data of Dhariyabad station, the maximum gauge of 207.40 m was obtained in 31.07.1991. Total watershed area for the Dhariyabad observation sites is 1225.97 Sq km. SWAT model for Dhariyabad is simulated for 25 years from 1981 to 2005 with 4 years of warm up period.

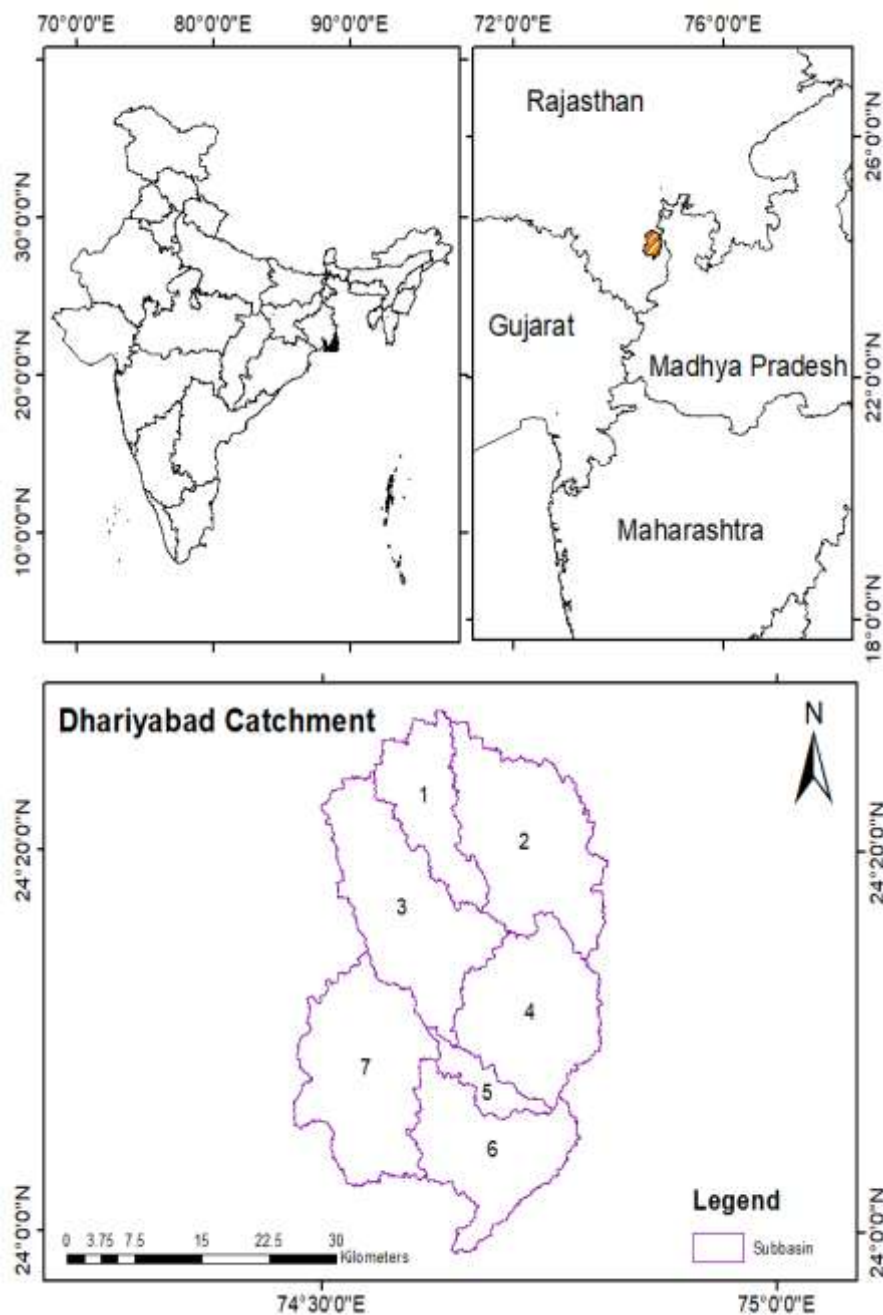


Figure 7.14:

Dhariyabad station

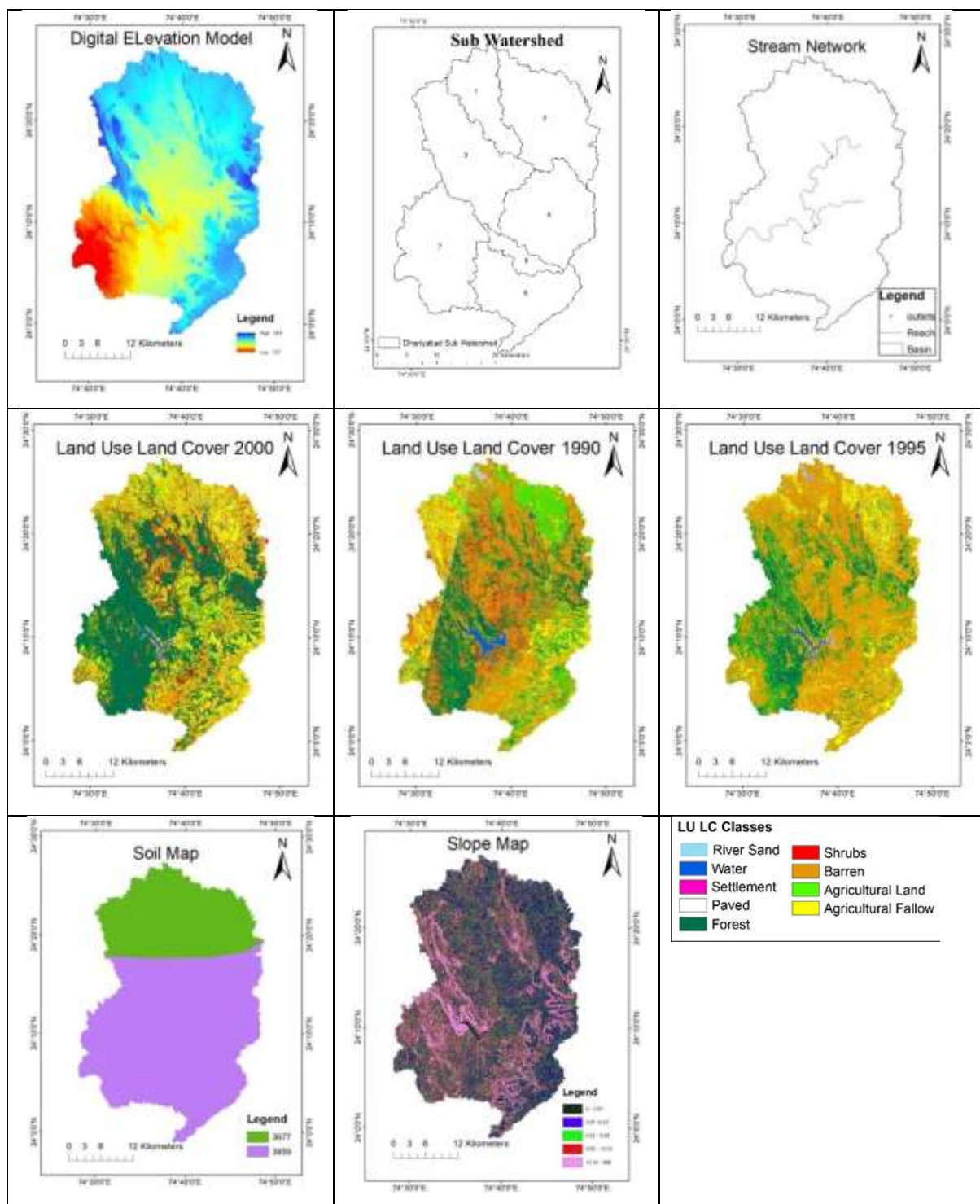


Figure 7.15: Watershed characteristics for Dhariyabad observation site

Digital Elevation Model

Table 7.17 Details of Digital elevation model for Dhariyawad observation site

Minimum Elevation	197m
Maximum Elevation	589m
Mean Elevation	239.4m
Standard Elevation	112.6m

Sub Basin

Subbasins have been generated for the Dhariyawad observation site. There are a total of 7 subbasins obtained during delineation of DEM data. Final outlet is at 2nd order stream. Table No.--provides the details of subbasins for Dhariyawad observation site

Table 7.18 Details of basin for Dhariyawad Observation site

Number of Subbasins	7
Maximum Area	236 Km ²
Minimum Area	37 Km ²
Average Area	166 Km ²

Streams

In Dhariyawad observation site 7 streams generated from 7 subbasins from delineation of dem data. Table 7.18 provide stream network details and table– provide stream order for dhariyawad observation site.

Table 7.18 Details of river network for Dhariyawad observation site

Number of streams	7
Maximum Length	27.369 Km
Minimum Length	2.570 Km
Average Length	12.604 Km
Standard Deviation	9.245 Km

Stream Order

Table 7.19 Stream Order for Dhariyawad observation site

Stream Order	Length (Km)
1 st Order	38.875
2 nd Order	55.682

Landuse and Landcover

Table 7.20 and figure shows the LULC details from year 1990 to 2000

Table 7.20 Landuse and Landcover class distribution for Dhariyawad observation site

Land use classes	LU_SWAT code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	16.66	1.36	7.86	0.64	9.85	0.8
Paved	URLD	0.02	0.002	0	0	0.03	0.002
Settlement	URHD	0.1	0.01	2.46	0.2	10.82	0.88
Forest	FRSD	246.25	20.09	213.07	17.38	487.9	39.8
Shrub	RNGB	56.76	4.63	16.92	1.38	107.32	8.75
Barren	BARR	564.31	46.03	658.92	53.75	199.31	16.26
Agriculture land	AGRR	203.27	16.58	181.38	14.79	109.15	8.9
Fallow land	AGRC	129.74	10.58	138.36	11.29	299.04	24.39
Sand	WETN	8.86	0.72	6.99	0.57	2.55	0.21

(Chow; Applied hydrology, 1988)

Soil Data

There are two types of soils covered in dhariyawad observation site. Most dominant soil types is Vc-21-3a-3859 which spread in 842.88 sq.km of the total area. Details of soils for Dhariyawad observation site provided below in Table---

Table 7.21 Soil class distribution for Dhariyawad observation site

Soil Type	Area in Km ²
Be76-2b-3677	383.0832
Vc21-3a-3859	842.8842

Slope

There are lots of hilly areas in the study area. Five types of slope have been considered for the model as shown in **figure** . Variation of slope is observed from 0 to 172.23% having standard deviation of the slope is 7.50%. Details of Slope distribution in Dhariyawad provided in Table 7.22

Table 7.22 Details of Slope distribution for Dhariyawad observation site

Slope in percentage of Rise	Area in Km ²
0.00-3.97	278.68
3.97-6.62	294.76
6.62-9.93	269.83
9.93-15.23	220.62

Simulation details

Table 7.23 Details of simulation for Dhariyawad observation site

Simulation Length	25 years
Warm up Period	4
Number of HRUs	277

Number of Subbasins	7
Output time step	Monthly
Basin area	1225 Km ²
Precipitation Data Method	Measured

Water Balance

Water balance components and their values provided in Table 7.24.

Table 7.24 Average Annual Basin Values at the time of simulation

Description	Values in mm
Precip	641.1
Surface runoff Q	7.8
Lateral soil Q	10.08
Tile Q	0.00
Groundwater Q	195.81
Revap (shal aq => soil/plants)	48.54
Deep aq recharge	12.27
Total water yield	213.69
Percolation out of soil	245.35
ET	409.5
PET	2546.8

Water balance components ratio

Table 7.25 No:Details of water balance components ratio for Dhariyawad observation site

Water Balance components	Ratio
Streamflow / Precipitation	0.31
Baseflow /Total Flow	0.96
Surface Runoff /Total Flow	0.04
Percolation /Precipitation	0.38
Deep Recharge /Precipitation	0.02

Evapotranspiration /Precipitation	0.64

Continuity error

Total flow = surface runoff + base flow = 201.42 mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $641.1 + 49.54 = 690.64$ mm

Total outflow = $7.8 + 10.08 + 195.81 + 409.5 + 12.27 = 635.46$ mm

Continuity error = 7.99 %

Water Balance at Outlet

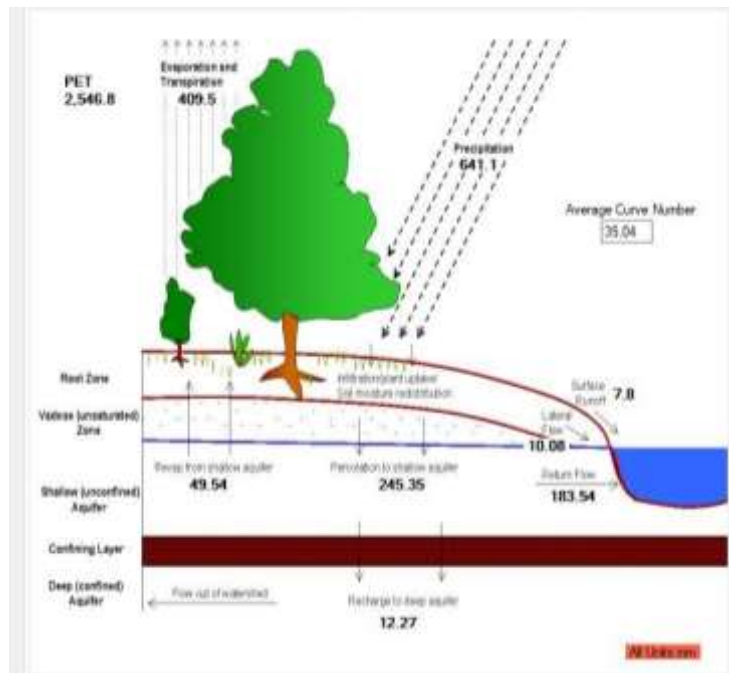


Figure 7.16: Water Balance Components at outlet of Dhariyabad station

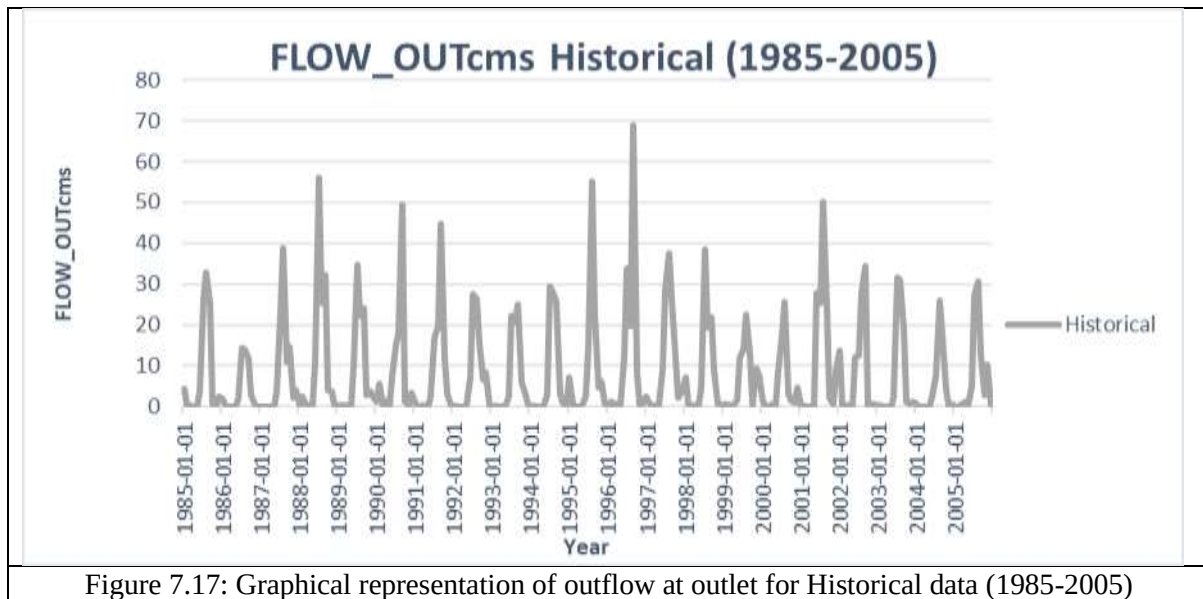


Figure 7.17: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.4. Mataji Observation site

Mataji station is situated in Ratlam district of Madhya Pradesh on Mahi river. The station is placed at 23°20'57" N and 74°43'31" E. Mataji station observes Gauge, Discharge, Sediment and Water quality from year 1982. According to the data of Mataji station, the Peak Water Level of 309.035 m was observed on 28.07.1996.

Total watershed area for the Mataji observation sites is 3770.49Sq km. The SWAT model for Mataji is simulated for 25 year from 1981 to 2005 with 4 years of warm up period.

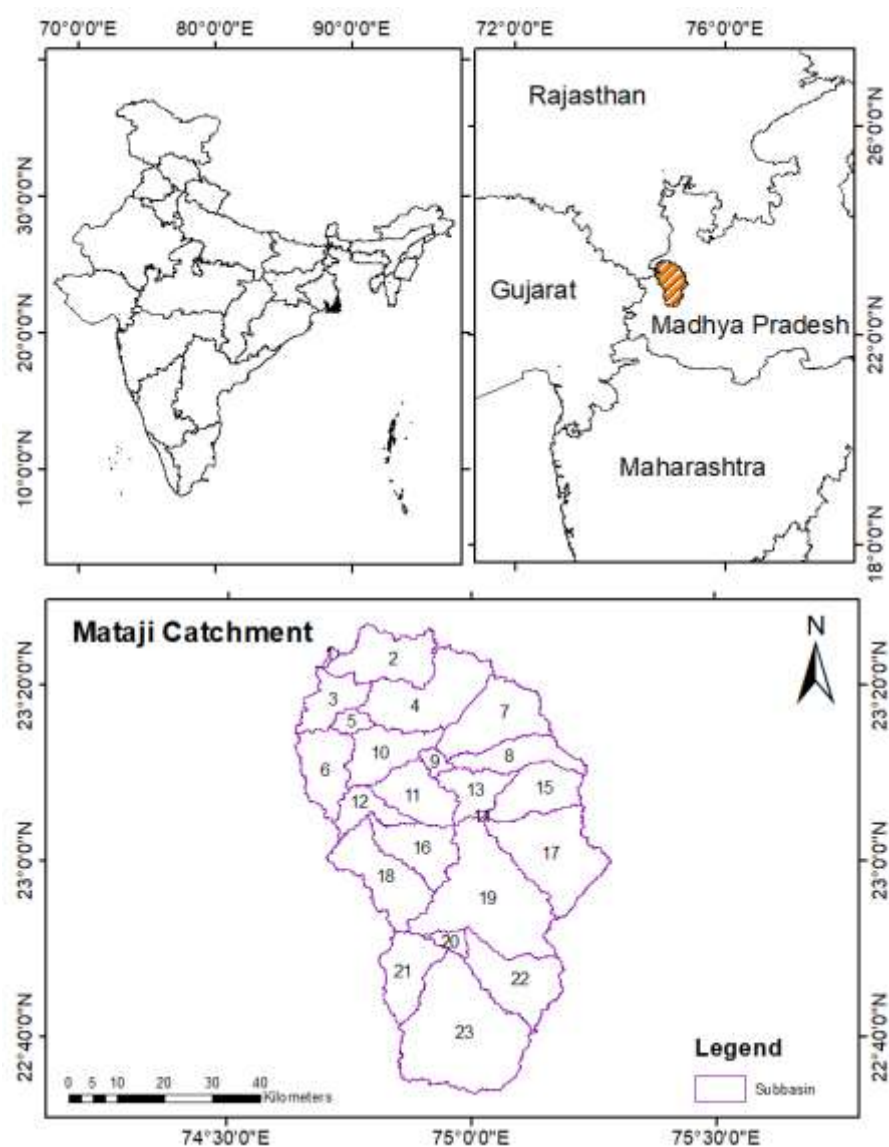


Figure 7.18: Mataji station

5.3.2. Digital Elevation Model

Table 7.26 Details of Digital elevation model for Mataji Observation site

Minimum Elevation	251m
Maximum Elevation	614m
Mean Elevation	433.46m
Standard Deviation	104.56m

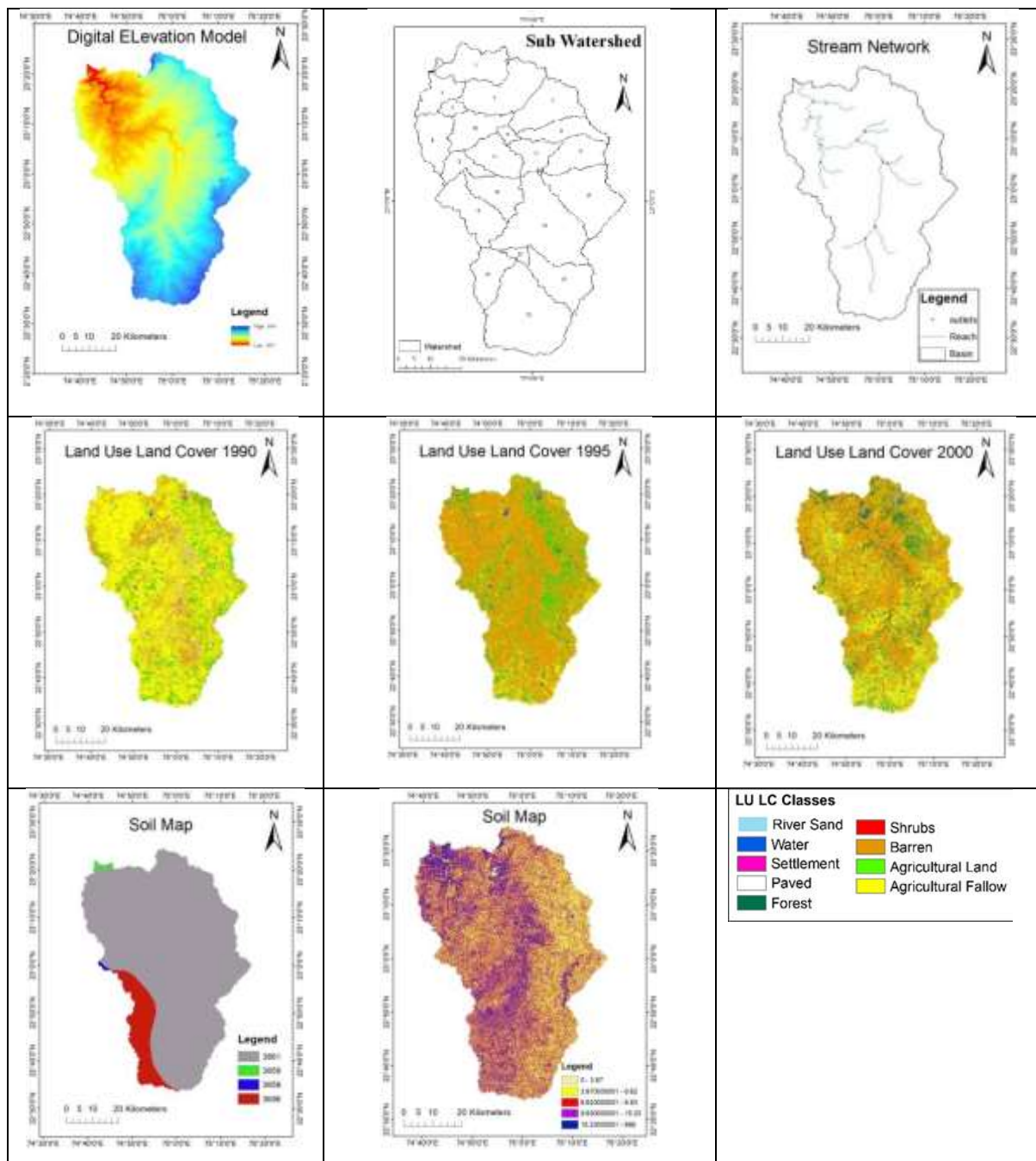


Figure 7.19 Watershed characteristics for Mataji observation site

5.3.3. Sub Basin

Total 21 number of subbasin are generated for the Mataji watershed area. Final outlet is at 3rd order stream. Details of subbasin provided in Table no:--

Table 7.27 Details of subbasins of Mataji Observation site

Number Of Subbasins	23
Maximum Area	532 Km ²
Minimum Area	3 Km ²
Average Area	180 Km ²

Streams

Table 7.28 Details of stream network for Mataji observation site

Number of Streams	21
Maximum length of streams	28.52 Km
Minimum Length of streams	2.42 Km
Average length of streams	13.73 Km
Standard deviation	6.51 Km

Stream Order

Table 7.29 Details of Stream Order for Mataji Observation site

Stream Order	Length (Km)
1 st	156.9
2 nd	52.74
3 rd	15.73

Landuse and Landcover

LULC classes are well distributed in Mataji Observation site. There are 9 LULC classes obtained in the classification of satellite images for 1990 to 2000. Table 7.30 shows the details of LULC classes and their percentage share area in the Mataji observation site.

Table 7.30 LULC classes distribution from 1990 to 2000 for Mataji observation site .

Land use classes	LU_SWAT code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Water Bodies	WATR	26.21	0.7	44.95	1.19	65.03	1.72
Paved	URLD	0.17	0	0.14	0	0.71	0.02
Settlement	URHD	47.91	1.27	6.97	0.18	5.08	0.13
Forest	FRSD	2.3	0.06	152.62	4.05	381.81	10.13
Shrub	RNGB	59.96	1.59	4.49	0.12	48.44	1.28
Barren	BARR	694.29	18.41	2529.5	67.09	2000.39	53.05
Agriculture land	AGRR	500.79	13.28	601.75	15.96	189.45	5.02
Fallow land	AGRC	2304.11	61.11	429.48	11.39	1071.76	28.42
Sand	WETN	134.75	3.57	0.59	0.02	7.83	0.21

(Chow; Applied hydrology, 1988)

Soil Data

Mataji Observation site has 4 types of soils. Table 7.31 provides the details of soil class distribution. Most dominant soil class is Vc43-3ab-6861 which covers 3398.95 Sq.km area out of the total area. Minimum area covered by the soil Vc-13-2-3b-3858 which covers only 6.37 Sq.Km.

Table 7.31 Details of Soil Class for Mataji observation site

Soil Type	Area in Km ²
Vc43-3ab-3861	3398.95
Vc-3a-3859	13.32
Vc-13-2-3b-3858	6.37
Bv12-3b-3696	351.84

Slope

Slope of the area is calculated in percentage of rise. Then the area is classified based on types of slope of the area as shown in Figure 7.19. Percentage slope varies from 0 to 111.26% . Standard deviation of the slope is 6.043%. Table 7.32 provide slope details for Mataji observation site

Table 7.32 Details of Slope distribution in Mataji Observation site

Slope in percentage Rise	Area in Km ²
0.00-0.3.97	863.41
0.397-6.62	931.78
6.62-9.93	870.97
9.93-15.23	705.90
15.23-999	425.56

Simulation details

Table 7.33 Details of simulation for Mataji observation site

Simulation Length	25 Years
Warm Up Period	4 Years
Number of HRUs	1216
Number of Subbasin	23

Simulation Time stem	Monthly
Basin area	3972.58 Km ²
Precipitation Data	Measured

Water Balance

Table 7.34 Average Annual Basin Values at the time of simulation for Mataji observation site

Description	Values in mm
Precip	933.9
Surface runoff Q	317.94
Lateral soil Q	8.56
Tile Q	0.00
Groundwater Q	156.82
Revap (shal aq => soil/plants)	48.2
Deep aq recharge	10.25
Total water yield	483.4
Percolation out of soil	205.02
ET	409.4
PET	2455.2

Water Balance Ratio

Table 7.35 Details of water balance ration for Mataji observation site

Water Balance Components	Ratio
Streamflow /Precipitation	0.51
Baseflow / Total flow	0.33
Surface Runoff/Total flow	0.67
Percolation/Precipitation	0.22
Deep Recharge /Precipitation	0.01

Evapotranspiration(ET)/Precipitation	0.44

Continuity error

Total flow = surface runoff + base flow = 473.15 mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $933.9 + 48.2 = 982.1$ mm

Total outflow = $317.94 + 8.56 + 156.82 + 409.4 + 10.25 = 902.97$ mm

Continuity error = 8.06 %

Water Balance at Outlet

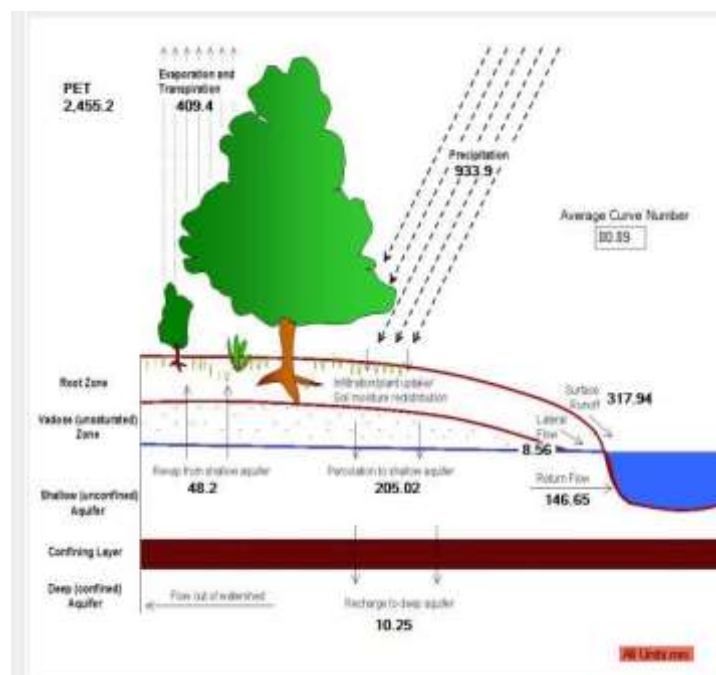


Figure 7.20: Water Balance Components at outlet of Mataji station

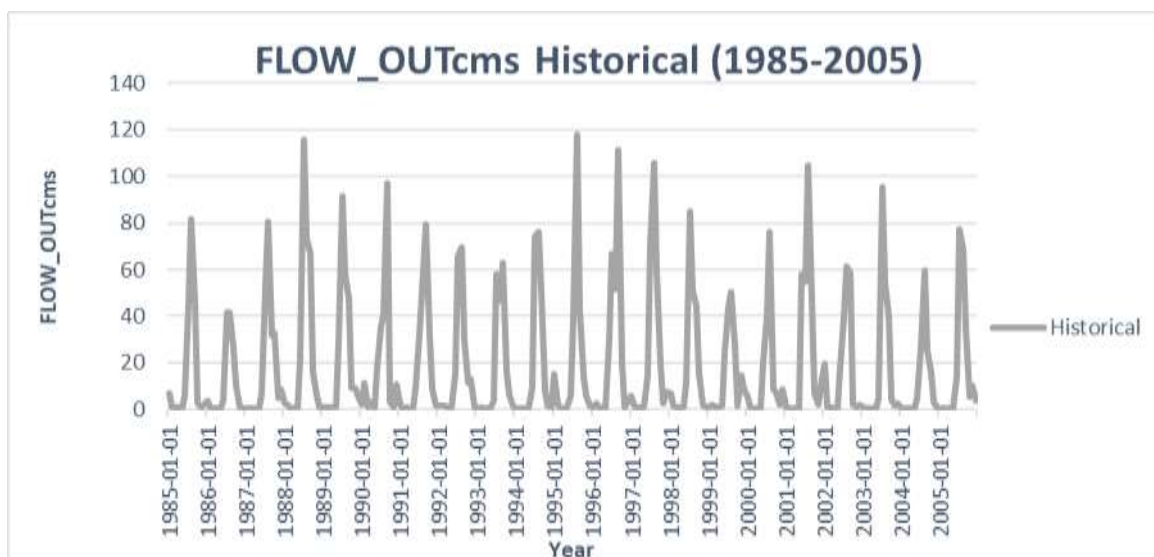


Figure 7.21: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.5. Paderdibadi Observation site

Paderdibadi station is situated in Dungarpur district of Rajasthan on Mahi river. The station is placed at Latitude 23°46'02"N and 74°08'12" E longitude. Paderdibadi station observes Gauge, Discharge, Sediment and Water quality. This station is operational for Gauge, Discharge and Water quality from 1978. According to the data of Paderdibadi station, the Peak Water Level 147.525 m was observed on 19/08/2006.

Total watershed area for the Paderdibadi observation sites is 16,378.43 Sq km. SWAT model for Paderdibadi was simulated for 25 years from 1981 to 2005 with 4 years of warm up period.

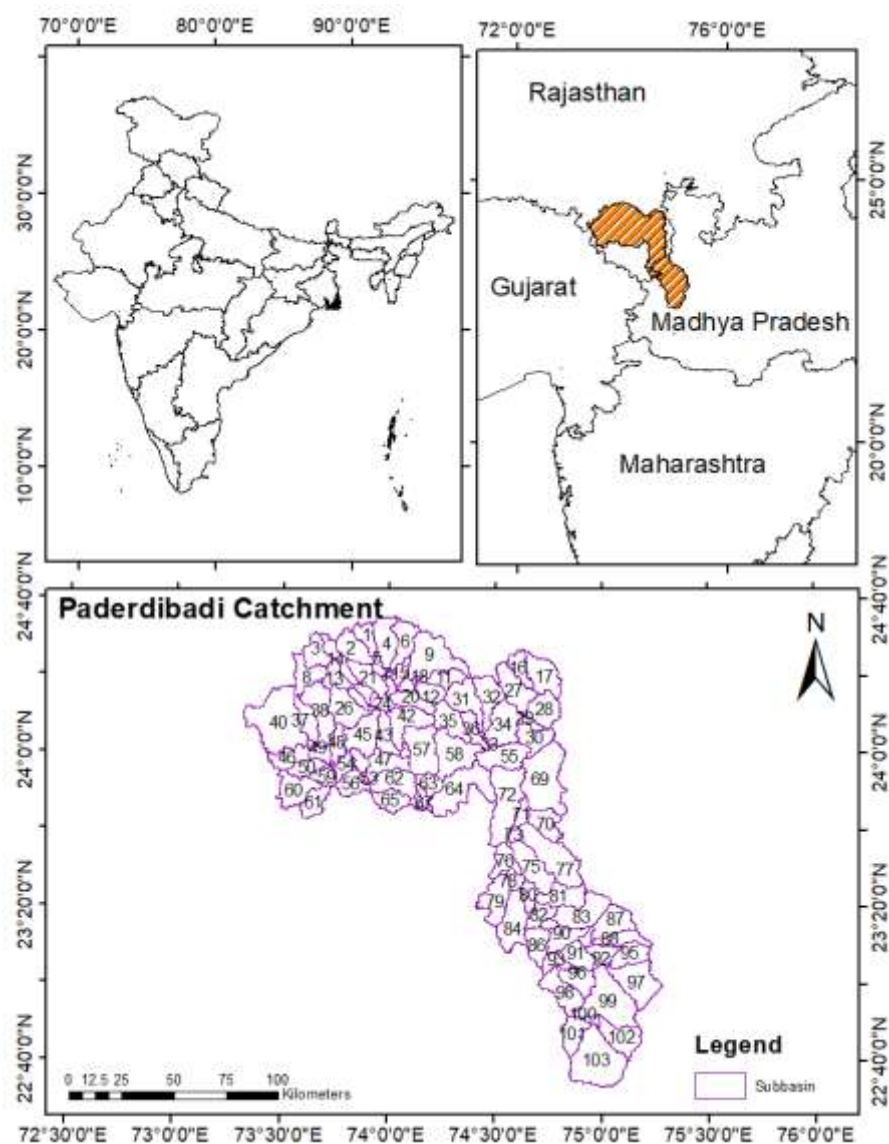


Figure 7.22: Paderdibadi station

Digital elevation Model

Table 7.36 Details of Digital Elevation Model for Paderdibadi observation site

Minimum Elevation	125m
Maximum Elevation	1017m
Mean Elevation	569.50m
Standard Deviation	256.93m

Table 7.37: Details of Subbasin for Paderdibadi observation site

Number of subbasins	103
Maximum Area	601 Km ²
Minimum Area	1Km ²
Average Area	161Km ²

Streams

Table 7.38 Details of stream order for Paderdibadi observation site

Number of streams	103
Maximum length of streams	48.79 Km
Minimum length of streams	0.585 Km
Average streams length	13.93 Km
Standard Deviation	10.39 Km

Landuse Landcover

Table 7.39 Shows the LULC details from year 1990 to 2000

Land use classes	LU_SWA T code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	37.47	274.67	1.68	283.33	1.73	331.72
Paved	URLD	7.51	2.97	0.02	8.3	0.05	20.64
Settlement	URHD	35.21	100.21	0.61	56.05	0.34	35.56
Forest	FRSD	3.16	467.2	2.85	1164.73	7.11	2419.39
Shrub	RNGB	182.88	257.26	1.57	66.55	0.41	546.65

Barren	BARR	1127.14	5494.3 2	33.55	10873.1	66.39	7409.4 4
Agriculture land	AGRR	403.34	1710.6 8	10.44	1930.77	11.79	1545.0 2
Fallow land	AGRC	1645.08	7828.7 3	47.8	1888.96	11.53	3957.9
Sand	WETN	105.37	241.99	1.48	106.25	0.65	111.71

(Chow; Applied hydrology, 1988)

Soil Data

Eight types of soils are observed in Paderdibadi watershed area as shown in figure..

Table 7.40 Soil Class distribution for Paderdibadi observation site

Soil type	Area in sq km	Soil type	Area in sq km
Be76-2b-3677	1789.51	Vc21-3a-3859	4420.93
Vc43-3ab-3861	3676.22	WATER-6997	93.28
I-Be-Lc-b-3715	1655.45	Vc-13-2-3b-3858	676.13
Lc70-1-2b-3774	3715.88	Bv12-3b-3696	350.64

Slope

Slope of the watershed area is calculated in percentage of rise. Slope varies from 0 to 172.23%.

The slope map is classified into 5 classes as shown in figure.

Table 7.40 No:Details of Slope distribution in Paderdibadi observation site

Slope In Percentage Rise	Area in Km ²
0.00-3.97	3140.82
0.397-6.662	3397.34
6.62-9.93	3380.73
9.93-15.23	3091.10
15.23-999	3486.53

Table 7.41 Details of simulation of Paderdibadi observation site

Simulation Length	25 Years
Warm Up Period	4
Number of HRUs	4922
Number of subbasin	103
Output Time step	Monthly
Basin Area	16378 Km ²
Precipitation Data	Measured

Water Balance

Table 7.42 Average Annual Basin Values at the time of simulation for Paderdibadi site

Description	Values in mm
Precip	731.9
Surface runoff Q	104.61
Lateral soil Q	17.88
Tile Q	0.00
Groundwater Q	189.53
Revap (shal aq => soil/plants)	48.64
Deep aq recharge	11.91
Total water yield	312.32
Percolation out of soil	238.17
ET	395.9
PET	2513

Table 7.43 Water Balance components ratio for Paderdibadi observation site

Water balance Components	Ratio
Streamflow/Precipitation	0.41
Baseflow/Total Flow	0.65
Surface Runoff/Total Flow	0.35
Percolation/Precipitation	0.33
Deep Recharge /Precipitation	0.02
Evapotranspiration(ET)/Precipitation	0.54

Continuity error

Total flow = surface runoff + base flow = 300.41 mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $731.9 + 48.64 = 780.54$ mm

Total outflow = $104.61 + 17.88 + 189.53 + 395.9 + 11.91 = 719.83$ mm

Continuity error= 7.78 %

Water Balance at Outlet

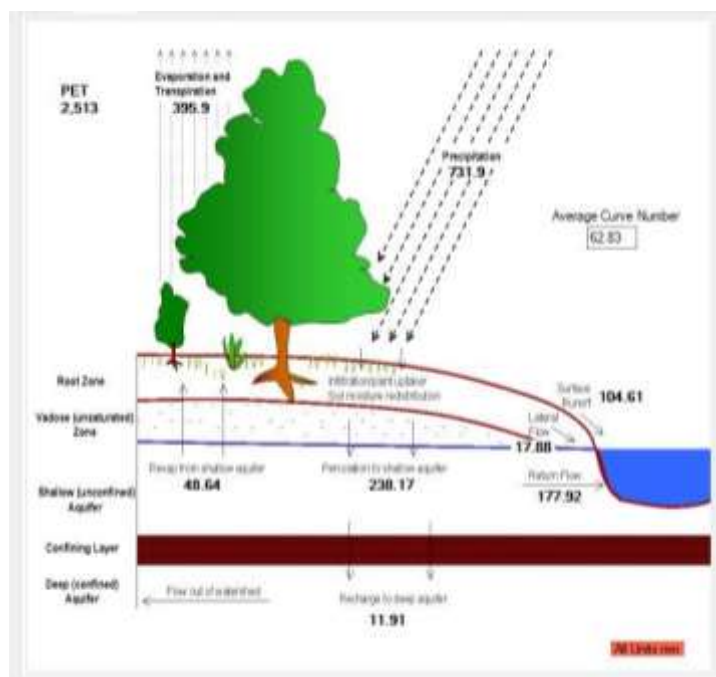


Figure 7.23: Water Balance Components at outlet of Paderdibadi station

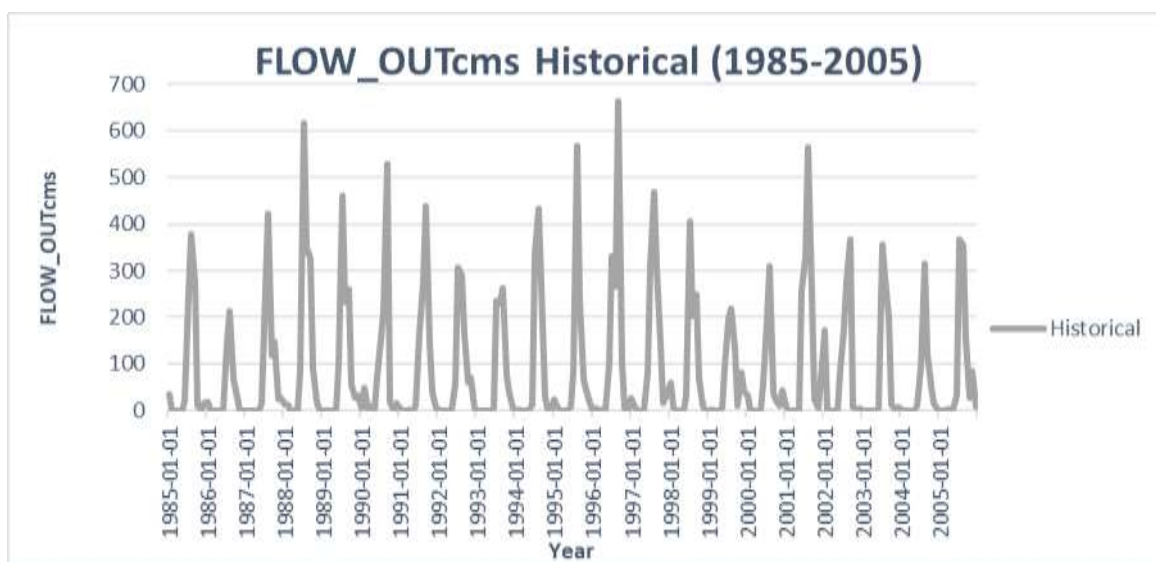


Figure 7.24: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.6. Rangeli Observation site

Rangeli station is situated on Som river at Dungarpur district of Rajasthan. The station is placed at 23°52'22" N and 74°13'25" E. Rangeli station observes Gauge, Discharge and Water

quality. The discharge observation at the station was started in 1978. According to the data of Rangeli station, the peak water level was observed 158.240 m on 19/08/2006.

Total watershed area for the Rangeli observation sites is 8523.88 Sq km. SWAT model for Rangeli station is simulated for 25 year from 1981 to 2005 with 4 years of warm up period.

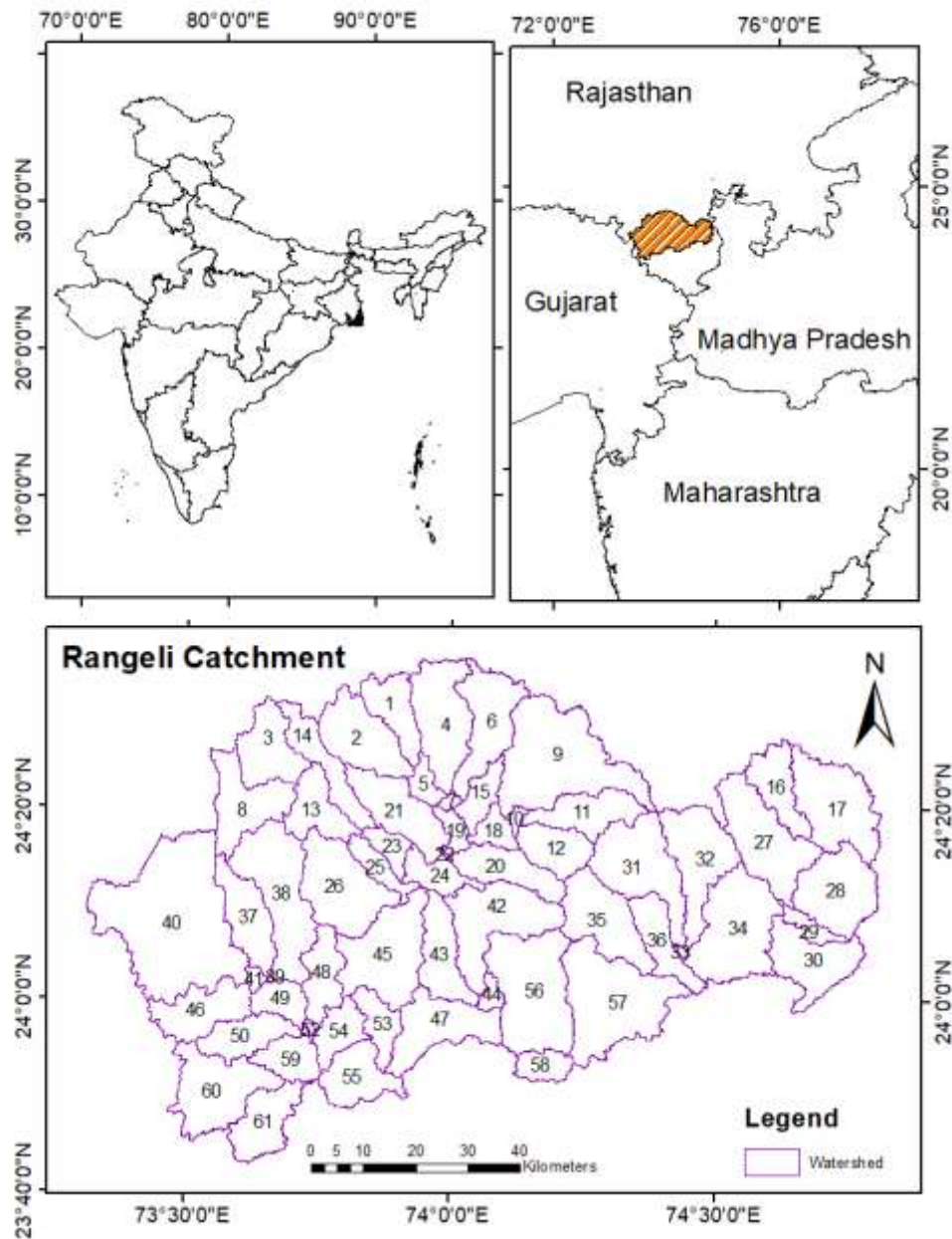


Figure 7.24: Rangeli station

Digital elevation Model

Table 7.44 Digital elevation model details for Rangeli observation site

Minimum Elevation	133 m
Maximum Elevation	1017m
Mean Elevation	575.48m
Standard elevation	253.50

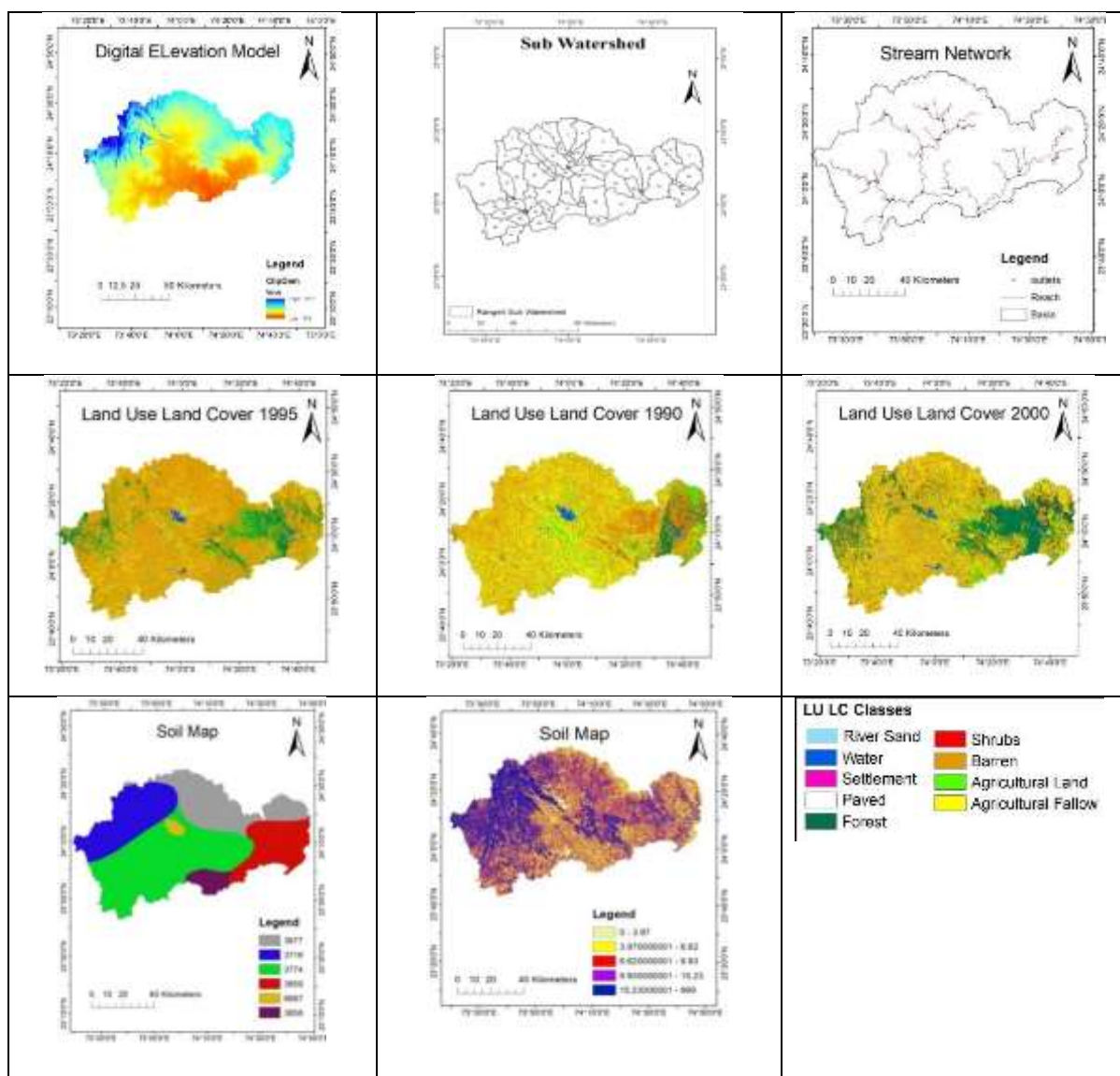


Figure 7.25 Watershed characteristics for Rangeli observation site

Sub Basin

Total 61 number of sub basins has been generated in Rangeli watershed area as shown in figure.

Table 7.45 Details of subbasin for Rangeli Observation site

Number of subbasin	61
Maximum Area	601.01 Km ²
Minimum Area	1.10 Km ²
Average Area	144 Km ²

Streams

Table 7.46 Details of river streams for Rangeli observation site

Number of streams	61
Maximum Length	45.95 Km
Minimum Length	0.58 Km
Average Length	12.34 Km
Standard Deviation	9.5 Km

Table 7.47 Details of stream order for Rangeli observation site

Stream Order	Length (Km)
1 st	388.91
2 nd	204.47
3 rd	128.74
4 th	49.42

Landuse Landcover

Table and figure shows the LULC details from year 1990 to 2000

Table 7.48 Landuse and Landcover class distribution for Rangeli observation site

Land use classes	LU_SWA T code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	104.97	1.23	79.51	0.93	165.87	1.95
Paved	URLD	1.74	0.02	6.4	0.08	17.5	0.21
Settlement	URHD	23.99	0.28	29.51	0.35	19.11	0.22
Forest	FRSD	347.82	4.08	707.92	8.31	1413.93	16.59
Shrub	RNGB	117.19	1.37	41.79	0.49	406.56	4.77
Barren	BARR	3888.86	45.62	5765.54	67.64	3389.33	39.76
Agriculture land	AGRR	782.1	9.18	789.28	9.26	867.3	10.17
Fallow land	AGRC	3209.68	37.66	1022.35	11.99	2160.62	25.35
Sand	WETN	47.52	0.56	81.58	0.96	83.66	0.98

(Chow; Applied hydrology, 1988)

Soil Data

Rangeli watershed has 6 types of soils as shown in figure

Table 7.49 Soil Class distribution for Rangeli observation site

Soil Type	Area in Km ²
Be76-2b-3677	1791.24
I-Be-Lc-b-3715	1655.88
Lc70-1-2b-3774	3450.74
Vc21-3a-3859	1207.37

WATER-6997	93.28
Vc-13-2-3b-3858	325.41

Slope

Slope of the area is calculated in percentage of rise and classified into five types of slope intervals as shown in figure. Slope varies from 0 to 172.23%.

Table 7.50 Slope distribution for Rangeli observation site

Slope in Percentage Rise	Area in Km²
0.00-3.97	1470.61
3.97-6.62	1626.80
6.62-9.93	1661.61
9.93-15.23	1606.64
15.23-999	2220.15

Simulation details

Table 7.51 Details of Simulation for Rangeli observation site

Simulation Length	25 Years
Warm Up Period	5 Years
Number of HRUs	3797
Number of subbasin	61
Output timestep	Monthly
Basin area	8524.3 Km ²
Precipitation Data	Measured

Water Balance

Average Annual Basin Values at the time of simulation

Table 7.52 Annual average water balance component and their values for Rangeli observation site

Water balance components	Values in mm
Precip	688.6
Surface runoff Q	150.51
Lateral soil Q	17.6
Tile Q	0.00
Groundwater Q	120.58
Revap (shal aq => soil/plants)	48.73
Deep aq recharge	8.47
Total water yield	288.68
Percolation out of soil	169.31
ET	367.2
PET	2507.1

Table 7.53 Water Balance components ratio for Rangeli observation site

Streamflow /Precipitation	0.41
Baseflow /Tota flow	0.46
Surface Runoff /Total Flow	0.54
Percolation/Precipitation	0.25
Deep Recharge /Precipitation	0.01
ET/Precipitation	0.53

Continuity Error

Total flow = surface runoff + base flow = 280.21mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $688.6 + 48.73 = 737.33$ mm

Total outflow = $150.51 + 17.6 + 120.58 + 367.2 + 8.47 = 664.36$ mm

Continuity error= 9.89 %

Water Balance at Outlet

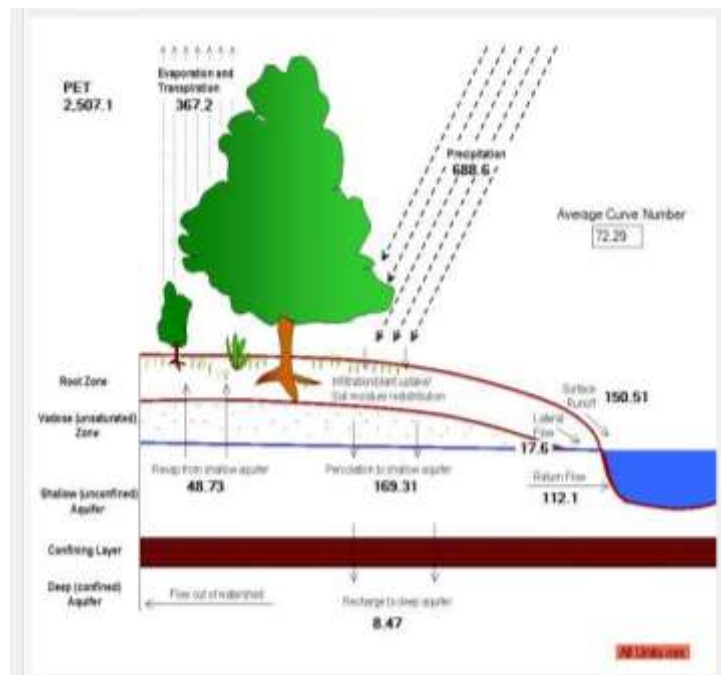


Figure 7.26: Water Balance Components at outlet of Rangeli station

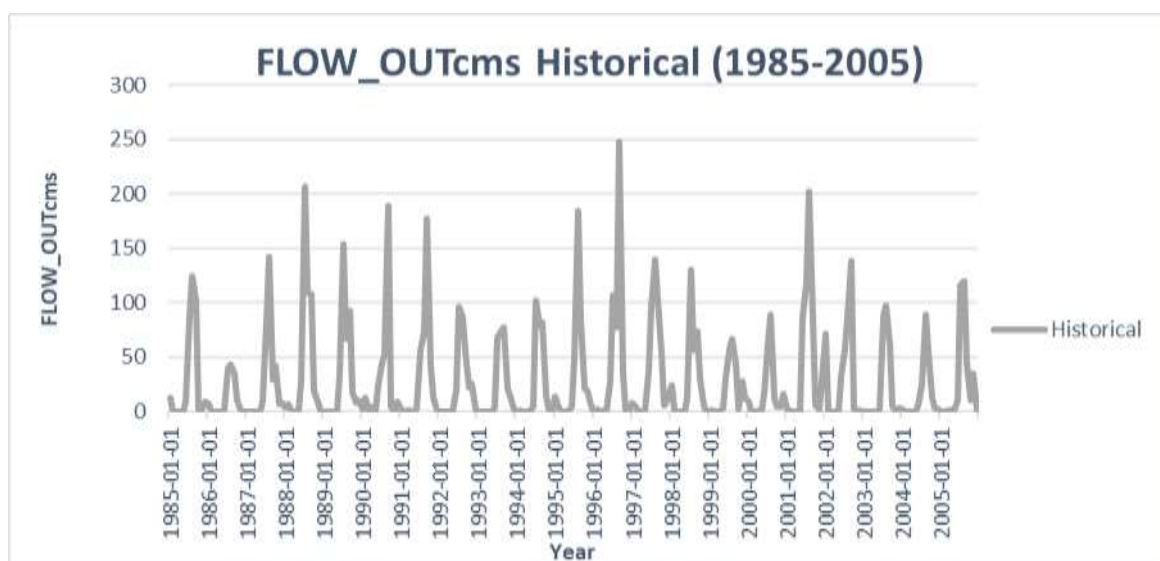


Figure 7.27: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.7. Mahisagar Observation site

Mahi Bajaj Sagar Dam is a dam across the Mahi River. It is situated at 16 kilometres from Banswara town in Banswara district Rajasthan, India. The dam was constructed between 1972 and 1983 for the purposes of hydroelectric power generation and water supply. It is the longest dam and second largest dam in Rajasthan. It is named after Jamnalal Bajaj. It is the biggest multipurpose project for tribal area of Rajasthan.

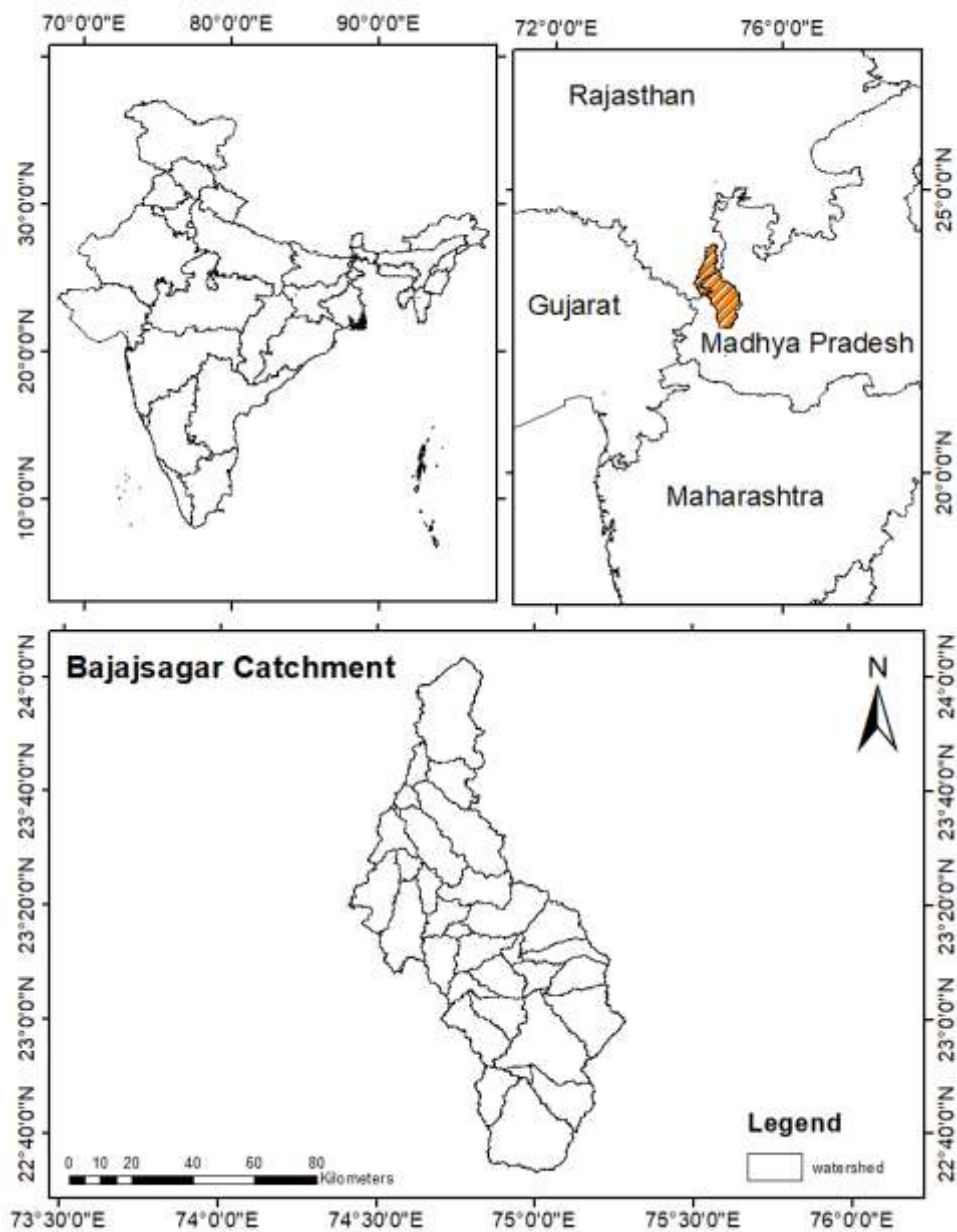


Figure 7.28: Mahi Bajaj Sagar Station

Digital Elevation Model

Table 7.54 Details of digital elevation model for Mahi Bajaj Sagar Observation site

Minimum Elevation	244m
Maximum Elevation	614m
Mean elevation	430.55m
Standard Deviation	70.32m

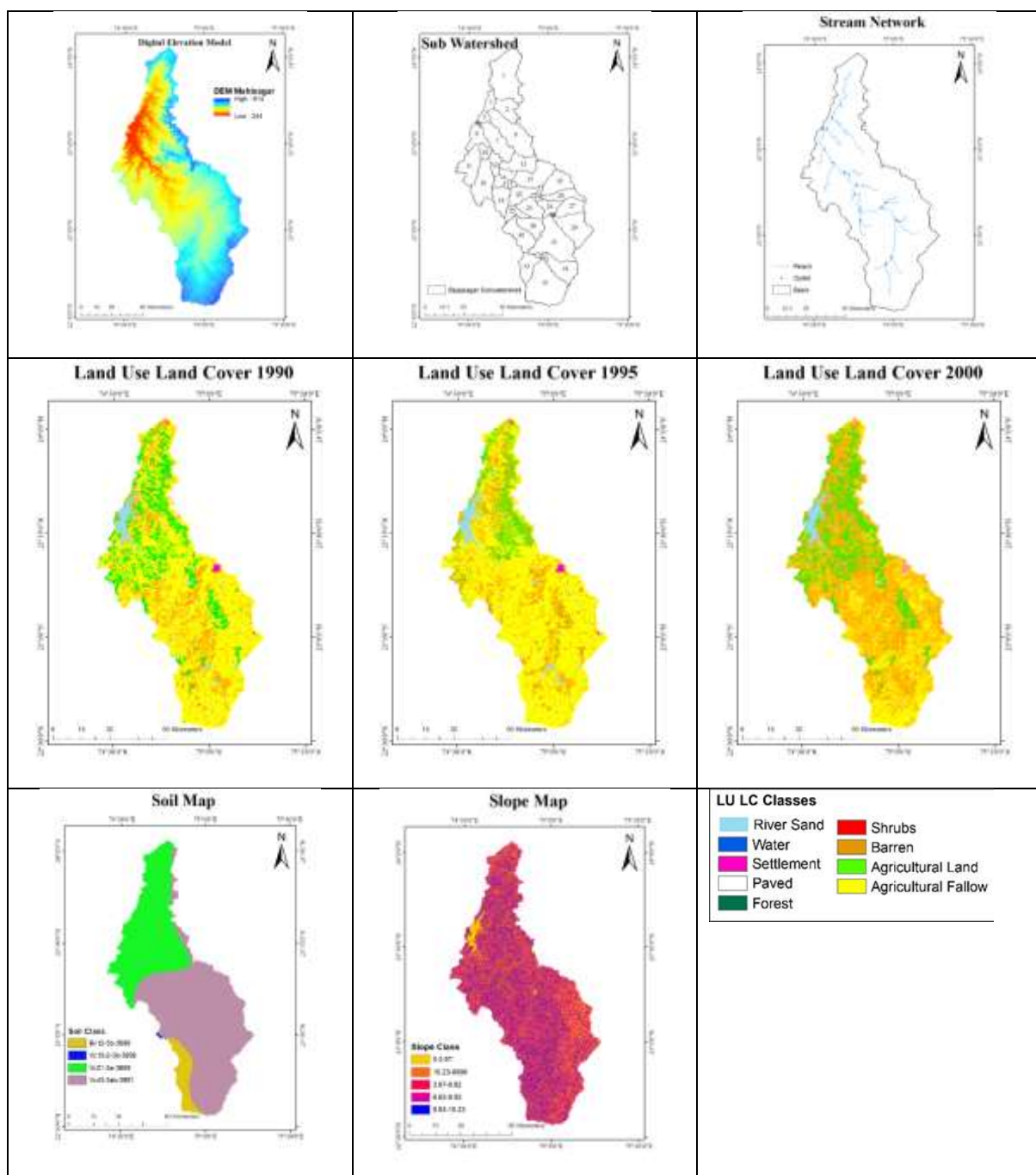


Figure 7.29: Watershed characteristics for Bajajsagar observation site

Subbasin

Table 7.55 Details of Subbasins for Mahi Bajaj Sagar observation site

Number of subbasin	35
Maximum Area	534.23 Km ²
Minimum Area	2.14Km ²
Mean Area	184.35Km ²
Standard Area	140.51 Km ²

Table 7.56 Details of Stream network for Mahi Bajaj sagar observation site

Number of Streams	35
Maximum Length	487 Km
Minimum Length	154.53 Km
Average Length	158.80Km
Standard Deviation	100.03 Km

Landuse Landcover

Table 7.57 Landuse and Landcocer class distribution for Mahi bajaj sagar observation site

Land use classes	LU_SWAT code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	104.97	1.23	79.51	0.93	165.87	1.95
Paved	URLD	1.74	0.02	6.4	0.08	17.5	0.21
Settlement	URHD	23.99	0.28	29.51	0.35	19.11	0.22
Forest	FRSD	347.82	4.08	707.92	8.31	1413.93	16.59
Shrub	RNGB	117.19	1.37	41.79	0.49	406.56	4.77
Barren	BARR	3888.86	45.62	5765.54	67.64	3389.33	39.76
Agriculture land	AGRR	782.1	9.18	789.28	9.26	867.3	10.17
Fallow land	AGRC	3209.68	37.66	1022.35	11.99	2160.62	25.35
Sand	WETN	47.52	0.56	81.58	0.96	83.66	0.98

Soil Data

Table 7.58 Soil Class distribution for Mahi Bajaj Sagar Observation site

Soil Type	Area in Km²
Vc43-3ab-3861	58.46
Vc21-3a-3859	35.85
Vc13-2-3b-3858	0.10
Bv12-3b-3696	5.59

Slope

Table 7.59 Details of slope distribution for Mahi Bajaj sagar observation site

Slope in Percentage Rise	Area in Km²
0.00-3.97	1346.48
3.97-6.62	994.11
6.62-9.93	1403.49
9.93-15.23	1359.71
15.23-999	1180.60

Simulation Details

Table 7.60 Details of simulation for Mahi Bajaj Sagar observation site

Simulation Length	25 Years
Warm Up Period	4 Years
Number of HRUs	1095
Number of Subbasins	35
Output Time step	Monthly
Basin Area	6284.41 Km ²
Precipitation data	Measured

Water Balance Components

Table 7.61 Annual average water balance and their value for Mahi Bajaj Sagar observation site

Description	Values in mm
Precip	980.2
Surface runoff Q	200.93
Lateral soil Q	13.4
Tile Q	0.00
Groundwater Q	237.86
Revap (shal aq => soil/plants)	36.43
Deep aq recharge	13.71
Total water yield	452.23
Percolation out of soil	274.29
ET	510.3
PET	1903.8

Water Balance components ratio

Table 7.62 Water balance components ratio for Mahi Bajaj Sagar observation site

Water balance components	Ratio
Streamflow /Precipitation	0.45
Baseflow/Total flow	0.54
Surface runoff/Total flow	0.46
Percolation/Precipitation	0.28
Deep recharge	0.01
Evapotranspiration/Precipitation	0.52

Continuity Error

Total flow = surface runoff + base flow = 438.52mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $980.2 + 36.43 = 1016.63 \text{ mm}$

Total outflow = $200.93 + 13.4 + 237.86 + 510.3 = 962.49 \text{ mm}$

Continuity error = 5.33 %

Water Balance at Outlet

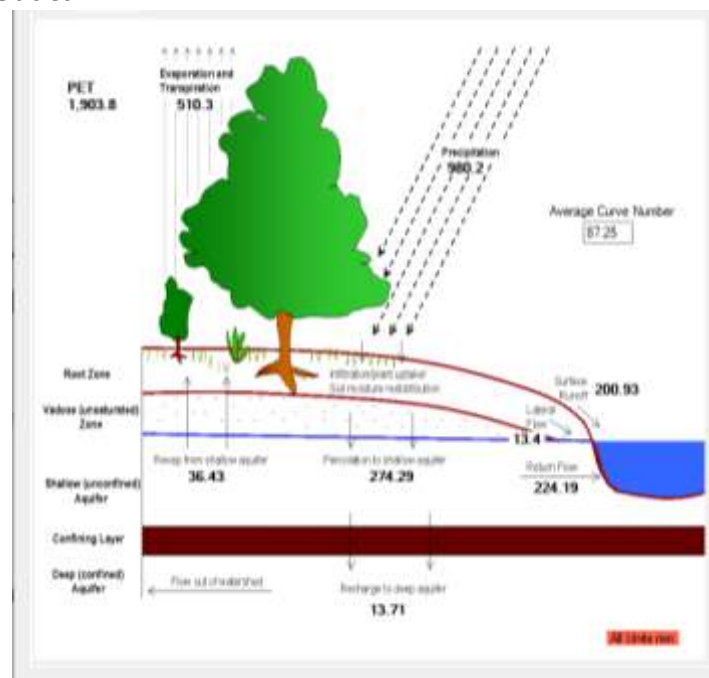


Figure 7.30: Water Balance Components at outlet of Bajajsagar station

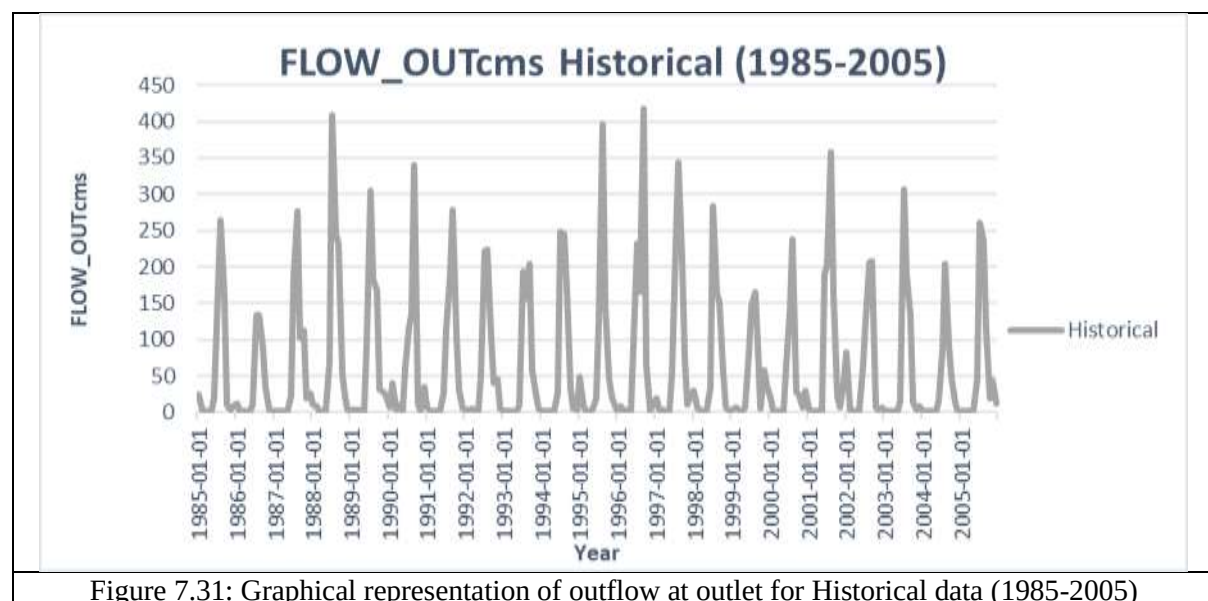


Figure 7.31: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.4.8. Kadana Observation site

Kadana is a village and tehsil in the Mahisagar district of the Indian state of Gujarat. It is situated on the riverbank of Mahi River. Kadana is the site of the Kadana Dam, which generates 240MW of hydroelectric power. The dam was built between 1979 and 1989 and is a part of Santrampur.

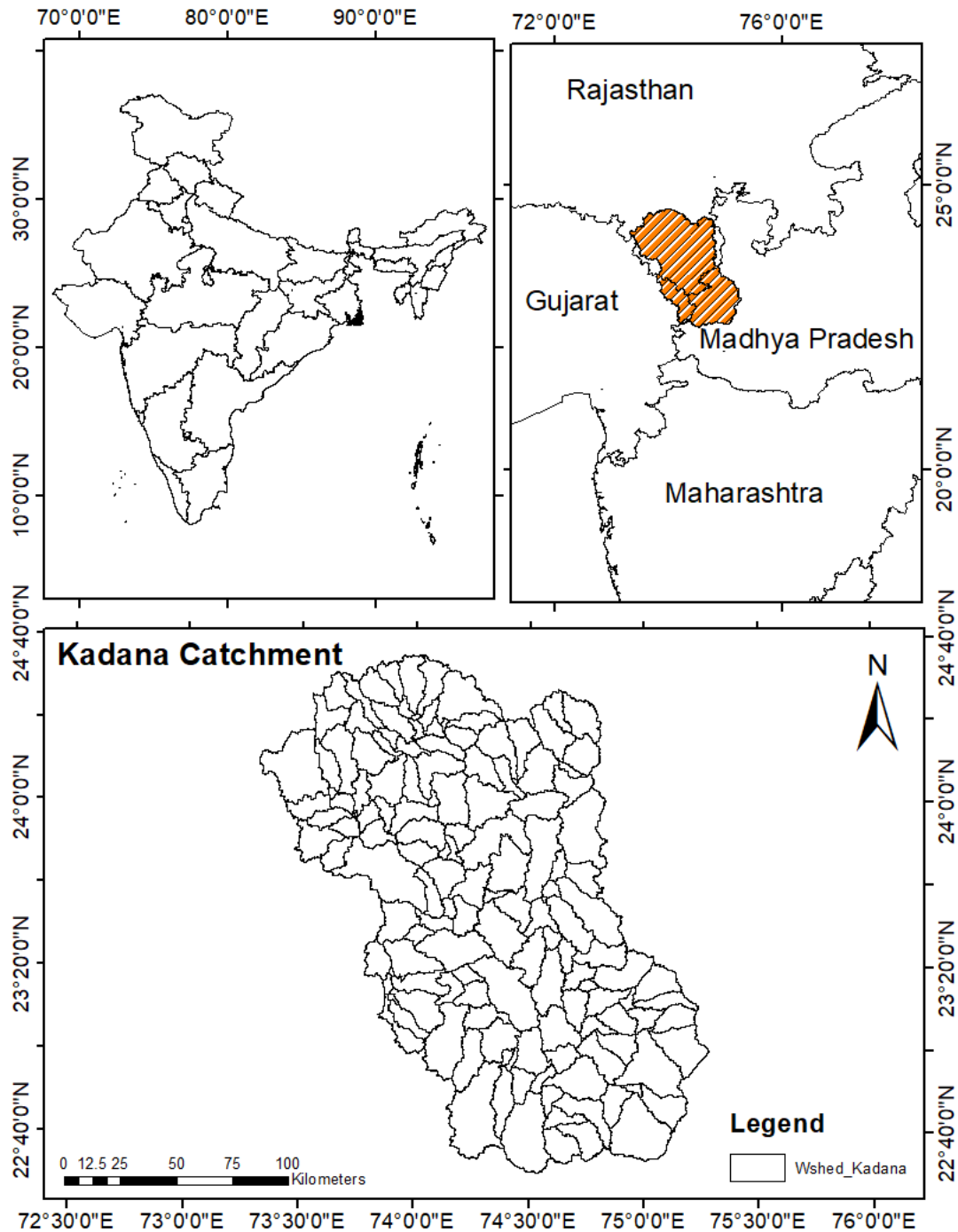
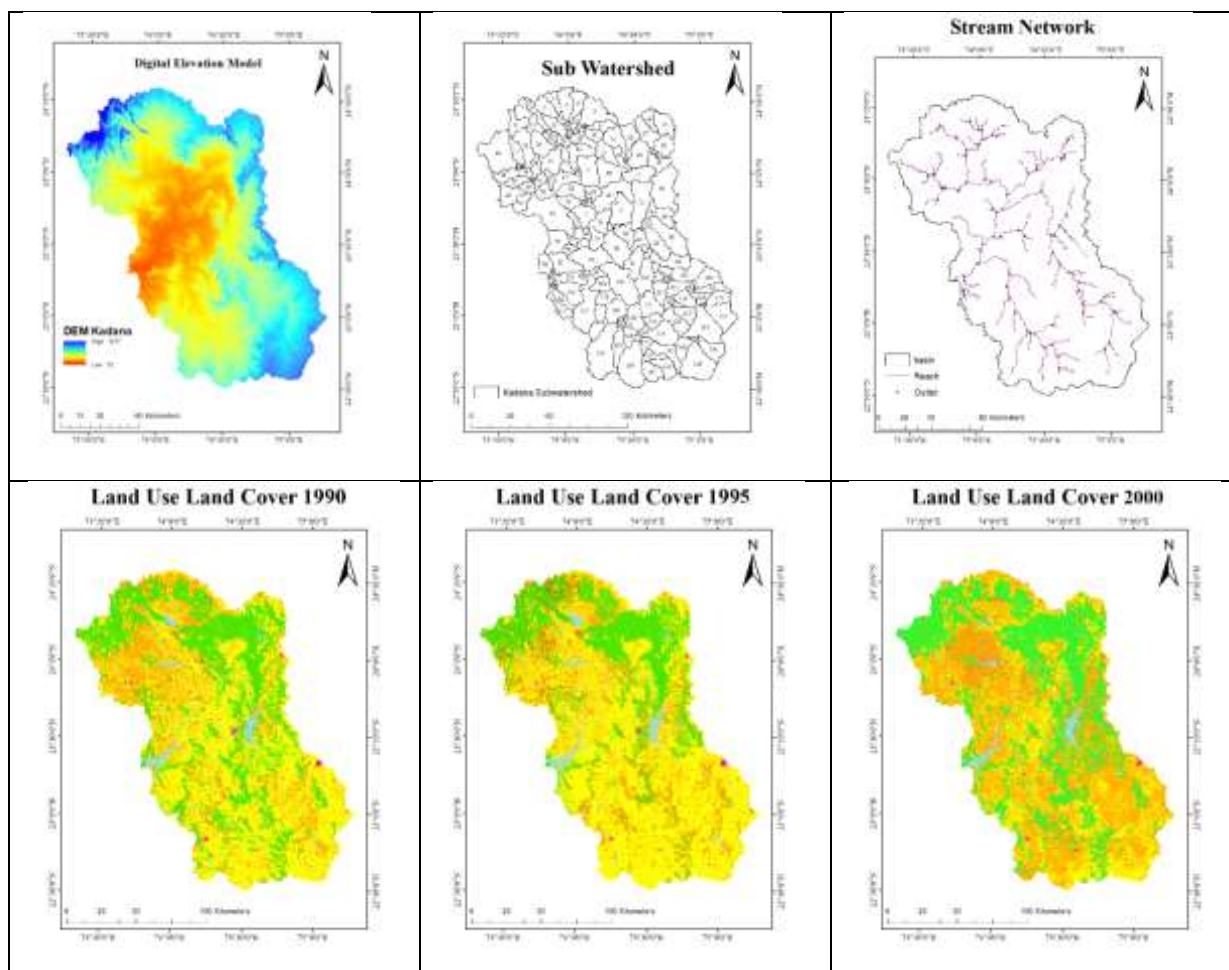


Figure 7.32: Kadana station

Digital Elevation Model

Table 7.63 Details of digital elevation model for Kadana observation site

Minimum Elevation	72m
Maximum Elevation	1017m
Mean Elevation	344.82m
Standard Deviation	119.52m



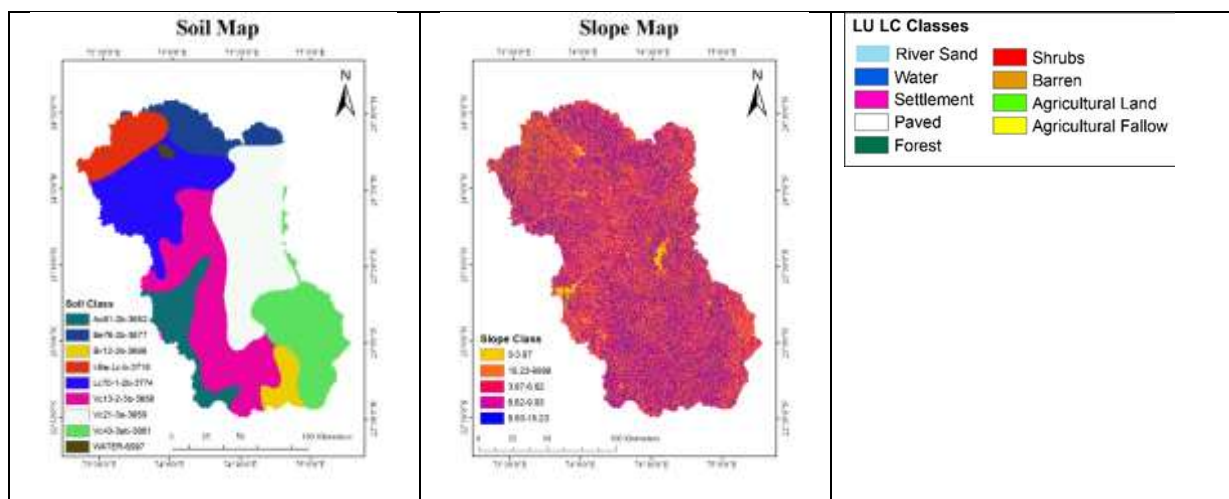


Figure 7.33 Watershed characteristics for Kadana observation site

Subbasin

Table 7.64 Details of subbasin for Kadan observation site

Number of subbasins	149
Maximum Area	696.98 Km ²
Minimum Area	1.10 Km ²
Average Area	176.69 Km ²
Standard Deviation	139.04 Km ²

Streams

Table 7.65 Details of stream network for Kadana observation site

Number of Streams	149
Maximum Length	515.44 Km
Minimum Length	5.85 Km
Average Length	148.75 Km
Standard deviation	108.10 Km

Table 7.66 Details of Stream Order for adana observation site

Stream Order	Length (Km)
1 st	499.83
2 nd	369.06
3 rd	128.70
4 th	72.12

Landuse and Landcover

Table 7.67 Landuse and landcover class distribution for Kadana observation site

Land use classes	LU_SWAT code	Area Sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	104.97	1.23	79.51	0.93	165.87	1.95
Paved	URLD	1.74	0.02	6.4	0.08	17.5	0.21
Settlement	URHD	23.99	0.28	29.51	0.35	19.11	0.22
Forest	FRSD	347.82	4.08	707.92	8.31	1413.93	16.59
Shrub	RNGB	117.19	1.37	41.79	0.49	406.56	4.77
Barren	BARR	3888.86	45.62	5765.54	67.64	3389.33	39.76
Agriculture land	AGR	782.1	9.18	789.28	9.26	867.3	10.17
Fallow land	AGRC	3209.68	37.66	1022.35	11.99	2160.62	25.35
Sand	WETN	47.52	0.56	81.58	0.96	83.66	0.98

(Chow; Applied hydrology, 1988)

Soil Data

Table 7.68 Soil Classes distribution for kadana observation site

Soil Type	Area in Km²
Ao81-2b-3652	1937.26
Be76-2b-3677	1790.32
Bv12-3b-3696	834.39
I-Be-Lc-b-3716	1656.28
Lc70-1-2b-3774	4515.38
Vc13-2-3b-3858	5691.66
Vc21-3a3859	5714.23
Vc43-3ab-3861	3748.81
WATER-6997	93.27

Slope

Table 7.69 Details of slope distribution for Kadana observation site

Slope in percentage Rise	Area in Km²
0.00-3.97	5064.08
3.97-6.62	4977.85
6.62-9.93	5494.66
9.93-15.23	5484.30
15.23-999	4960.68

Simulation Details

Table 7.70 Details of simulation for Kadana observation site

Simulation Length	25 Years
Warm Up period	4 Yeras
Number of HRUs	9520
Number of Subbasins	149
Output time step	Monthly
Basin Area	25981 Km ²
Precipitation Data	Measured

Water Balance components

Table 7.71 Average annual water balance components for Kadana observation site

Description	Values in mm
Precip	871.2
Surface runoff Q	145.47
Lateral soil Q	15.93
Tile Q	0.00
Groundwater Q	197.95
Revap (shal aq => soil/plants)	38.56
Deep aq recharge	11.83
Total water yield	360
Percolation out of soil	236.51
ET	495.6
PET	2011.2

Water Balance components ratio

Table 7.72 Water balance components ratio for Kadana observation site

Water Balance Components	Ratio
Streamflow/Precipitation	0.40
Baseflow/Total flow	0.58

Surface runoff /Total flow	0.42
Percolation/Precipitation	0.27
Deep recharge/Precipitation	0.01
Evapotranspiration/Precipitation	0.57

Continuity Error

Total flow = surface runoff + base flow = 348.19 mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Total Inflow = $871.2 + 38.56 = 909.76$ mm

Total outflow = $145.47 + 15.93 + 197.95 + 495.6 + 11.83 = 866.78$ mm

Continuity error= 4.73 %

Water Balance at Outlet

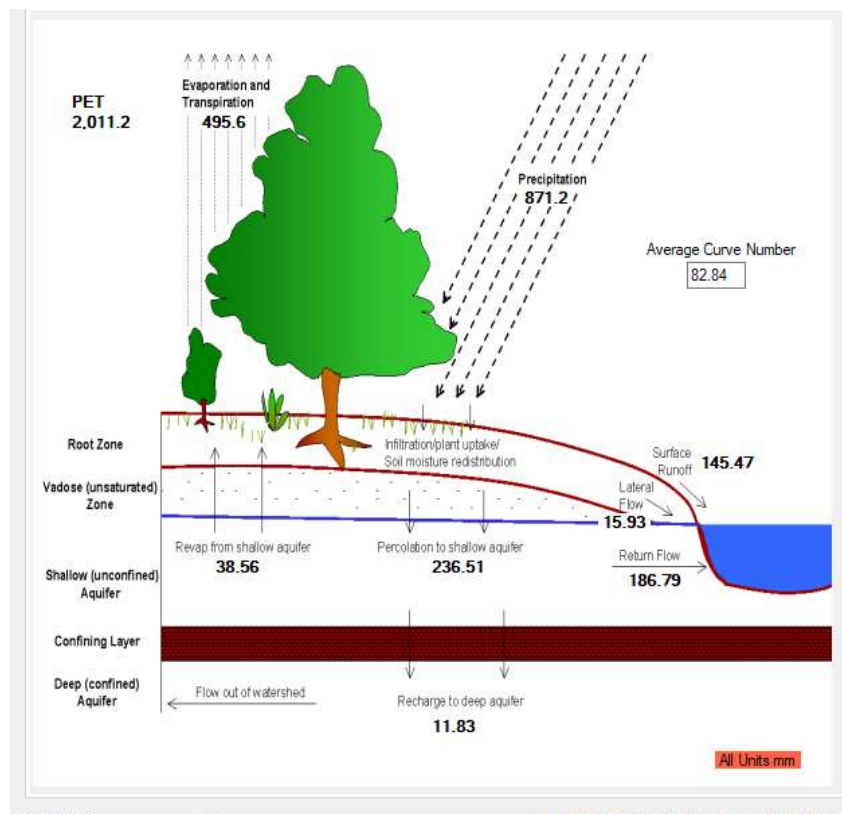


Figure 7.34: Water Balance Components at outlet of Kadana station

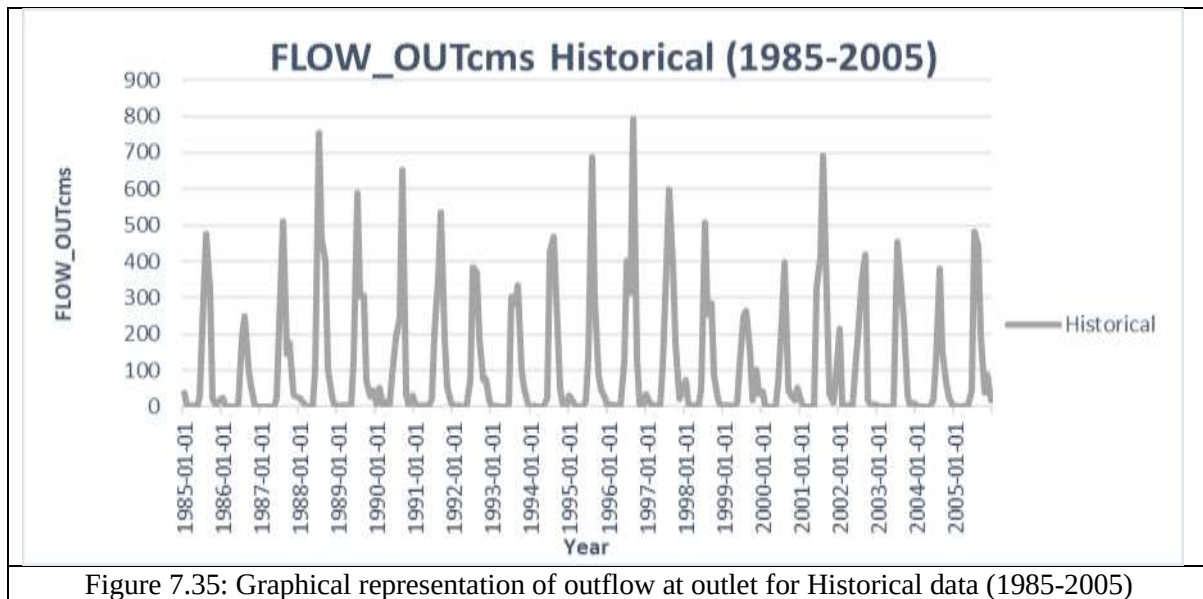


Figure 7.35: Graphical representation of outflow at outlet for Historical data (1985-2005)

Calibration and Validation of the Model

7.4.9. Panam Observation Site

The Panam Dam is constructed over the Panam River in India. It is located at Santrampur Taluka of Mahisagar district in Gujarat state. Panam is a tributary of the Mahi River, it originates from Devgad Baria Taluka of Dahod district. The Panam river merges with the Mahi river 25 kilometres (16 mi) downstream of the Panam Dam.

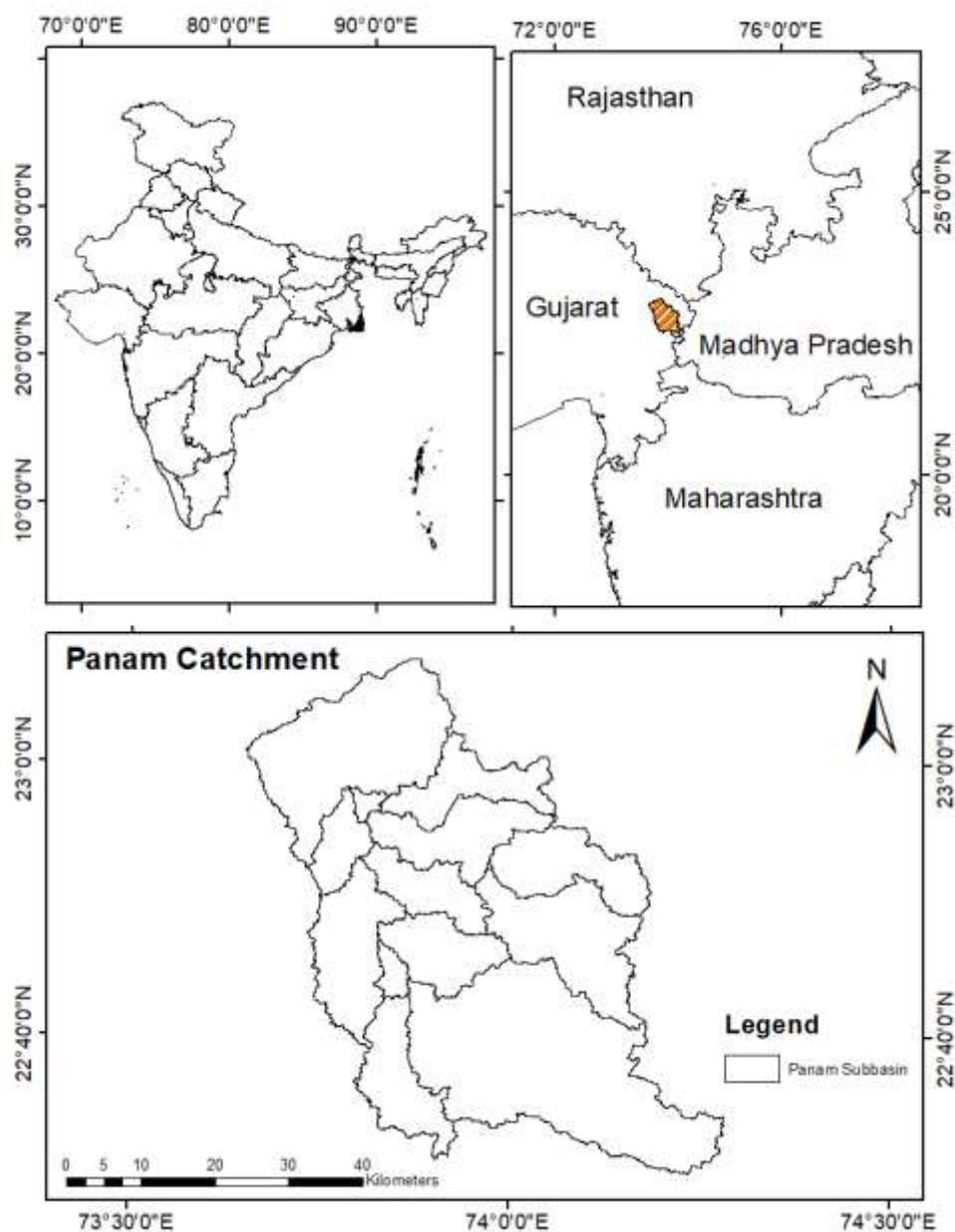


Figure 7.36: Panam station

Digital Elevation Model

Table 7.73 Details of digital elevation model for Panam observation site

Minimum Elevation	90m
Maximum Elevation	680m
Mean elevation	230.48
Standard Deviation	85.68

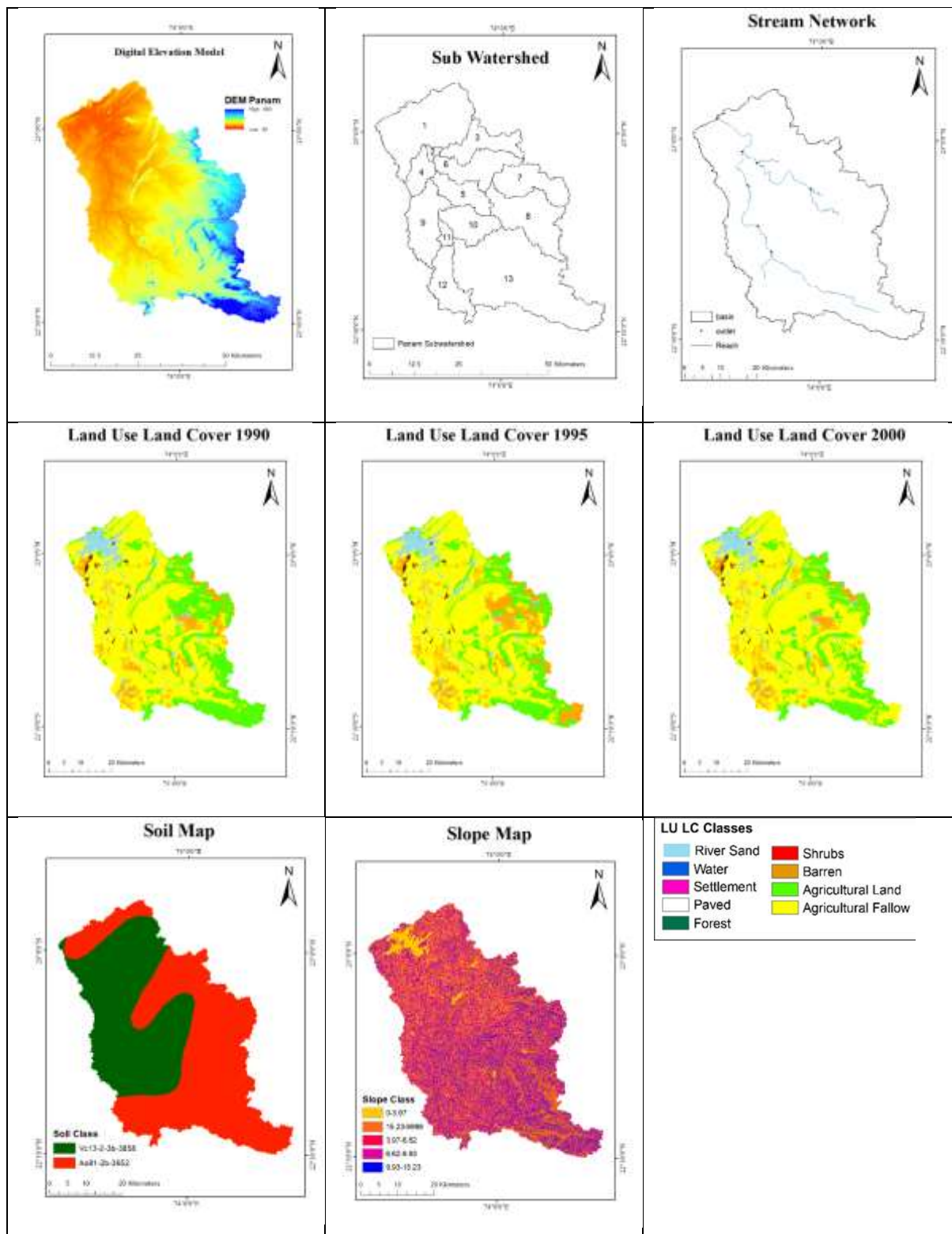


Figure 7.37 Watershed characteristics for Panam observation site

Subbasin

Table 7.74 Details of subbasin for Panam observation site

Number of Subbasins	13
Maximum Area	665.90 Km ²
Minimum Area	12.72 Km ²
Average Area	202.01 Km ²
Standard Deviation	166.86 Km ²

Stream Network

Table Details of stream network for Panam observation site

Number of streams	13
Maximum length	405.76 Km
Minimum length	8.35 Km
Average length	142.68 Km
Standard deviation	104 Km

Stream Order

Table 7.75 Details of stream order for Panam observation site

Stream Order	Length (Km)
1 st	209.25
2 nd	42.15
3 rd	80.16
4 th	14.37

Landuse Landcover

Table 7.76 Landuse and landcover class distribution for Panam observation site

Land use classes	LULC_SW AT code	Area sq. km					
		1990	Area %	1995	Area %	2000	Area %
Waterbody	WATR	104.97	1.23	79.51	0.93	165.87	1.95
Paved	URLD	1.74	0.02	6.4	0.08	17.5	0.21
Settlement	URHD	23.99	0.28	29.51	0.35	19.11	0.22
Forest	FRSD	347.82	4.08	707.92	8.31	1413.93	16.59
Shrub	RNGB	117.19	1.37	41.79	0.49	406.56	4.77
Barren	BARR	3888.86	45.62	5765.54	67.64	3389.33	39.76
Agriculture land	AGRR	782.1	9.18	789.28	9.26	867.3	10.17
Fallow land	AGRC	3209.68	37.66	1022.35	11.99	2160.62	25.35
Sand	WETN	47.52	0.56	81.58	0.96	83.66	0.98

(Chow; Applied hydrology, 1988)

Soil Data

Table 7.77 Soil Class distribution for Panam observation site

Soil Type	Area In Km ²
Ao81-2b-3652	1345.275
Vc13-2-3b-3858	1006.303

Slope

Table 7.78 Details of slope distribution in Panam observation site

Slope in Percentage Rise	Area in Km²
0.00-3.97	354.55
3.97-6.62	367.33
6.62-9.93	497.78
9.93-15.23	560.42
15.23-999	571.50

Simulation Details

Table 7.79 Details of simulation for Panam observation site

Simulation Length	25 Years
War Up Period	4 Years
Number of HRUs	874
Number of Subbasins	13
Output Time step	Monthly
Basin Area	2351 Km ²
Precipitation Data	Measured Data

Water Balance Components

Table 7.80 Water Balance components and their values for Panam observation site

Water Balance components	Values in mm
Precipitation	939.40
Surface Runoff	156.93
Lateral Soil flow	17.67
Tile flow	0.00
Groundwater flow	234.52
Revap(Shall=>Soil/Plants)	38.74
Deep aq. Recharge	13.66
Total water yeild	410.00
Percolation out of soil	273.26
ET	528.70
PET	2059.1

Simulation Details

Table 7.81 Details of simulation for Panam observation site

Water balance components	Ratio
Streamflow /Precipitation	0.42
Baseflow/Total flow	0.6
Surface runoff/Total flow	0.4
Percolation/Precipitation	0.29
Deep recharge/Precipitation	0.01
Evapotranspiration/Precipitation	0.56

Continuity Error

Total flow = surface runoff + base flow = 395.46mm

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM mannual)

Total Inflow = $939.4 + 38.74 = 978.14$ mm

Total outflow = $156.93 + 17.67 + 234.52 + 528.7 + 13.66 = 951.48$ mm

Continuity error= 2.73 %

Water Balance at Outlet

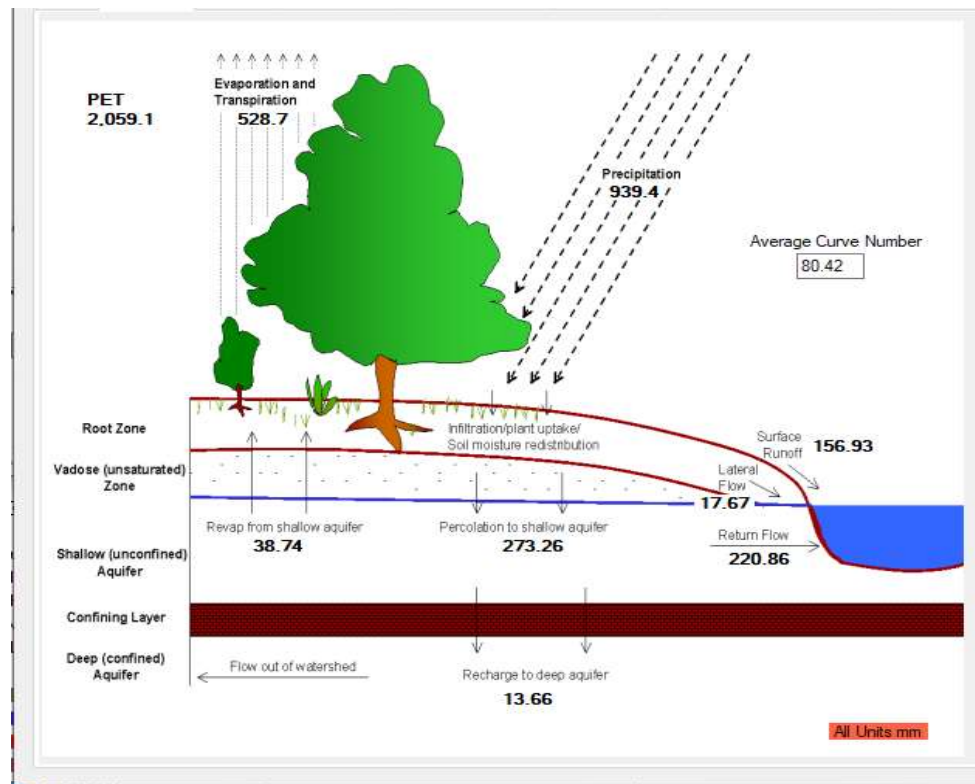


Figure 7.38: Water Balance Components at outlet of Panam station

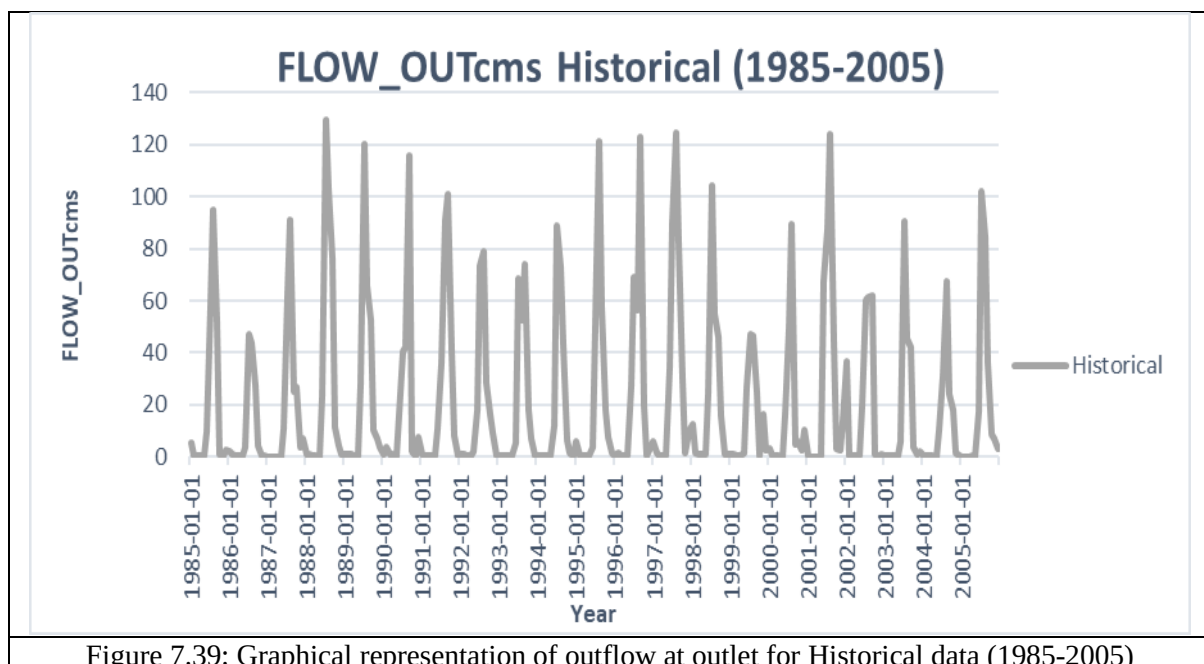


Figure 7.39: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.5 Calibration and Validation of the Model

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions.

The SWAT model uses the water balance equation as a driving force behind everything that happens in the watershed on a daily basis. The USDA SCS runoff curve number is used to estimate surface runoff from daily precipitation. An improved dynamic curve number method is used which automatically adjusts the curve number on the basis of the moisture conditions prevailing in the watershed. Auto calibration techniques have been adopted using SWAT CUP which provide the essential information like sensitive parameters, range or value that has to be applied to various parameters to arrive at optimum parameter value. This study used built in interfaces of these tools in the SWAT model to identify important hydrologic controlling parameters, optimize them and test the calibrated model using various performance indices and input data sets, and document SWAT model application techniques, in order to highlight area of hydrologic modelling improvement.

After running auto calibration process the application provides sensitive parameters which are controlling the hydrological processes. The sensitive parameters are given below in the table:

Table 7.82 Sensitive Parameters controlling the hydrological process

Parameter	Description	Units
CN2	Curve number (Management operations)	
GW_DELAY	Groundwater delay (Groundwater)	Days
ALPHA_BF	Baseflow alpha factor (Groundwater)	Days
GW_REVAP	Groundwater "revap" coefficient (Groundwater)	
RCHRG_DP	Deep aquifer percolation fraction (Groundwater)	
SOL_K()	Saturated hydraulic conductivity (Soil)	mm/hr
CH_K2	Effective hydraulic conductivity in main channel alluvium	mm/hr
ESCO	Soil evaporation compensation factor (Evapotranspiration)	
SOL_AWC()	Available water capacity of the soil layer (Soil)	
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur	mm
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (Groundwater)	mm

These parameters is broadly falls under two categories:

- **General Parameters:** Values of which are applied to the entire basin which include Groundwater delay, deep aquifer percolation factor and ESCO.
- **Catchment Specific Parameter:** Values of these parameters are area specific which include soil parameters like Soil permeability and available moisture content and management parameters like CN, irrigation source etc.

The soil in the Mahi Basin is predominantly Sandy Loam. After various simulation and parameter calibrations it was found that groundwater parameters were most sensitive in this region. Generally the model takes default values according to the provided input data (landuse, soil profile, DEM, reservoir details, etc.). The model is then made to run with default values and then compared with observed data. After such comparison and looking at the flow regime of observed and simulated values, sensitive parameters were adjusted and a series of test runs were carried out to reach the optimum parameter value. There are a large number of parameters which operate during simulation. Out of them, some major parameters that were adjusted during calibration.

Model Performance

There are three main statistical parameters that are used for evaluating a hydrological model performance viz. Nash–Sutcliffe model efficiency coefficient (NSE), RSR, and co-efficient of determination (R^2).

The range of these parameters are presented in following Table 7.83

Table 7.83 Criteria for SWAT Model performance in hydrological modelling at basin scale

Performance	Nash–Sutcliffe Efficiency Coefficient(NSE)	RSR	Coefficient of Determination (R^2)
Unsatisfactory	$NSE < 0.50$	$RSR > 0.70$	$R^2 < 0.50$
Satisfactory	$0.50 \leq NSE < 0.65$	$0.60 < RSR < 0.70$	$0.50 \leq R^2 \leq 0.65$
Good	$0.65 < NSE < 0.75$	$0.50 < RSR < 0.60$	$0.65 < R^2 < 0.75$
Very Good	$0.75 < NSE < 1.00$	$0.00 < RSR < 0.50$	$0.75 < R^2 < 1.00$

Calibration validation has been performed at 6 river gauge stations in Mahi River basin.

SWAT-CUP Model

SWAT-CUP consists of a calibration and uncertainty program combined with the SWAT hydrological model. The program links many algorithms, like SUFI-2, Particle Swarm Optimization (PSO), Generalized Likelihood Uncertainty Estimation (GLUE), and Markov Chain Monte Carlo (MCMC) to perform uncertainty and sensitivity analyses. Parameter

optimization and calibration using an inverse problem always brings uncertainty, since it starts with the results and only then calculates the parameter values causing those results. In hydrology, we perform this often – therefore, the model’s results are inevitably uncertain. In this study, a sequential uncertainty fitting algorithm, referred to as SUFI-2 [23], is used for uncertainty analysis. Starting with the initial parameter ranges, SUFI-2 is iterated many times so that 95% prediction uncertainty band (95PPU) brackets most of the measured data (p factor), maintaining a small width band (r factor). Here is the step-by-step procedure to apply the SUFI-2 algorithm:

1. Decide the model’s objective function. Since there is no pre-conceived, unique formulation of the objective function, this choice depends on the purpose of the study and model. Here, we used Nash-Sutcliffe Efficiency (NSE) [17] as the objective function.
2. Select the absolute meaningful range of parameters. Due to a lack of knowledge of parameter distribution, we assumed that all parameters are uniformly distributed (Gaussian distribution) within their respective range.
3. Carry out sensitivity analysis for all parameters to identify their effects on the output variable.
4. Select initial ranges for parameters in the first round of Latin Hypercube sampling. A wide range is acceptable, since it is changeable and frequently updated.
5. Perform Latin Hypercube sampling [22], resulting in n parameter combination where n represents the number of simulation trials run. This number should be large (around 1000). The algorithm iterates n times and the output variable is saved. Then, the objective function is calculated for each simulation.
6. Calculate 95PPUs of predicted/output variable (here discharge) using n Latin Hypercube simulations. After, the fit is measured for output variable from the p factor, r factor, R_2 , and NSE. Ideally, p factor should be 100% and r factor 0 in actual circumstances, however, these numbers are near impossible. Thus, the values of p factor and r factor are accepted as around 70% and less than the standard deviation, respectively.
7. First sampling results would not, like the high value of r factor with 100% of the data, be within the 95PPU. Hence, further sampling with simultaneous updating of the parameters’ ranges is needed. The newer range would be less than the original range and would be such that it reduces the initial r factor.
8. Continue procedure until the resulting parameter ranges are at the optimum range to solve the problem. Otherwise, recheck the model’s structure and boundary conditions.

Table 7.84 Model Sensitivity analysis parameters results Parameter for Mataji observation site

Mataji			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.1068	-0.200	0.1991
2:V__ALPHA_BF.gw	0.5669	0.0000	0.5897
3:V__GW_DELAY.gw	28.9070	0.0000	284.7988
4:V__ESCO.bsn	0.5553	0.0000	0.6126
5:R__SOL_AWC(..).sol	0.1417	0.1374	0.7126
6:R__REVAPMN.gw	552.3552	197.7002	593.2999

Table 7.85 Model Sensitivity analysis parameters results Parameter for Khanpur observation site

Khanpur			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.0084	-0.1126	0.0958
2:R__ALPHA_BF.gw	0.5470	0.2734	0.8206
3:R__GW_DELAY.gw	107.5000	-88.7996	303.7996
4:R__GWQMN.gw	2585.0000	1292.0110	3877.9900
5:R__GW_REVAP.gw	0.1757	0.0978	0.2535
6:R__RCHRG_DP.gw	0.9910	0.4954	1.4866
7:R__SOL_K(..).sol	2.0000	-997.2020	1001.2020
8:V__CH_K2.rte	46.4991	-180.3520	273.3507
9:V__ESCO.bsn	0.7510	0.3754	1.1266
10:R__SOL_AWC(..).sol	0.8830	0.4414	1.3246
11:R__REVAPMN.gw	177.5000	16.2003	338.7997

Table 7.86 Model Sensitivity analysis parameters results Parameter for Dhariyabad observation site

Dharyabad			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.0122	-0.1183	0.0939
2:R__ALPHA_BF.gw	0.7545	0.37722	1.1318
3:R__GW_DELAY.gw	36.7500	-194.8920	268.3922
4:R__GW_REVAP.gw	0.0361	-0.0458	0.1181
5:R__RCHRG_DP.gw	0.5885	0.2942	0.8828
6:R__SOL_K(..).sol	25.0000	-962.5740	1012.5740
7:V__CH_K2.rte	111.74923	-82.4073	305.9057
8:V__ESCO.bsn	0.8875	0.4437	1.3313
9:R__SOL_AWC(..).sol	0.9975	0.4987	1.4963
10:R__REVAPMN.gw	475.75	237.8574	713.6426

Table 7.87 Model Sensitivity analysis parameters results Parameter for Chakaliya observation site

Chakaliya			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	0.1172	-0.0414	0.2758
2:R__ALPHA_BF.gw	0.9190	0.4594	1.3786
3:R__GW_DELAY.gw	347.5000	173.6998	521.3002
4:R__GWQMN.gw	2045.0000	567.0144	3522.9860
5:R__GW_REVAP.gw	0.0677	0.0015	0.1339
6:R__RCHRG_DP.gw	0.1190	-0.3216	0.5596
7:R__SOL_K(..).sol	218.0000	-673.2050	1109.2050
8:V__CH_K2.rte	118.4992	-72.3285	309.3270
9:V__ESCO.bsn	0.4750	0.2124	0.7376
10:R__SOL_AWC(..).sol	0.1730	-0.2406	0.5866
11:R__REVAPMN.gw	214.5000	71.6996	357.3004

Table 7.88 Model Sensitivity analysis parameters results Parameter for Mahi Bajaj Sagar observation site

Mahi Bajajsagar			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.1106	-0.1643	0.0787
2:V__ALPHA_BF.gw	0.4696	0.3274	0.9825
3:V__GW_DELAY.gw	520.6672	214.5488	583.8111
4:R__RCHRG_DP.gw	0.6900	0.3854	1.1566
5:R__SOL_K(..).sol	43.7927	-955.1971	1015.1971
6:V__CH_K2.rte	165.6226	149.1996	447.7996
7:V__ESCO.bsn	0.6705	0.1854	0.7286
8:R__SOL_AWC(..).sol	1.1249	0.4424	1.3276
9:R__REVAPMN.gw	203.5844	68.6997	356.3003
10:V__GWQMN.gw	0.7771	-0.8892	1.0372

Table 7.89 Model Sensitivity analysis parameters results Parameter for Rangeli observation site

Rangeli			
Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.1405	-0.2116	0.0716
2:R__ALPHA_BF.gw	0.8589	0.4610	1.4800
3:R__GW_DELAY.gw	626.0239	222.7289	702.2710
4:R__GWQMN.gw	4998.2905	1832.6533	5917.3467
5:R__GW_REVAP.gw	0.1210	0.06442	0.1646
6:R__RCHRG_DP.gw	0.5477	0.4449	1.4051
7:R__SOL_K(..).sol	1434.3689	735.6967	2364.3033

8:V__CH_K2.rte	169.2410	56.8936	368.1052
9:V__ESCO.bsn	0.3534	0.2473	0.8027
10:R__SOL_AWC(..).sol	0.442731	-0.1797	0.6297
11:R__REVAPMN.gw	104.944695	97.9681	377.0319

Table 7.90 Model Sensitivity analysis parameters results Parameter for Panam observation site

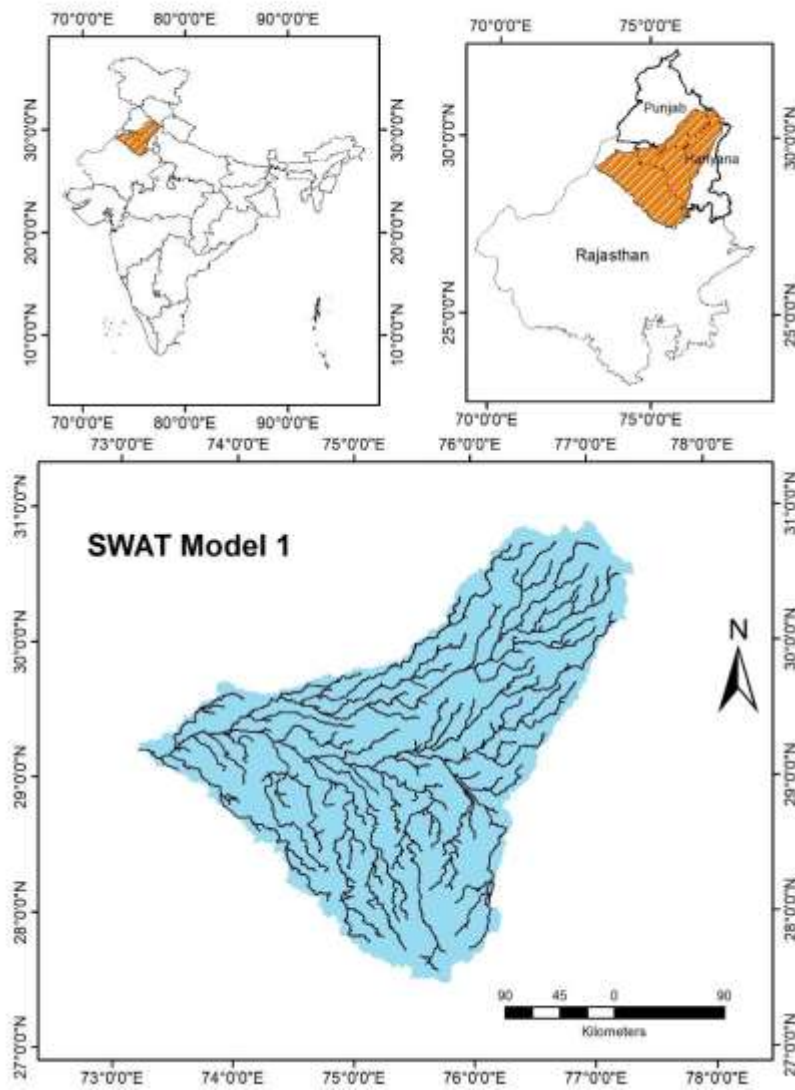
Parameter	Minimum	Maximum	Fitted value	Function
CN2.mgt	-0.14138	0.1358	0.9564	Multiply
ALPHA_BF.gw	0.31793	1.0638	0.6860	Add
GW_DELAY.gw	54.5476	444.0622	277.8914	Replace
GWQMN.gw	922.6972	3329.8397	2407.2670	Replace
GW_REVAP.gw	0.0295	0.16752	0.1001	Replace
RCHRG_DP.gw	0.2597	1.0981	0.5872	add
SOL_K(..).sol	-570.4960	1300.4962	344.6323	Replace
CH_K2.rte	-25.7990	340.8977	122.3222	Add
ESCO.bsn	0.2440	0.8899	0.6154	Add
SOL_AWC(..).sol	0.1832	1.0129	1.6270	Multiply
REVAPMN.gw	115.0209	456.0625	288.1057	Replace

7.5.1 Area of Inland Drainage

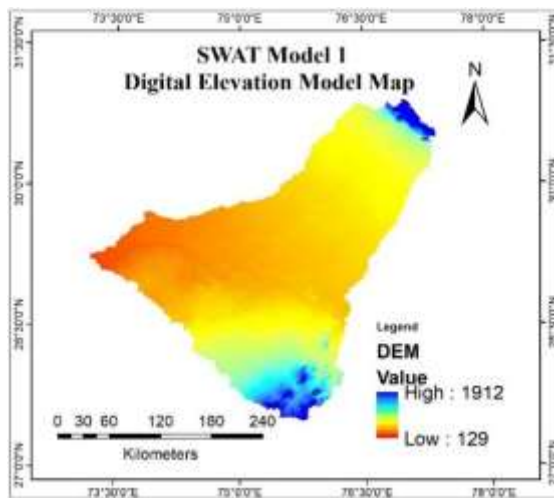
The basin spreads over the Rajasthan and Haryana state. It covers Major desert area and has shortage of water to generate river streams. Major parts of the AID are covered with river sand. In hydrological modelling of AID area, it is suitable to divide the whole area into smaller sub basins according to the delineation process of DEM data to generate a stream network. There are 18 Sub basins generated by the delineation process of DEM data. These 18 Sub basin locations shown in Figure 5.18. Prioritization of 18 Sub basins according to their size was done and selected all 18 models for Hydrological modelling study. Sub basins of AID Basin given their name randomly as shown in Table 7.91 and all sub sub basins have rank according to their size.

7.5.2 SWAT Model 1 of AID

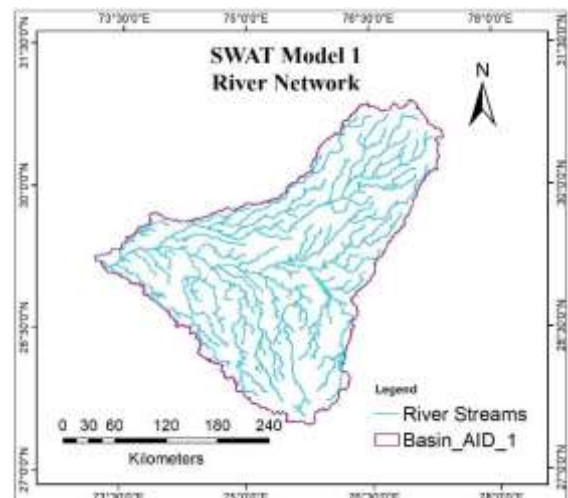
SWAT Model 1 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at 29°10'18" N 75°20'28" E. It is the largest sub basin of Inland drainage area according to Table no– rank assigned to each sub basin with area. In this area the main river channel flow direction is east to west. Total watershed area for the SWAT Model 1 of AID is 68100.61 Sq. km. The SWAT model for sub basin 1 of AID is simulated for 25 years from 1985 to 2005 with 4 years of warm up period.



SWAT Model 1 of AID



a



b

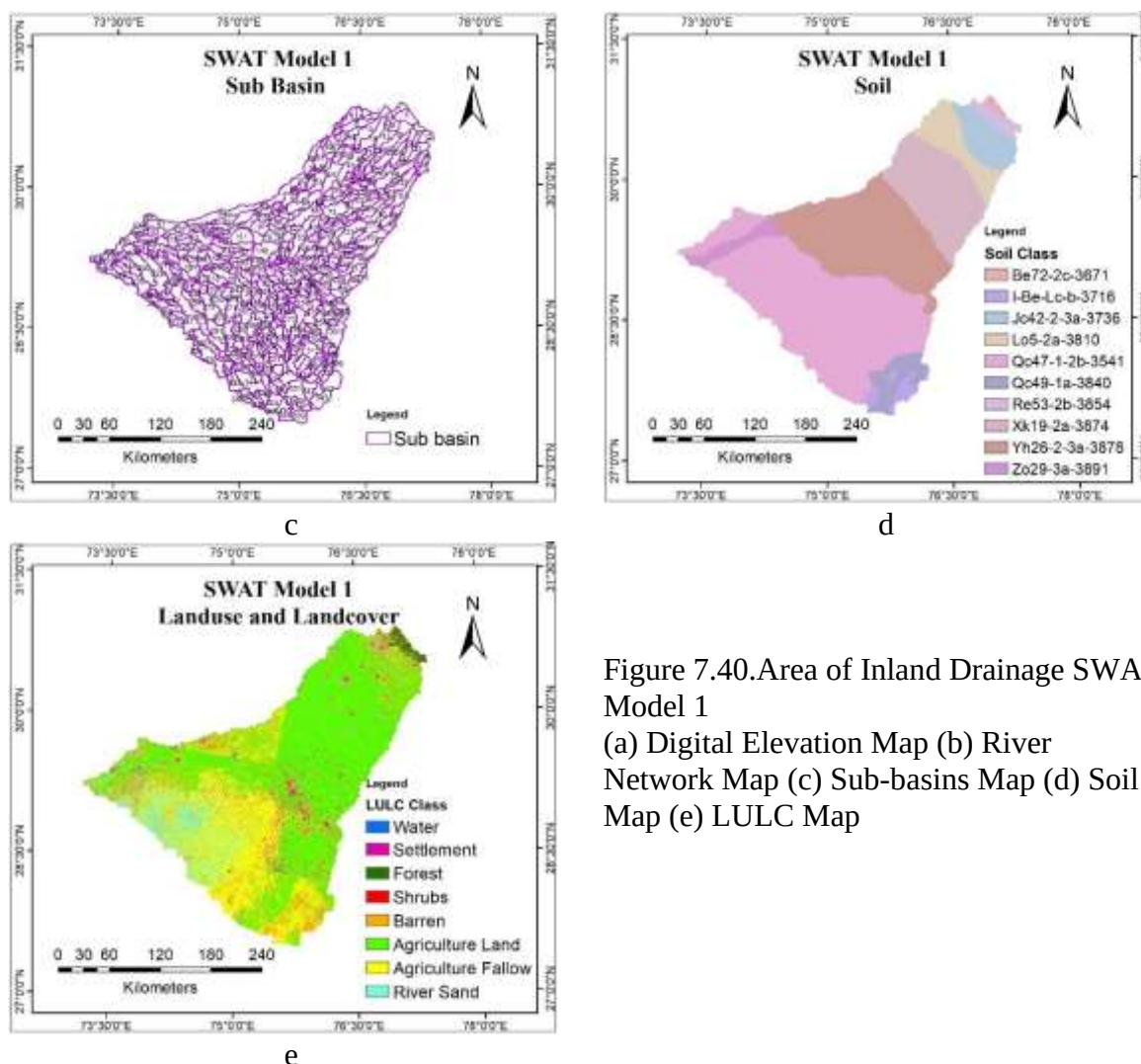


Figure 7.40. Area of Inland Drainage SWAT Model 1
(a) Digital Elevation Map (b) River Network Map (c) Sub-basins Map (d) Soil Map (e) LULC Map

Figure 7.40 (a) shows a digital elevation map for the area of inland drainage Sub-basins named SWAT model 1. The maximum elevation in the sub-basin is 1912 meters, and the minimum elevation is 129 meters. ASTER 30-meter DEM was adopted for the delineation of the watershed for the study area. It well represented the distribution of elevation across the sub-basin of Area of Inland drainage of Rajasthan Figure 7.40 (b) shows the river network in the Sub-basin 1 of the area of Inland drainage after delineation of watershed for SWAT model. It consists of 359 small streams, and all the streams have a total length of 7853.06 Km. Figure 7.40(c) shows the Sub-basin Map generated by SWAT model 1 for Area of Inland Drainage. There are 3961 HRUs obtained and 359 sub-basin in the SWAT model 1. Figure 7.40 (d) shows the Soil Map for SWAT Model 1. It is obtained from the Food and Agriculture Organization. There are ten classes covered in SWAT model 1. The code of soil given in the global database for the study area is used for swat model setup for hydrological modelling. A brief description of each code and its interpretation are given in the introduction section. Figure 7.40 (e) shows Landuse and landcover Map for Area of Inland Drainage Sub-basin 1, generated using the Satellite image of the year 2000. There are eight classes covered in the SWAT model 1 and has

a good distribution of all classes in the AID area. In sub-basin 1 of AID, Agriculture land is dominated, followed by agriculture fallow land as 48.43% and 27.27%, respectively. It is observed that there is less % coverage of water bodies, only 0.23% of the total area covered by SWAT model 1 basin. SWAT Model 1 Run for Historical and Future Period with five years of the warm-up period. Simulation length 25 years for the historical period (1985-2005), including the 4 years warm-up period. The number of HRUs is 3961, and the number of Sub basins in the Model is 359. SWAT model 1 output step taken as Monthly time step and total area of the basin is 68100.61 square kilometre.

Table 7.91 Criteria of dividing the AID area into smaller sub basins according to their area weightage

SNO.	AID Sub Bain Name	Area in Descending Order (Sq.Km)	Rank of sub basin
1	AID SWAT Model 1	68100.61	1
2	AID SWAT Model 2	19025.19	2
3	AID SWAT Model 3	15314.19	3
4	AID SWAT Model 4	15287.30	4
5	AID SWAT Model 7	12265.29.	5
6	AID SWAT Model 8	4663.18	6
7	AID SWAT Model 16	4268.00	7
8	AID SWAT Model 11	3883.66	8
9	AID SWAT Model 5	2718.70	9
10	AID SWAT Model 12	2518.67	10
11	AID SWAT Model 6	2112.50	11
12	AID SWAT Model 10	2014.69	12
13	AID SWAT Model 9	1991.29	13
14	AID SWAT Model 15	1716.61	14
15	AID SWAT Model 17	1706.09	15
16	AID SWAT Model 13	1619.00	16
17	AID SWAT Model 18	1303.00	17
18	AID SWAT Model 14	937.00	18

Table 7.92 Details of DEM for SWAT model 1 of AID

DEM Details	Meters
Min. Elevation	129
Max Elevation	1912
Mean Elevation	255.98
Standard Deviation	98.45
DEM Threshold Value	100 (Km ²)

Table 7.93 Details of river network for SWAT model 1 of AID

River Parameters	Description
No. of Stream	359
Total Length of all Streams	7853.064 km
No. of Sub-basin	359

Table 7.94 Details of LULC class distribution of SWAT Model 1 of AID

LULC Class	LULC Code	Area (km ²)	Sub basin share Area (%)
Water	WATR	147.3066	0.23
Settlement	URLD	2350.90	3.45
Forest-Deciduous	FRSD	663.84	0.97
Range-Brush	RNGB	620.44	0.91
Barren	BARR	6831.28	10.03
Agricultural Land-Row Crops	AGR	32983.62	48.43
Agricultural Land-Close-grown	AGRC	18571.50	27.27
Wetlands-Non-Forested	WETN	5931.68	8.71
Total		68100.60	100

Table No.7.95 Details of Soil class distribution for SWAT Model 1 of AID

FAO Soil Class	Area in (Km ²)	Sub basin share % Area
Be72-2c-3671	325.51	0.48
Re53-2b-3854	932.92	1.37
Jc42-2-3a-3736	3232.71	4.75
Lo5-2a-3810	3862.51	5.67
Xk19-2a-3874	9933.27	14.59
Yh26-2-3a-3878	16676.13	24.49
Qc47-1-2b-3541	27947.27	41.04
Zo29-3a-3891	1667.40	2.45
Qc49-1a-3840	2347.92	3.45
I-Be-Lc-b-3716	1174.91	1.73
Total	68100.60	100

Table 7.96 Details of Sub basin of SWAT Model 1 of AID

Sub basin details	Values
No of HRUs	3961
No of Sub basin	359
Watershed Area (Km ²)	68100.61

Table 7.97 Simulation Details of SWAT Model 1 of AID

Sub basin Simulation Details	Values
Simulation Length	25 Years
Warm up period	4 Years
Number of HRUs	3961
Number of Sub Basins	359
Output Time Step	Monthly
Precipitation Method	Measured
Watershed Area (Km2)	68100.61

Table 7.98 Average annual values generated by SWAT model 1 of AID for the period 1985-2005 for 25 years for water balance components.

Average Annual Sub basin water balance value	
Water Balance Component	Values in mm
Precipitation	488.9
Surface Runoff	140.9
Lateral Flow	2.5
Groundwater Shallow (Aq.)	34.93
Groundwater (Deep aq.)	2.75
Revap (Shal Aq.=>Soil/Plant)	20.17
Deep Aq. Recharge	2.76
Total Aq. Recharge	55.2
Total water Yield	181.08
Percolation Out from Soil	55.18
ET	292
PET	1387.7
Total sediment Loading	29.54t/ha

Water Balance calculations

Total flow = surface runoff + base flow = 140.9mm+34.93mm = 175.83mm

A preliminary check perform using the SWAT check tool which gives the ratio for the watershed parameters simulation for accuracy purpose. Table 7.99 shows water balance components ratio for SWAT model 1 of AID

Table 7.99 Details of Water balance components of SWAT Model 1 of AID

Water Balance Ratios	
Component	Ratio Value
Streamflow/Precipitation	0.36
Base flow /Total flow	0.21
Surface Runoff/Total flow	0.79
Percolation/precipitation	0.11
Deep Recharge/Precipitation	0.01
ET/Precipitation	0.6

The continuity error is calculated from total inflow and total outflow from the output database. A zero percent continuity error means the model is correct, continuity error less than 1 percent is an excellent continuity error, less than 2 percent is great and less than 5 percent was good or at least acceptable (SWMM manual) .

Continuity error

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity Error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity Error = $100 \times (1 - (127859.131 \div 127995.1))$

Continuity error = 0.10%

Water Balance at outlet of the watershed of Inland drainage area for SWAT model 1 as shown in figure--all the water balance component with the hydrological cycle is presented.

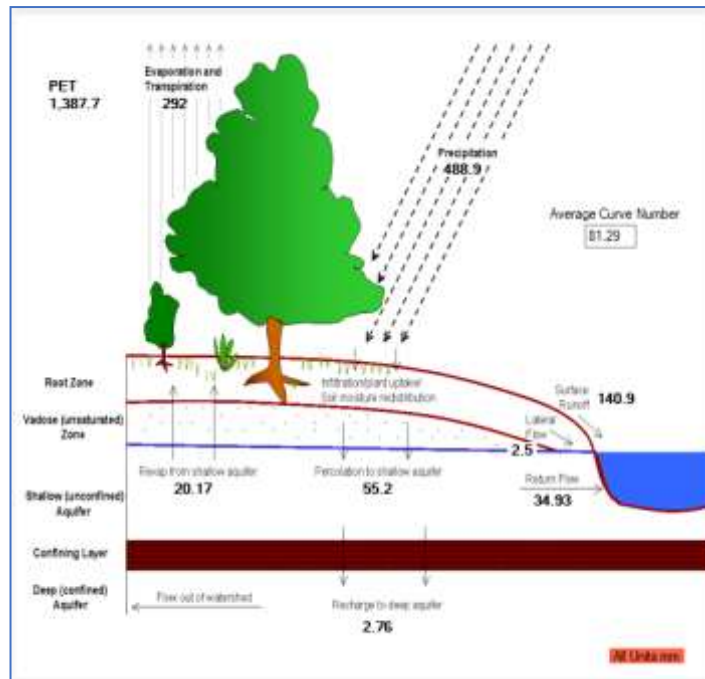


Figure 7.41: Pictorial representation of water balance components in SWAT model 1

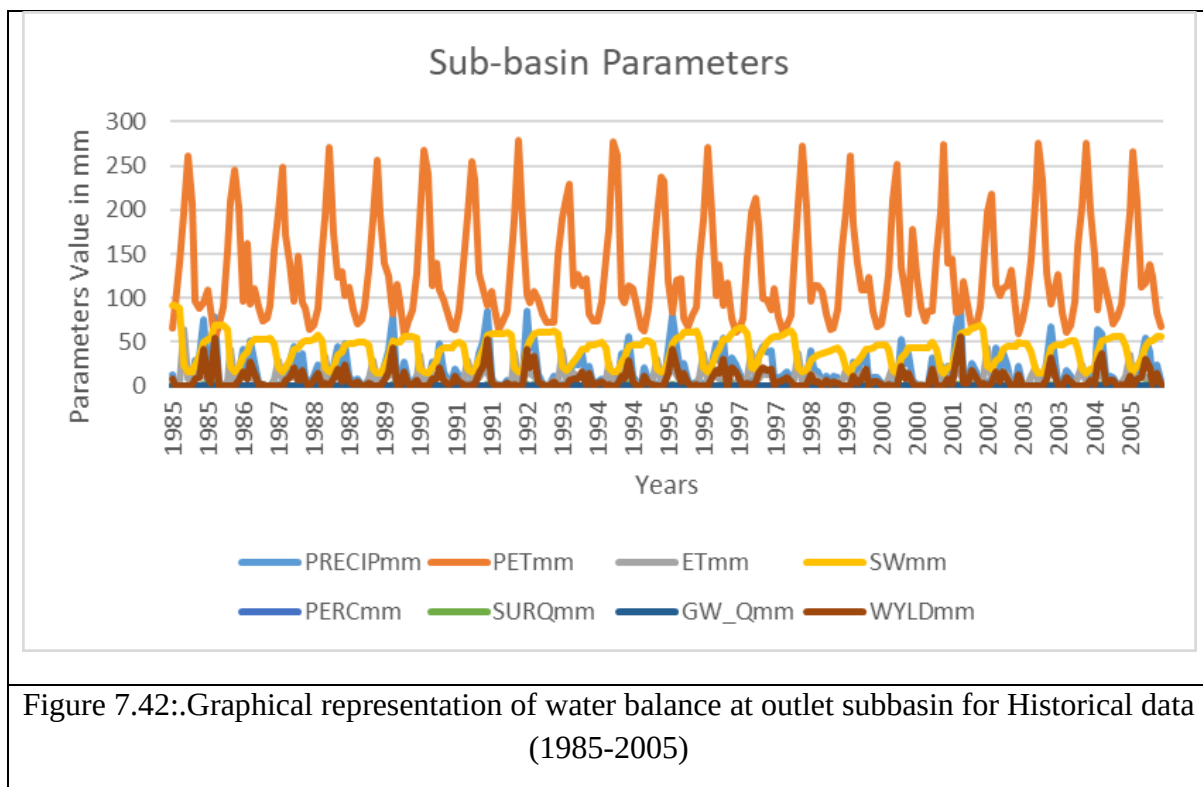


Figure 7.42: Graphical representation of water balance at outlet subbasin for Historical data (1985-2005)

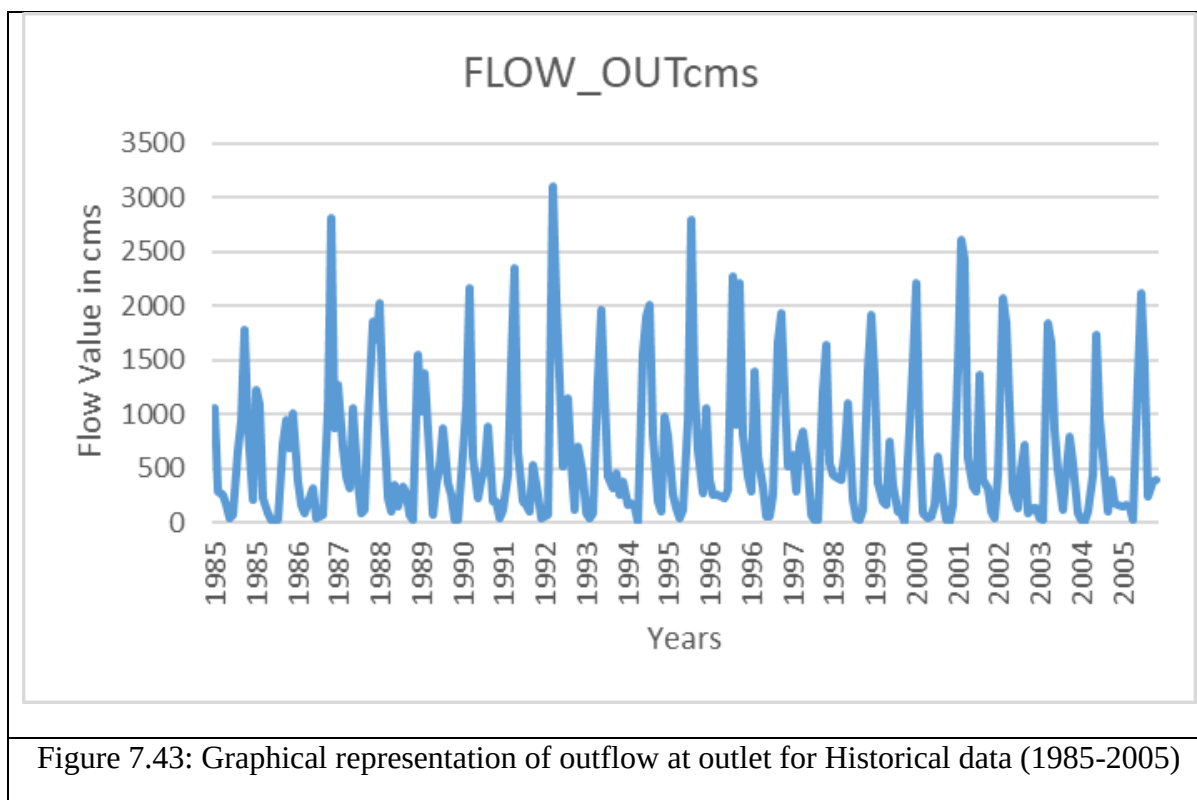


Figure 7.43: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.5.3 SWAT Model 2 of AID

SWAT Model 2 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at 28°2'2.56" N 73°33'29.78" E. It is the 2nd largest sub basin of inland drainage area. In this area the main river channel flow direction is east to west. Total watershed area for the SWAT Model 2 of AID is 19,025.19 Sq. km. The SWAT model for sub basin 2 of AID is simulated for 25 years from 1985 to 2005 with 4 years of warm up period.

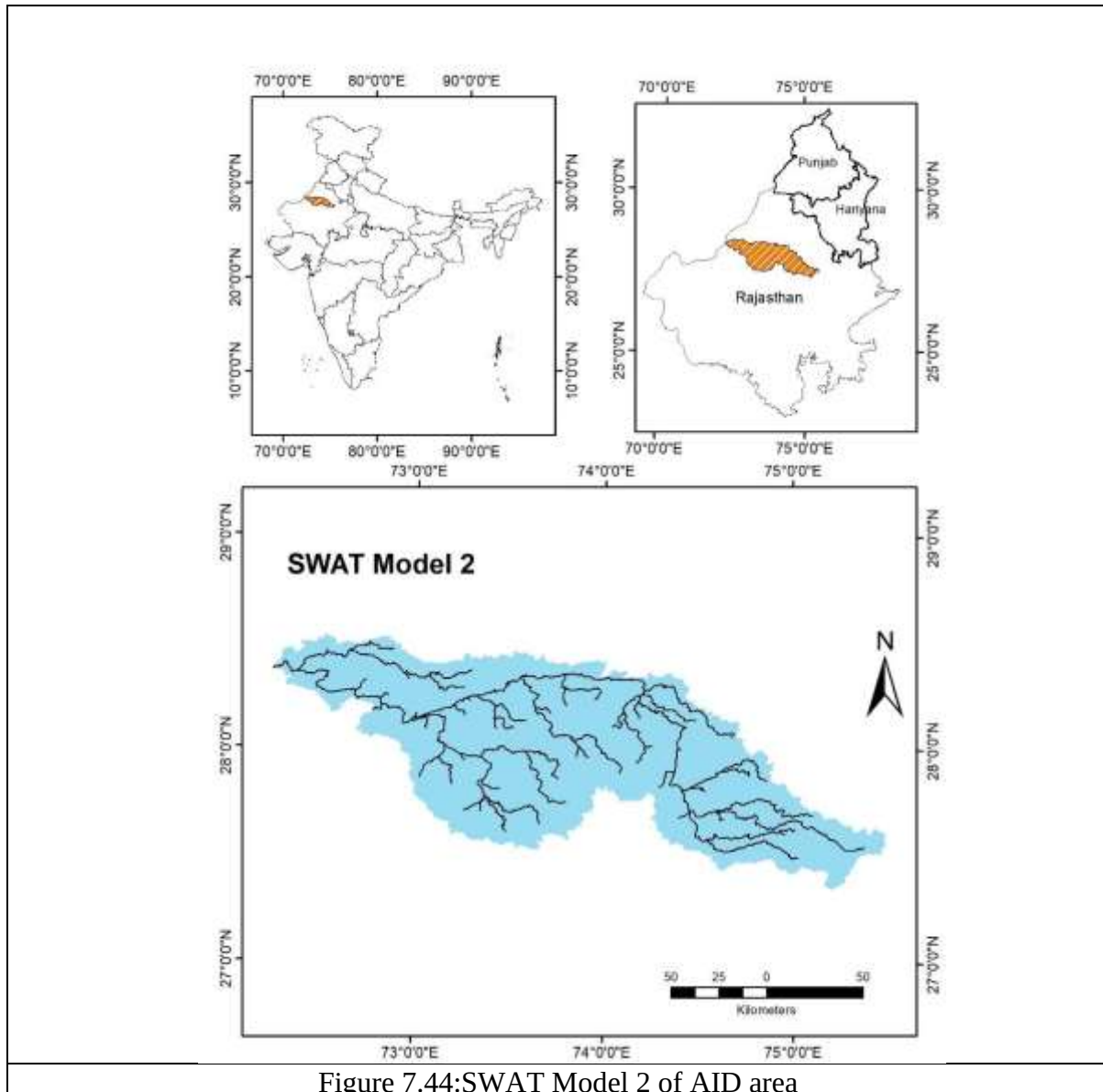
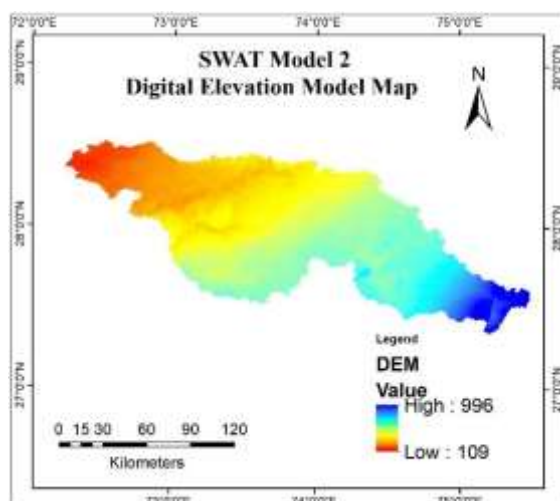
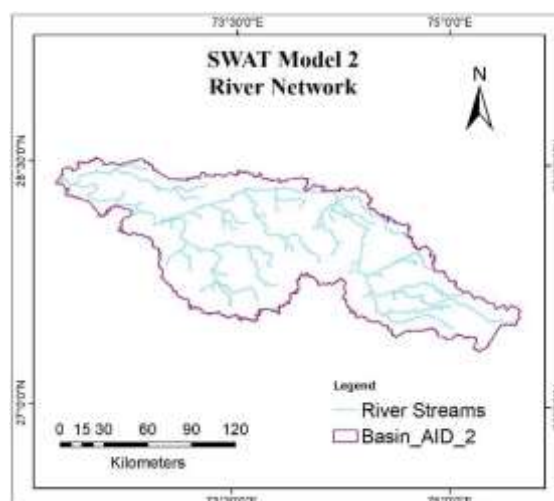


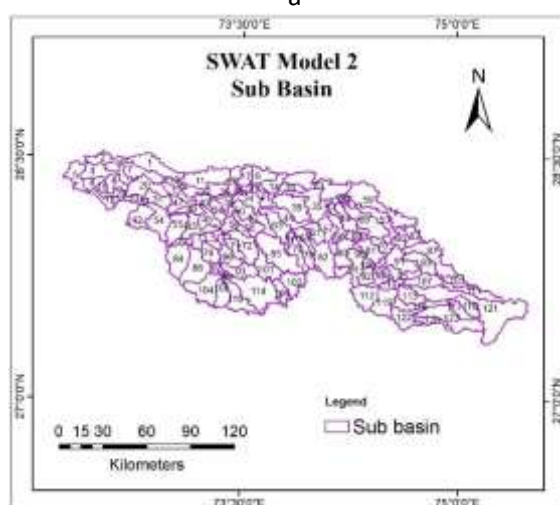
Figure 7.44:SWAT Model 2 of AID area



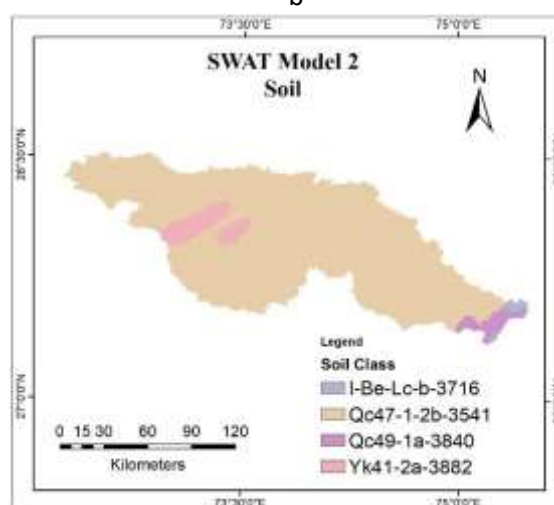
a



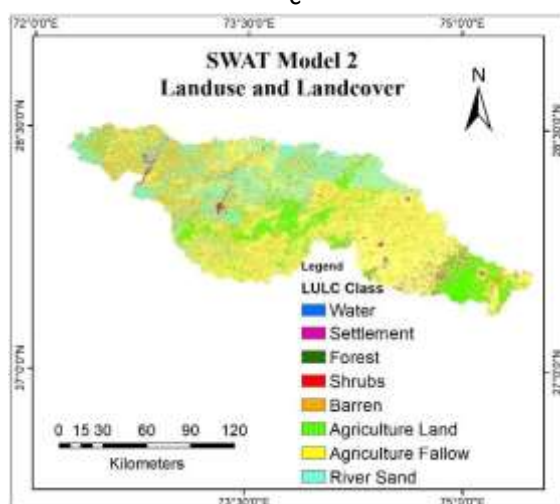
b



c



d



e

Figure 7.45: Area of Inland Drainage
SWAT Model 2
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.45 (a) Shows the Digital elevation model for the area of inland Drainage SWAT model 2. It has a maximum elevation of 996 meters and a minimum elevation of 109 meters. DEM threshold value 100 Sq.km for generating the river Figure 45(b) shows the river network map area of inland drainage SWAT model 2. 123 streams have a total length of 2017.362 km and produce 123 sub-basins while delineating the watershed. Figure 7.45(c) shows the sub-basin Map for the area of inland drainage SWAT model 2. The total area of the sub-basin is 19025.19 Square Kilometer which has 1019 HRUs and 123 sub-basins. Figure 7.45 (d) shows the Soil Map for the area of inland drainage SWAT model 2. It has four soil classes which are well distributed in the sub-basin, and the most dominated class of soil Qc47-1-2b-23541, which covered 91% of the total area of watershed and less area % shared by the Soil class I-be-Lc-b-3716 only 0.77% Area. Figure 7.45 (e) shows landuse and landcover Map for Area of inland drainage SWAT model 2. It has eight classes which are well distributed by model and LULC map prepared by LULC of the year 2000 satellite image. Most dominated class Agriculture fallow land covered the 48.13% of the total land cover area and less dominant land-use and landcover is water which shared only 0.04% of the total area. The Water class shared only 0.04% of total sub-basin area followed by the Forest class which only shared 0.3% of the total area of the sub-basin. SWAT Model 2 Run for Historical and Future Period with five years of warm-up period. Simulation length 25 years for the historical period, including the 4 years of warm up period. The number of HRUs is 1019, and the number of Sub-basin in the Model is 123. SWAT model 1 output step taken as Monthly time step and total area of the basin is 19025.20 square kilometre

Table 7.100 Details of Digital Elevation Model for SWAT Model 2 of AID

DEM Details	Meters
Min. Elevation	109
Max Elevation	996
Mean Elevation	271.1
Standard Deviation	80.49
DEM Threshold Value	100(Km ²)

Table 7.101 Details of Stream network of SWAT Model 2 of AID

River Parameters	Values
No. of Stream	123
Total Length of all rivers	2017.362 km
No. of Sub-basin	123

Table 7.102 Details of LULC class distribution for SWAT Model 2 of AID

LULC Class	LULC Code	Area (km²)	Sub-basin Area (%)
Water	WATR	7.57	0.04
Settlement	URLD	355.19	1.86
Forest-Deciduous	FRSD	5.56	0.03
Range-Brush	RNGB	22.01	0.12
Barren	BARR	3384.84	17.79
Agricultural Land-Row Crops	AGRRC	2446.82	12.86
Agricultural Land-Close-grown	AGRC	9156.34	48.13
Wetlands-Non-Forested	WETN	3646.82	19.17
Total		19025.19	100

Table 7.103 Details of Soil Class of SWAT Model 2 of AID

Soil Type	Area in Km²	Sub-basin Share (%)
Qc47-1-2b-23541	17494.50	91.95
Yk41-2a-3882	957.71	5.03
Qc49-1a-3840	427.41	2.25
I-be-Lc-b-3716	145.58	0.77
Total Area	19025.19	100

Table 7.104 Details of Sub basin of SWAT Model 2 of AID

Sub-basin details	Values
Number of HRUs	1019
Number of Sub basins	123
Watershed Area in Km ²	19025.19

Sub basin Simulation Details

SWAT Simulation details provided in Table – In SWAT model 2 for the execution of SWAT model for the historical period 1985 to 2005 warm up period taken 4 years and time step for the execution of simulation taken as monthly precipitation method adopted as measured.

Table 7.105 Details of simulation of SWAT Model 2 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number of HRUs	1019
Number of Sub basins	123
Output Time step	Monthly
Precipitation Method	Measured
Watershed Area in Km ²	19025.19

Average annual values generated by SWAT model for the period 1985-2005 for 25 years for water balance component as shown in Table 7.106

Table 7.106 Details of water balance component of SWAT Model 2 of AID

Water Balance Component	Value in mm
Precipitation	338.3
Surface Runoff Q	63.79
Lateral Flow Through Soil	2.3
GW (Shallow AQ)	95.31
GW (Deep AQ)	6.71
REVAP (Shallow =>Soil/Plant)	32.29
Deep Aquifer Recharge	6.72
Total Aquifer Recharge	134.36
Total Water Yield	168.11
Percolation Out of Soil	138.35
ET	138.4
PET	1644
Total Sediment Loading	14.89t/ha

Water Balance calculations

Total flow = Surface runoff + Base flow = 63.79 mm+95.31 mm=159.1mm

A preliminary check perform using the SWAT check tool which gives the ratio for the watershed parameters simulation for accuracy purpose which are shown as Table 7.107

Table 7.107 No. Water balance ratio details of SWAT Model 2 of AID

Water Balance Component	Ratio Value
Streamflow/Precipitation	0.48
Base flow /Total flow	0.6
Surface Runoff/Total flow	0.4
Percolation/precipitation	0.4
Deep Recharge/Precipitation	0.2
ET/Precipitation	0.41

We have calculated the continuity error from total inflow and total outflow from the output database. A zero percent continuity error means the model is correct, continuity error less than 1 percent is an excellent continuity error, less than 2% error is great and less than 5% error is good or at least acceptable for hydrological modelling at basin scale (SWMM manual).

Continuity error

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity error = $100 \times (1 - (32712.19 \div 32809.78))$

Continuity error = 0.29 %

Water Balance at outlet of the watershed of Inland drainage area for SWAT model 1 as shown in figure--all the water balance component with the hydrological cycle is presented

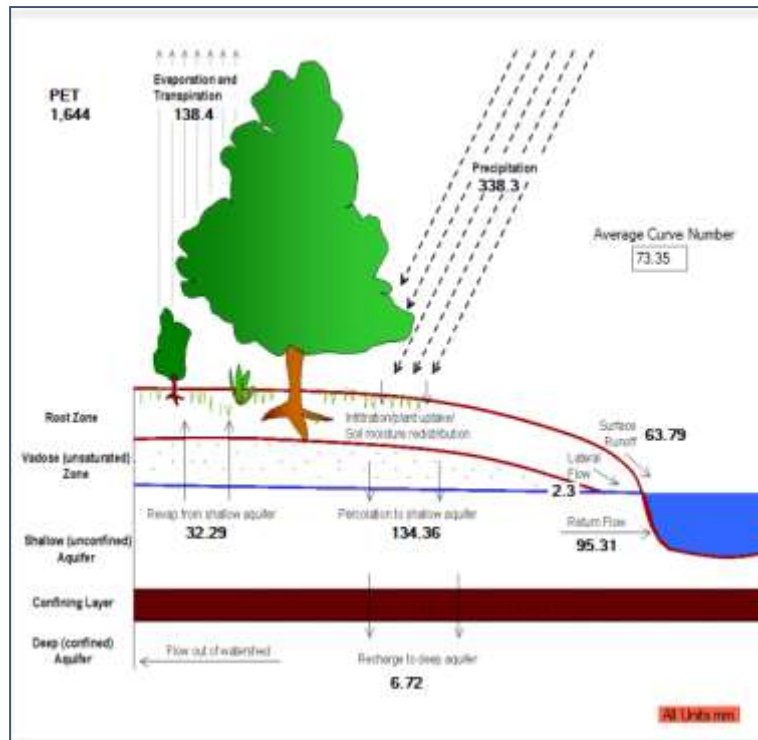


Figure 7.46: Pictorial representation of water balance components in SWAT model 2

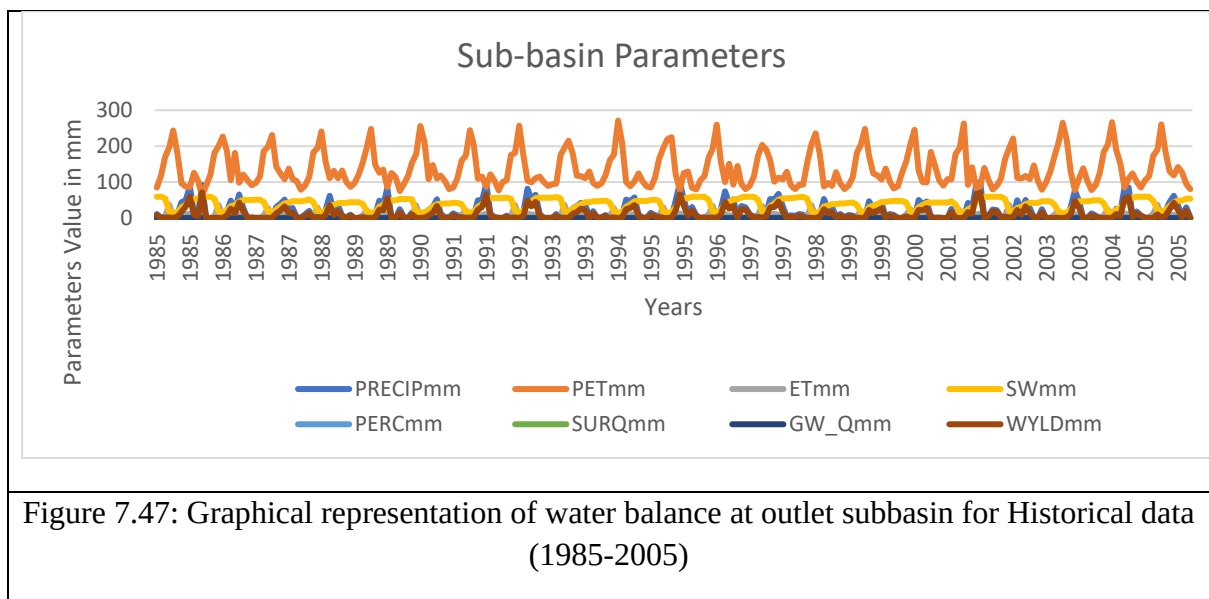


Figure 7.47: Graphical representation of water balance at outlet subbasin for Historical data (1985-2005)

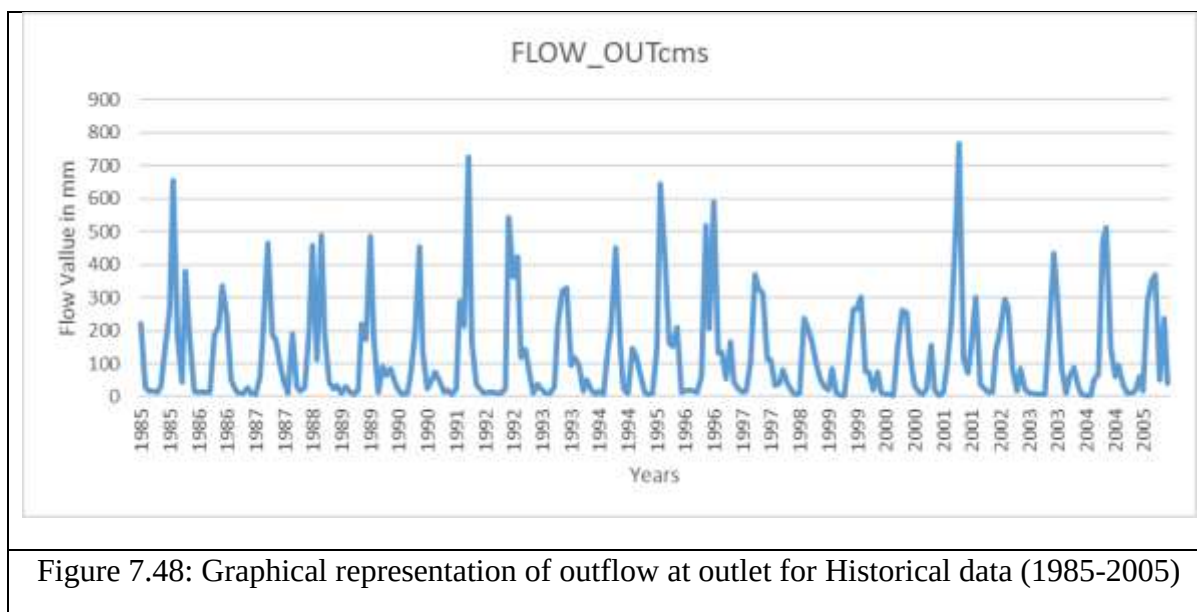


Figure 7.48: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.5.4 SWAT Model 3 of AID

SWAT Model 3 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude 27°19'35.31" N and 72°27'30.13" E longitude. It is the 3rd largest sub basin of Inland drainage. In this area the main river channel flow direction is east to west. Total sub-basin area for the SWAT Model 3 of AID is 15314.19Sq. km. The SWAT model for sub basin 3 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

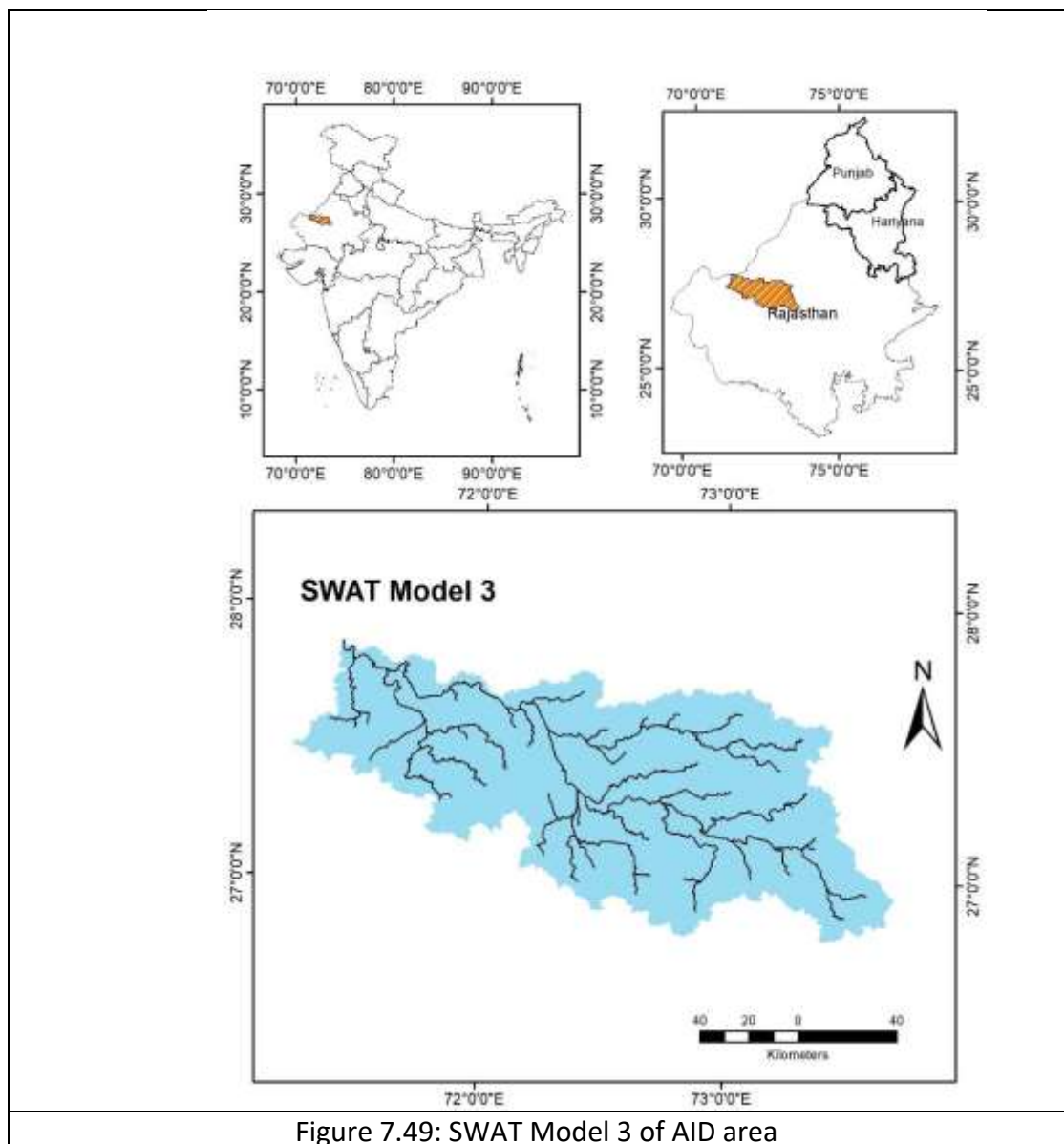
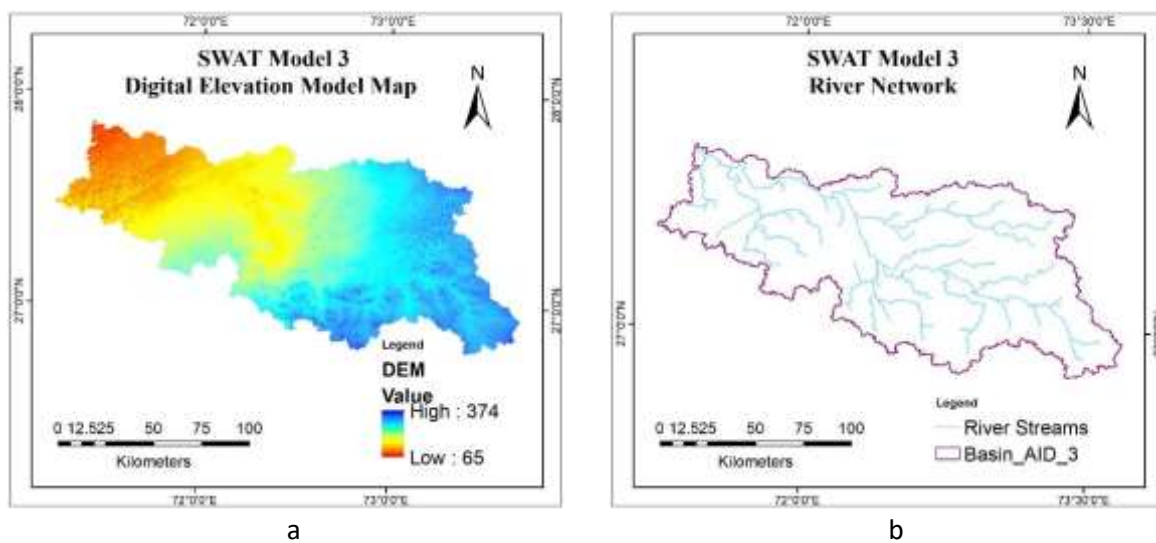


Figure 7.49: SWAT Model 3 of AID area



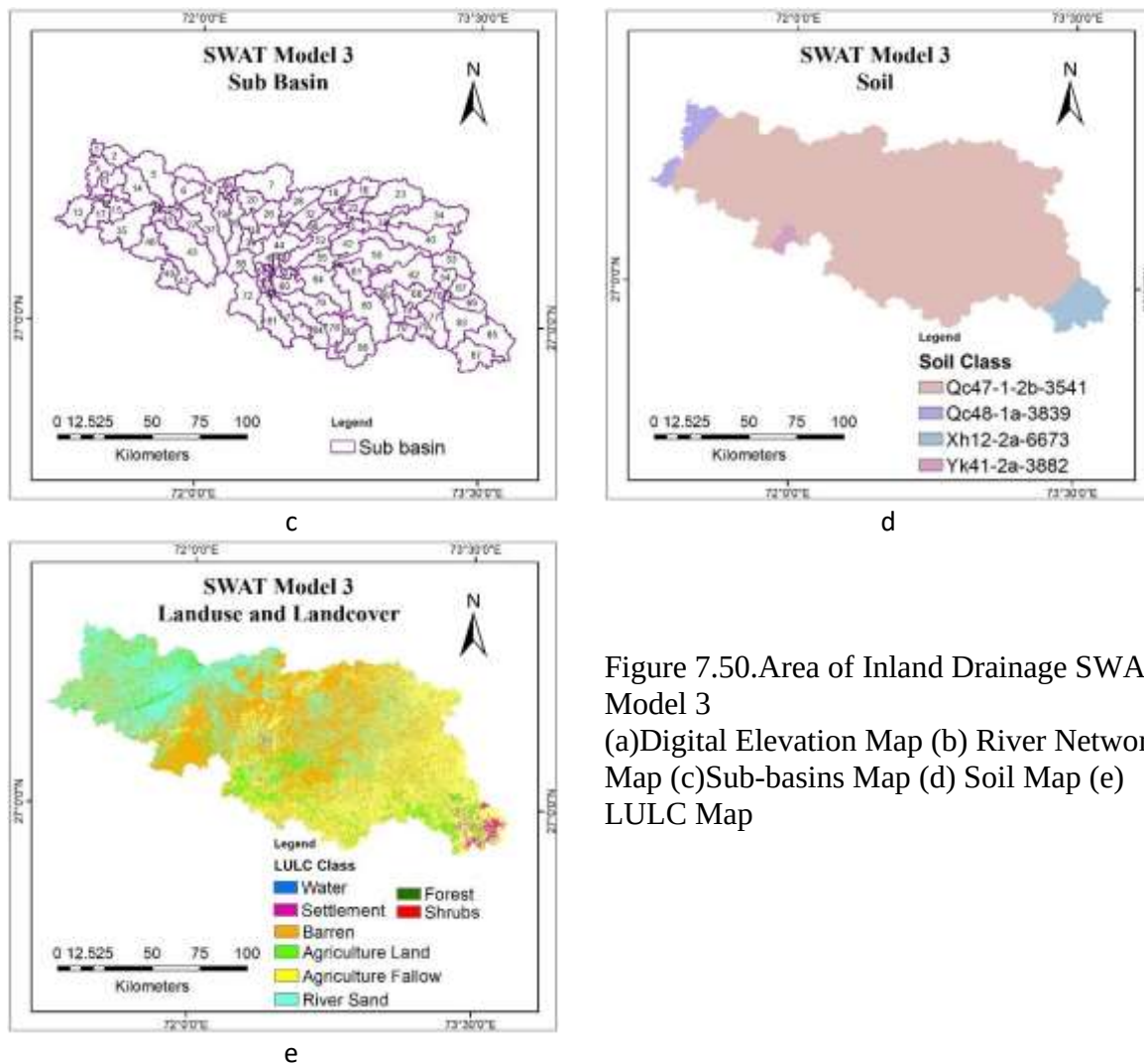


Figure 7.50. Area of Inland Drainage SWAT Model 3
(a) Digital Elevation Map (b) River Network Map (c) Sub-basins Map (d) Soil Map (e) LULC Map

Figure 7.50 (a) shows the digital elevation model for the area of inland drainage SWAT model 3. It has a maximum elevation of 374 meters and a minimum elevation of 65 meters. DEM threshold value 100 Sq.km for generating the river network. Figure 7.50(b) shows the sub basin Map for SWAT model 3. It has the total number of sub-basin 87. The Watershed Area covered by the SWAT model 3 is 15314.19 Km² and the Number of HRUs generated are 682. Figure 7.50 (d) shows the soil map of SWAT Model 3 of the Area of inland drainage. Four types of soil were covered in the basin, type 1 soil as Qc48-1a-3839 covered 2.54 % of area out of the total SWAT model 3 basin area and typed two soil as Qc47-1-2b-3541 covered 92.83% area out of the total basin area. Figure 7.50 (e) shows the Landuse and Landcover map for SWAT model 3. It has eight classes well distributed in the sub-basin. The dominant LULC class in the basin is settlement land, which occupies 35% area of the basin out of the basin's total area, followed by Shrubs, which cover 29.82% of the area.

Table 7.108. Details of Digital elevation Model of SWAT Model 3

DEM Details	Values in meters
Min. Elevation	65
Max Elevation	374
Mean Elevation	240.17
Standard Deviation	60.95
DEM Threshold Value	100 (Km ²)

Table 7.109 Details of river network for SWAT Model 3 of AID

Item	Description
No. of Stream	87
Total Length of all rivers	1601.8 Km
No. of Sub-basin	87

Table 7.110 Details of LULC for SWAT model 3 of AID

LULC Class	LULC Code	Area (km ²)	Sub-basin share (%)
Water	WATR	9.70	0.06
Settlement	BARR	5393.70	35.16
Forest-Deciduous	AGRR	1139.74	7.43
Range-Brush	AGRC	4574.20	29.82
Barren	WETN	4028.13	26.26
Agricultural Land-Row Crops	URHD	147.60	0.96
Agricultural Land-Close-grown	FRSD	18.46	0.12
Wetlands-Non-Forested	RNGB	2.65	0.02
Total		15314.19	100

Table 7.111 No. Soil details of SWAT model 3 of AID

Soil Type	Area in Km2	Subbasin Share (%)
Qc48-1a-3839	389.17	2.54
Qc47-1-2b-3541	14216.40	92.83
Yk41-2a-3882	125.95	0.82

Xh12-2a-6673	582.64	3.8
	15314.19	100

Table 7.112 No. Details of Sub basin of SWAT Model 3 of AID

Item	Description
No of HRUs	682
No of Sub basin	87
Subbasin Area (Km ²)	15314.19

Simulation Details

SWAT Simulation details provided in Table 7.113. In SWAT model 3 for the execution of SWAT model for the historical period 1985 to 2005 (25 years) with a warm up period of 4 years and time step for the execution of simulation taken as monthly precipitation method adopted as measured from the respective meteorological station.

Table 7.113 Details of simulation of SWAT Model 3 of AID

Simulation Details	Values
Simulation Length	25 Years
Warm up period	4 Years
Number of HRUs	682
Number of Sub Basins	87
Output Time Step	Monthly
Precipitation Method	Measured
Subbasin Area (Km ²)	15314.19

Average annual values generated by SWAT model for the period 1985-2005 for 25 years for water balance component as shown in Table 7.114.

Table 7.114 Details of water balance components of SWAT model 3 of AID

Water Balance Component	Values in mm
Precipitation	272.1
Surface Runoff	38.65
Lateral Flow	2.81
Groundwater Shallow (Aq.)	4.67
Groundwater (Deep aq.)	1.66
Revap (Shal Aq. => Soil/Plant)	25.85

Deep Aq. Recharge	1.66
Total Aq. Recharge	33.19
Total Water Yield	47.79
Percolation out from Soil	33.19
ET	198.4
PET	1816
Total Sediment Loading	17.18 (t/ha)

Water Balance calculations

Total flow = Surface Runoff + Base Flow = 38.65 mm+4.67 mm = 175.83 mm

A preliminary check perform using the SWAT check tool which gives the ratio for the subbasin parameters simulation for accuracy purpose which are shown as Table 7.115

Table 7.115 Details of water balance ratio of SWAT model 3 of AID

Component	Ratio Value
Streamflow/Precipitation	0.17
Base flow /Total flow	0.16
Surface Runoff/Total flow	0.84
Percolation/precipitation	0.12
Deep Recharge/Precipitation	0.01
ET/Precipitation	0.73

Continuity error

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity error = $100 \times (1 - (7093.70 \div 7126.42))$

Continuity error = 0.45 %

Water Balance at outlet of the subbasin for the inland drainage area for SWAT model 3 as shown in Figure--.

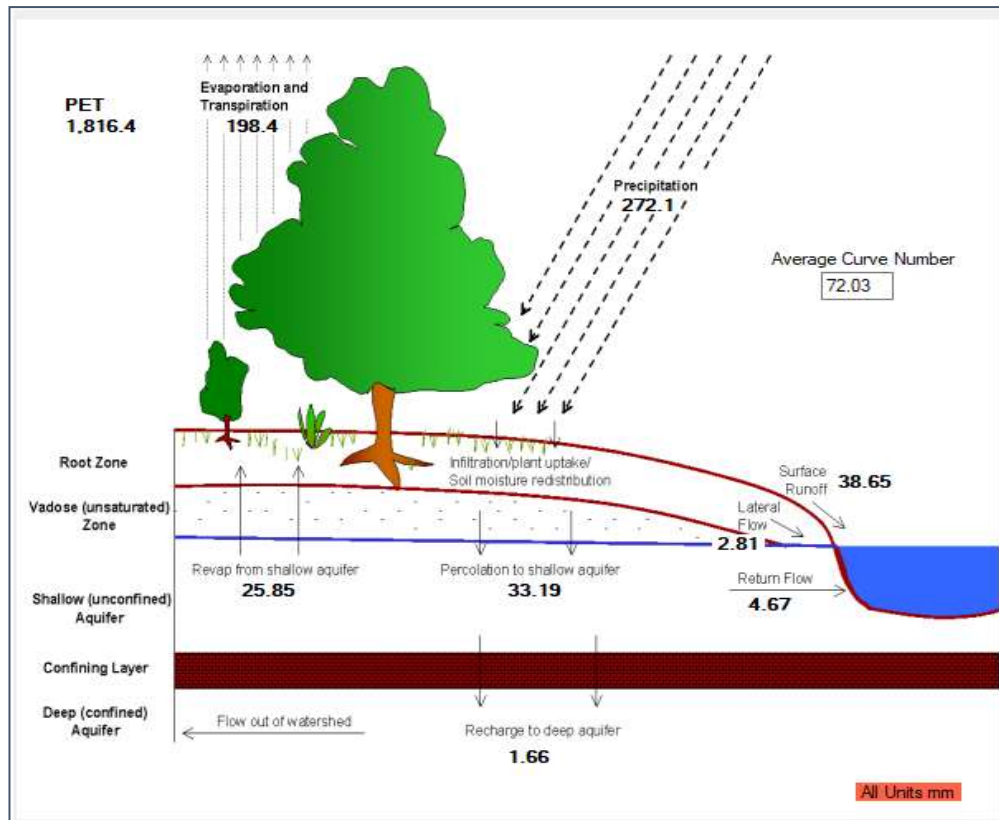


Figure 7.51: Pictorial representation of water balance components in SWAT model 3

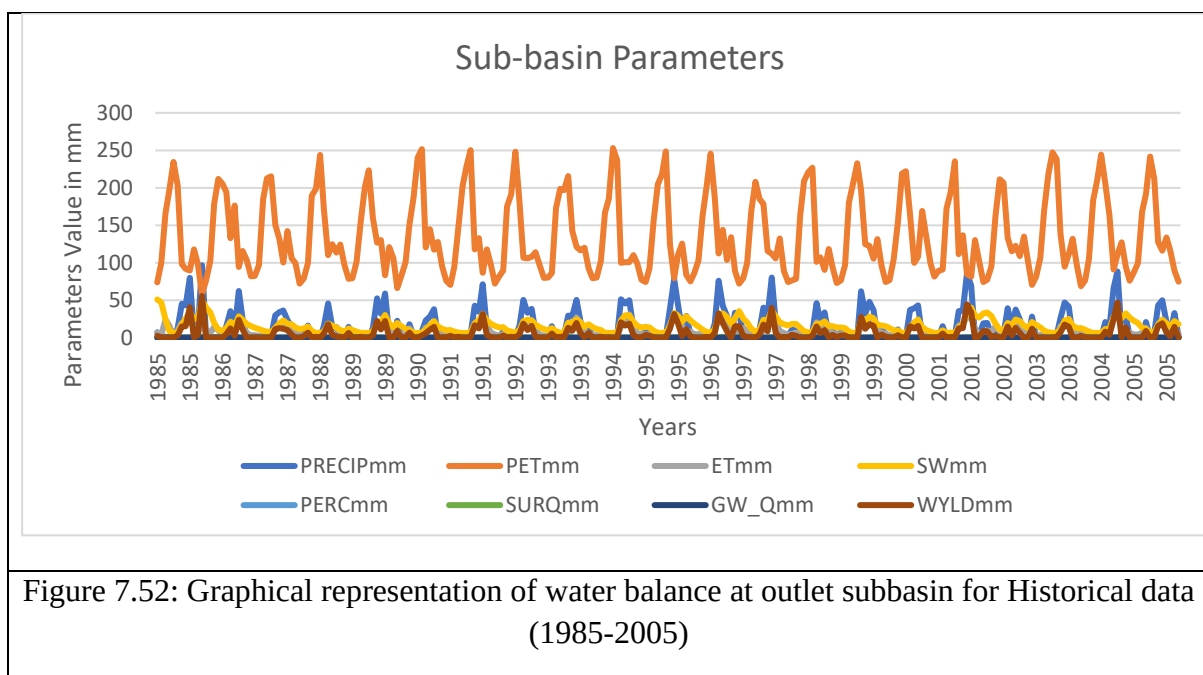
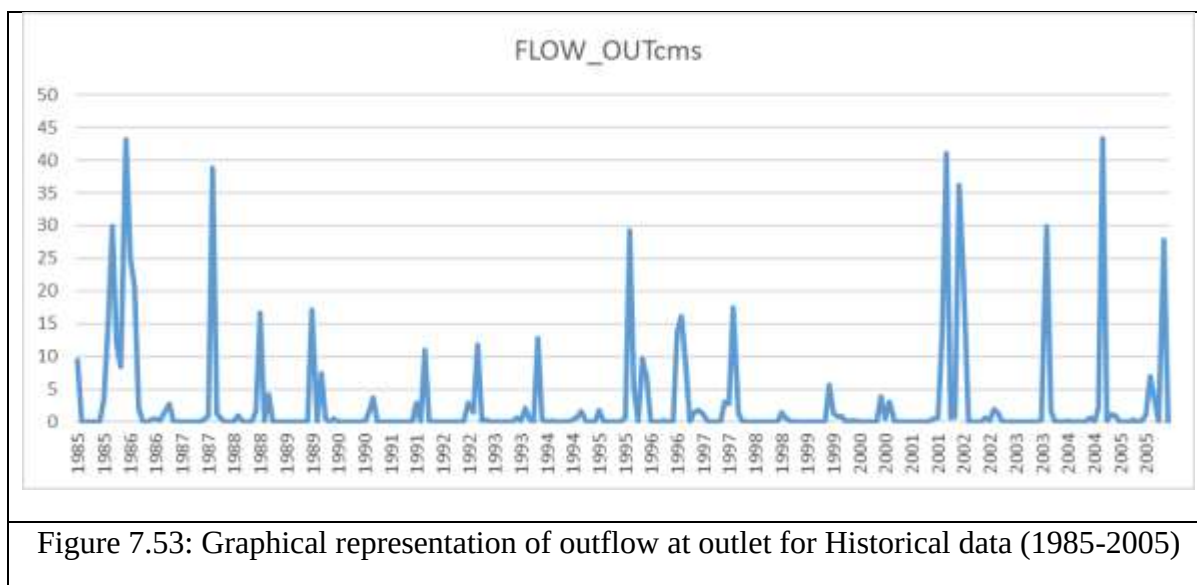


Figure 7.52: Graphical representation of water balance at outlet subbasin for Historical data (1985-2005)



7.5.5 SWAT Model 4 of AID

SWAT Model 4 sub basin of AID area is situated on the west side of Rajasthan state of India. The sub basin is placed at latitude 27°4'16.61" N and 71°12'57.38" E longitude. It is the 4th largest sub basin of Inland drainage area. In this area the main river channel flow direction is west to east. Total subbasin area for the SWAT Model 4 of AID is 15287.3 Sq. km. The SWAT model for sub basin 4 of AID is simulated for 25 years from 1985 to 2005 with 4 years of warm up period.

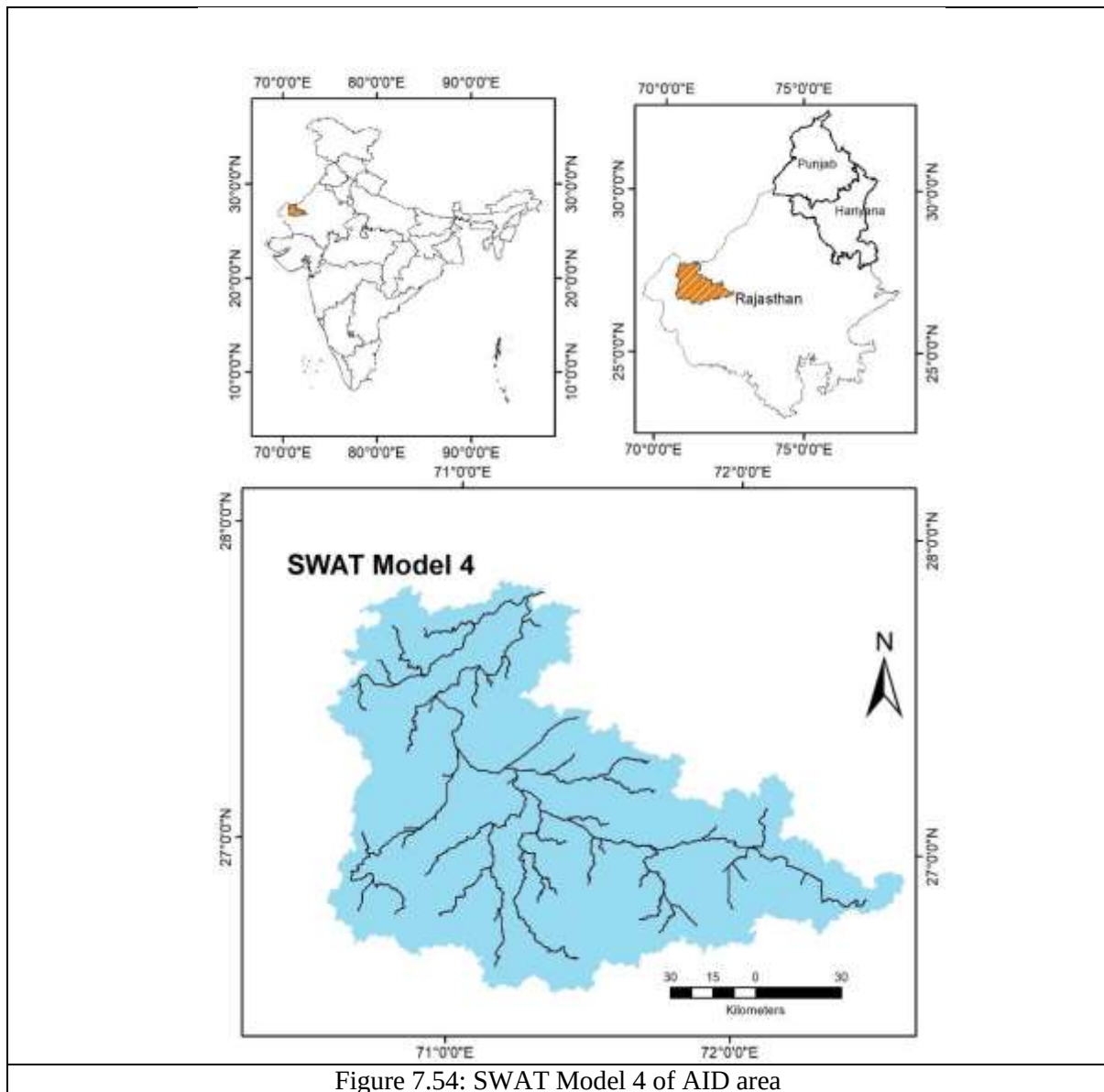
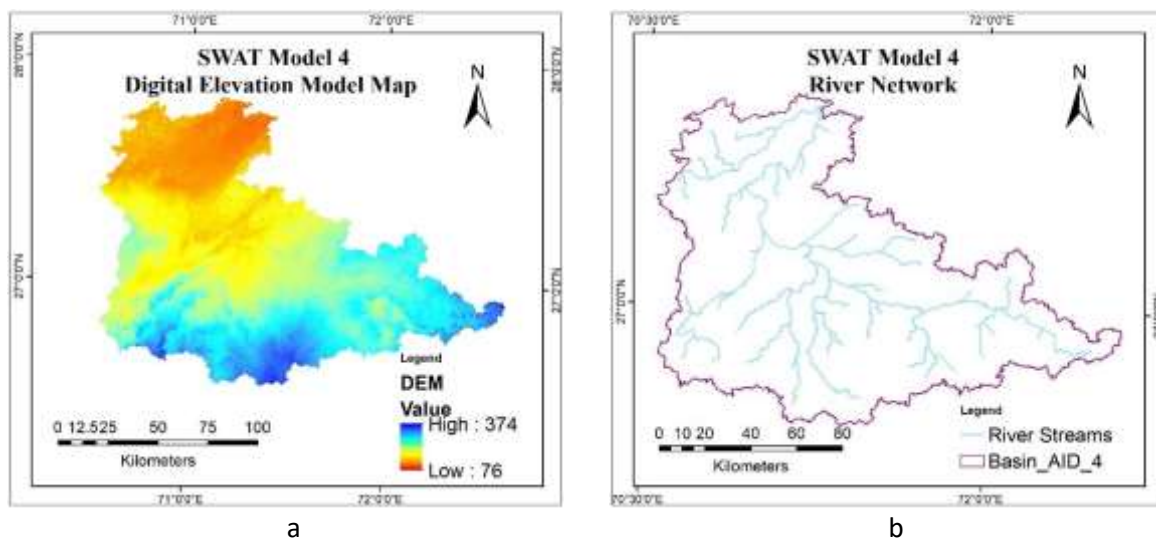


Figure 7.54: SWAT Model 4 of AID area



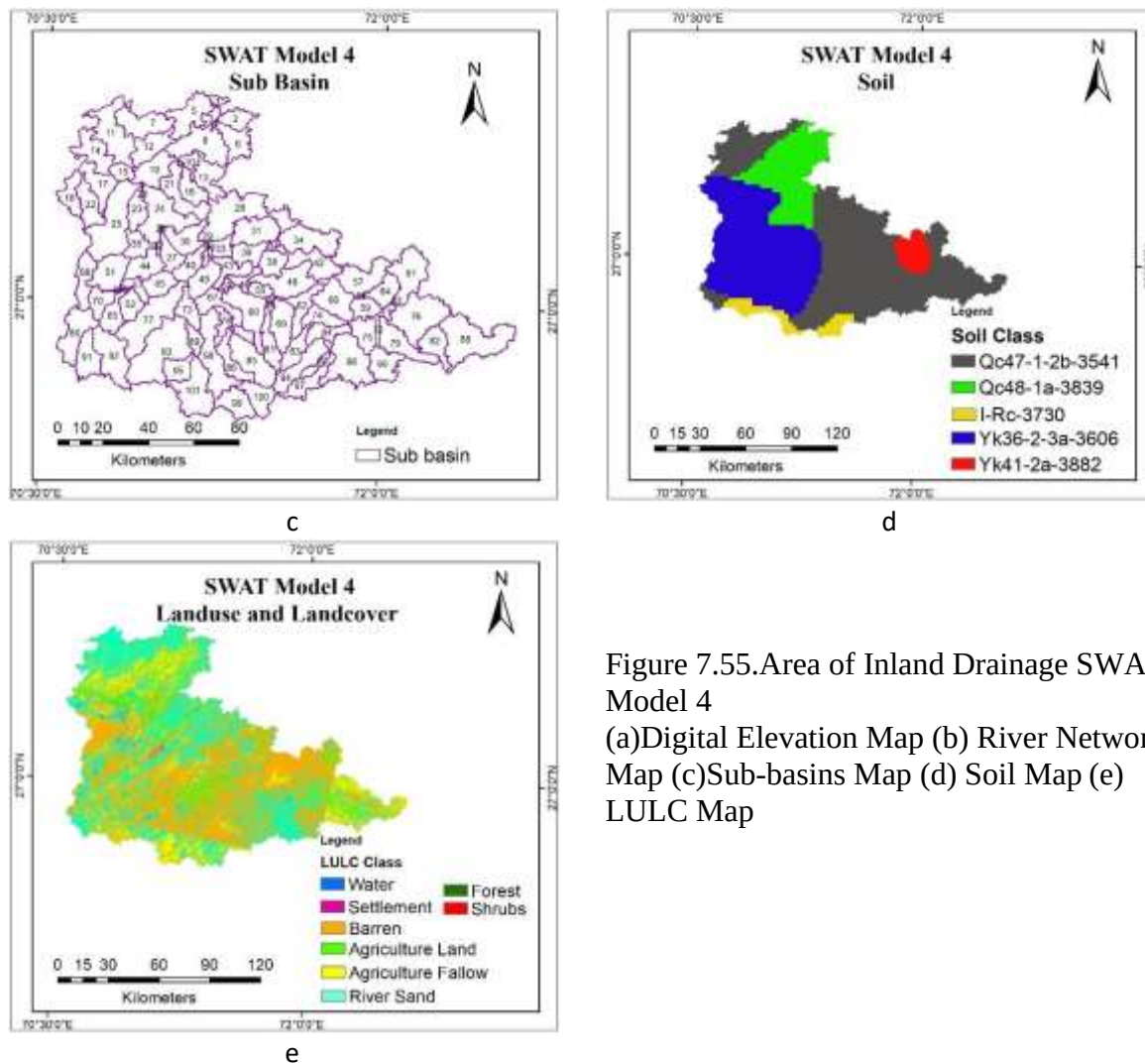


Figure 7.55. Area of Inland Drainage SWAT Model 4
(a) Digital Elevation Map (b) River Network Map (c) Sub-basins Map (d) Soil Map (e) LULC Map

Figure 7.55 (a) shows the Digital elevation Map for SWAT model 4 for the area of inland drainage. The maximum value is 374 meters, and the minimum elevation value is 76 meters. In this basin, the standard deviation of elevation measured is 55.64 meters, and the mean elevation in the basin is 202.96 meters. Figure 7.55(b) shows the river network generated by the SWAT model at a threshold of 100 Sq.km while processing the basin's delineation for further hydrological process analysis at the basin scale. Figure 7.55 (c) shows the sub-basin generated by the SWAT model; 101 sub-basin were obtained from the delineation of the basin. The total area of sub-basin for SWAT model 4 of AID is 15287.13 sq. km, and it is the fourth largest basin of AID area among all basins. Figure 7.55 (d) shows the soil distribution in the sub-basin. There are five types of soil in the basin of AID. Soil type 1, as named Qc47-1-2b-3541, covered 47.52% of the area out of the total area, followed by soil type 3 as named Yk36-2-3a-3606, which is covered the area by 31.24% out of the total basin area. Figure 7.55 (e) shows the land-use and landcover map for the SWAT model 4 basin. This basin also has eight LULC classes which are well distributed in the basin. The most dominated LULC class is Barren land which covered 43.26% of area out of total basin area, followed by the LULC class

River sand, which covered 36.28% of area out of the total area. Water and Forest class have negligible % coverage in the basin.

Table 7.116 Details of Digital elevation model for SWAT Model of 4 of AID

DEM Details	Meters
Min. Elevation	76
Max Elevation	374
Mean Elevation	202.96
Standard Deviation	55.64
DEM Threshold Value	100 Km ²

Table 7.117 Details of river network for SWAT model 4 of AID

River Parameters	Values
Length of all rivers	1465 km
Number of rivers	101
Sub basin area	15287.13 km ²

Table 7.118 Details of LULC for SWAT Model 4 of AID

LULC Class	LULC Code	Area (km²)	Sub-basin share (%)
Water	WATR	22.20	0.15
Residential-High Density	URHD	46.71	0.3
Range-Brush	RNGB	10.89	0.07
Barren	BARR	6613.21	43.26
Forest-Deciduous	FRSD	18.07	0.12
Agricultural Land-Row Crops	AGRR	1131.35	7.4
Agricultural Land-Close-grown	AGRC	1898.91	12.42
Wetlands-Non-Forested	WETN	5545.78	36.28
Total Area		15287.13	100

Table 7.119 Details of Soil for SWAT model 4 of AID

Soil Type	Area in (Km²)	Sub-basin share (%)
Qc47-1-2b-3541	7263.77	47.52
Qc48-1a-3839	2160.15	14.13
Yk36-2-3a-3606	4775.88	31.24
Yk41-2a-3882	506.19	3.31
I-Rc-3730	581.11	3.8

Table 7.120 Details of Sub basin for SWAT model 4 of AID

Sub basin Details	Values
Number of HRUs	1028
Number of sub basin	101
Area of subbasin	15287.13

Simulation details

SWAT Simulation details provided in Table 7.121. In SWAT model 4 for the execution of SWAT model for the historical period 1985-2005 warm up period taken 4 years and time step for the execution of simulation taken as monthly precipitation method adopted as measured

Table 7.121No. Details of Simulation for SWAT Model 4 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number of HRUs	1028
Number of Sub basins	101
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km ²	15287.13

Average annual values generated by SWAT model for the period 1985-2005 for 25 years for water balance component as shown in Table 7.122.

Table 7.122 Details of water balance components for SWAT model 4 of AID

Water Balance Component	Value in mm
Precipitation	232.8
Surface Runoff Q	32.17
Lateral Flow Through Soil	1.78
GW (Shallow AQ)	0.84
GW (Deep AQ)	0.79
REVAP (Shallow =>Soil/Plant)	15.35

Deep Aquifer Recharge	0.79
Total Aquifer Recharge	15.84
Total Water Yield	36.13
Percolation Out of Soil	15.84
ET	184.7
PET	1741
Total Sediment Loading	28.87(t/Ha)

Water Balance Calculations

Total flow = Surface runoff + Base flow = 32.17mm+ 0.84 mm=33.01mm

A preliminary check is performed using the SWAT check tool which gives the ratio for the subbasin parameters simulation for accuracy purposes which are shown as Table 7.123.

Table 7.123 Details of water balance ratio for SWAT model 4 of AID

Water Balance Ratios	
Component	Ratio Value
Streamflow/Precipitation	0.15
Base flow /Total flow	0.07
Surface Runoff/Total flow	0.93
Percolation/precipitation	0.07
Deep Recharge/Precipitation	0
ET/Precipitation	0.79

Continuity error

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity error = $100 \times (1 - (5558.71 \div 5565.53))$

Continuity error = 0.12 %

Water Balance at outlet of the subbasin of area of inland drainage for SWAT model 4 as shown in Figure--.

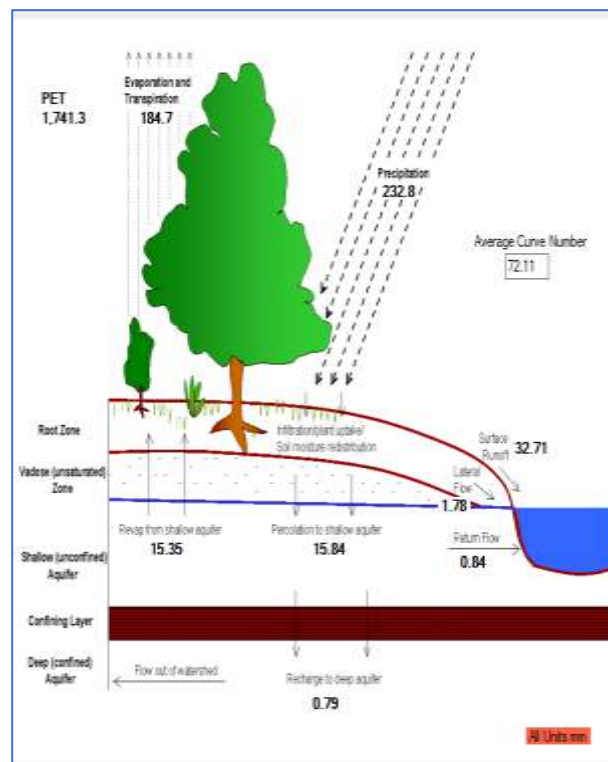


Figure 7.56: Pictorial representation of water balance components in SWAT model 4

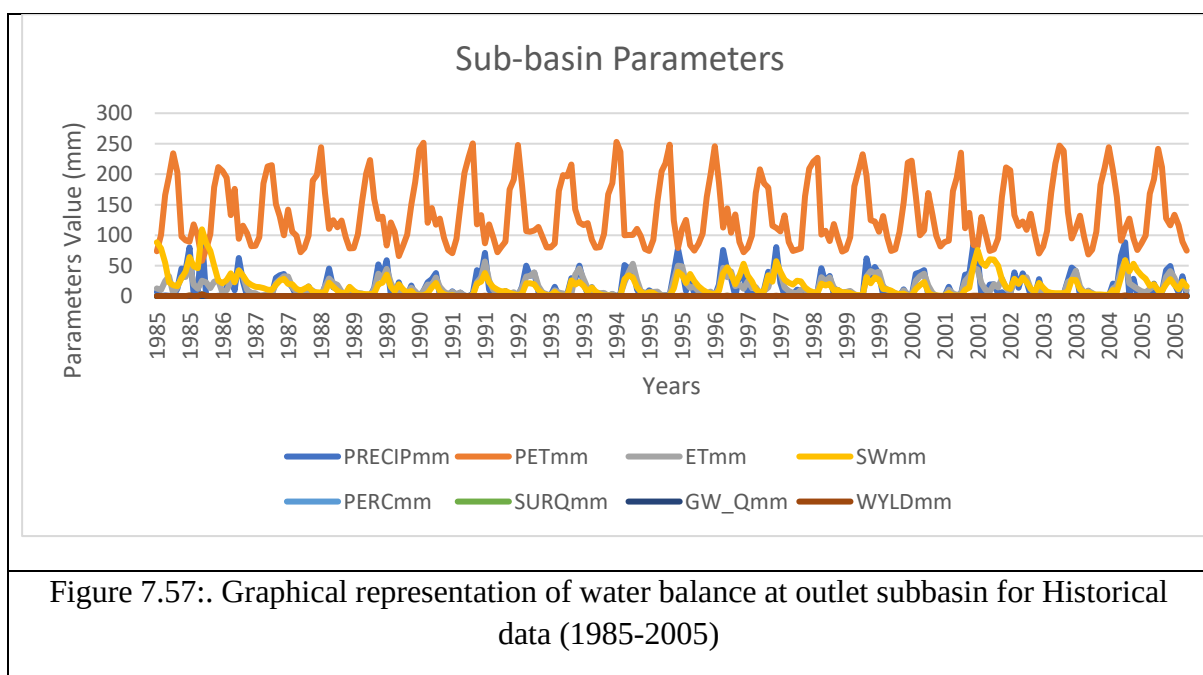
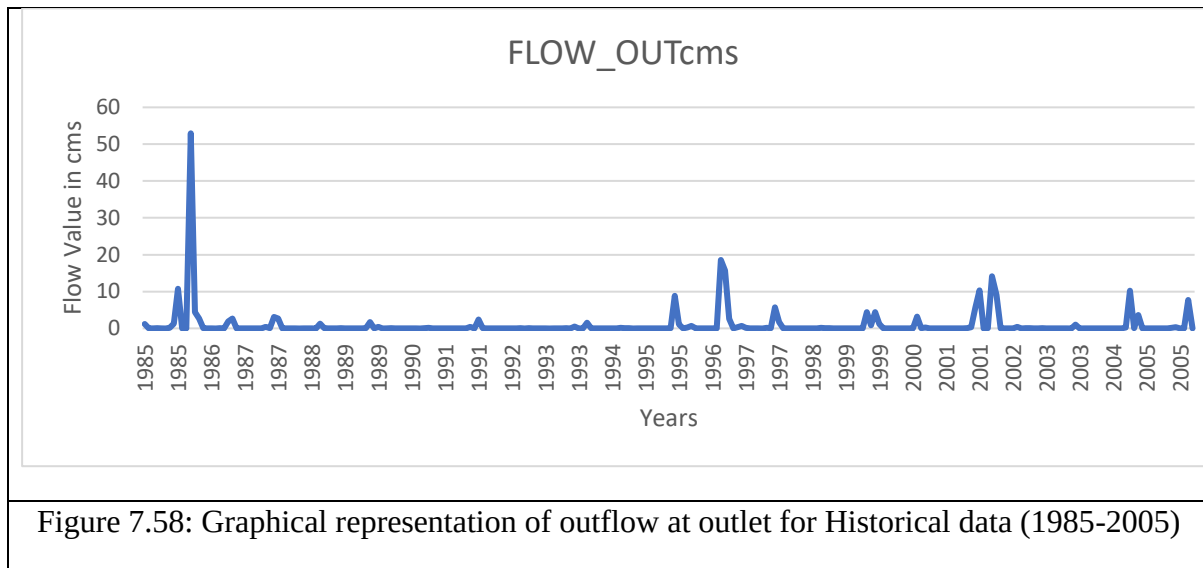


Figure 7.57:. Graphical representation of water balance at outlet subbasin for Historical data (1985-2005)



7.5.6 SWAT Model 5 of AID

SWAT Model 5 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude 27°20'39.82" N and 70°25'38.76" E longitude. It is the 9th largest sub basin among the all 18-sub basins of the Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 5 of AID is 2718.7 Sq. km. The SWAT model for sub basin 5 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

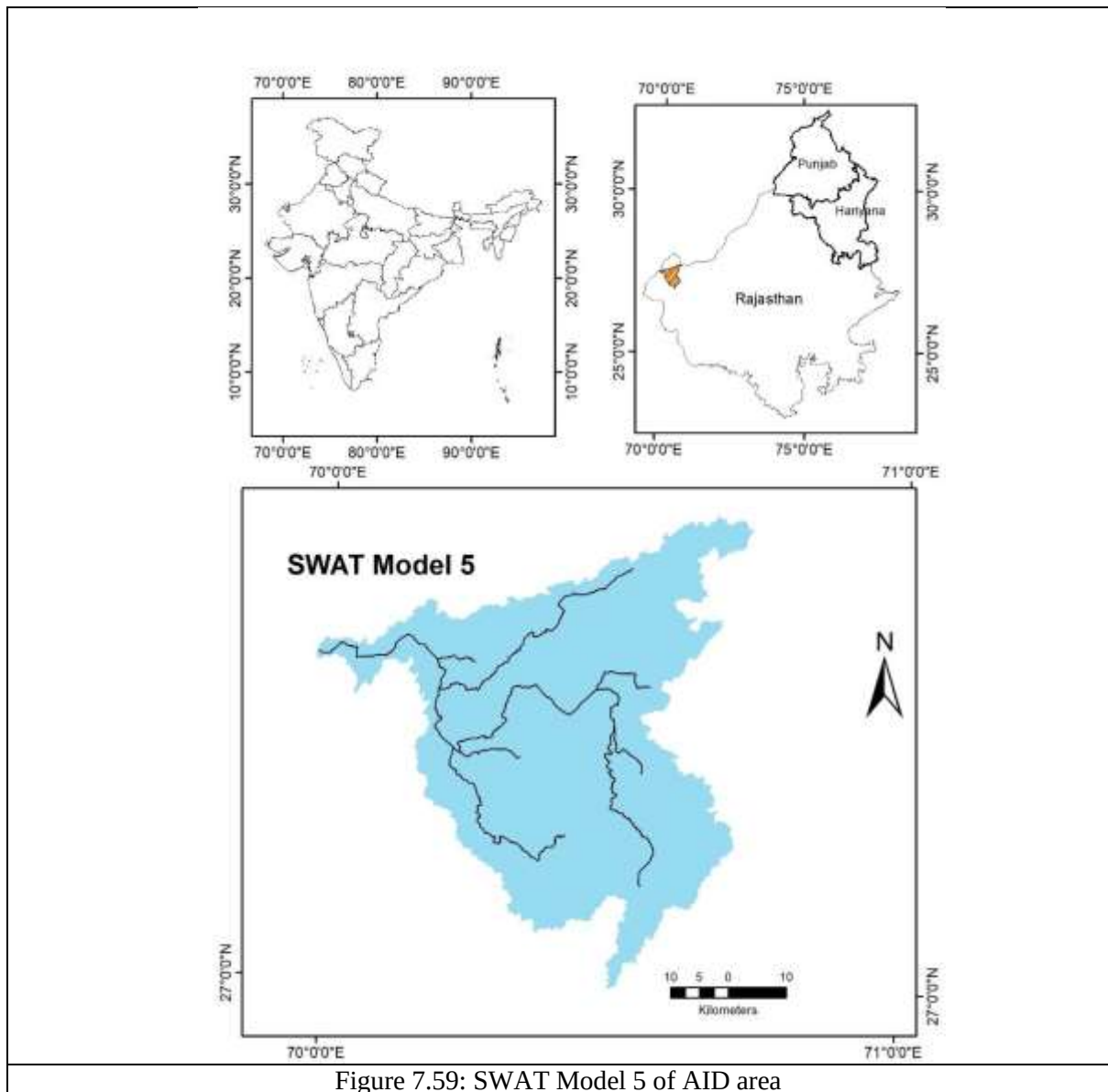
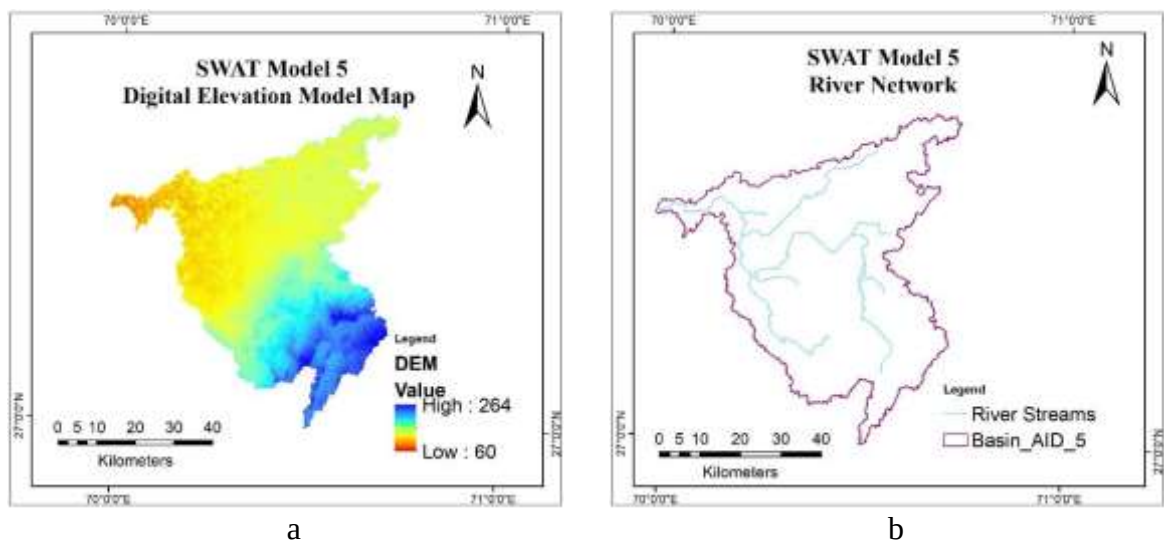
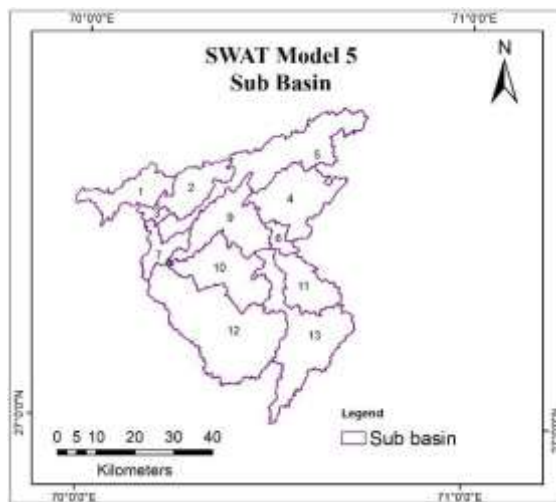
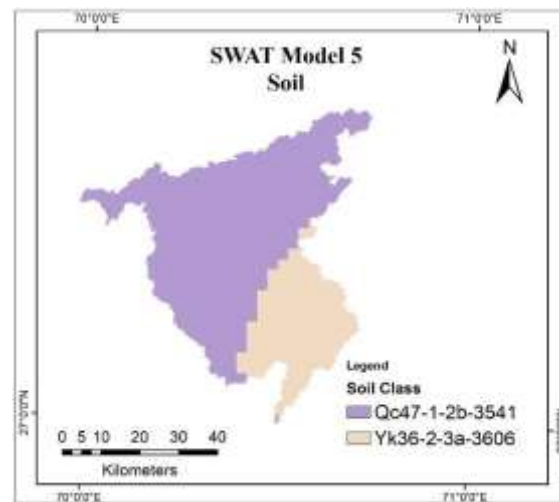


Figure 7.59: SWAT Model 5 of AID area

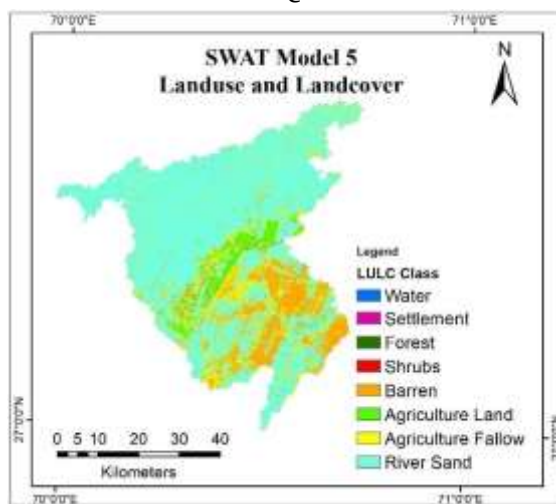




c



d



e

Figure 7.60: Area of inland drainage SWAT Model 5
(a) Digital Elevation Map (b) River Network Map (c) Sub-basins Map (d) Soil Map (e) LULC Map

Figure 7.60 (a) shows a digital elevation map for the SWAT model 5 basin. It has a maximum elevation of 264 meters and a minimum elevation of 60 meters. The mean elevation in the basin is 145.18 meter, and the standard deviation in elevation estimated is 34.54 the basin. High elevation values are distributed in the south of the basin, and low values are distributed in the north of the basin. The number of streams generated in the delineation of the basin at a threshold value of 100 Sq. Km is 13. The River network is shown in Figure 7.60 (b). The total length of all the streams is estimated to be 291.15 km, and the basin area is 2718.73 Sq. Km. The number of sub-basin in the basin is 13 as shown in Figure 7.60 (c). It is the 9th basin by size in all 18 basins in the area of inland drainage. Figure 7.60 (d) shows the soil distribution map in the basin. There are two types of soil covered in the basin soil type 1, as named Qc47-1-2b-3541 which covered 73.45 % of the area out of the total area of basin and soil type covered 26.55% area out of the total area of the basin. Figure 7.60 (e) illustrates the LULC map for the SWAT model 5. For this basin, eight classes covered the watershed. The most dominated LULC class

is the River Sand class, which covers 70.9% of the watershed. The least dominated LULC class is the Urban class, which only covers 0.1% of the watershed.

Table 7.124 Details of digital elevation model for SWAT model 5 of AID

DEM Details	Meters
Min. Elevation	60
Max Elevation	264
Mean Elevation	145.18
Standard Deviation	34.54
DEM Threshold Value	100(Km ²)

Table 7.125 Details of river network for SWAT model 5 of AID

Item	Description
No. of Stream	13
Total Length of all rivers in Km	291.15
No. of Sub-basin	13
subbasin Area Km ²	2718.73

Table7.126 Details of LULC for SWAT model 5 of AID

LULC Class	LULC Code	Area (km²)	Sub-basin share (%)
Water	WATR	1.87	0.07
Residential-High Density	URHD	2.83	0.1
Range-Brush	RNGB	6.59	0.24
Barren	BARR	370.92	13.64
Agricultural Land-Row Crops	AGRR	114.80	4.22
Agricultural Land-Close-grown	AGRC	313.39	11.53
Wetlands-Non-Forested	WETN	1907.16	70.15
Forest-Deciduous	FRSD	1.14	0.04

Table 7.127 No. Details of Soil class for SWAT model 5 of AID

Soil Type	Area in (Km²)	Subbasin share (%)
Qc47-1-2b-3541	1997.10	73.45
Yk36-2-3a-3606	721.72	26.55

Simulation Details

SWAT Simulation details provided in Table 7.128. In SWAT model 5 for the execution of SWAT model for the historical period 1985 to 2005 warm up period taken 4 year and time step for the execution of simulation taken as monthly precipitation method adopted as measured from the respective meteorological station.

Table 7.128 Details of simulation for SWAT model 5 of AID

Simulation Details	Values
Simulation Length	25years
Warm up (Model Initial Run) Period	4 years
Number of HRUs	125
Number of Sub basins	13
Output Time step	Monthly
Precipitation Method	Measured
Watershed Area in Km ²	2718.7

Average annual values generated by SWAT model for the period 1985-2005 for 25 years for water balance component as shown in Table 7.129.

Table 7.129 Details of water balance components for SWAT model 5 of AID

Water Balance Component	Value in mm
Precipitation	173
Surface Runoff Q	10.75
Lateral Flow Through Soil	1.68
GW (Shallow AQ)	0
GW (Deep AQ)	0.76
REVAP (Shallow =>Soil/Plant)	17.51
Deep Aquifer Recharge	0.74
Total Aquifer Recharge	14.79
Total Water Yield	13.19
Percolation Out of Soil	14.77
ET	148.6
PET	1731.5

Total Sediment Loading	5.67t/ha

Water Balance calculations

Total flow = Surface runoff + Base flow = 10.75 mm + 0 mm=10.75 mm

A preliminary check perform using the SWAT check tool which gives the ratio for the Subbasin parameters simulation for accuracy purpose which are shown as Table 7.130

Table 7.130 No. details of water balance ratios of SWAT model 5 of AID

Component	Ratio Value
Streamflow/Precipitation	0.07
Base flow /Total flow	0.14
Surface Runoff/Total flow	0.86
Percolation/precipitation	0.09
Deep Recharge/Precipitation	0
ET/Precipitation	0.86

We have calculated the continuity error from total inflow and total outflow from the output database. A zero percent continuity error means the model is correct, continuity error less than 1 percent is an excellent continuity error, less than 2 percent is great and less than 5 percent was good or at least acceptable (SWMM manual).

Continuity Error

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity error = $100 \times (1 - (333.8068 \div 343.6455))$

Continuity error = 2.8%

Water Balance at outlet of the subbasin of area of inland drainage for SWAT model 5 as shown in Figure--.

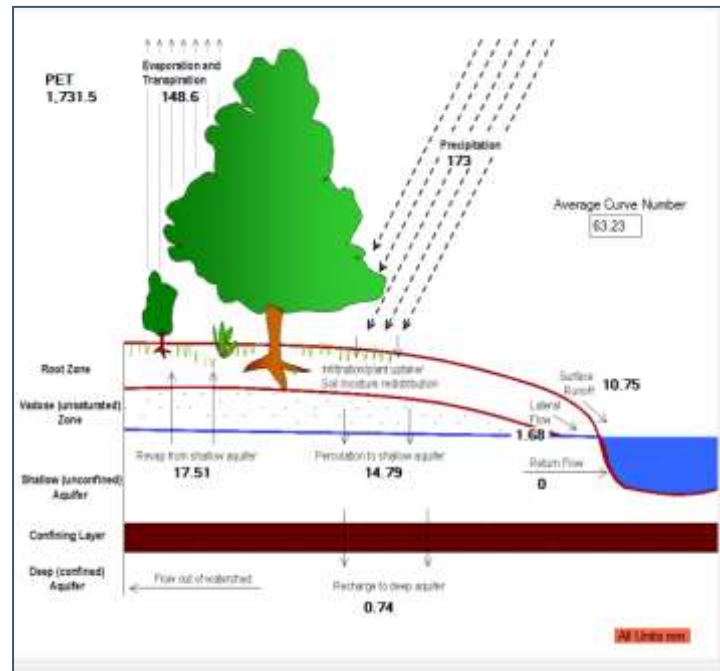


Figure 7.61: Pictorial representation of water balance components in SWAT model 5

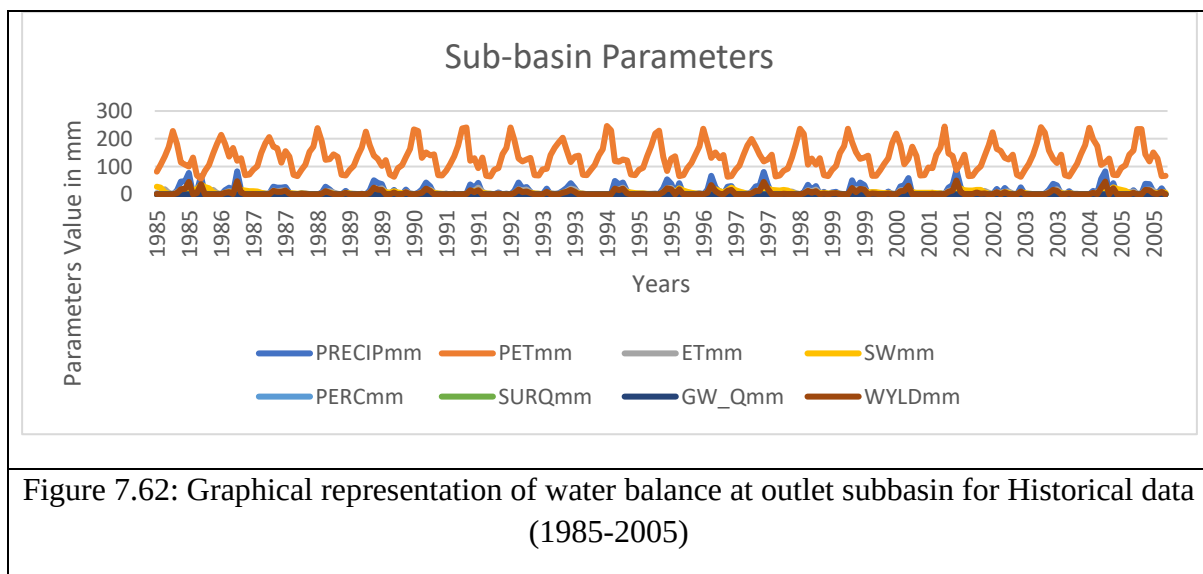


Figure 7.62: Graphical representation of water balance at outlet subbasin for Historical data (1985-2005)

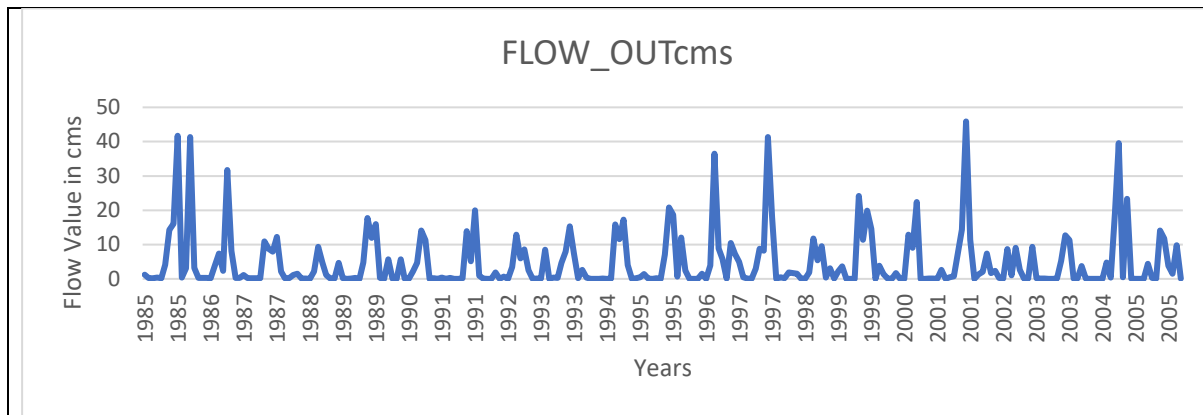
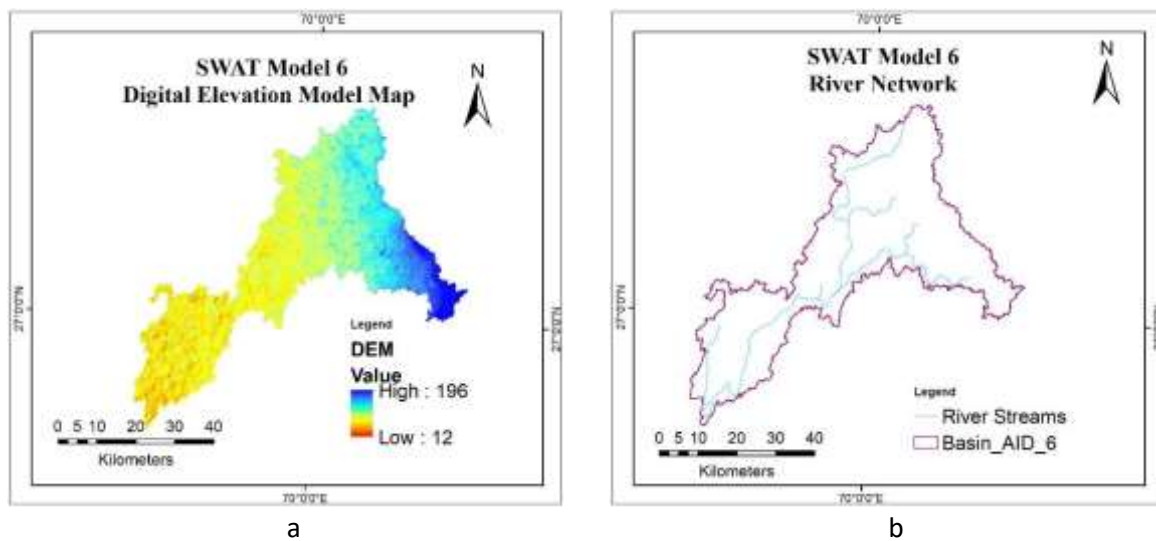
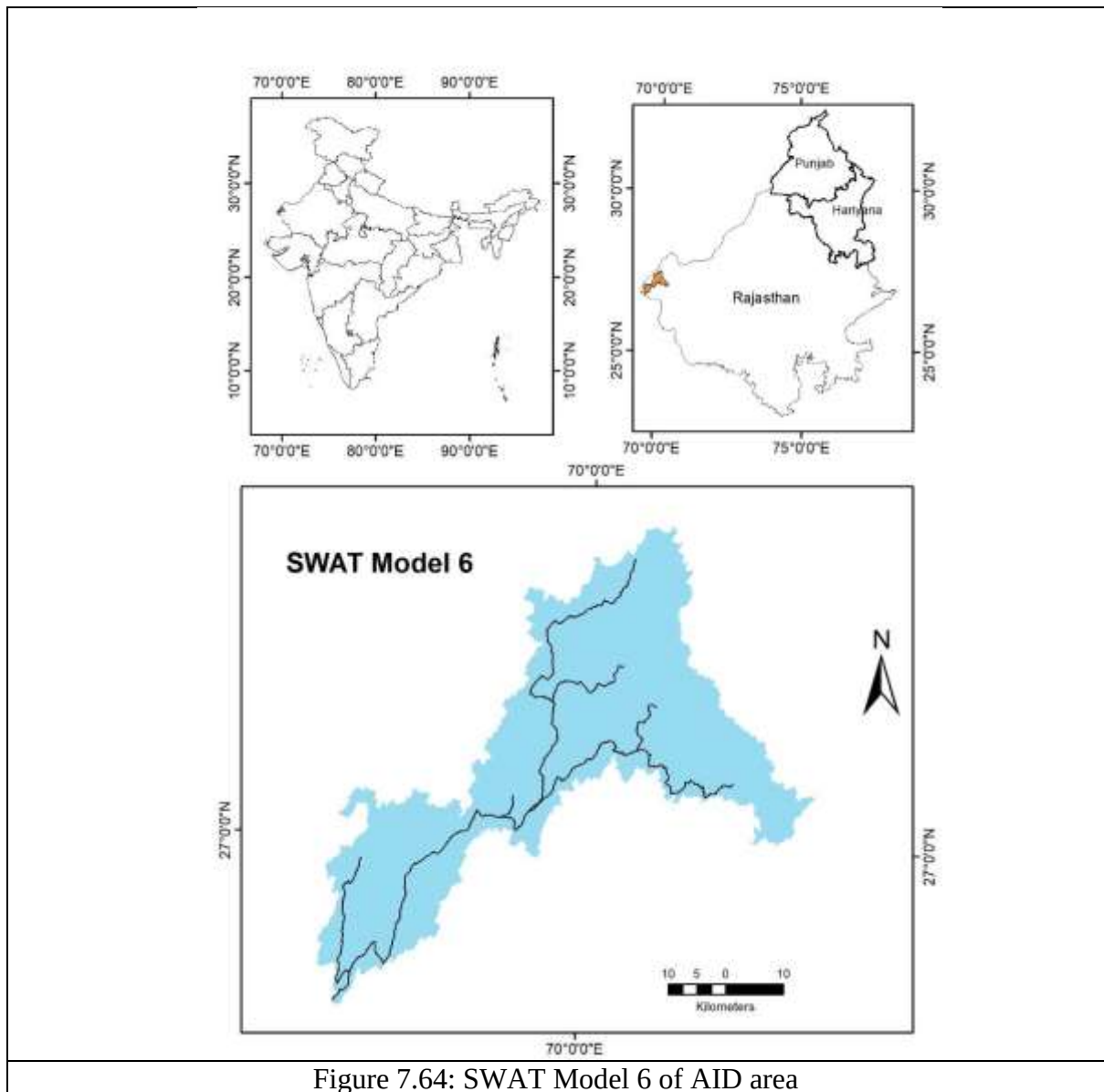


Figure 7.63: Graphical representation of outflow at outlet for Historical data (1985-2005)

7.5.7 SWAT Model 6 of AID

SWAT Model 6 sub basin of AID is situated east side of Rajasthan state of India. The sub basin is placed at latitude $27^{\circ}4'43.98''$ N and $69^{\circ}51'30.10''$ E longitude. It is the 11th largest sub basin of Inland drainage area. In this area the main river channel flow direction is north to south. Total subbasin area for the SWAT Model 6 of AID is 2112.5 Sq. km. The SWAT model for sub basin 6 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.



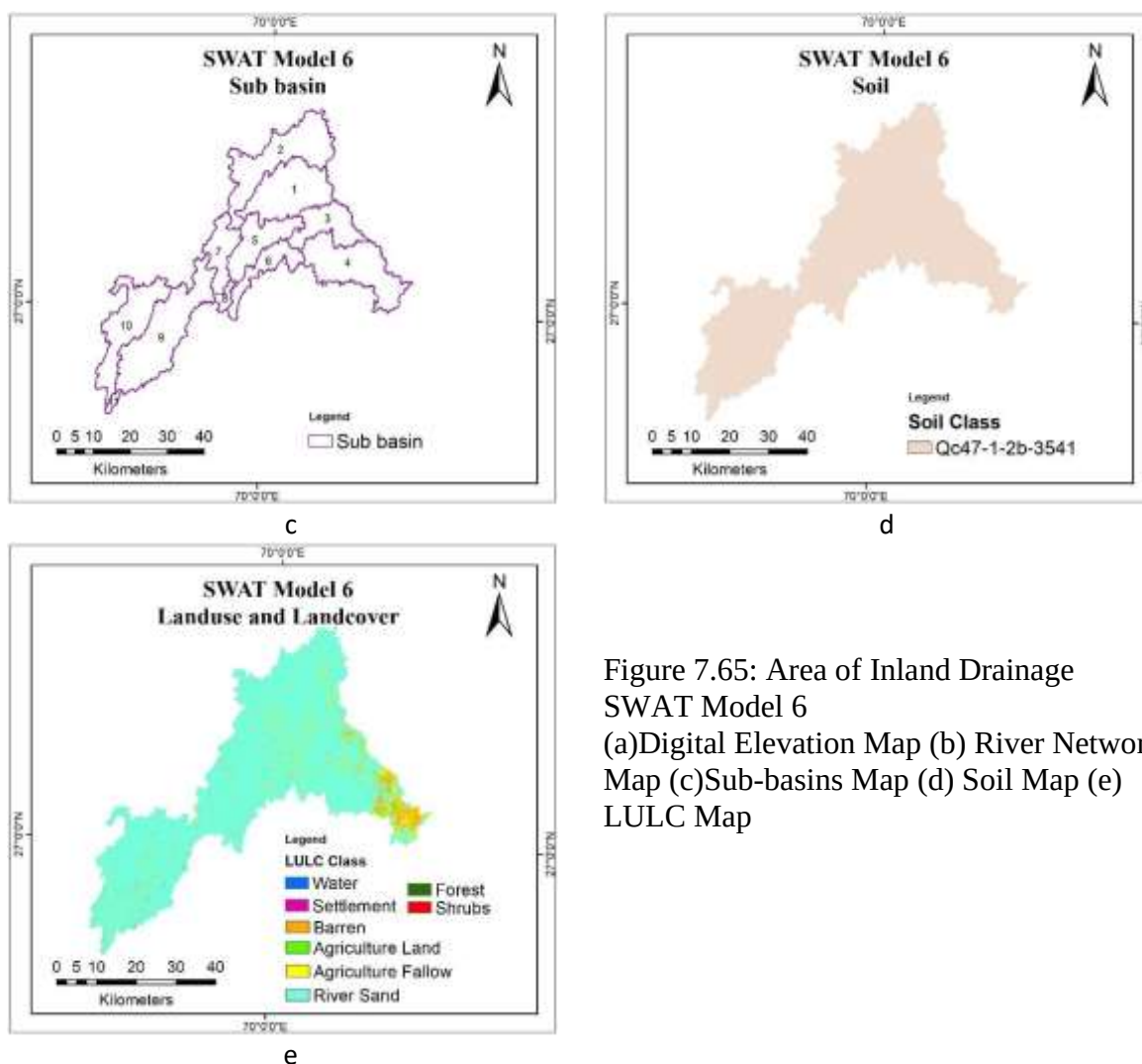


Figure 7.65: Area of Inland Drainage
SWAT Model 6
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.65 (a) shows the Digital elevation Model Map for SWAT Model 6. It has a maximum elevation of 196 meters and a minimum elevation of 12 meters. This DEM Data was obtained from ASTER and had a resolution of 30 meters. It has a standard deviation of 25.9 meters and a mean elevation of 88.98 meters. Figure 7.65 (b) shows the drainage network of SWAT model 6 of the sub-basin of AID. In this Model, the stream network is generated by the SWAT model. This basin has 11 streams and the Total length of all streams comprises 268.02 Km. Figure 7.65 (c) shows the sub-basin map for SWAT model 6 of the AID area. SWAT model 6 total number of 73 HRUs generated by Model and there are 11 sub-basin consisting of AID SWAT model 6. The total subbasin area is 2112.5 square km. Figure 7.65 (d) represents the area of the inland drainage soil map for SWAT model 6. SWAT Model 6 covered only one soil named Qc47-1-2b-3541 obtained from FAO organization data. Area of Inland drainage land use and landcover map for SWAT Model 6 is represented by Figure 7.65 (e) show LULC Map for SWAT Model 6 of AID. It consists of eight classes of LULC. In this basin, 90.10% area is covered by the river sand class of LULC followed by Agriculture fallow land, which covers only 5% of the total area of AID.

Table7.131. Details of digital elevation model for SWAT model 6 of AID

Item	Value
Min. Elevation	12m
Max. Elevation	196m
Mean Elevation	88.98m
Std. Deviation	25.9m

Table 7.132. Details of river network for SWAT Model 6 of AID

Number of Stream	11
Total Length	268.02 km
Number of sub-basin	11
Maximum length	53.93km
Minimum length	4.91km
Average length	24.36km

Table 7.133. Details of LULC for SWAT model 6 of AID

LULC Class	LULC CODE	Area (km ²)	Sub-basin share (%)
Water	WATR	1.81	0.09
Settlement	URBN	1.49	0.07
Shrubs	RNGB	0.60	0.03
Barren Land	BARR	85.19	4.03
Agriculture Land	AGRC	6.40	0.30
Agriculture Fallow	AGRR	113.53	5.37
River Sand	WETN	1903.13	90.10
Forest	FRSD	0.00	0.00

Table 7.134 Details of Soil class for SWAT model 6 of AID

Soil Type	Area (km ²)	Subbasin Share Area (%)
Qc47-1-2b-3541	2112.50	100

Table 7.135 Details of sub basin of SWAT 6 of AID

Number of HRUs	73
Number of Sub-basin	11
Total Area of subbasin	2112.5(km ²)

Subbasin simulation details

SWAT model details provided in Table 7.136 for SWAT model 6 of AID. SWAT model executed for historical period of 25 years 1985-2005 with warm up period 4 years and time step taken monthly for the calculation of subbasin parameters and precipitation calculation for SWAT model selected as measured

Table 7.136 Simulation details SWAT model 6 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	73
Number of Sub basins	11
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km ²	2112.5

Average annual values for water balance in the SWAT model 6 represented by the Table 7.137 for the historical period 1985-2005.

Table 7.137 Water balance component for SWAT model 6 of AID

Water Balance Component	Value in mm
Precipitation	157.1
Surface Runoff Q	1.43
Lateral Flow Through Soil	86.8
GW (Shallow AQ)	0
GW(Deep AQ)	0.69
REVAP (Shallow =>Soil/Plant)	2.78
Deep Aquifer Recharge	0.65
Total Aquifer Recharge	1.02
Total Water Yield	88.92
Percolation Out of Soil	0.75
ET	70.8
PET	1714
Total Sediment Loading	1.01t/ha

Water Balance Calculations

Total flow = Surface runoff + Base flow = 1.43 mm+ 0.69 mm = 2.12 mm

A preliminary check perform using the SWAT check tool which gives the ratio for the Subbasin parameters simulation for accuracy purpose which are shown as Table 7.138

Table 7.138 Water balance ration for SWAT model 6 of AID

Water balance Ratio	Values
Streamflow/Precipitation	0.56
Base flow /Total flow	0.9
Surface Runoff/Total flow	0.02
Percolation/precipitation	0.1
Deep Recharge/Precipitation	0
ET/Precipitation	0.45

Continuity Error Calculation

Total Inflow = Precipitation + Revap

Total outflow = Surface Runoff + Lateral flow + Groundwater + Evapotranspiration + Deep Aquifer Recharge

Continuity error = $100 \times (1.0 - (\text{Total outflow} / \text{total inflow}))$ (SWMM manual)

Continuity error = $100 \times (1 - (159.88 \div 160.41))$

Continuity error = 1.53%

Water Balance at outlet for historic period 25 years (1985-2005)

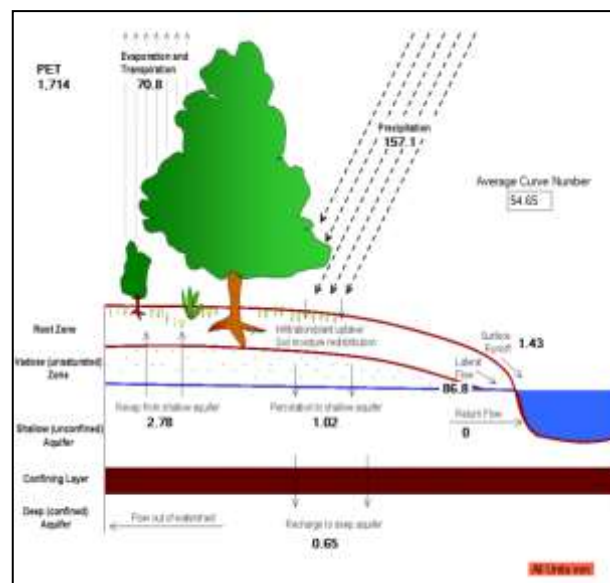
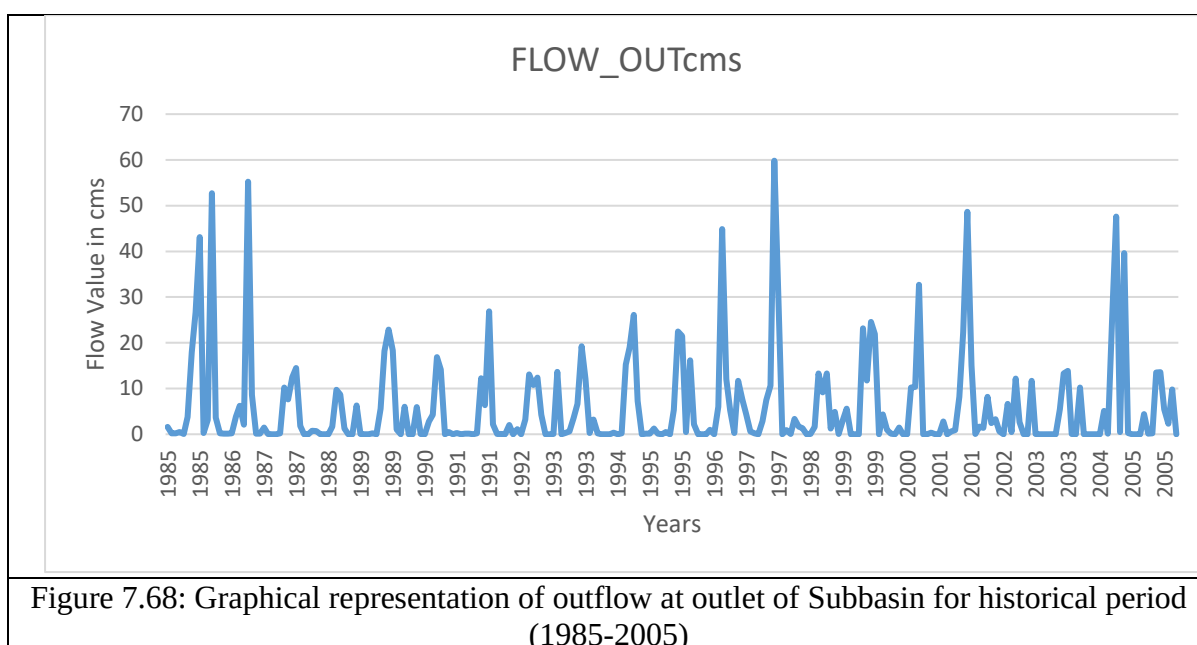
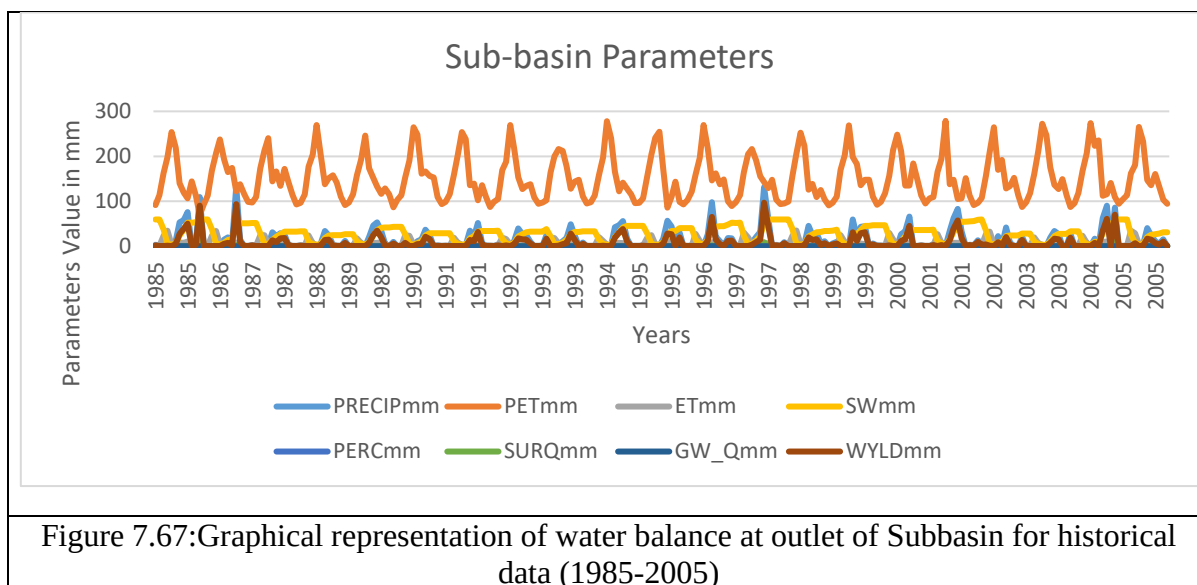


Figure.7.66: Water Balance at outlet of Subbasin SWAT model 6 of AID



7.5.8 SWAT Model 7 of AID

SWAT Model 7 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude 30°1'49.86" N 74°36'7.98" E longitude. It is the 5th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 7 of AID is 12265.29 Sq. km. The SWAT model for sub basin 7 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

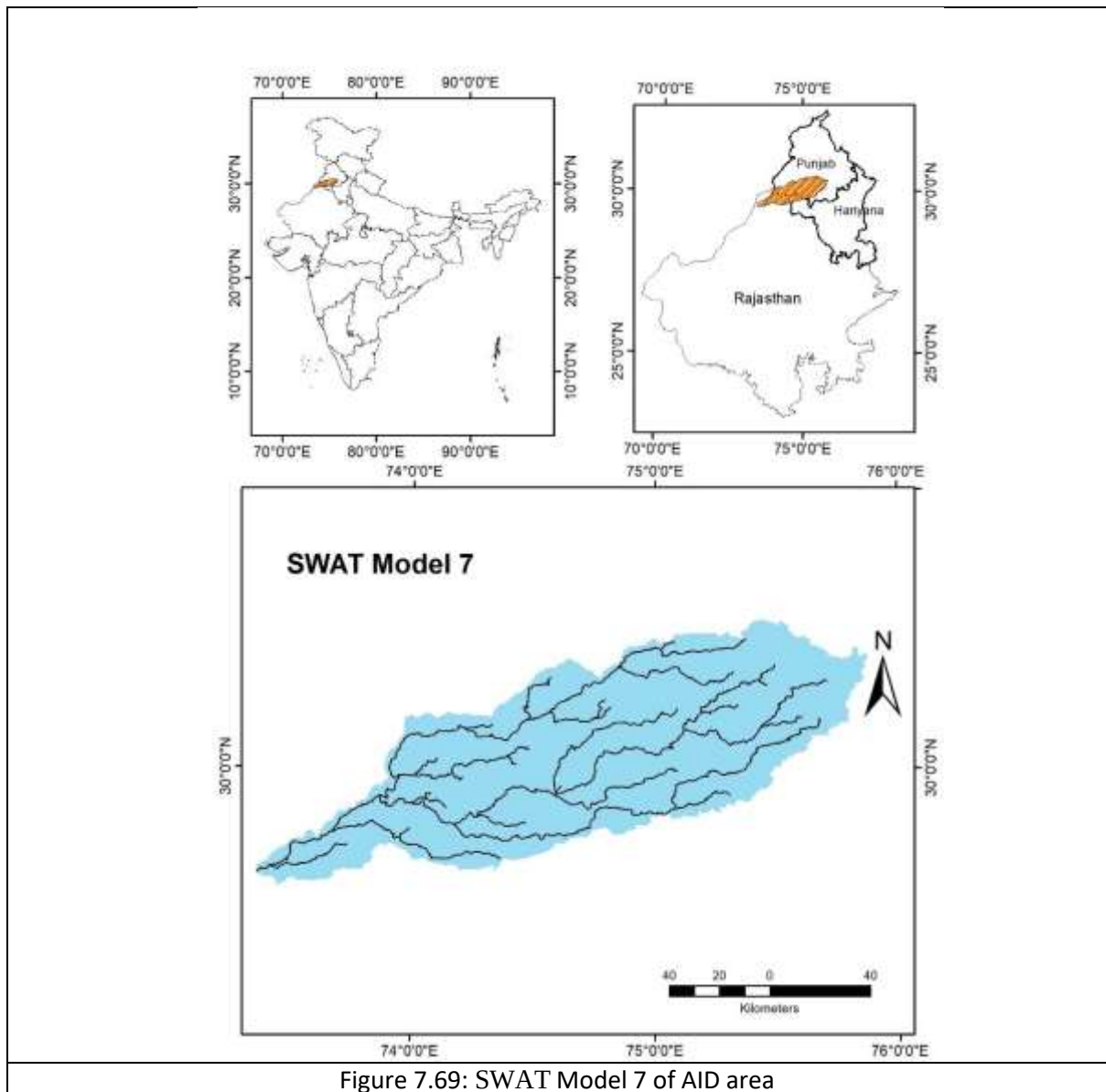
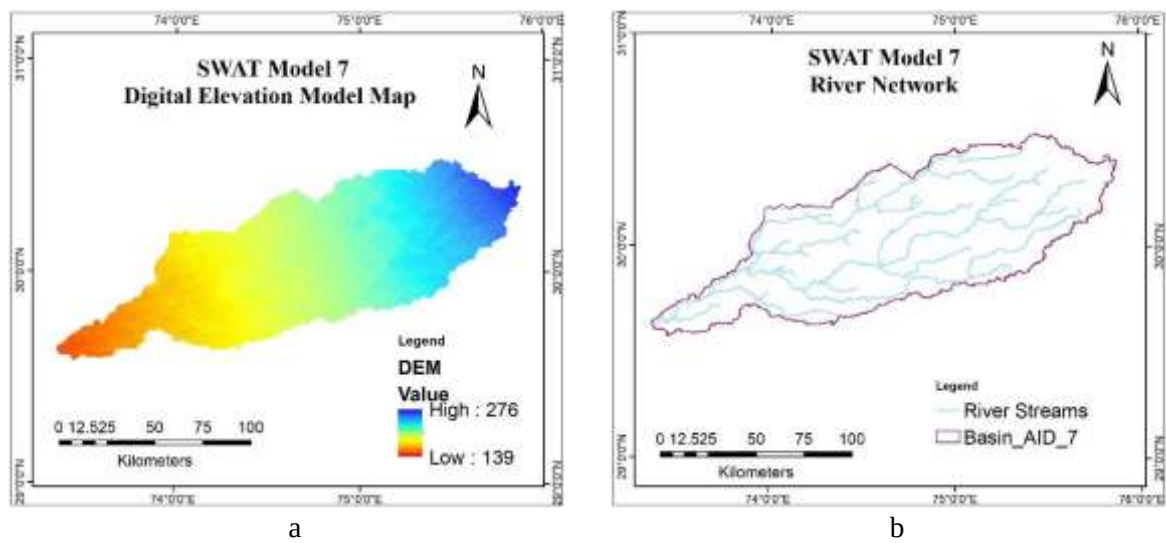


Figure 7.69: SWAT Model 7 of AID area



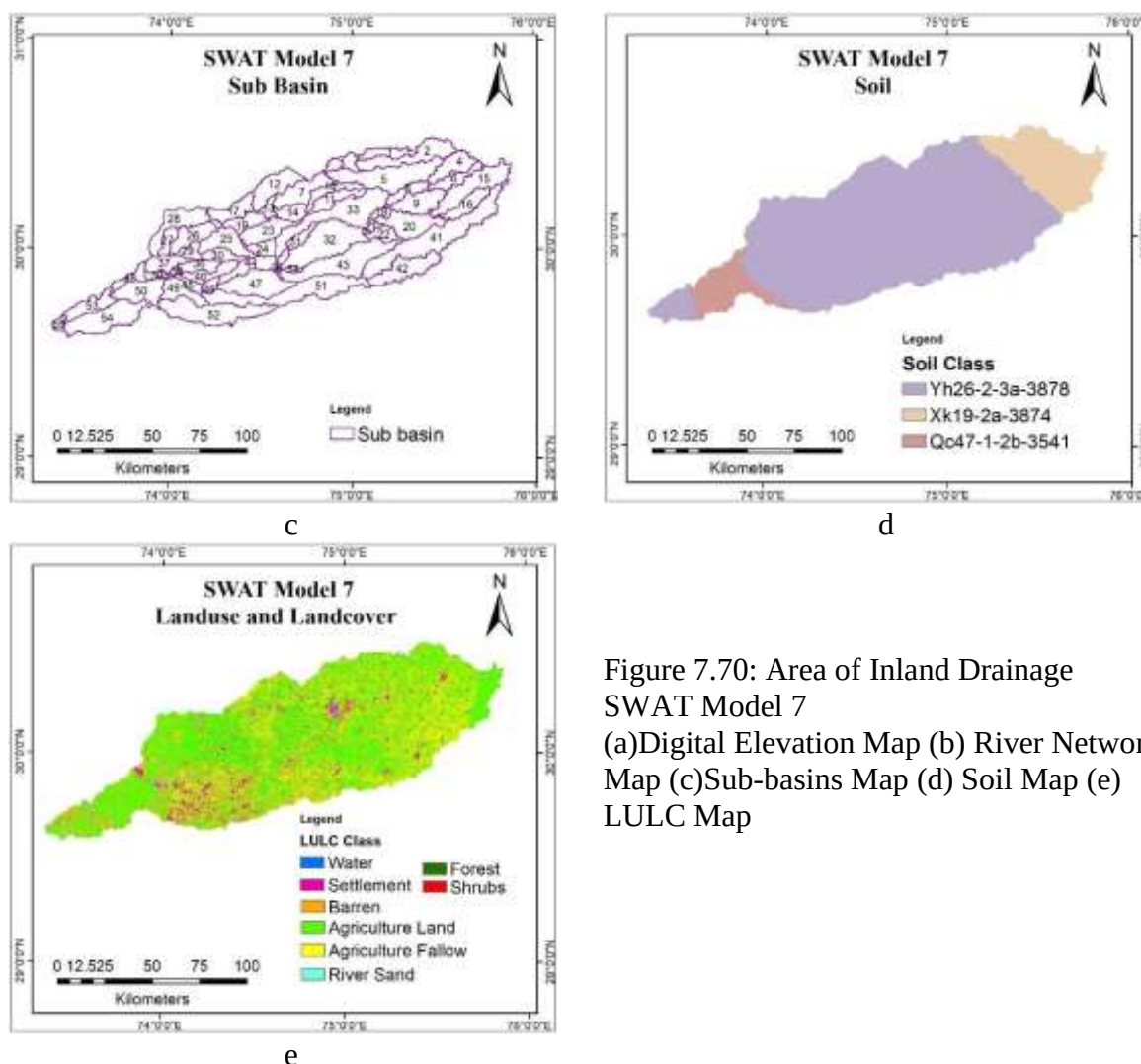


Figure 7.70: Area of Inland Drainage
SWAT Model 7
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.70 (a) shows a digital elevation map for SWAT model 7 of AID. It has a high elevation of 276 meters and a minimum elevation of 139 meters. This elevation map has a standard deviation value of 18.5 meters and a mean elevation of 200.93 meters. Figure 7.70 (b) shows the river network of SWAT model 7. The total number of streams generated is 55 and has a total length of 1530 sq. km. The direction of all streams toward the west. Figure 7.70(c) shows the subbasin map for SWAT model 7 of AID. Figure 7.70(d) Soil Map for the SWAT Model 7 of AID. It has three soil types; Yh 26-2-30-3878 covered 80% of the area. Soil type Xk19-20-3874 covered 13.21% area, and soil type Qc47-1-2b-3541 6.50% area of total area. Figure 7.70 (e) Landuse and landcover map for SWAT model 7. This Model has eight LULC Classes in the watershed, which is well distributed. In this sub-basin, the most dominant LULC class is Agriculture Land which is 55.97% of the total subbasin area, followed by agriculture fallow which is 27.15% area of total sub-basin area and less dominated LULC Class water, Shrubs.

Table 7.139 Details of digital elevation model for SWAT model 7 of AID

Min. Elevation	139m
Max. Elevation	276m

Mean Elevation	200.93m
Deviation	18.5m

Table 7.140 Details of river network for SWAT model 7 of AID

Number of stream	55
Number of sub-basin	55
Total length of stream	1530.27km
Minimum length	0.08km
Maximum length	121.45km
Avg. Length	27.82km

Table 7.141 Details of LULC for SWAT model 7 of AID

LULC Class	LULC Code	Area (Km ²)	Sub-basin share (%)
Water	WATR	42.71	0.35
Settlement	URLD	763.16	6.22
Forest	FRSD	160.96	1.31
Shrubs	RNGB	73.26	0.6
Barren	BARR	873.04	7.12
Agriculture Land	AGRRL	6864.68	55.97
Agriculture Fallow	AGRC	3329.50	27.15
River sand	WETN	157.97	1.29

Table 7.142 Details of Soil class for SWAT model 7 of AID

Soil Type	Area (km ²)	Subbasin share (% Area)
Xk19-20-3874	1620	13.21
Yh26-2-30-3878	9847.80	80.29
Qc47-1-2b-3541	797	6.50

Table 7.143 Details of Sub-basin of SWAT model 7 of AID

Number of HRUs	631
Number of sub basin	55
Subbasin Area	12265.29 km ²

Subbasin simulation details

SWAT model simulation details provided in Table 7.144 for SWAT model 7 of AID. SWAT model executed for historical period (1985-2005) for 25 years with warm-up period of 4 years and time step taken monthly for calculation of water balance component.

Table 7.144 Subbasin simulation details for SWAT Model 7 of AID

Simulation Details	Value
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	631
Number of Sub basins	55
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	12,265.29

Average annual water balance component value generated by SWAT model run for the period 25 years (1985-2005) shown in Table 7.145.

Table 7.145 Annual average water balance component and their values for SWAT model 7 of AID

Water balance component	Values in mm
Precipitation	356.7
Surface Runoff Q	16.02
Lateral Flow Through Soil	0.27
GW (Shallow AQ)	0.91
GW(Deep AQ)	0.21
REVP (Shallow AQ=>Soil/Plant	10.64
Deep Aquifer Recharge	0.16
Total Aquifer Recharge	3.25
Total Water Yield	17.44
Percolation Out of Soil	3.17
ET	343.4
PET	1252
Total Sediment Loading	2.00 T/HA

Water Balance Calculation

Total flow = surface runoff +base flow = 16.02mm+0.21mm=16.23mm

A preliminary check for performance using SWAT check tool run which gives the ratio for the Subbasin simulation for accuracy shown in Table 7.146

Table 7.146 Water balance Ratio for SWAT model 7 of AID

Component	Value
Streamflow/Precipitation	0.05
Base flow /Total flow	0.07
Surface Runoff/Total flow	0.93
Percolation/precipitation	0.01
Deep Recharge/Precipitation	0
ET/Precipitation	0.96

Continuity Error Calculation

Continuity error Calculated for SWAT model 7 as per the SWMM manual

Total inflow = Precipitation + Revamp

Total Outflow = Surface runoff + Lateral flow + Groundwater + ET + Deep aquifer recharge

Continuity Error = $100 * (1 - \text{Total inflow} / \text{Total Outflow})$

Continuity Error = $100 * (1 - 367.73 / 366.76)$

Continuity Error = 0

Water Balance components at outlet pictorial representation shown in Figure No.-

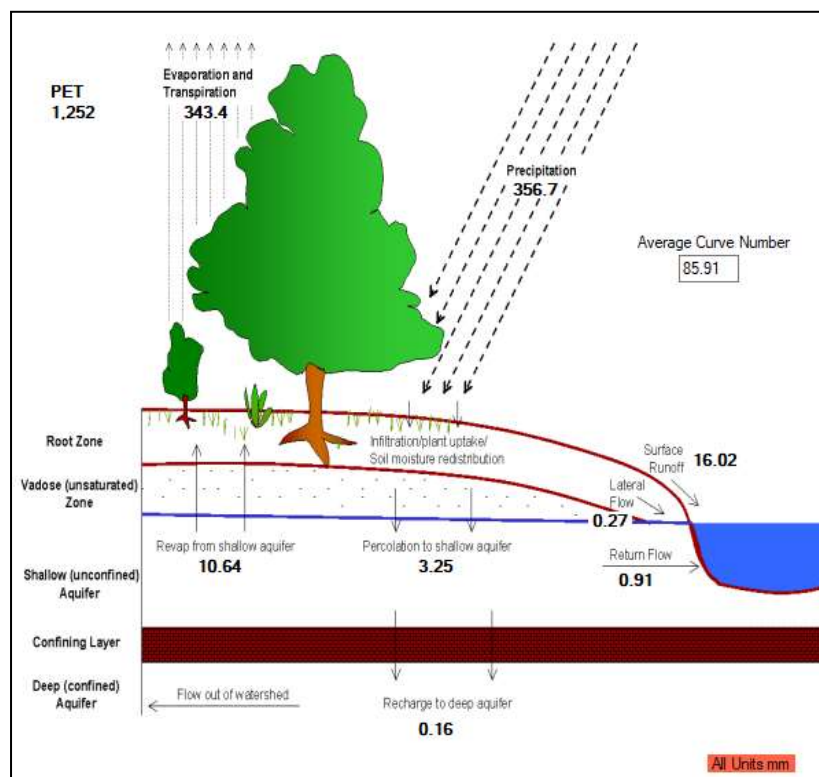


Figure 7.71: Pictorial representation of water balance component at outlet of Subbasin for SWAT Model 7 of AID

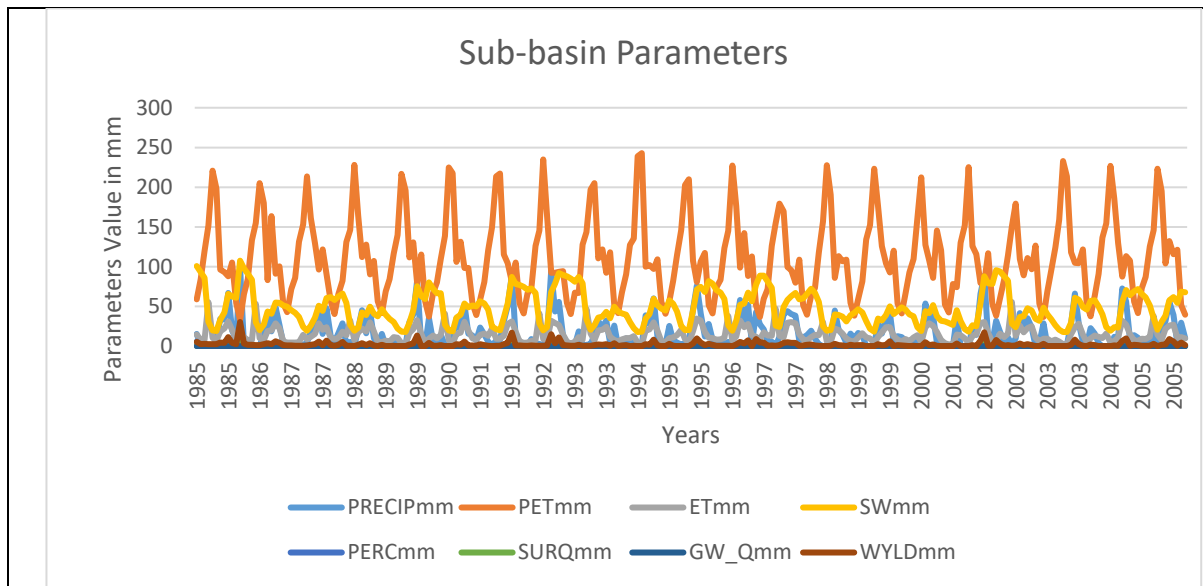


Figure7.72: Graphical representation of water balance at outlet of Subbasin for historical data(1985-2005)

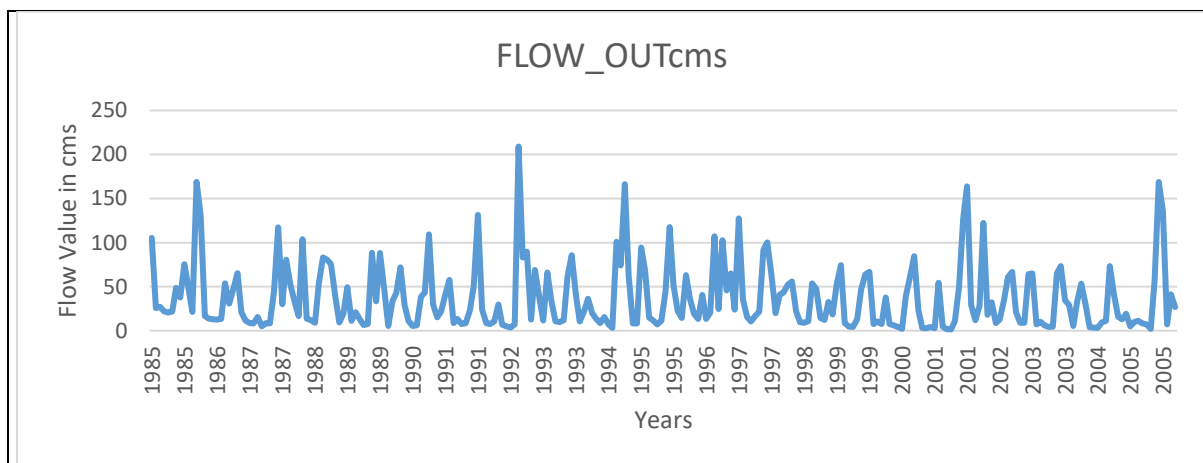


Figure 7.73: Graphical representation of Flow out at outlet of Subbasin for historical data (1985-2005)

7.5.9 SWAT model 8 of AID

SWAT Model 8 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $28^{\circ}38'34.70''$ N and $73^{\circ}46'50.60''$ E longitude. It is the 6th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total Subbbasin area for the SWAT Model 8 of AID is 4663.18 Sq. km. The SWAT model for sub basin 8 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

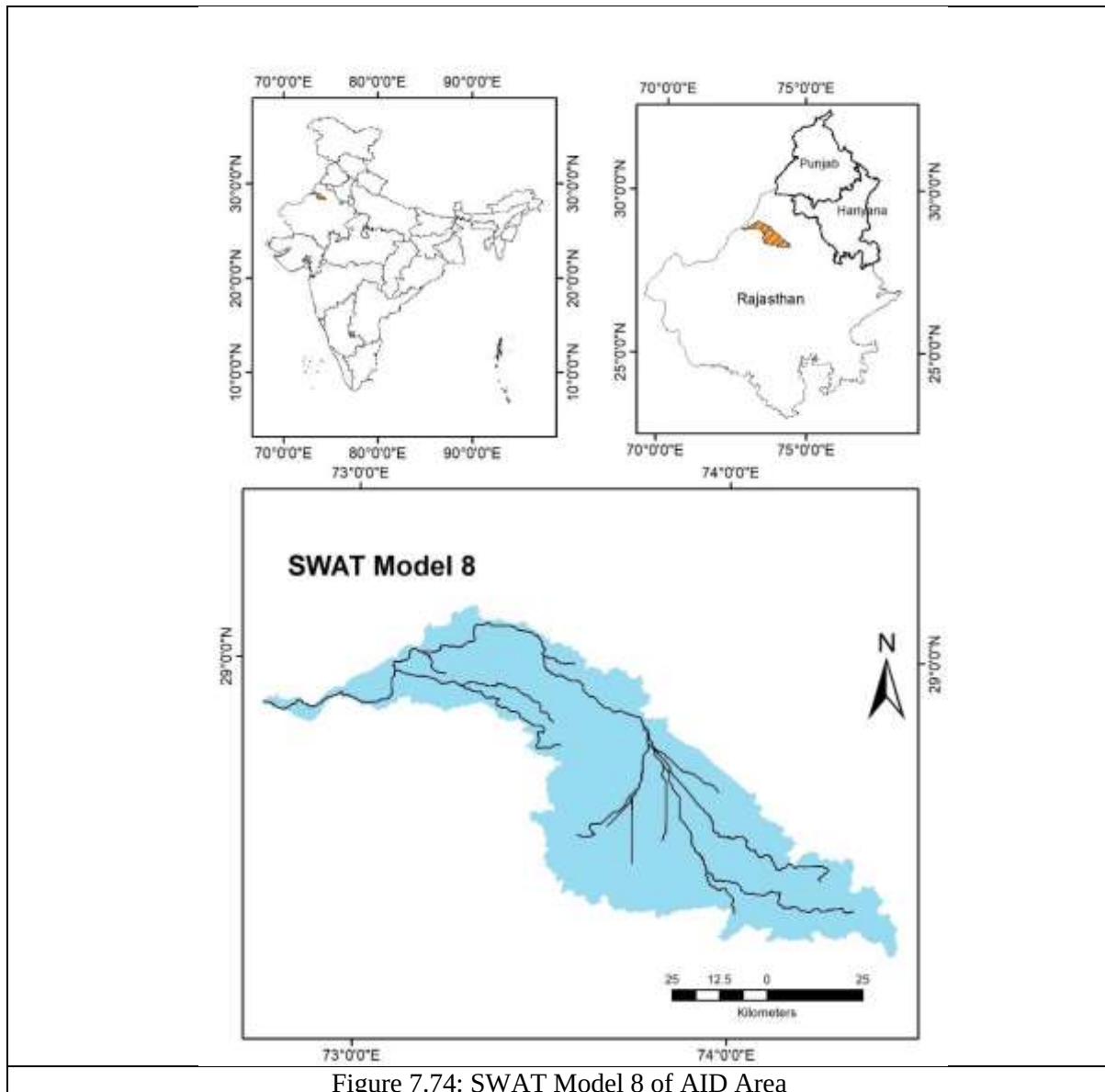
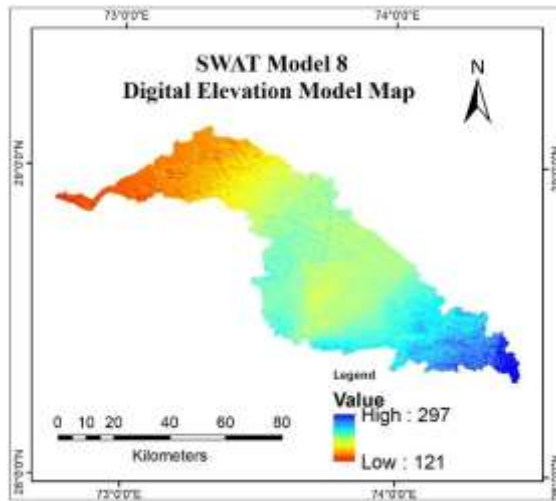
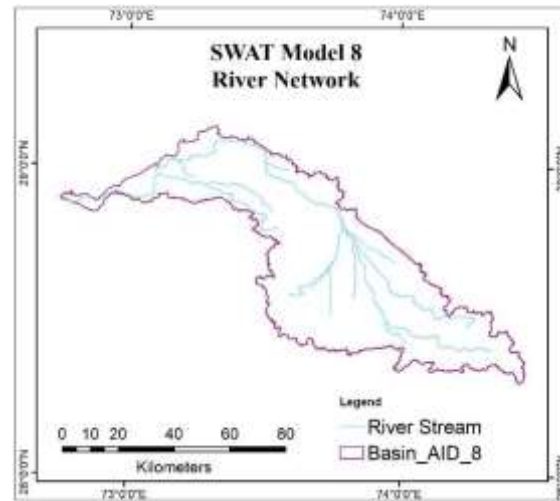


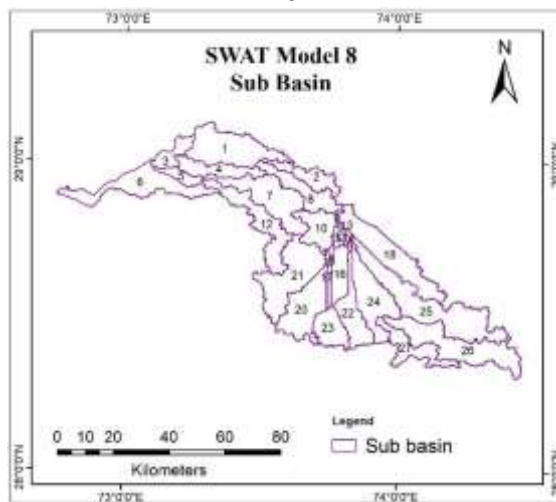
Figure 7.74: SWAT Model 8 of AID Area



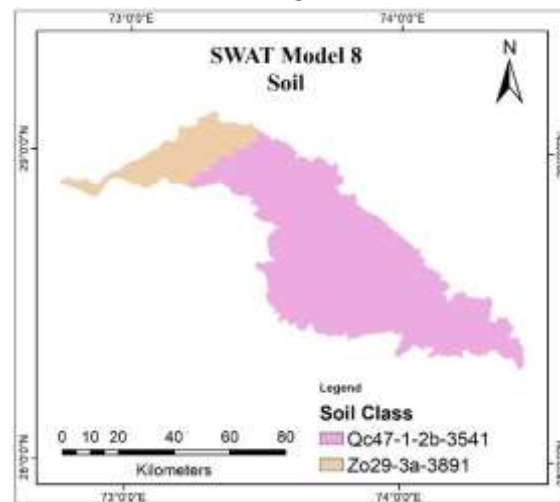
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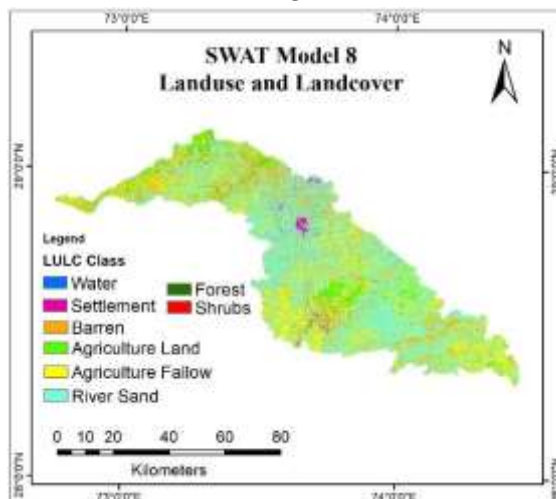
b



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d



e

Figure 7.75: Area of Inland Drainage
SWAT Model 8
(a) Digital Elevation Map (b) River
Network Map (c) Sub-basins Map (d) Soil
Map (e) LULC Map

Figure 7.75 (a) digital elevation model map for SWAT Model 8. It has a maximum elevation of 297 meters and a minimum elevation of 121 meters. It has a standard deviation of 25.35meter and a mean elevation of 198.56 meters. Figure 7.75 (b) shows the river network of SWAT model 8 of AID. It has a total number of sub-basin 27, and the number of streams generated by the SWAT model is 27, which comprises a total length of 577.25 Km. Figure 8 Figure 7.75 (c) shows the sub-basin map of SWAT Model 8. It has a total area of 4663.18Sq Km. The number

of HRUs generated by the SWAT model is HRUs 214 within the total 27 sub-basin. Figure 7.75 (d) shows the soil map for SWAT model 8 of AID. There are two types of soil covered in this basin. Soil type Qc47-1-2b-3541 covered 84.62% of the total basin area, and soil type Zo29-3a-3891 covered 15.38% area of the basin. Figure 7.75(e) shows the LULC Map for SWAT model 8 of AID. River sand is dominated by 50.79% out of the total basin area. Barren land covered 21.1% area followed by the agriculture fallow land by 19.29 % out of total basin area. Less dominated LULC class is the forest with a subbasin percentage of 0.01% of the total subbasin area.

Table 7.147 Details of Digital elevation model of SWAT model 8 of AID

Min. Elevation	121m
Max Elevation	297m
Mean Elevation	198.56m
Std. Deviation	25.35m

Table 7.148. Details of river network for SWAT model 8 of AID

Number of streams	27
Number of sub-basin	27
Total length	577.25km
Minimum length	1.32km
Maximum length	76.56km
Average length	21.38km

Table 7.149 Details of LULC for SWAT model 8 of AID

LULC Class	LULC Code	Area (Km ²)	Sub-basin share (%)
Water	WATR	0.79	0.2
Settlement	URLD	109.93	2.36
Forest	FRSD	0.33	0.01
Shrubs	RNGB	1.55	0.03
Barren	BARR	984.08	21.1
Agriculture Land	AGRC	299.98	6.43
Agriculture Fallow	AGRR	899.68	19.29
River sand	WETN	2366.75	50.79

Table 7.150 Details of Soil class for SWAT model 8 of AID

Soil Type	Area (km ²)	Subbasin share (% area)
Qc47-1-2b-3541	3945.90	84.62
Zo29-3a-3891	717.28	15.38

Table 7.151 Details of Sub-basin of SWAT model 8 of AID

Number of HRUs	214
Number of sub-basin	27
Total Area of watershed	4663.18 km ²

Subbasin Simulation Details

SWAT model simulation details provided in Table 7.152 for SWAT model 8 of Inland drainage area .SWAT model setup and run for the period of 25years for historical data (1985-2005)

Table 7.152 Simulation details for SWAT Model 8 of AID area

Simulation details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	214
Number of Sub basins	27
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	4663.18

Average annual water balance value generated by the SWAT model ran for a historical period of 25 years (1985-2005). Water balance components and their values shown in Table 7.153.

Table 7.153 Average annual water balance component for SWAT model 8 of AID area

Water Balance component	Value in mm
Precipitation	254.7
Surface Runoff Q	2.24
Lateral Flow Through Soil	107.17
GW (Shallow AQ)	0
GW(Deep AQ)	2.01
REVAP (Shallow AQ=>Soil/Plant	9.91
Deep Aquifer Recharge	1.9
Total Aquifer Recharge	2.98
Total Water Yield	111.42
Percolation Out of Soil	2.31
ET	144.4
PET	1367
Total Sediment Loading	0.32 t/ha

Water balance calculation

Total flow =Surface runoff +Baseflow =2.34mm + 2.01mm = 4.35mm

Continuity Error Calculation

Continuity error calculation for SWAT model 8 as per the SWMM manual

Total inflow =Precipitation +Revap

$$=254.7\text{mm}+9.91\text{mm}=264.61\text{mm}$$

Total Outflow = Surface Runoff + Lateral Flow + ET+ GW+ Deep aquifer Recharge

$$=2.24\text{mm}+107.17\text{mm}+144.4\text{mm}+0.00\text{mm}+1.9\text{mm}$$

$$=255.71\text{mm}$$

Continuity error = $100 \times (1 - \text{Inflow} / \text{Outflow})$

Continuity error = $100 \times (1 - 264.61 / 255.71)$

Continuity error = -3.4%

Pictorial repetition of water Balance component at outlet of subbasin for SWAT model 8

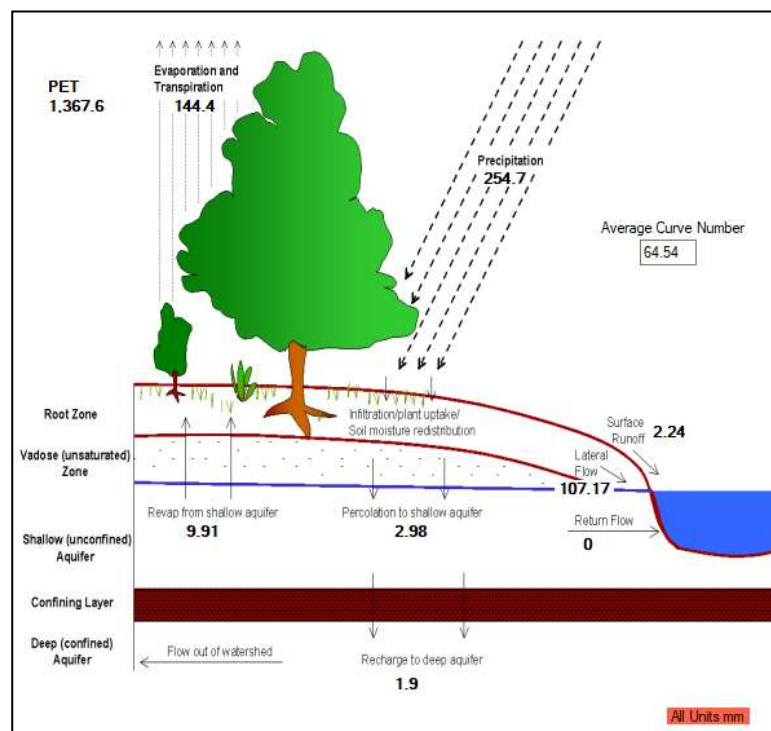


Figure 7.76: Water Balance component pictorial representation for SWAT model 8

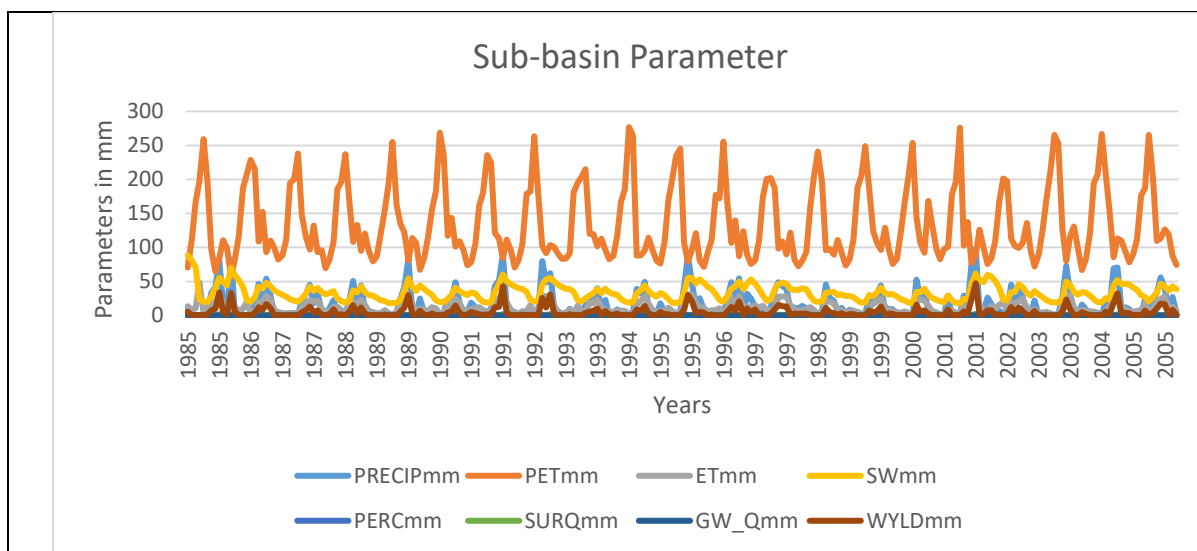


Figure 7.77: Graphical representation of water balance component at outlet of subbasin for SWAT model 8 for Historical period (1985-2005)

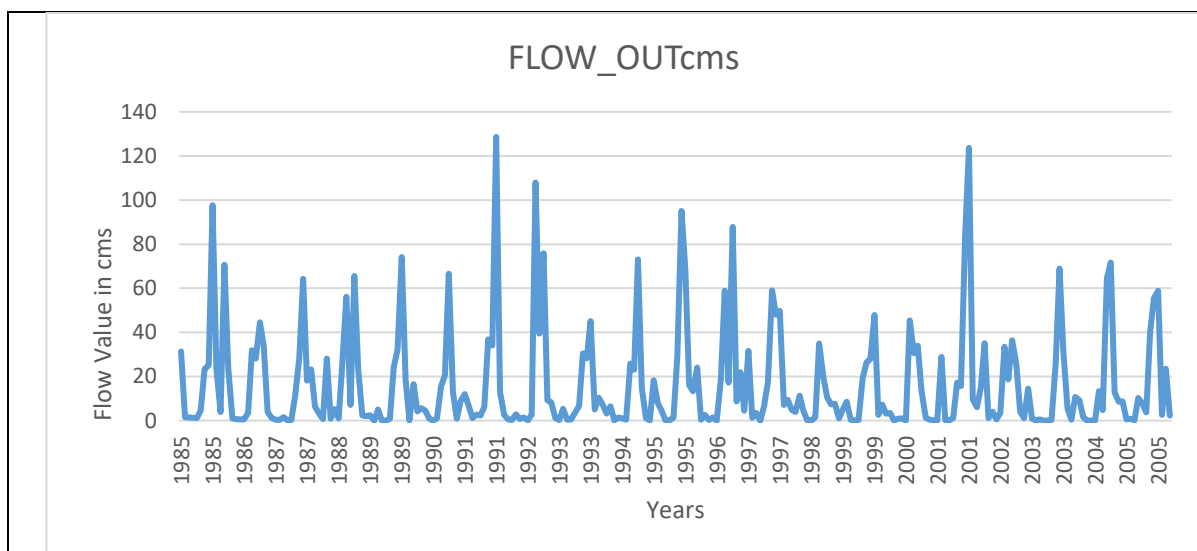


Figure 7.78: Graphical representation Outflow at subbasin outlet of subbasin of SWAT model 8 for historical period (1985-2005)

7.5.10 SWAT Model 9 of AID

SWAT Model 9 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude 28°47'23.20" N and 73°4'58.17" E longitude. It is the 13th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 1 of AID is 1991.29 Sq. km. The SWAT model for sub basin 9 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

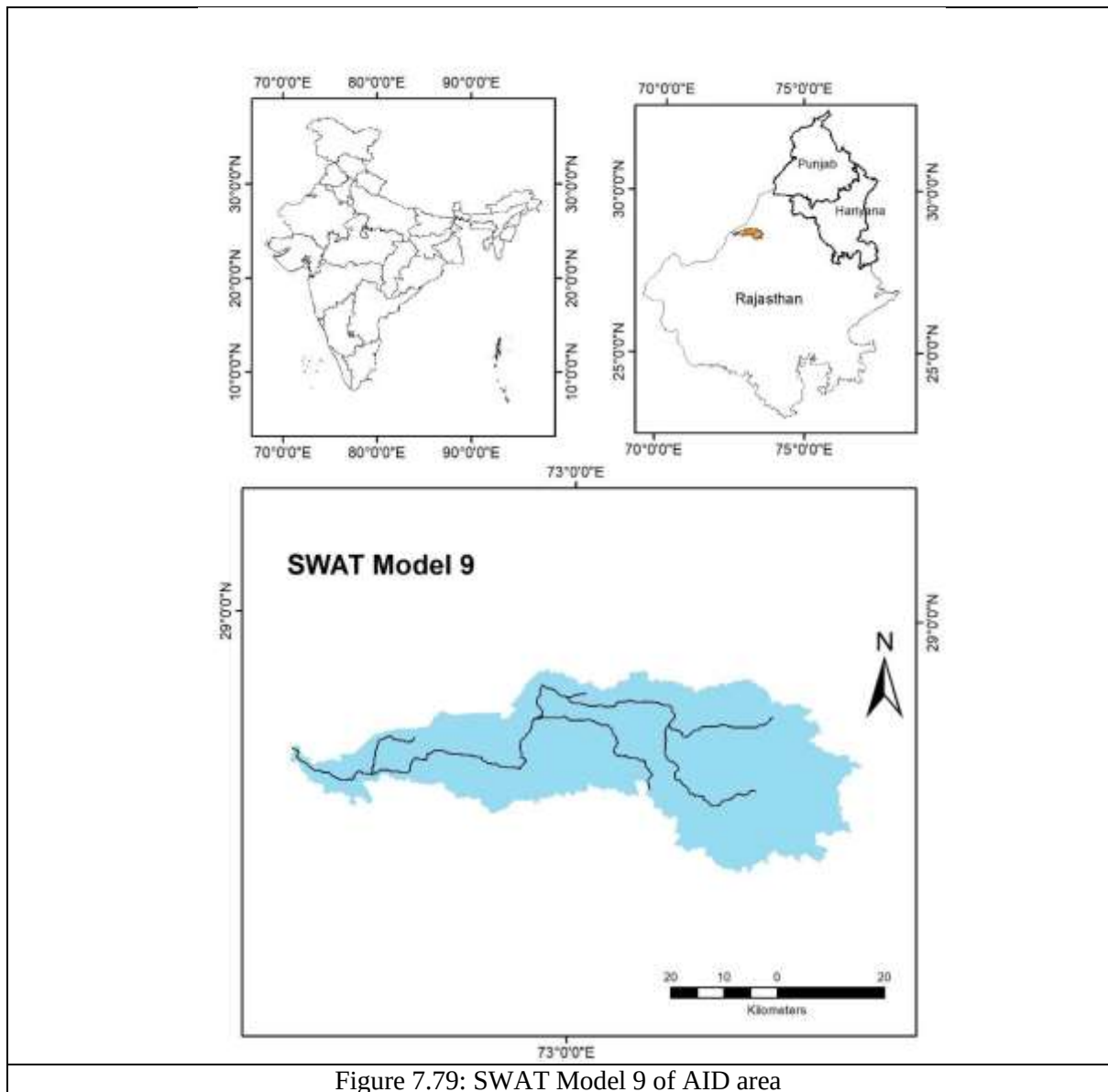
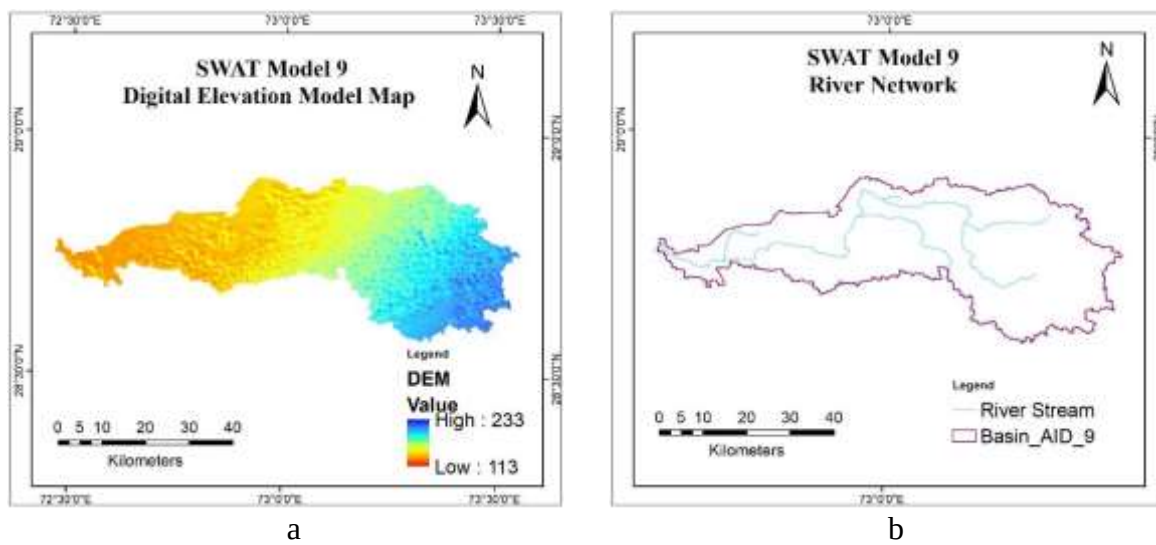


Figure 7.79: SWAT Model 9 of AID area



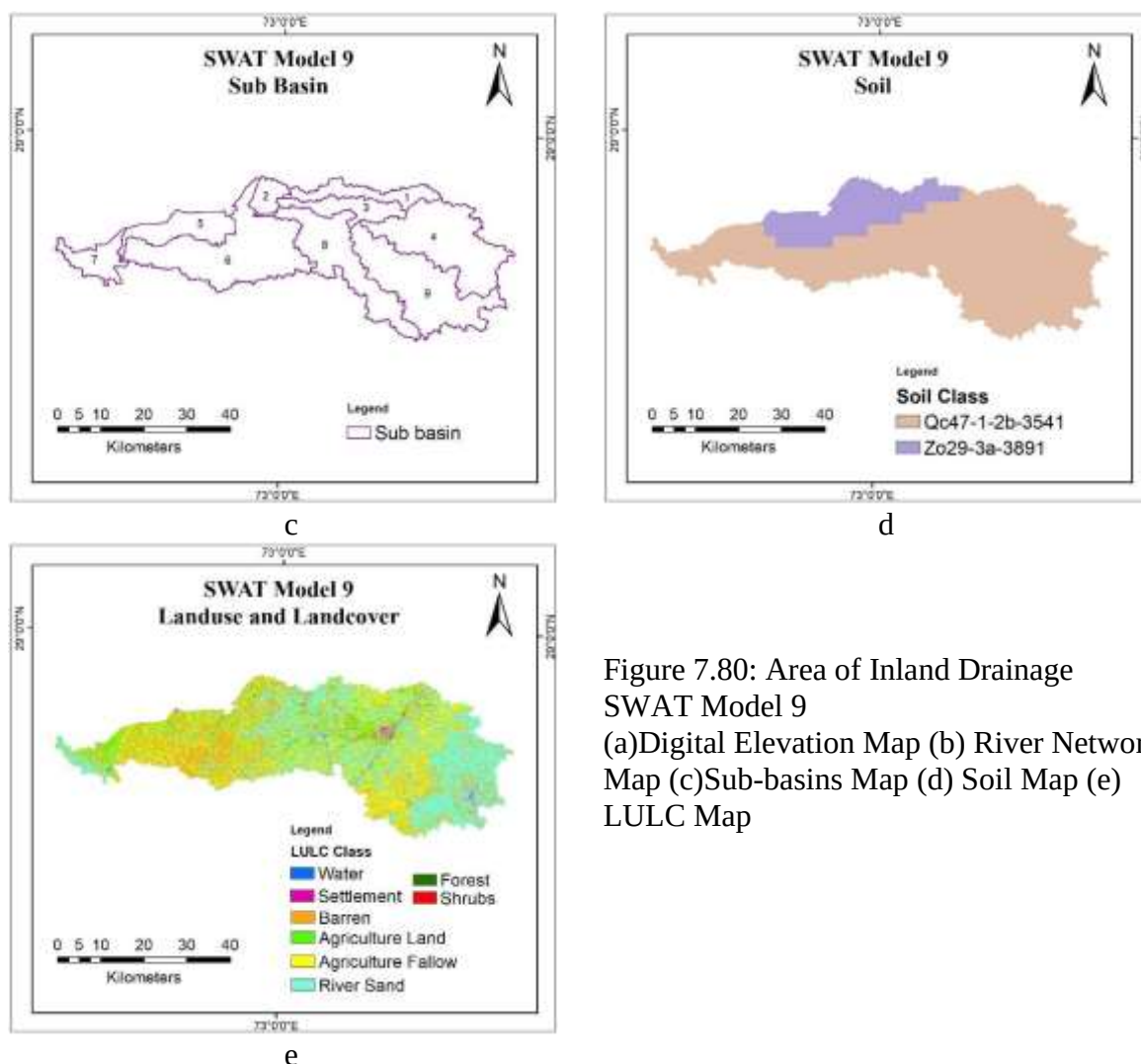


Figure 7.80: Area of Inland Drainage
SWAT Model 9
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.80 (a) shows the digital elevation model for SWAT model 9 of AID. The highest elevation in the basin is 233 meters, and the lowest elevation in the basin is 113 meters. The mean elevation is 167.21 meters. Figure 7.80(b) shows the river network in the sub-basin. In this sub-basin, the total number of sub-basins is nine, and the total number of rivers are 9. The total length of all rivers is 216.08 km. Figure 7.80(c) shows the sub-basin map. It has 108 HRUs in the basin, and the total basin area is 1991.24 Sq. Km. Figure 7.80(d) shows the soil map for SWAT model 9. It has two soil types. Soil type Qc47-1-2b-3541 is covered 81.65% of the total basin area, and soil type Zo29-3a-3891 covers 18.35 % out of the total basin area: Figure 7.80 (e) Landuse and landcover map for SWAT model 9, which has eight classes. Land use and land cover are well distributed in the basin. The dominant class is river sand which covers 50% of the total basin area. The less dominant LULC class is Water bodies which have a subbasin percentage share of approximately 0.04% out of the total basin area. Barren land comprises only 26.95% out of the total basin area.

Table 7.154 Details of digital elevation model for SWAT model 9 of AID

Min. Elevation	113m
Max. Elevation	233m
Mean. Elevation	167.21m

Std. Deviation	24.68m

Table 7.155 Details of river network for SWAT model 9 of AID

Number of streams	9
Number of sub basin	9
Total length of stream	216.08km
Minimum length of streams	4.0km
Maximum length of streams	46.46km
Average length of streams	24.00km

Table 7.156 No. Details of LULC for SWAT model 9 of AID

LULC Class	LULC Code	Area (km²)	Sub-basin share (%)
Water	WATR	0.82	0.04
Settlement	URLD	42.17	2.12
Forest	FRSD	1.19	0.06
Shrubs	RNGB	1.16	0.06
Barren	BARR	536.66	26.95
Agriculture Land	AGRC	142.57	7.16
Agriculture Fallow	AGRR	400	20.09
River Sand	WETN	866.64	43.52

Table 7.157 Details of Soil class for SWAT model 9 of AID

Soil Type	Area (km²)	Subbasin Share (% Area)
Qc47-1-2b-3541	1625.88	81.65
Zo29-3a-3891	365.24	18.35

Table 7.158 Details of Sub-basin of SWAT model 9 of AID

Number of HRUs	108
Number of Sub-basin	9
Area of Subbasin	1991.24 km ²

Subbasin Simulation Details

SWAT model simulation details presented in Table 7.159 for SWAT Model 9 of AID .SWAT model set and run for period of 25 years (1985-2005) with warm-up period 4 years

Table 7.159 Subbasin simulation details for SWAT Model 9 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	108
Number of Sub basins	9
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km ²	1991.24

Average annual Values of water balance component generated by SWAT model 9 for period 25years (1985-2005) Shown in Table 7.160

Table 7.160 Average annual values of Water balance component for SWAT model 9 of AID

Water Balance Component	Values in mm
Precipitation	213.7
Surface Runoff Q	1.41
Lateral Flow Through Soil	86.91
GW (Shallow AQ)	0
GW(Deep AQ)	0
REVAP (Shallow AQ=>Soil/Plant	5.75
Deep Aquifer Recharge	0.77
Total Aquifer Recharge	1.2
Total Water Yield	89.12
Percolation Out of Soil	0.97
ET	126.5
PET	1549.5
Total Sediment Loading	0.24t/ha

Water balance Calculation

Total flow = surface runoff + base flow =1.41mm+0=1.41mm

A preliminary check for performance of SWAT model done for accuracy purpose swat check tool run which gives the ratio for subbasin shown in Table 7.161.

Table 7.161 Water balance ratio for SWAT model 9 of AID

Subbasin component	Values
Streamflow/Precipitation	0.41
Base flow /Total flow	0.58
Surface Runoff/Total flow	0.02
Percolation/precipitation	0.01
Deep Recharge/Precipitation	0
ET/Precipitation	0.59

Continuity Error Calculation

Continuity error calculation for SWAT model 9

Total inflow =Precipitation +Revap

$$=213.7\text{mm}+5.75\text{mm}$$

$$=219.45\text{mm}$$

Total Outflow =Surface runoff +Lateral flow +GW+ ET + Deep Aquifer Recharge

$$=1.41\text{mm}+86.91\text{mm}+0\text{mm}+126.5\text{mm}+0.77\text{mm}$$

$$215.59\text{mm}$$

Continuity Error =100*(1-Total Inflow/Total Outflow)

Continuity Error =100*(1-219.45/215.59)

Continuity Error = -1.79%

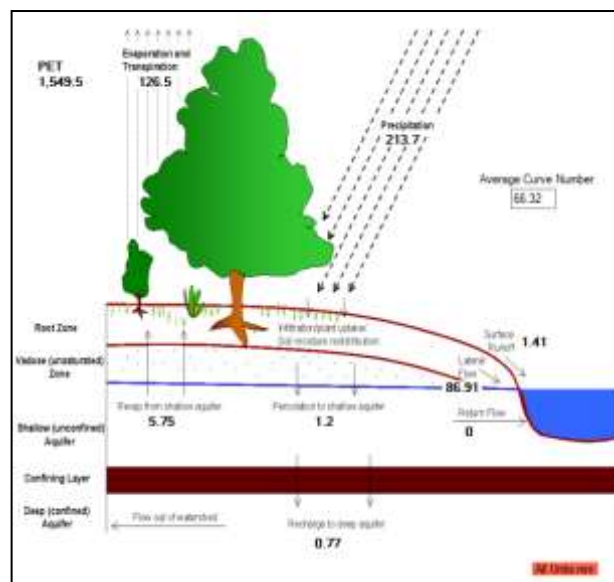


Figure 7.81: Pictorial representation of water Balance component at outlet of subbasin for period (1985-2005)

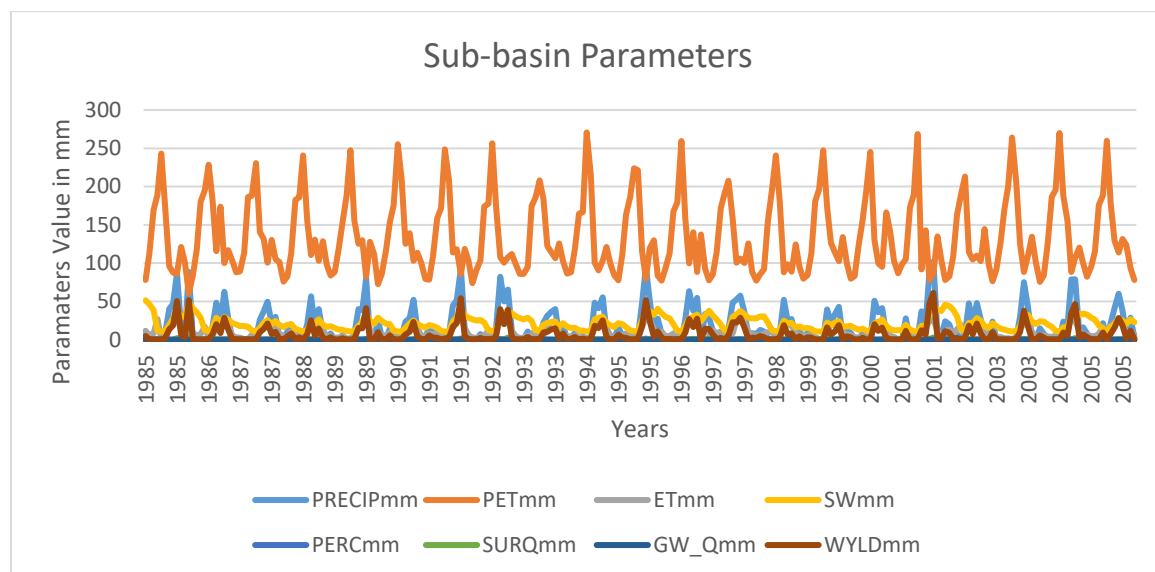


Figure 7.82: Graphical representation of water balance at outlet of subbasin for historical period (1985-2005)

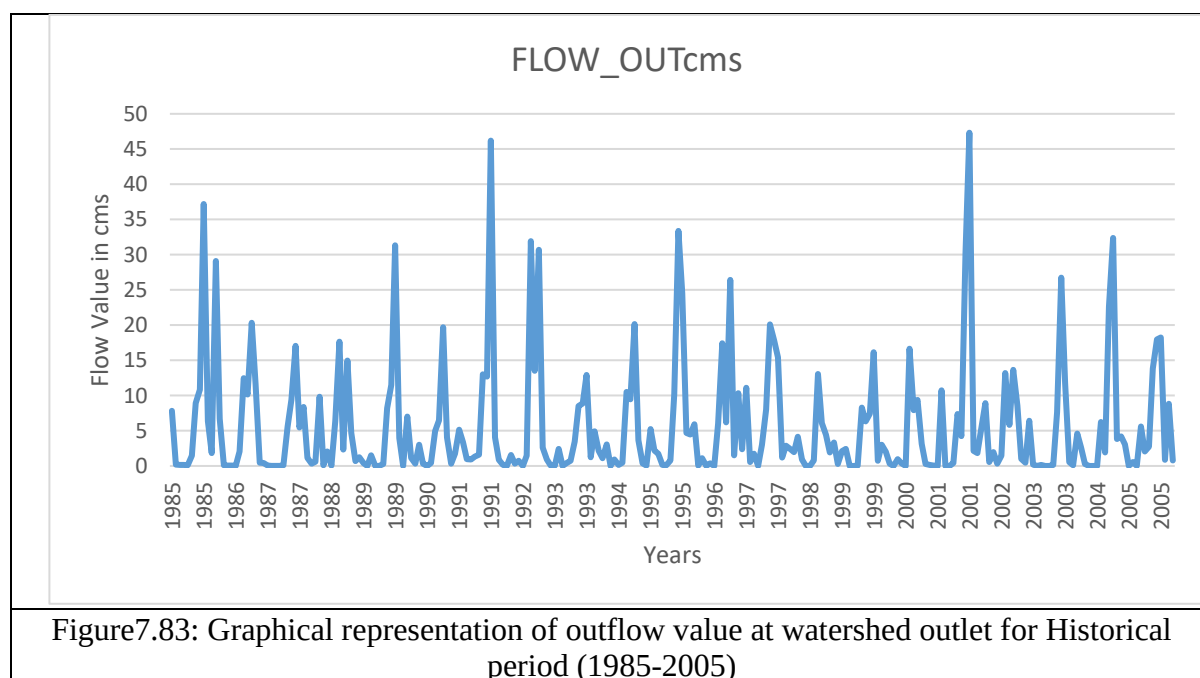


Figure7.83: Graphical representation of outflow value at watershed outlet for Historical period (1985-2005)

7.5.11 SWAT Model 10 of AID

SWAT Model 10 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $28^{\circ}35'8.40''$ N and $73^{\circ}2'31.60''$ E longitude. It is the 12th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 10 of AID is 2014.69 Sq. km. The SWAT model for sub basin 10 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

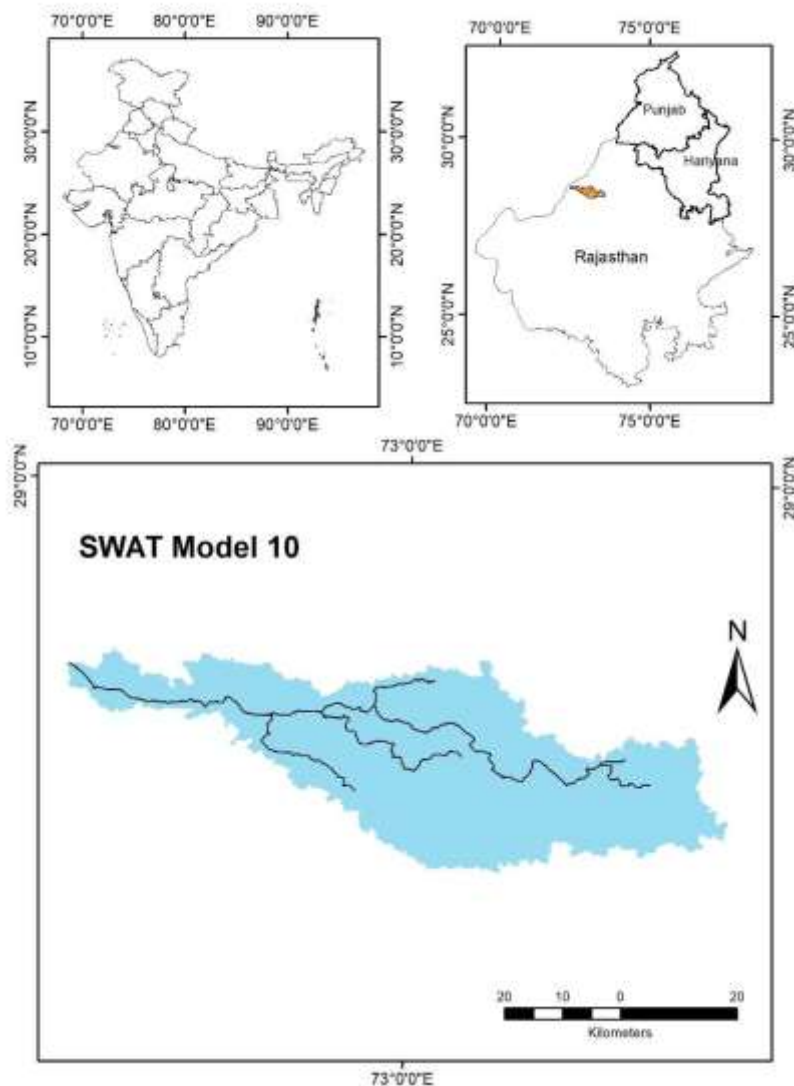


Figure7.84: SWAT Model 10 of AID area

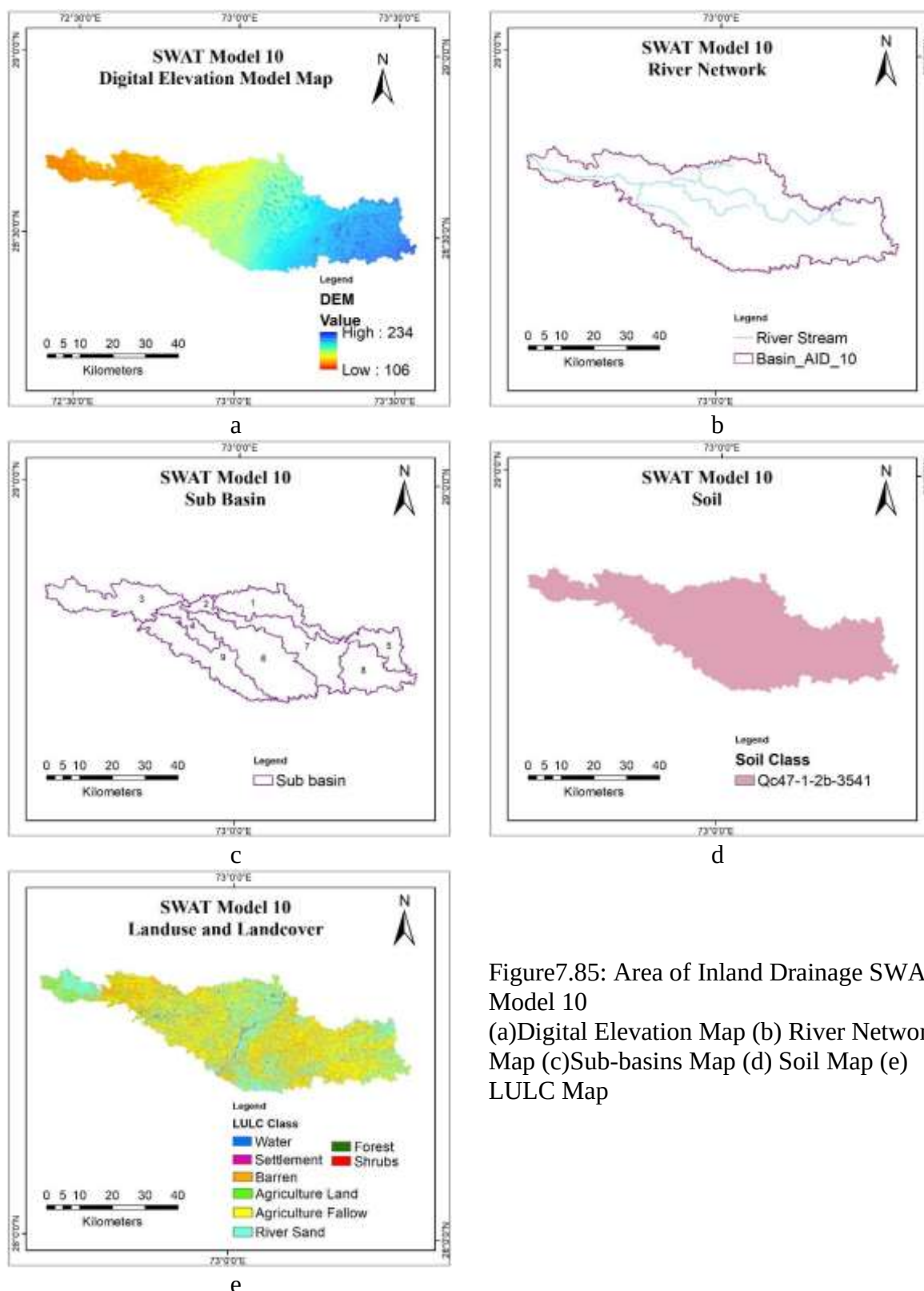


Figure7.85: Area of Inland Drainage SWAT Model 10

(a)Digital Elevation Map (b) River Network Map (c)Sub-basins Map (d) Soil Map (e) LULC Map

Figure 7.85 (a) shows the digital elevation of SWAT model 10 of AID. In this basin the high elevation is 233 meters and the low elevation is 113 meters. The mean elevation of the basin is 167.21 meters. Figure 7.85 (b) shows the river network in the basin. The total number of rivers in the basin is nine, and the total length of all rivers is 226.68km. Figure 7.85(c) shows the sub-basin map for SWAT model 10. It has the total number of sub-basin nine, and it has the total number of HRUs 62, which is generated by the SWAT model. This basin has a total area of

2014.69 sq. km. Figure 7.85 (d) shows the soil map for SWAT model 10. It has only one soil type, Qc47-1-2b-3541, which covers 100% of the total area of the basin. Figure 7.85 (e) shows the LULC map for SWAT model 10 of AID. In this SWAT model, 10 AID area have eight classes of Landuse and land cover, which is well distributed in the area. The most dominated LULC class is river sand, with subbasin percentage share by this class is 37.28% out of the total subbasin area followed by barren land 34.05% out of total basin area. The percentage subbasin area shared by four LULC classes like water, Settlement, forest and shrubs is 0.03%, 1.02%, 0.03% and 0.01%, respectively.

Table 7.162 Details of Digital elevation model for SWAT model 10 of AID

Min. Elevation	113m
Max. Elevation	233m
Mean. Elevation	167.21m
Std. Deviation	24.68m

Table 7.163 Details of river network for SWAT model 10 of AID

Number of streams	9
Number of sub basin	9
Total length of streams	226.68km
Minimum length of streams	5km
Maximum length of streams	60km
Avg. Length of streams	25.18km

Table 7.164 Details of LULC for SWAT model 10 of AID

LULC Class	LULC Code	Area (Km ²)	Sub-basin share (%)
Water	WATR	0.58	0.03
Settlement	URLD	20.46	1.02
Forest	FRSD	0.59	0.03
Shrubs	RNGB	0.15	0.01
Barren	BARR	685.94	34.05
Agriculture Land	AGRC	37.29	1.85
Agriculture Fallow	AGRR	518.67	25.74
River Sand	WETN	751.02	37.28

Table No. Details of Soil class for SWAT model 10 of AID

Soil Type	Area (Km ²)	Subbasin share (% area)
Qc47-1-2b-3541	2014.69	100

Table 7.165 Details of Sub-basin of SWAT model 10 of AID

Number of HRUs	62
Number of sub basin	9
Total area of subbasin	2014.69km ²

Subbasin Simulation details

SWAT model simulation details presented in Table 7.166 for SWAT model 10. SWAT model set-up and run for 25 years period (1985-2005)

Table 7.166 Subbasin simulation details for SWAT Model 9 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	62
Number of Sub basins	9
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	2014.69

Average annual water balance component value generated by SWAT model run for period of 25 years (1985-2005) shown in Table 7.167.

Table 7.167 Average annual water balance values for SWAT model 10 of AID

Water Balance Component	Values in mm
Precipitation	227.4
Surface Runoff Q	1.22
Lateral Flow Through Soil	0.95
GW (Shallow AQ)	0.11
GW(Deep AQ)	0.3
REVAP (Shallow AQ=>Soil/Plant	14.57
Deep Aquifer Recharge	0.2
Total Aquifer Recharge	3.91
Total Water Yield	2.58
Percolation Out of Soil	3.74
ET	223.5
PET	1433.5
Total Sediment Loading	0.23t/ha

Water Balance Calculation

Total flow =Surface runoff + Baseflow =1.22mm+0.3mm = 1.52mm

A preliminary check for performance of the SWAT model done by SWAT check tools which gives a ratio for water balance components which are shown in Table 7.168.

Table 7.168 Annual average water balance component and their values for SWAT model 10 of AID

Component	Ratio Value
Streamflow/Precipitation	0.01
Base flow /Total flow	0.46
Surface Runoff/Total flow	0.54
Percolation/precipitation	0.02
Deep Recharge/Precipitation	0
ET/Precipitation	0.98

Continuity Error Calculation

Total Inflow =Precipitation + Revap

=227.4mm+14.57mm

=241.97mm

Total Outflow =Surface Runoff +Lateral flow +GW + ET+ Deep aquifer Recharge

=1.22mm+0.95mm+0.3mm+223.5mm+0.2mm

=226.17mm

Continuity Error =100*(1-Total Inflow/Total Outflow)

=100*(1-241.97/226.17)

= -6.9%

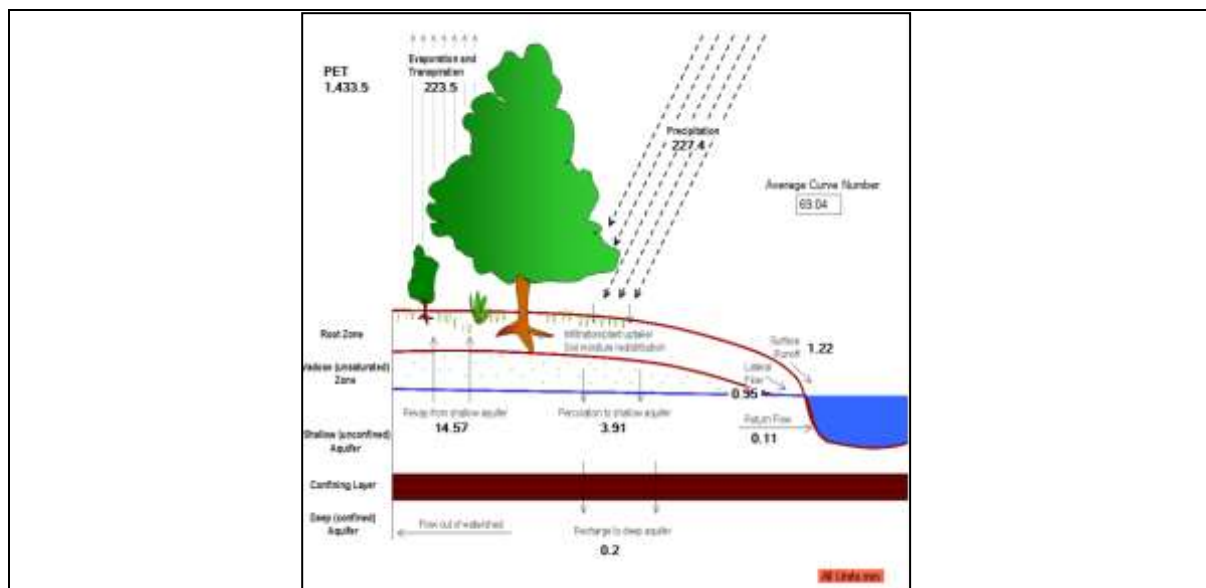


Figure 7.86: Pictorial representation of water balance at the watershed outlet for historical period (1985-2005)

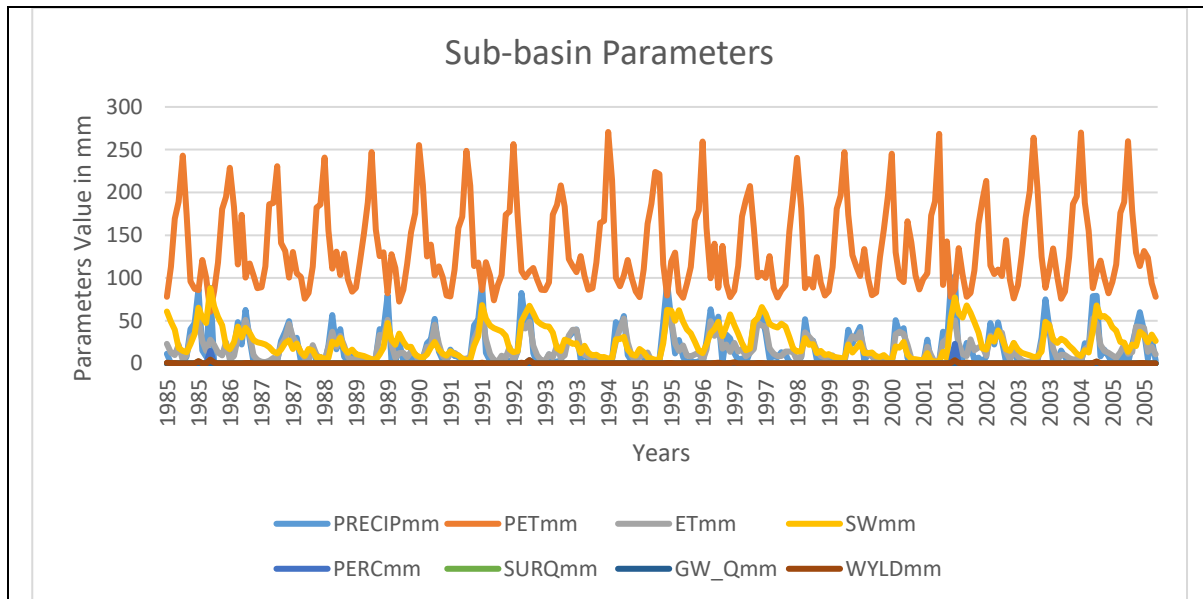


Figure7.87: Graphical representation of water Balance component at subbasin outlet for Historical period (1985-2005)

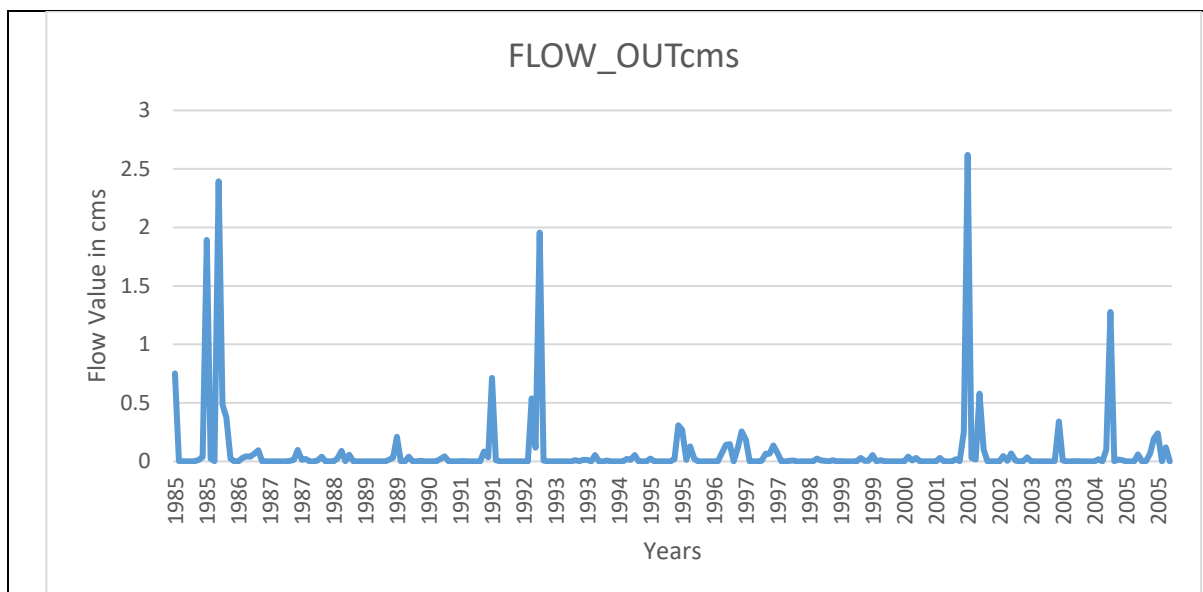


Figure 7.88: Graphical representation of outflow value at subbasin outlet for Historical period (1985-2005)

7.5.12 SWAT model 11 of AID

SWAT Model 11 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $26^{\circ}20'34.82''$ N and $70^{\circ}44'17.55''$ E longitude. It is the 8th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 11 of AID is 3883.66 Sq. km. The SWAT model for sub basin 11 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

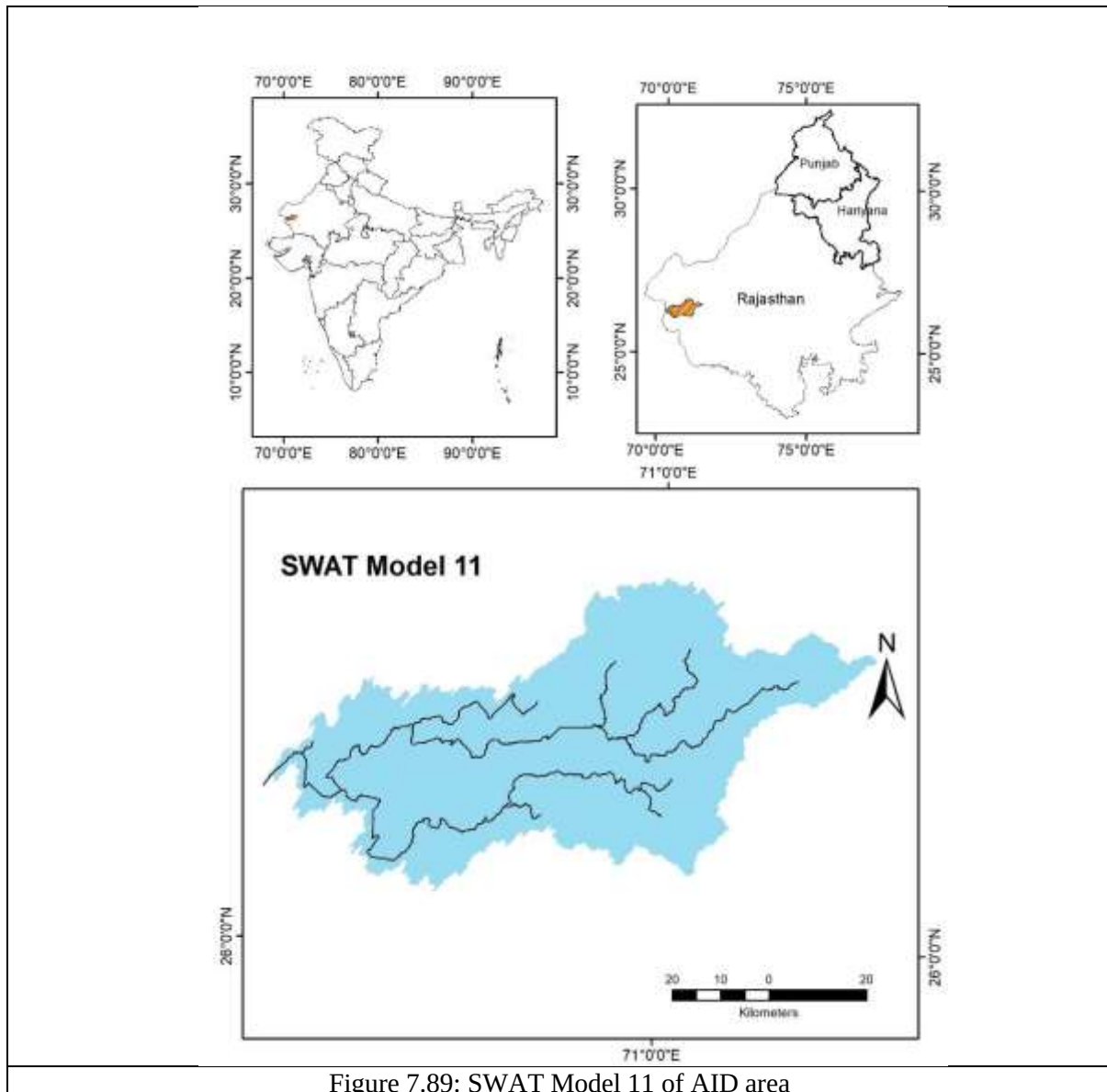
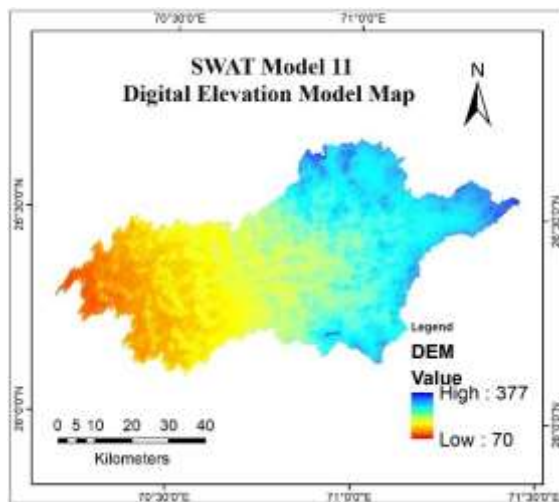
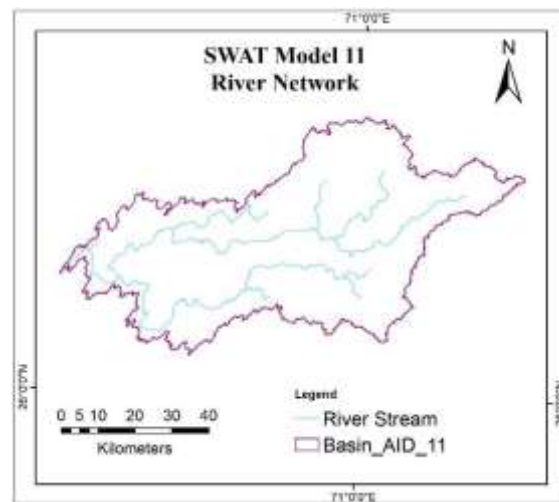


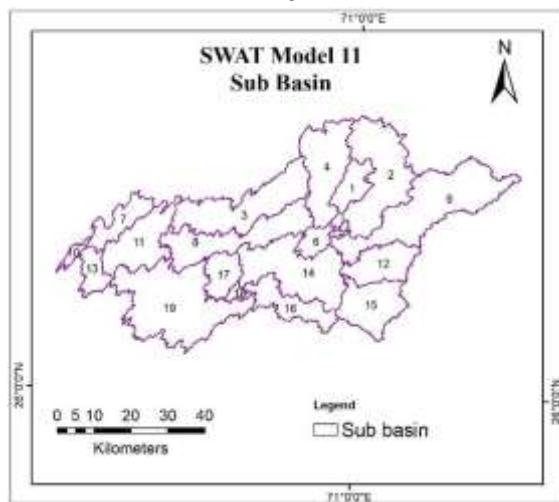
Figure 7.89: SWAT Model 11 of AID area



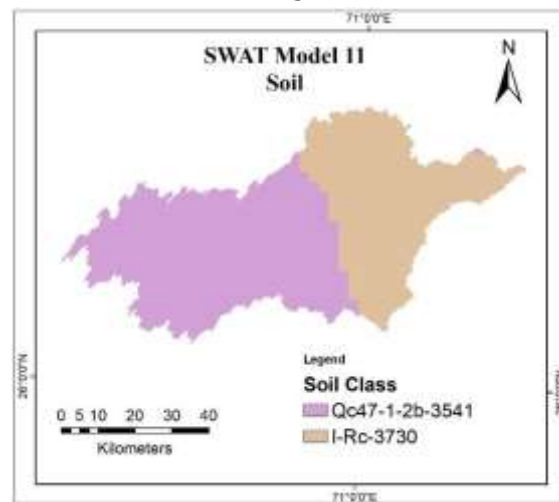
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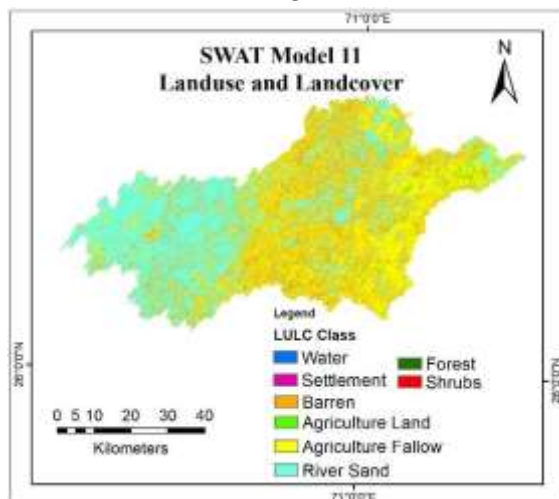
b



c



d



e

Figure 7.90: Area of Inland Drainage
SWAT Model 1
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.90 (a) shows the digital elevation model for SWAT model 11 of AID. It has a minimum elevation of 70 meters and a maximum elevation of 377 meters. The mean elevation is 209.17 meters. Figure 7.90 (b) shows the river network map for SWAT model 11. It has 19 total numbers of the river, which originates from 19 sub-basin in the basin. The total length of all rivers is 433.16 Km. Figure 7.90 (c) shows a sub-basin map for SWAT model 11 of AID. It has 19 sub-basin and 169 HRUs. The total basin area is 3883.66 sq. km. Figure 7.90 (d) shows

the soil map for SWAT model 11 of AID. There are two types of soil covered in the basin. One type of soil named Qc47-1-2b-3541 covers 58.42% area out of the total area, the second type of soil named I-Rc-3730 covers 41.58% area out of the total basin area. Figure 7.90 (e) shows Landuse and landcover map for SWAT Model 11 of AID. It has eight classes of LULC, which is well distributed in the basin. The most dominated LULC class is River sand which covers 39.56% of the area out of the total basin area, followed by the Barren land class, which covers 28.56% of the area out of the total basin area. Less dominated LULC classes are Water, Settlement and forest, which covers only 0.2%, 0.4% and 0.2 % out of the total basin area.

Table 7.169 Details of Digital elevation model for SWAT model 11 of AID

Min. Elevation	70m
Max. Elevation	377m
Mean. Elevation	209.17m
Std. Deviation	56.6m

Table 7.170 Details of river network for SWAT model 11 of AID

Number of streams	19
Number of sub basin	19
Total length of stream	433.60km
Minimum length of stream	0.19km
Maximum length of streams	65.15km
Average length of stream	22.82km

Table 7.171 Details of LULC for SWAT model 11 of AID

LULC Class	LULC Code	Area (km ²)	Subbasin (% Area)
Water	WATR	0.69	0.2
Settlement	URLD	1.50	0.4
Forest	FRSD	0.78	0.02
Shrubs	RNGB	8.89	0.23
Barren	BARR	1104.28	28.56
Agriculture Land	AGRC	61.95	1.6
Agriculture Fallow	AGRR	1164.21	29.98
River Sand	WETN	1536.33	39.56

Table 7.172 Details of Soil class for SWAT model 11 of AID

Soil Type	Area (km ²)	Subbasin (% Area)
I-Rc-3730	1614.8	41.58
Qc47-1-2b-3541	2268.0	58.42

Table 7.173 Details of Sub-basin of SWAT model 11 of AID

Number of HRUs	169

Number of sub-basin	19
Total Area of subbasin	3883.66km ²

Subbasin Simulation Details

SWAT Model simulation details provided in Table 7.174 for SWAT Model 11 of AID SWAT model setup and run for historical period initially (1985-2005)

Table 7.174 Subbasin simulation details for SWAT Model 11 of AID

Simulation details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years w
Number Of HRUs	169
Number of Sub basins	19
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	3883.66

Average annual water balance component values generated by SWAT model 11 for the period of 25 years (1985-2005) shown in the Table 7.175.

Table 7.175 Annual average water balance component and their values for SWAT model 11 of AID

Water Balance component	Value in mm
Precipitation	185.7
Surface Runoff Q	3.3
Lateral Flow Through Soil	72.16
GW (Shallow AQ)	0
GW(Deep AQ)	2.26
REVAP (Shallow AQ=>Soil/Plant	6.51
Deep Aquifer Recharge	2.15
Total Aquifer Recharge	3.37
Total Water Yield	77.72
Percolation Out of Soil	2.75
ET	108.6
PET	1570
Total Sediment Loading	3.40t/ha

Water Balance calculation

Total flow =Surface runoff +Baseflow

$$=3.3\text{mm}+2.26\text{mm}=5.56$$

A preliminary check for SWAT performance using SWAT check Tools done for accuracy in simulation run which gives ratios shown in Table 7.176.

Table 7.176 Details of Water balance components ratio for SWAT Model 11 of AID

Component	Ratio Value
Streamflow/Precipitation	0.41
Baseflow /Total flow	0.96
Surface Runoff/Total flow	0.04
Percolation/precipitation	0.02
Deep Recharge/Precipitation	0.01
ET/Precipitation	0.58

Continuity Error Calculation

Total Flow = Precipitation +Revamp

$$=185.7\text{mm}+6.51\text{mm}$$

$$=192.21 \text{ mm}$$

Total outflow =Surface runoff +Lateral flow+ GW +ET + Deep aquifer Recharge + Percolation

$$=3.3\text{mm}+72.12\text{mm}+2.26\text{mm}+108.6\text{mm}+3.37\text{mm}+2.95$$

$$=192.6\text{mm}$$

Continuity Error in Water Balance in subbasin

Continuity Error =100*(1-Total Inflow /Total outflow)

$$=100*(1-192.22/192.6)$$

$$=0.19\%$$

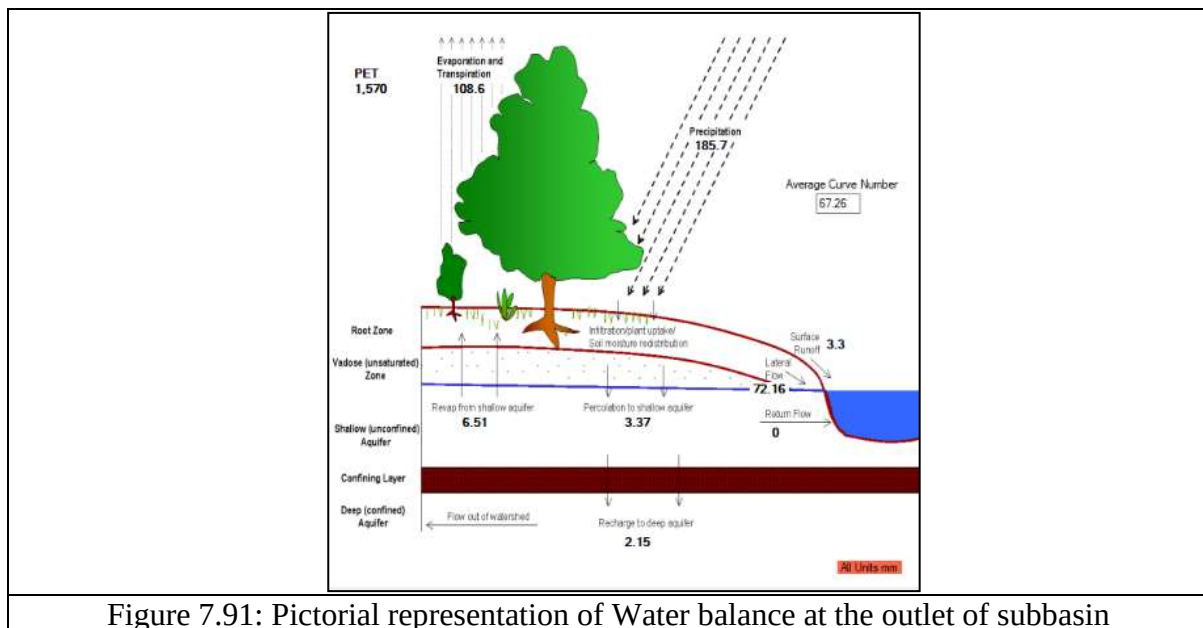
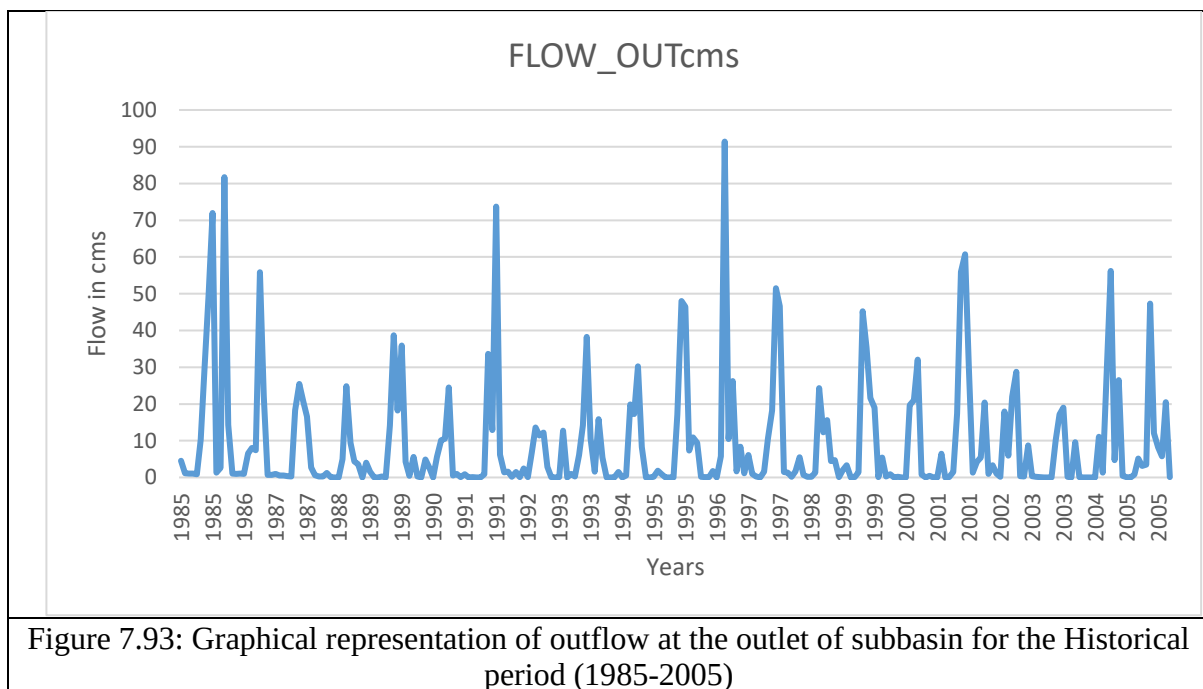
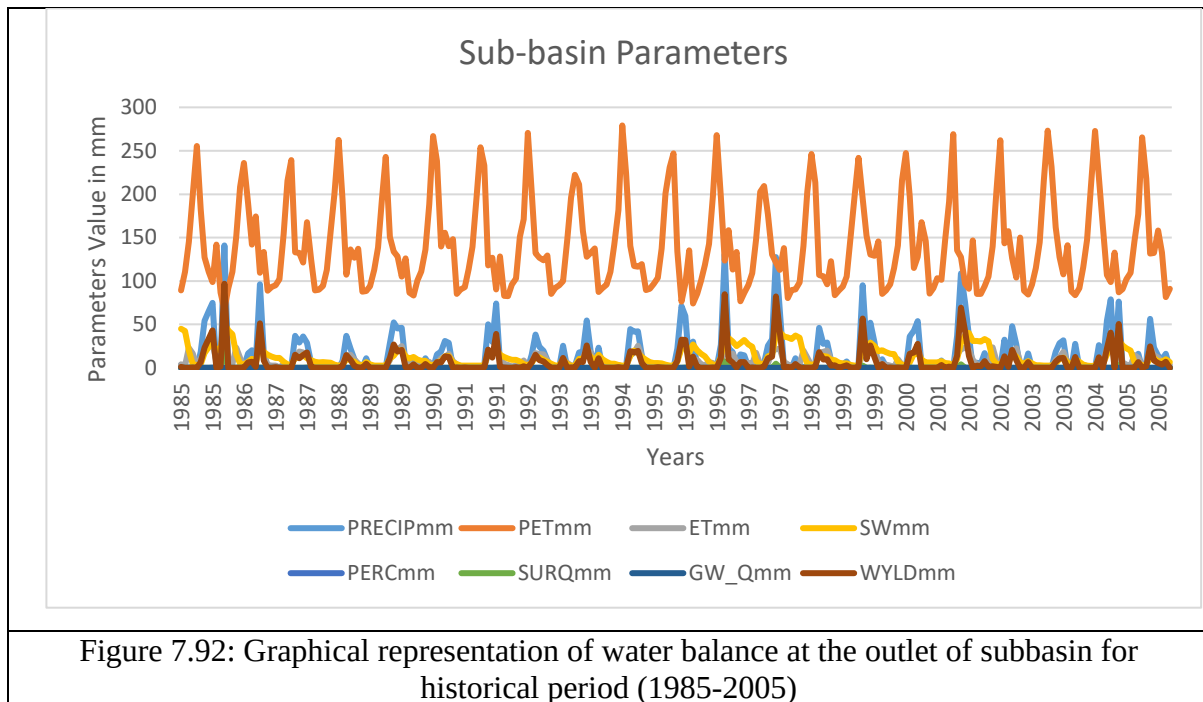


Figure 7.91: Pictorial representation of Water balance at the outlet of subbasin



7.5.13 SWAT model 12 of AID

SWAT Model 12 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $25^{\circ}58'26''$ N and $70^{\circ}28'28''$ E longitude. It is 10th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. In this sub basin two adjacent river flows so we have selected both river outlets for delineation in the SWAT model. Total subbasin area for the SWAT Model 12 of AID is 2518.67 Sq. km. SWAT model for sub basin 12 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

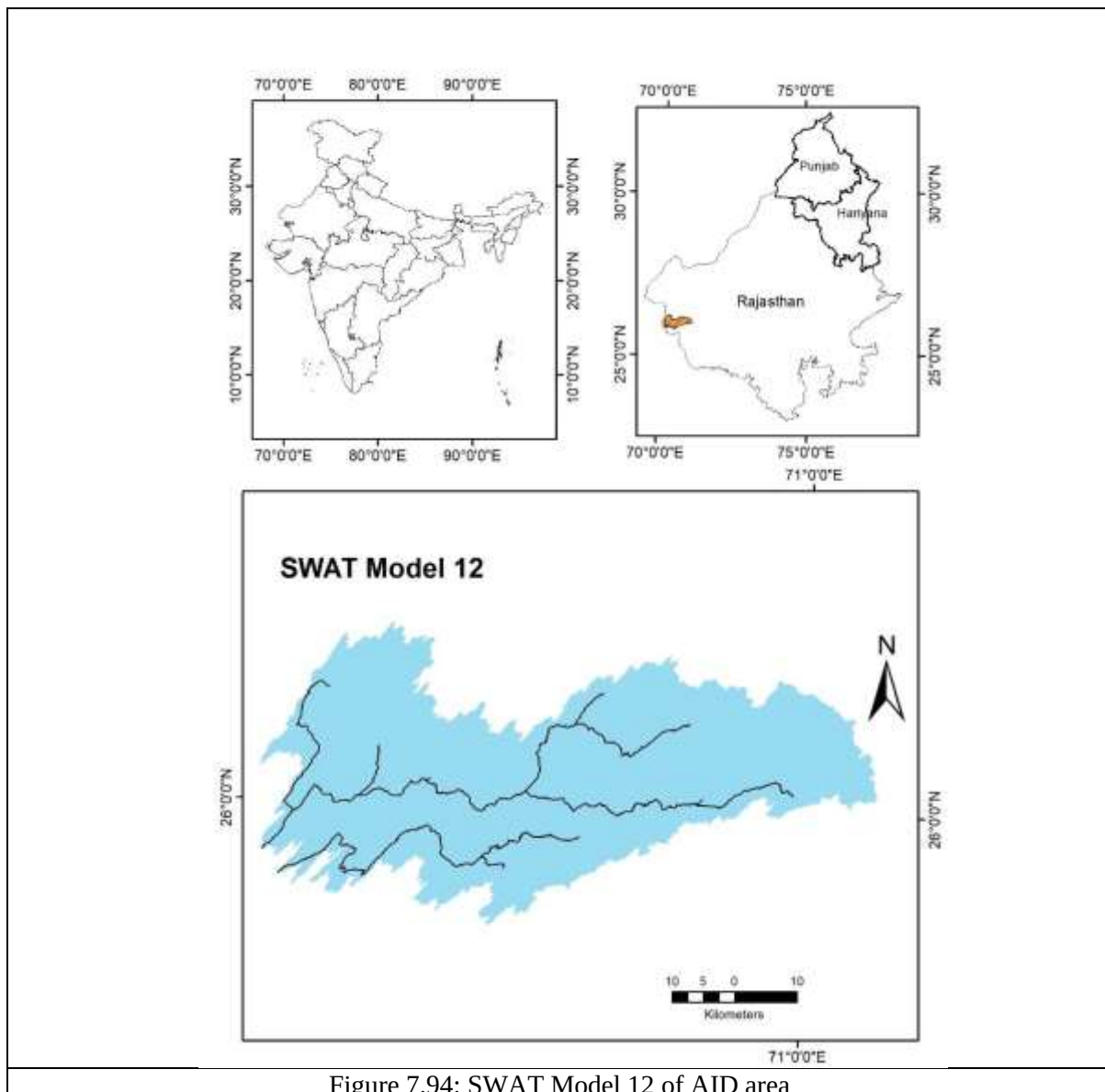
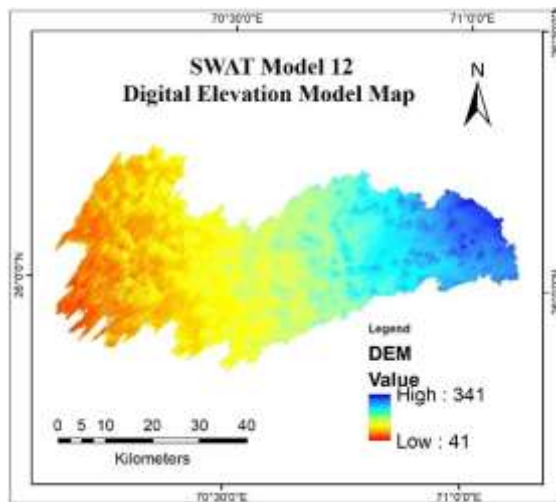
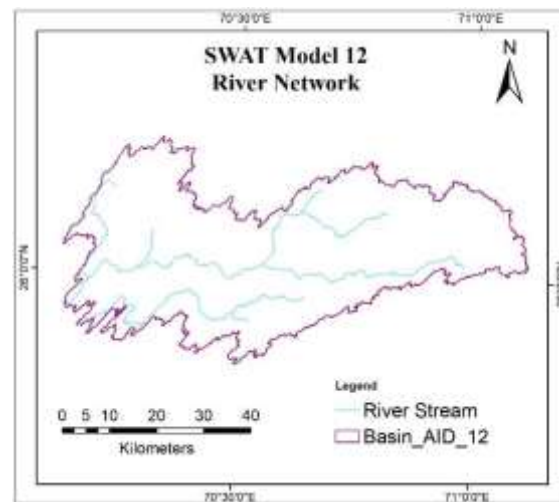


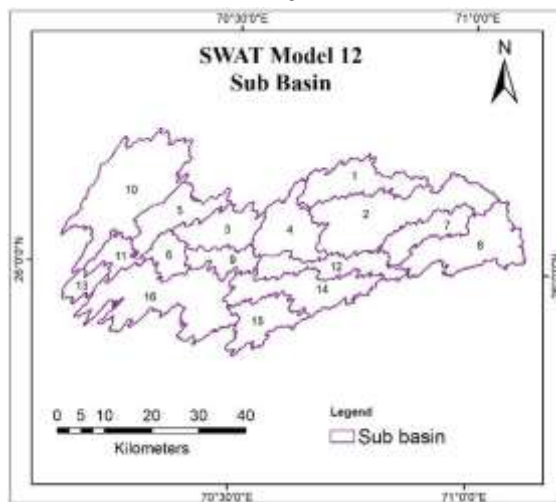
Figure 7.94: SWAT Model 12 of AID area



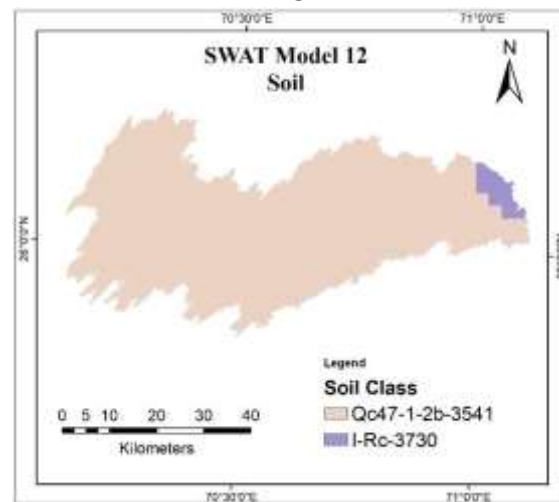
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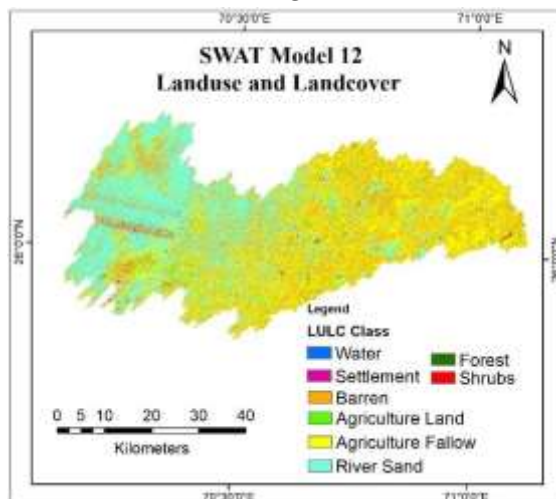
b



c



d



e

Figure 7.95: Area of Inland Drainage
SWAT Model 12
(a)Digital Elevation Map (b) River Network
Map (c)Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.95 (a) shows the digital elevation model for SWAT model 12 of AID. It has a minimum elevation of 41 meters and a maximum elevation of 341 meters. The mean elevation is 156.87 meters. Figure 7.95 (b) shows the Area Inland drainage network map for SWAT model 12 of AID. In this basin the number of streams are 16, which is generated from the sub-basin. The total length of streams is 300.63 km for this basin. Figure 7.95 (c) shows the sub-basin map for SWAT Model 12 of AID. It has a total 129 number of HRUs, and the total area

of the basin is 2518.67 sq. km. Figure 7.95 (d) shows the soil map for SWAT model 12 of the AID area. It has Qc47-1-2b-3541 soil, which covered 97.54% of the total Area and I-Rc-3730, which covered 2.46% of the total basin area. Figure 7.95 (e) shows the Landuse and landcover map for the SWAT model. In this Sub-basin of AID, eight classes were covered. The most dominated LULC class is sand which covered 34.83% out of the total watershed. Area covered by four LULC classes. Water, Settlement, Forest and Shrubs with 0.27%, 0.63%, 0.02% and 0.85% covered basin area out of total subbasin area respectively.

Table 7.177 details of Digital elevation model for SWAT model 11 of AID

Min. Elevation	41m
Max. Elevation	341m
Mean. Elevation	156.87m
Std. Deviation	56m

Table 7.178 Details of river network for SWAT model 12 of AID

Number of streams	16
Number of sub basin	16
Total length of streams	300.63km
Minimum length of streams	1km
Maximum length of streams	59.24km
Average length of streams	18.79km

Table 7.179 No. Details of LULC for SWAT model 12 of AID

LULC Class	LULC Code	Area (km²)	Subbasin Share (% Area)
Water	WATR	6.69	0.27
Settlement	URLD	15.83	0.63
Forest	FRST	0.44	0.02
Shrubs	RNGB	21.34	0.85
Barren	BARR	745.89	29.61
Agriculture Land	AGRC	58.81	2.33
Agriculture Fallow	AGRR	792.41	31.42
River sand	WETN	877.19	34.83

Table 7.180 Details of Soil class for SWAT model 12 of AID

Soil Type	Area (Km²)	Subbasin Share (% Area)
Qc47-1-2b-3541	2456.62	97.54
I-Rc-3730	62.06	2.46

Table 7.181 Details of Sub-basin of SWAT model 12 of AID

Number of HRUs	129
Number of sub basin	16
Total subbasin area	2518.67km ²

Subbasin Simulation Details

Subbasin simulation details provided in Table 7.182 for SWAT model 12 of AID

Table 7.182 Subbasin simulation details for SWAT Model 12 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number of HRUs	129
Number of Sub basins	16
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km ²	2518.67

Average annual water balance component value generated by SWAT model for period historical (1985-2005) shown in Table 7.183.

Table 7.183 Annual average water balance component and their values for SWAT model 12 of AID

Water Balance component	Values in mm
Precipitation	213.6
Surface Runoff Q	3.35
Lateral Flow Through Soil	2.94
GW (Shallow AQ)	0.78
GW(Deep AQ)	0.41
REVP (Shallow AQ=>Soil/Plant	16.19
Deep Aquifer Recharge	0.32
Total Aquifer Recharge	6.34
Total Water Yield	7.48
Percolation Out of Soil	6.18
ET	205.9
PET	1508.7
Total Sediment Loading	3.51 T/HA

Water Balance Calculations

Total flow = Surface runoff + Baseflow =3.35mm+0.41mm=3.76mm

A preliminary check for performance of SWAT model SWAT check tool which gives ration for subbasin simulation results for accuracy shown in Table 7.184

Table 7.184 Water balance Ratio for SWAT model 12 of AID

Component	Ratio Value
Streamflow/Precipitation	0.03
Baseflow /Total flow	0.53
Surface Runoff/Total flow	0.47
Percolation/precipitation	0.03
Deep Recharge/Precipitation	0
ET/Precipitation	0.96

Continuity Error Calculation

Total inflow =Precipitation + Revamp

$$=213.6\text{mm}+16.19\text{mm}$$

$$=229.79\text{mm}$$

Total outflow =Surface runoff +Lateral flow +GW + ET+ Percolation out of soil +Deep aquifer Recharge

$$=3.35\text{mm}+2.94\text{mm}+0.41\text{mm}+205.9\text{mm}+6.18\text{mm}+0.34\text{mm}$$

$$=219.12\text{mm}$$

Continuity error =100*(1-Inflow /Outflow)

$$=100*(1-229.7/219.12)$$

$$=-4.79\%$$

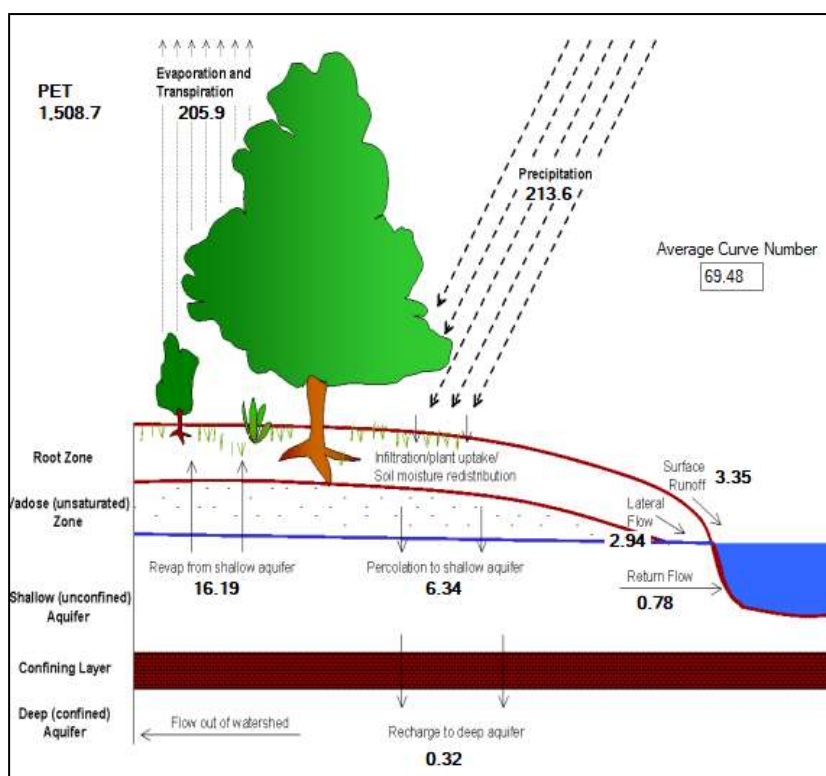


Figure 7.96: Water balance component at subbasin outlet pictorial representation for Historical period (1985-2005)

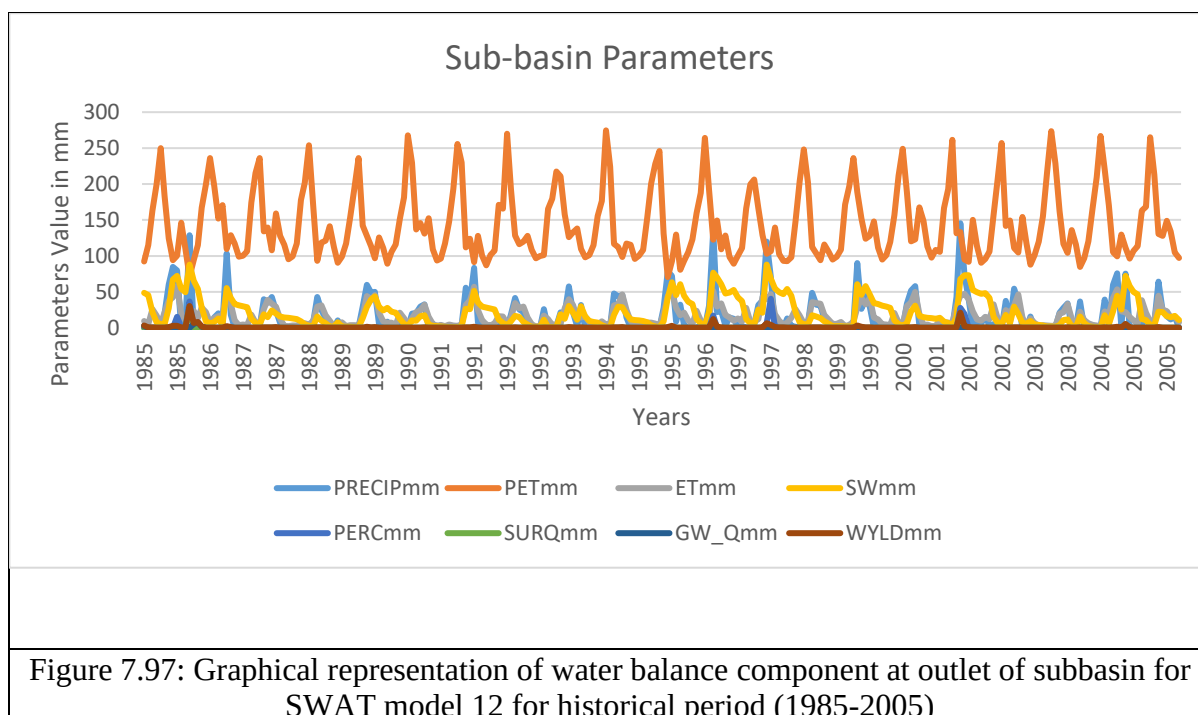


Figure 7.97: Graphical representation of water balance component at outlet of subbasin for SWAT model 12 for historical period (1985-2005)

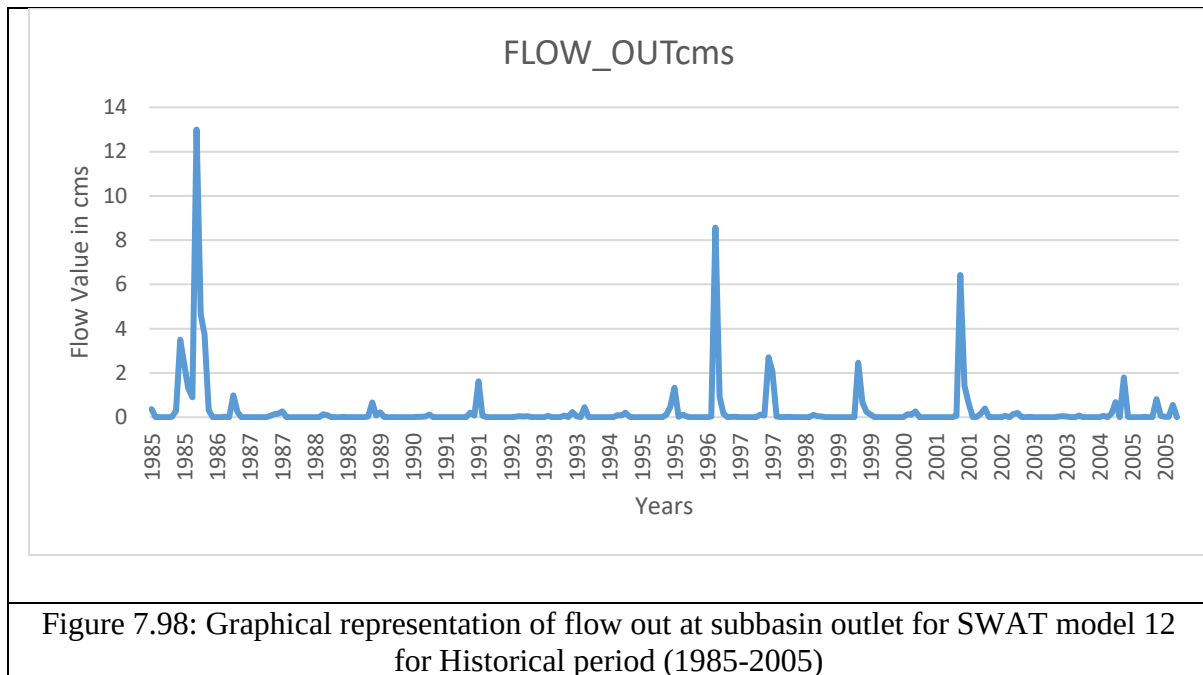


Figure 7.98: Graphical representation of flow out at subbasin outlet for SWAT model 12 for Historical period (1985-2005)

7.5.14 SWAT model 13 of AID

SWAT Model 13 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $26^{\circ}48'58''$ N and $70^{\circ}17'40''$ E longitude. It is the 16th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 13 of AID is 1619 Sq. km. The SWAT model for sub basin 13 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

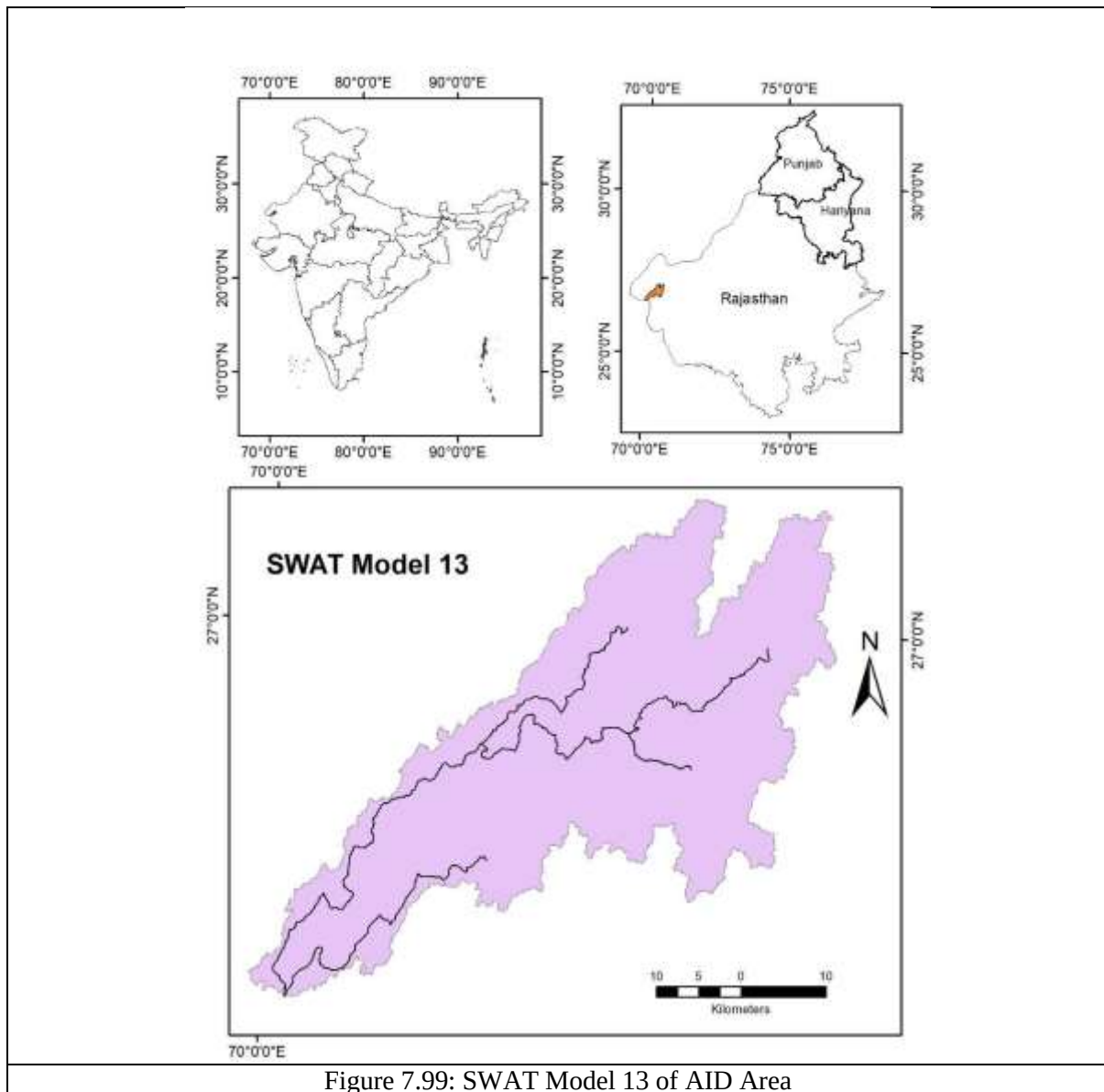
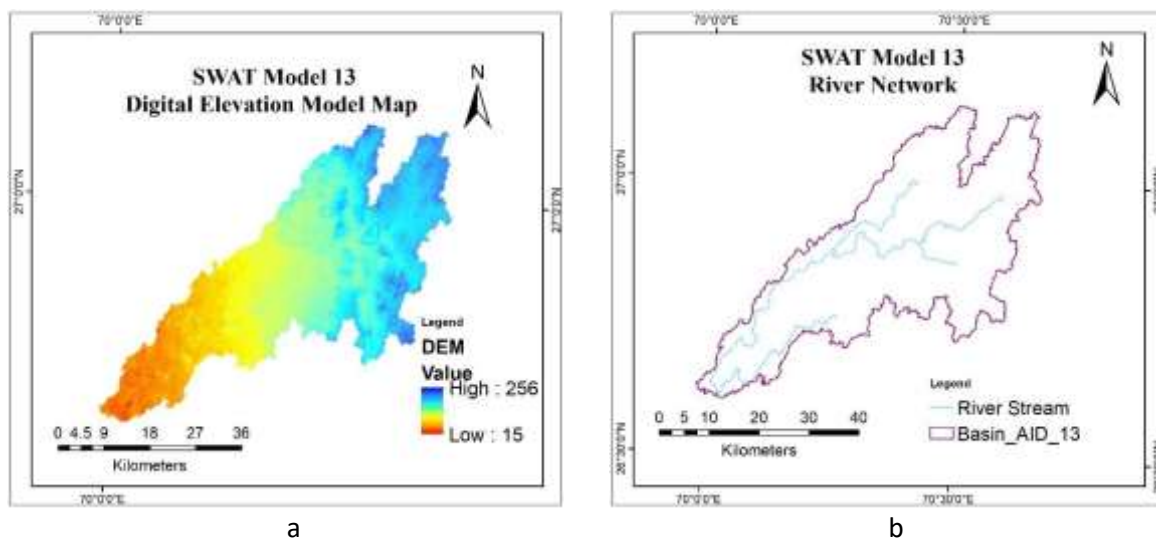


Figure 7.99: SWAT Model 13 of AID Area



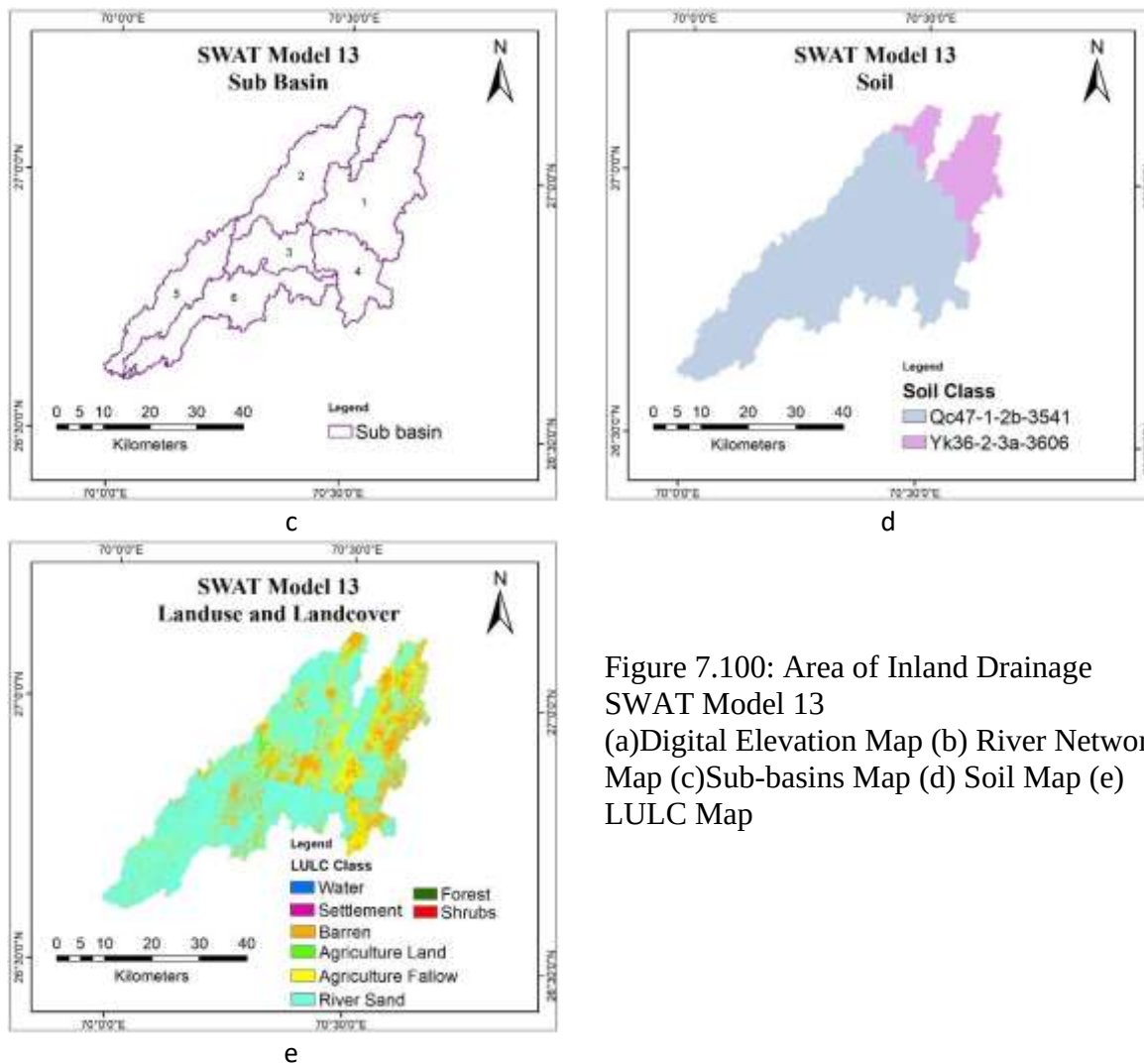


Figure 7.100: Area of Inland Drainage
SWAT Model 13
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.100 (a) shows the digital elevation model for SWAT model 13 of AID. It has a minimum elevation of 15 meters and a maximum elevation of 256 meters. The mean elevation is 155.09 meters. Figure 7.100 (b) shows the Area Inland drainage network map for SWAT model 13 of AID. In this basin the number of streams are 7, which is generated from 7 sub-basin of SWAT model 13. The total length of all rivers is 203.14 km. Figure 7.100 (c) shows sub-basin distribution by SWAT model delineation of digital elevation model. It has 63 HRUs generated by the SWAT model. Figure 7.100 (d) shows the Soil Map for the SWAT model of the AID area. It has two types of soil. Type 1 soil named Qc47-1-2b-3541 covered 82.82% area out of the total area. Type 2 soil named Yk36-2-3a-3606 covered 17.18% area out of the total basin area. Figure 7.100 (e) shows the Landuse and landcover map of SWAT model 13 of AID. It has eight classes. Dominant LULC class is River sand with 68.54% out of total basin area followed by barre land. Less dominant LULC classes are Water, Settlement Shrubs and agriculture with 0.01%, 0.02%, 0.10% and 0.62 % out of the total basin.

Table 7.185 Details of Digital elevation model for SWAT model 13 of AID

Min. Elevation	15m
Max. Elevation	256m
Mean. Elevation	155.09m
Std. Deviation	42.57m

Table 7.186 Details of river network for SWAT model 13 of AID

Number of streams	7
Number of Sub basin	7
Total length of streams	203.14km
Minimum length of streams	0.02km
Maximum length of streams	54.35km
Average length of streams	29.02km

Table 7.187 Details of LULC for SWAT model 13 of AID

LULC Class	LULC Code	Area (km ²)	Sub-basin share (%)
Water	WATR	0.22	0.01
Settlement	URLD	0.24	0.02
Forest	FRSD	0.06	0.00
Shrubs	RNGB	1.69	0.10
Barren	BARR	268.26	16.56
Agriculture Land	AGRC	10.05	0.62
Agriculture Fallow	AGR	229.17	14.15
River Sand	WETN	1110.26	68.54

Table 7.188 Details of Soil class for SWAT model 13 of AID

Soil Type	Soil Area (km ²)	Subbasin Share (% area)
Qc47-1-2b-3541	1341.66	82.82
Yk36-2-3a-3606	278.30	17.18

Table 7.189 Details of Sub-basin of SWAT model 13 of AID

Number of HRUs	63
Number of Sub basin	7
Total watershed Area	1619 km ²

Subbasin Simulation Details

SWAT model simulation details provided in Table 7.190 for AID SWAT Model 13.

Table 7.190 Subbasin simulation details for SWAT Model 13 of AID

Subbasin Simulation details	Values
Simulation Length	25
Warm up (Model Initial Run) Period	4
Number of HRUs	63
Number of Sub basins	7
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	1,619.00

Average annual values for water balance component value generation by SWAT model run for a period of 25 years (1985-2005).Table 7.191 shows the water balance components and their values for SWAT model 13 of AID.

Table 7.191 Annual average water balance component and their values for SWAT model 13 of AID

Components	Values
Precipitation	170.5
Surface Runoff Q	0.55
Lateral Flow Through Soil	49.61
GW (Shallow AQ)	0
GW(Deep AQ)	0.01
REVAP (ShallowAQ=>Soil/Plant	0
Deep Aquifer Recharge	0.01
Total Aquifer Recharge	0.01
Total Water Yeild	50.17
Percolation Out of Soil	0.01
ET	122.1
PET	1625.3
Total Sediment Loading	0.60t/ha

Water balance calculation

Total inflow =Surface runoff +Baseflow =0.55mm+0.01=0.56mm

A preliminary check for SWAT performance using SWAT check tool run which gives the ratio for Subbasin simulation results shown in Table 7.192.

Table 7.192 Water balance Ratio for SWAT model 13 of AID

Component	Ratio Value
Streamflow/Precipitation	0.29
Baseflow /Total flow	0.99
Surface Runoff/Total flow	0.01
Percolation/precipitation	0

Deep Recharge/Precipitation	0
ET/Precipitation	0.72

Continuity Error Calculation

Continuity error calculation for SWAT model 13 as per SWMM manual

Total inflow =Precipitation +Revamp

$$=170.5\text{mm}+0\text{mm}$$

$$=170.5\text{mm}$$

Total outflow =Surface runoff +Lateral flow +GW+ ET+ Percolation Deep aquifer recharge

$$=0.55\text{mm}+49.61+0.01+122.1\text{mm}+0.01\text{mm}+0.01$$

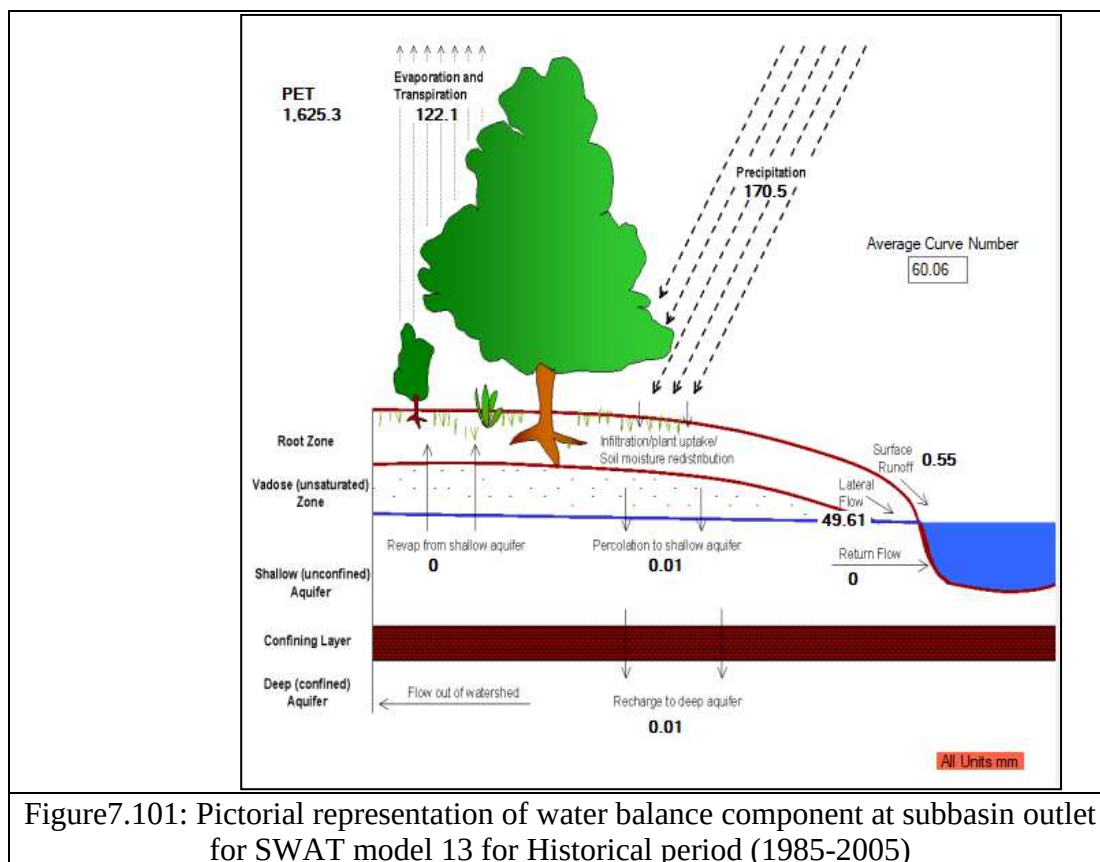
$$=172.29\text{mm}$$

Continuity error = $100 \times (1 - \text{Inflow} / \text{Outflow})$

$$= 100 \times (1 - (170.5/172.29))$$

$$=1.03\%$$

Water Balance component pictorial representation at Subbasin outlet



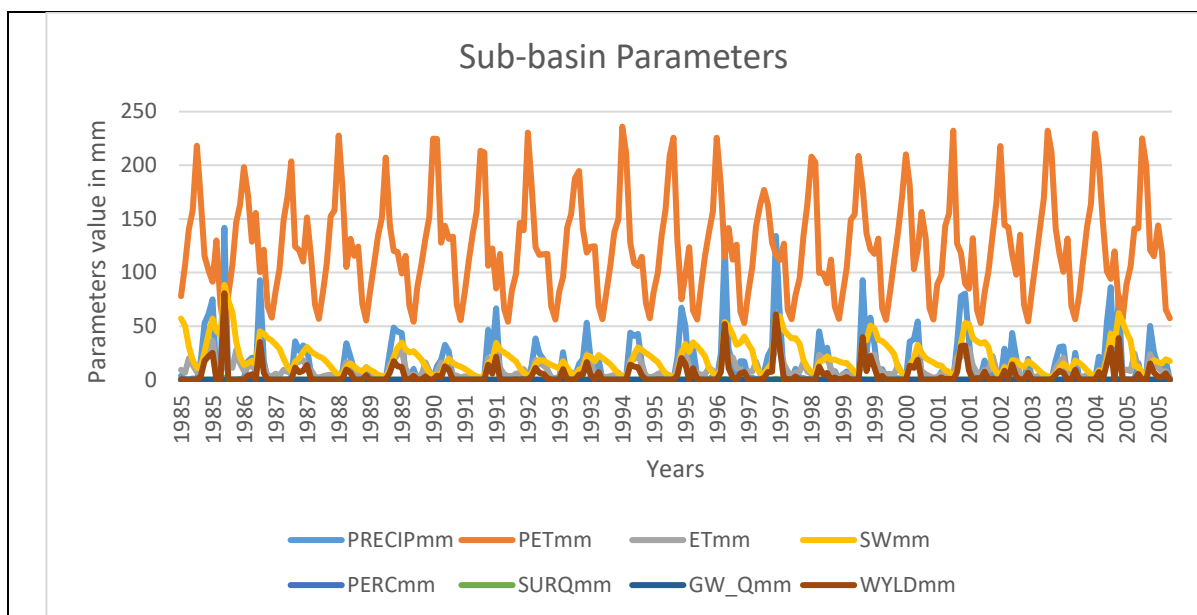


Figure 7.102:—Graphical representation of subbasin water balance component at the outlet of subbasin for historical period (1985-2005)

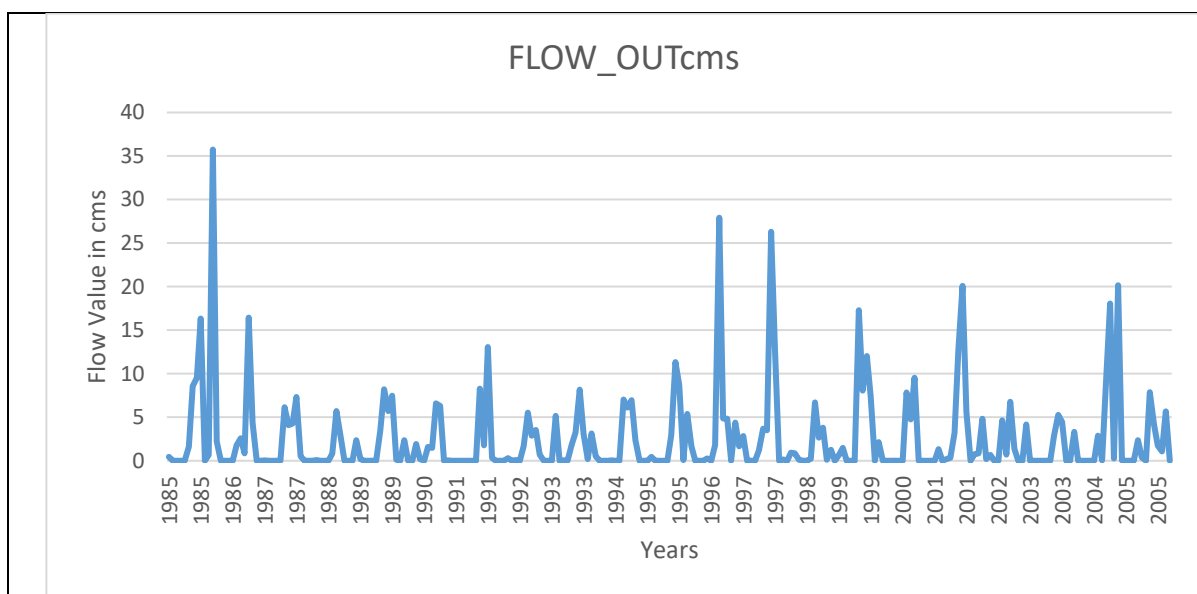


Figure 7.104: Graphical representation of subbasin outflow at the outlet of subbasin for historical period (1985-2005)

7.5.15 SWAT model 14 of AID

SWAT Model 14 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at latitude $25^{\circ}50'27''$ N and $70^{\circ}40'11''$ E longitude. It is the 18th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 14 of AID is 937Sq. km. The SWAT model for sub basin 14 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

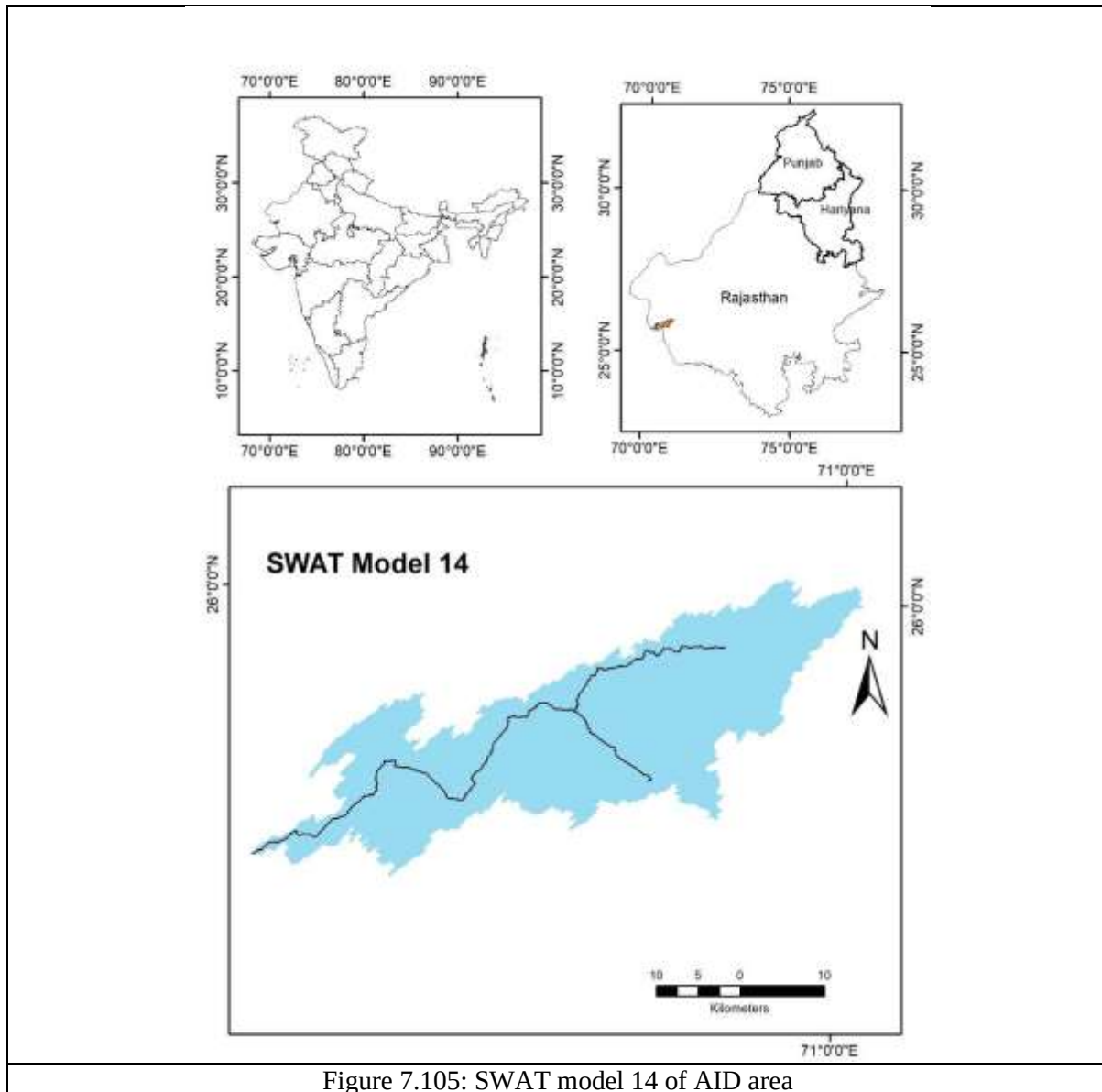
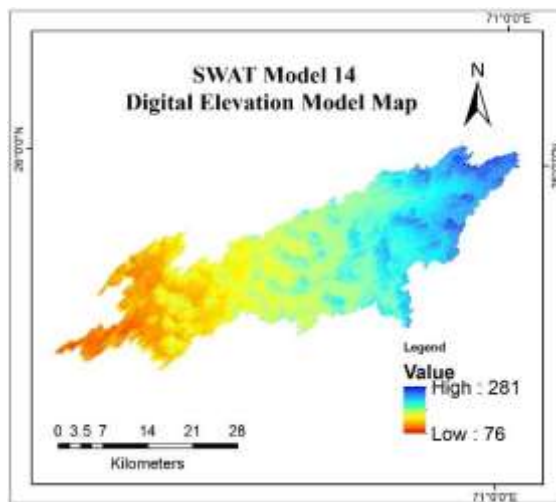
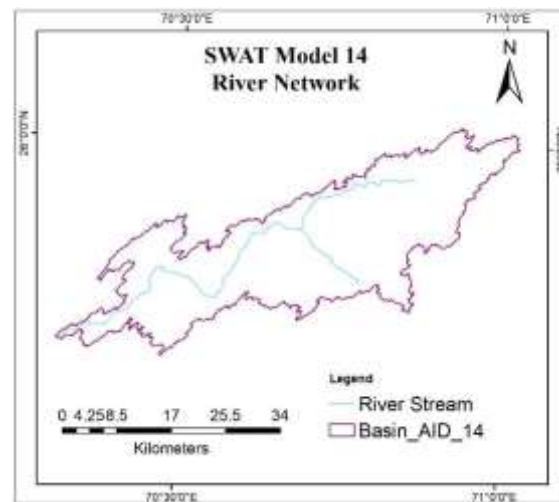


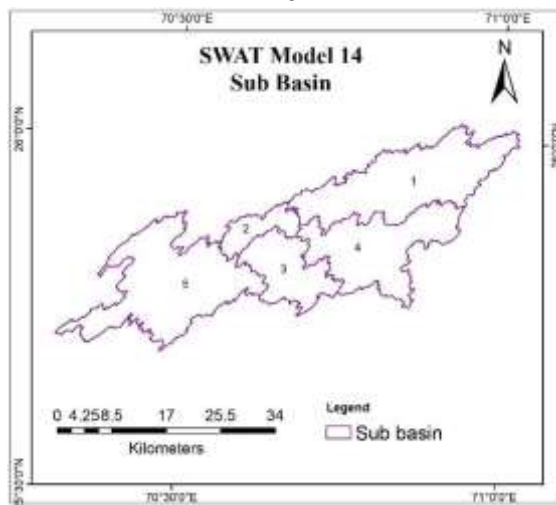
Figure 7.105: SWAT model 14 of AID area



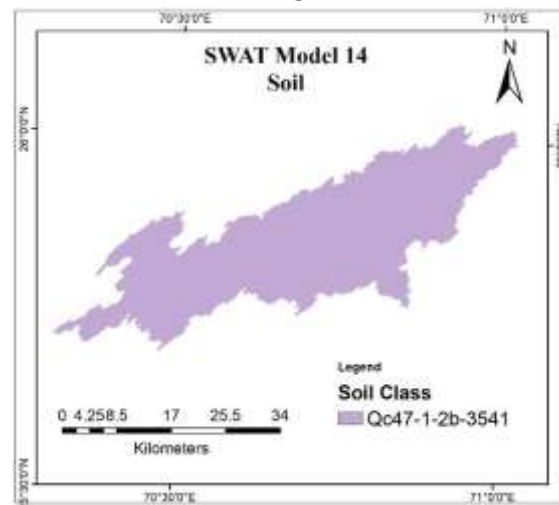
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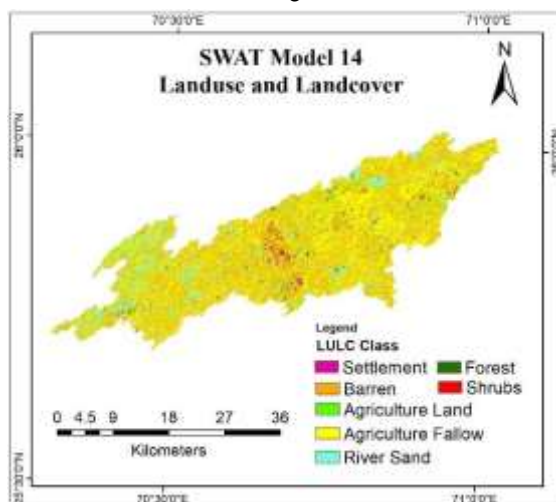
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d



e

Figure 7.106: Area of Inland Drainage
SWAT Model 14
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.106 (a) shows the digital elevation model for SWAT model 14 of AID. It has a minimum elevation of 76 meters and a maximum elevation of 281 meters. The mean elevation is 171.64 meters. Figure 7.106 (b) shows the Area Inland drainage network map for SWAT model 14 of AID. In this basin the number of streams are 5, which is generated from 5 sub-basin of SWAT model 14. The total length of all rivers is 99.65 km. Figure 7.106 (c) shows

sub-basin distribution by SWAT model delineation of digital elevation model. It has 33 HRUs generated by the SWAT model. Figure 7.106 (d) shows the Soil Map for the SWAT model of the AID area. It has one type of soil. Type 1 soil named Qc47-1-2b-3541 covered 100% area. Figure 7.106 (e) shows the Landuse and landcover map of SWAT model 14 of AID. It has seven classes. Dominant LULC class is River sand with 68.54% out of total basin area followed by barre land. Less dominant LULC classes are Settlement, forest and agriculture, with 0.0%, 0.07% and 5.07 % out of the total basin.

Table 7.193 Details of Digital elevation model for SWAT model 14 of AID

Min. Elevation	76m
Max. Elevation	281m
Mean. Elevation	171.64m
Std. Deviation	38.71m

Table 7.194 Details of river network for SWAT model 14 of AID

Number of streams	5
Number of sub basin	5
Total length of stream	99.65km
Minimum length of stream	0.22km
Maximum length of streams	43.60km
Average length of streams	19.93km

Table 7.195 Details of LULC for SWAT model 14 of AID

LULC Class	LULC Code	Area (km ²)	Sub-basin share (%)
Settlement	URLD	0.01	0
Forest	FRSD	0.63	0.07
Shrubs	RNGB	32.67	3.49
Barren	BARR	321.43	34.3
Agriculture Land	AGRC	47.49	5.07
Agriculture Fallow	AGRR	436.78	46.6
River sand	WETN	98.22	10.48

Table 7.196 Details of Soil class for SWAT model 14 of AID

Soil Type	Soil Area (km ²)	Subbasin Share (% Area)
Qc47-1-2b-3541	937.23	100

Table 7.197 Details of Sub-basin of SWAT model 14 of AID

Number of HRUs	33
Number of Sub basin	5
Total Subbasin Area	937km ²

Subbasin Simulation details

SWAT model simulation details provide in Table 7.198 for SWAT model 14 of AID area

Table 7.198 Subbasin simulation details for SWAT Model 14 of AID

Simulation details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	33
Number of Sub basins	5
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km ²	937

Average annual water balance component value generated by SWAT model run for period (1985-2005). Table 7.199 shows water balance components and their values for SWAT Model 14 of AID.

Table 7.199 Annual average water balance component and their values for SWAT model 14 of AID

Water Balance Component	Value in mm
Precipitation	236.5
Surface Runoff Q	4.78
Lateral Flow Through Soil	2.42
GW (Shallow AQ)	1.7
GW(Deep AQ)	0.62
REVAP (Shallow AQ=>Soil/Plant)	19.6
Deep Aquifer Recharge	0.51
Total Aquifer Recharge	10.2
Total Water Yield	9.53
Percolation Out of Soil	10.05
ET	219.6
PET	1548.3
Total Sediment Loading	4.43t/ha

Water Balance calculation

Total inflow = Surface runoff + Baseflow = 4.78mm+0.62mm=5.4mm

A preliminary check for swat model performance using SWAT check tool run which gives the ratio for subbasin provided in Table 7.200

Table 7.200 Water balance Ratio for SWAT model 14 of AID

Component	Ratio Value
Streamflow/Precipitation	0.04
Baseflow /Total flow	0.46
Surface Runoff/Total flow	0.54
Percolation/precipitation	0.04
Deep Recharge/Precipitation	0
ET/Precipitation	0.93

Continuity error Calculation

Continuity error calculation for SWAT model 14

Total inflow =Precipitation +Revap

$$=236.5\text{mm}+19.6\text{mm}$$

$$=256.1\text{mm}$$

Total outflow = Surface runoff +lateral flow +GW+ET+ Percolation +Deep aquifer recharge

$$=4.78\text{mm}+2.42\text{mm}+1.7\text{mm}+219.6\text{mm}+10.05\text{mm}+0.51\text{mm}$$

$$=239.51\text{mm}$$

Continuity error =100*(1-Inflow /Outflow)

$$=100*(1-256.1/239.51)$$

$$=-6.92\%$$

Water balance component at the subbasin outlet pictorial representation

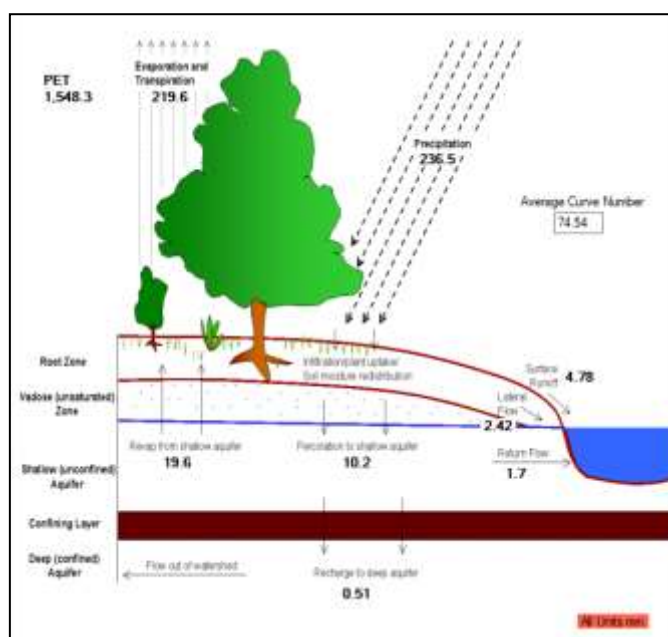
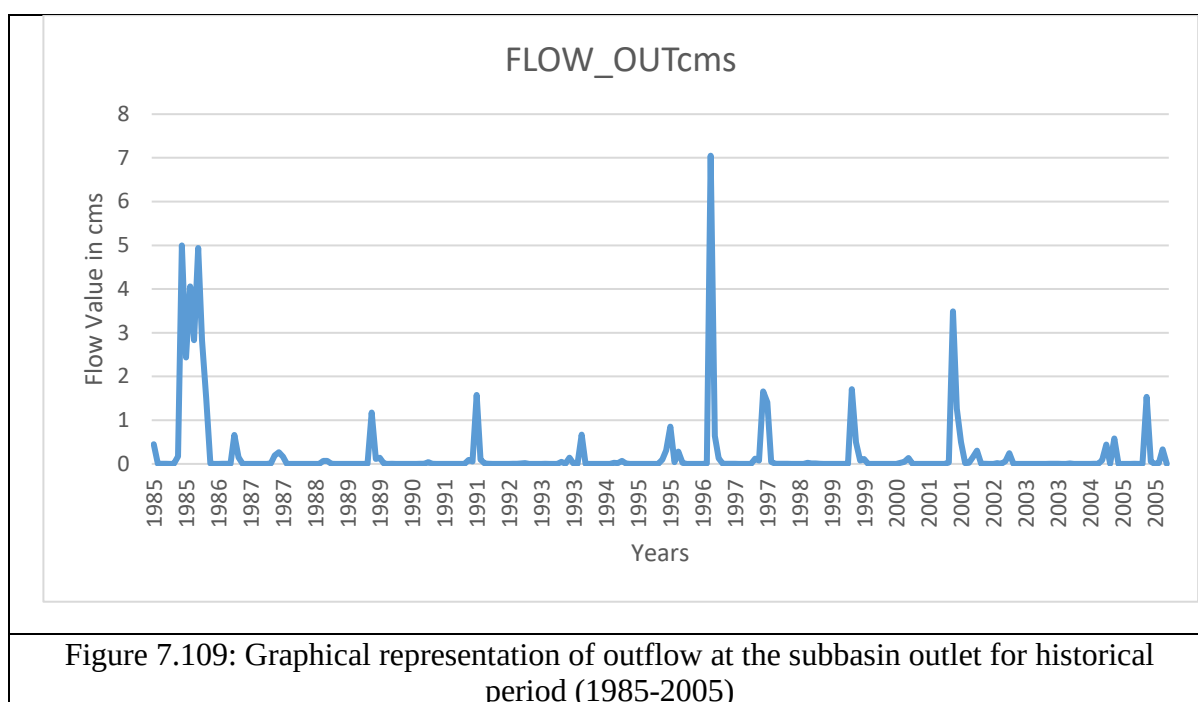
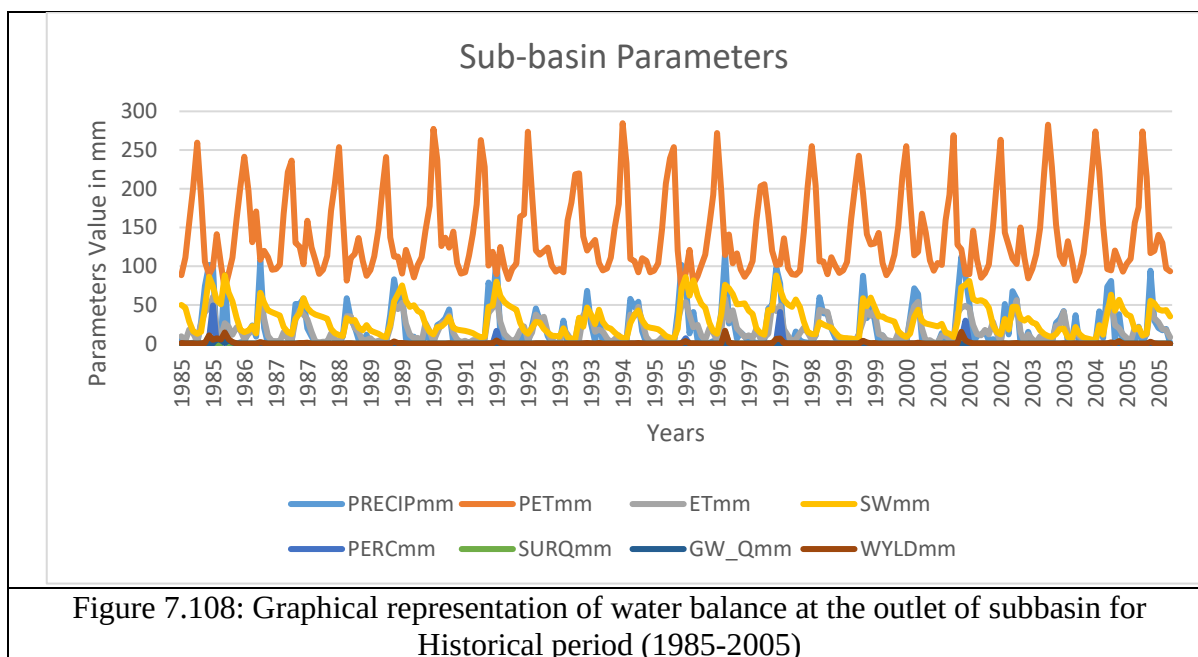
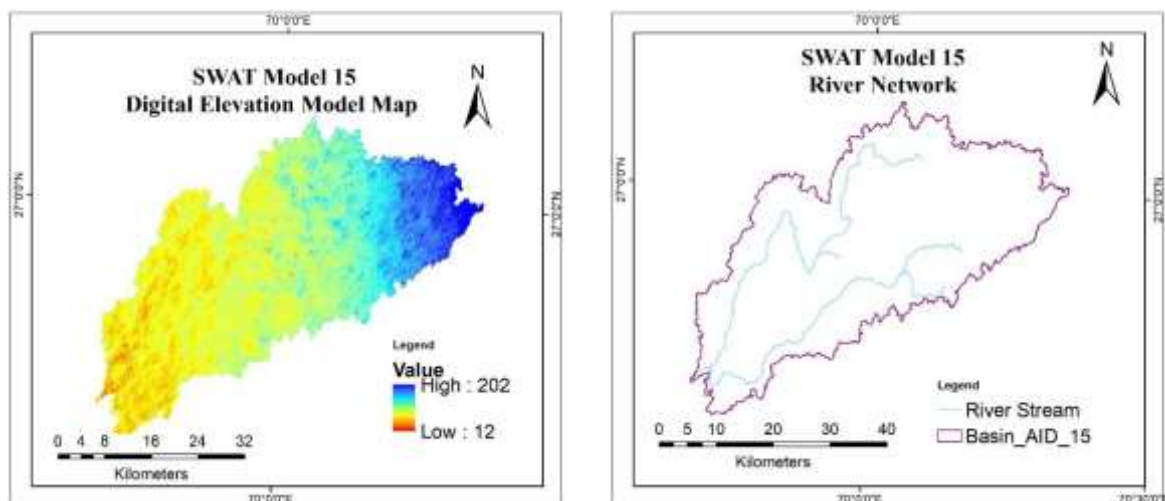
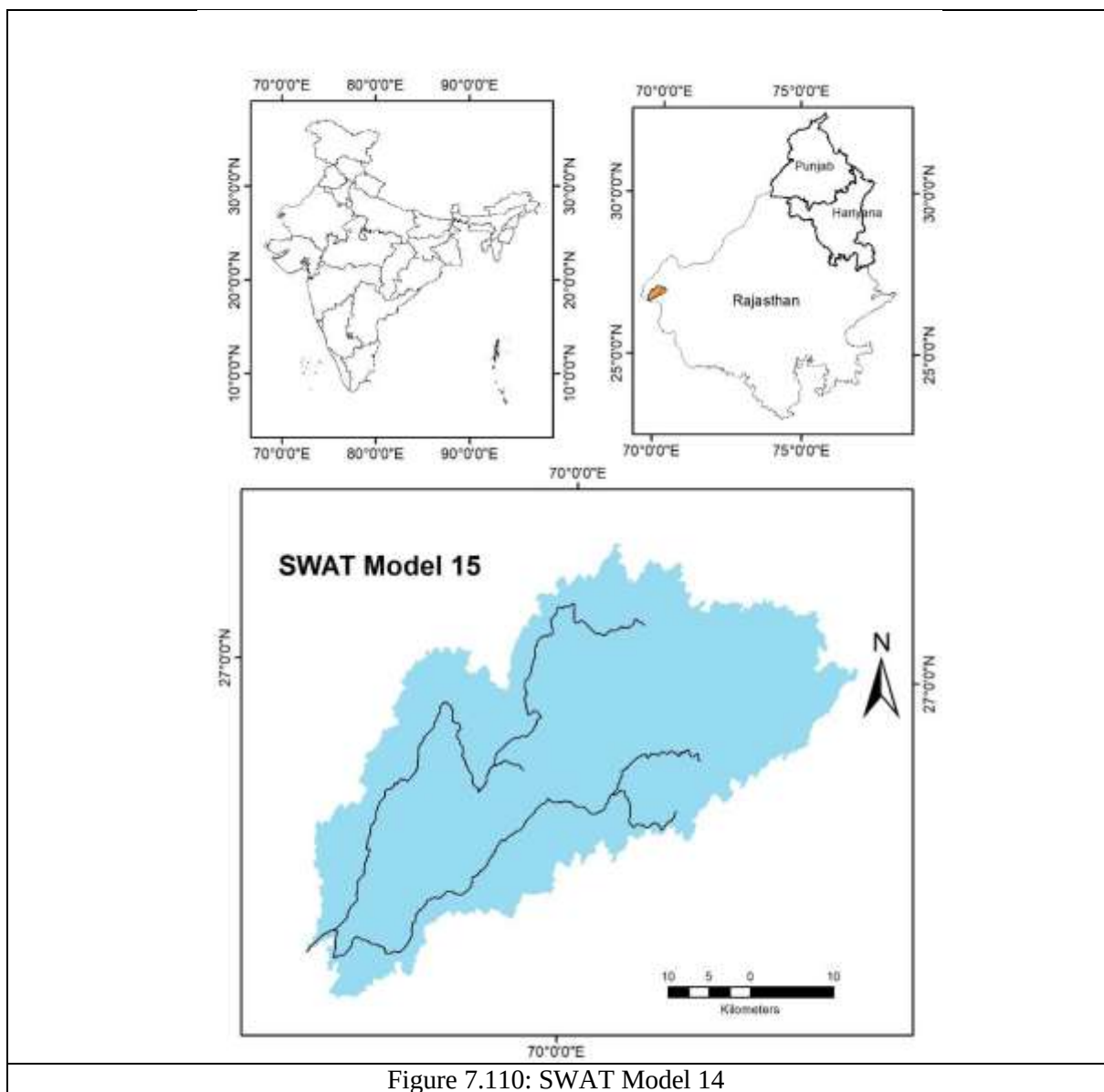


Figure 7.107: Pictorial representation of water balance component at the outlet of subbasin for historical period (1985-2005)



7.5.16 SWAT model 15 of AID

SWAT Model 15 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at 26°52'51" N 69°56'41" E. It is the 14th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 15 of AID is 1716.61 Sq. km. The SWAT model for sub basin 15 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.



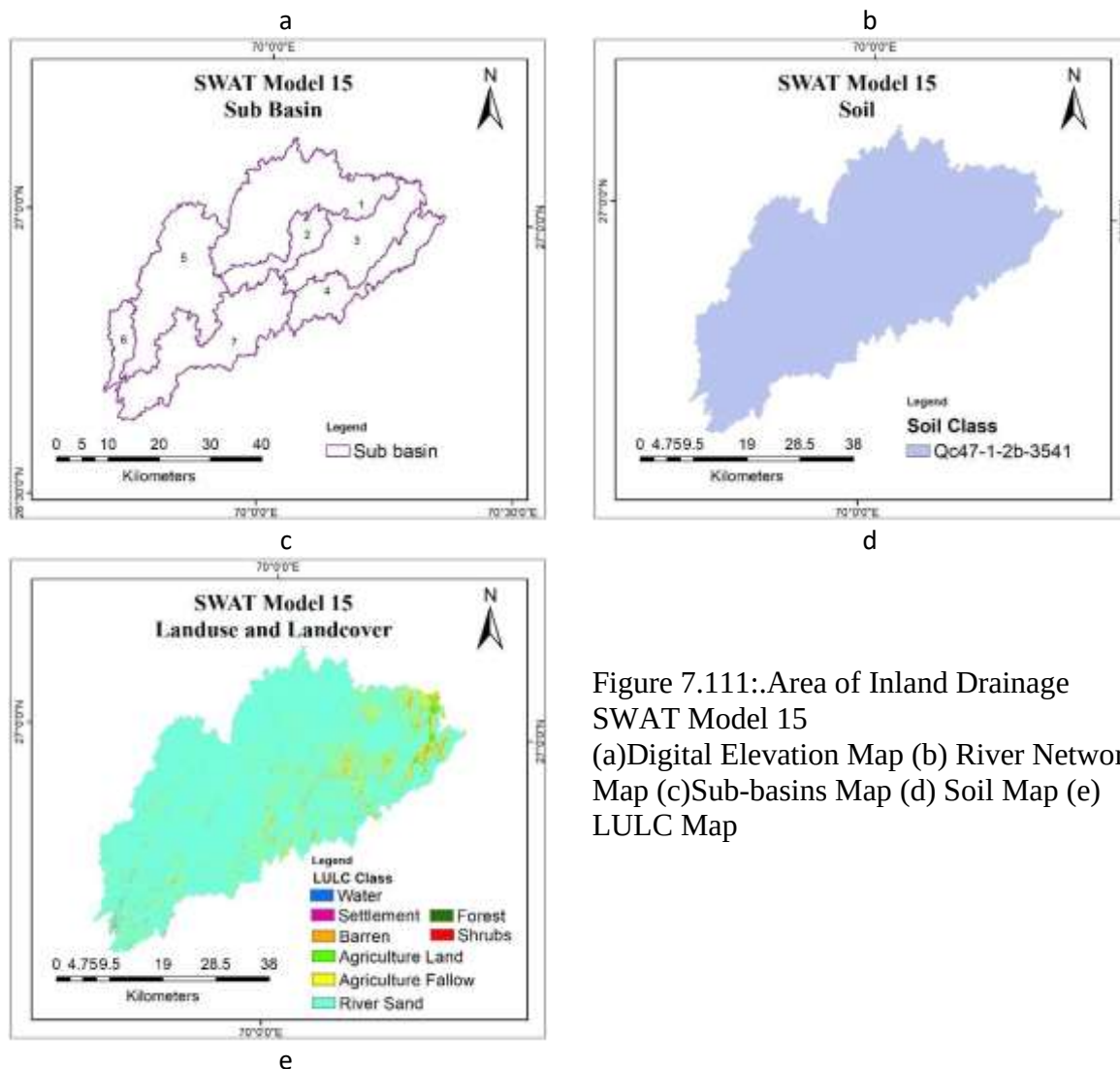


Figure 7.111: Area of Inland Drainage
SWAT Model 15
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.111 (a) shows the digital elevation model for SWAT model 15 of AID. It has a minimum elevation of 12 meters and a maximum elevation of 202 meters. The mean elevation is 84.5 meters. Figure 7.111 (b) shows the Area Inland drainage network map for SWAT model 15 of AID. In this basin the number of streams are 7, which is generated from 7 sub-basin of SWAT model 15. The total length of all rivers is 192.80km. Figure 7.111 (c) shows sub-basin distribution by SWAT model delineation of digital elevation model. It has 47 HRUs generated by the SWAT model. Figure 7.111 (d) shows the Soil Map for the SWAT model 15 of the AID area. It has one type of soil. Type 1 soil named Qc47-1-2b-3541 covered 100% of the total area. Figure 7.111 (e) shows the Landuse and landcover map of SWAT model 15 of AID. It has eight classes. Dominant LULC class is River sand with 90.12 % out of total basin area followed by Agriculture fallow land with 6.09% out of total basin area. Less dominant LULC classes are Water, Settlement, Shrubs and agriculture, with 0.08%, 0.10%, 0.03% and 0.38 % out of the total basin.

Table 7.201 Details of Digital elevation model for SWAT model 15 of AID

Min. Elevation	12m
Max. Elevation	202m
Mean Elevation	84.5m
Std. Deviation	21.83m

Table 7.202. Details of river network for SWAT model 15 of AID

Number of streams	7
Number of sub basin	7
Total length of streams	192.80km
Minimum length of streams	4.27km
Maximum length of streams	54.84km
Average length of streams	27.54km

T

Table 7.203 Details of LULC for SWAT model 15 of AID

LULC Class	LULC Code	Area (Km ²)	Sub-basin share (%)
Water	WATR	1.44	0.08
Settlement	URLD	1.72	0.10
Forest	FRSD	0.03	0.00
Shrubs	RNGB	0.5	0.03
Barren	BARR	54.72	3.1
Agriculture Land	AGRC	6.57	0.38
Agriculture Fallow	AGRR	104.48	6.09
River sand	WETN	1547.07	90.12

Table 7.204 Details of Soil class for SWAT model 15 of AID

Soil Type	Area (km ²)	Subbasin share (% area)
Qc47-1-2b-3541	1716.61	100

Table 7.205 Details of Sub-basin of SWAT model 15 of AID

Number of HRUs	47
Number of Sub basin	7
Total Subbasin area (km ²)	1716.61

Subbasin simulation Details

SWAT simulation details provided in Table 7.206 for SWAT model 15 of the AID area. SWAT model set-up and run for historical period (1985-2005).

Table 7.206 Subbasin simulation details for SWAT Model 15 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	47
Number of Sub basins	7
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	1716.61

Average annual water balance component value generation by SWAT model shown in Table 7.207.

Table 7.207 Annual average water balance component and their values for SWAT model 15 of AID

Water Balance Components	Values in mm
Precipitation	164.4
Surface Runoff Q	1.09
Lateral Flow Through Soil	1.46
GW (Shallow AQ)	0
GW(Deep AQ)	0.16
REVAP (Shallow AQ=>Soil/Plant	11.79
Deep Aquifer Recharge	0.16
Total Aquifer Recharge	3.14
Total Water Yield	2.74
Percolation Out of Soil	3.04
ET	162.4
PET	1690.3
Total Sediment Loading	1.44t/ha

Water Balance calculation

Total flow = Surface runoff +Baseflow =1.09mm+0.16mm=1.25mm

A preliminary Check for SWAT model performance using SWAT check tool run which gives the ratio for subbasin simulation shown in Table 7.208

Table 7.208 Water balance Ratio for SWAT model 15 of AID

Component Ration	Values
Streamflow/Precipitation	0.4

Baseflow /Total flow	0.57
Surface Runoff/Total flow	0.43
Percolation/precipitation	0.02
Deep Recharge/Precipitation	0
ET/Precipitation	0.99

Continuity Error Calculation

Continuity error calculation for SWAT model 15

Total inflow = precipitation + Revap

$$=164.4\text{mm}+11.79\text{mm}$$

$$=176.19\text{mm}$$

Total outflow =Surface runoff +Lateral flow + GW + ET+ Percolation Deep aquifer recharge

$$=1.09\text{mm}+1.46\text{mm}+0.16\text{mm}+162.4+3.04+0.16$$

$$=168.31\text{mm}$$

Continuity Error =100*(1-Inflow/Outflow)

$$=100*(1-176.19/168.31)$$

$$=-4.6\%$$

Water Balance component at outlet of subbasin pictorial representation

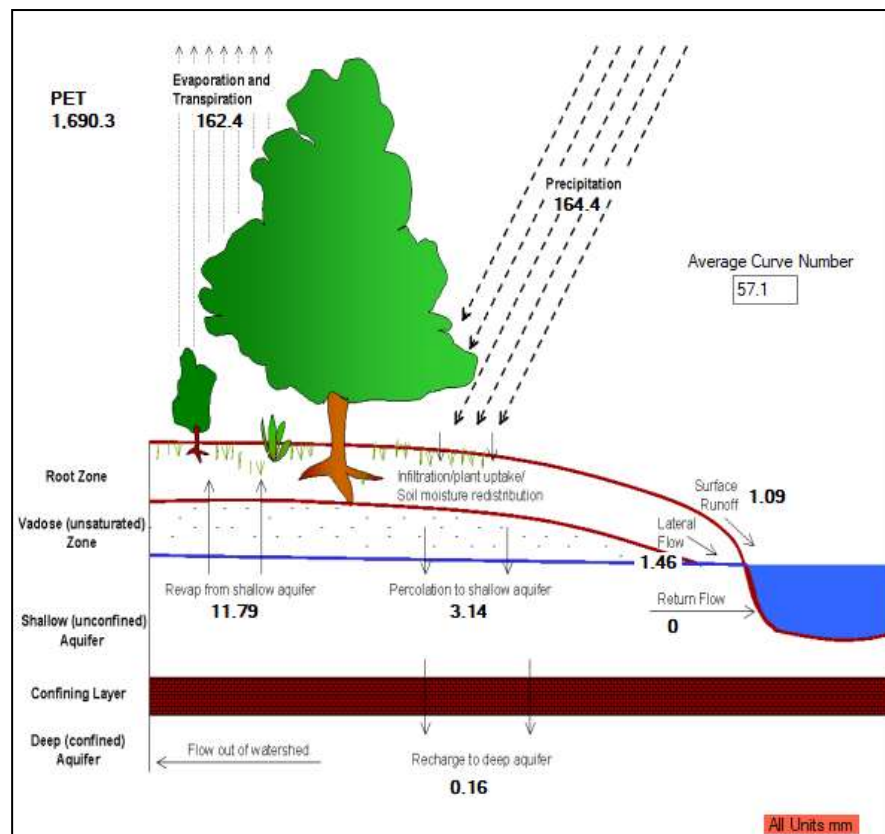


Figure 7.112: Pictorial representation of water balance components at the subbasin outlet for historical period (1985-2005)

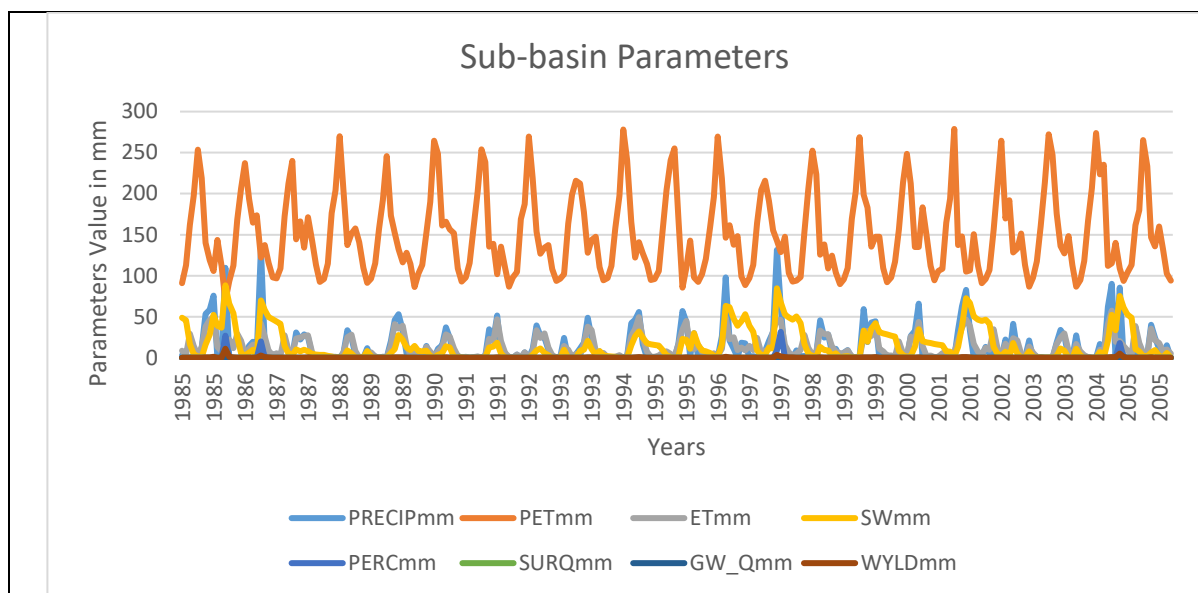


Figure 7.113: Graphical representation of water balance components at the subbasin outlet for historical period (1985-2005)

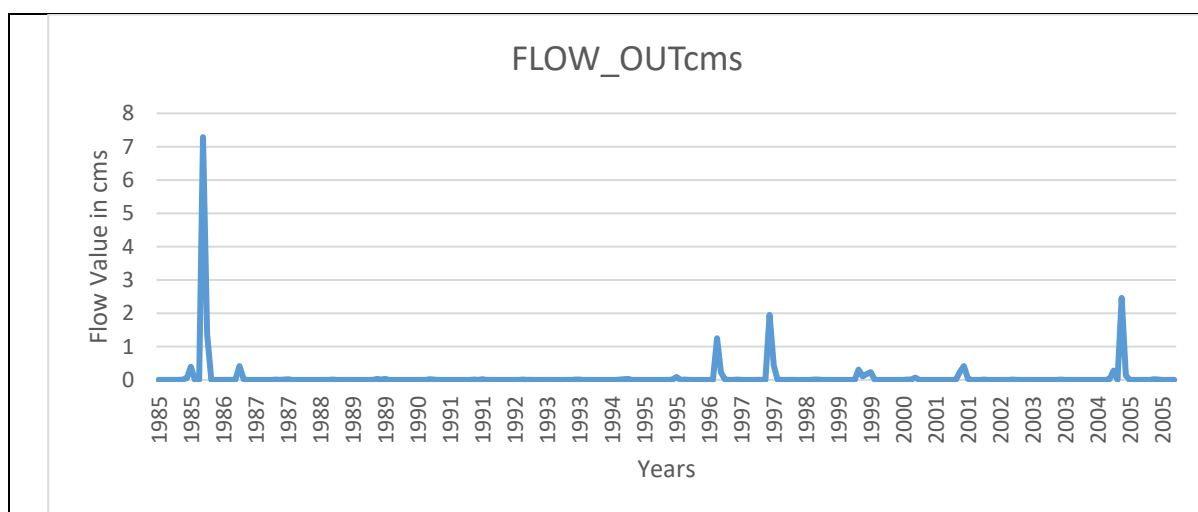
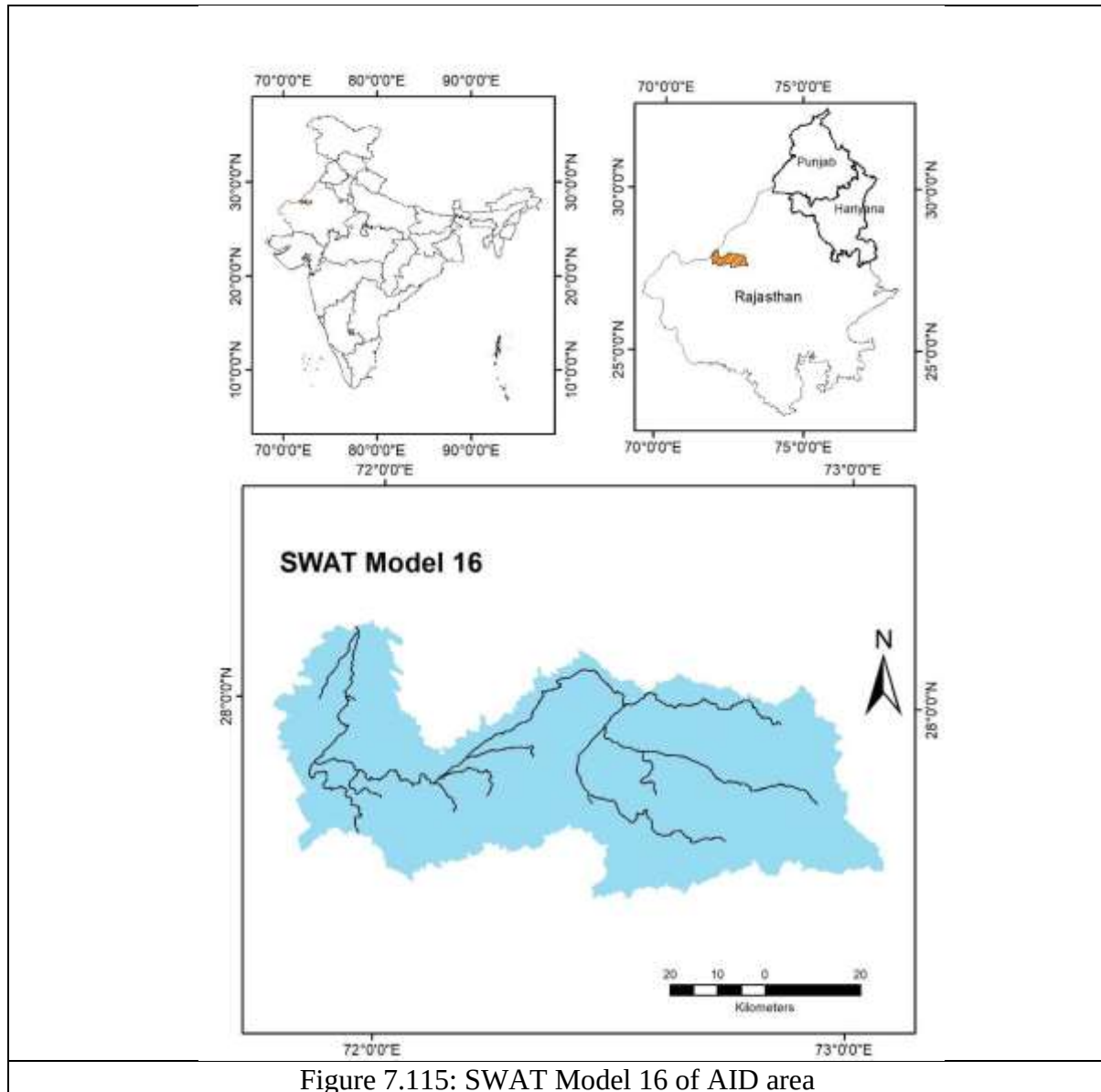


Figure 7.114: Graphical representation of flow out at the subbasin outlet for historical period (1985-2005)

7.5.17 SWAT model 16 of AID

SWAT Model 16 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at 27°53'26" N 72°25'35" E. It is the 7th largest sub basin of Inland drainage

area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 16 of AID is 4268 Sq. km. The SWAT model for sub basin 16 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.



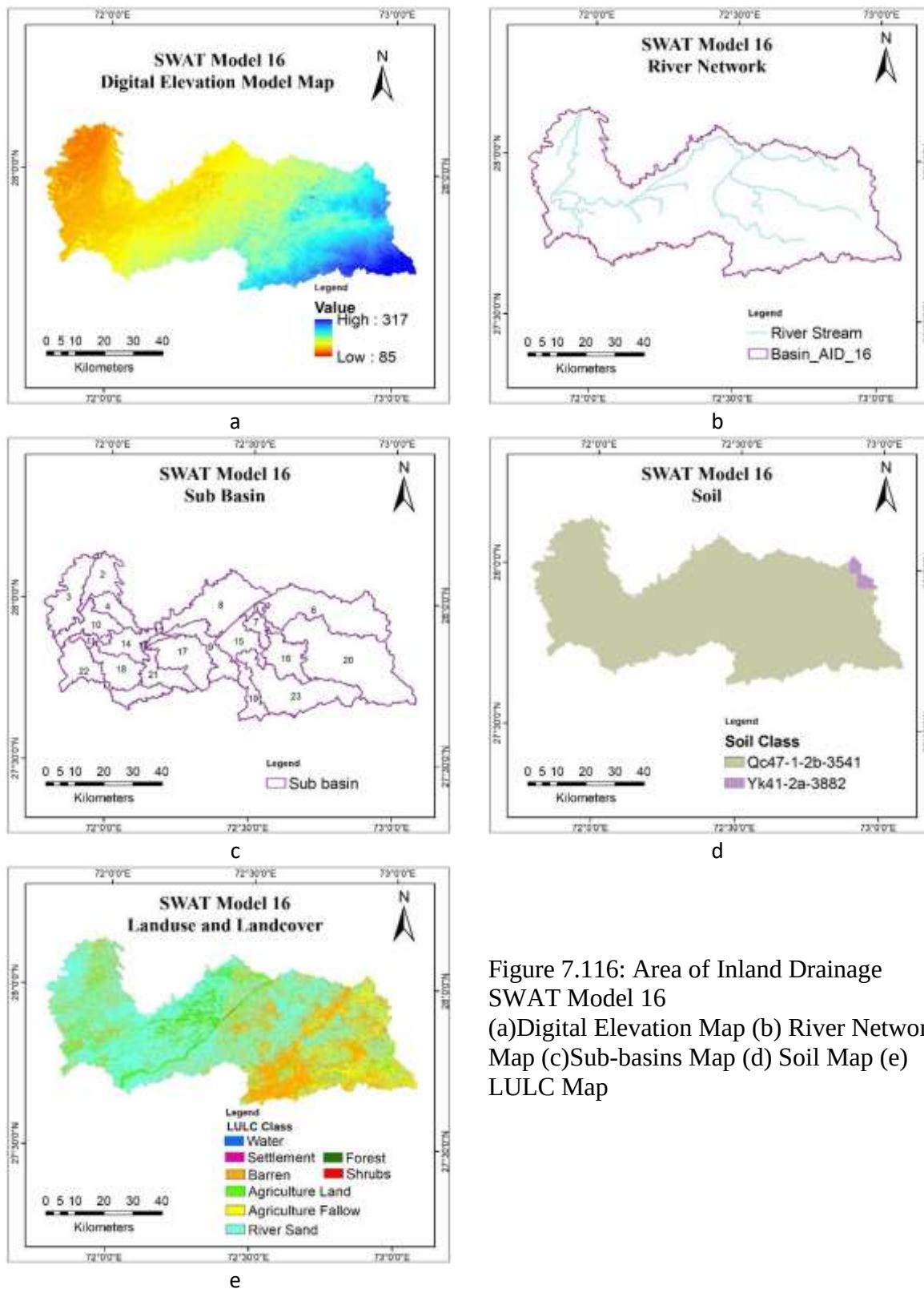


Figure 7.116: Area of Inland Drainage
SWAT Model 16
(a)Digital Elevation Map (b) River Network
Map (c)Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.116 (a) shows the digital elevation model for SWAT model 16 of AID. It has a minimum elevation of 85 meters and maximum elevation of 317 meters. Mean elevation is 181.58 meters. Figure 7.116 (b) shows Area Inland drainage network map for SWAT model

16 of AID. In this basin the number of streams are 23 which are generated from 23 sub-basin of SWAT model 16. Total length of all rivers is 446.56 Km. Figure 7.116 (c) shows sub-basin distribution by SWAT model delineation of digital elevation model. It has 179 numbers of HRUs generated by the SWAT model. Figure 7.116(d) shows the Soil Map for the SWAT model 16 of the AID area. It has two types of soil. Type 1 soil named Qc47-1-2b-3541 covered 98.94% area out of total area and type 2 soil named as Yk41-2a-3882 covered 1.06% area out of total basin area. Figure 7.116(e) shows the Landuse and landcover map of SWAT model 16 of AID. It has eight classes. Dominant LULC class is River sand with 56.67 % out of total basin area, followed by Barren land with 27.34% area. Less dominant LULC classes are Water, Settlement, Shrubs and agriculture with 0.15%, 0.14%, 0.00% and 7.64 % out of total basin.

Table 7.209 Details of Digital elevation model for SWAT model 16 of AID

Min. Elevation	85m
Max. Elevation	317m
Mean Elevation	181.58m
Std. Deviation	43.53m

Table 7.210 Details of river network for SWAT model 16 of AID

Number of streams	23
Number of sub basin	23
Total length of streams	446.56km
Minimum length of streams	1.29km
Maximum length of streams	52.62km
Average length of streams	19.42km

Table 7.211 Details of LULC for SWAT model 16 of AID

LULC Class	LULC Code	Area (km ²)	Subbasin Share(% Area)
Water	WATR	6.5	0.15
Settlement	URLD	5.90	0.14
Forest	FRSD	21.28	0.50
Shrubs	RNGB	0.01	0.00
Barren	BARR	1166.76	27.34
Agriculture land	AGRC	325.9	7.64
Agriculture Fallow	AGRR	323.57	7.58
Sand	WETN	2418.04	56.67

Table 7.212 Details of Soil class for SWAT model 16 of AID

Soil Type	Area (km ²)	Subbasin share (%Area)
Qc47-1-2b-3541	4222.76	98.94
Yk41-2a-3882	45.23	1.06

Table 7.213 Details of Sub-basin of SWAT model 16 of AID

Number of HRUs	179
Number of sub basin	23
Total Subbasin Area (km ²)	4268

Subbasin Simulation Details

SWAT model simulation details provided in Table 7.214 for SWAT model 16 of AID

Table 7.214 Subbasin simulation details for SWAT Model 16 of AID

Simulation Details	Values
Simulation length	25 years
Warm up (Model Initial Run) period	4 years
Number of HRUs	179
Number of sub basins	23
Output time step	Monthly
Precipitation method	Measured
Subbasin area in Km ²	4268

Average annual water balance component value generated by SWAT model run for period (1985-2005) in Table 7.215

Table 7.215 Annual average water balance component and their values for SWAT model 16 of AID

Components	Values in mm
Precipitation	222.4
Surface Runoff Q	1.66
Lateral Flow Through Soil	2.3
GW (Shallow AQ)	0.53
GW(Deep AQ)	0.35
REVAP (Shallow AQ=>Soil/Plant	15.29
Deep Aquifer Recharge	0.22
Total Aquifer Recharge	4.5
Total Water Yield	4.84
Percolation Out of Soil	4.31
ET	217.4

PET	1382.5
Total Sediment Loading	1.02t/ha

Water Balance Calculation

Total flow =Surface runoff +baseflow =1.66mm+0.35mm=2.01mm

A preliminary SWAT check Tools run for SWAT performance which gives the ratio for components of subbasin shown in Table 7.216

Table 7.216 Water balance Ratio for SWAT model 16 of AID

Component	Ratio Value
Streamflow/Precipitation	0.02
Baseflow /Total flow	0.63
Surface Runoff/Total flow	0.37
Percolation/precipitation	0.02
Deep Recharge/Precipitation	0
ET/Precipitation	0.98

Continuity Error Calculation

Continuity error calculation for SWAT model 16

Total inflow =Precipitation +Revap
=222.4mm+15.29mm
=237.69mm

Total outflow =Surface runoff +Lateral flow +GW + ET+ Percolation +Deep aquifer recharge
= 1.66mm + 2.3mm+0.35mm+217.4mm+4.31+4.5mm
= 230.52mm

Continuity error calculation =100*(1-Inflow /Outflow)
=100*(1-237.69/230.52)
=-3%

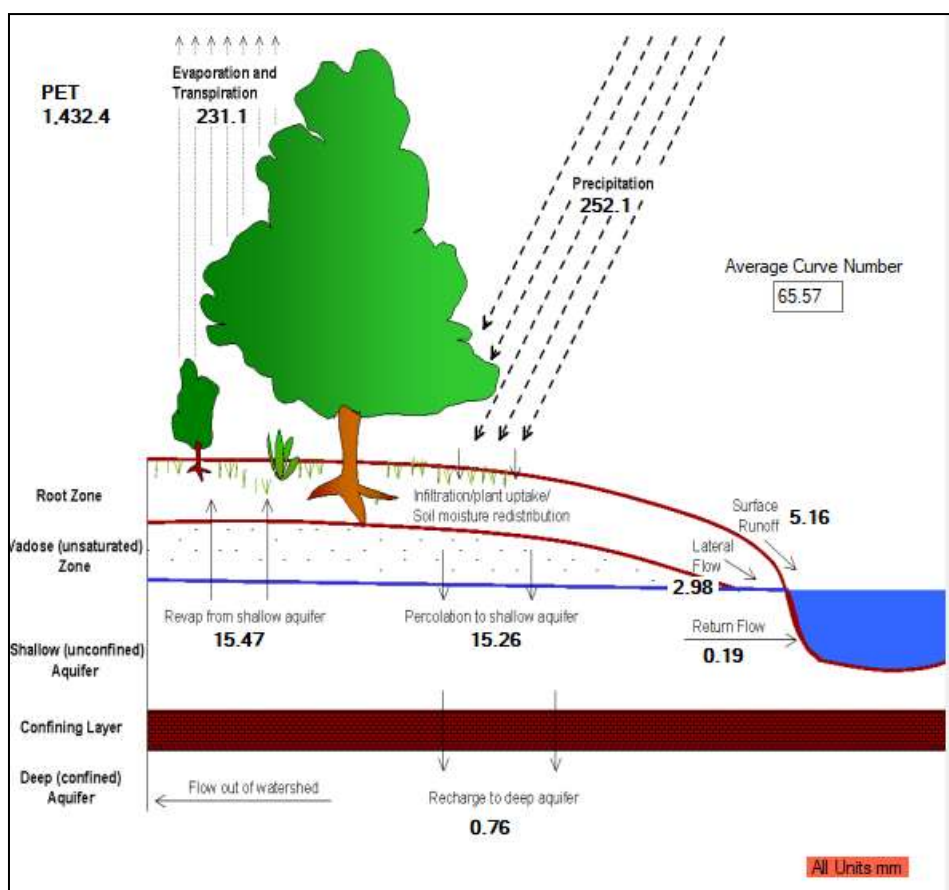


Figure 7.117: Pictorial representation of water balance components at the subbasin outlet for historical period (1985-2005)

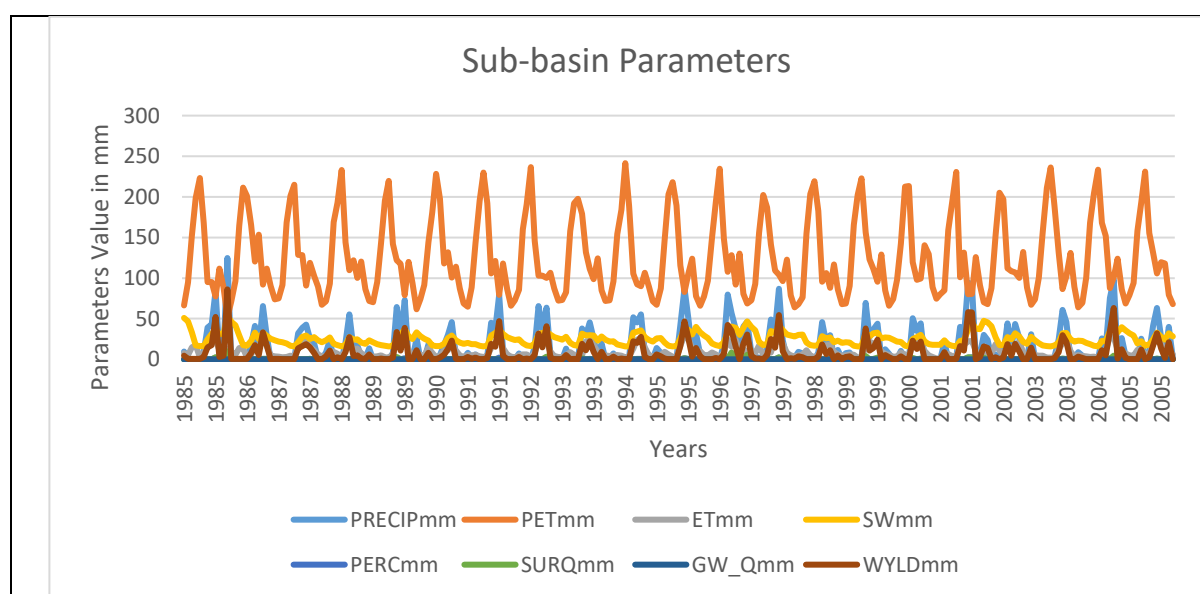
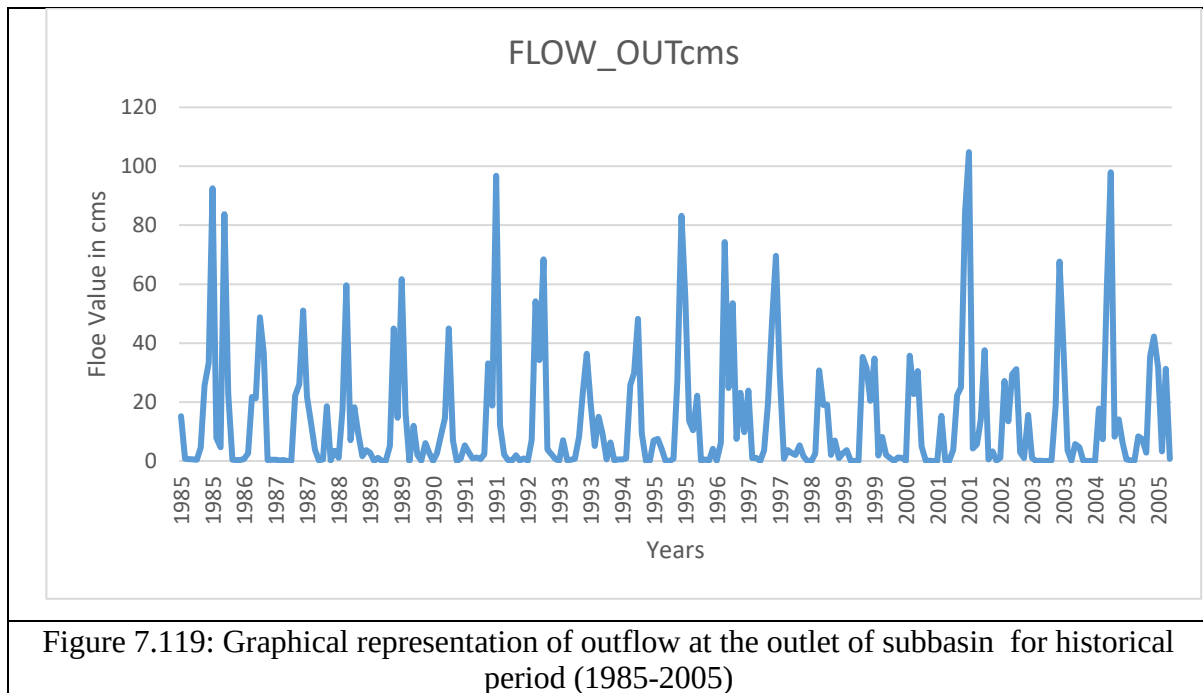


Figure 7.118: Graphical representation of water balance at the outlet of subbasin for historical period (1985-2005)



7.5.18 SWAT Model 17 of AID

SWAT Model 17 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at $28^{\circ}8'29''$ N $72^{\circ}17'39''$ E. It is the 15th largest sub basin of the AID. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 17 of AID is 1706.09 Sq. km. The SWAT model for sub basin 17 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

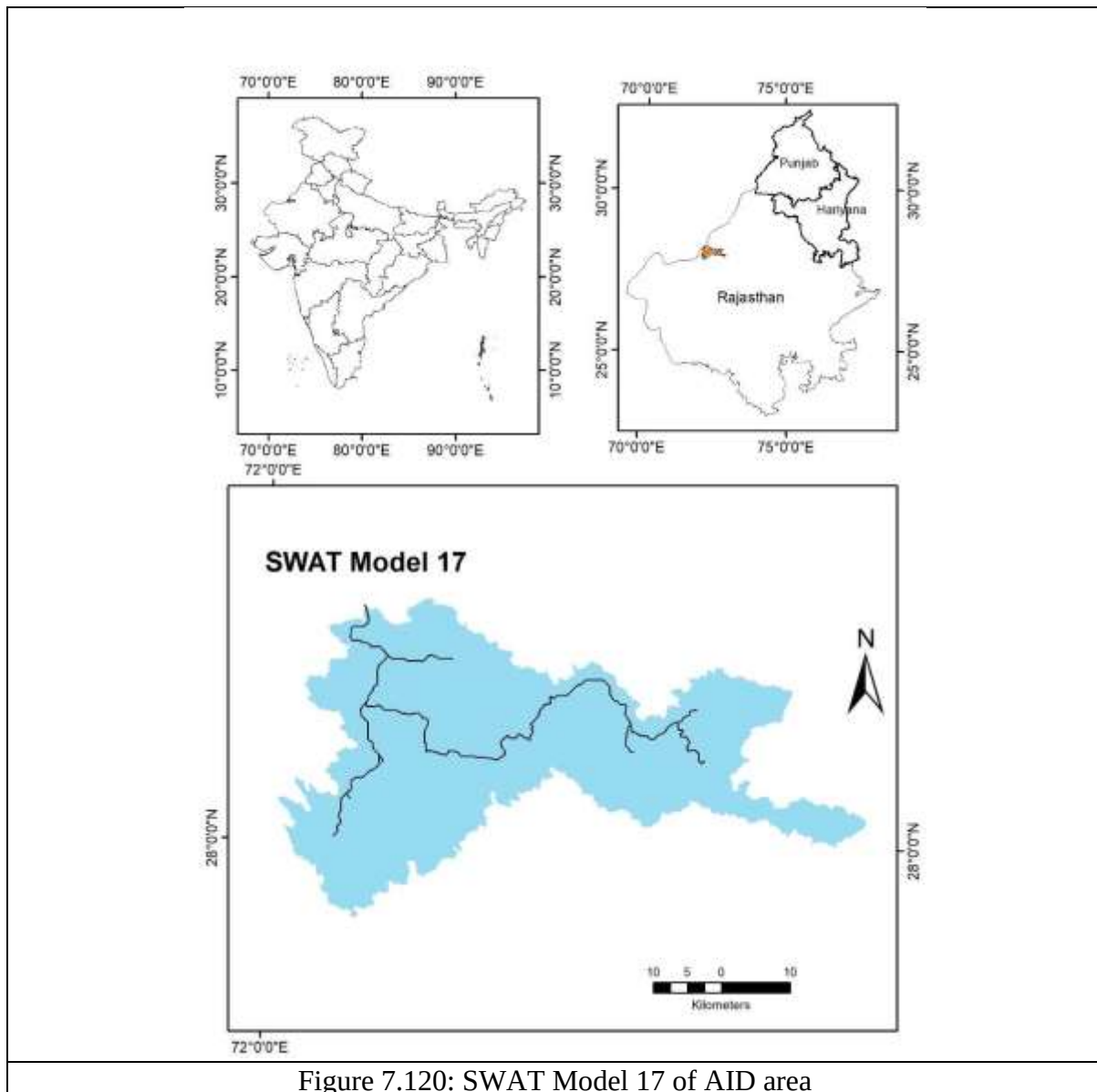


Figure 7.120: SWAT Model 17 of AID area

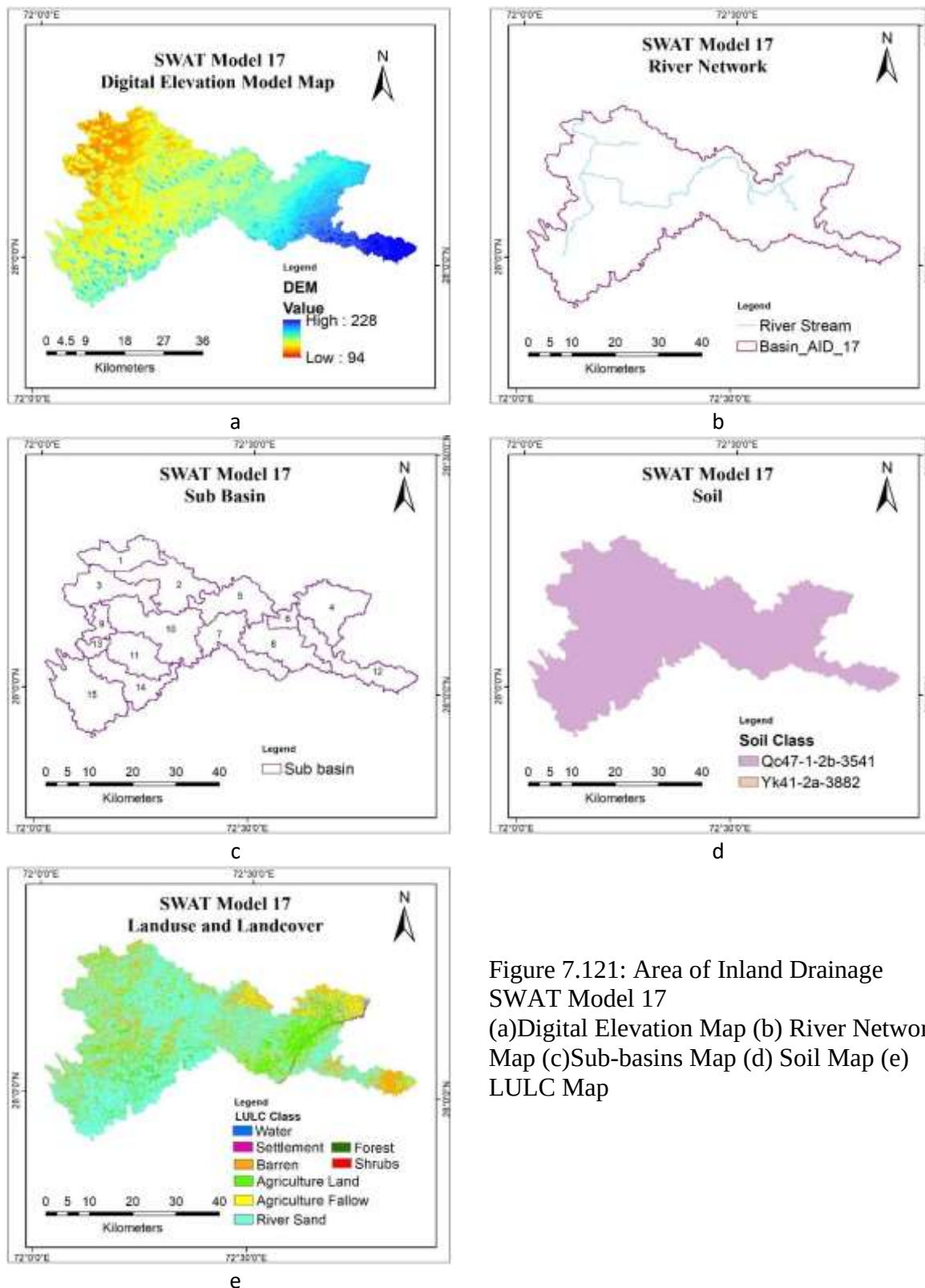


Figure 7.121: Area of Inland Drainage
SWAT Model 17
(a) Digital Elevation Map (b) River Network
Map (c) Sub-basins Map (d) Soil Map (e)
LULC Map

Figure 7.121 (a) shows the digital elevation model for SWAT model 17 of AID. It has a minimum elevation of 94 meters and a maximum elevation of 228 meters. The mean elevation is 146.78 meters. Figure 7.121 (b) shows the Area Inland drainage network map for SWAT model 17 of AID. In this basin the number of streams are 15, which is generated from 15 sub-

basin of SWAT model 17. The total length of all rivers is 154.43 Km. Figure 7.121 (c) shows the sub-basin distribution map. It has 122 HRUs generated by the SWAT model. Figure 7.121(d) shows the Soil Map for the SWAT model 17 of the AID area. It has two types of soil. Type 1 soil named Qc47-1-2b-3541 covered 99.97% area out of the total area, and type two soil named Yk41-2a-3882 covered 0.03% area out of the total basin area. Figure 7.121 (e) shows the Landuse and landcover map of SWAT model 17 of AID. It has eight classes. Dominant LULC class is River sand with 61.52 % out of total basin area, followed by Barren land with 19.85% area. Less dominant LULC classes are Water, Settlement, Shrubs and agriculture, with 0.27%, 0.55%, 0.01% and 11.46 % out of the total basin.

Table 7.217 Details of Digital elevation model for SWAT model 17 of AID

Min. Elevation	94m
Max. Elevation	228m
Mean Elevation	146.78m
Std. Deviation	19.14m

Table 7.218 Details of river network for SWAT model 17 of AID

Number of streams	15
Number of sub basin	15
Total length of streams	154.43km
Minimum length of streams	0.46km
Maximum length of streams	36.78km
Average length of streams	10.30km

Table 7.219 Details of LULC for SWAT model 17 of AID

LULC Class	LULC Code	Area (km ²)	Subbasin Share (% Area)
Water	WATR	4.69	0.27
Settlement	URLD	9.33	0.55
Forest	FRSD	8.79	0.52
Shrubs	RNGB	0.12	0.01
Barren	BARR	338.74	19.85
Agriculture land	AGRC	195.54	11.46
Agriculture Fallow	AGRR	99.37	5.82
River Sand	WETN	1049.50	61.52

Table 7.220 Details of Soil class for SWAT model 17 of AID

Soil Type	Area (km ²)	Subbasin share (% Area)
Qc47-1-2b-3541	1705.52	99.97
Yk41-2a-3882	0.56	0.03

Table 7.221 Details of Sub-basin of SWAT model 17 of AID

Number of HRUs	122
Number of sub basin	15
Total Subbasin Area (km ²)	1706.09

SWAT simulation details

SWAT simulation details provide in the Table 7.222 for SWAT model 17

Table 7.222 Subbasin simulation details for SWAT Model 17 of AID

Simulation details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number of HRUs	122
Number of Sub basins	15
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	1706.09

Average annual value of water balance component for historical period (1985-2005) provided in Table 7.223

Table 7.223 Annual average water balance component and their values for SWAT model 17 of AID

Components	Values in mm
Precipitation	218.5
Surface Runoff Q	1.59
Lateral Flow Through Soil	96.94
GW (Shallow AQ)	0
GW(Deep AQ)	0.9
REVAP (Shallow AQ=>Soil/Plant	8.53
Deep Aquifer Recharge	0.84
Total Aquifer Recharge	1.32
Total Water Yield	99.43
Percolation Out of Soil	0.96

ET	124.1
PET	1396.9
Total Sediment Loading	0.62t/ha

Water Balance calculation

Total flow =Surface runoff + Baseflow =1.59mm+0.9mm

A preliminary SWAT check tool run for SWAT model performance which gives ratio for subbasin hydrology parameters shown in Table 7.224.

Table 7.224 Water balance Ratio for SWAT model 17 of AID

Components	Ratio Value
Streamflow/Precipitation	0.45
Baseflow /Total flow	0.98
Surface Runoff/Total flow	0.02
Percolation/precipitation	0.01
Deep Recharge/Precipitation	0
ET/Precipitation	0.57

Continuity error Calculation

Continuity error Calculation for SWAT model 17

Total inflow = Precipitation +Revap

$$=218.5\text{mm}+8.53\text{mm}$$

$$= 227.03\text{mm}$$

Total outflow =Surface runoff +Lateral flow +GW+ET+ Percolation+ Deep aquafer recharge

$$=1.59\text{mm}+96.9\text{mm}+0.9\text{mm}+124.1\text{mm}+0.96\text{mm}+1.32\text{mm}$$

$$=225.77$$

Continuity error =100*(1-Inlfow /Outflow)

$$=100*(1-227.03/225.77)$$

$$= -0.5\%$$

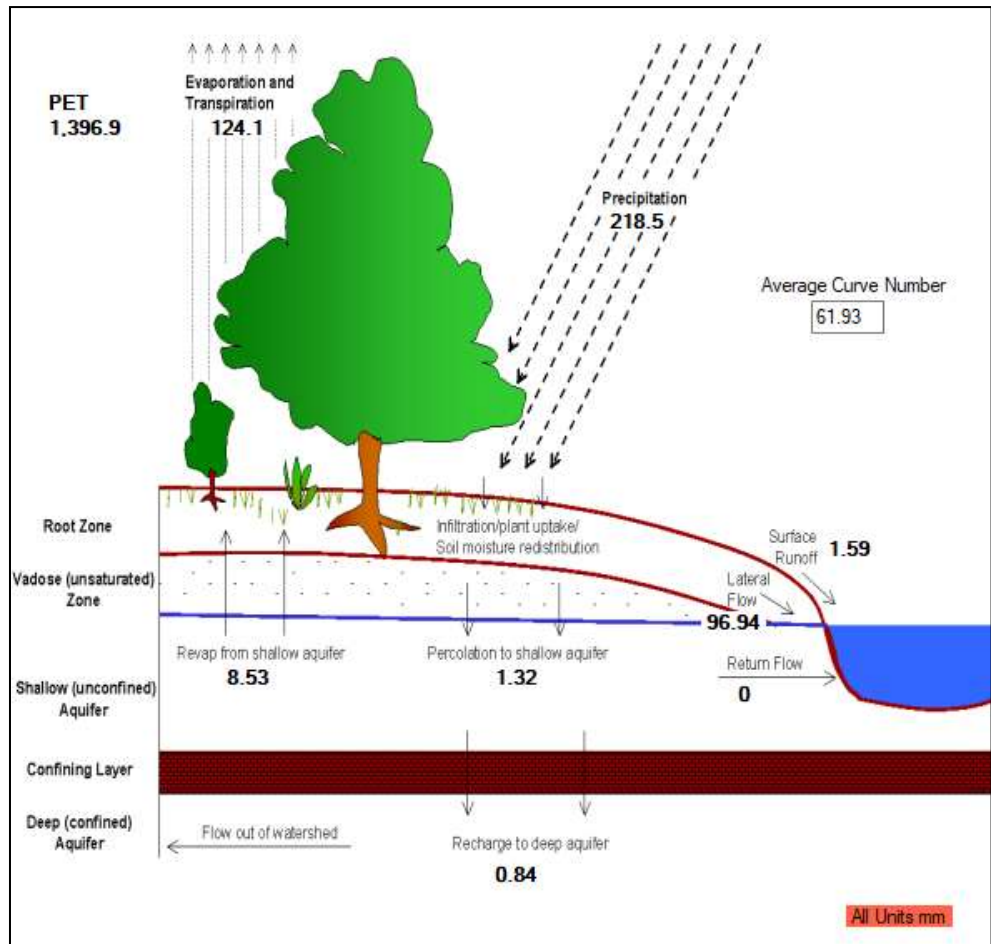


Figure 7.122: Pictorial representation of water balance components at the subbasin outlet for historical period (1985-2005)

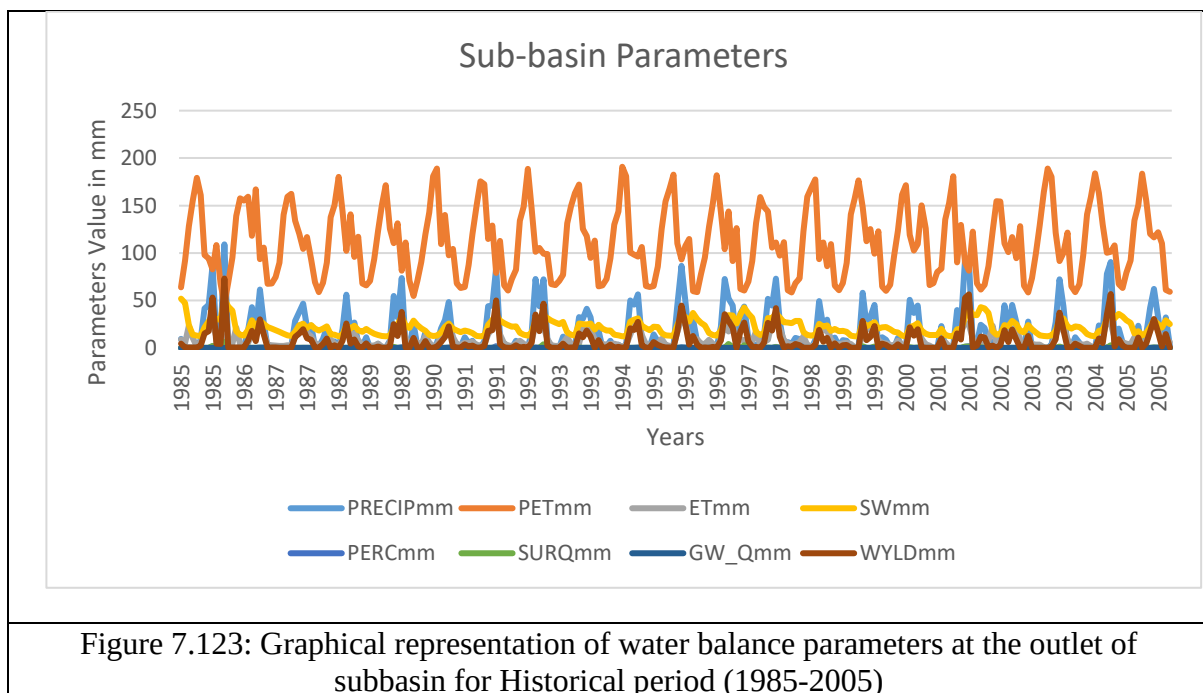


Figure 7.123: Graphical representation of water balance parameters at the outlet of subbasin for Historical period (1985-2005)

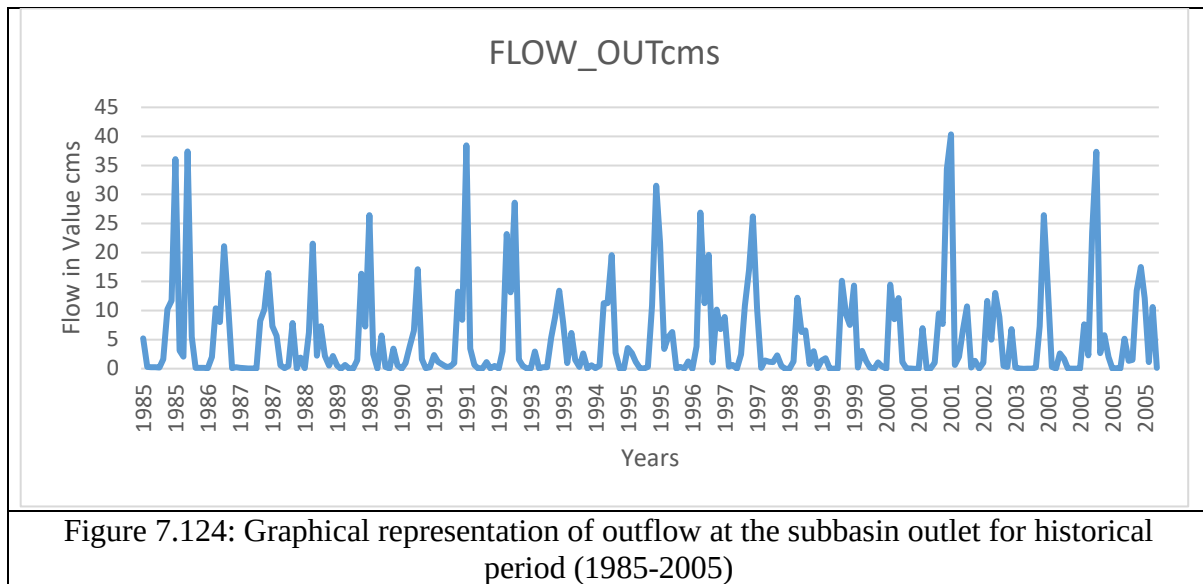


Figure 7.124: Graphical representation of outflow at the subbasin outlet for historical period (1985-2005)

7.5.19 SWAT model 18 of AID

SWAT Model 18 sub basin of AID is situated north side of Rajasthan state of India. The sub basin is placed at 26°34'49" N 70°32'51"E. It is the 17th largest sub basin of Inland drainage area. In this area the main river channel flow direction is east to west. Total subbasin area for the SWAT Model 18 of AID is 1303 Sq. km. The SWAT model for sub basin 18 of AID is simulated for 25 year from 1985 to 2005 with 4 years of warm up period.

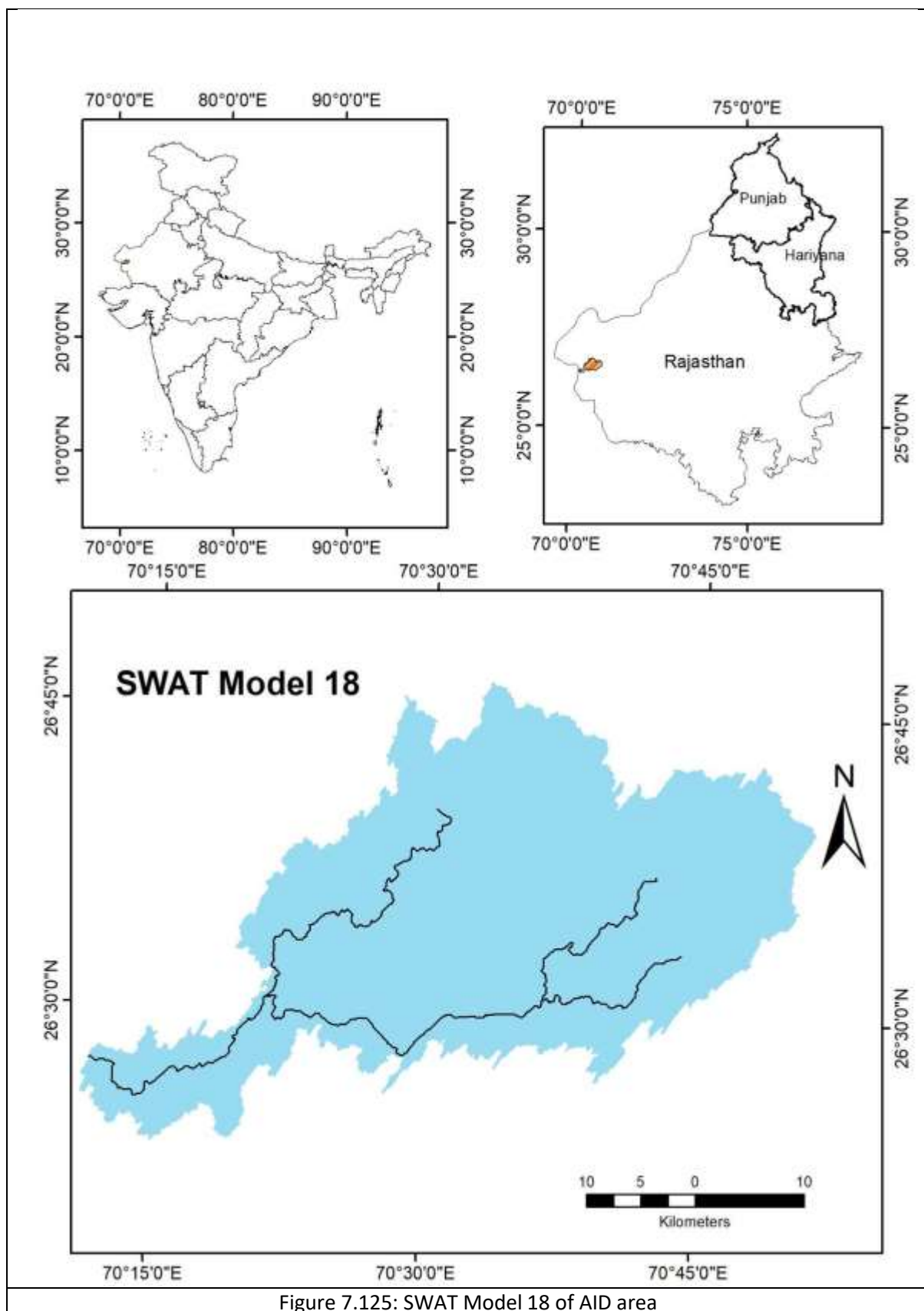


Figure 7.125: SWAT Model 18 of AID area

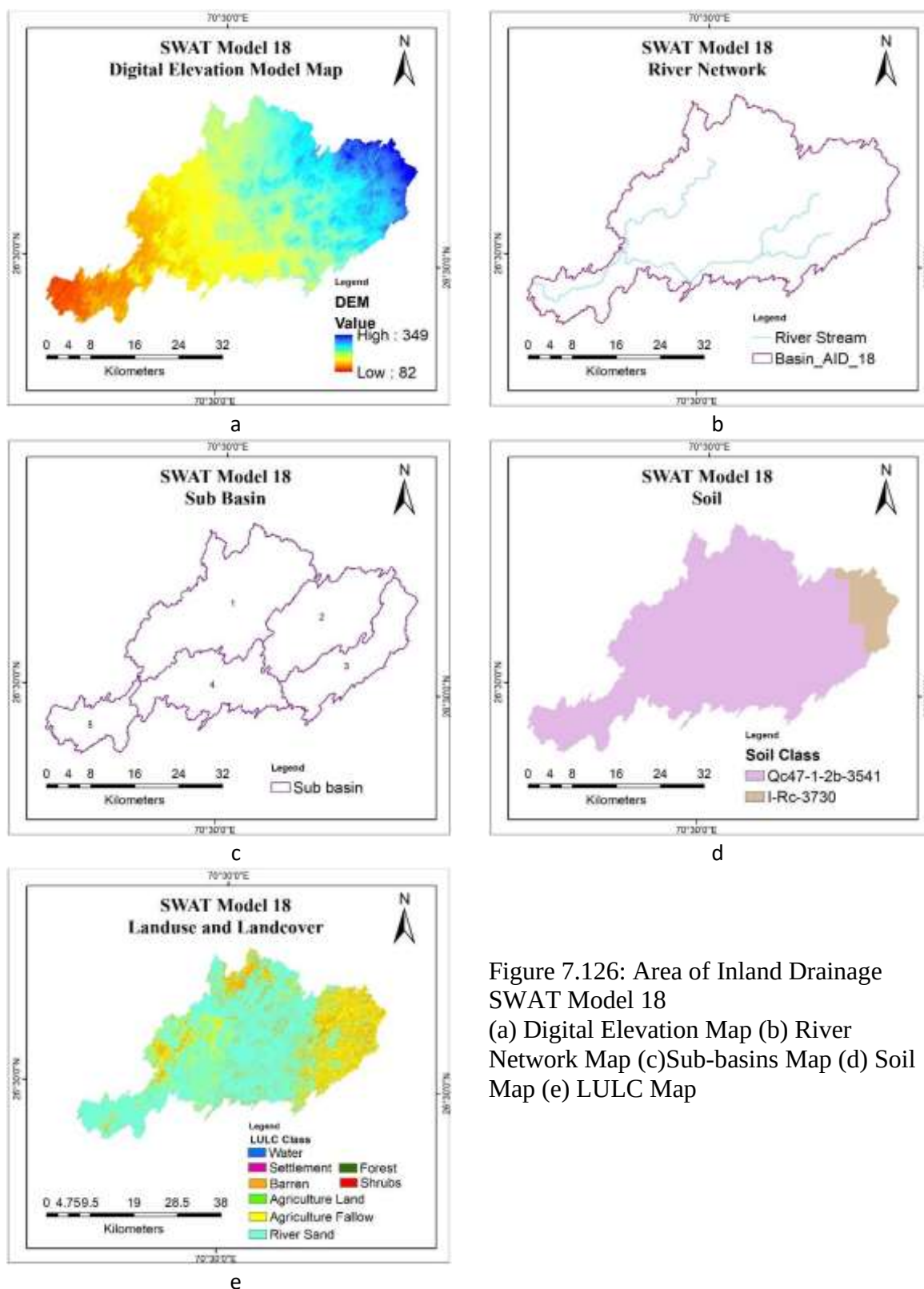


Figure 7.126: Area of Inland Drainage
SWAT Model 18
(a) Digital Elevation Map (b) River
Network Map (c) Sub-basins Map (d) Soil
Map (e) LULC Map

Figure 7.126 (a) shows the digital elevation model for SWAT model 18 of AID. It has a minimum elevation of 82 meters and a maximum elevation of 349 meters. The mean elevation is 192.68 meters. Figure 7.126 (b) shows the area Inland drainage network map for SWAT model 18 of AID. In this basin the number of streams are 5, which is generated from 5 sub-

basin of SWAT model 18. The total length of all rivers is 145.64 Km. Figure 7.126 (c) shows the sub-basin distribution map. It has 44 HRUs generated by the SWAT model. Figure 7.126 (d) shows the Soil Map for the SWAT model 18 of the AID area. It has two types of soil. Type 1 soil named Qc47-1-2b-3541 covered 92.77% area out of the total area and type 2 soil named as I-Rc-3730 covered 7.23% area out of the total basin area. Figure 7.126 (e) shows the Landuse and landcover map of SWAT model 18 of AID. It has eight classes. Dominant LULC class is River sand with 65.64 % out of total basin area followed by Barren land with 17.34% area out of total basin area. Less dominant LULC classes are Water, Settlement, Shrubs and agriculture with 0.2%, 0.2%, 0.014% and 0.32 % out of the total basin area.

Table 7.225 Details of Digital elevation model for SWAT model 18 of AID

Min. Elevation	82m
Max. Elevation	349m
Mean Elevation	192.68m
Std. Deviation	45.207m

Table 7.226 Details of river network for SWAT model 18 of AID

Number of streams	5
Number of sub-basin	5
Total length of streams	145.64km
Minimum length of streams	18.70km
Maximum length of streams	41.03km
Average length of streams	29.13km

Table 7.227 Details of LULC for SWAT model 18 of AID

LULC Class	LULC Code	Area (km ²)	Sub-basin share (%)
Water	WATR	0.32	0.02
Settlement	URLD	0.24	0.02
Forest	FRSD	0.20	0.02
Shrubs	RNGB	1.84	0.14
Barren	BARR	226.16	17.34
Agriculture land	AGRC	4.14	0.32
Agriculture Fallow	AGRC	215	16.5
River sand	WETN	855.33	65.64

Table 7.228 Details of Soil class for SWAT model 18 of AID

Soil Type	Area (km ²)	Subbasin Share (% Area)
Qc47-1-2b-3541	1208.90	92.77
I-Rc-3730	94.25	7.23

Table 7.229 Details of Sub-basin of SWAT model 18 of AID

Number of HRUs	47
Number of sub basin	5
Total subbasin Area (km ²)	1303

Subbasin simulation details

Subbasin simulation details provided in the Table 7.230 for SWAT model 18 of AID for Historical period (1985-2005).

Table 7.230 Subbasin simulation details for SWAT Model 18 of AID

Simulation Details	Values
Simulation Length	25 years
Warm up (Model Initial Run) Period	4 years
Number Of HRUs	47
Number of Sub basins	5
Output Time step	Monthly
Precipitation Method	Measured
Subbasin Area in Km2	1,303

Average annual water balance component values provided in the Table 7.231 for SWAT model 18 of AID for Historical period (1985-2005)

Table 7.231 Annual average water balance component and their values for SWAT model 17 of AID

Components	Values in mm
Precipitation	175.9
Surface Runoff Q	2.92
Lateral Flow Through Soil	76.18
GW (Shallow AQ)	0
GW(Deep AQ)	0.6
REVAP (Shallow AQ=>Soil/Plant	1.77
Deep Aquifer Recharge	0.57
Total Aquifer Recharge	0.9
Total Water Yield	79.69
Percolation Out of Soil	0.73
ET	97.9

PET	1773.2
Total Sediment Loading	3.99t/ha

Water Balance Calculation

Total flow = Surface runoff + Baseflow = 2.92mm+0.6mm=3.52mm

A preliminary SWAT check Tool run for accuracy for SWAT model run which gives the ratio for subbasin hydrology provided in Table 7.232.

Table 7.232 Water balance Ratio for SWAT model 18 of AID

Component	Ratio
Streamflow/Precipitation	0.45
Baseflow /Total flow	0.96
Surface Runoff/Total flow	0.04
Percolation/precipitation	0.01
Deep Recharge/Precipitation	0
ET/Precipitation	0.56

Continuity Error Calculation

Continuity error calculated for SWAT model 18 of AID

Total Inflow = Precipitation +Revap

$$=175.9\text{mm}+1.77\text{mm}$$

$$=177.67\text{mm}$$

Total Outflow =Surface runoff +Lateral flow +GW +ET+ Percolation + Deep aquifer

$$= 2.92\text{mm}+76.18\text{mm}+0.6\text{mm}+97.9\text{mm}+0.73+0.57\text{mm}$$

$$= 178.9\text{mm}$$

Continuity error =100*(1-Inflow /Outflow)

$$=100$$

$$=0.6\%$$

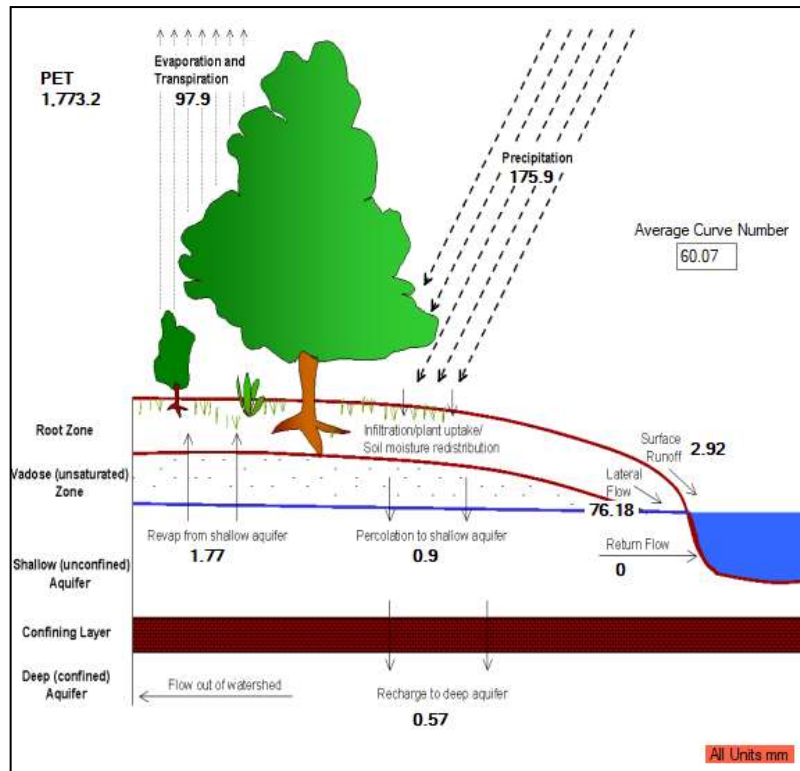


Figure 7.127: Pictorial representation of water balance at outlet of the subbasin for historical period (1985-2005)

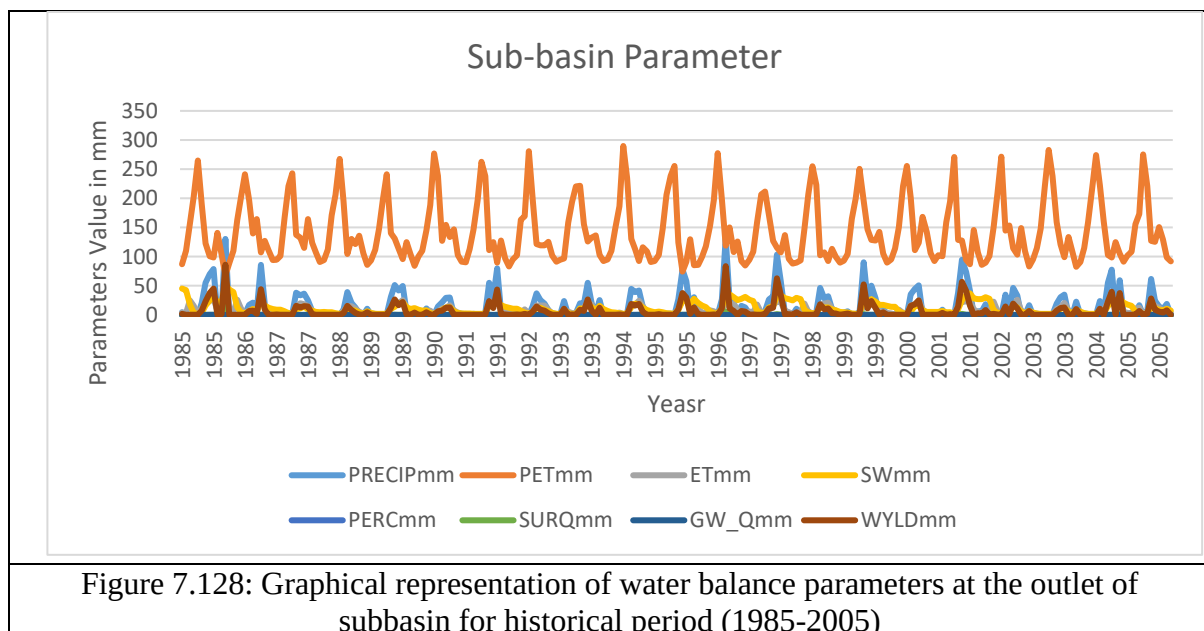
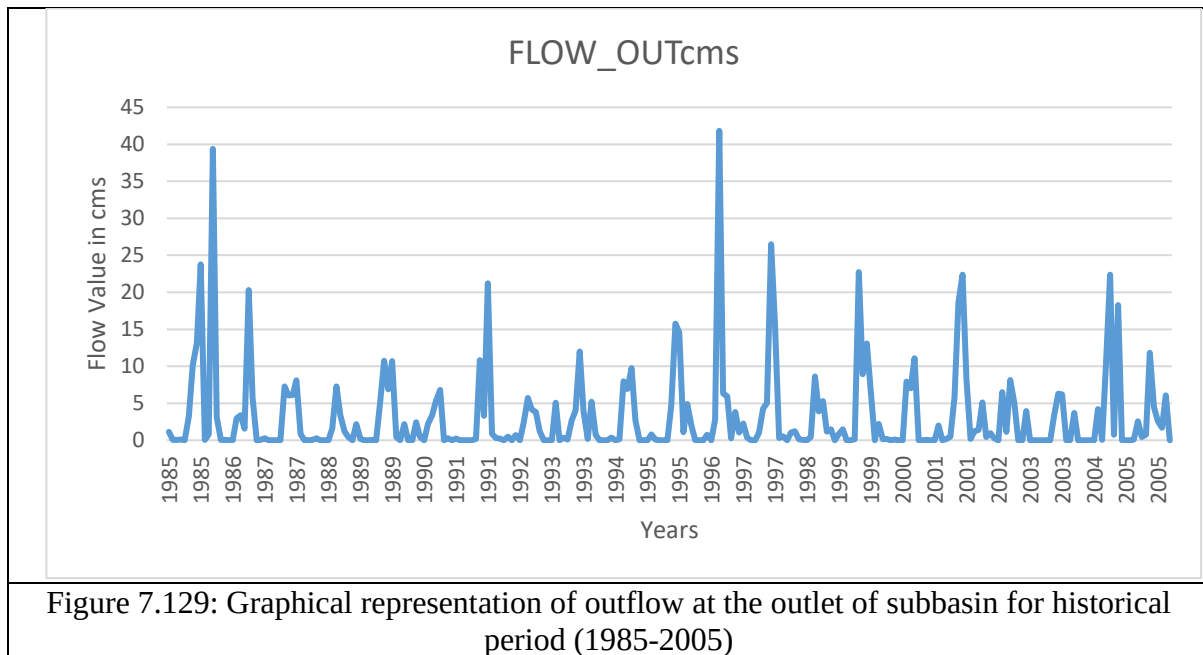


Figure 7.128: Graphical representation of water balance parameters at the outlet of subbasin for historical period (1985-2005)



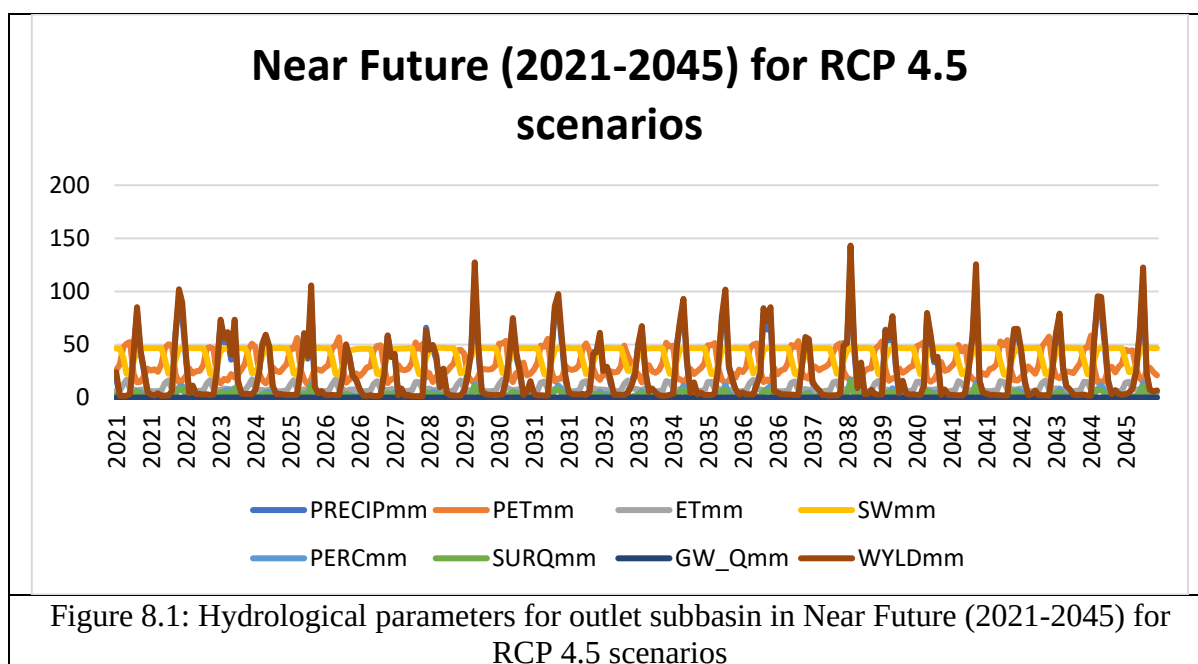
Chapter 8: Climate Change Impact Analysis

8. Hydrological Impact analysis for different climate change scenarios (RCP 4.5 and RCP 8.5)

8.1. Mahi River Basin

• 8.1.1. Bajaj Sagar

All the Water Balance parameters (Figure 8.1 to 8.6) values For the historical period it decreased after the year 1995. For Future RCP4.5 Both Near future and Far future Values are decreased. For Scenario RCP8.5 in the Near future Water Balance Parameters value may increase but far future water balance Values are found to decrease. The discharge near future period will increase in RCP4.5 as compared to RCP8.5. Discharge at the outlet for far future also has the same trend.



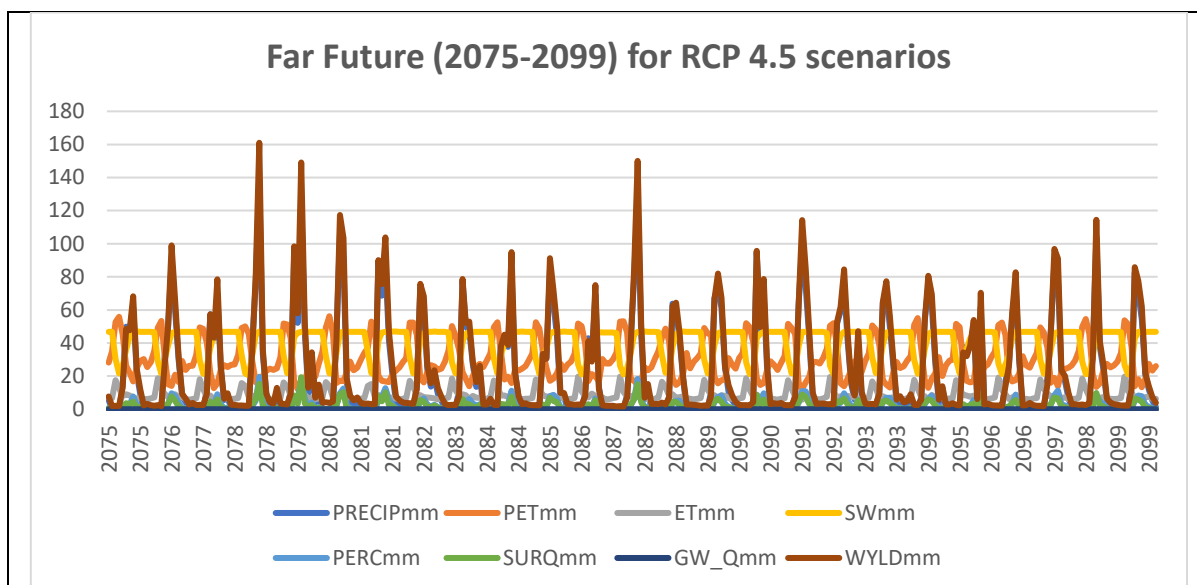


Figure 8.2: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

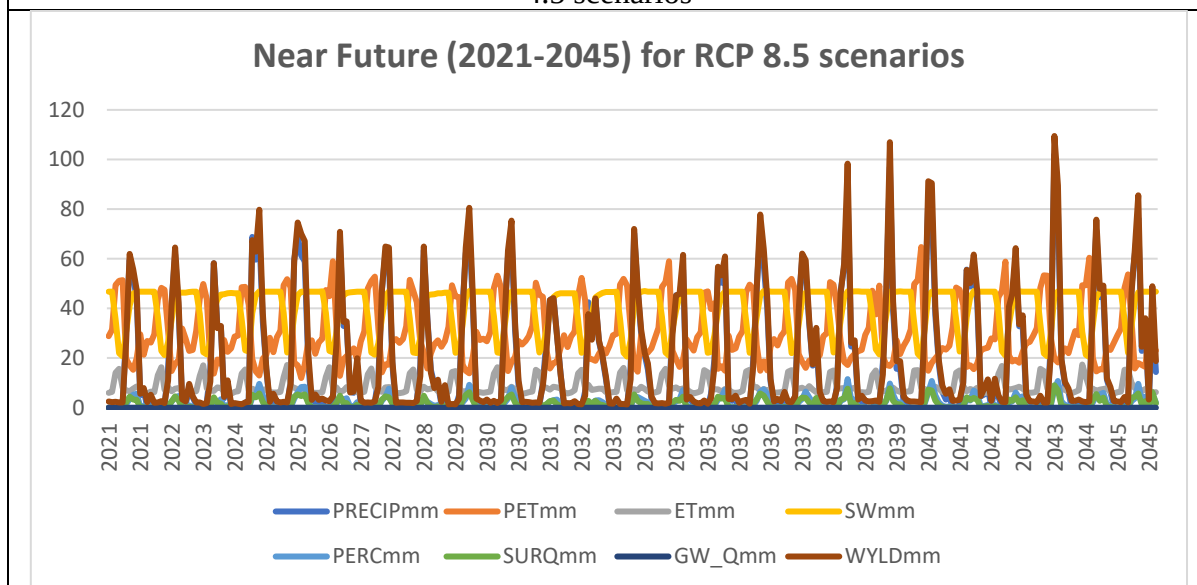


Figure 8.3: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

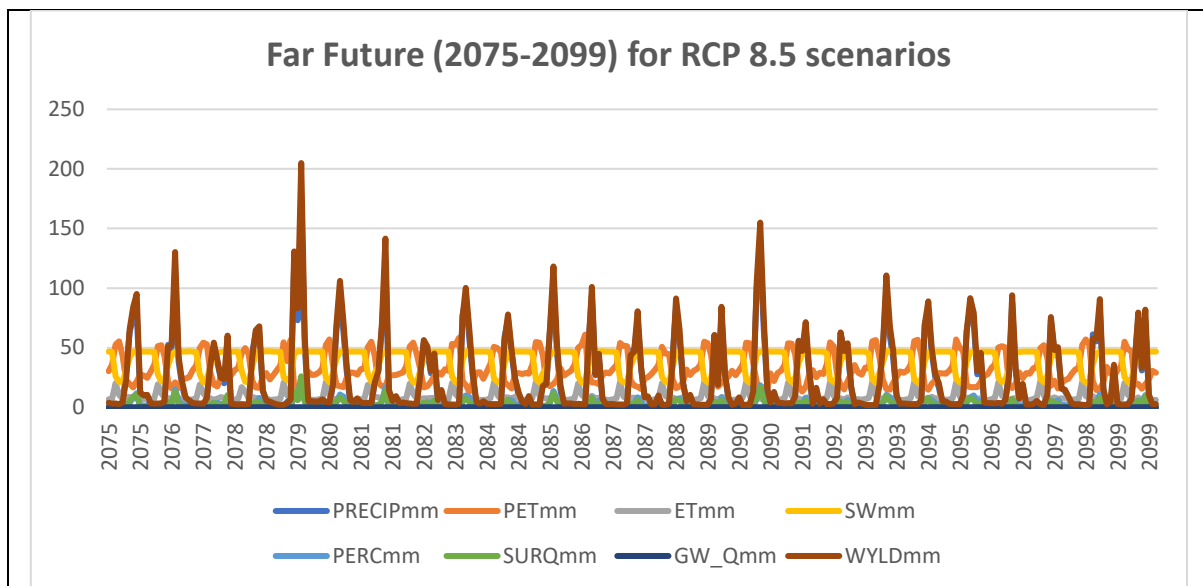


Figure 8.4 : Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

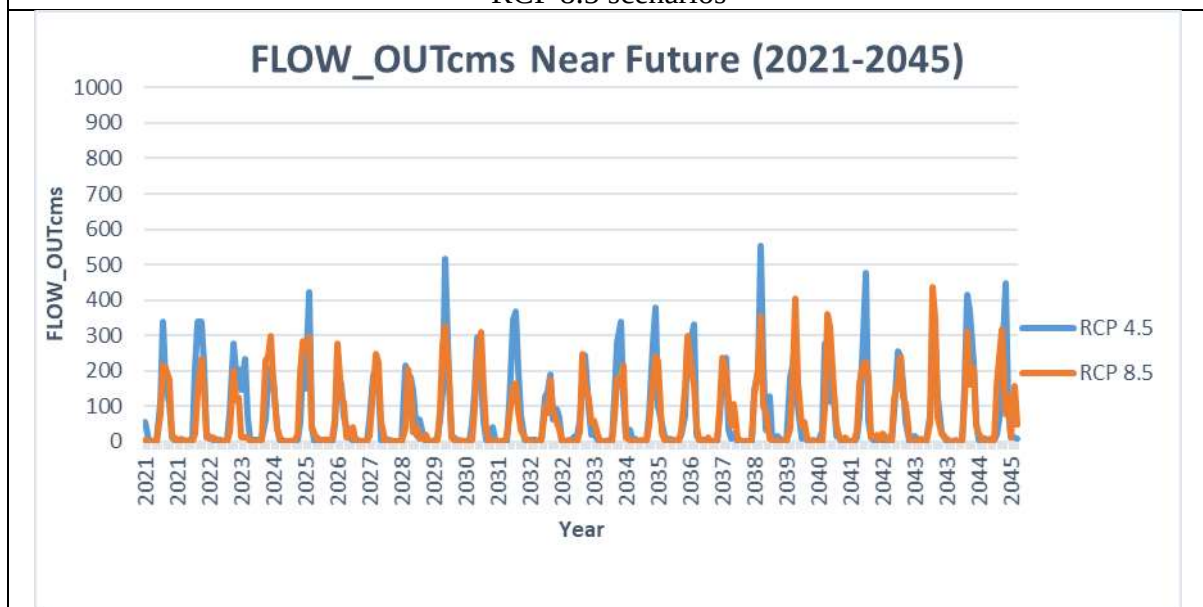


Figure 8.5: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

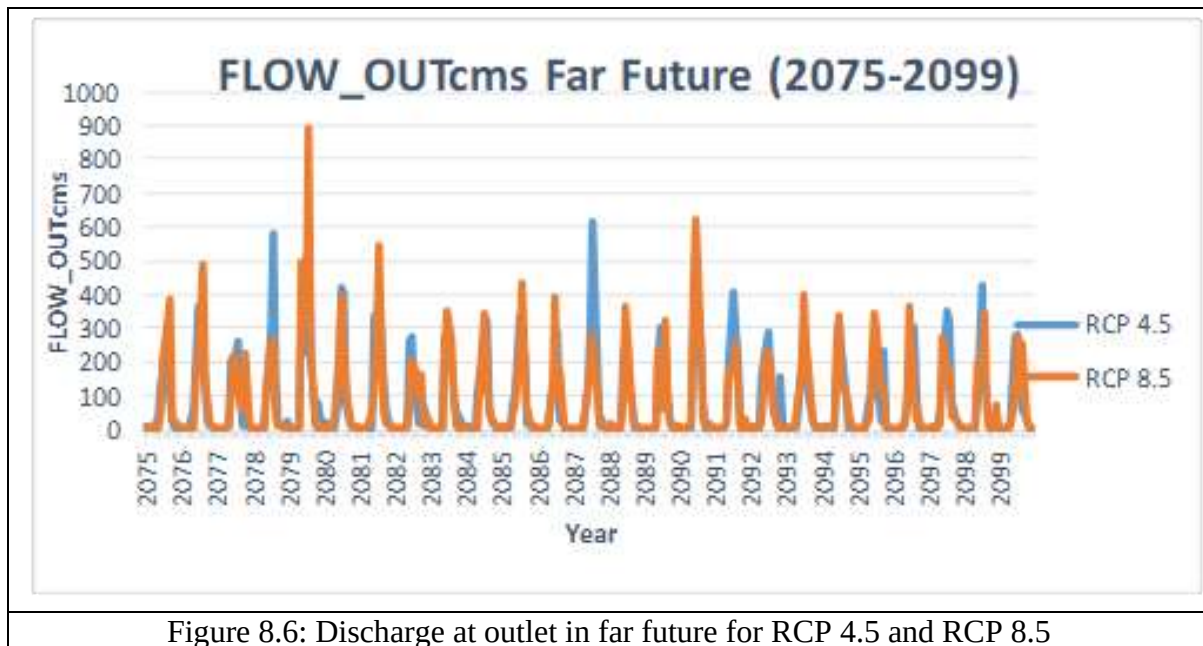


Figure 8.6: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.2 Chakaliya

Water balance parameters values in scenario RCP4.5 have the same trend for both periods (near future and far future) as compared to historical periods (figure 8.7 to 8.12). Water Balance parameters may decrease in the far future as compared to the near future in Scenario RCP8.5. Discharge at the outlet of the sub-basin will increase in RCP4.5 as compared to RCP8.5 in near future. Discharge value at the outlet of sub basin will increase in RCP8.5 as compared to RCP4.5 in the far future.

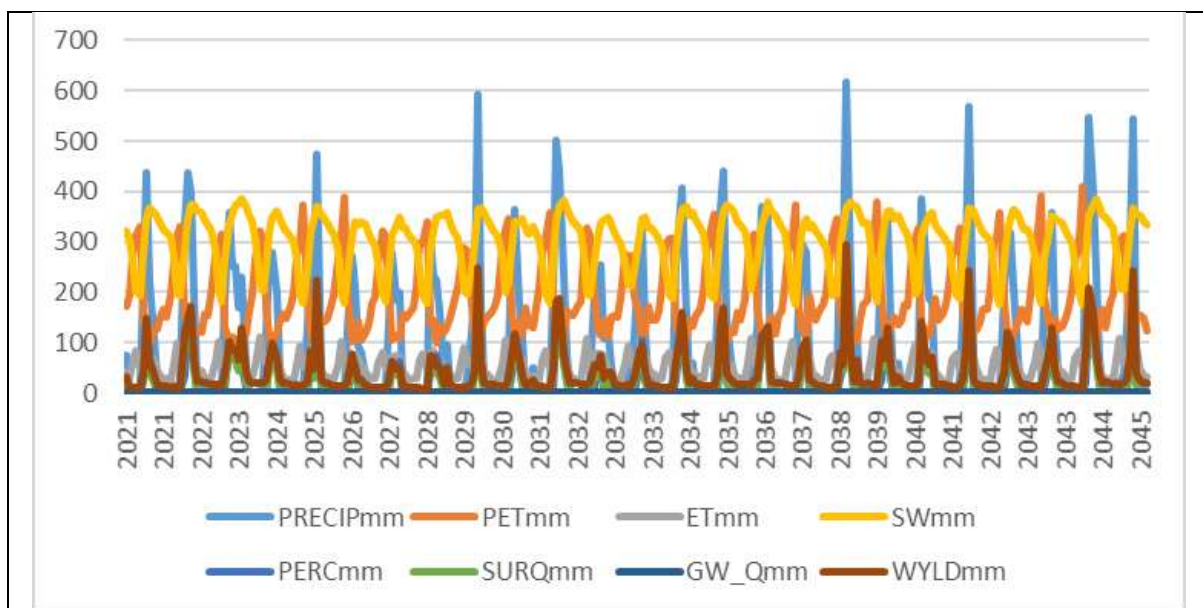


Figure 8.7: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

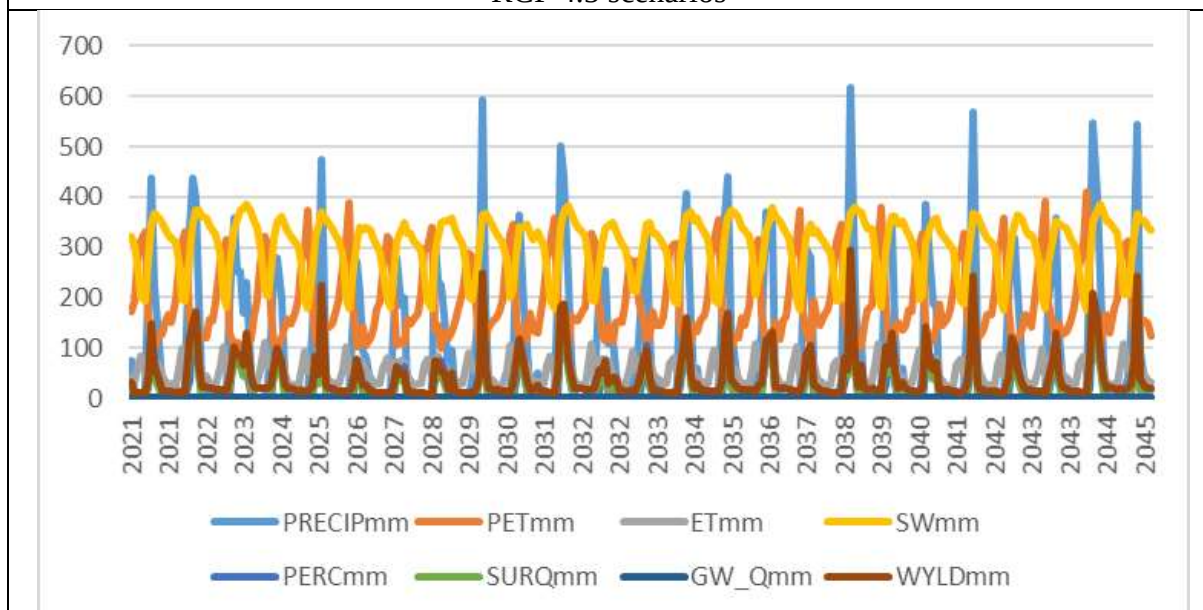


Figure 8.8: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

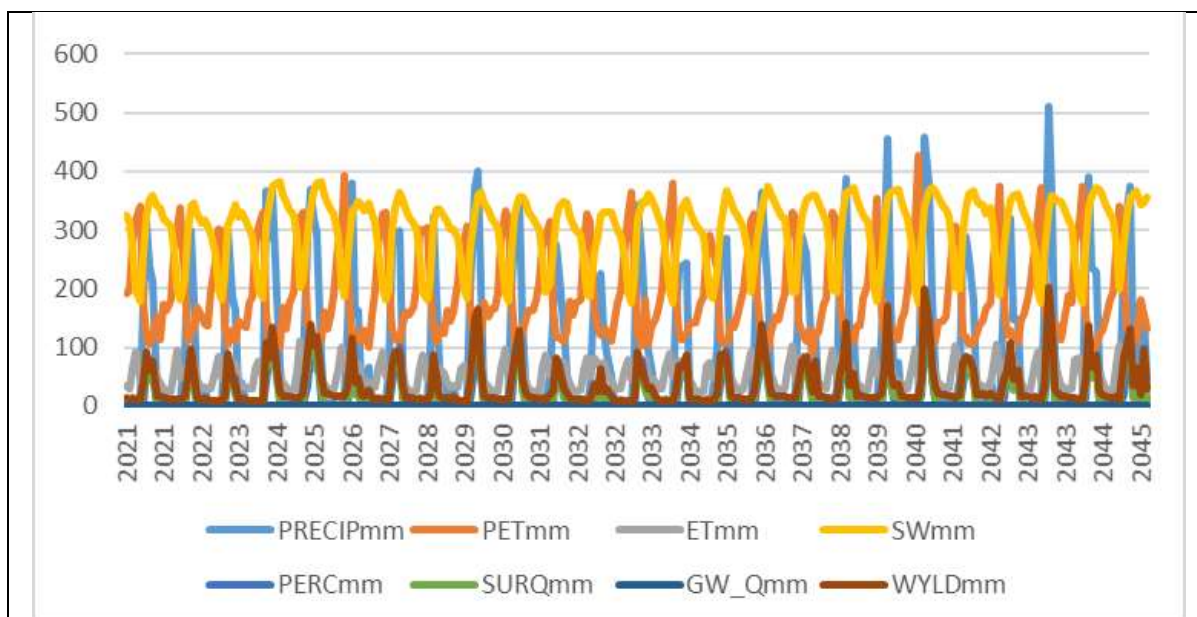


Figure 8.9: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

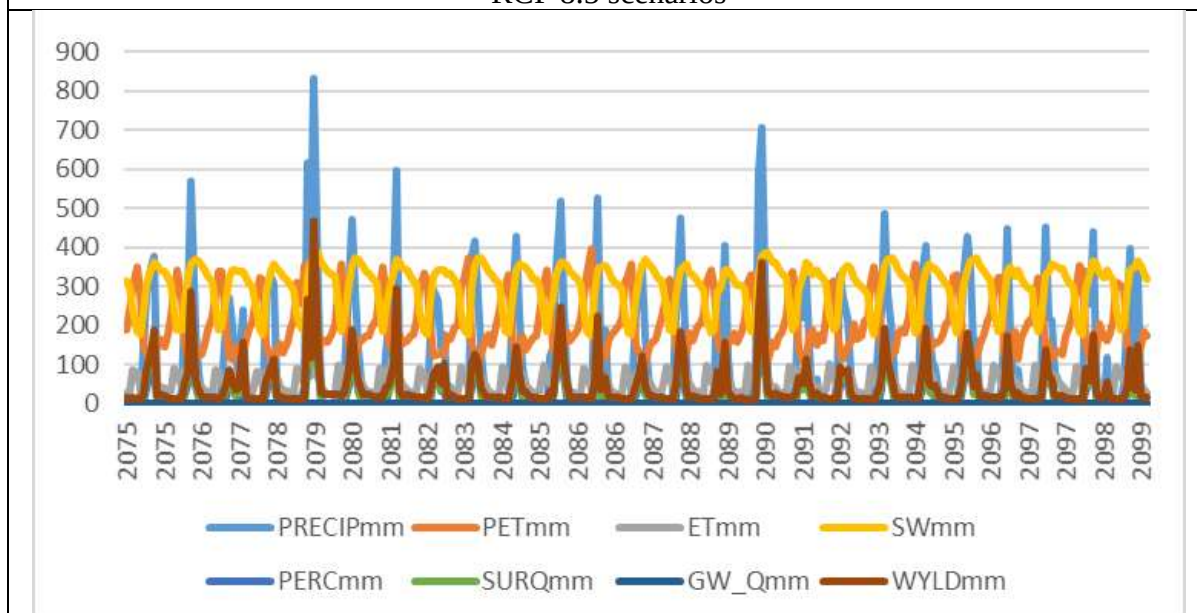


Figure 8.10: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

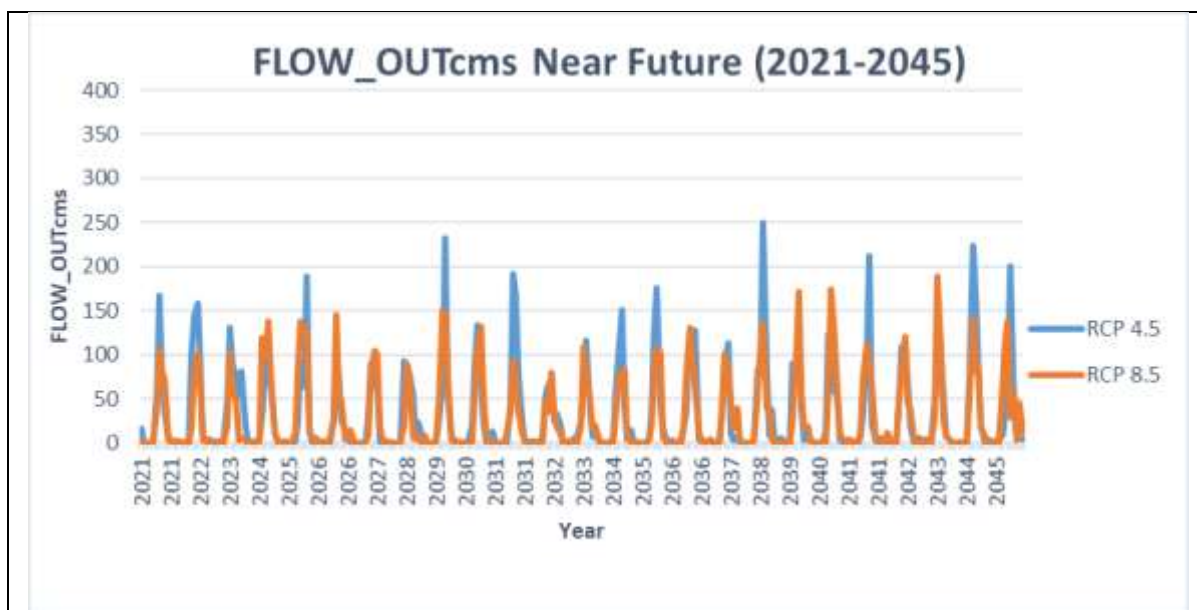


Figure 8.11: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

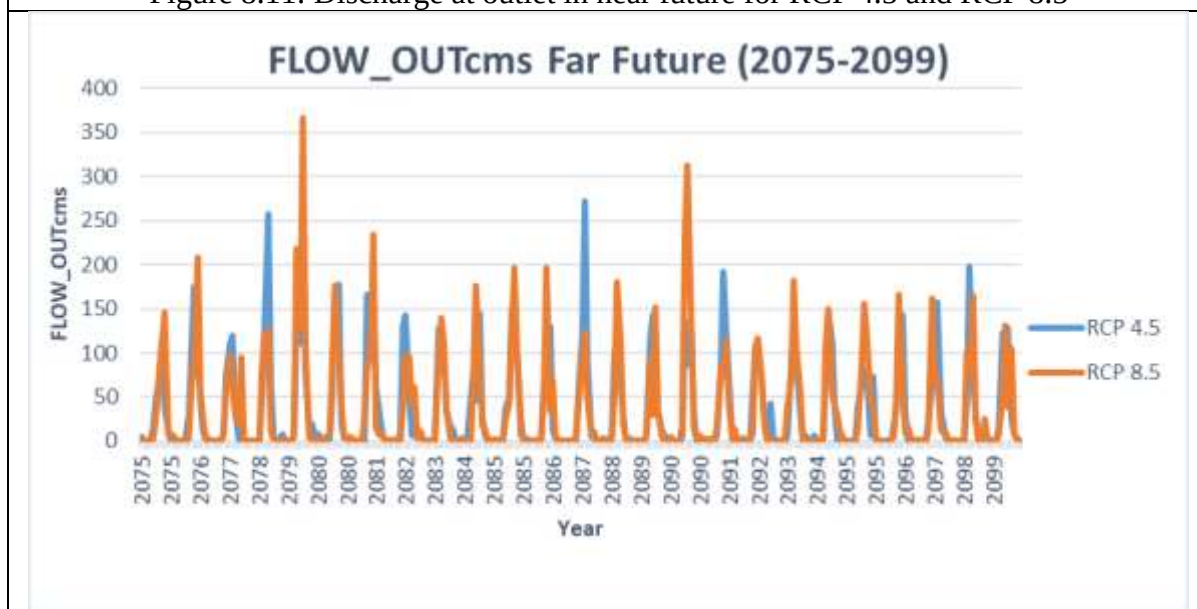


Figure 8.12: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.3 Dhariyabad

Water Balance parameters values for historical period higher as compared to the far-future period in RCP4.5 (Figure 8.13 to 8.18). Water balance parameter values may decrease in the far future in RCP 4.5. Water balance parameters may decrease in the far future as compared to the near future period in both scenarios RCP 4.5 and RCP8.5. ET value is expected to increase in both scenarios RCP 4.5 and RCP 8.5. Discharge is expected to decrease in the near & far future for both RCPs. Discharge is expected to decrease more in RCP8.5 as compared to RCP4.5.

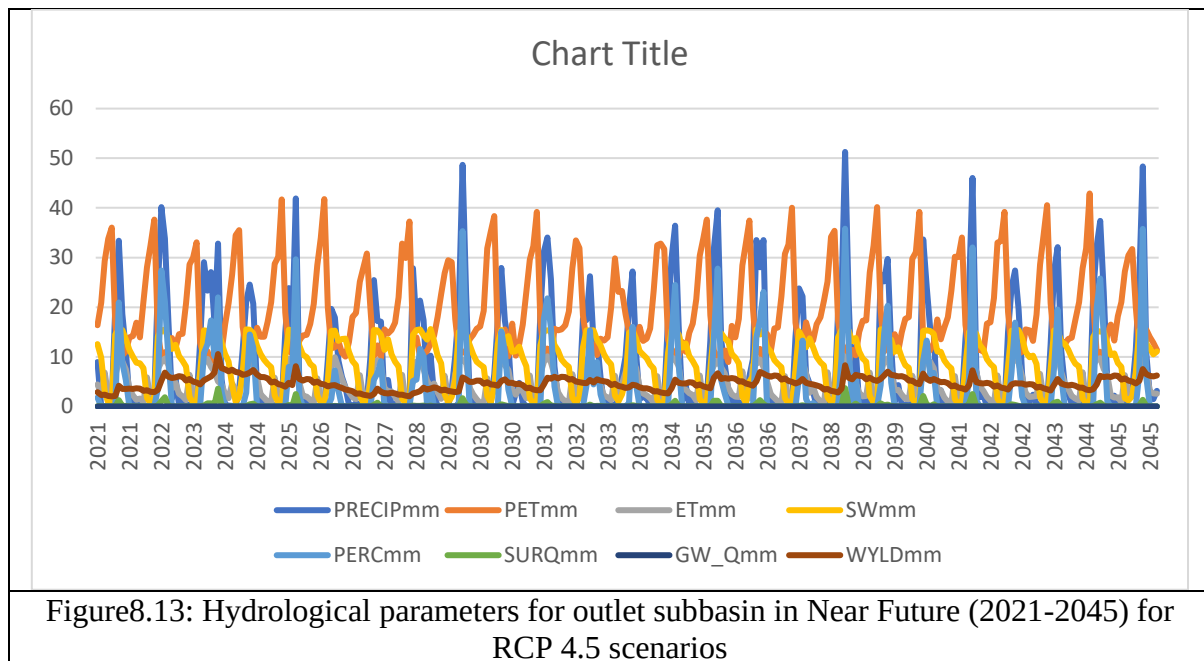


Figure8.13: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

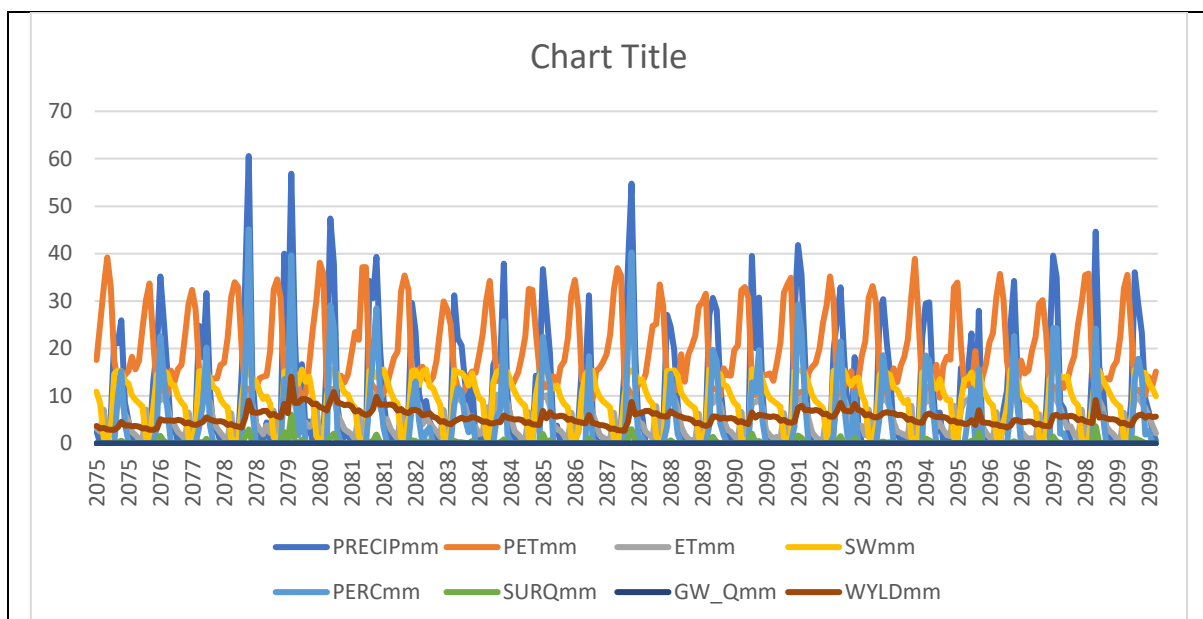


Figure 8.14: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

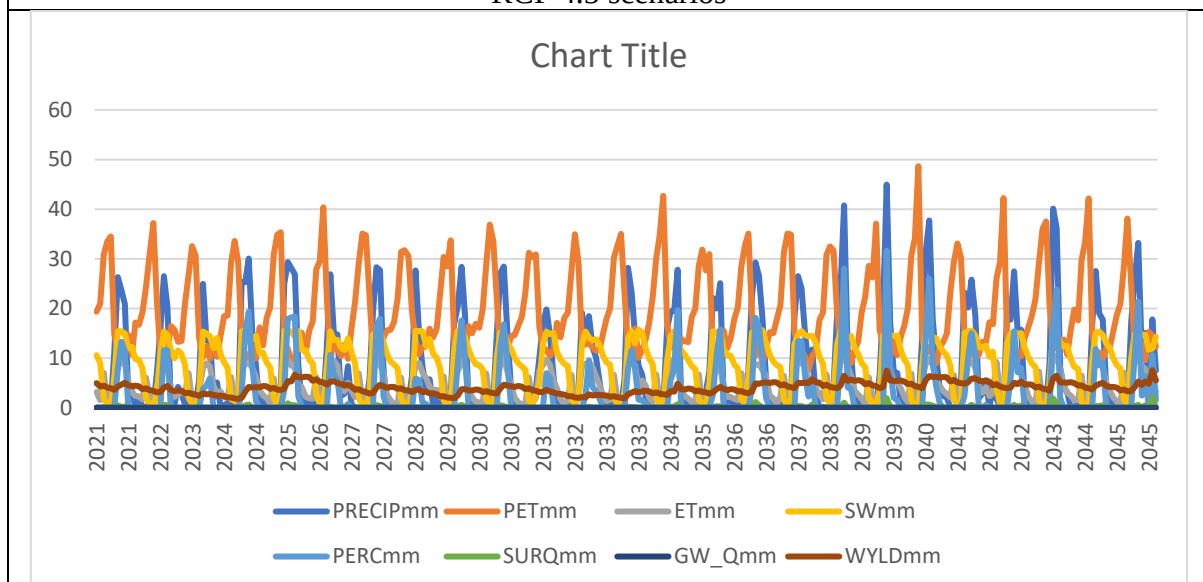


Figure 8.15: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

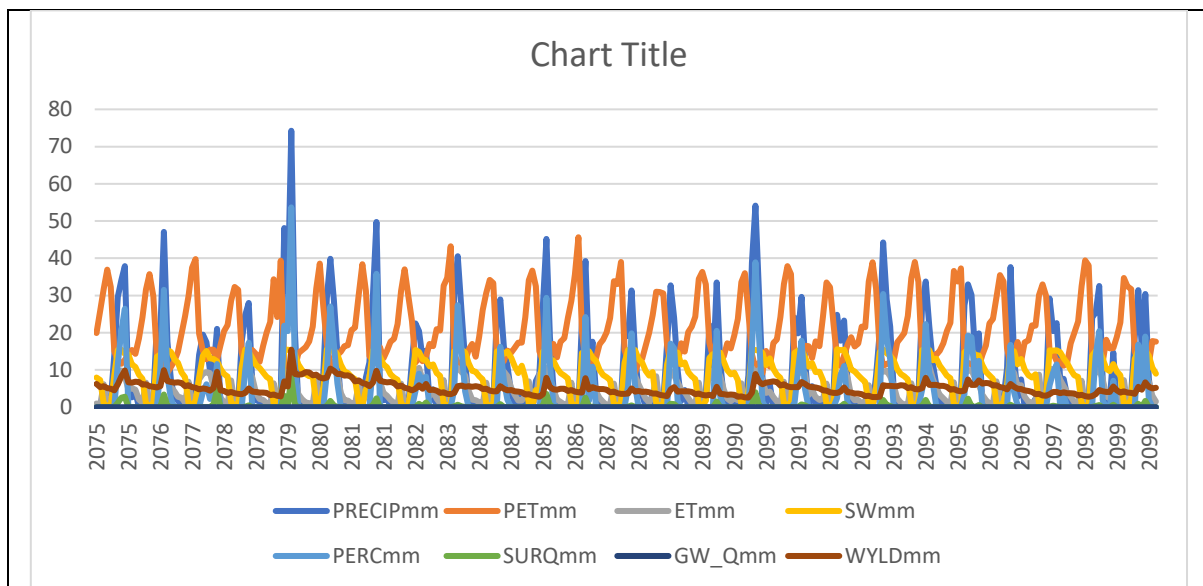


Figure 8.16: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

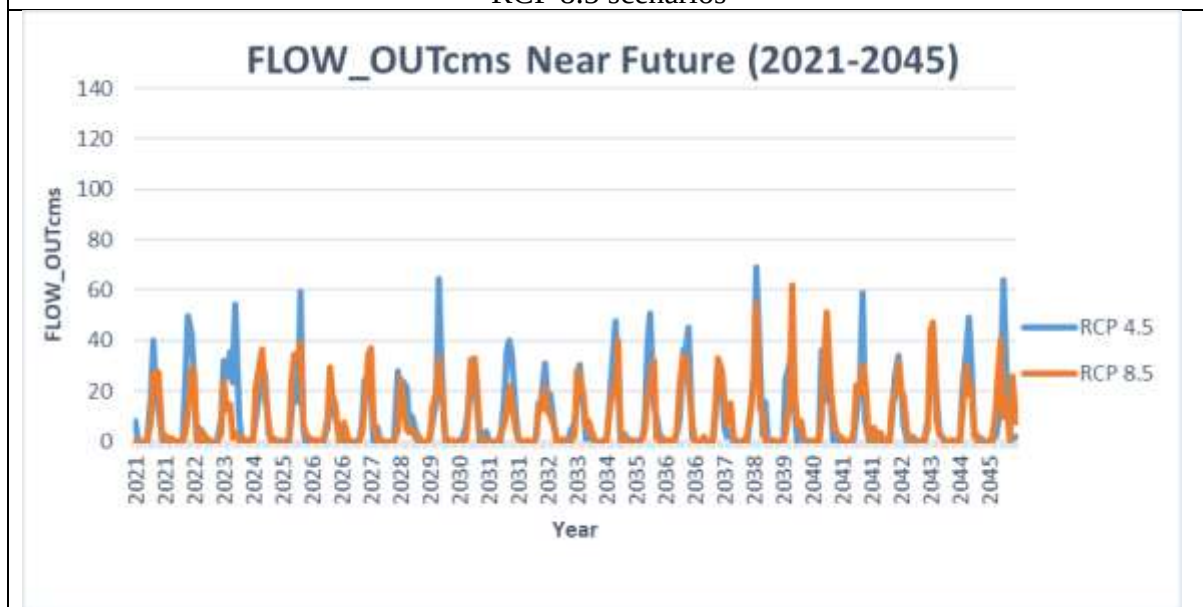


Figure 8.17 : Discharge at outlet in near future for RCP 4.5 and RCP 8.5

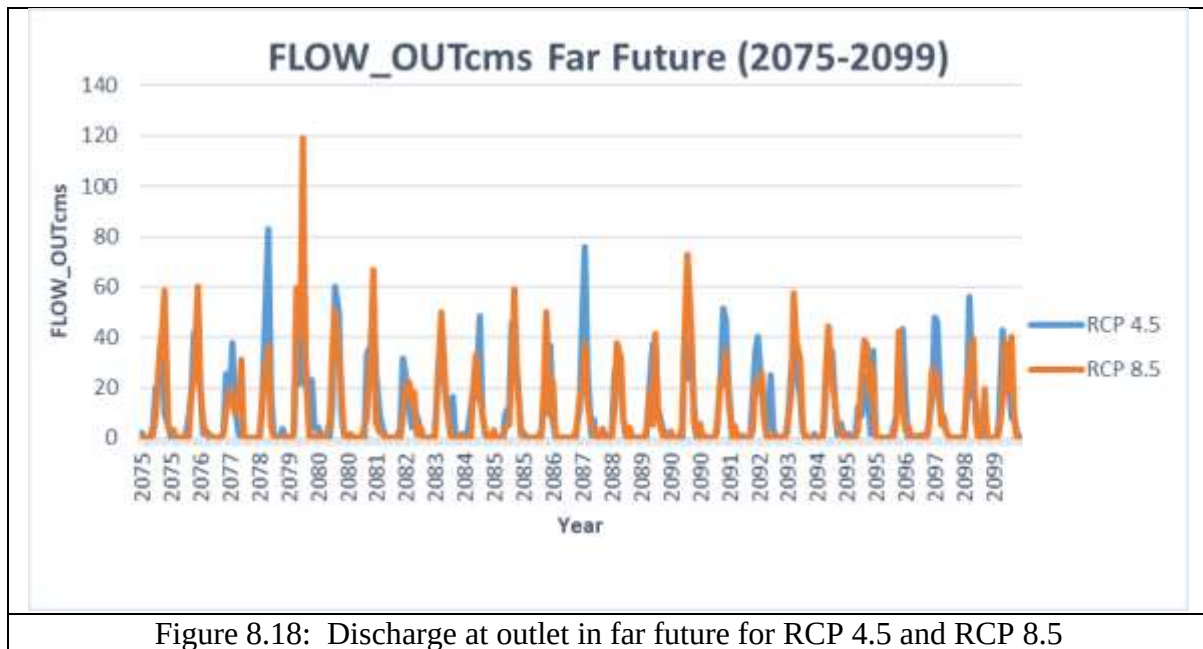


Figure 8.18: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.4 Kadana

Water balance parameters values for scenario RCP4.5 may decrease as compared to the historical period (Figure 8.19 to 8.24). Water balance parameters values in the far future period may decrease as compared to the near future period in scenario 8.5. Discharge value at the outlet of the sub basin will increase in the near future as compared to the Far future in RCP4.5. Discharge value at sub basin outlet may decrease in scenario RCP8.5.

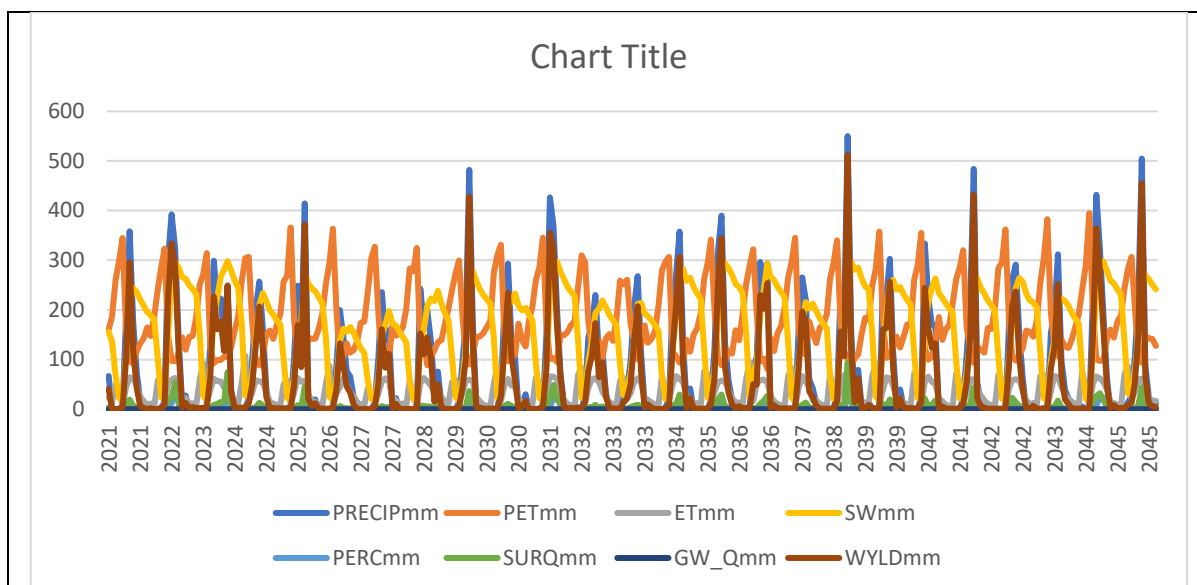


Figure 8.19: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

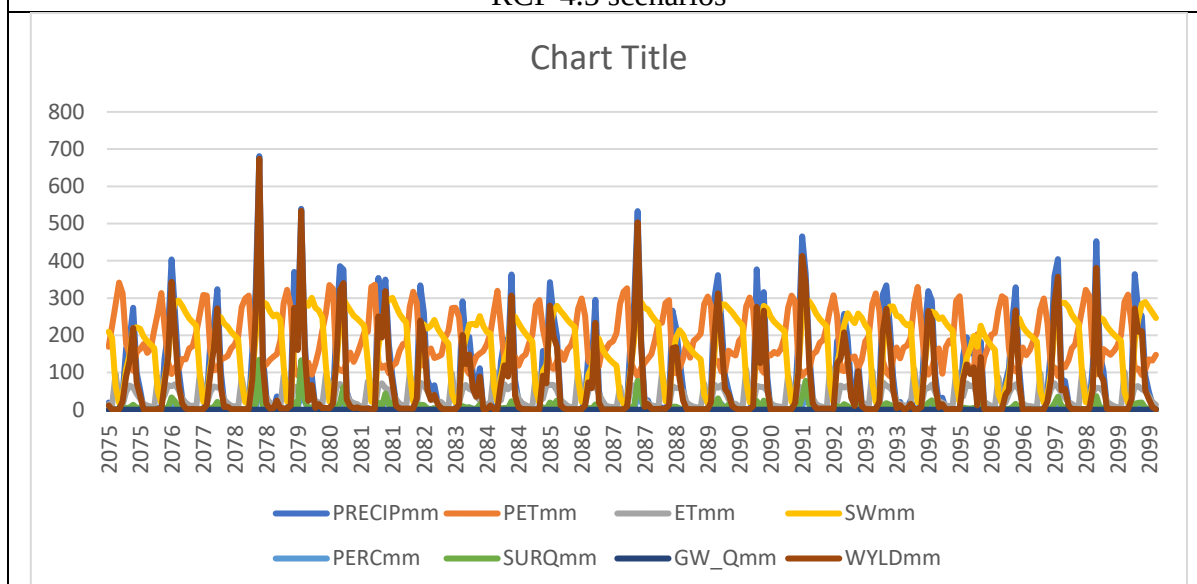
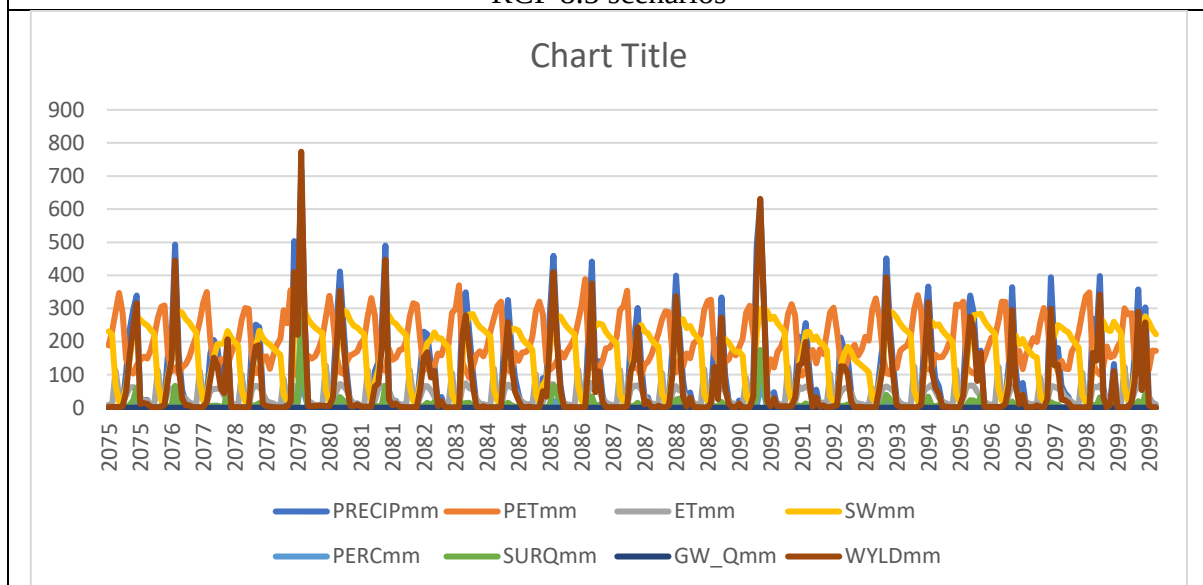
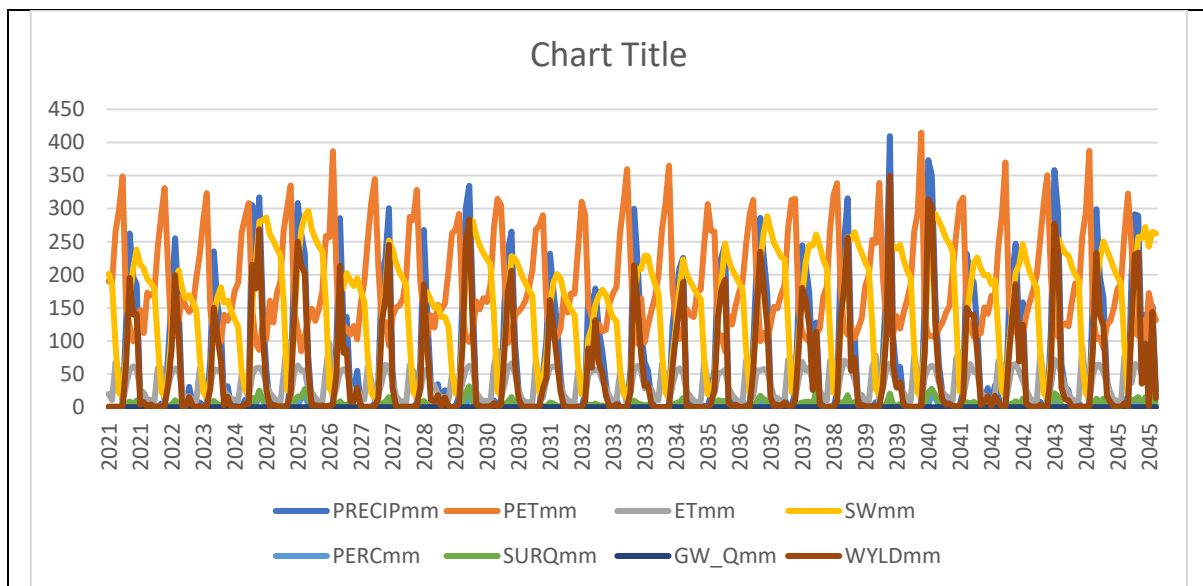


Figure 8.20: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios



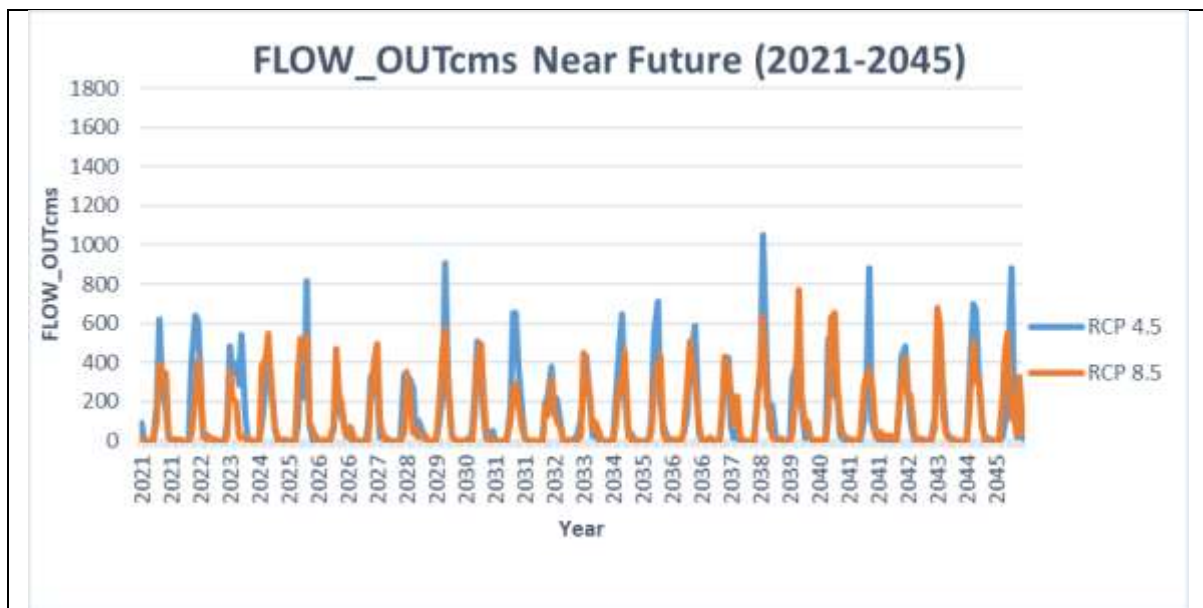


Figure 8.23: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

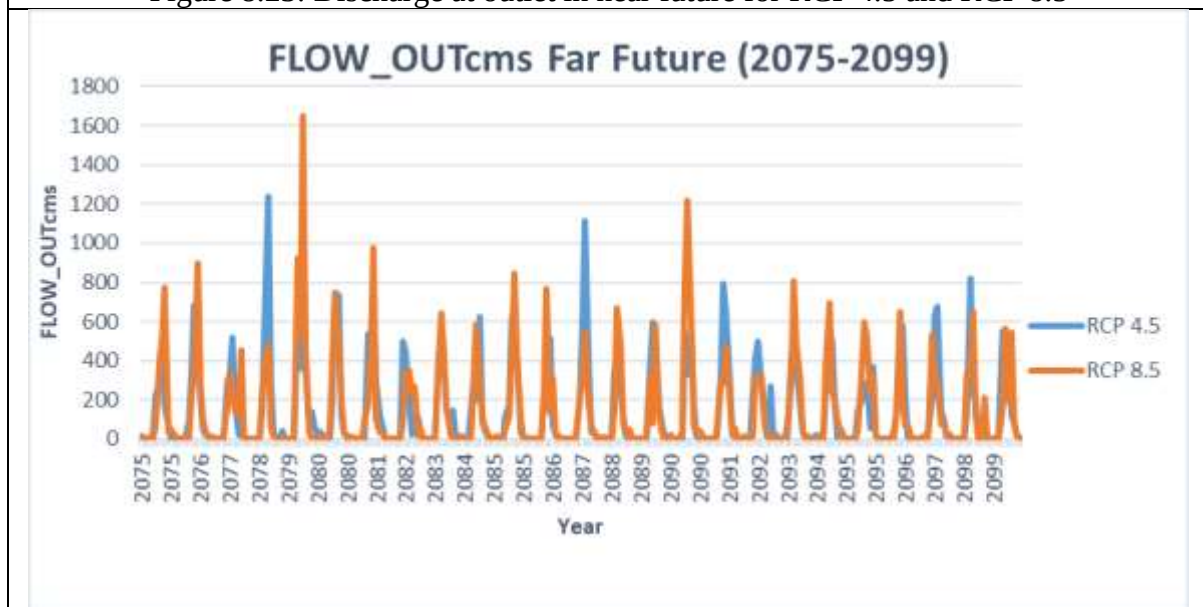


Figure 8.24: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.5 Mataji

Water balance parameters at the outlet of Mataji sub-basin decreased after 1995 in historical periods (Figure 8.25 to 8.30). Water balance parameters values may decrease in the far future as compared to near future RCP 4.5. Water balance parameters value may decrease in the far future as compared to the near future in RCP8.5 scenario. Discharge at the outlet of the sub-basin has decreased in historical periods. Discharge at the outlet of the sub-basin will increase in the RCP4.5 scenario in Near Future. Discharge at the outlet of the sub-basin will decrease in RCP8.5 scenario in the Far Future.

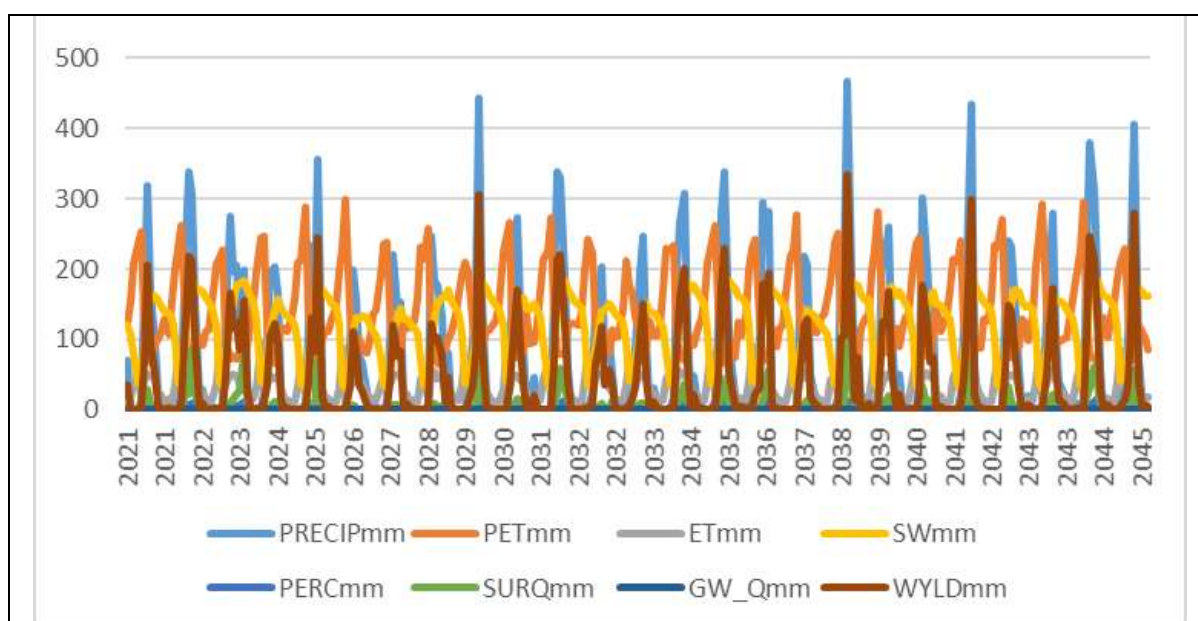


Figure 8.25: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

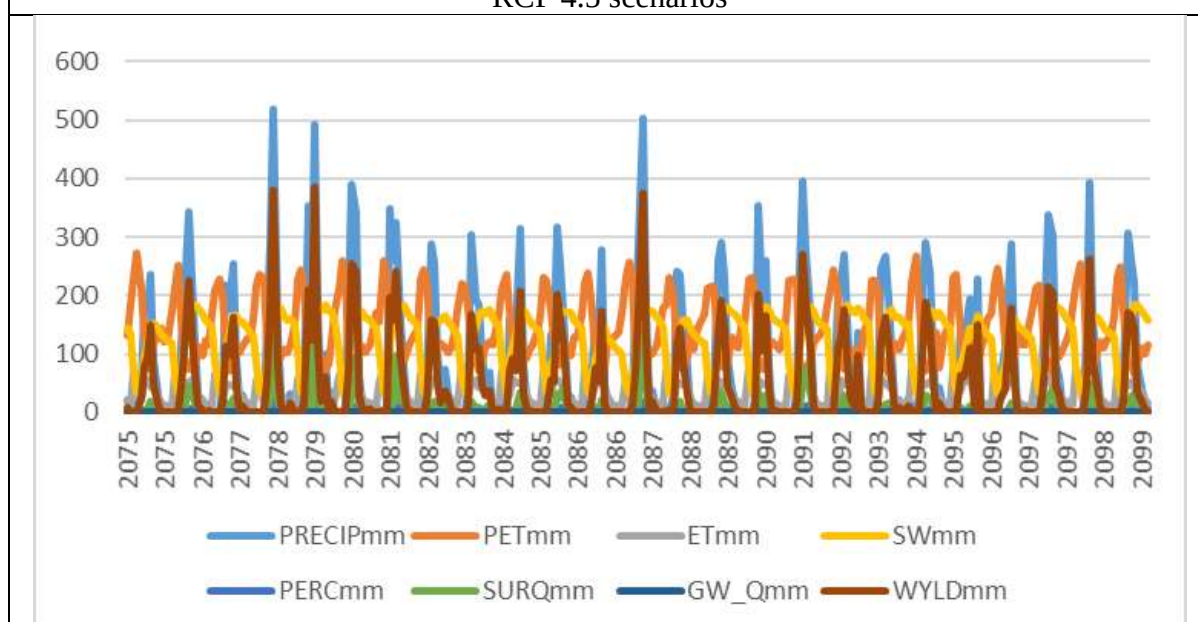


Figure 8.26: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

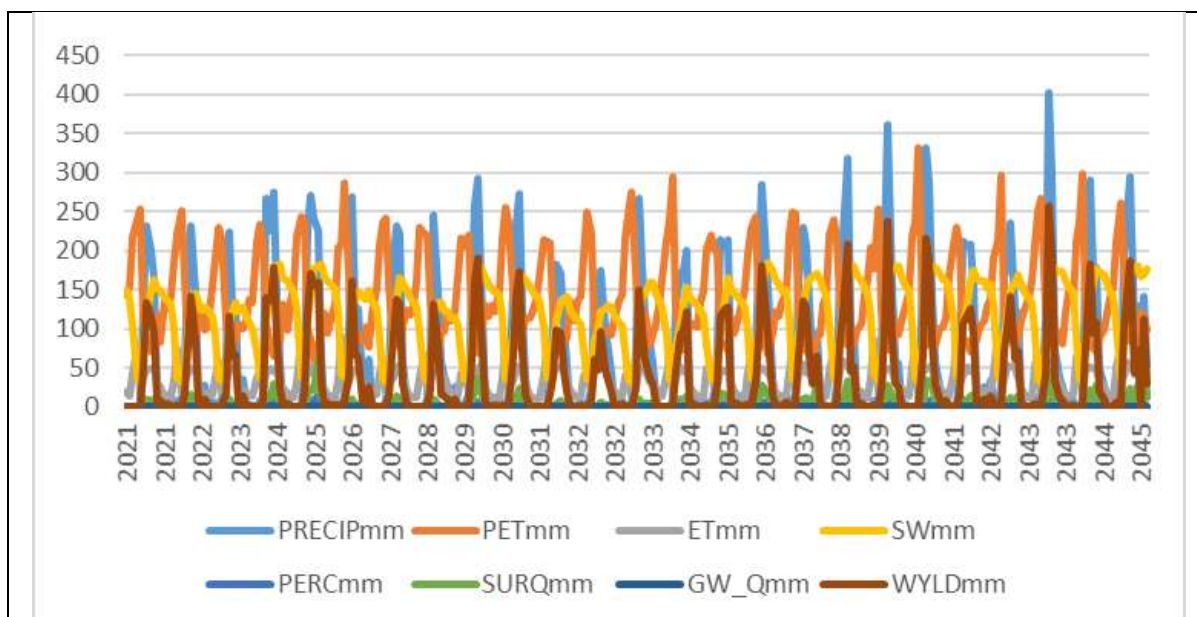


Figure 8.27: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

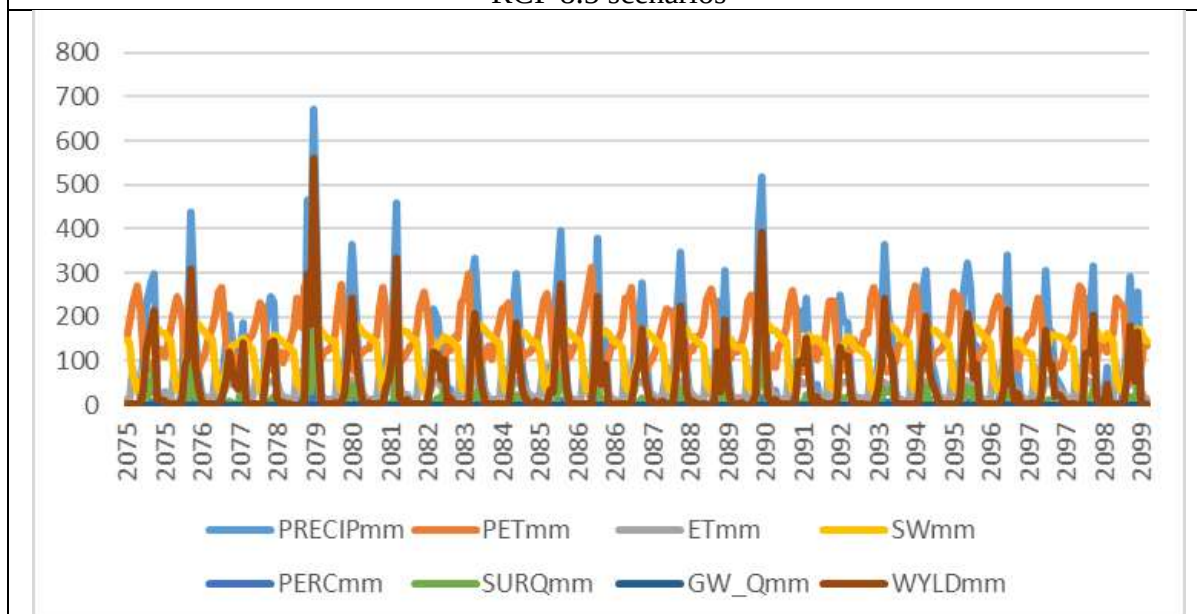


Figure 8.28: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

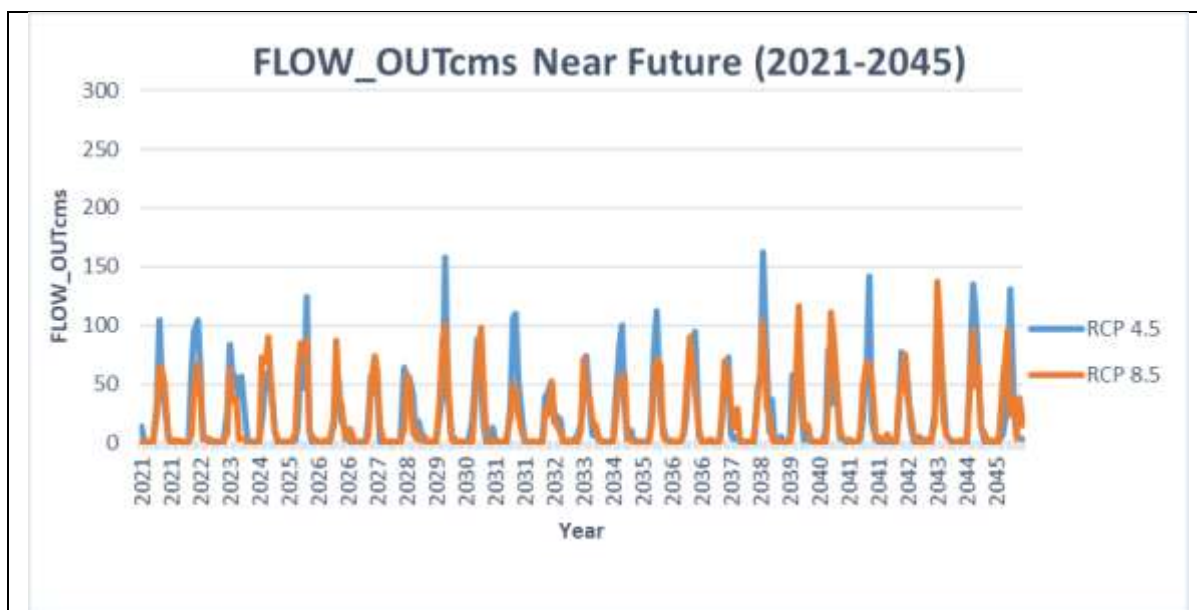


Figure 8.29: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

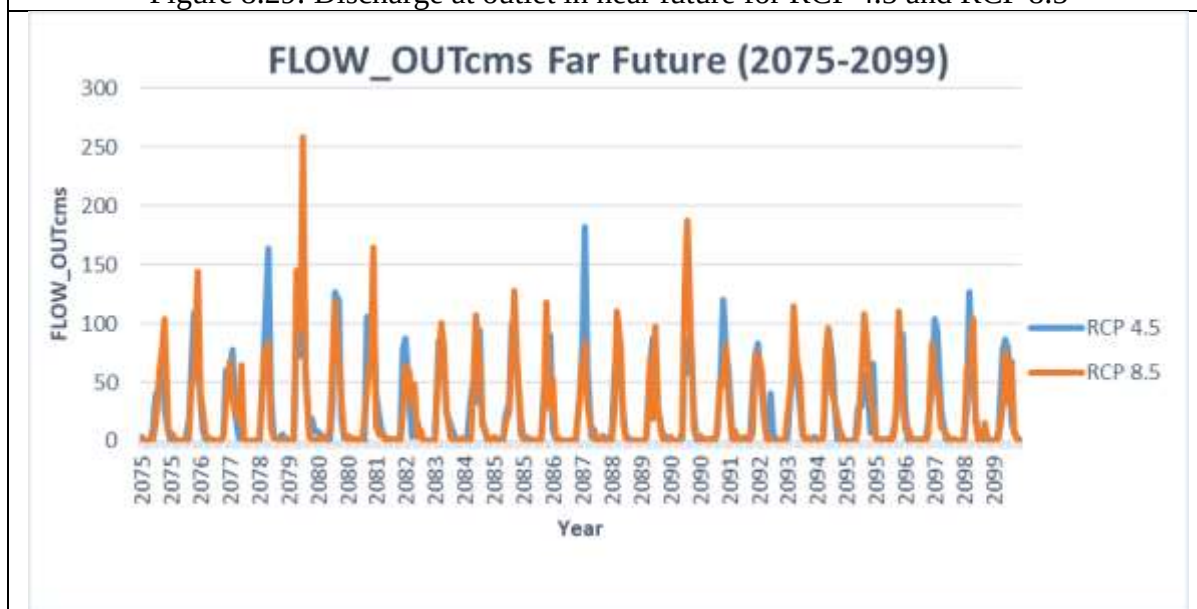


Figure 8.30: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.6 Paderdibadi

Water balance parameters may decrease in the near future period as compared to the far future period in Scenario RCP4.5. Water balance parameters value may decrease in the near future period as compared to the far future period in Scenario RCP8.5. Discharge value at the outlet of sub-basin may increase in scenario RCP4.5as compared to RCP8.5 in near future. Discharge value may increase in RCP8.5 as compared to RCP4.5 in the far future.

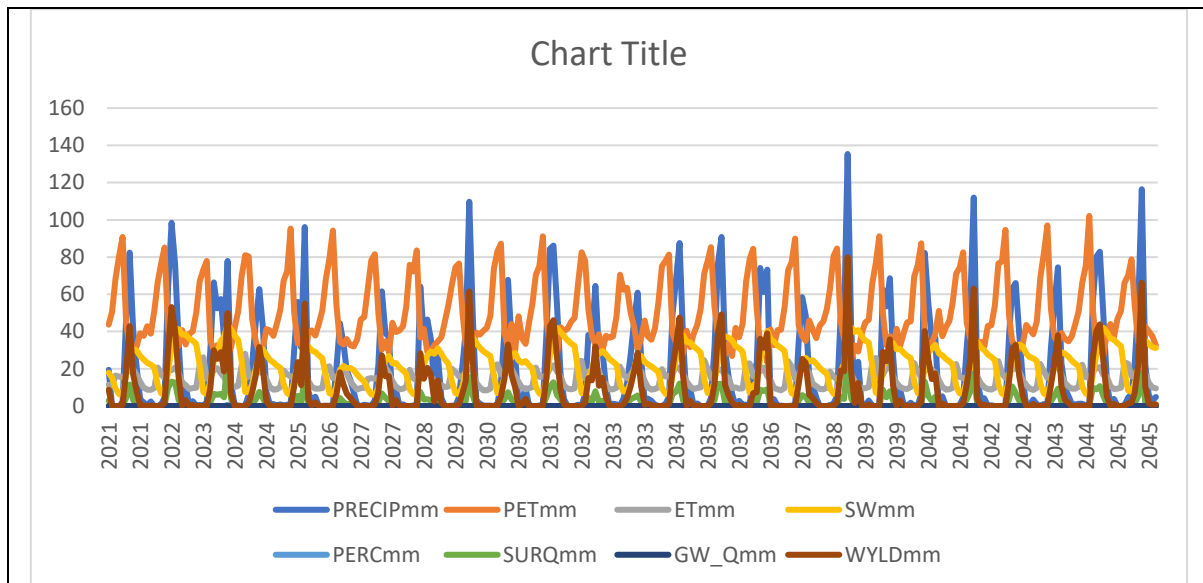


Figure8.30 Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

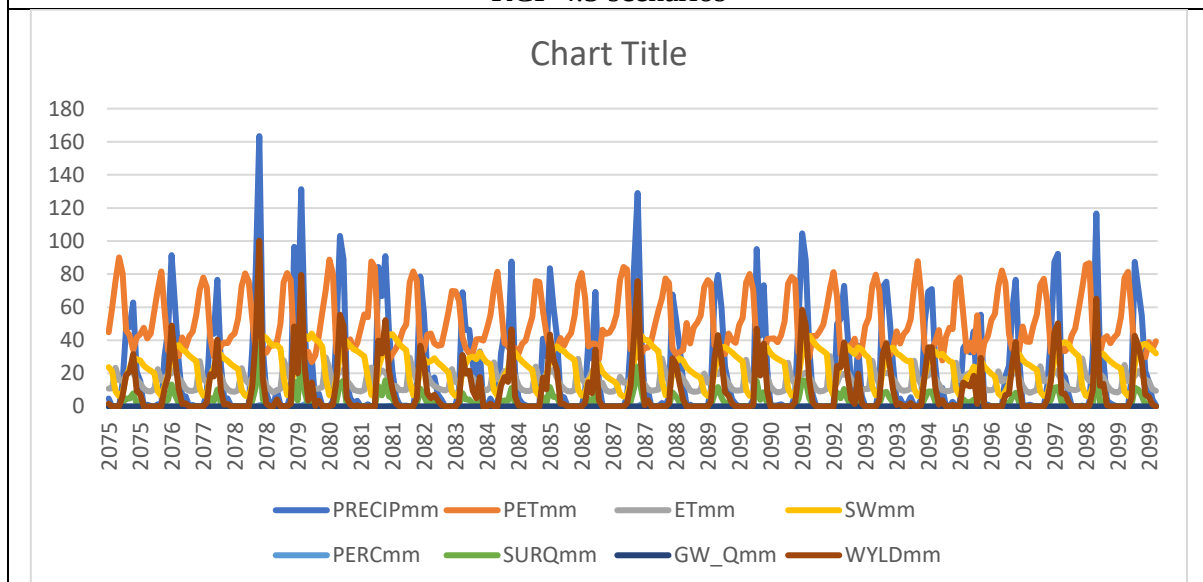


Figure 8.31: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

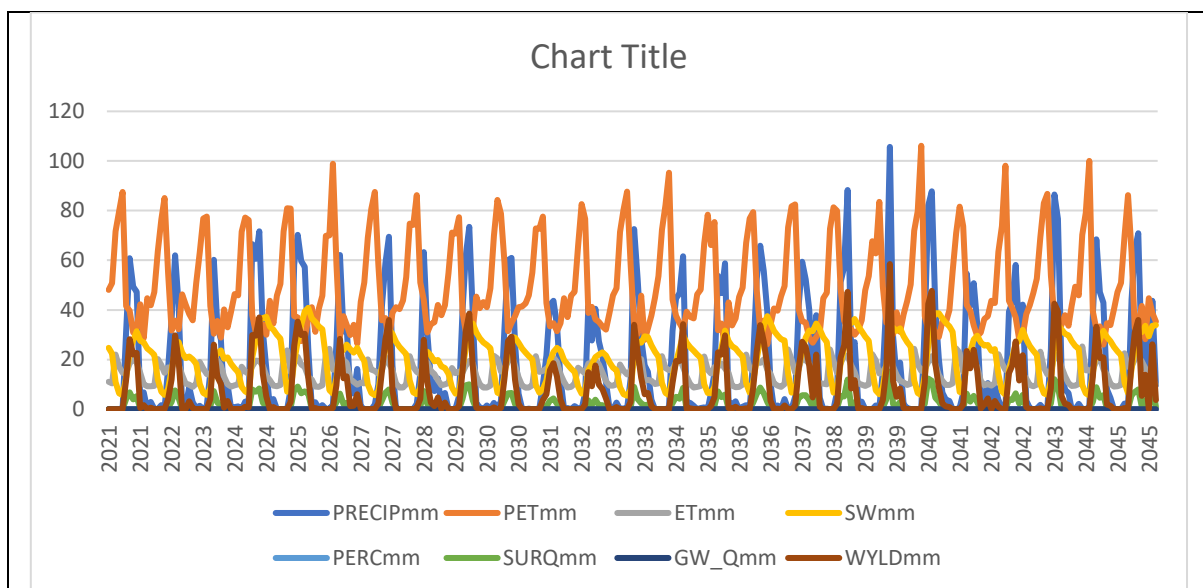


Figure 8.32: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

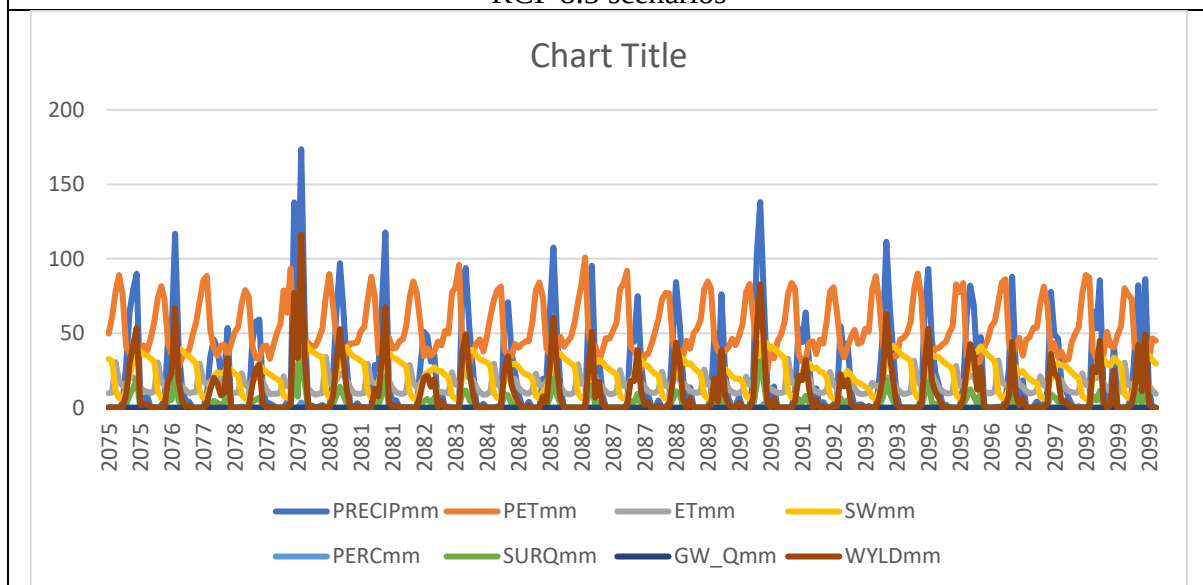


Figure 8.33: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

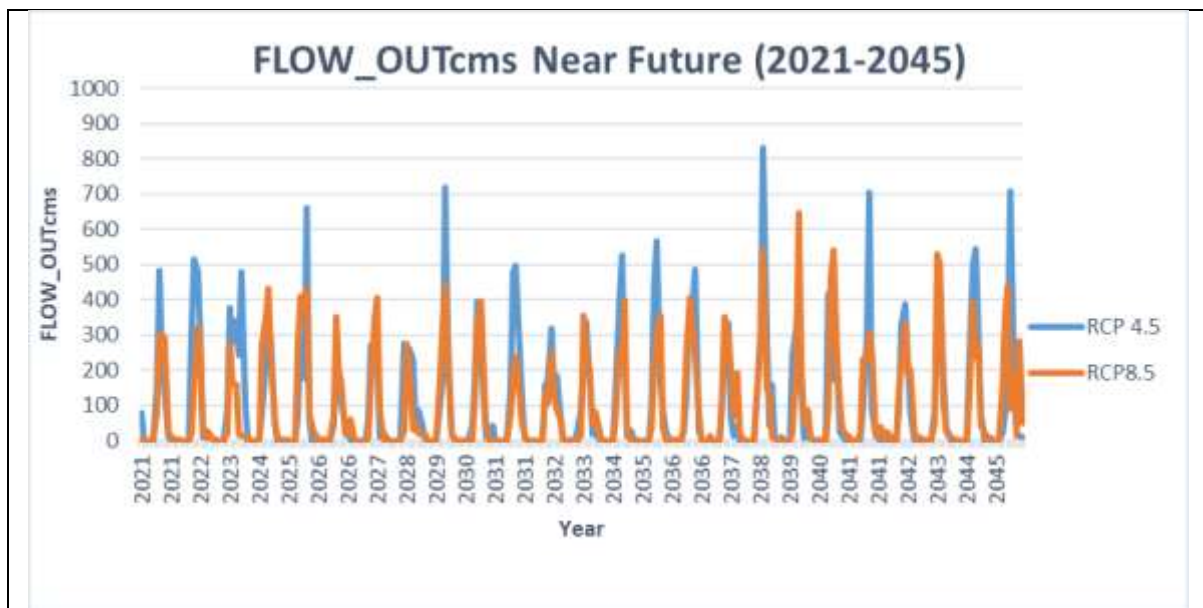


Figure 8.34: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

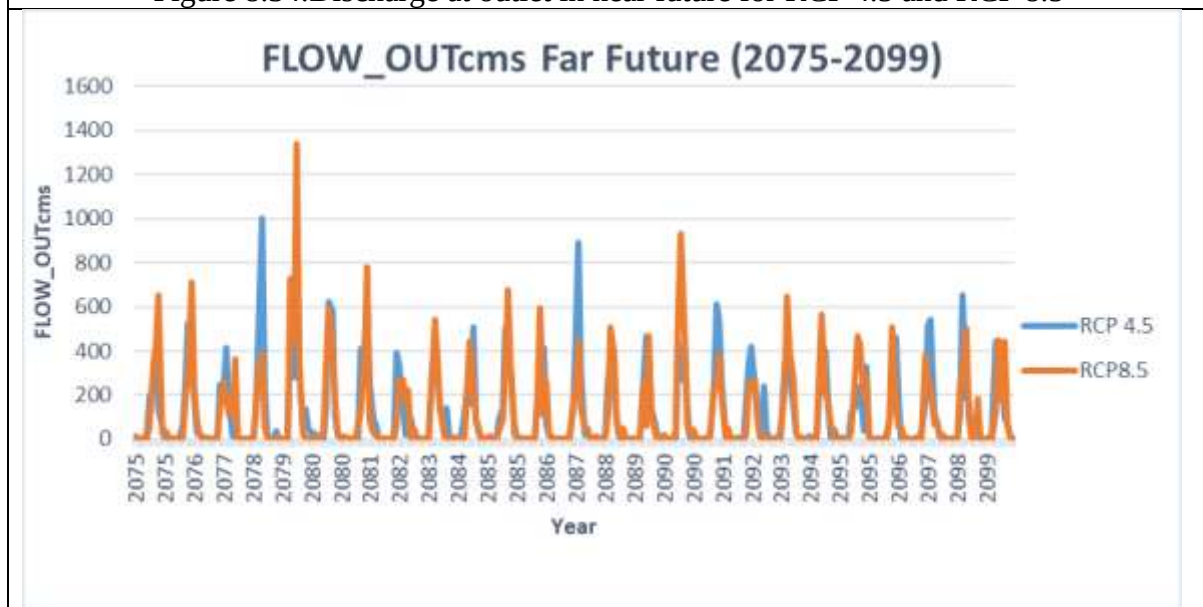


Figure 8.35: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.7 Panam observation site

Future projected runoff and remaining water balance parameters may increase in the near future as compared to the far future period in RCP4.5. Water balance parameters value may decrease in the far future as compared to the near future in RCP 8.5. Discharge value at the outlet of sub-basin may increase in RCP4.5 as compared to RCP 8.5 in near future. Discharge value at the outlet of sub-basin decreases in RCP 4.5 as compared to RCP 8.5 in the far future.

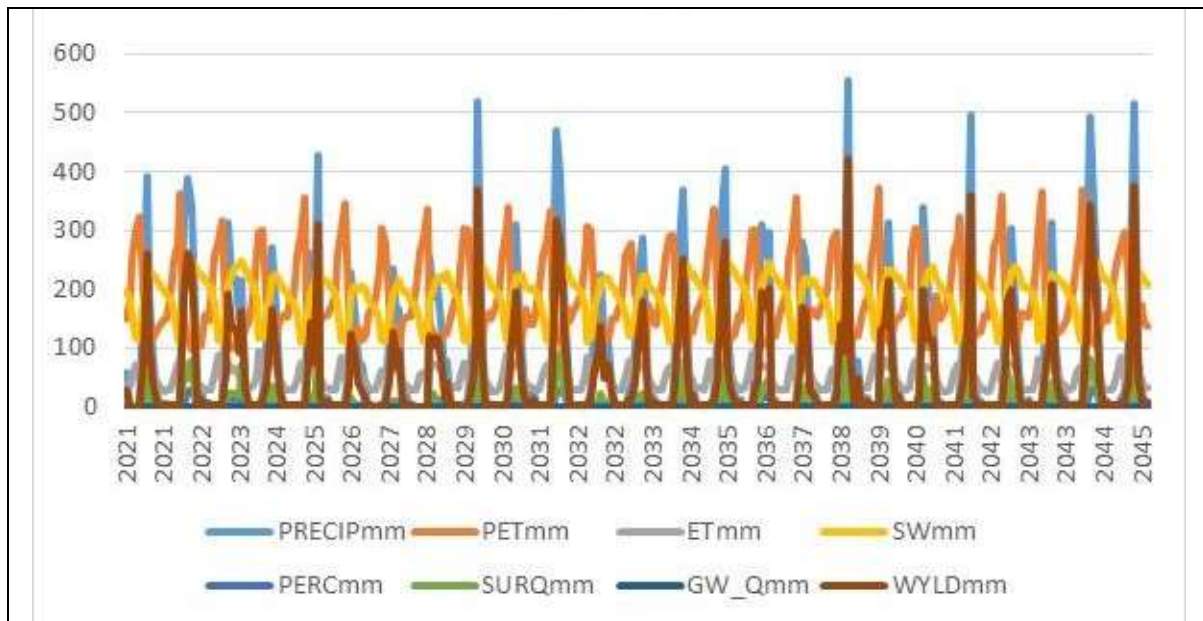


Figure 8.36: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

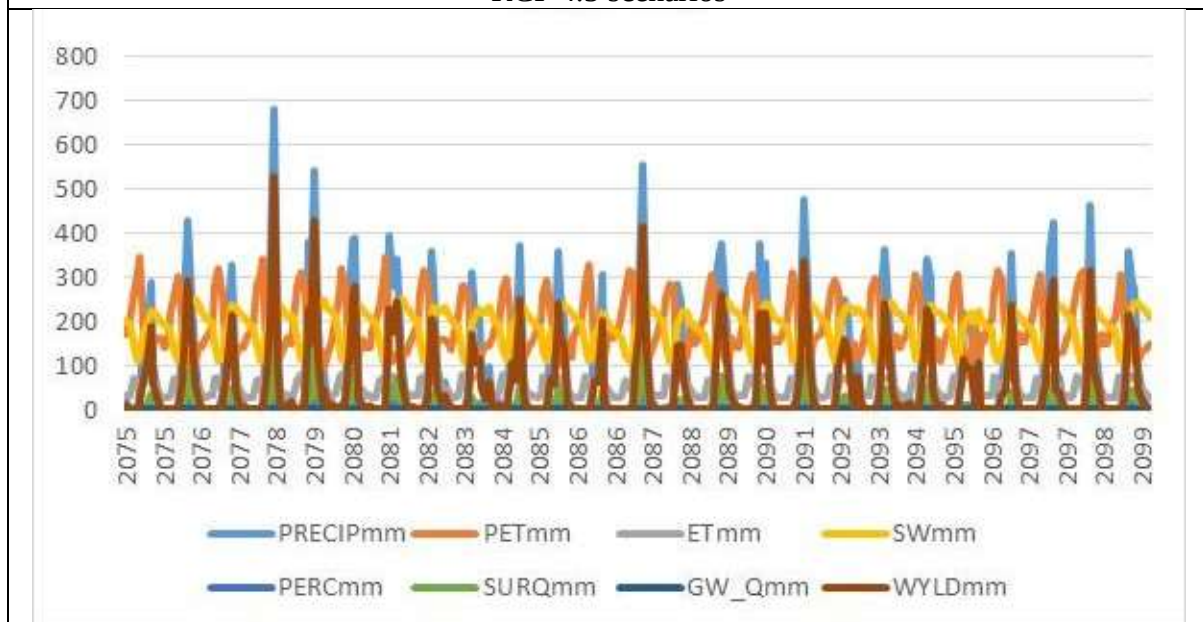


Figure 8.37: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

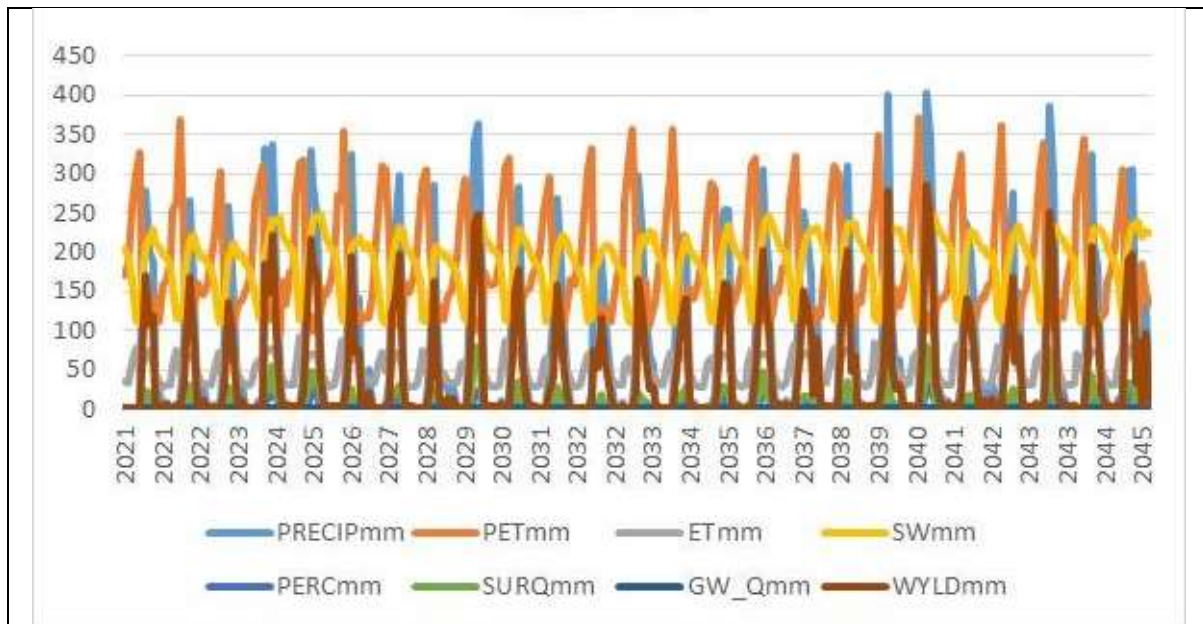


Figure 8.38: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

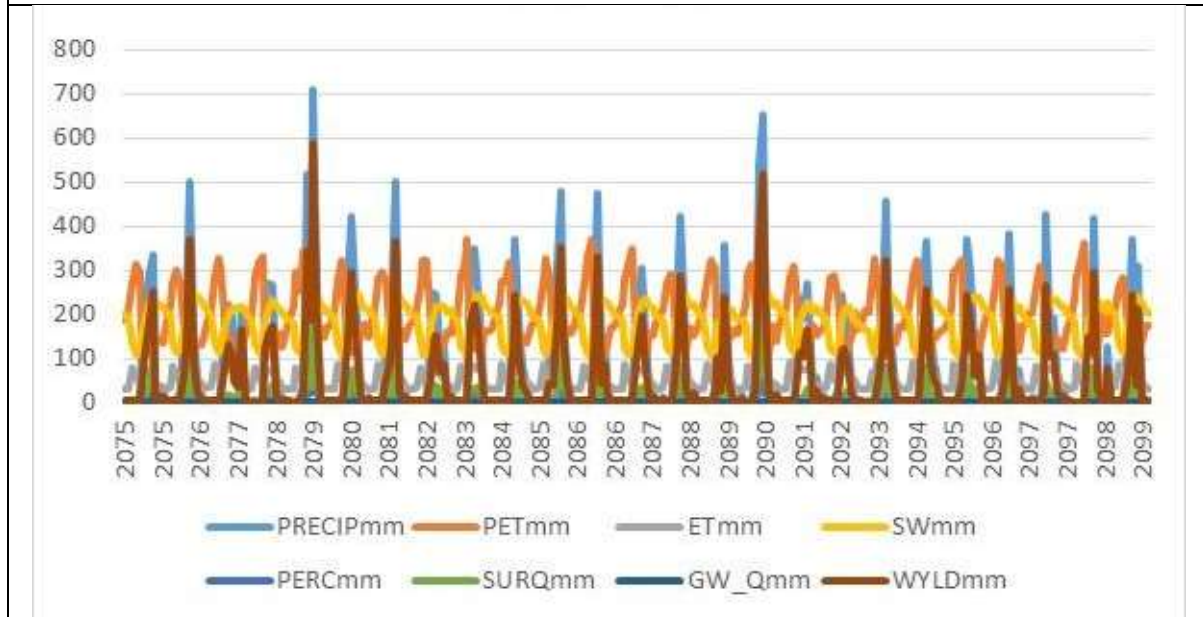


Figure 8.39: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

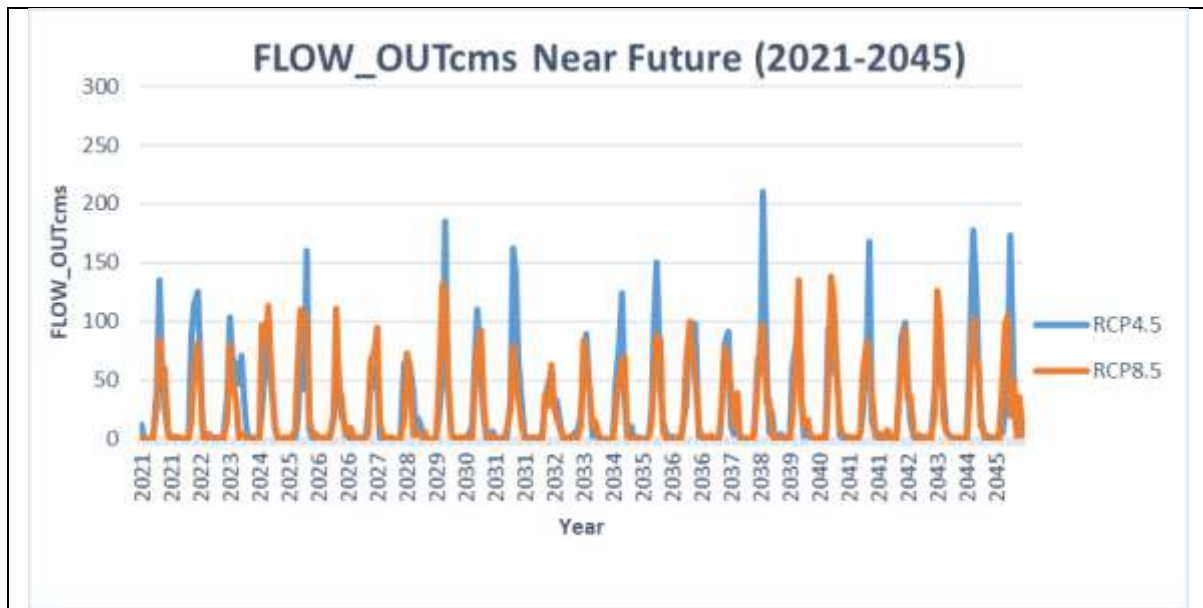


Figure8.4: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

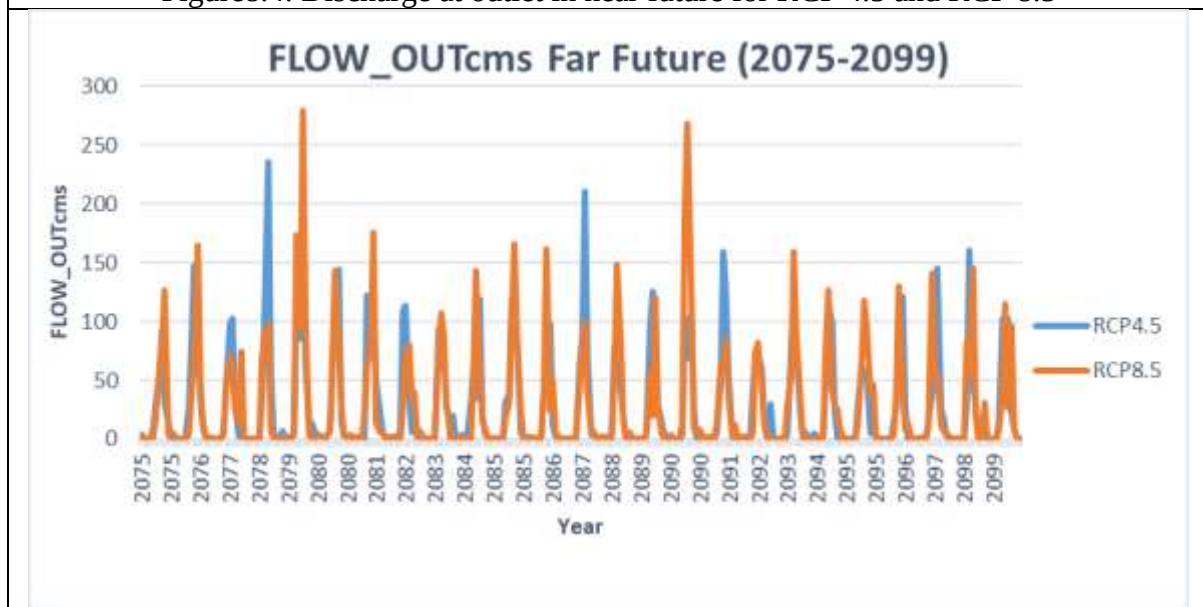


Figure 8.41: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.8 Rangeli

Water Balance parameters values for historical periods showed sudden change after 1995. Both Near future and far future water balance values are decreased in RCP 4.5 compared to RCP 8.5. Water balance values for scenario 8.5 in near future expected to increase and for far future expected to decrease. Precipitation in near future may increase and soil water expected to decrease in RCP 8.5. Discharge value at the outlet of sub-basin may increase in RCP 4.5 as compared to RCP 8.5 in both near and far future. In historical Period discharge value suddenly decreased after 1995 due to operation of Som-Kamla Dam.

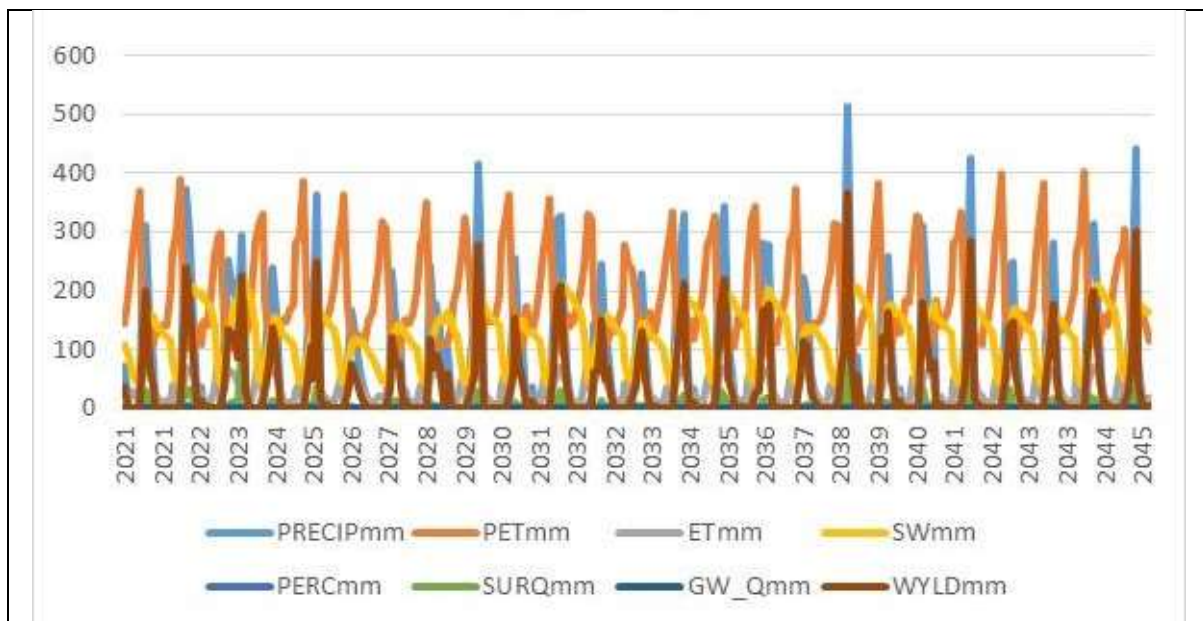


Figure 8.42: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

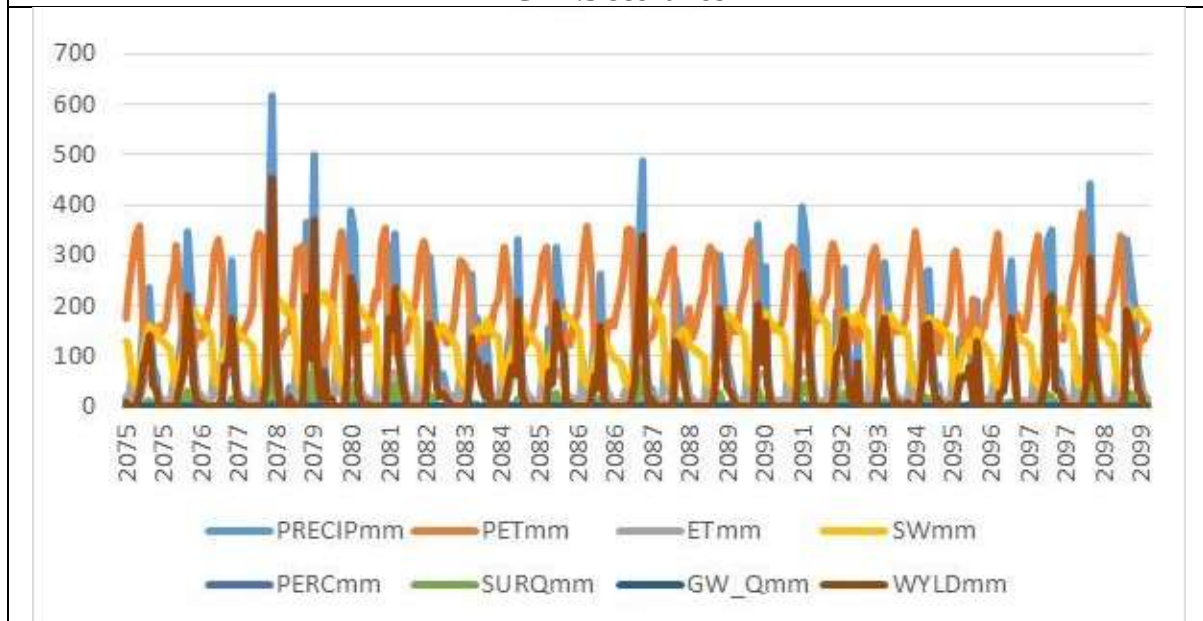


Figure 8.43: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

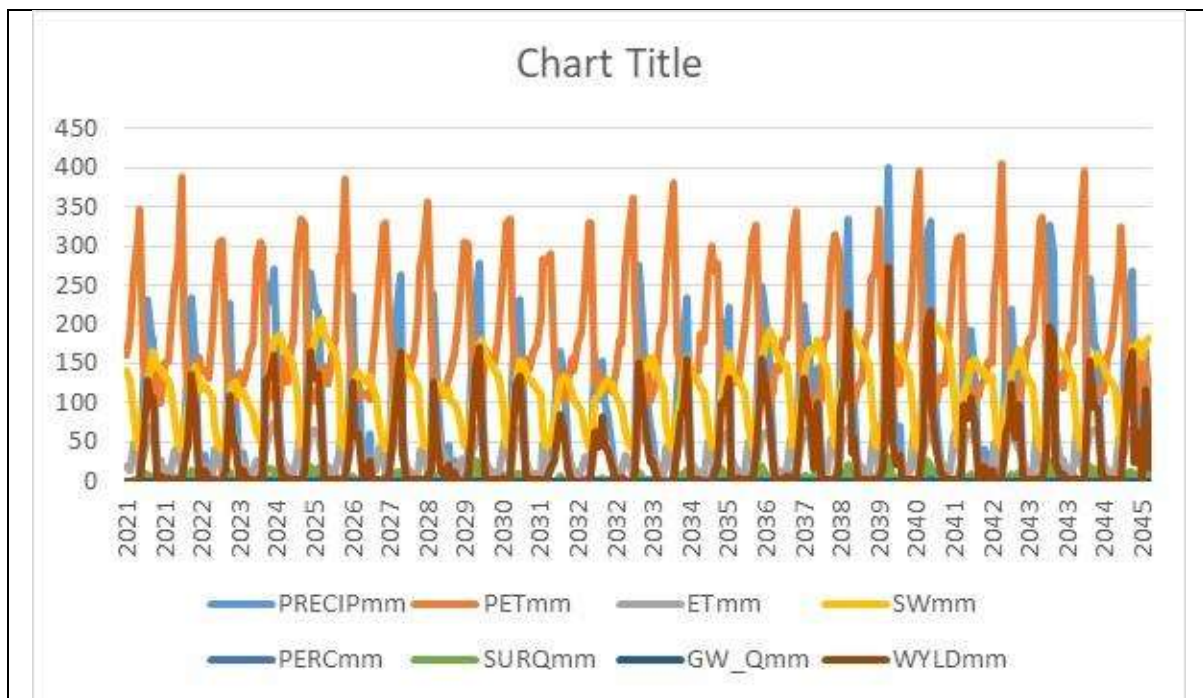


Figure 8.44: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

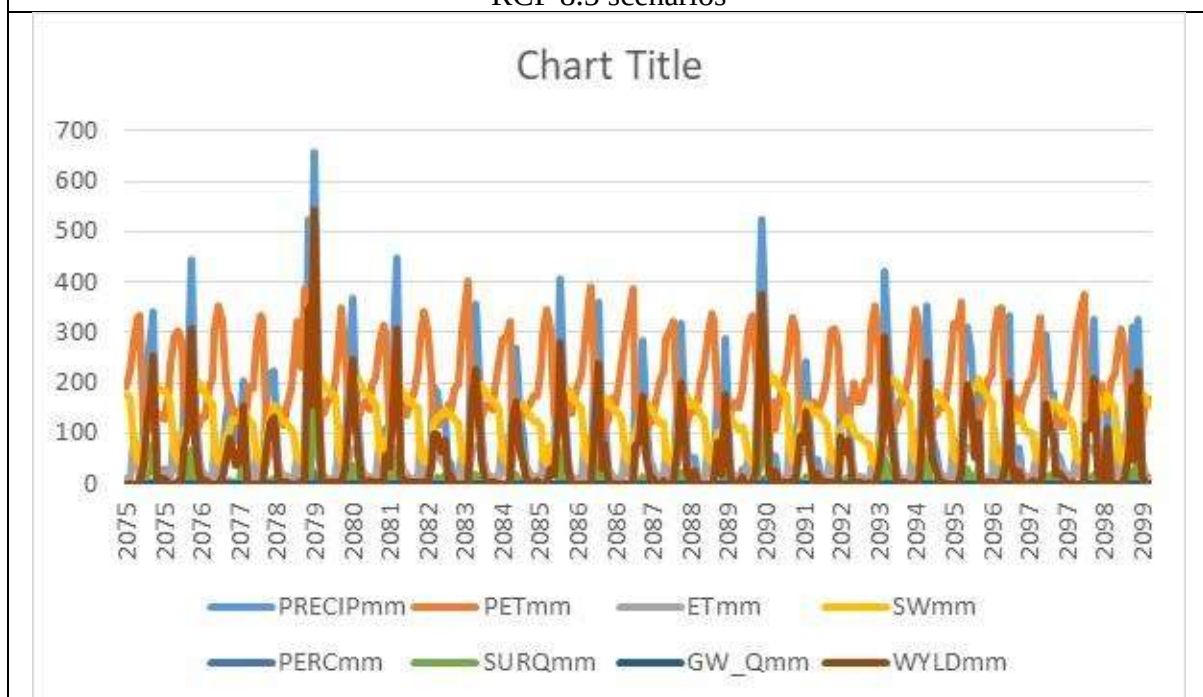


Figure 8.45: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

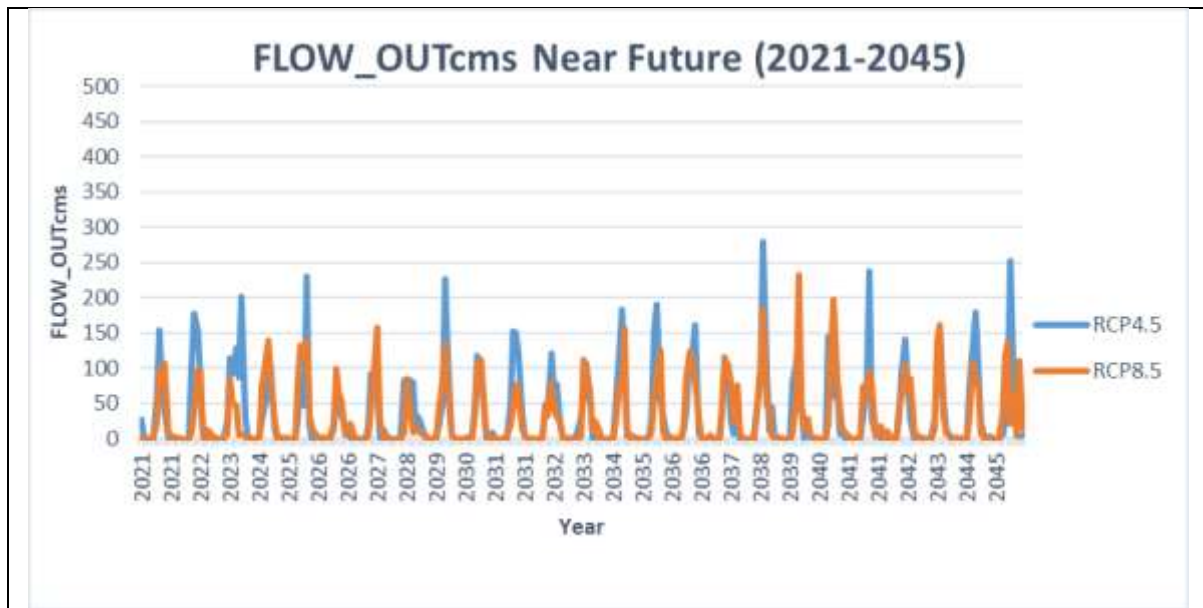


Figure 8.46: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

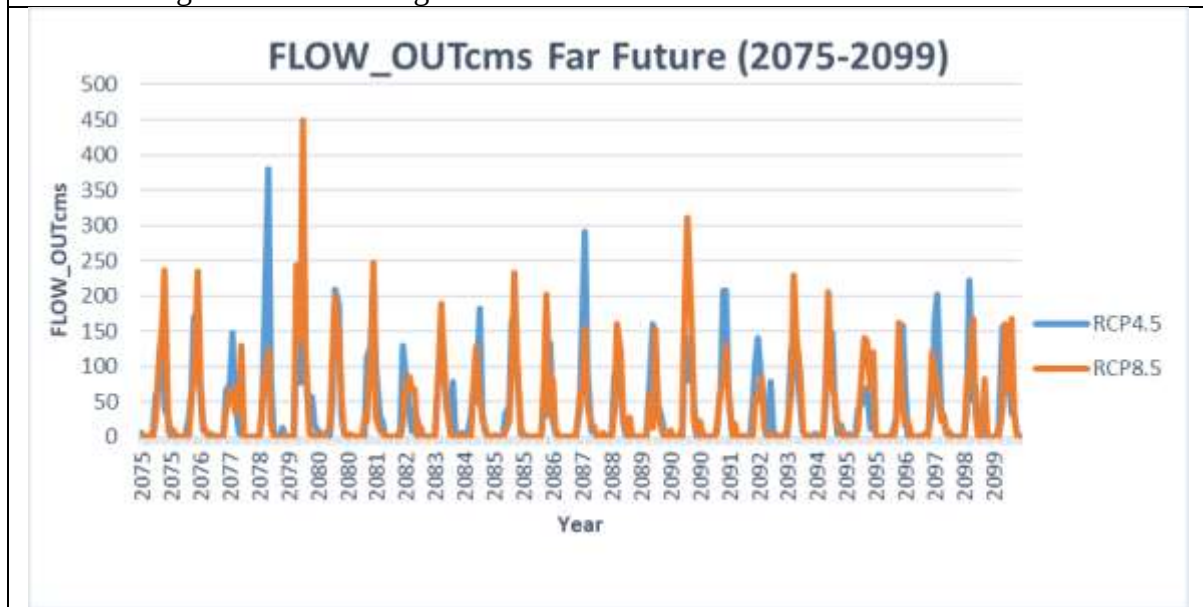


Figure 8.47: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.1.9 Khanpur

Water Balance parameters values for the Historical period have shown an increased trend as compared to RCP 4.5 for both periods. Both near future and far future water balance values are decreased in RCP 4.5 compared to RCP 8.5. Water balance values for scenario 8.5 in near future expected to increase and for far future expected to decrease. Precipitation in the near future will increase in RCP 8.5. Discharge at outlet Near Future period will increase in Scenario RCP4.5 as compared to Scenario RCP8.5. Discharge at outlet For Far future will increase in scenario RCP8.5.

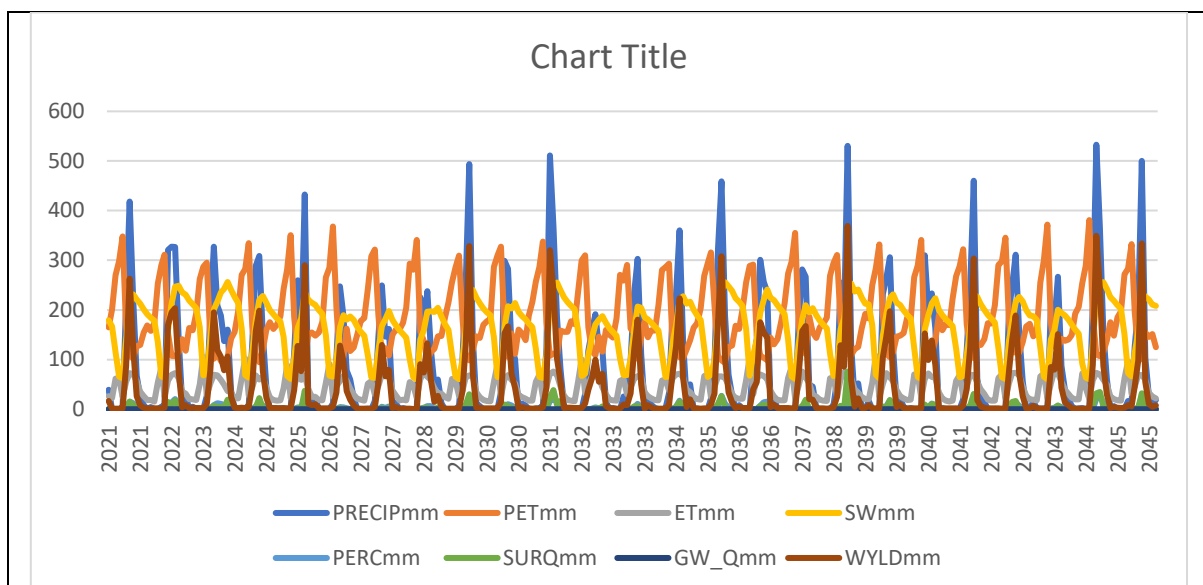


Figure 8.48: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

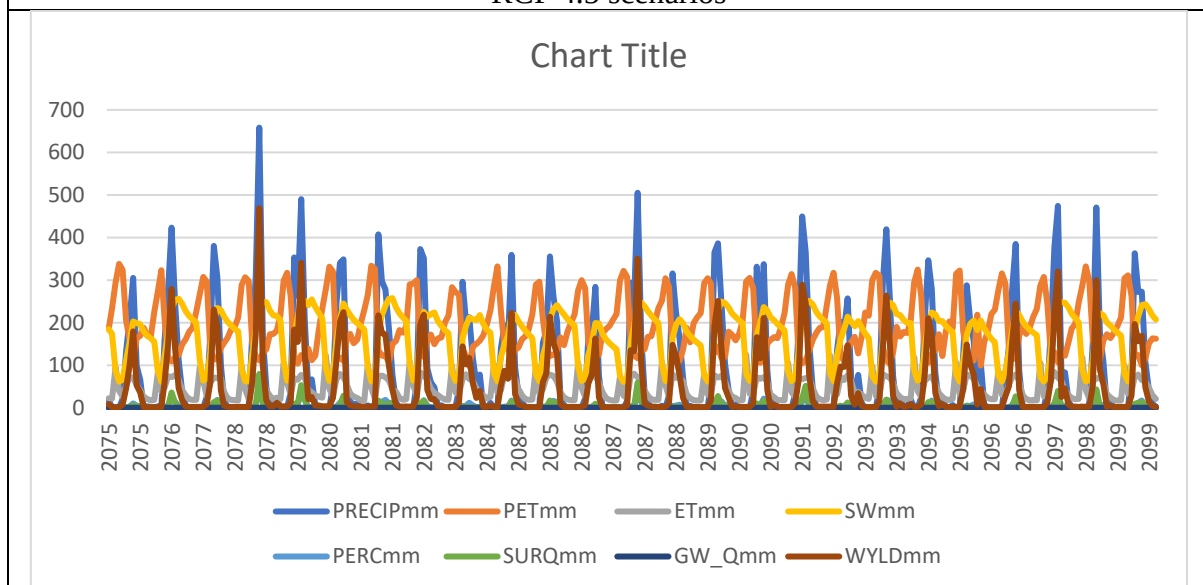


Figure 8.49: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

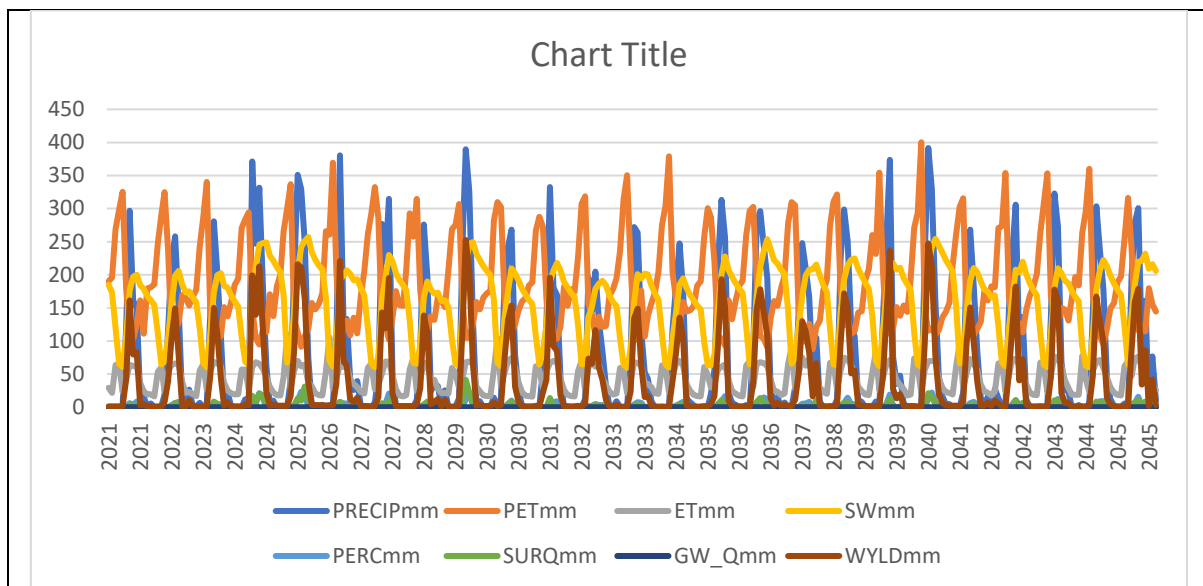


Figure 8.50: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

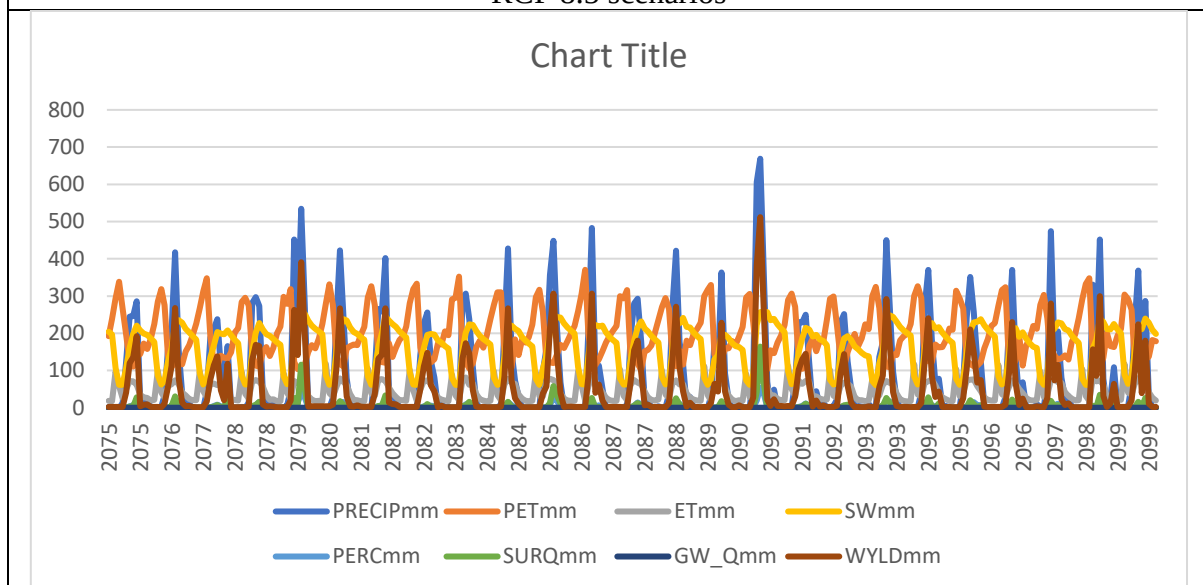


Figure 8.51: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

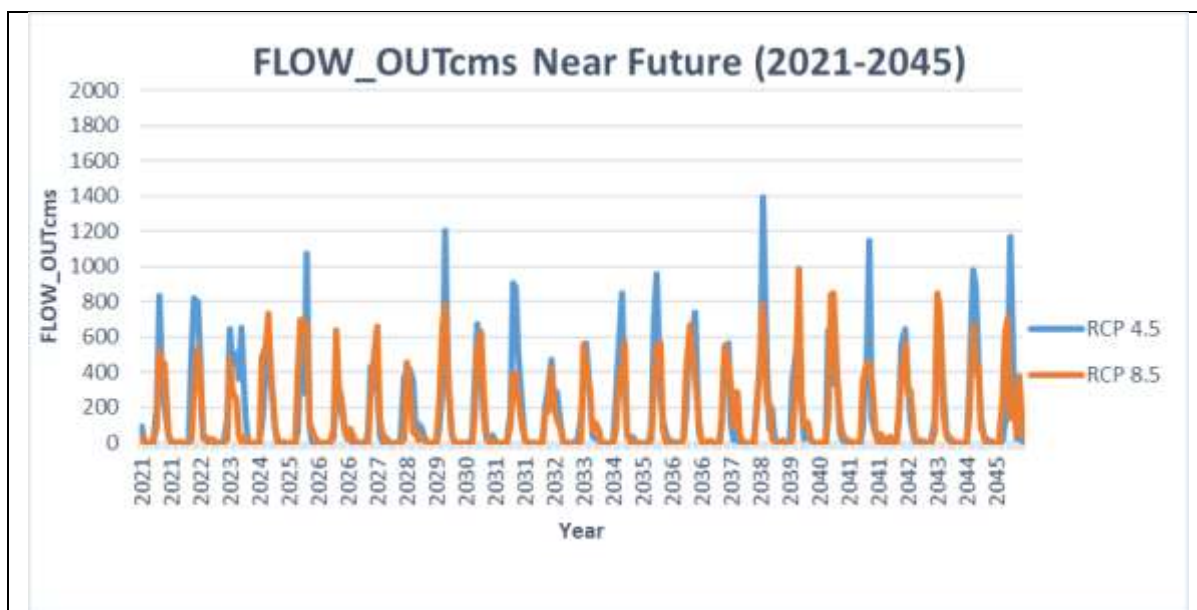


Figure 8.52: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

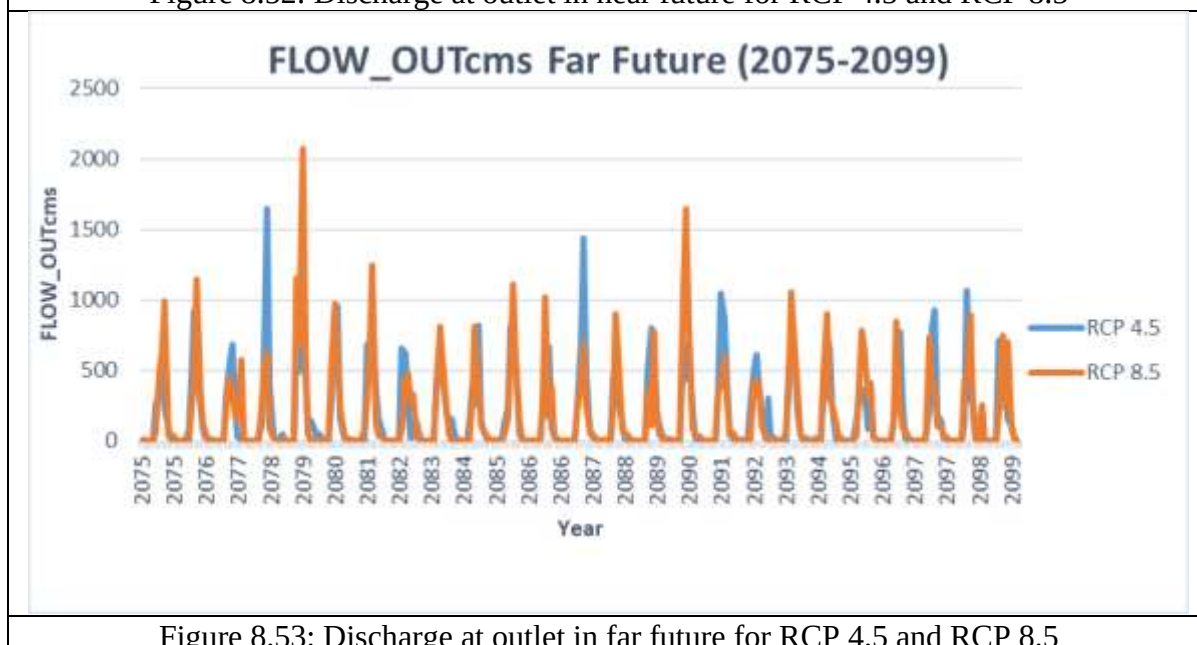


Figure 8.53: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

We quantified the effects of climate change on hydrological parameters such as Precipitation, ET, PET, SW, PERC, SURQ, GW, WYLD for the following periods: the Near Future (2021-2045), and the Far Future (2075-2099) under the RCP 4.5 and 8.5 scenarios for stations Rangeli, Mahi Bajajsagar, Dhariyawad, Khanpur, Panam, Kadana, Paderdibadi, Mataji and Chakaliya. We also compared the anomaly to the baseline period 1985–2005 under RCP 4.5 and 8.5 scenarios for each sub-watershed. Mahi Bajajsagar catchment shows decrease in water yield for all the scenarios as compared to base period and increase in surface runoff is observed. Relatively less surface runoff is observed in NF RCP 8.5 scenario. ET is annually reduced to 300% in future scenarios. Chakaliya shows increase in precipitation as compared to the base

period. All the hydrological parameters are increased in future scenarios. Maximum water yield is obtained in FF RCP 8.5. Almost all the parameters are increased in FF RCP 8.5. This scenario is considered to be the worst.

8.2. Inland Drainage area

8.2.1 SWAT Model 1 of AID

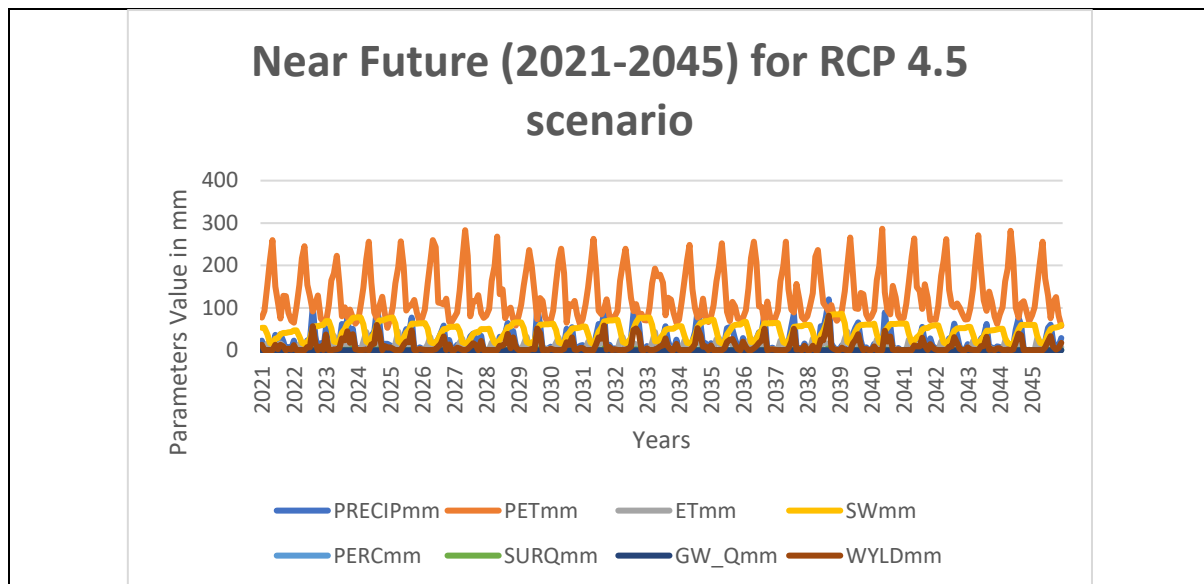


Figure 8.54: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

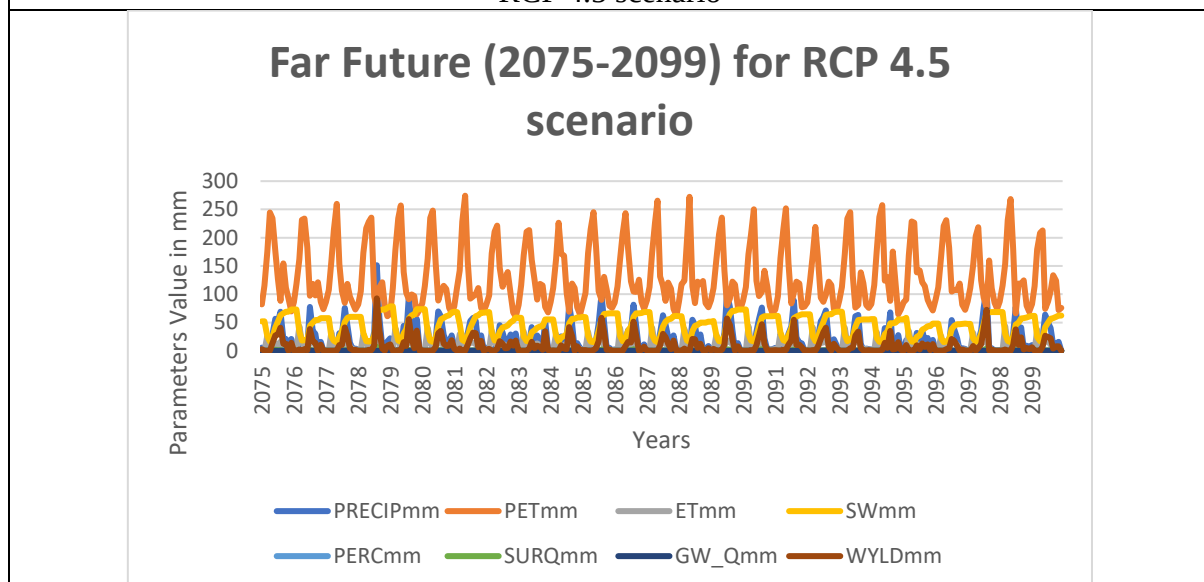


Figure 8.55 Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

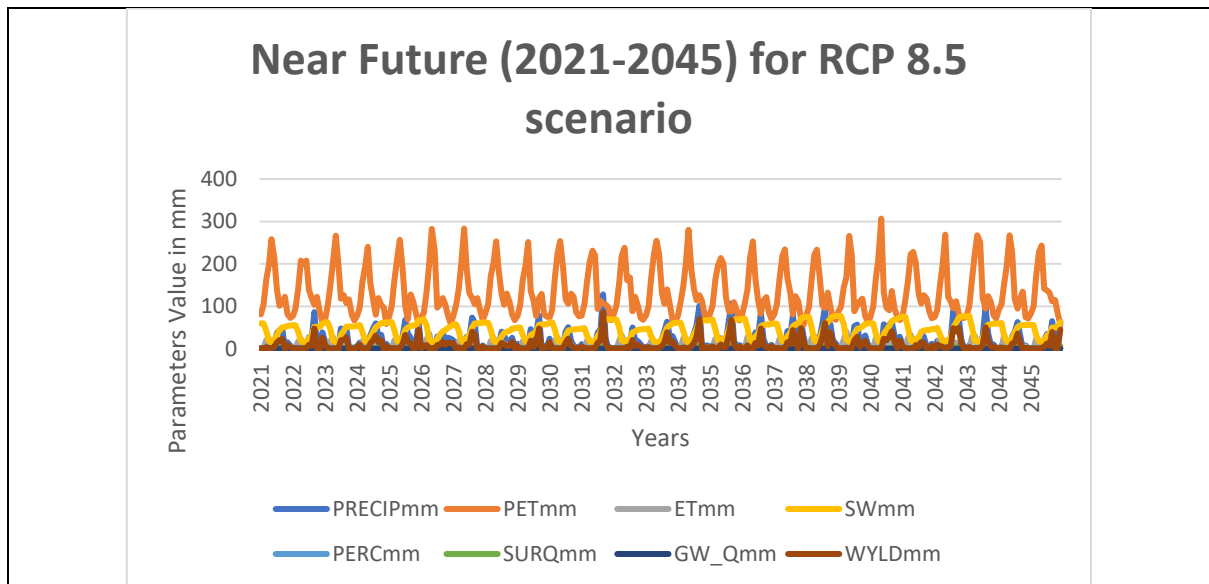


Figure 8.56: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

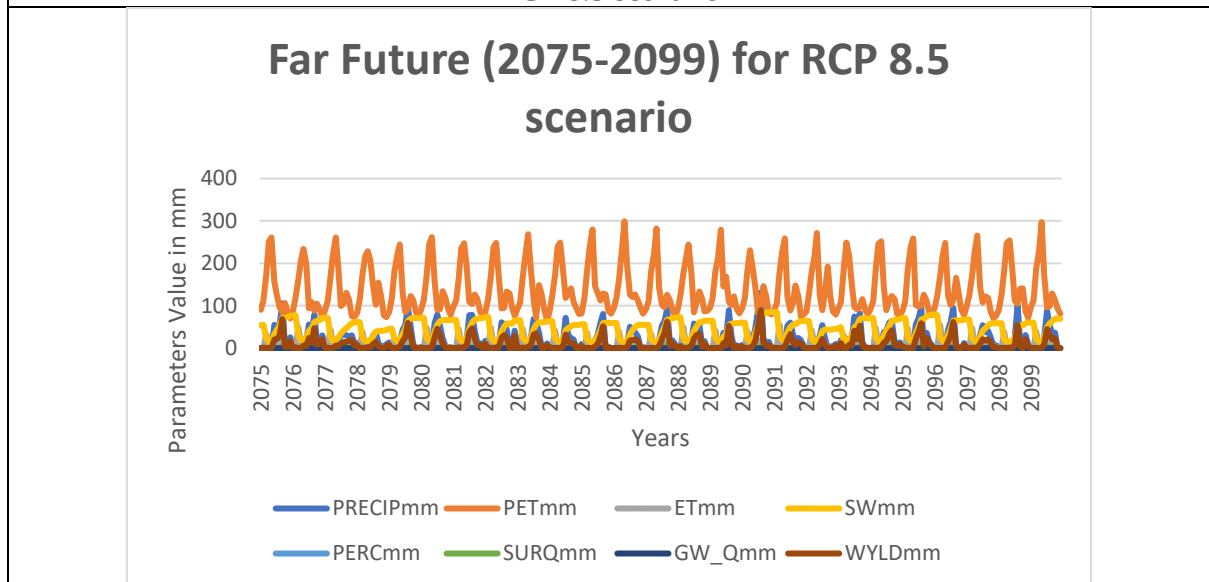


Figure 8.57: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

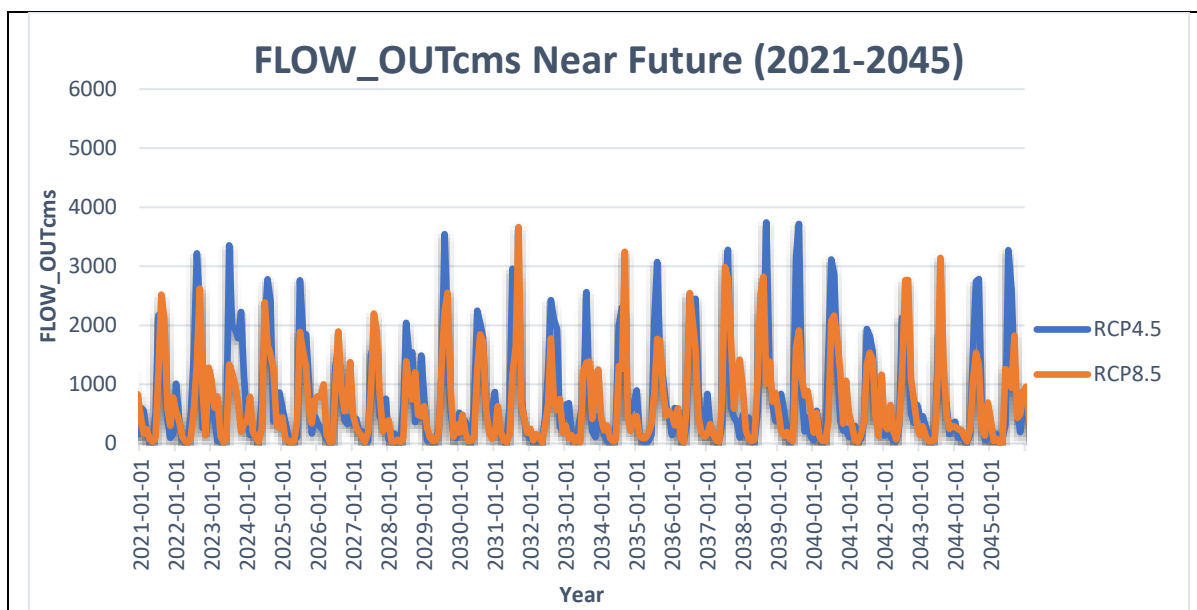


Figure 8.58: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

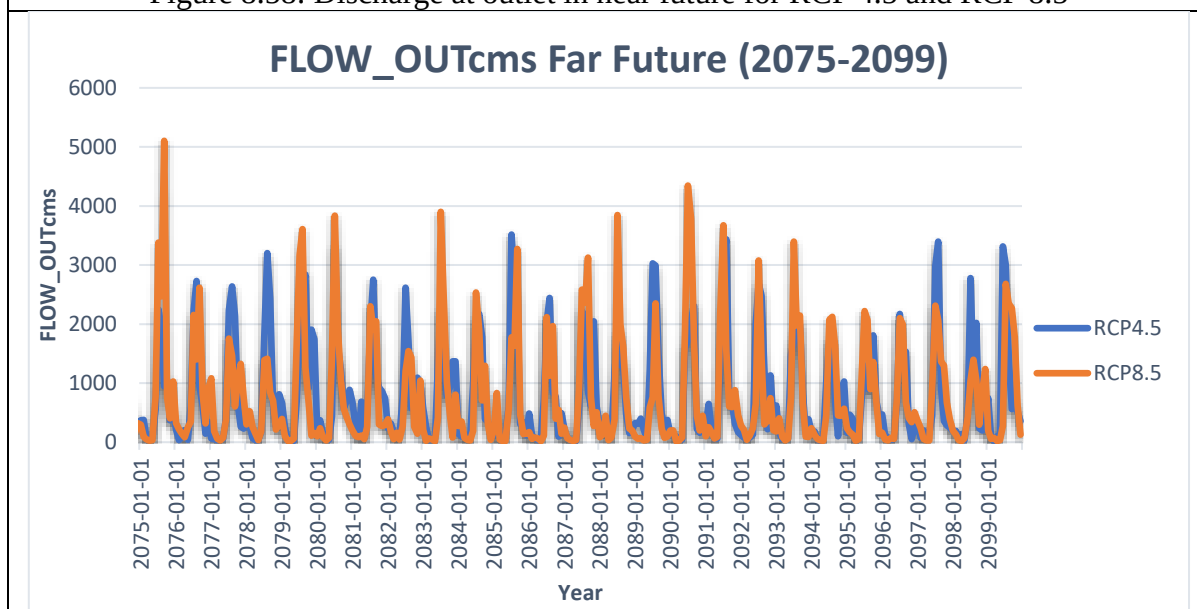


Figure 8.59: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.2 SWAT Model 2 of AID

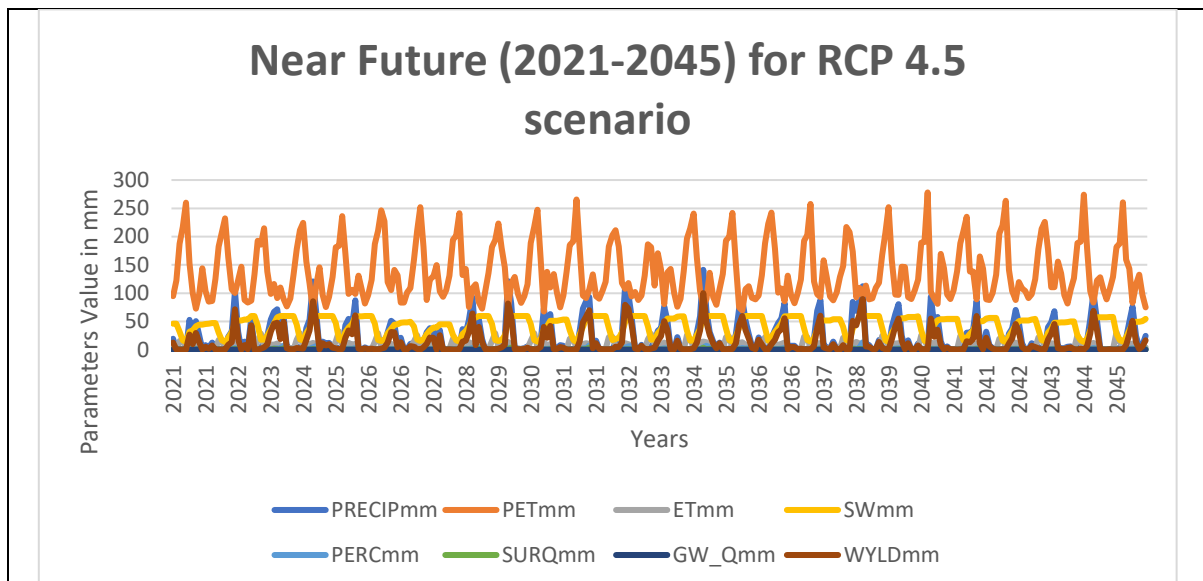


Figure 8.60: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

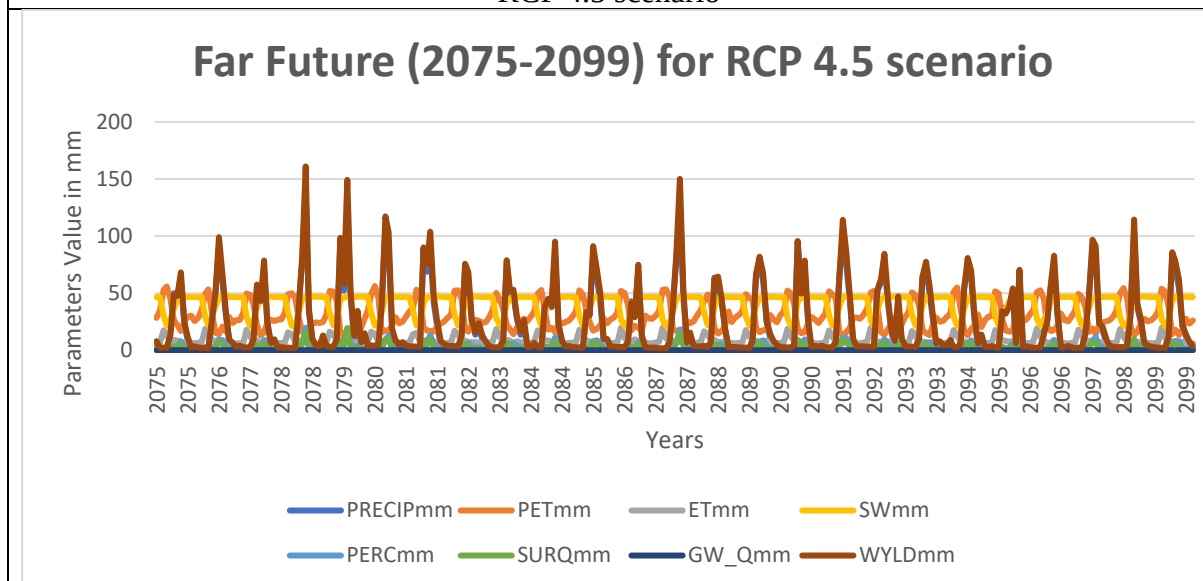


Figure 8.61: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

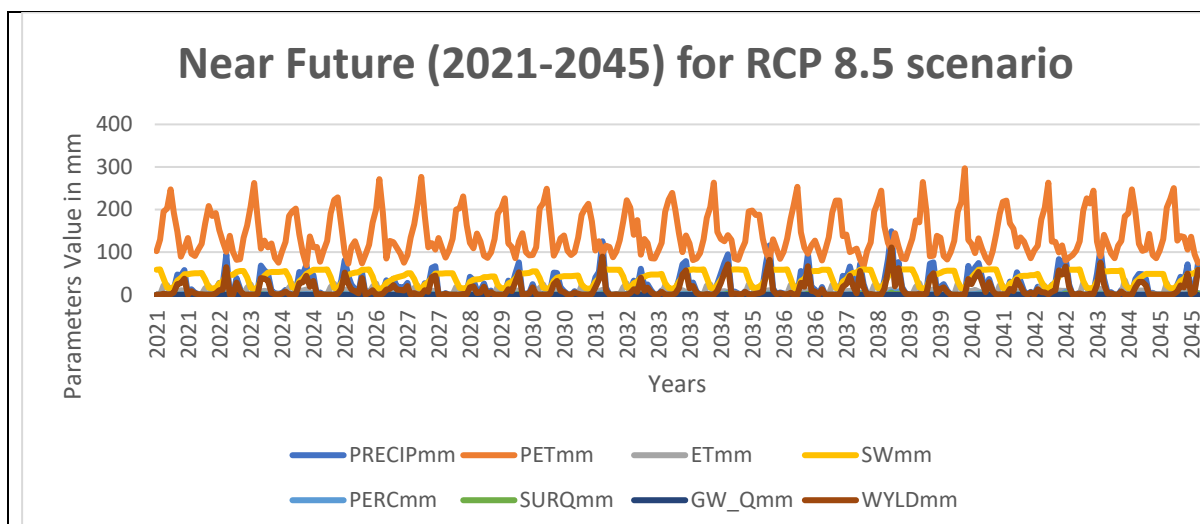


Figure 8.62: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

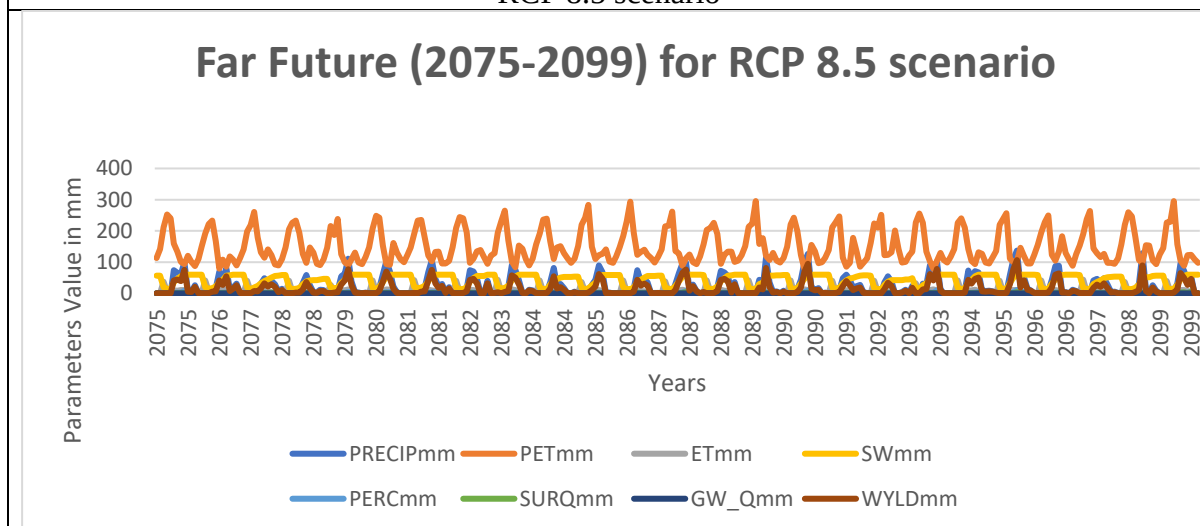


Figure 8.63: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

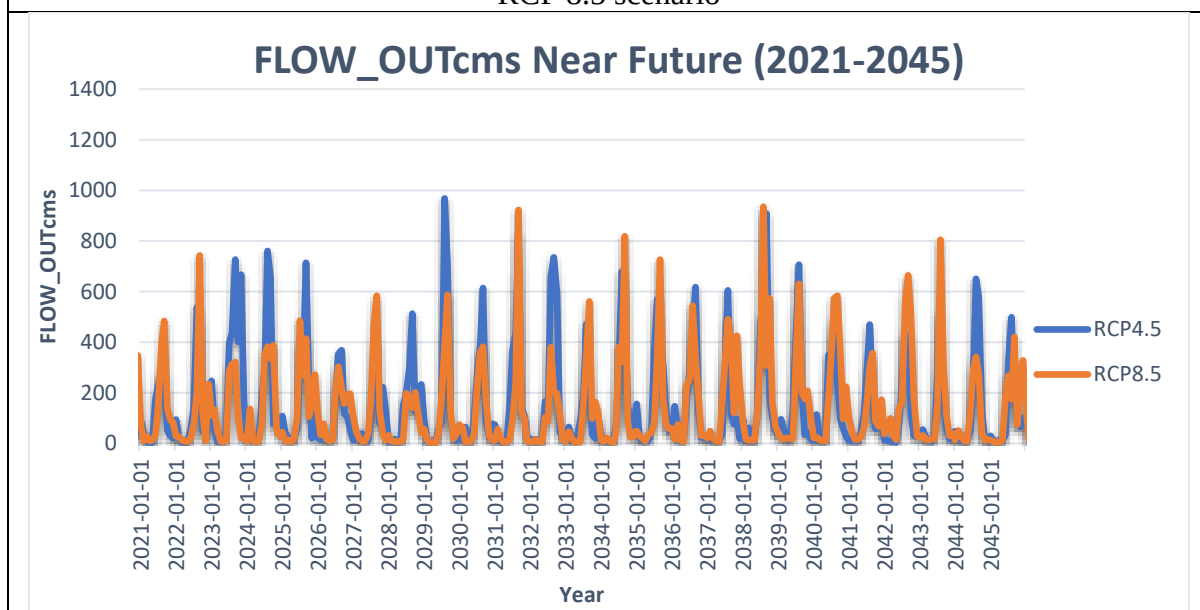


Figure 8.64: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

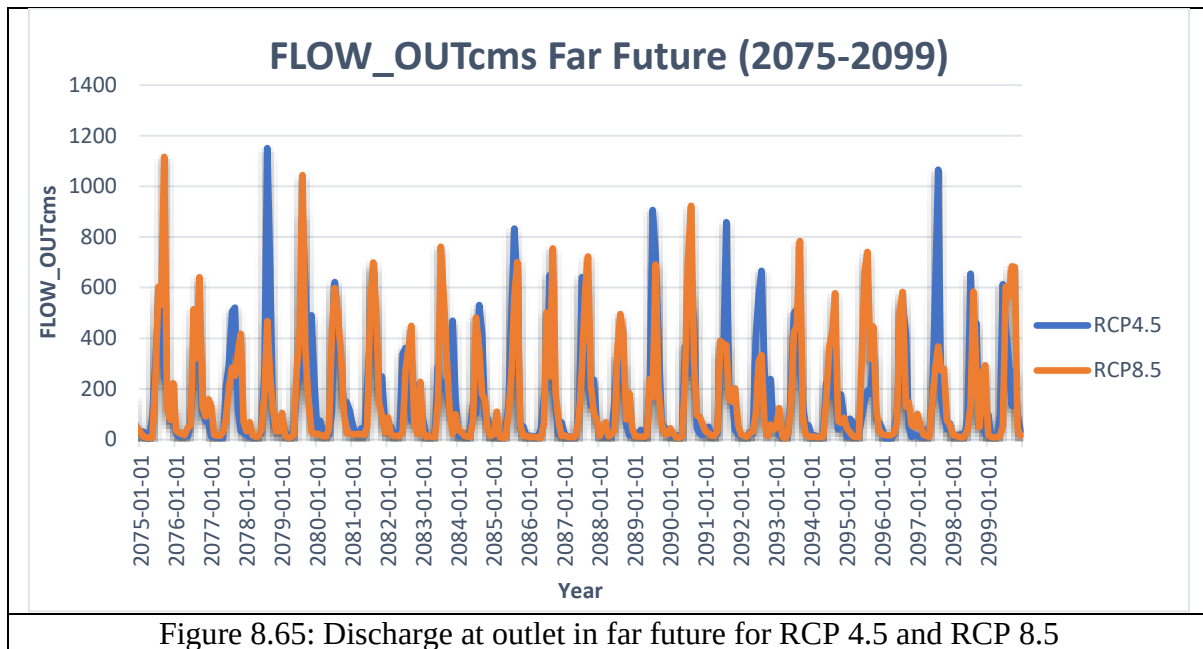


Figure 8.65: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.3 SWAT Model 3 of AID

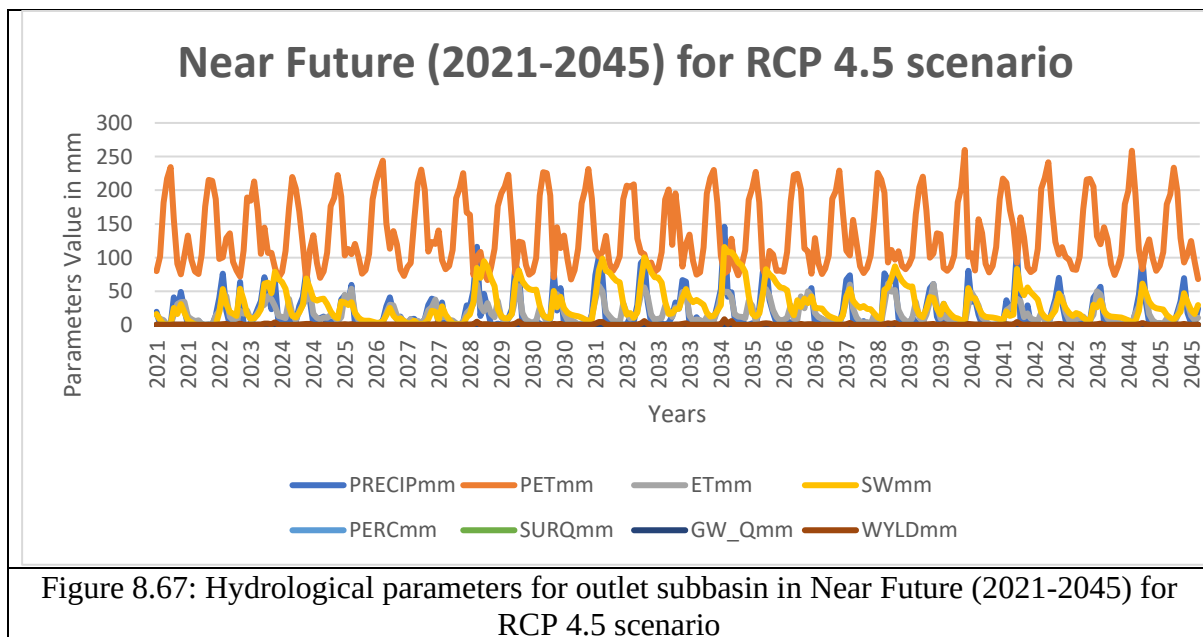


Figure 8.67: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

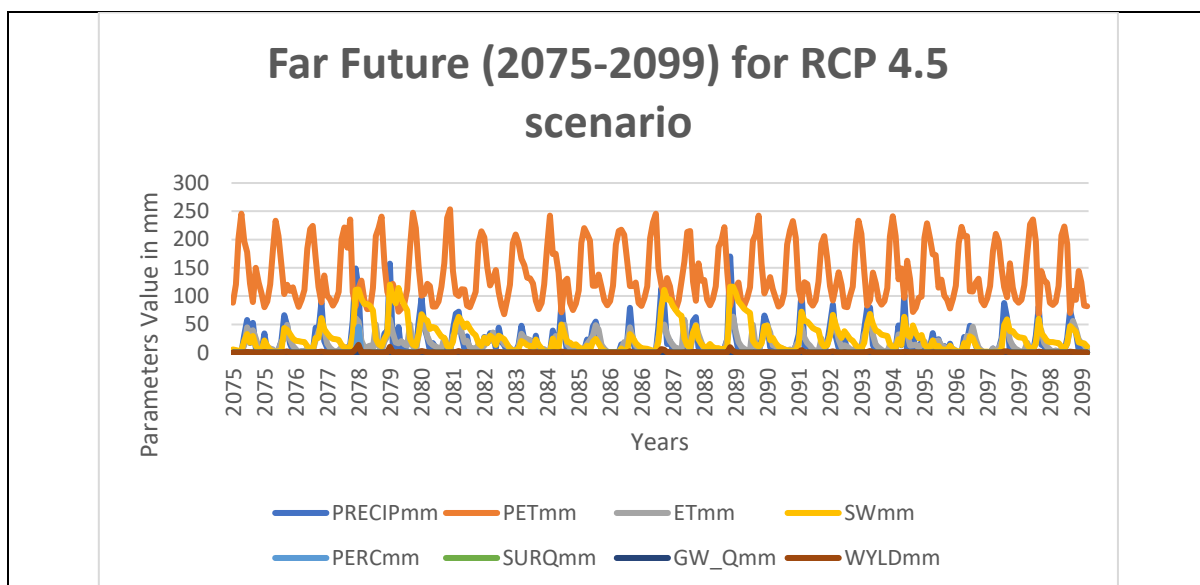


Figure 8.68: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

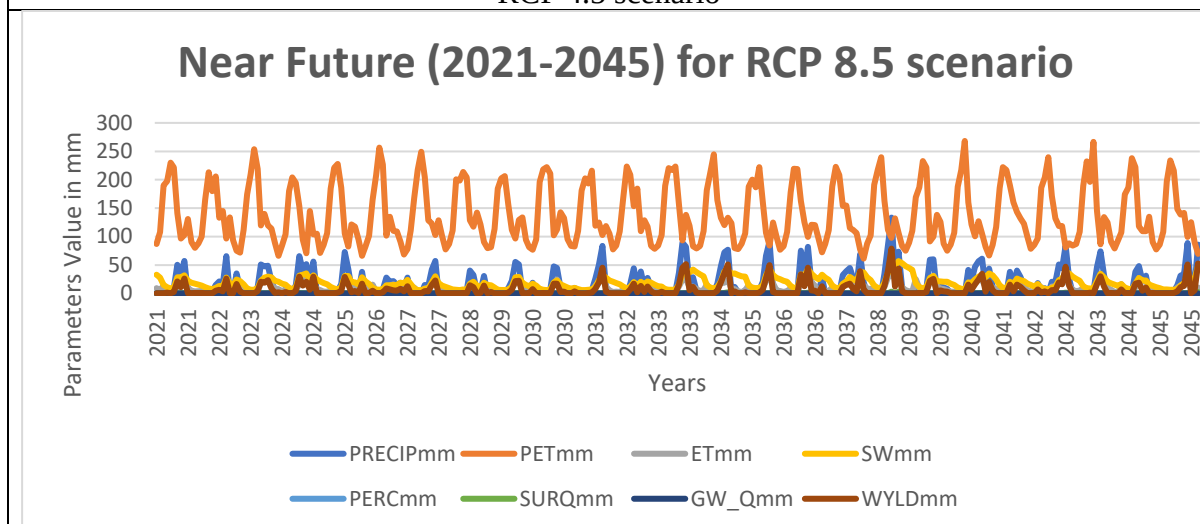


Figure 8.69: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

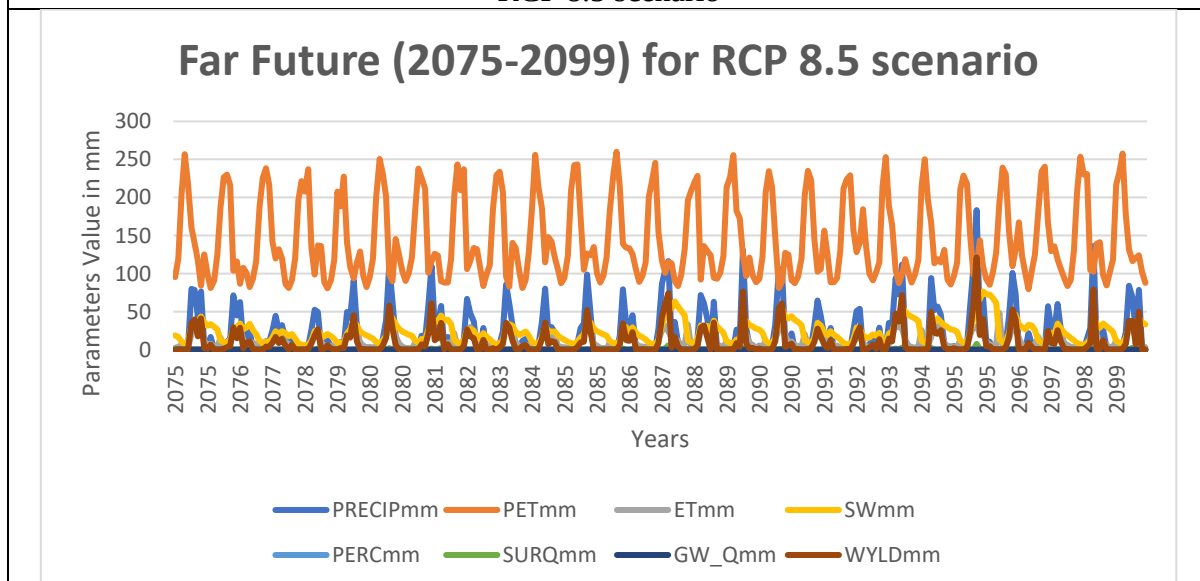


Figure 8.70: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

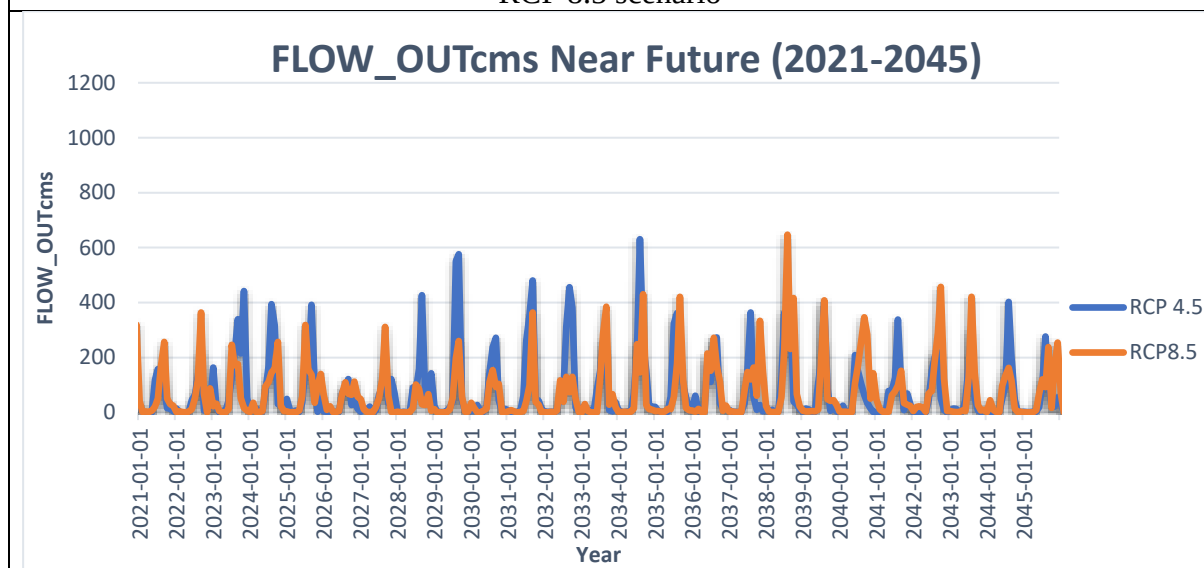


Figure 8.71: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

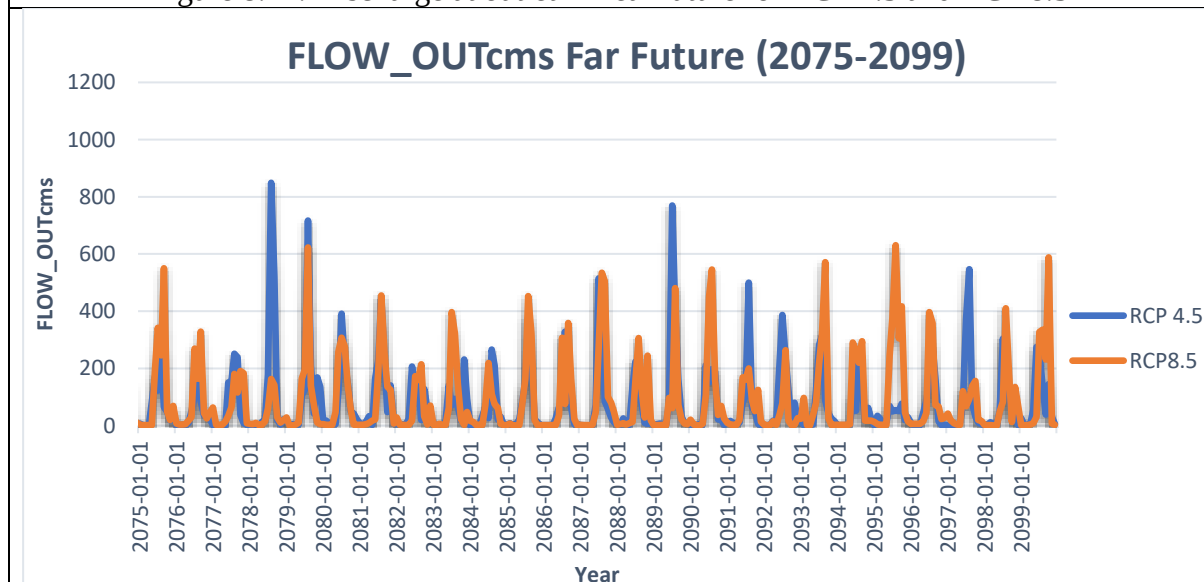


Figure 8.72: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

- **8.2.4 SWAT Model 4 of AID**

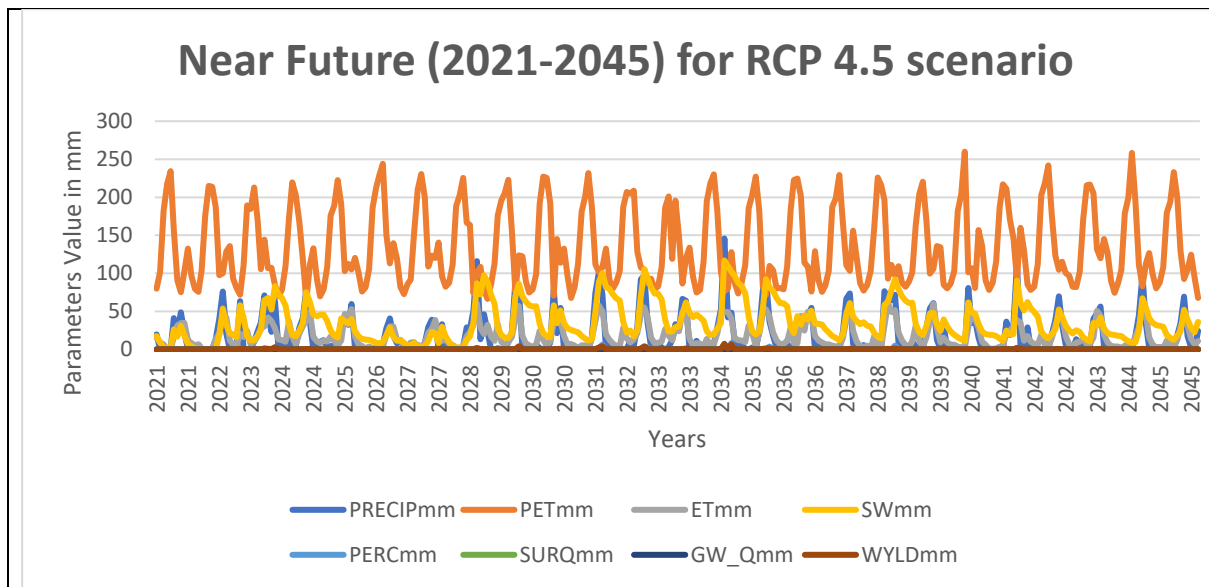


Figure 8.73: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

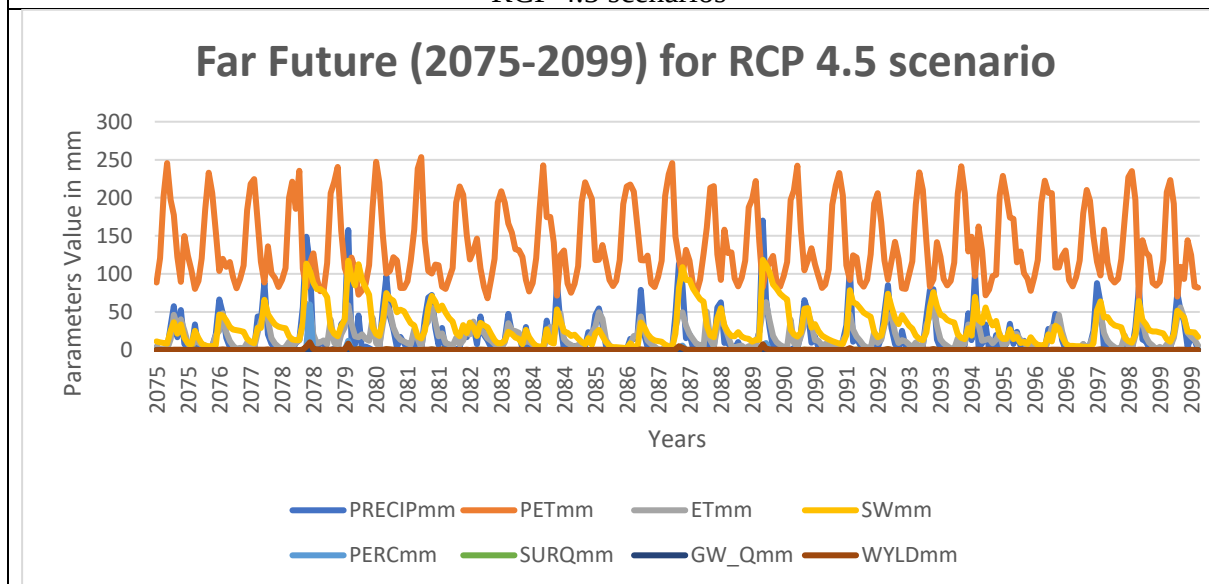


Figure 8.74: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

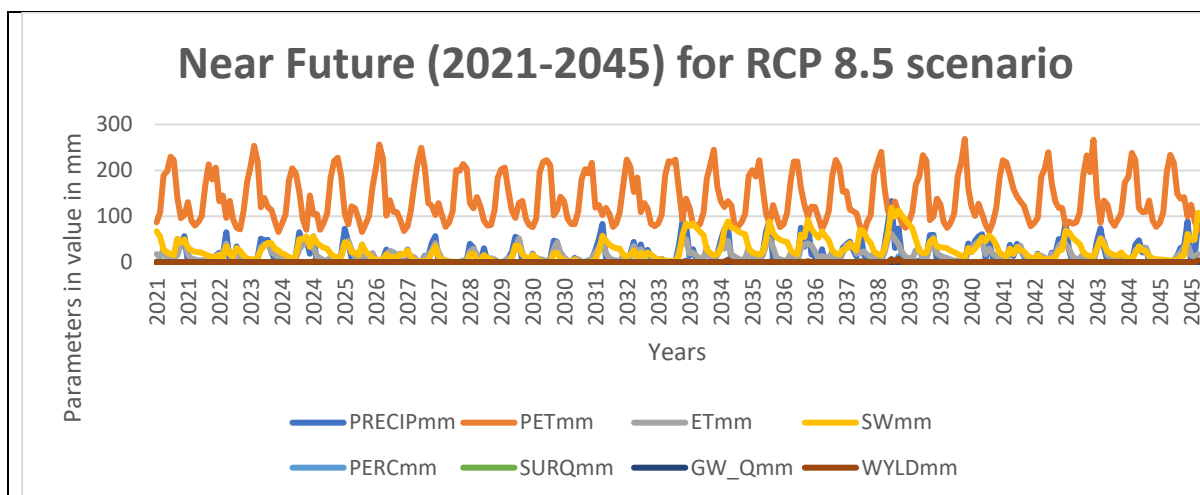


Figure 8.75: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

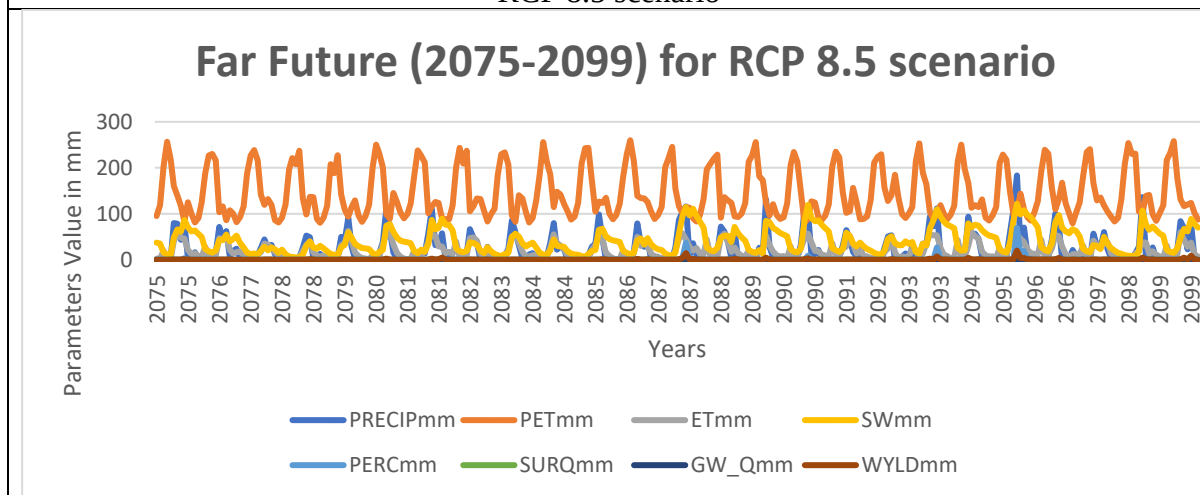


Figure 8.76: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

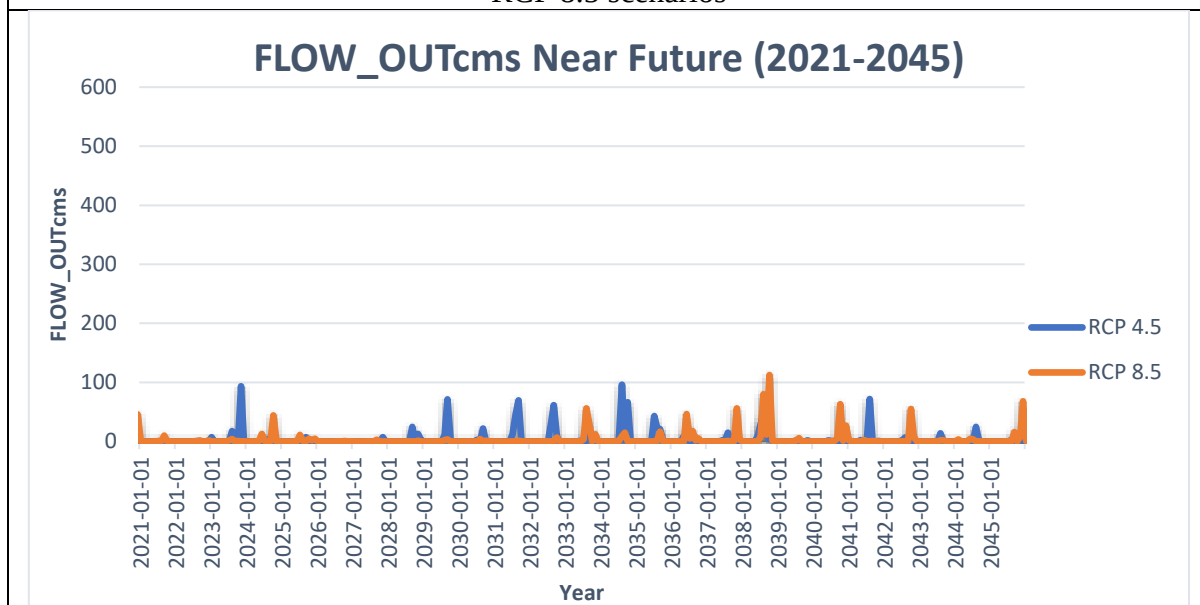


Figure 8.77: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

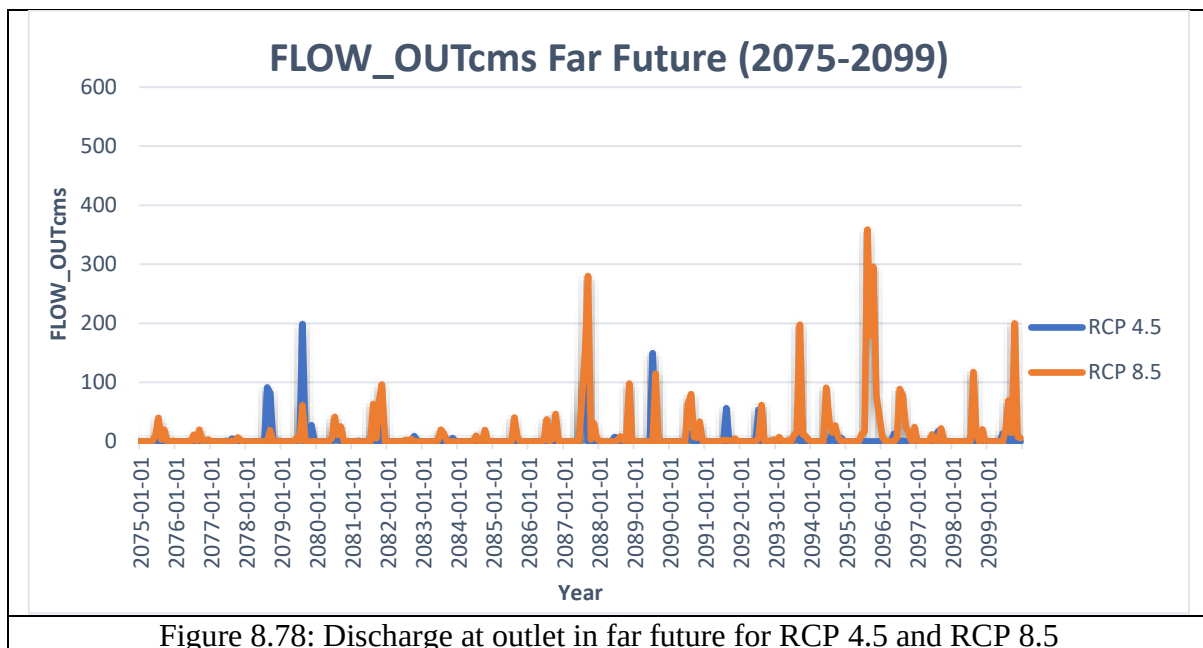


Figure 8.78: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

- 8.2.5 SWAT Model 5 of AID

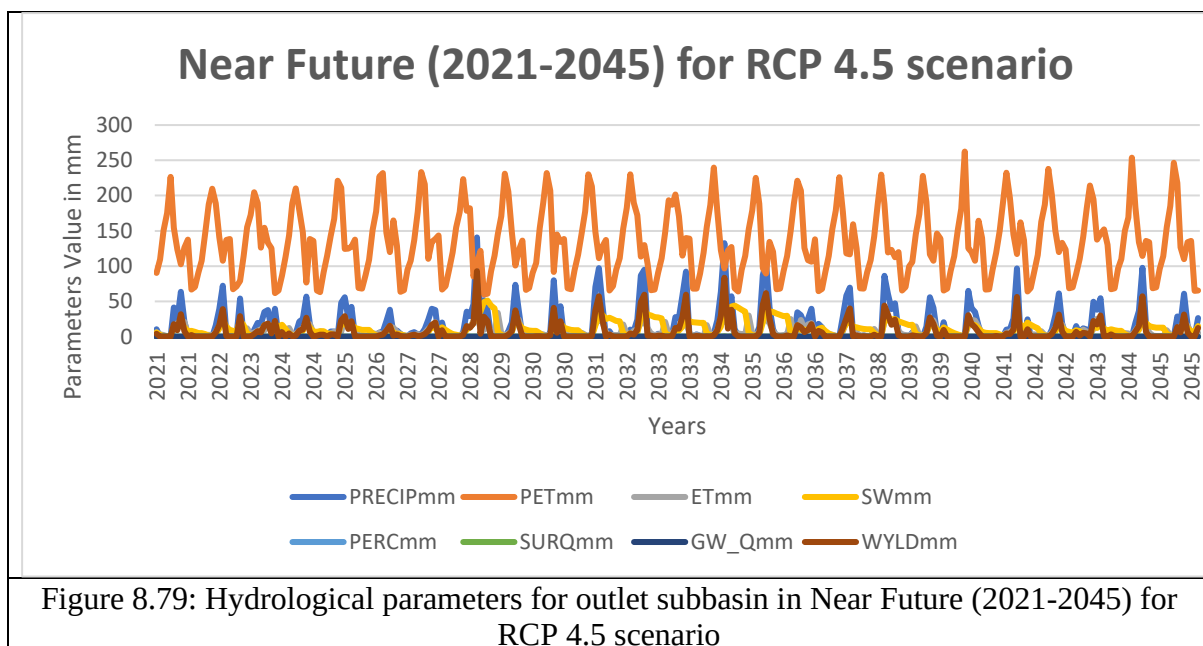


Figure 8.79: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

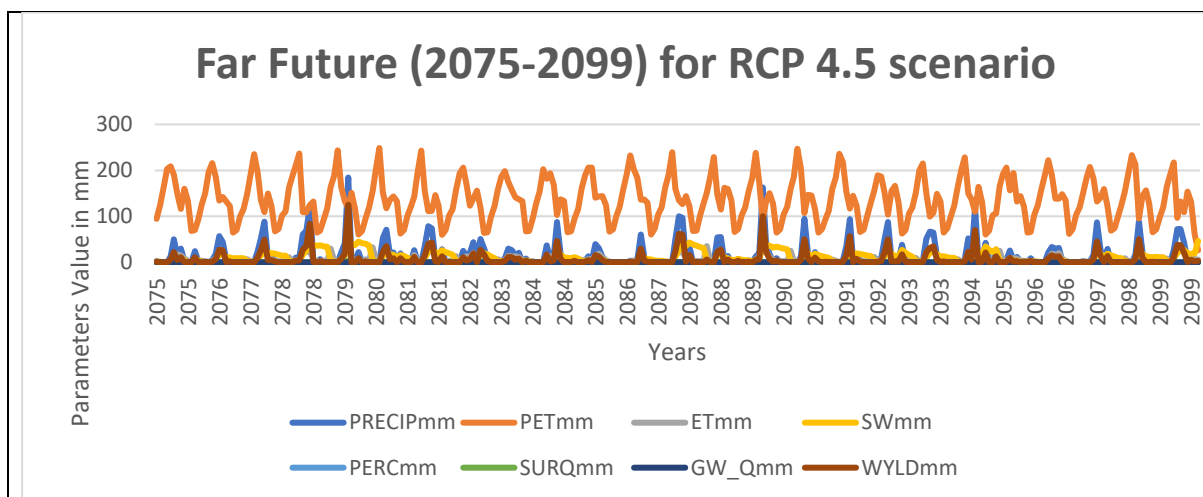


Figure 8.80: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

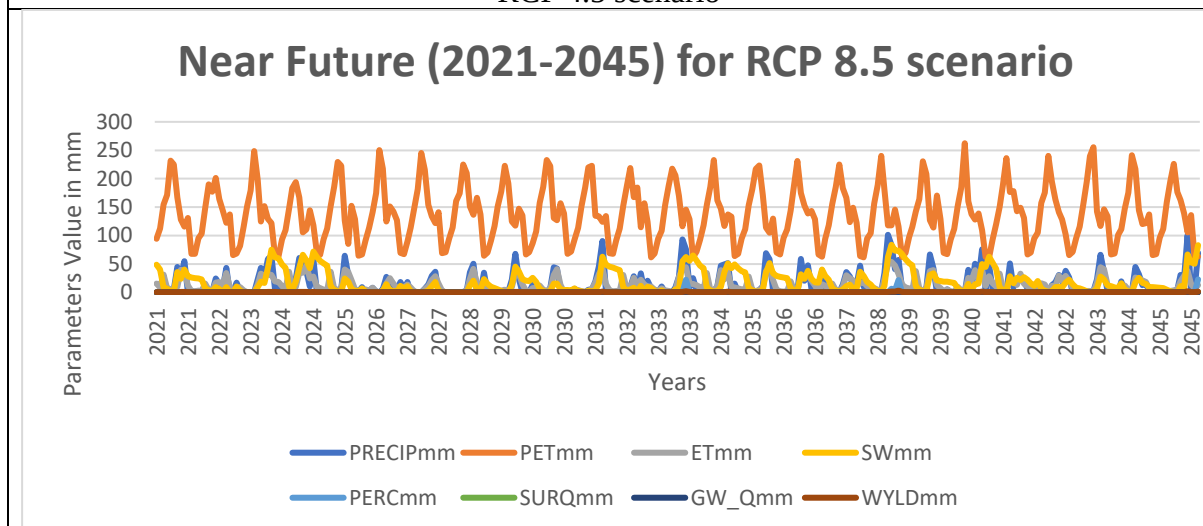


Figure 8.81: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

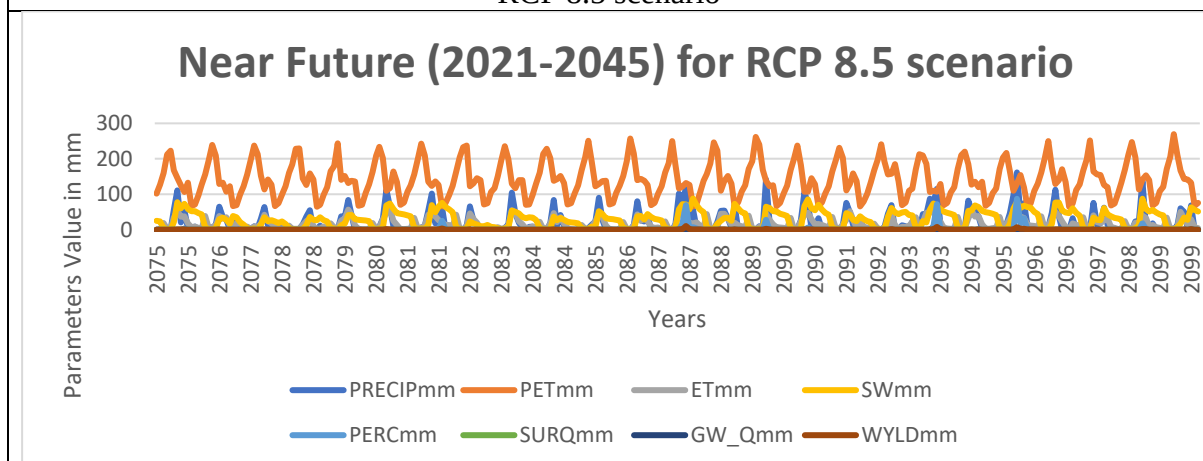


Figure 8.82: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

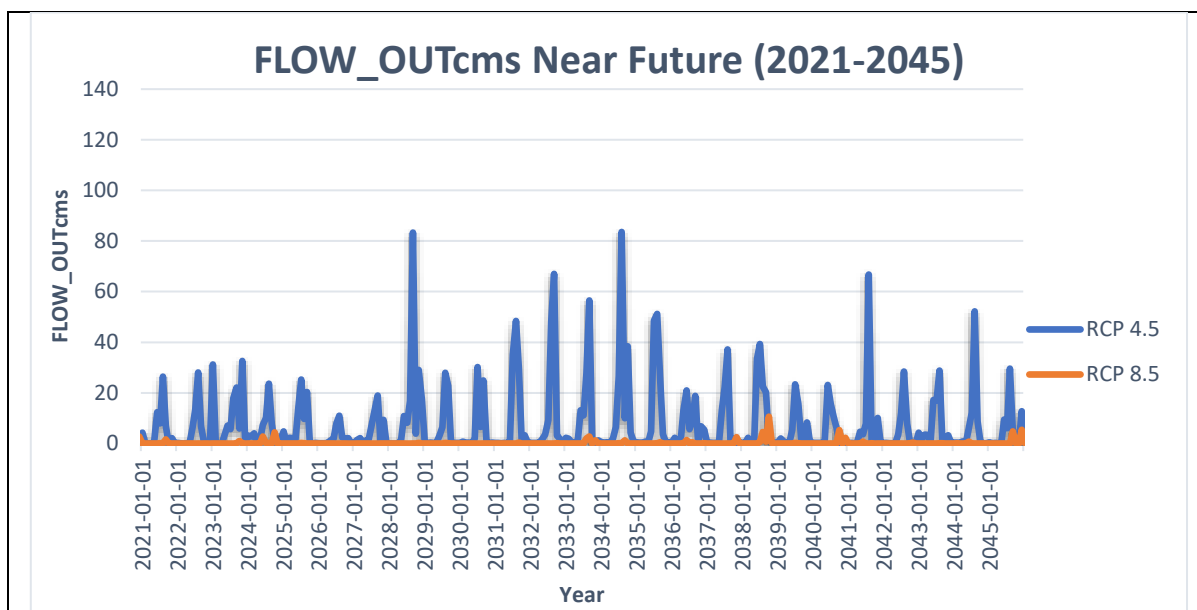


Figure 8.83: Discharge at outlet in near future for RCP 4.5 and RCP 8.5

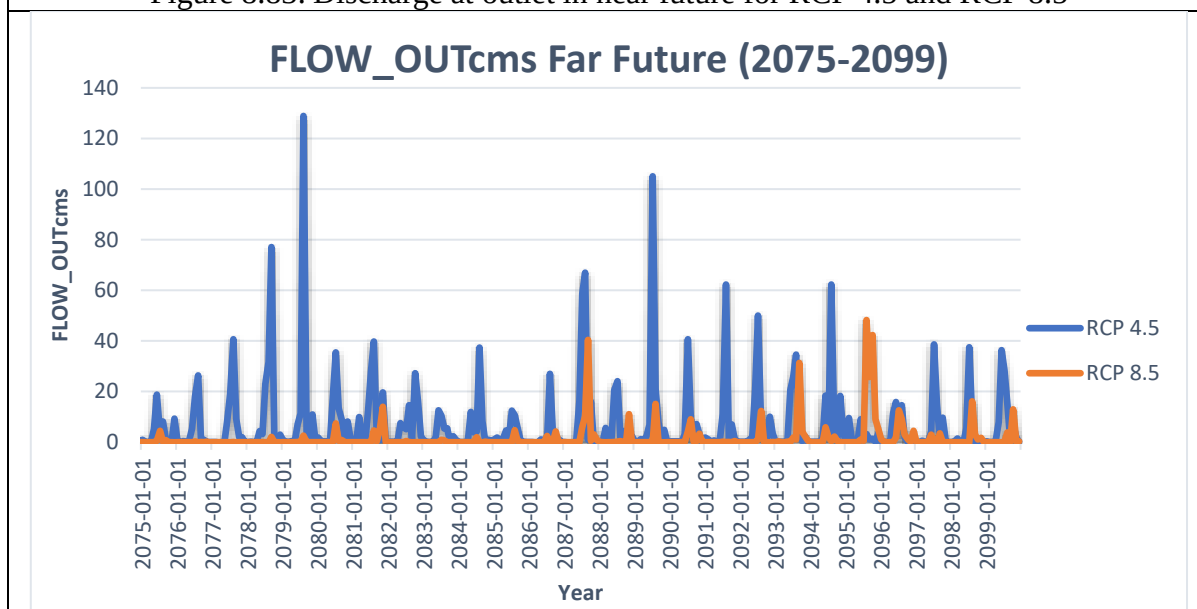


Figure 8.84: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.6 SWAT Model 6 of AID

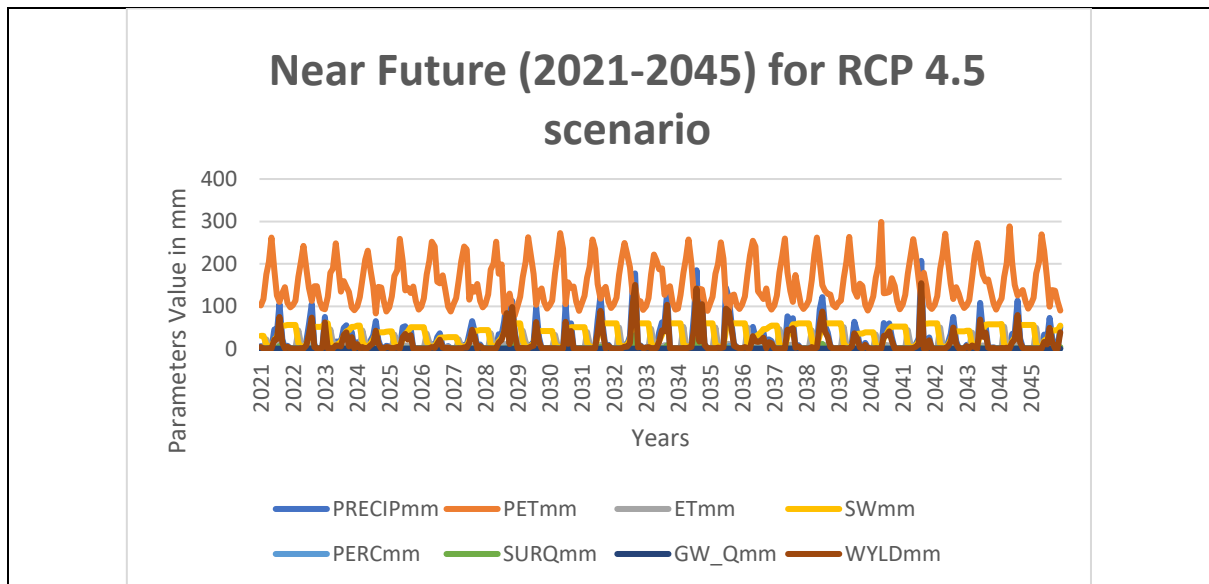


Figure 8.85: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

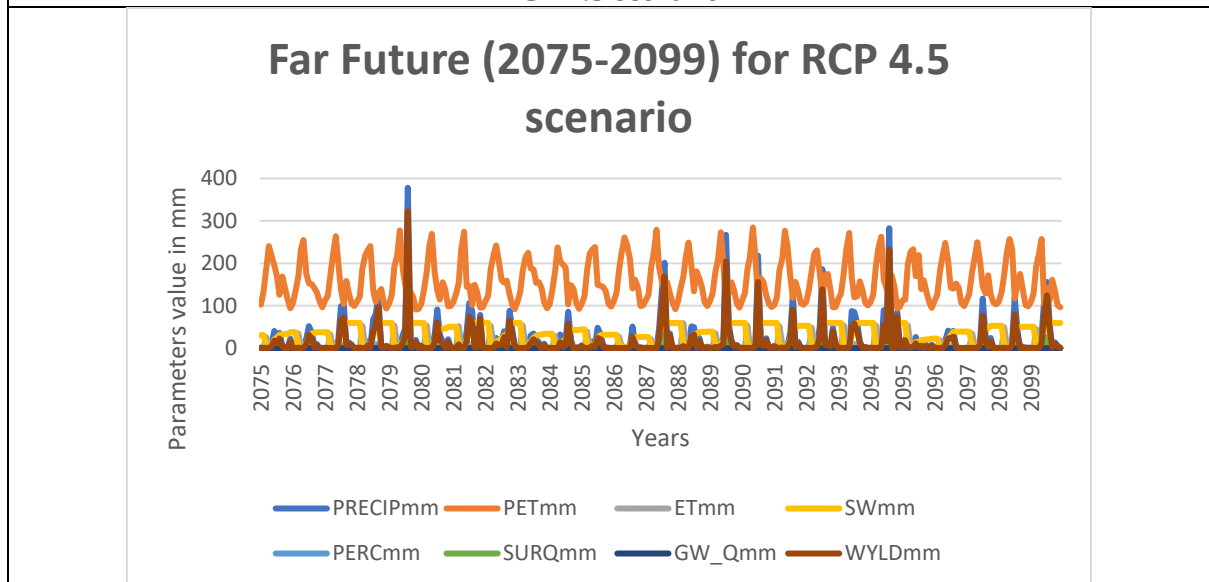


Figure 8.86: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

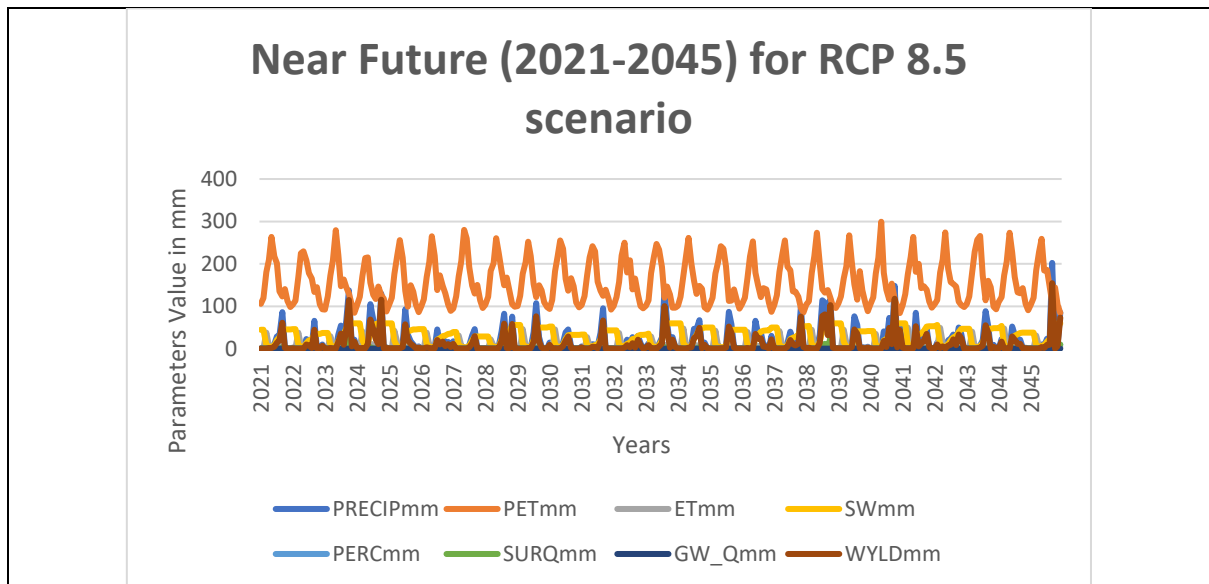


Figure 8.87: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

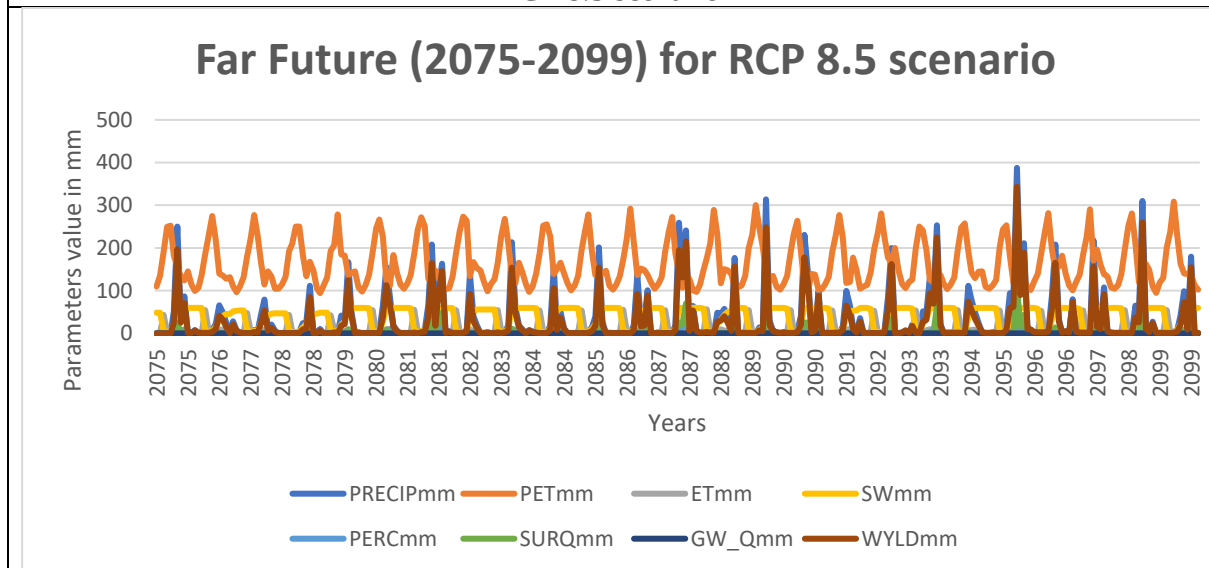


Figure 8.88: Hydrological parameters for outlet sub-basin in Far Future (2075-2099) for RCP 8.5 scenario

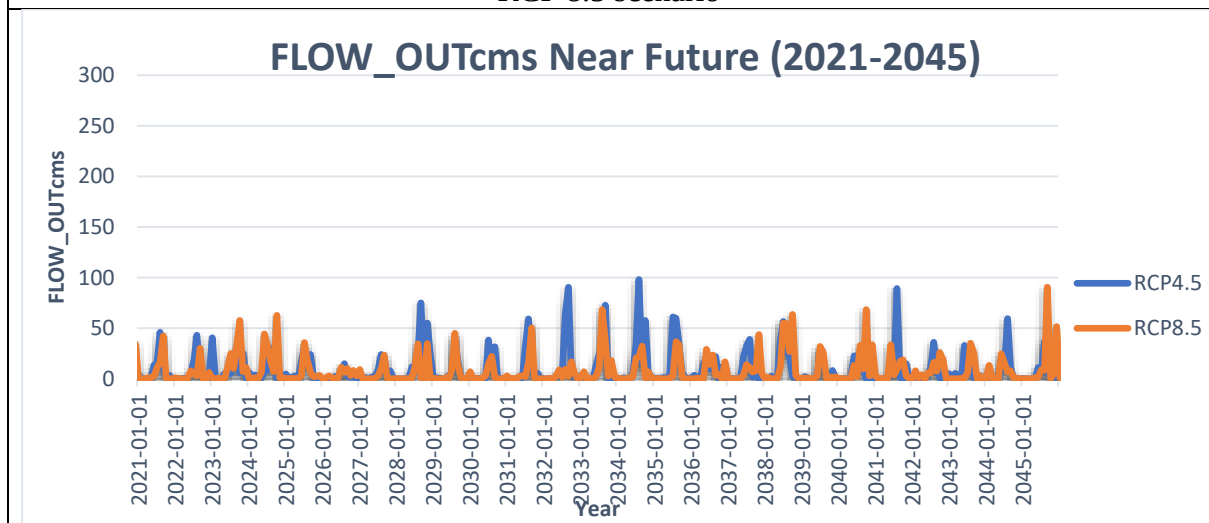


Figure 8.89: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

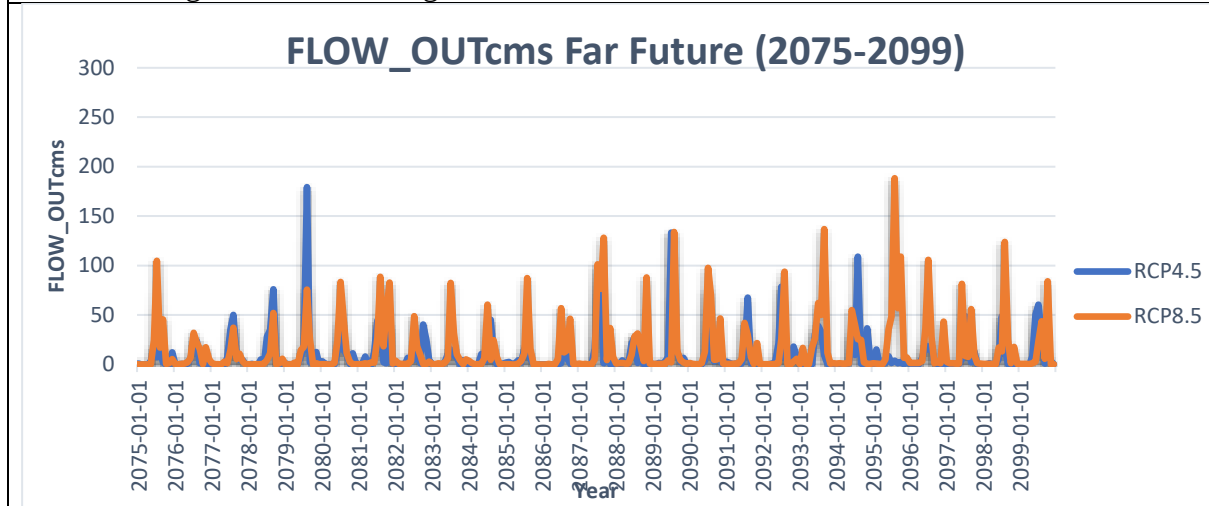


Figure 8.90: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.7 SWAT Model 7 of AID

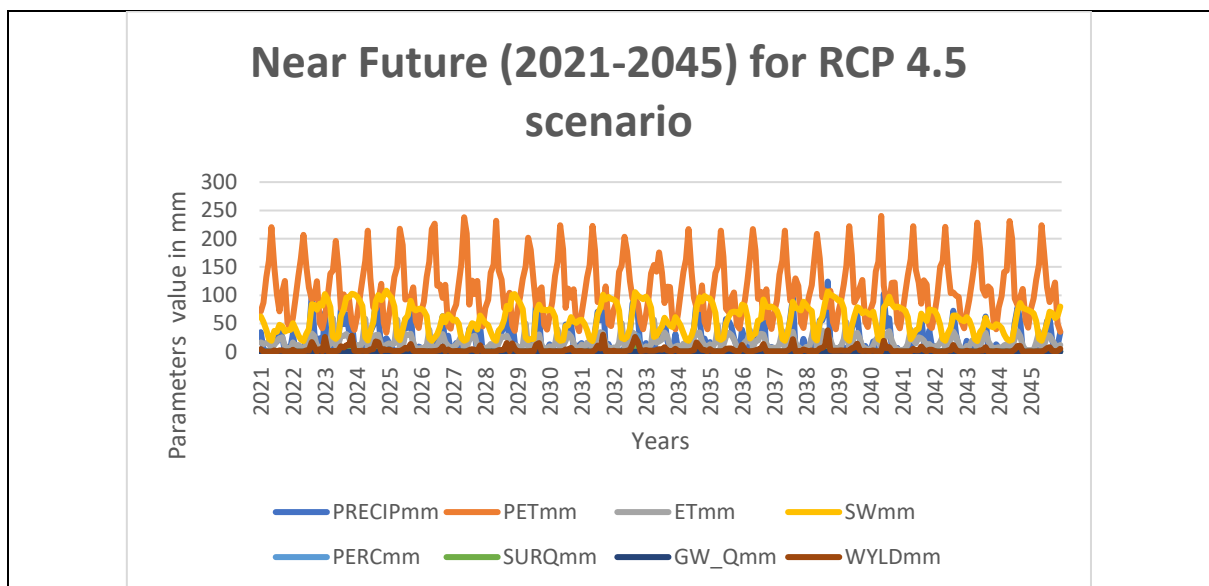


Figure 8.91: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

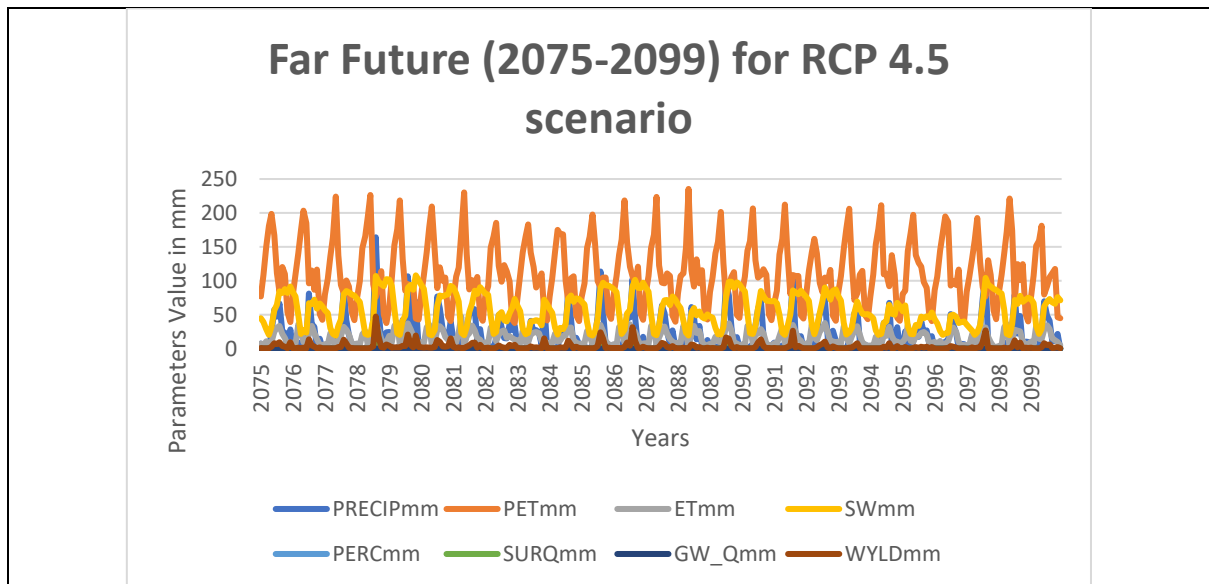


Figure 8.92: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

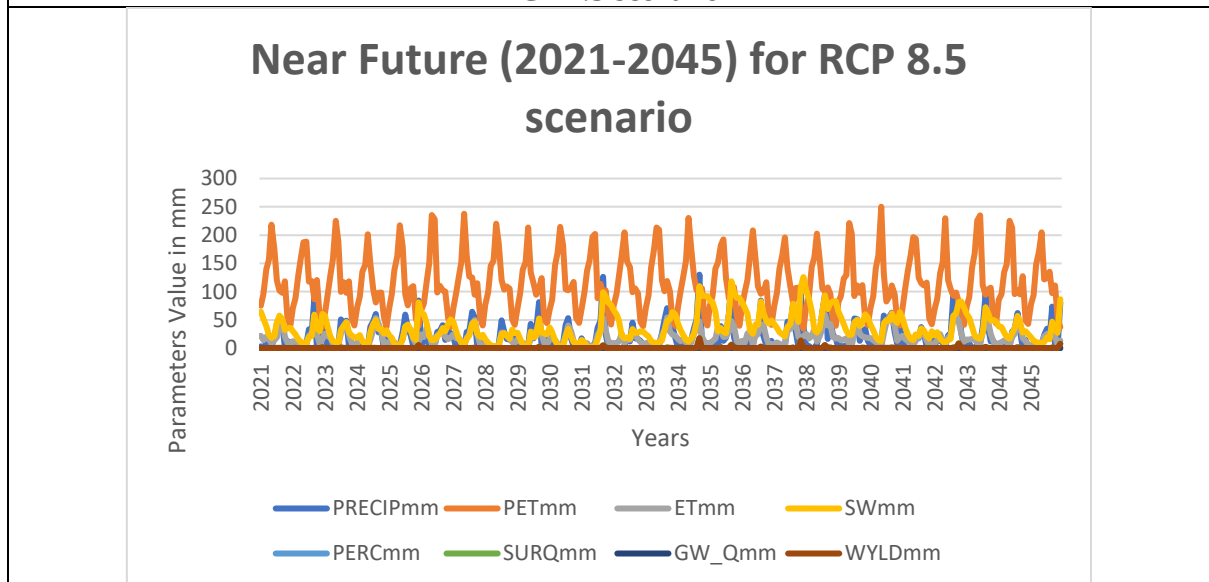


Figure 8.93: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

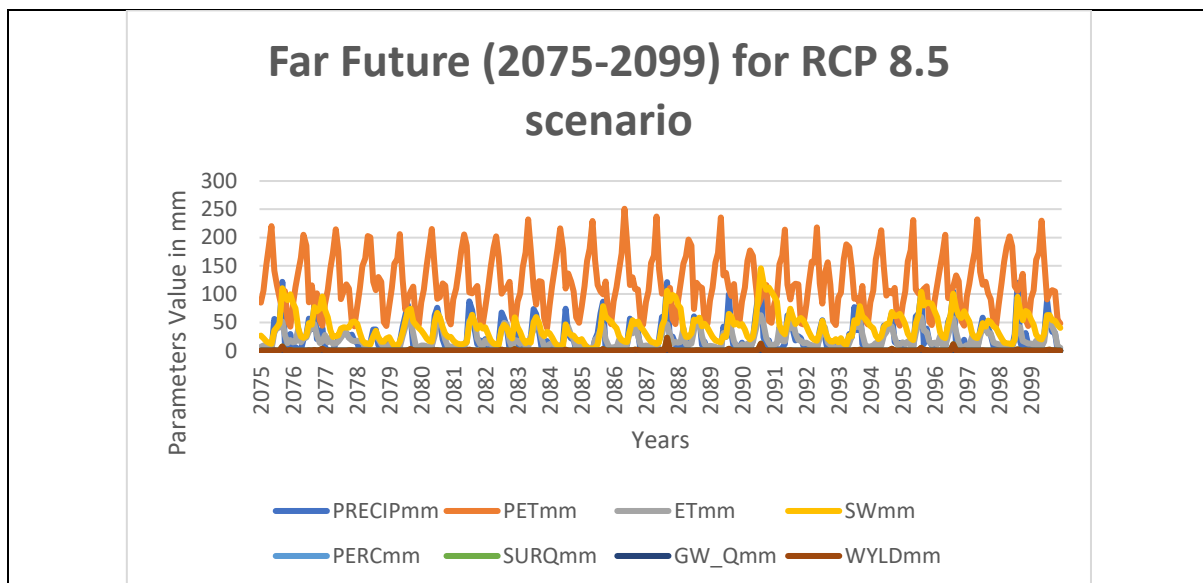


Figure 8.94: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

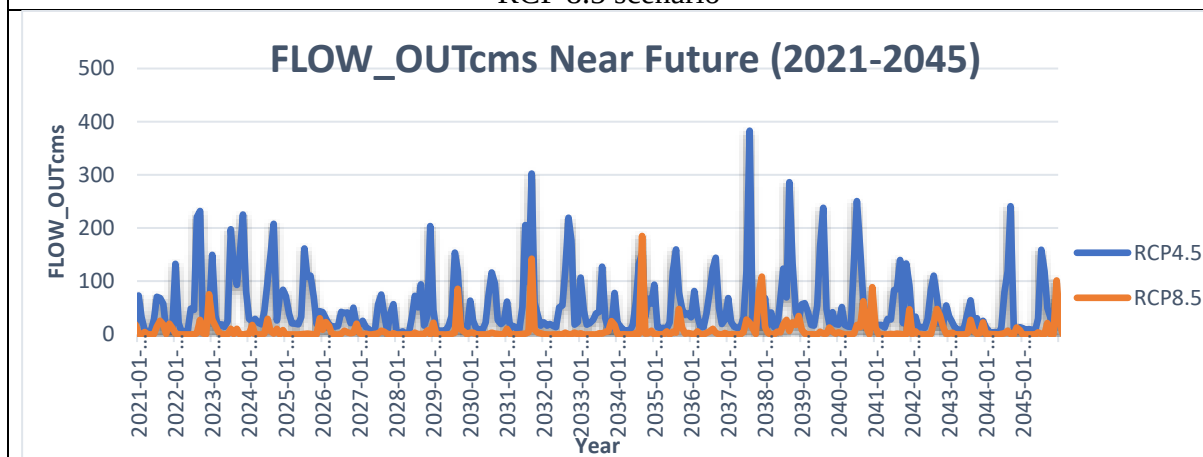


Figure 8.95: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

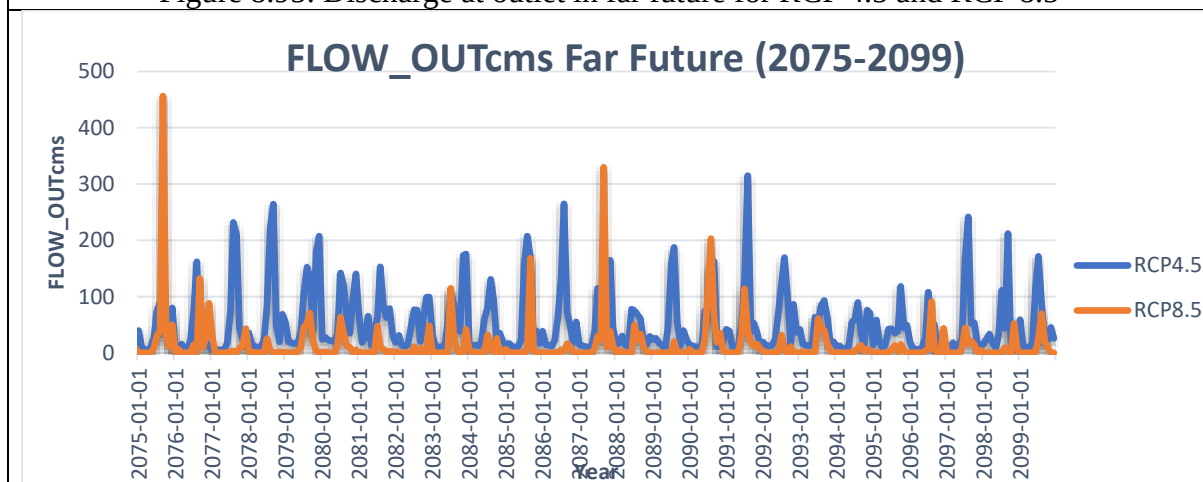


Figure 8.96: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.8 SWAT Model 8 of AID

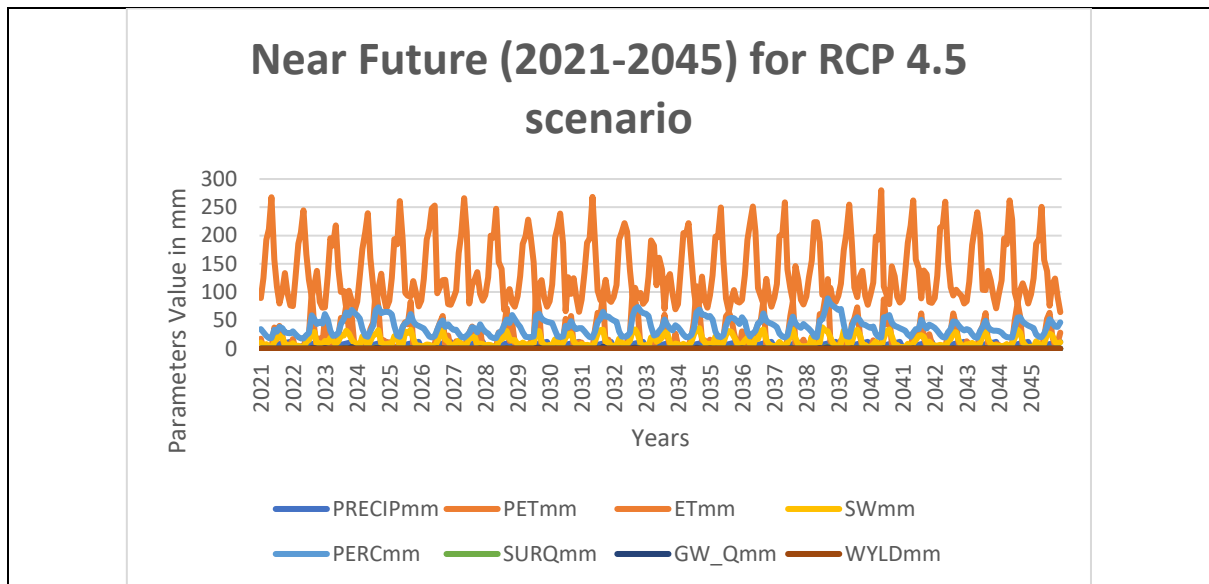


Figure 8.97: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

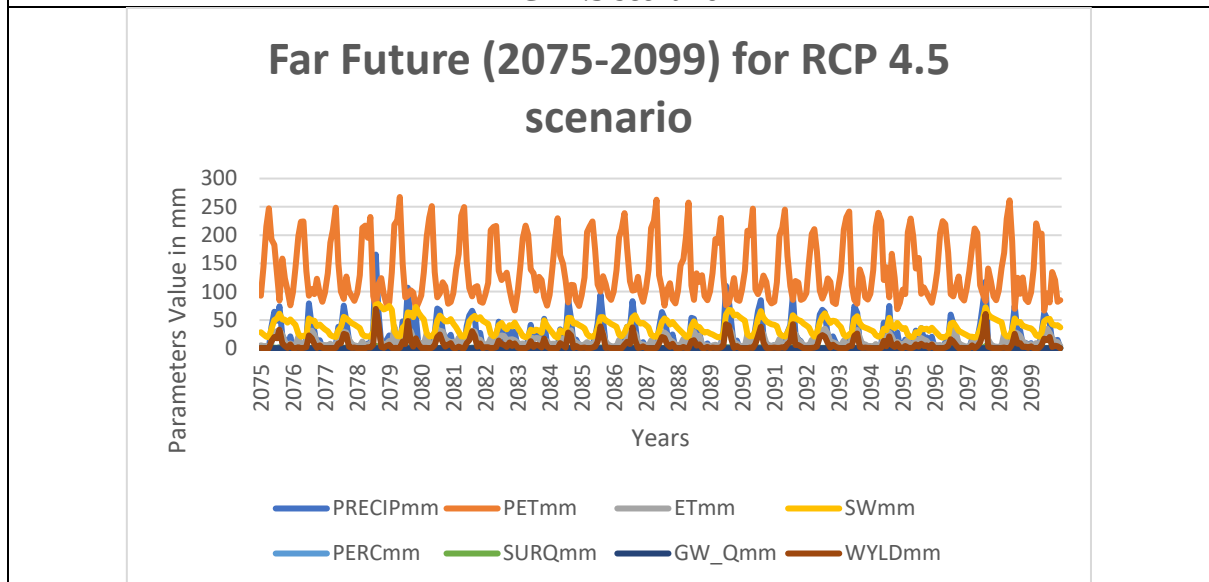


Figure 8.98: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

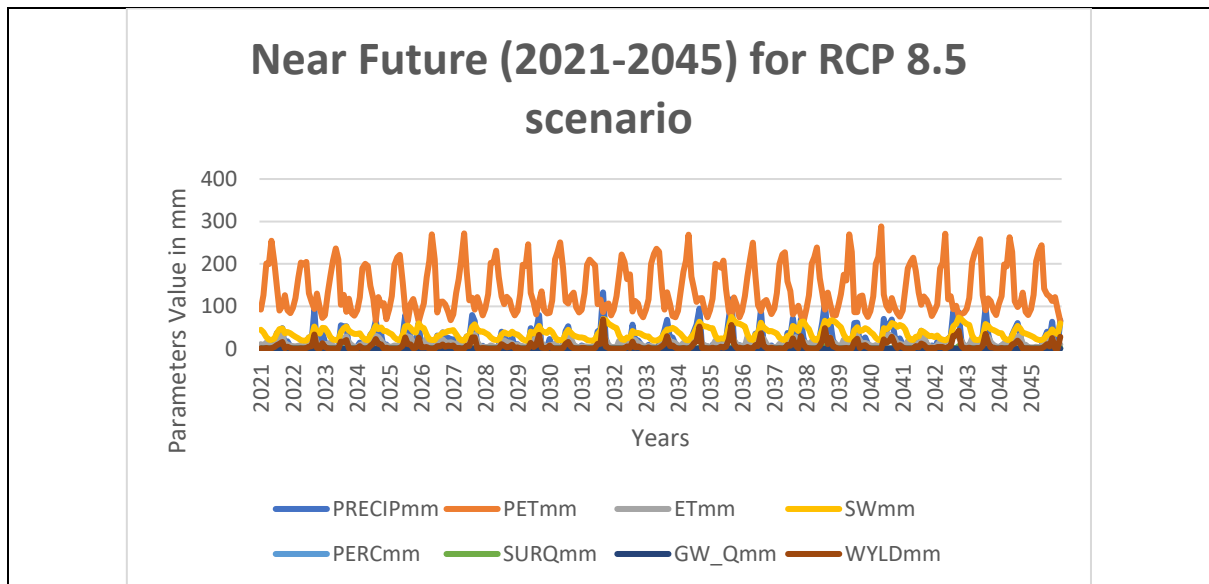


Figure 8.99: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

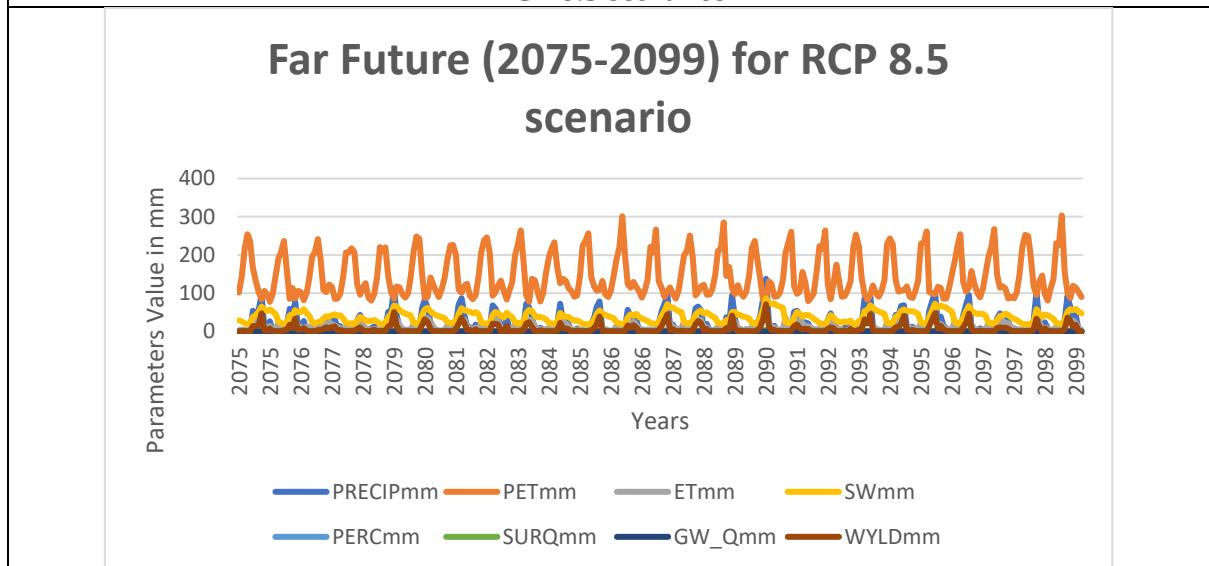


Figure 8.100: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

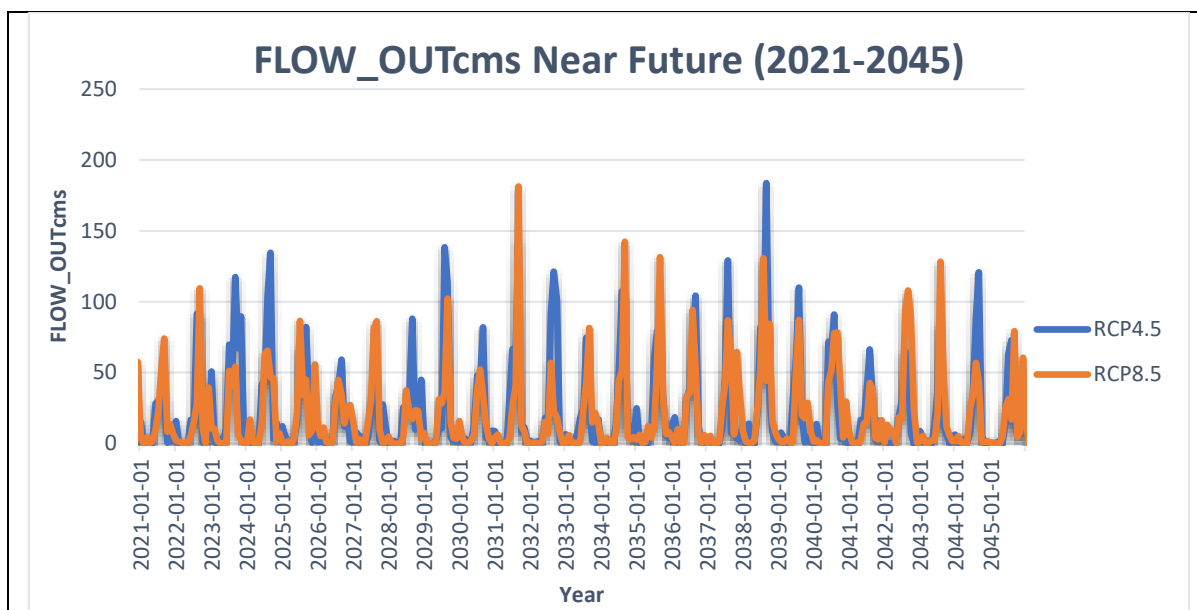


Figure 8.101 Discharge at outlet in far future for RCP 4.5 and RCP 8.5

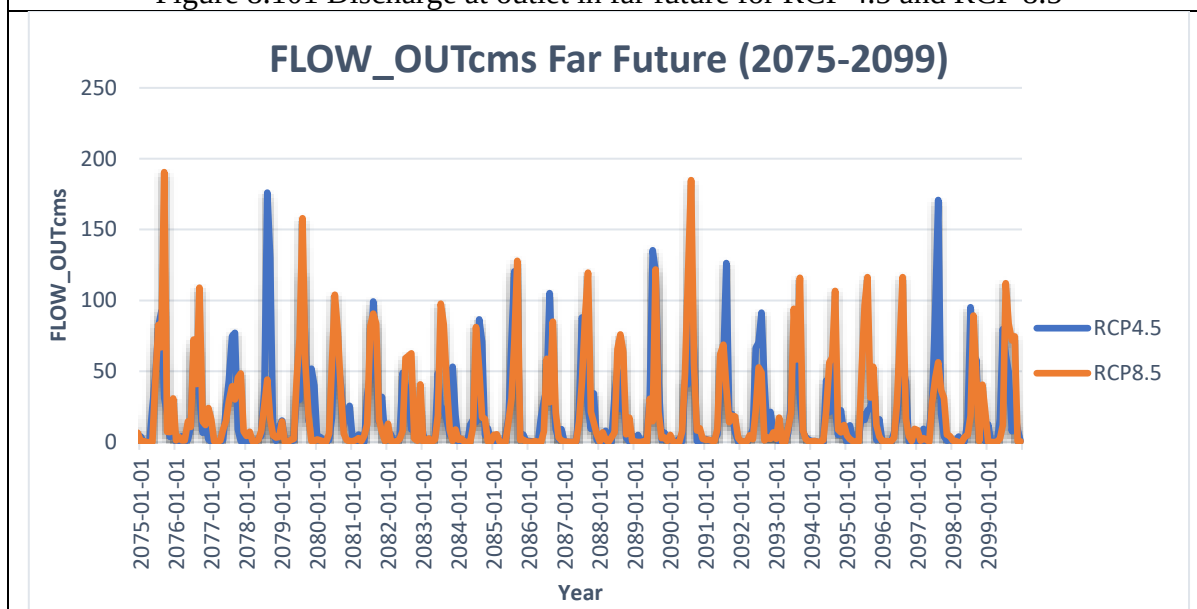


Figure 8.102: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.9 SWAT Model 9 of AID

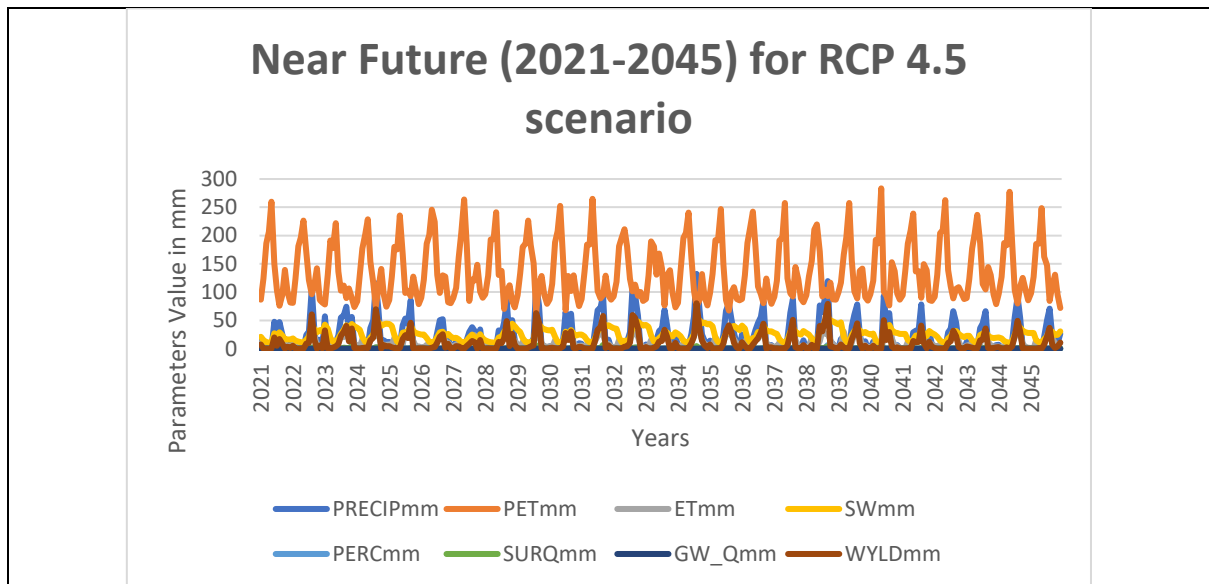


Figure 8.103: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

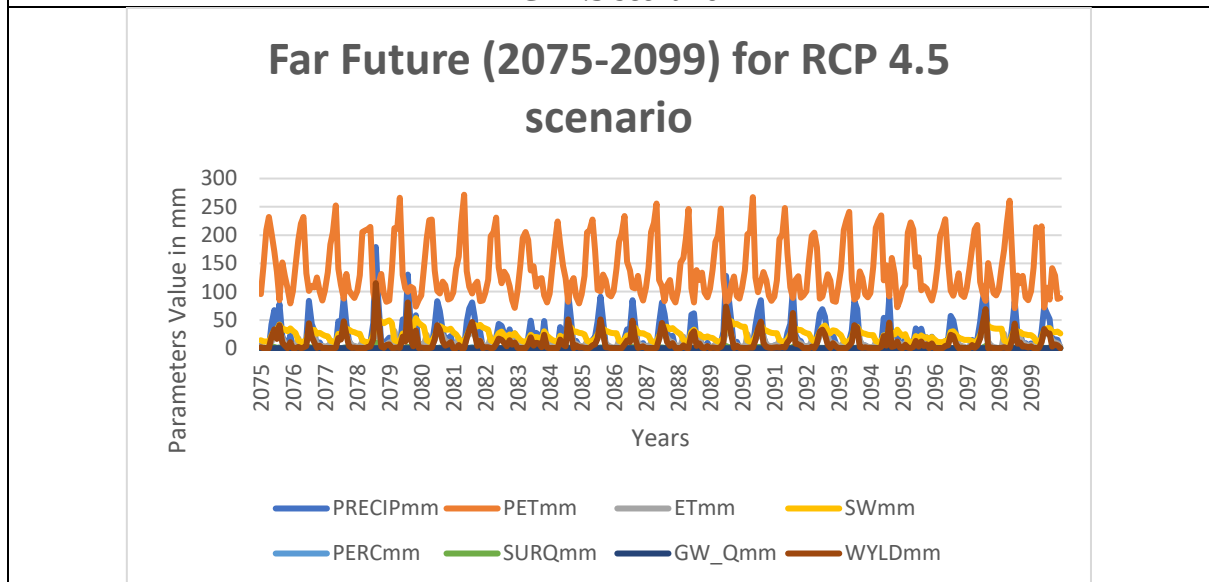


Figure 8.104: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

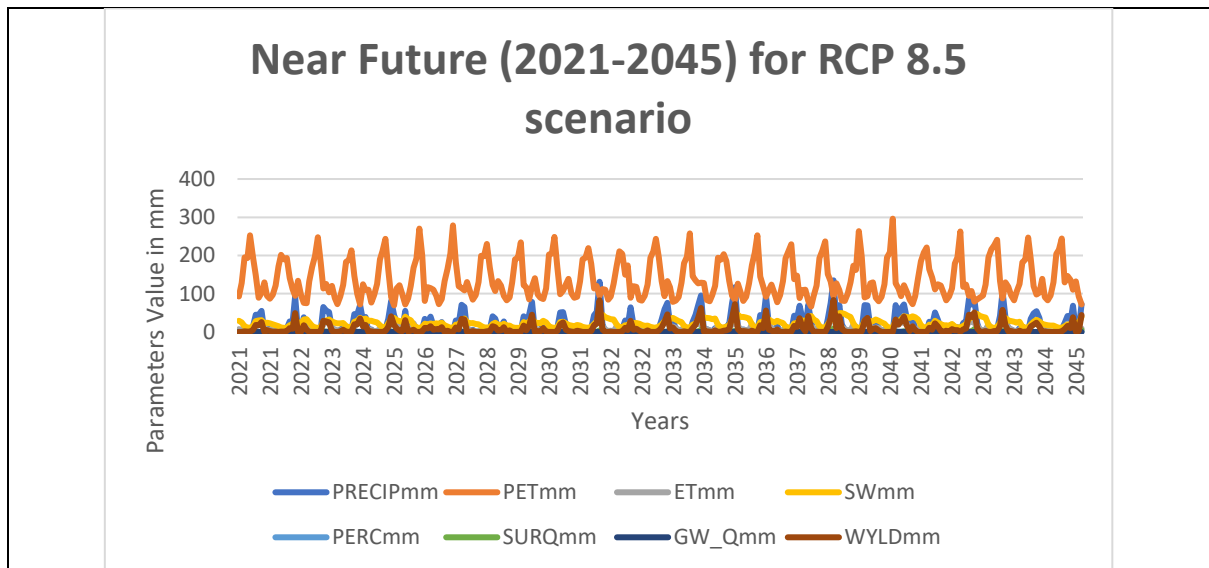


Figure 8.105: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

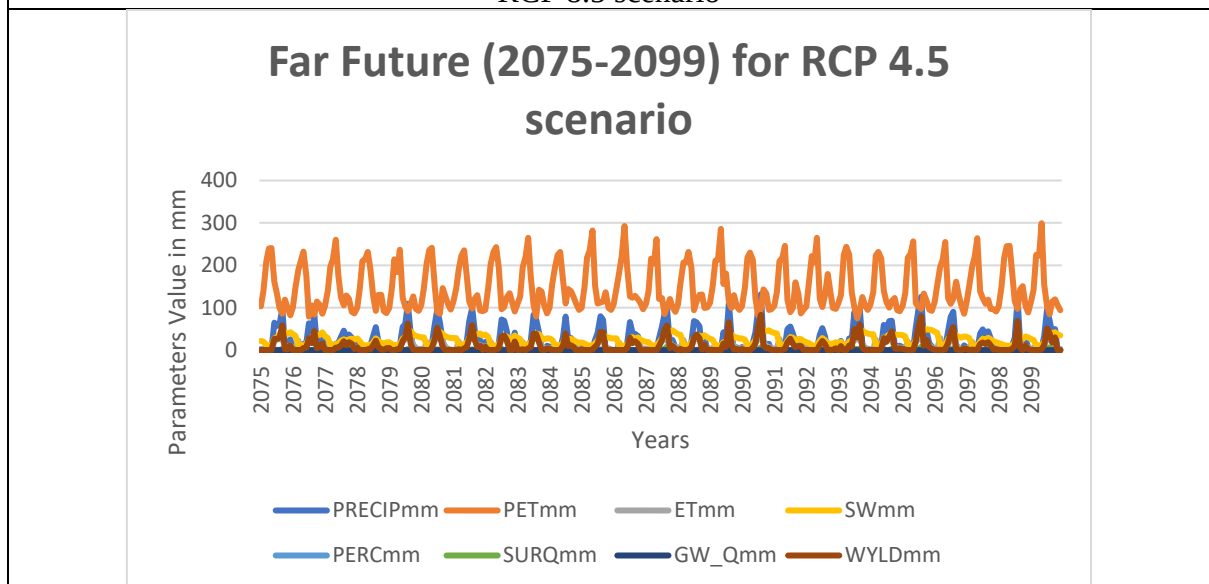


Figure 8.106: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

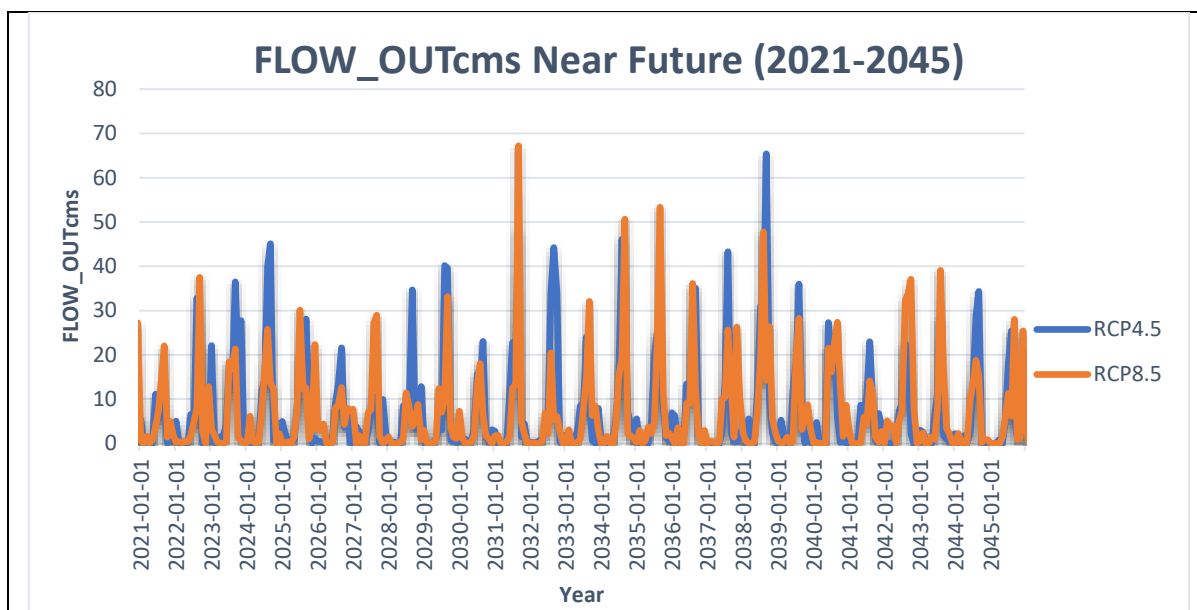


Figure 8.107: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

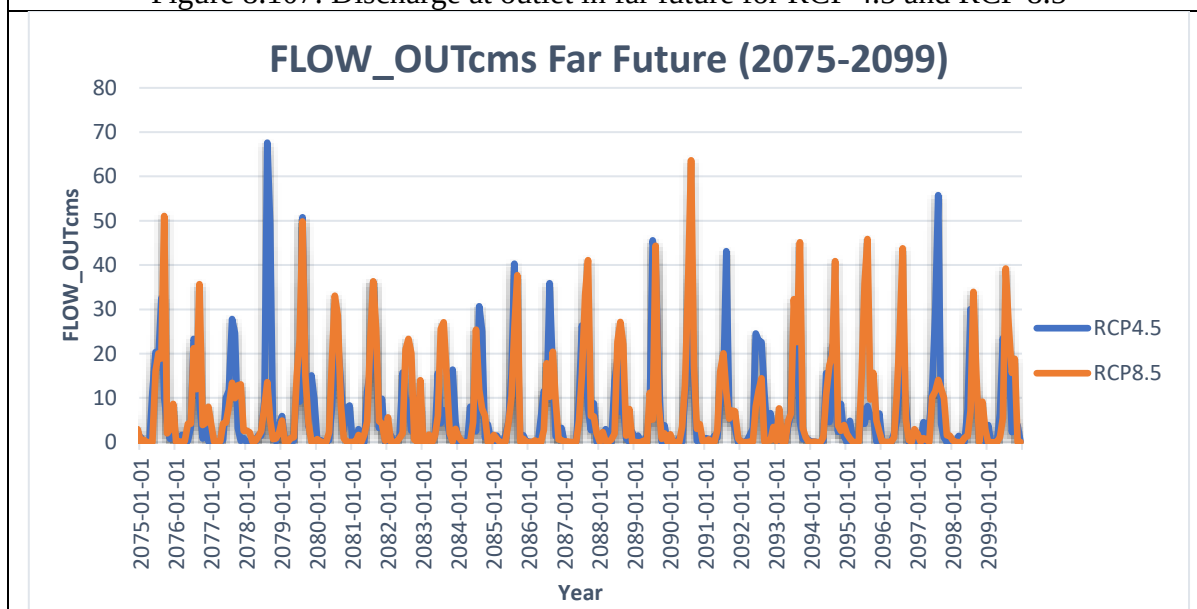


Figure 8.108: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.10 SWAT Model 10 of AID

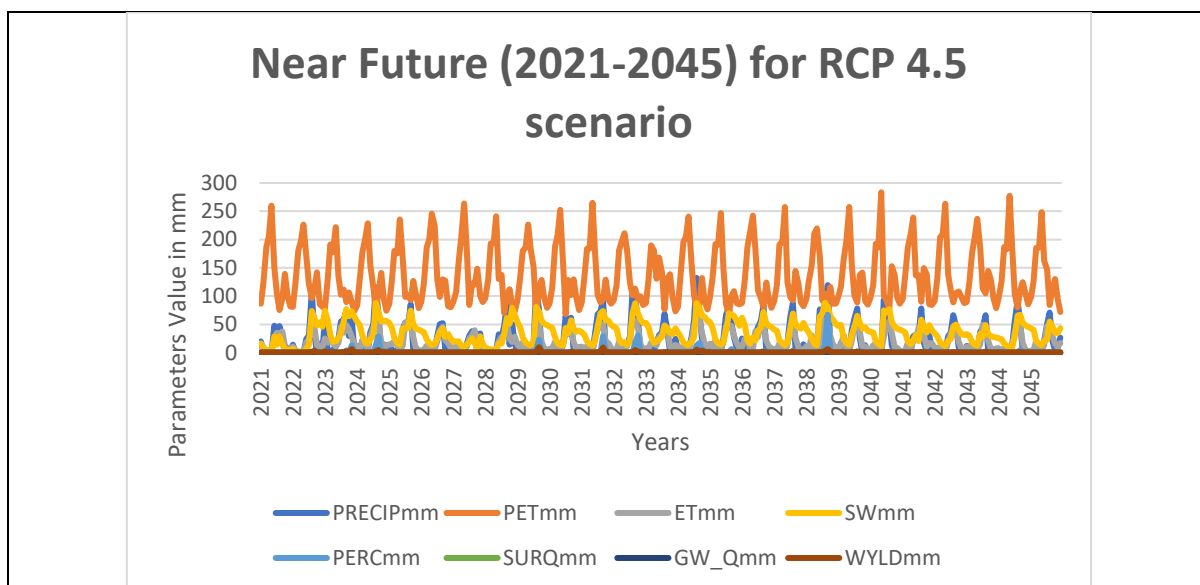


Figure 8.109 : Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

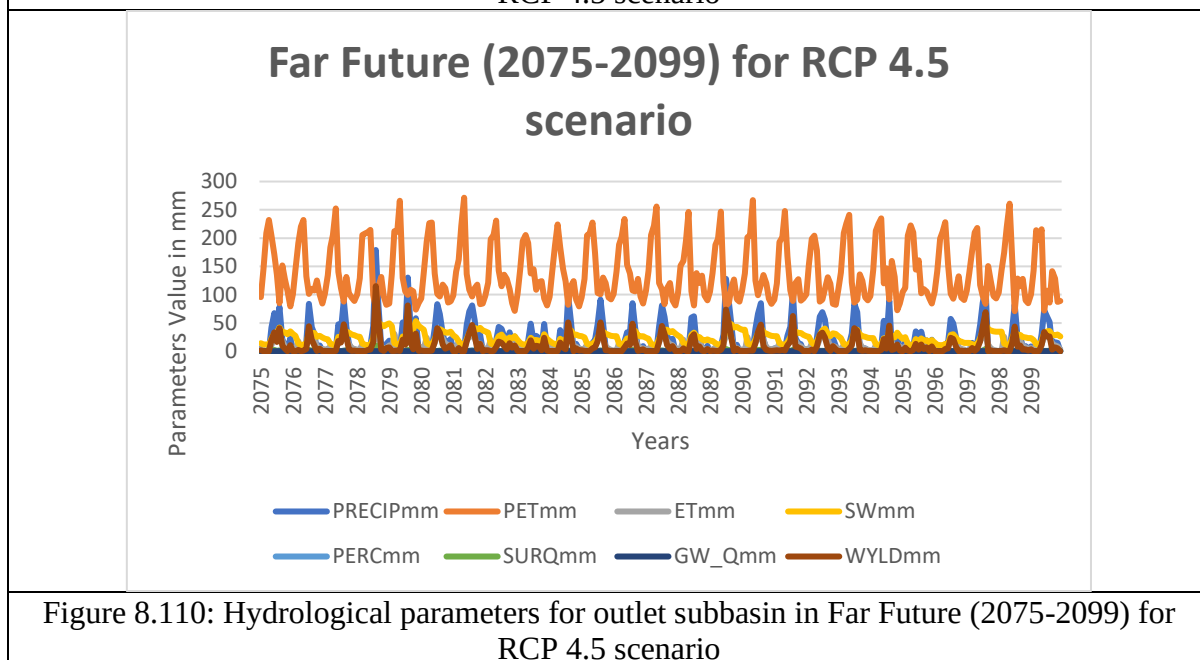


Figure 8.110: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

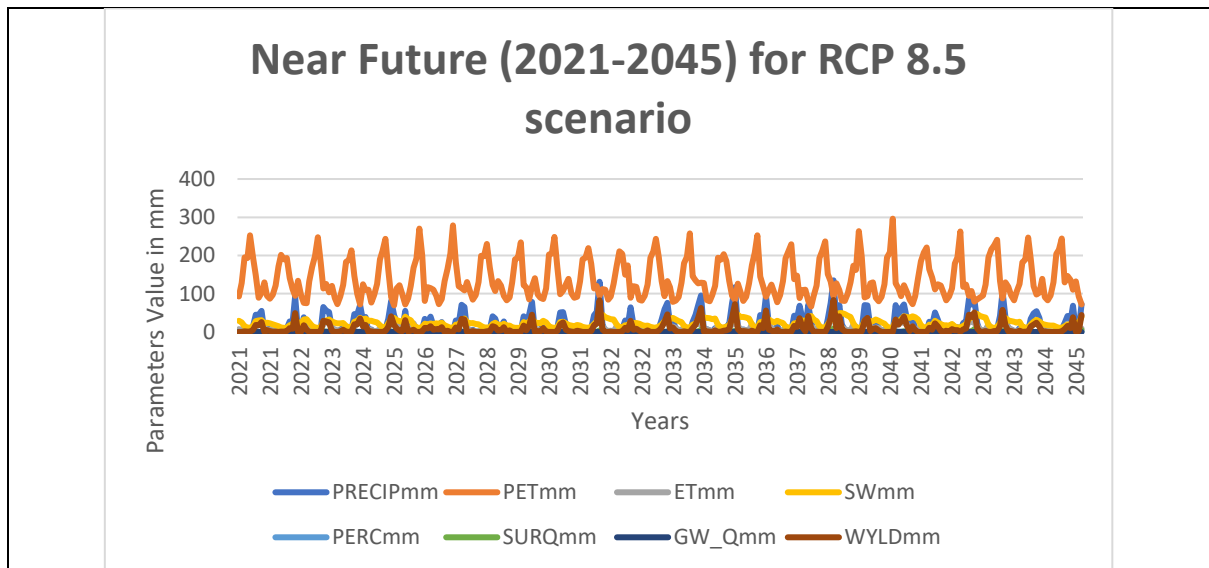


Figure 8.111: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

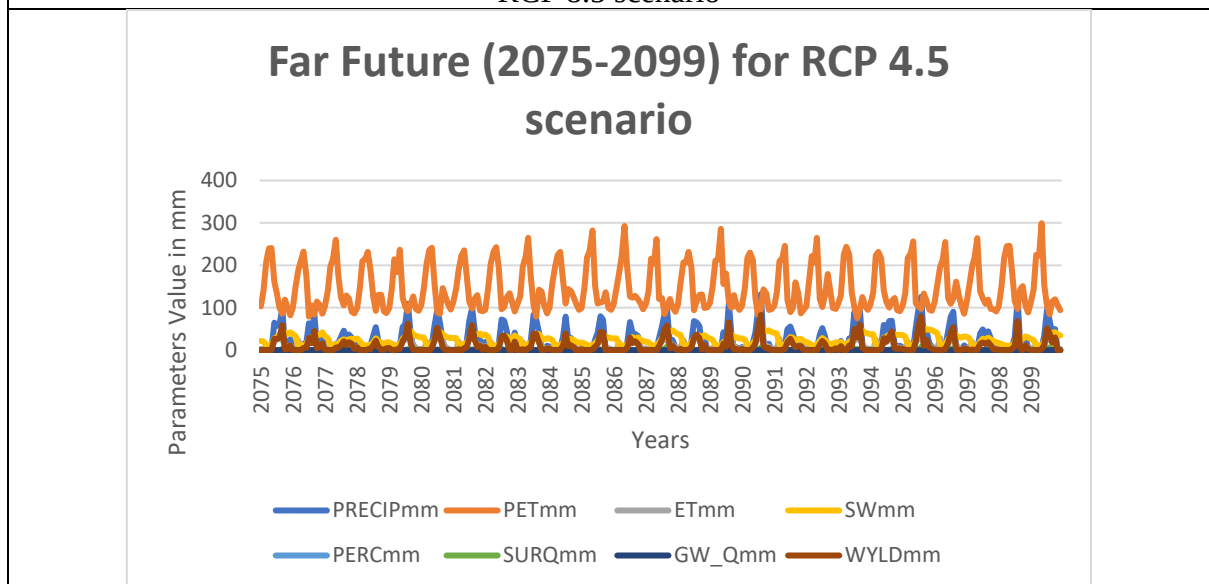


Figure 8.112: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

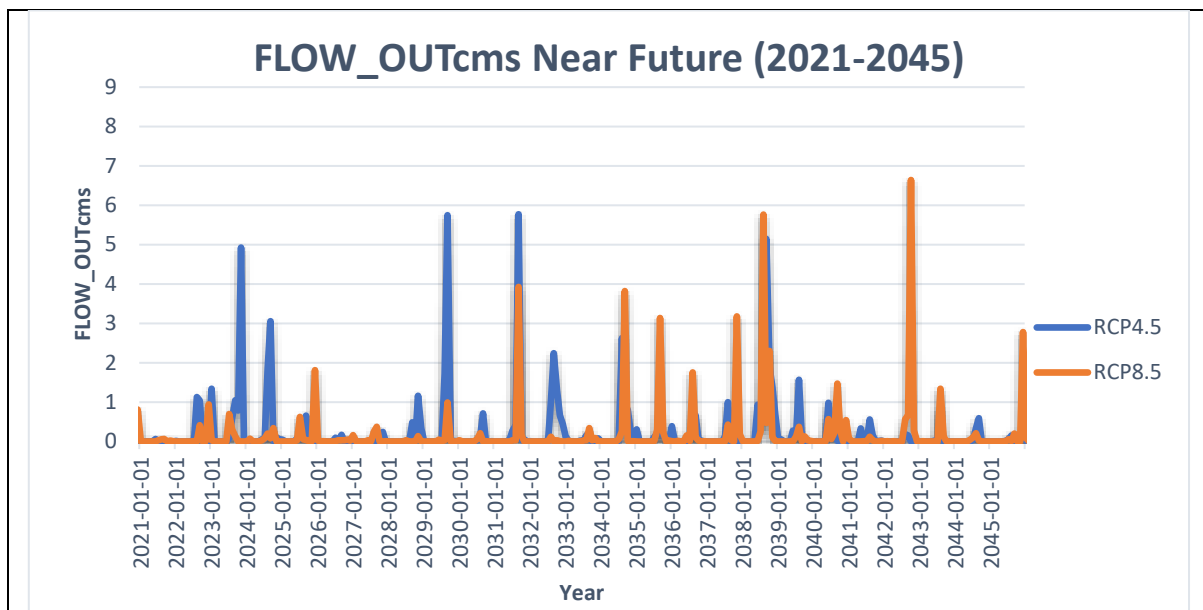


Figure 8.113: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

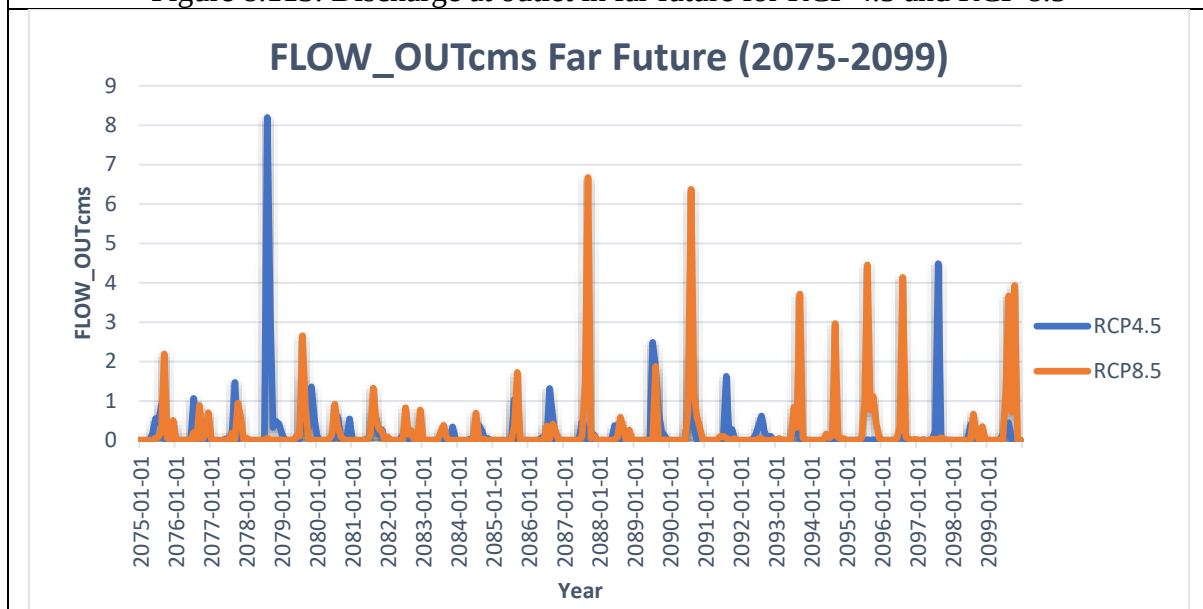


Figure 8.114: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.11 SWAT Model 11 of AID

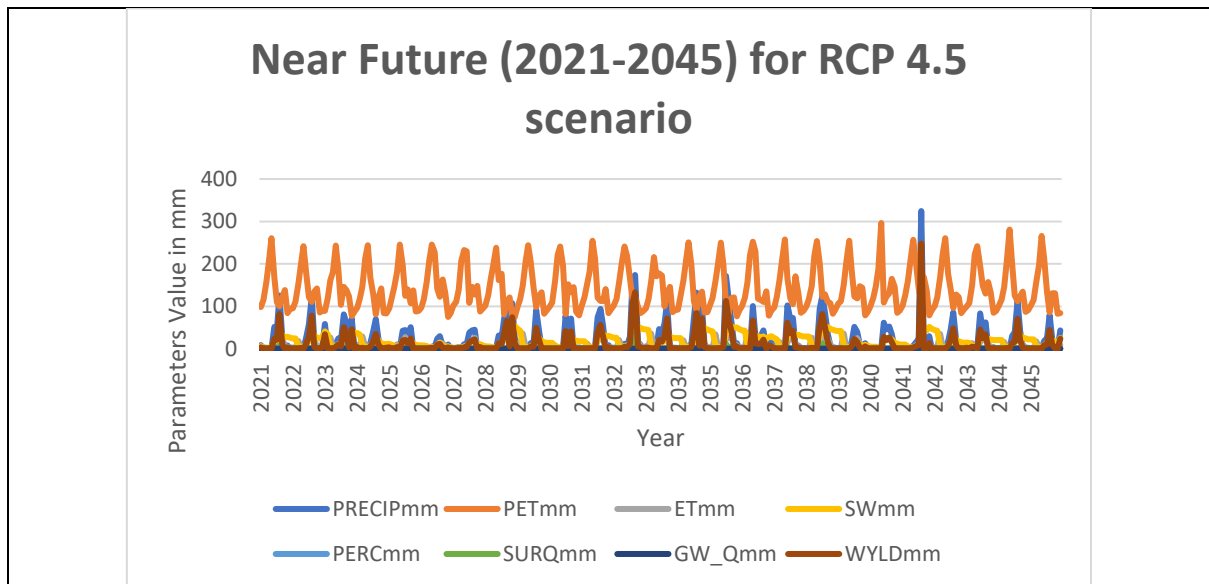


Figure 8.115: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

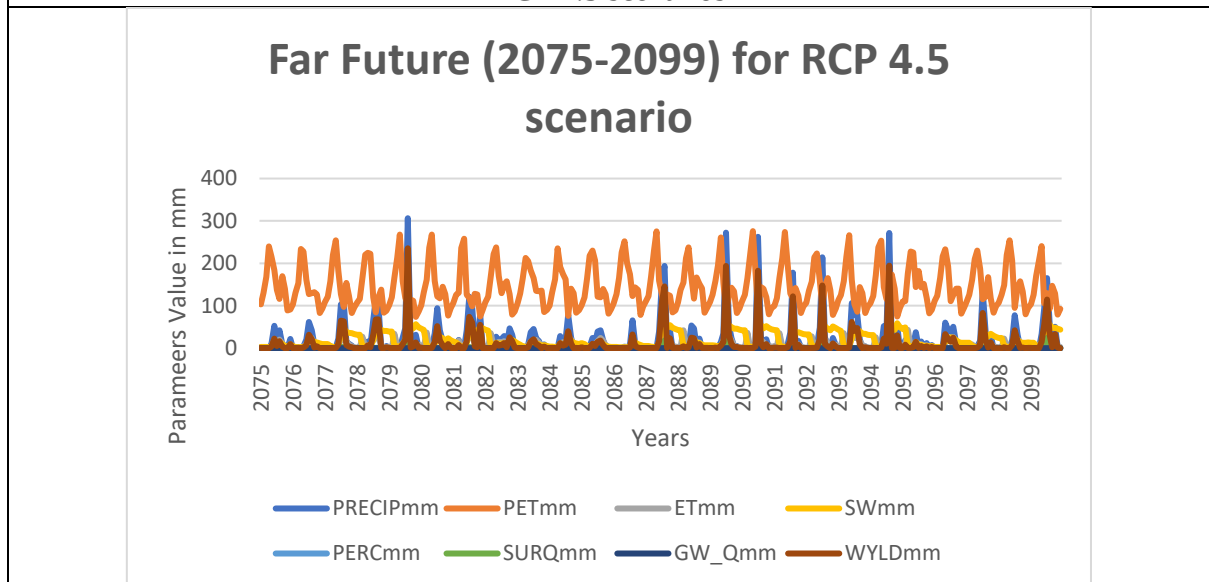


Figure 8.116: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

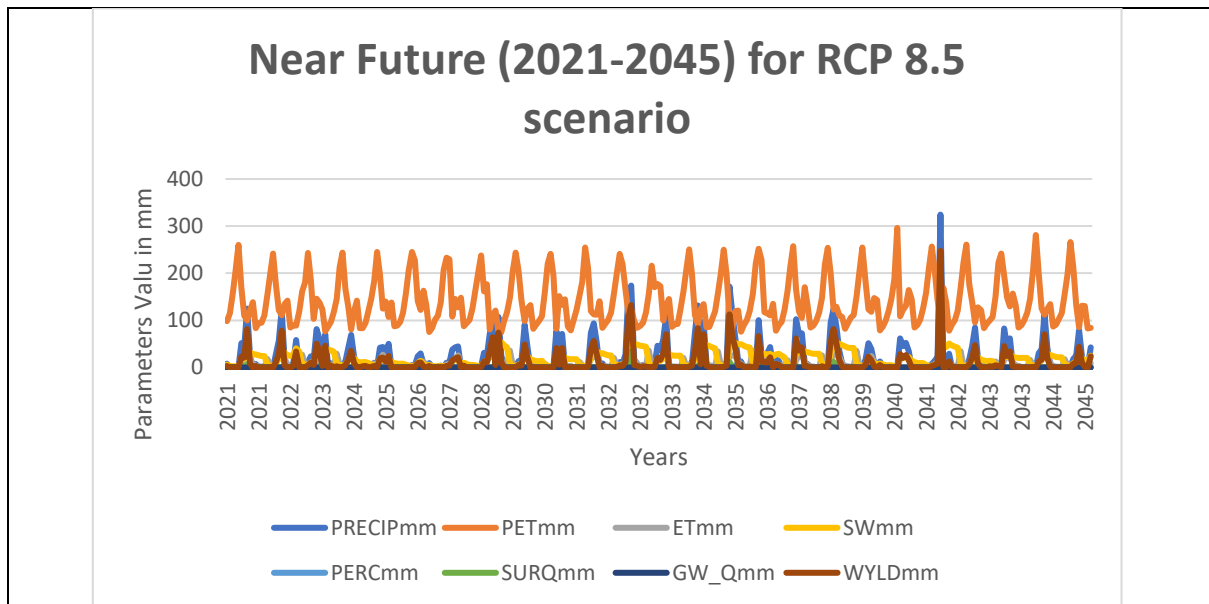


Figure 8.117: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

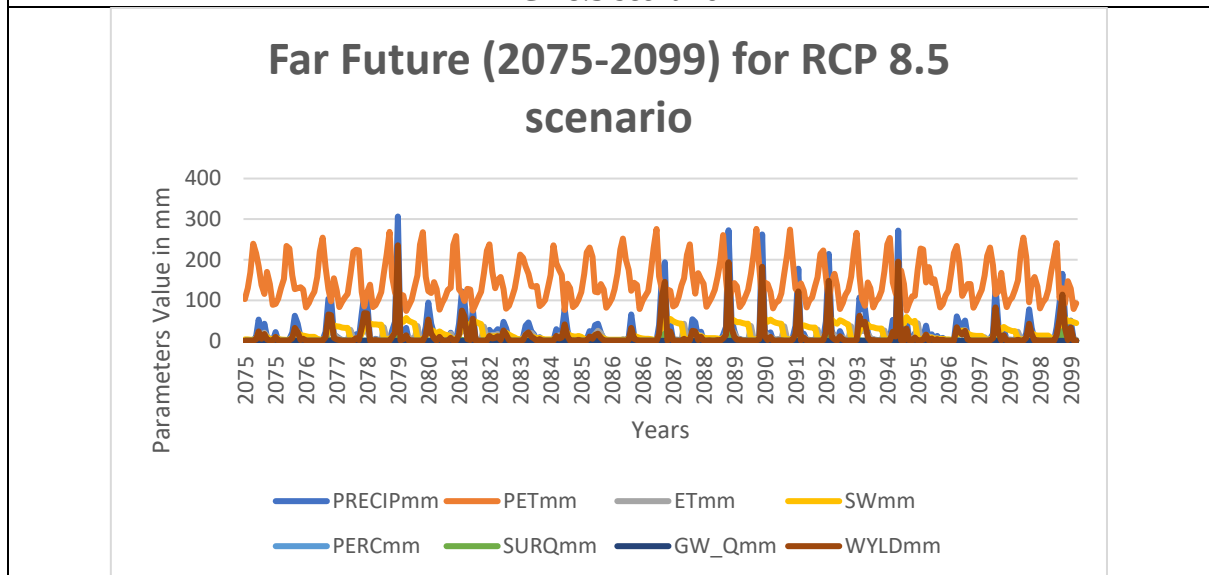


Figure 8.118: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

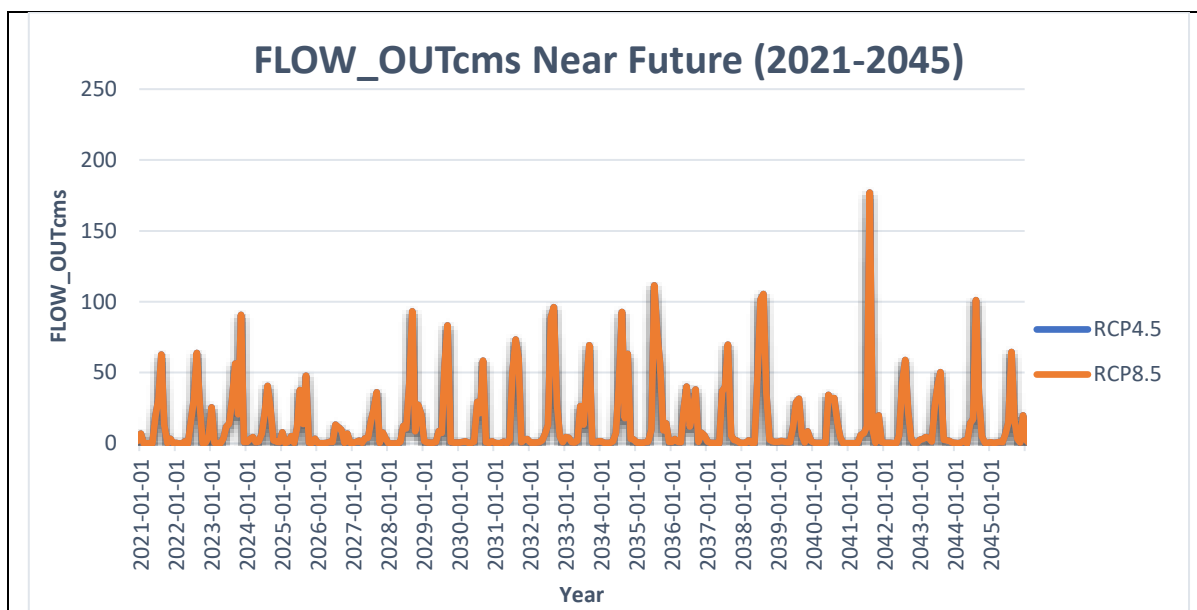


Figure 8.119: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

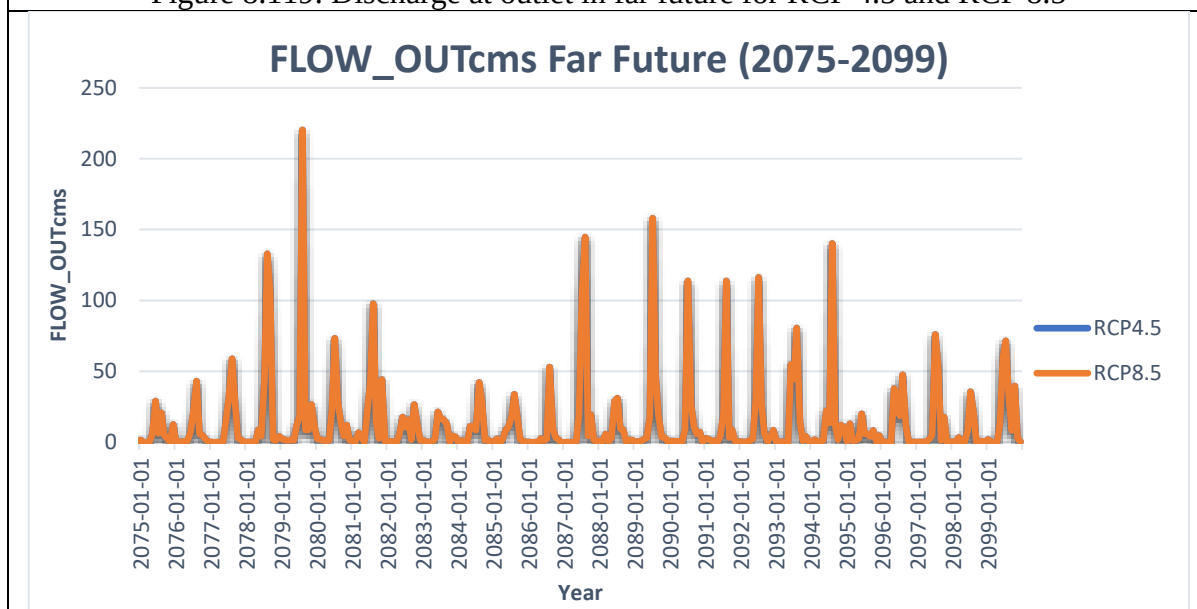


Figure 8.120: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.12 SWAT Model 12 of AID

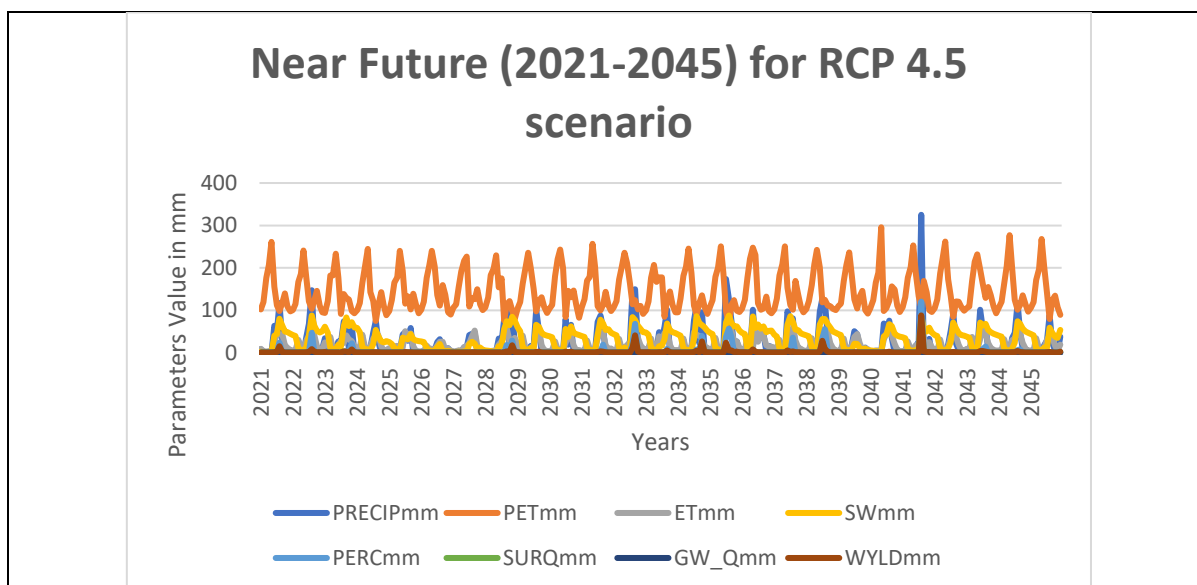


Figure 8.121: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

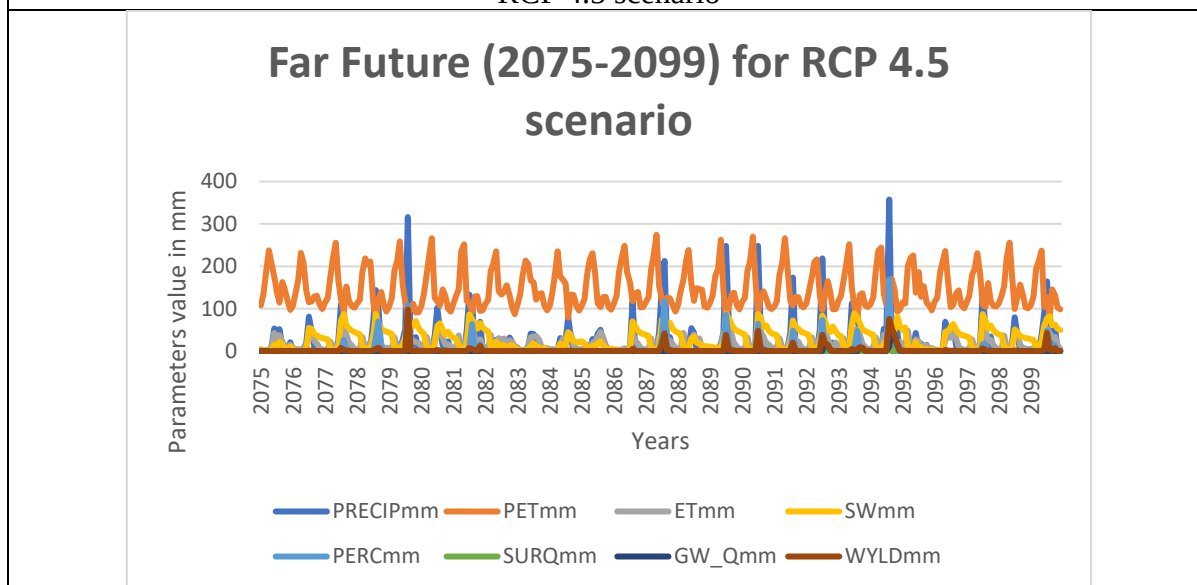


Figure 8.122: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

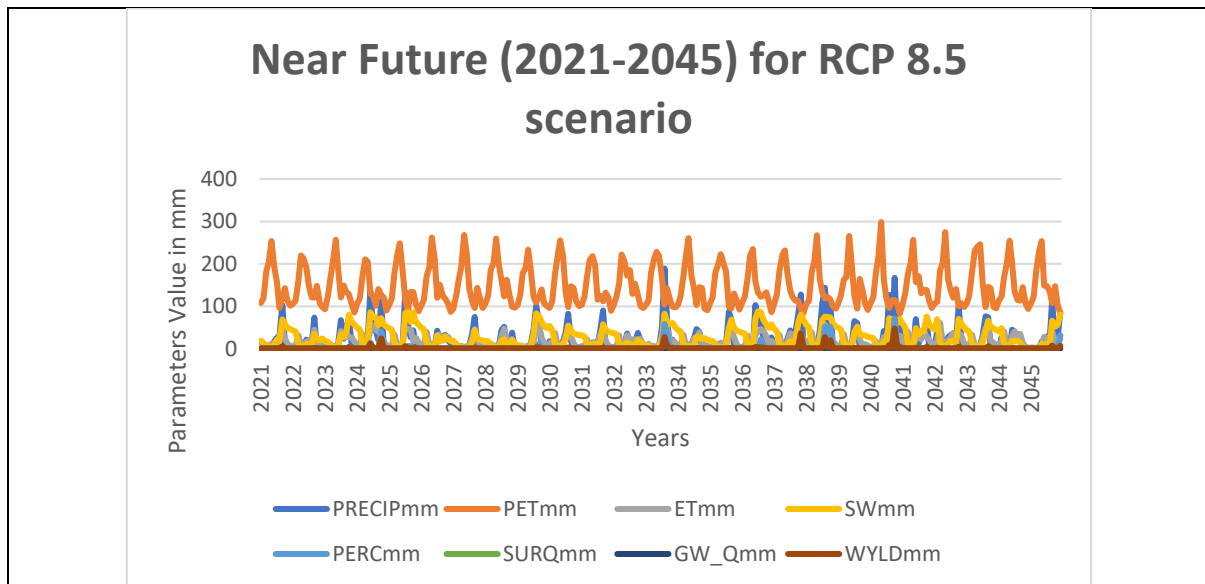


Figure 8.123: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

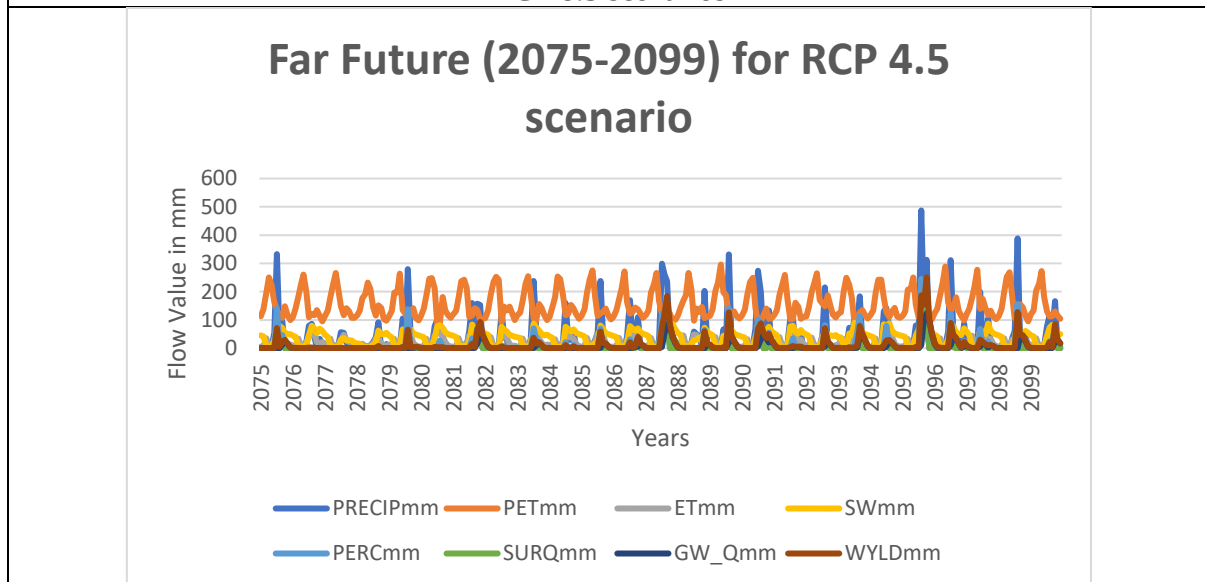


Figure 8.124: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

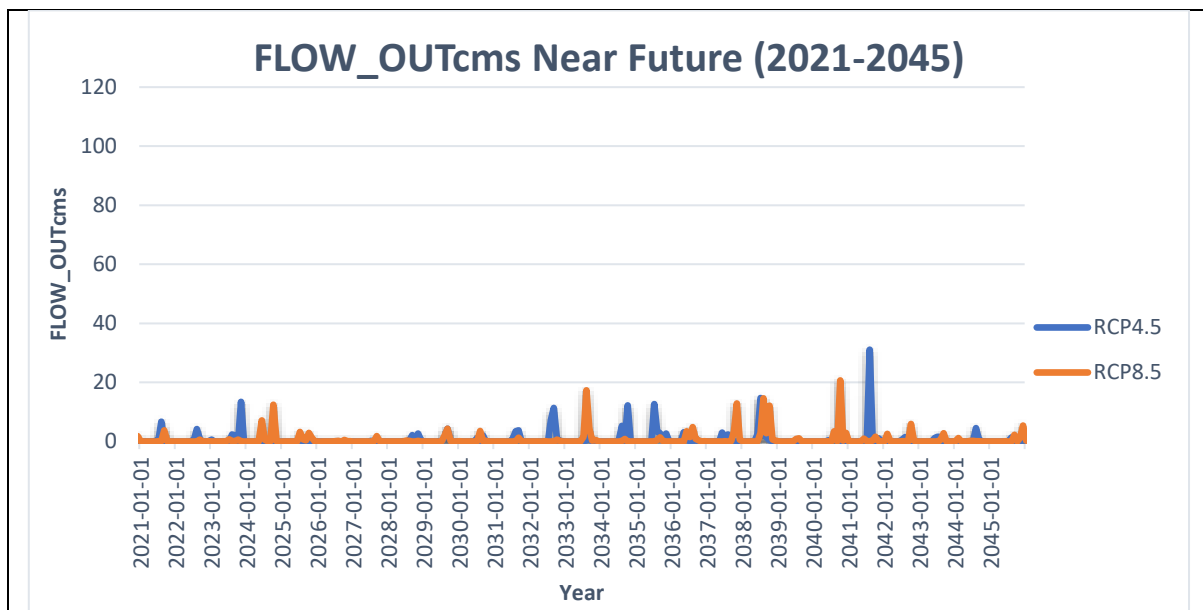


Figure 8.125: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

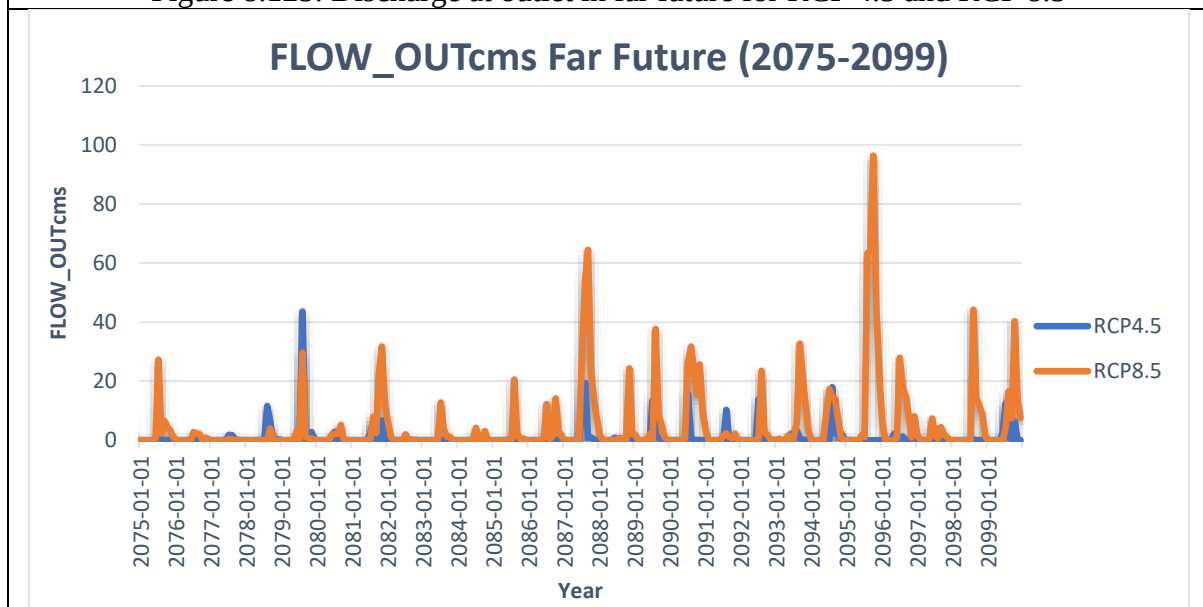


Figure 8.126: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.13 SWAT Model 13 of AID

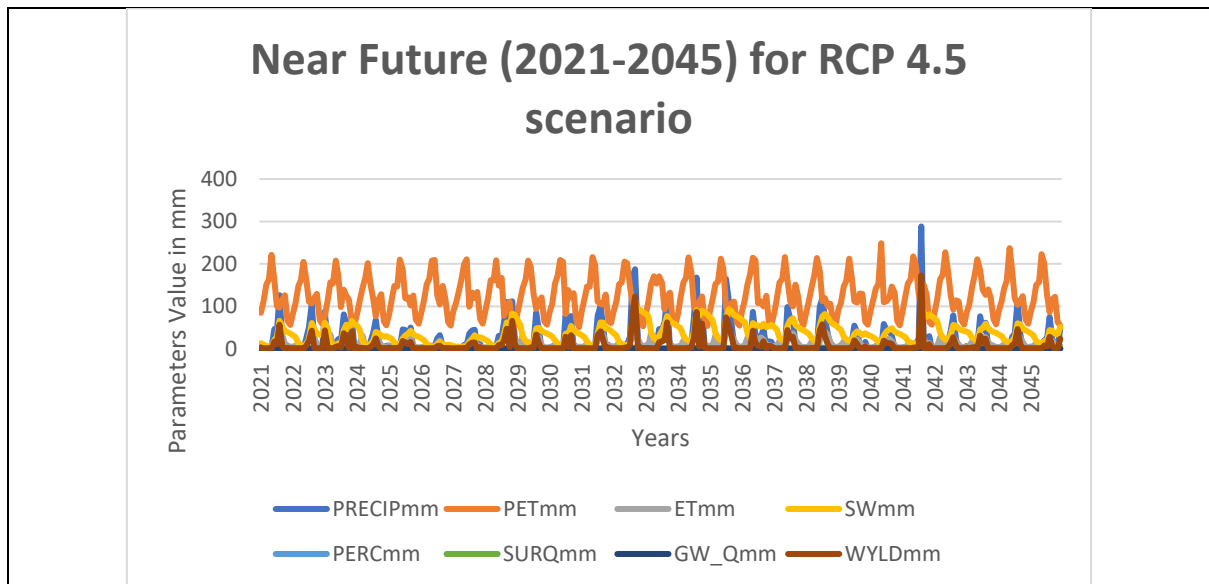


Figure 8.127: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

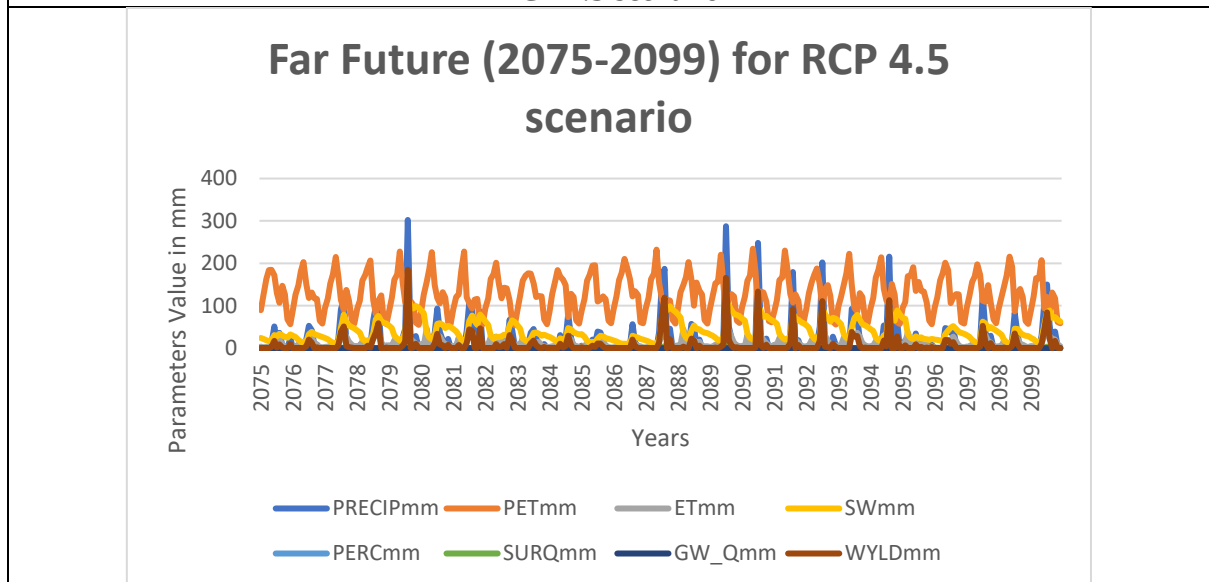


Figure 8.128: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

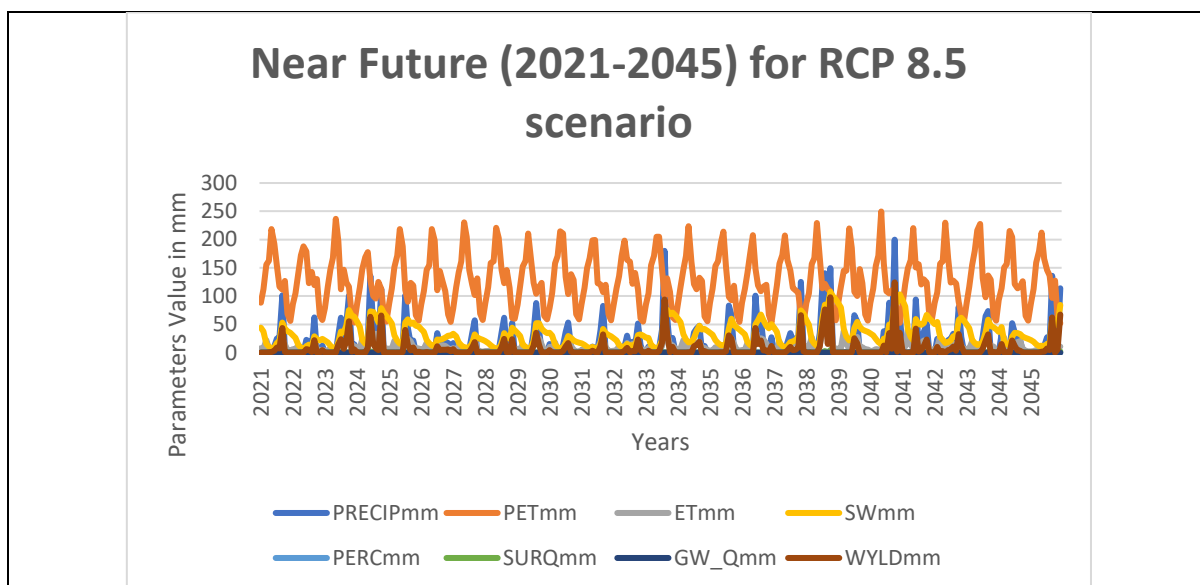


Figure 8.129: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

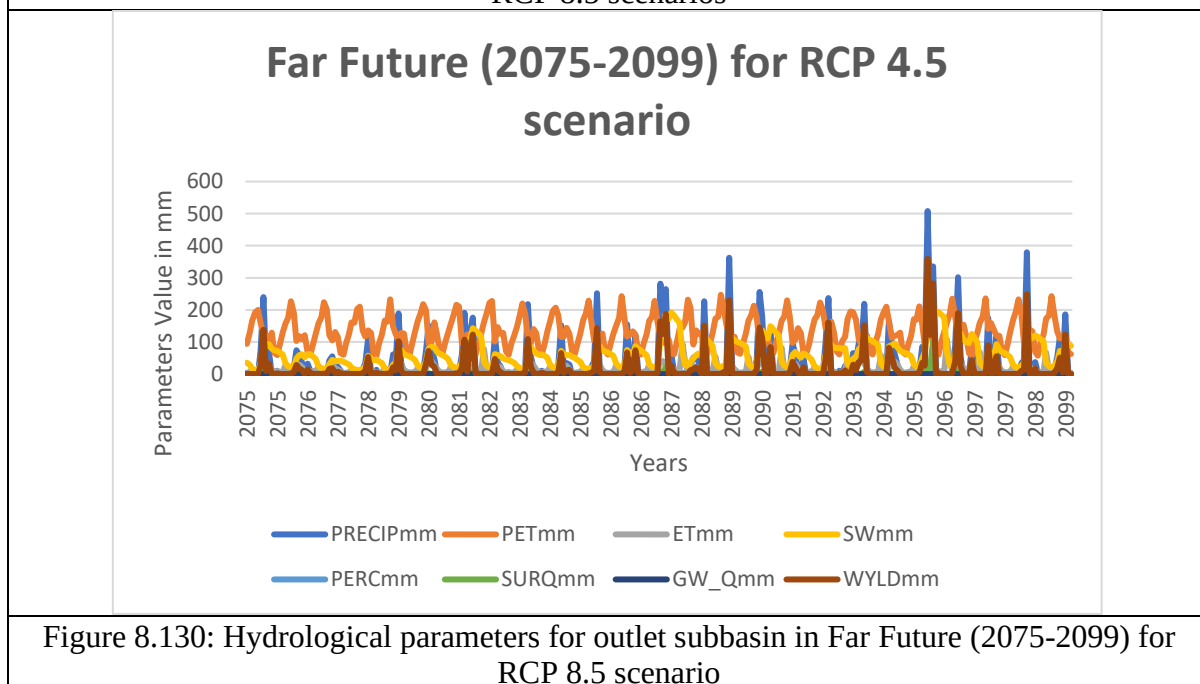


Figure 8.130: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

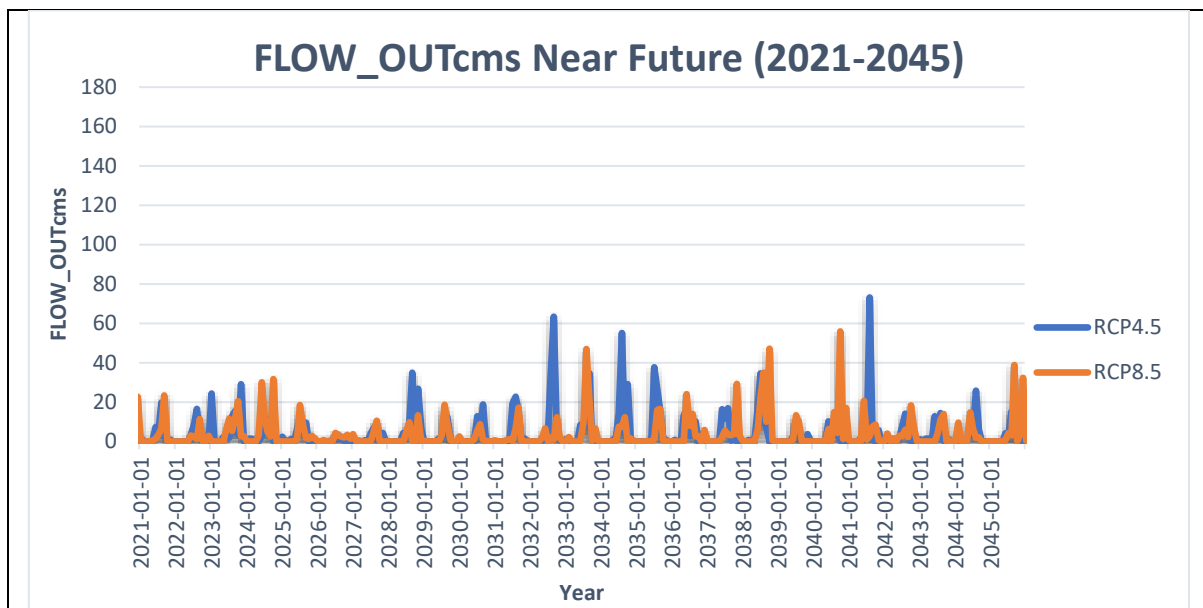


Figure 8.131: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

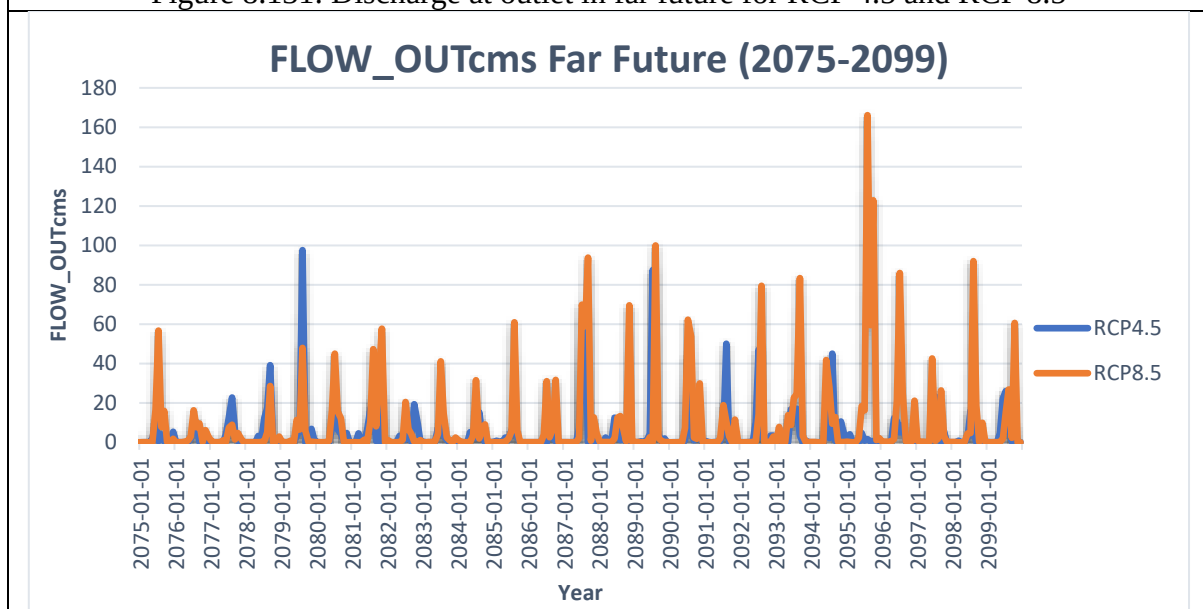


Figure 8.132: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.14 SWAT Model 14 of AID

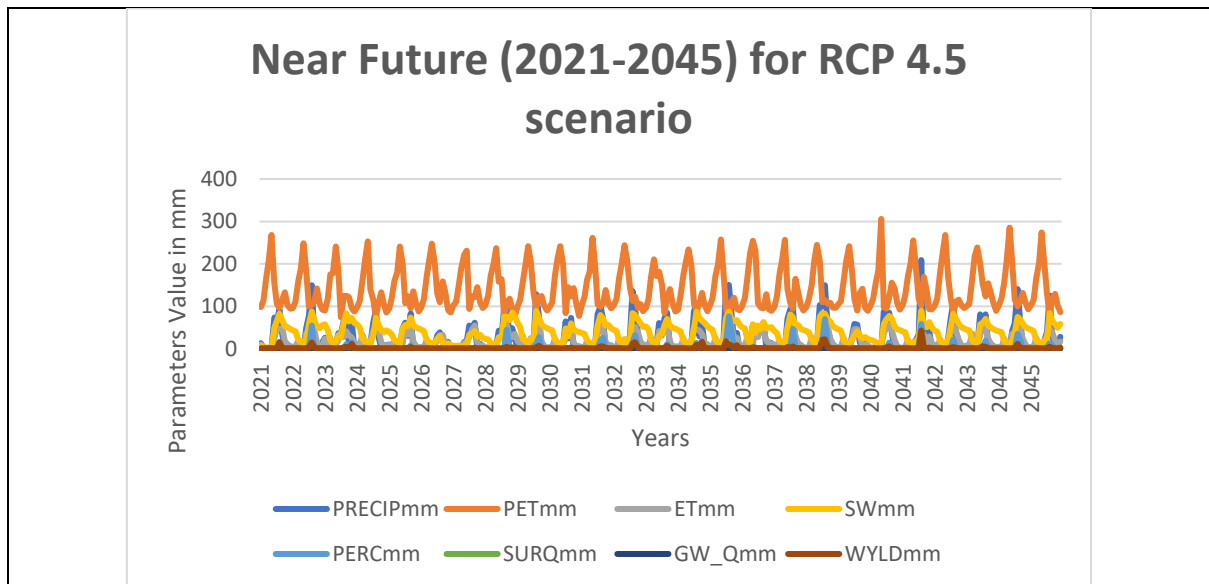


Figure 8.133: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

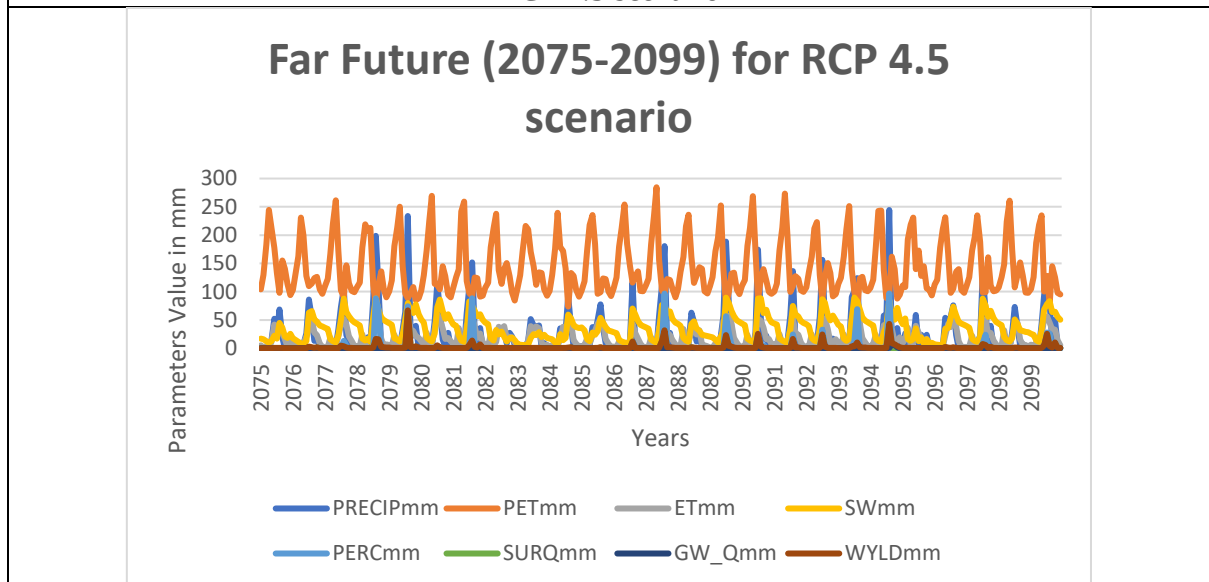


Figure 8.134: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

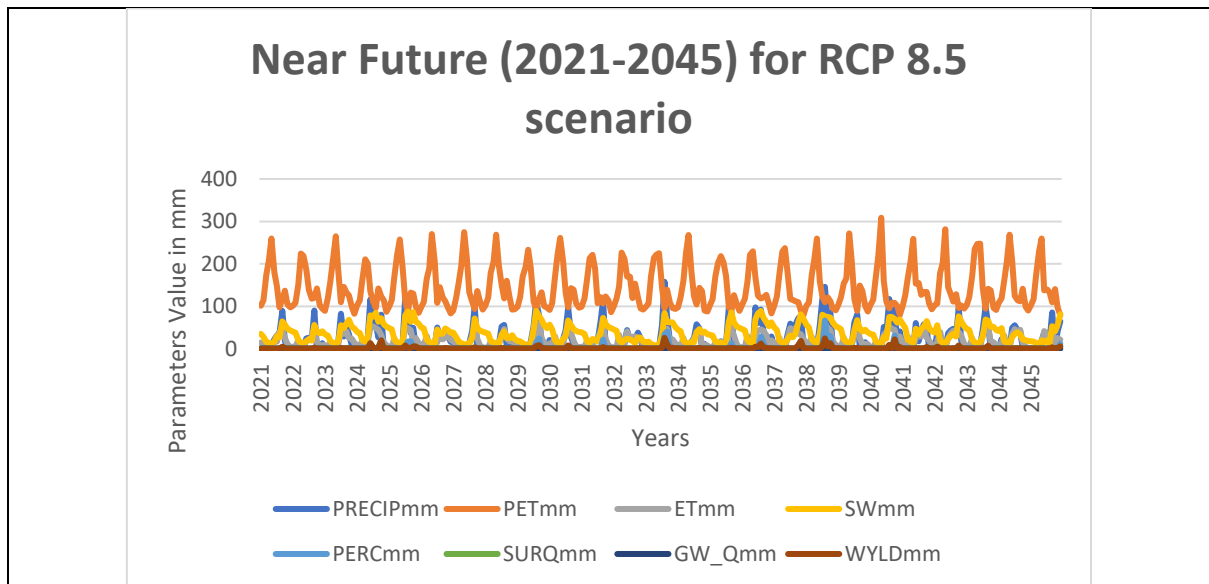


Figure 8.135: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

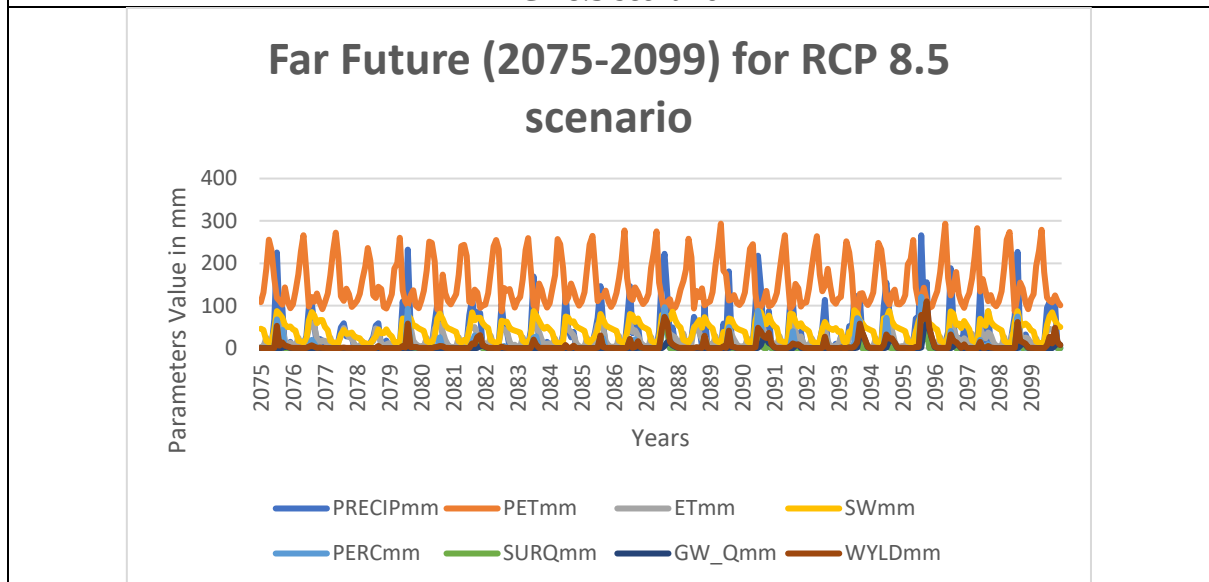


Figure 8.136: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

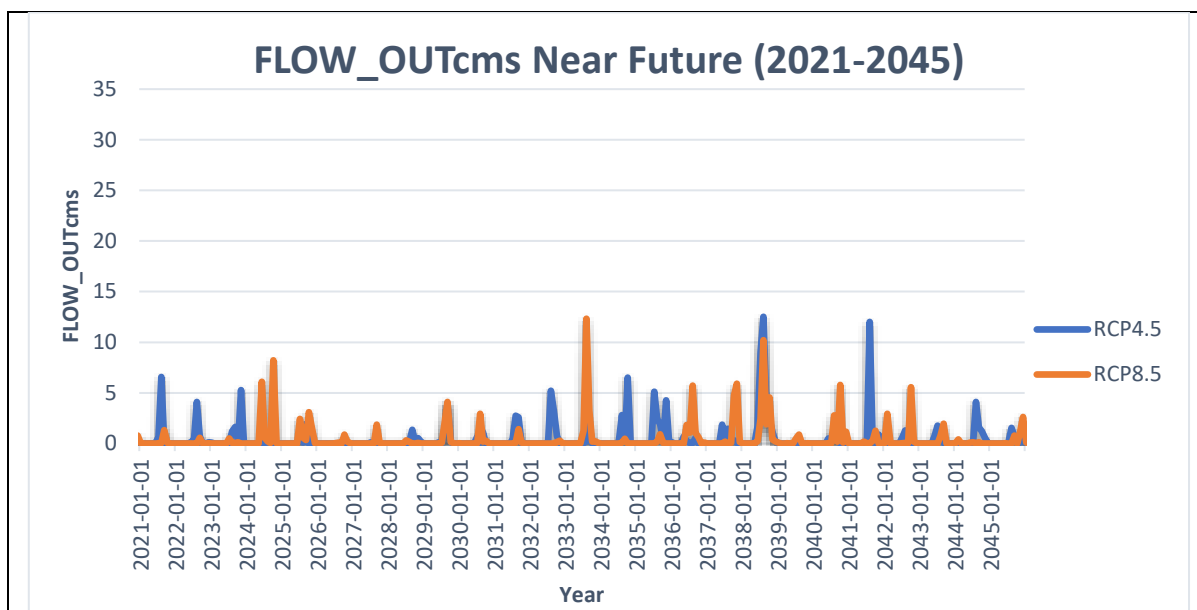


Figure 8.137: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

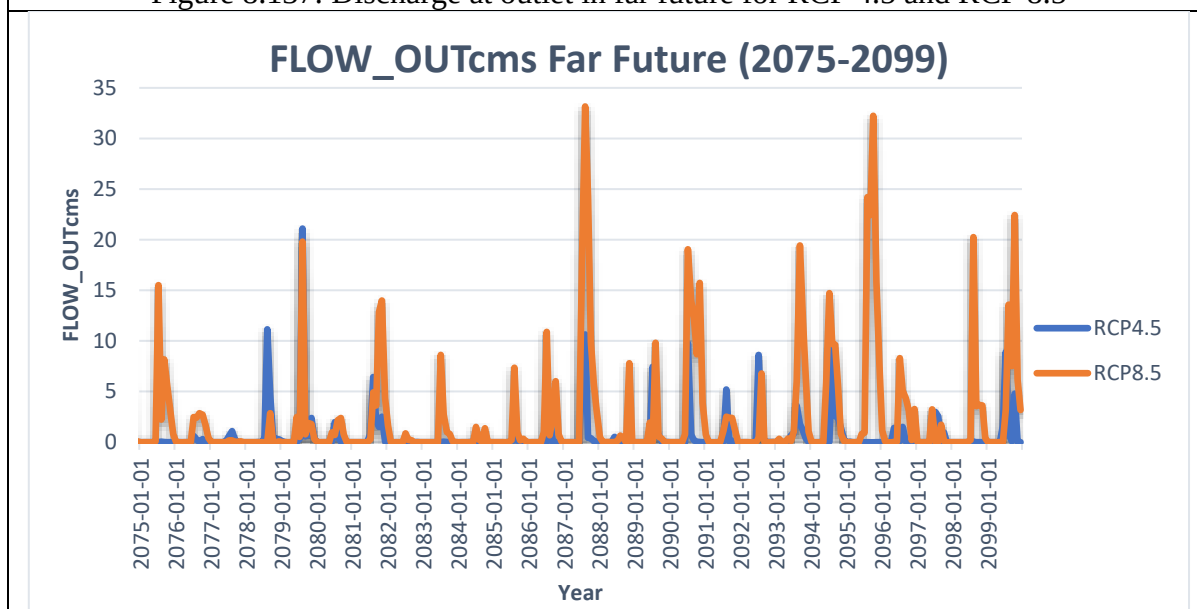


Figure 8.138: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.15 SWAT Model 15 of AID

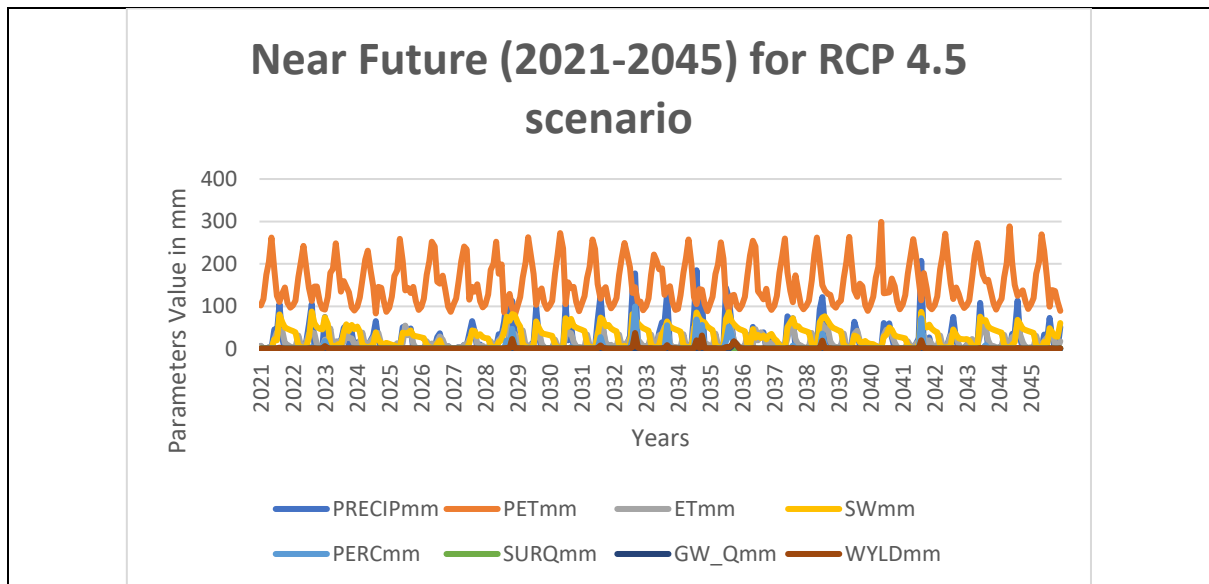


Figure 8.139: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

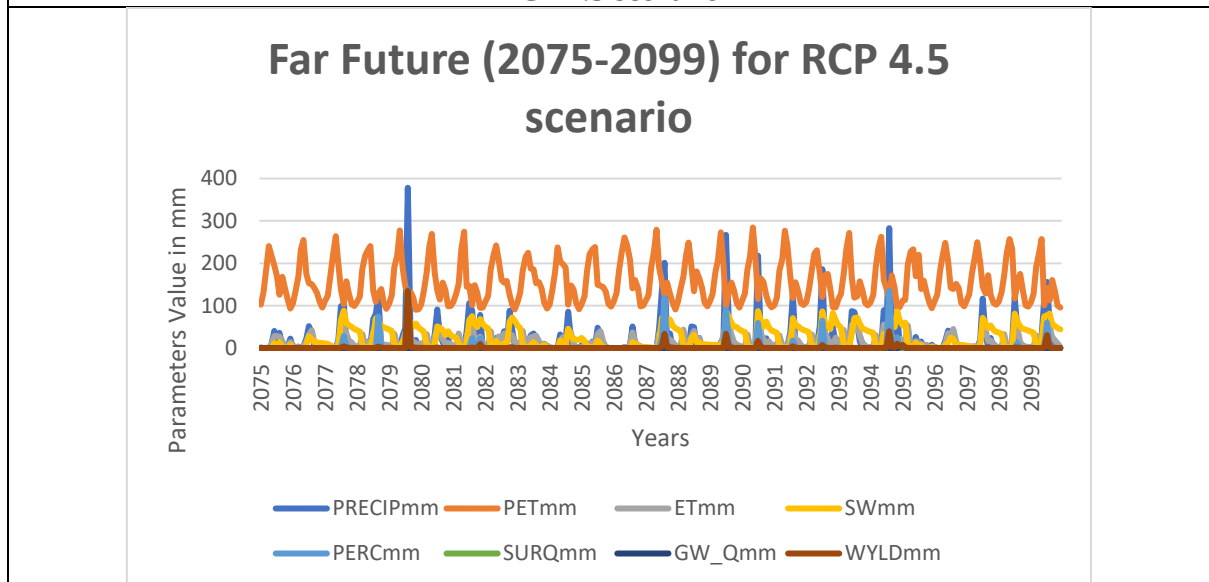


Figure 8.140: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

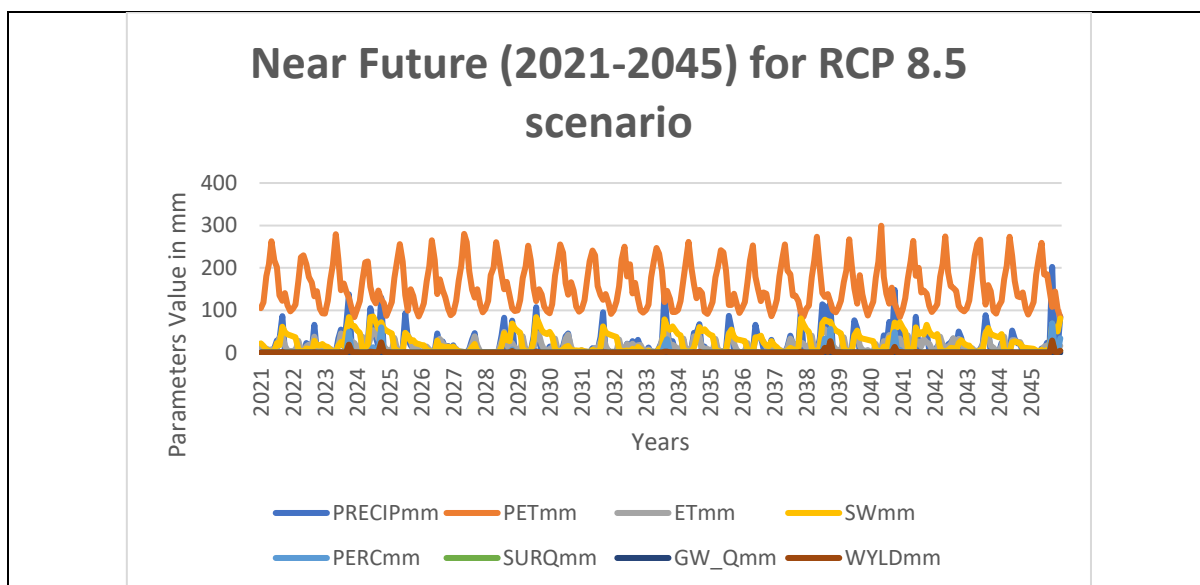


Figure 8.141: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenario

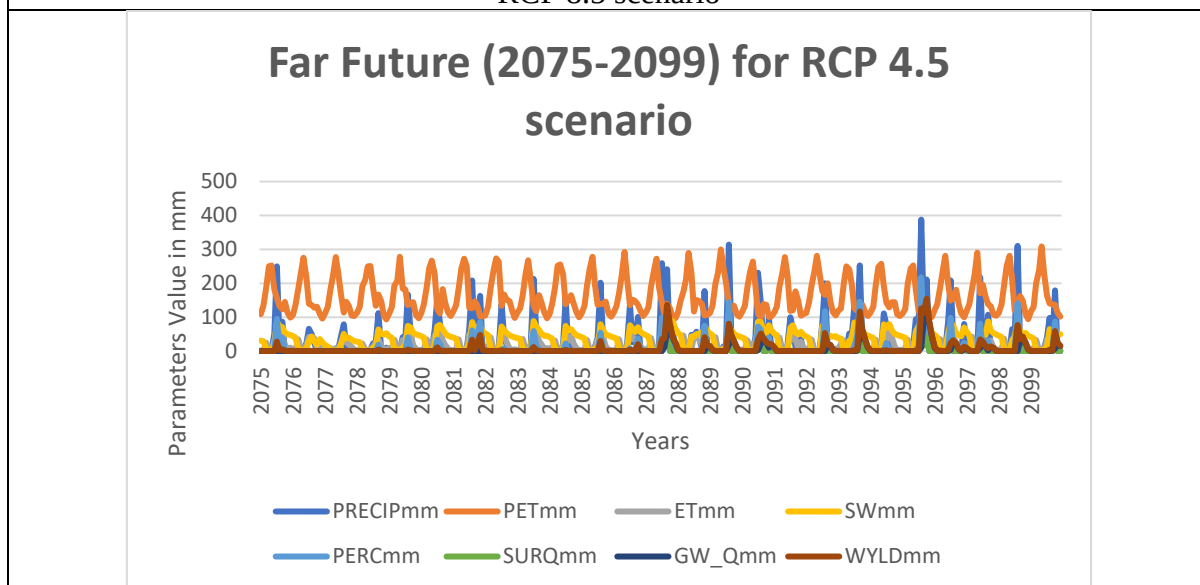


Figure 8.142: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenario

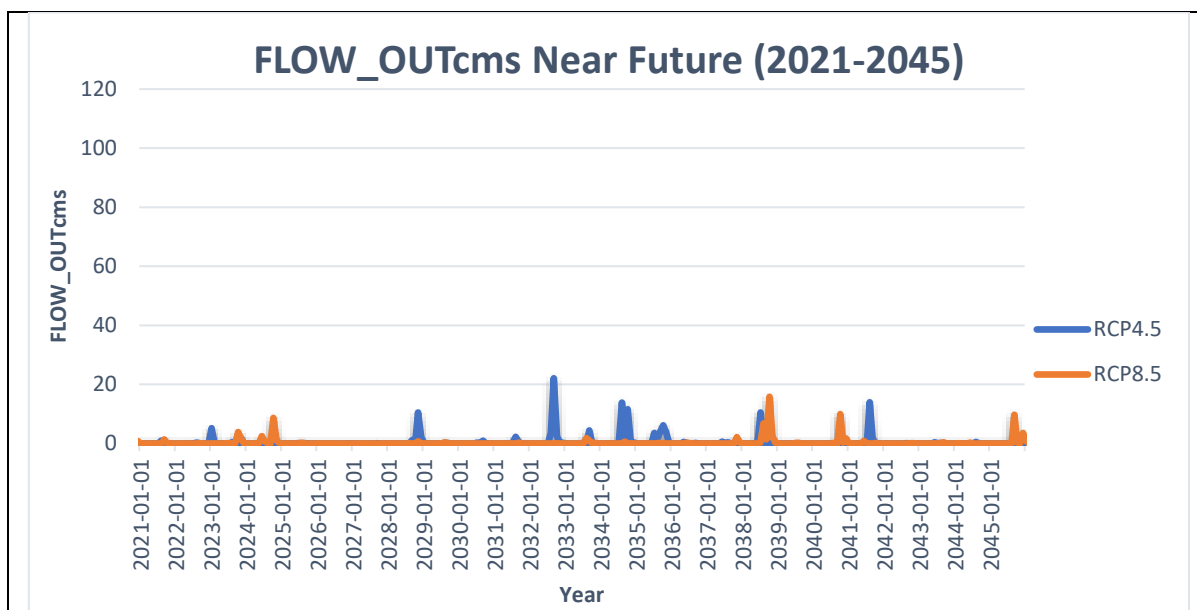


Figure 8.143: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

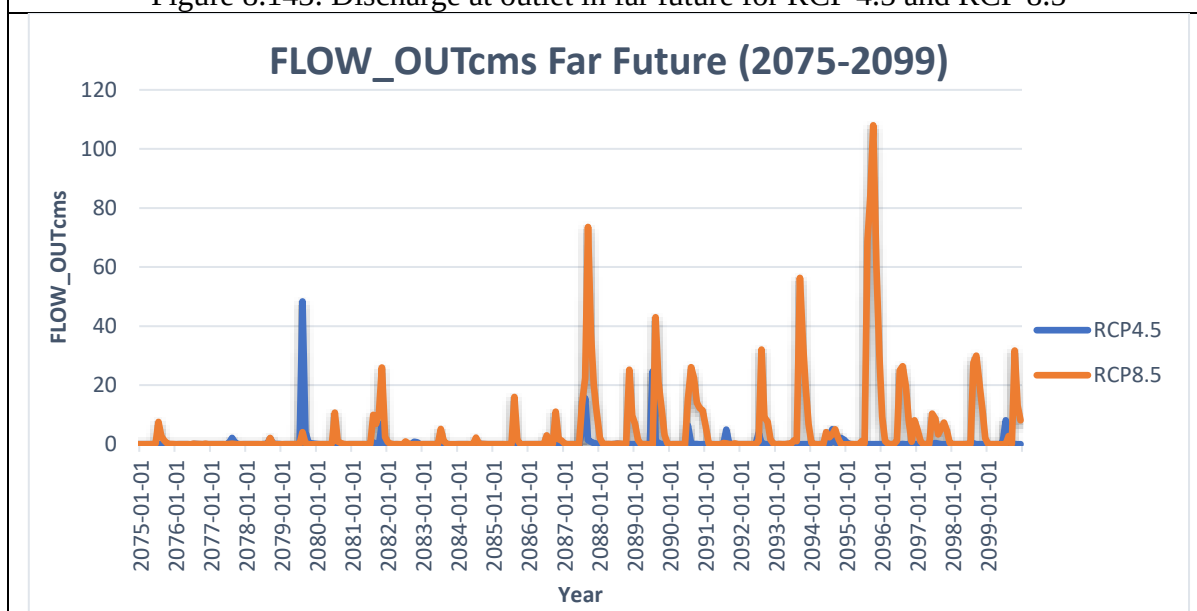


Figure 8.144: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.16 SWAT Model 16 of AID

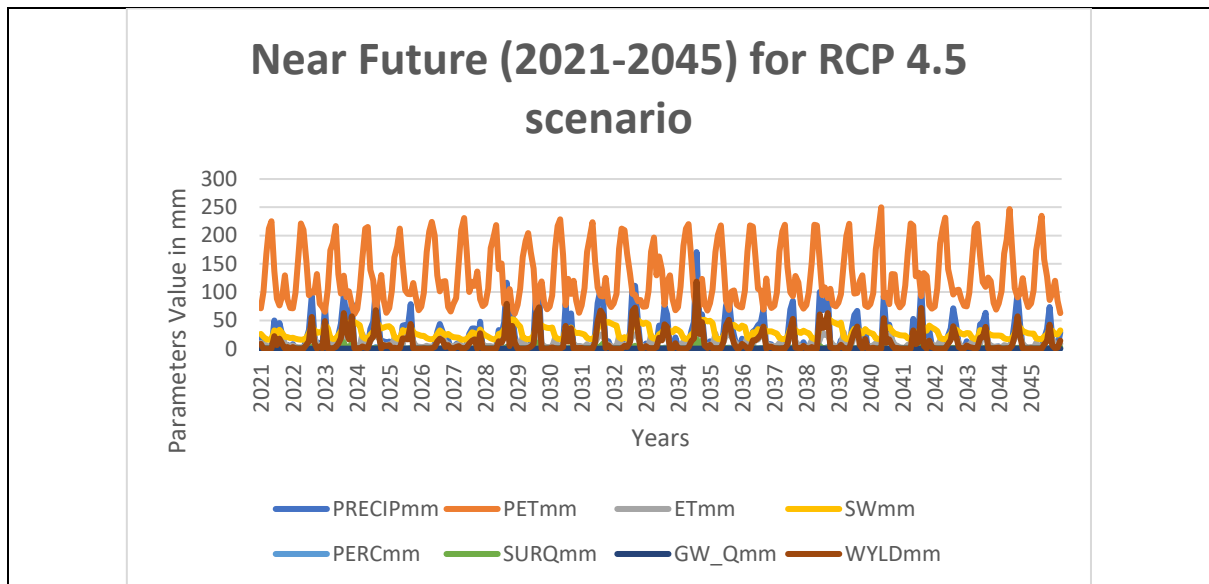


Figure 8.145: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenario

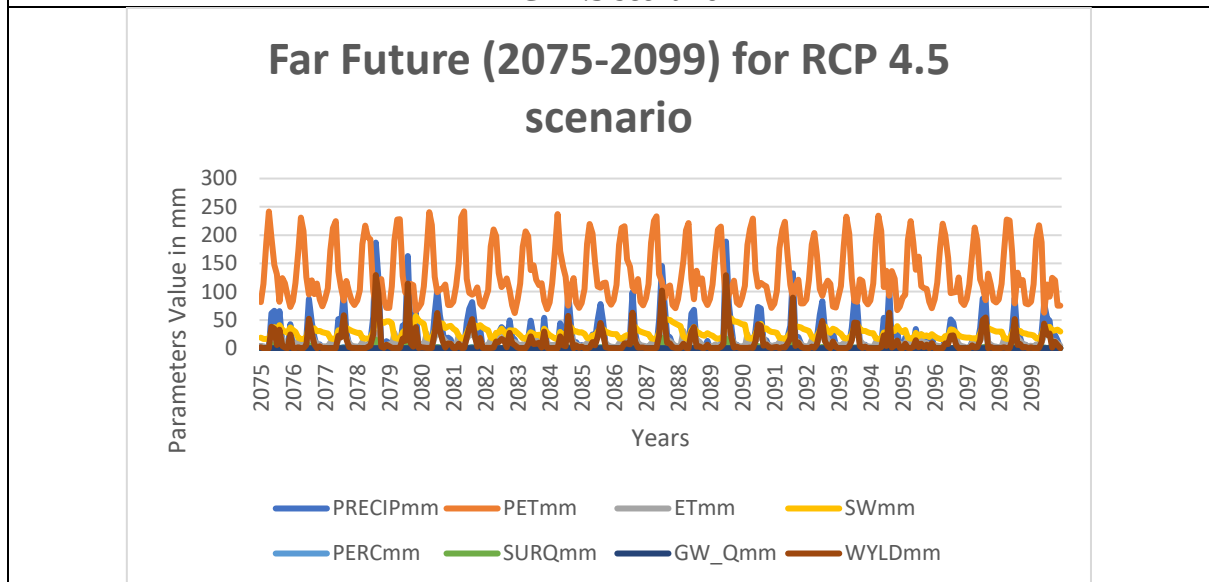


Figure 8.146: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

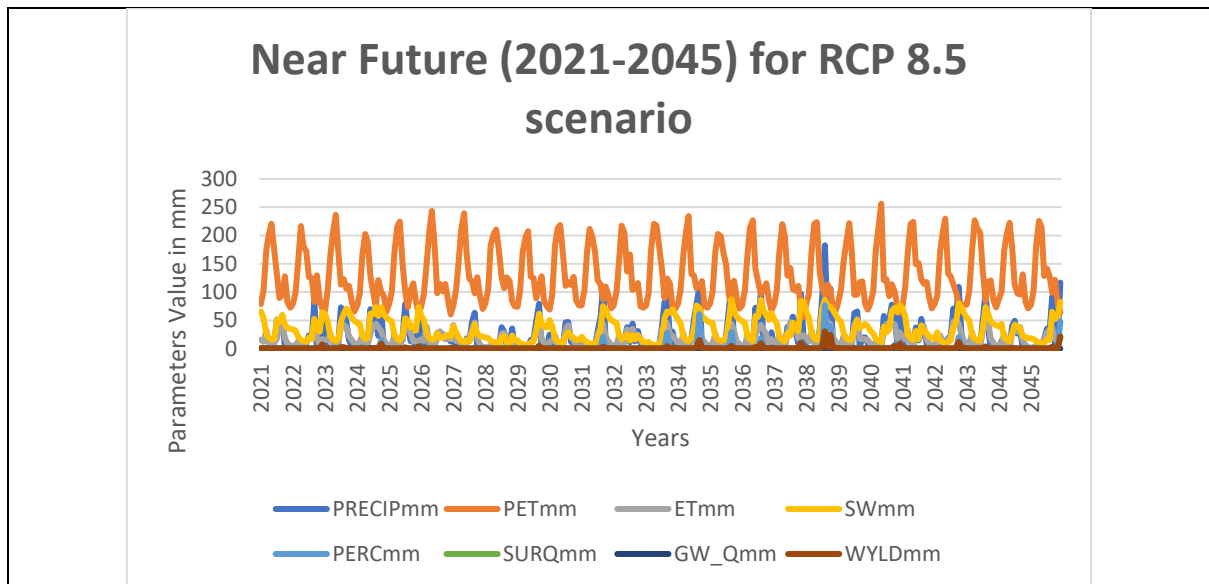


Figure 8.147: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

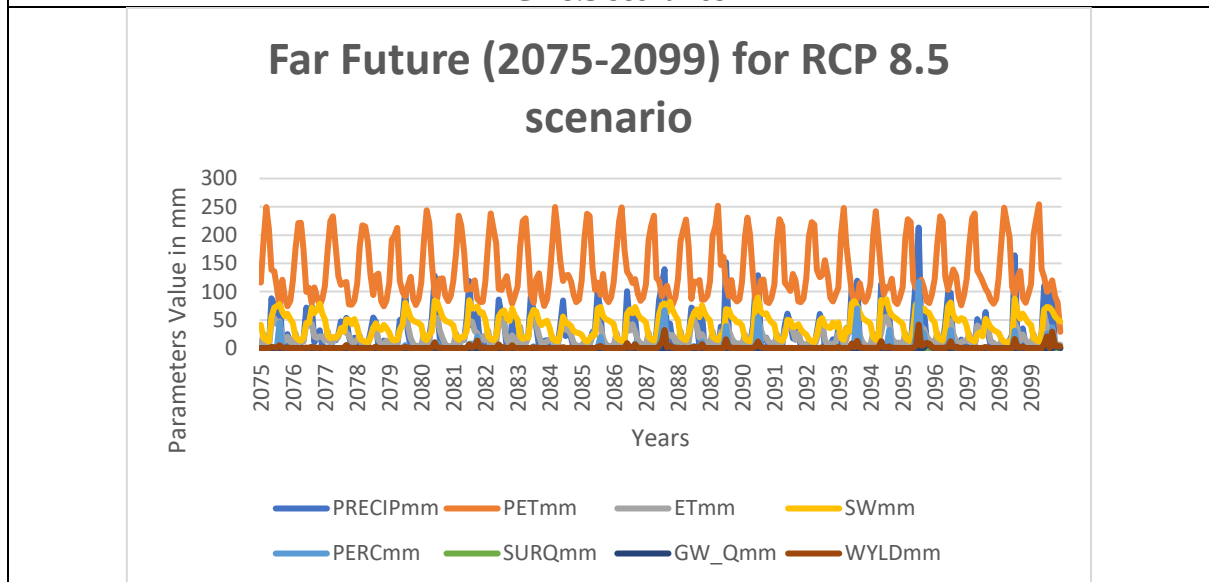


Figure 8.148: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

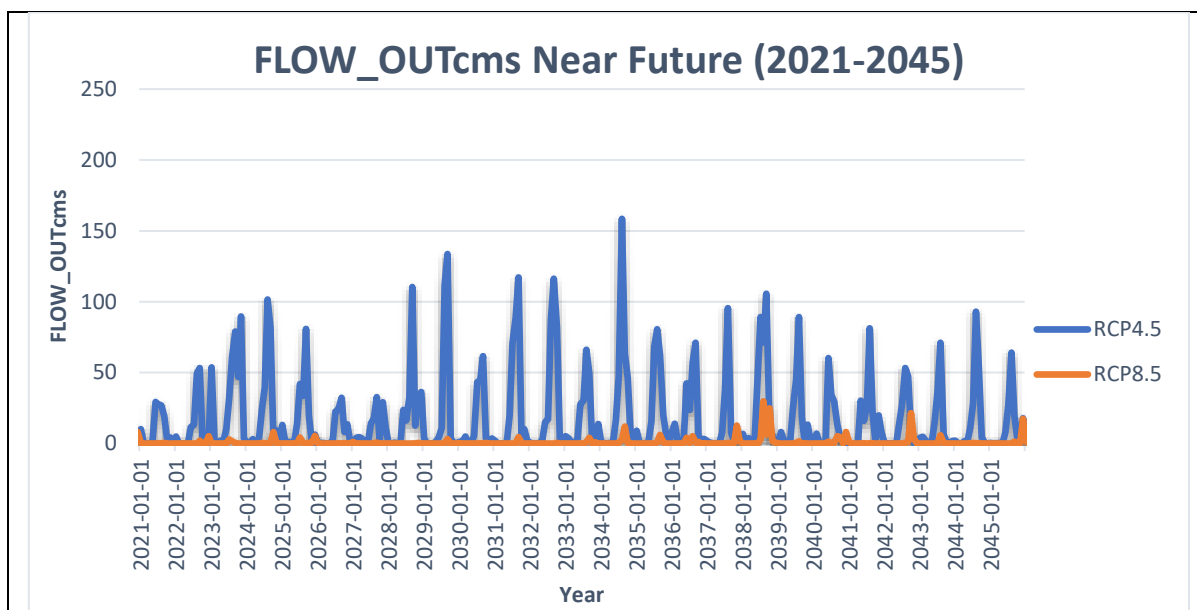


Figure 8.149: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

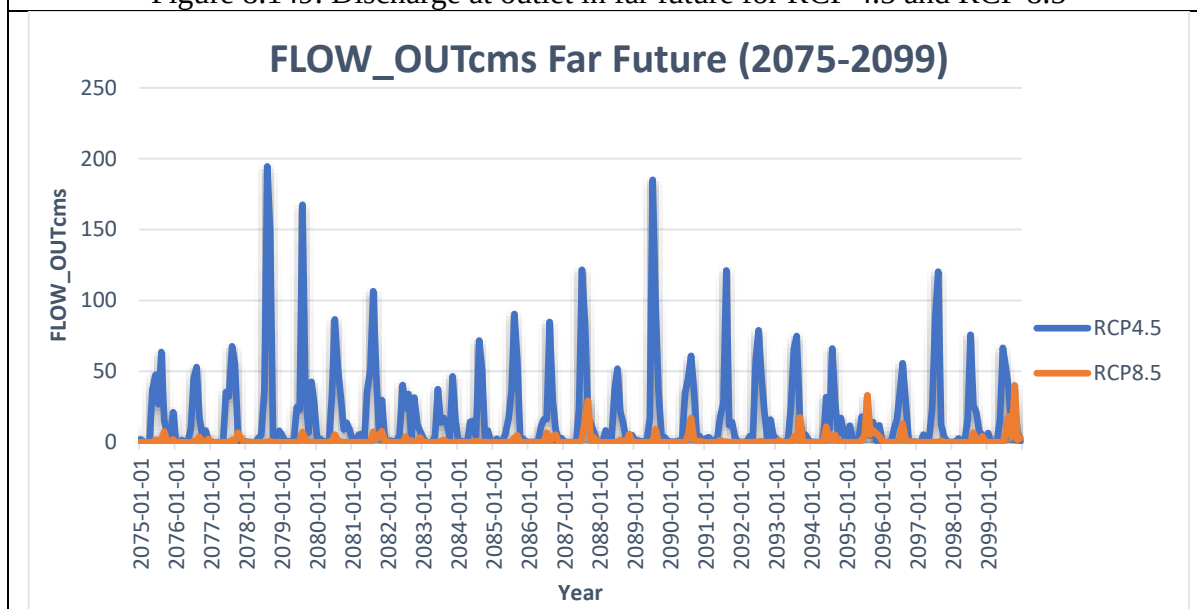


Figure 8.150: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.17 SWAT Model 17 of AID

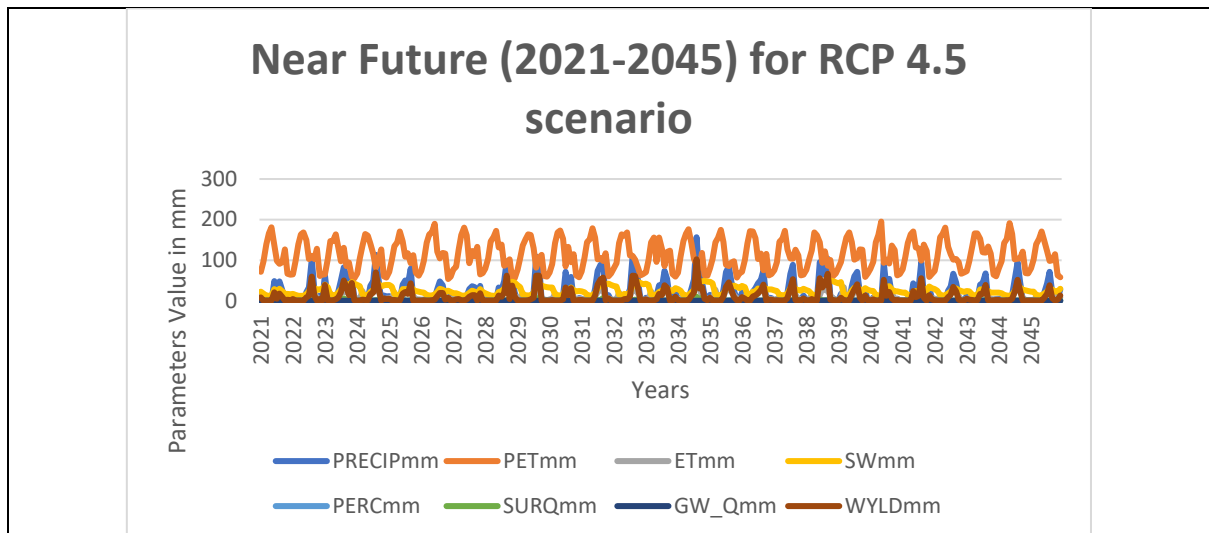


Figure 8.152: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

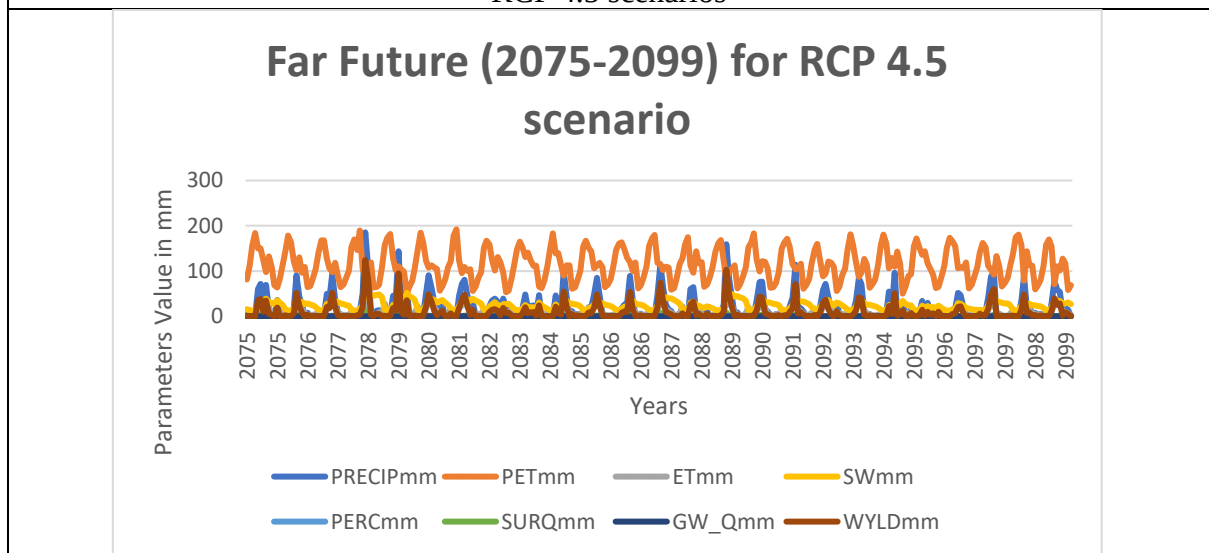


Figure 8.153: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenario

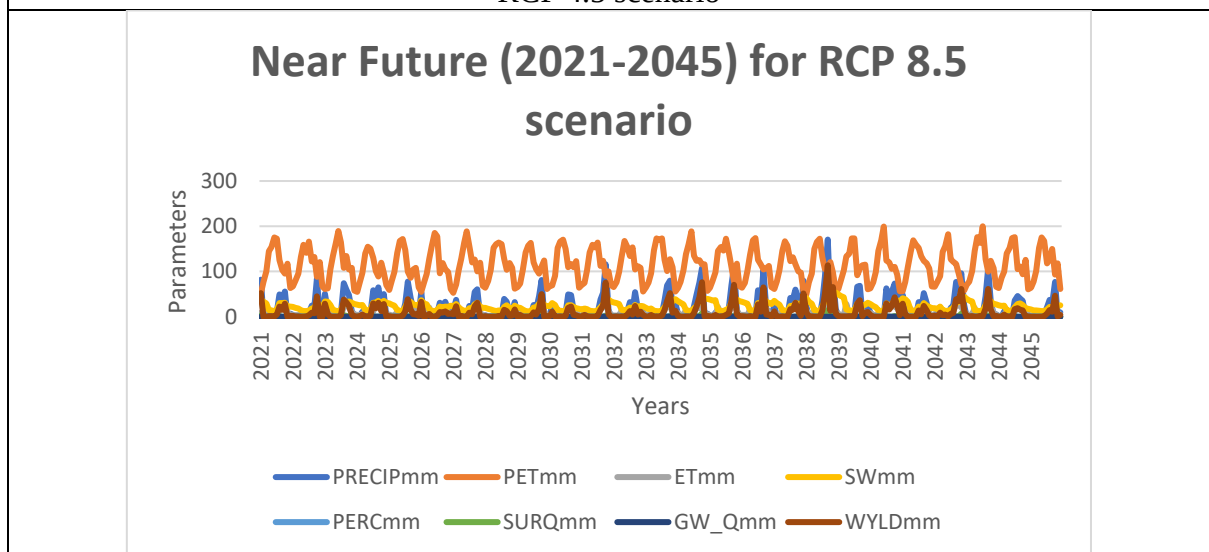


Figure 8.154: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

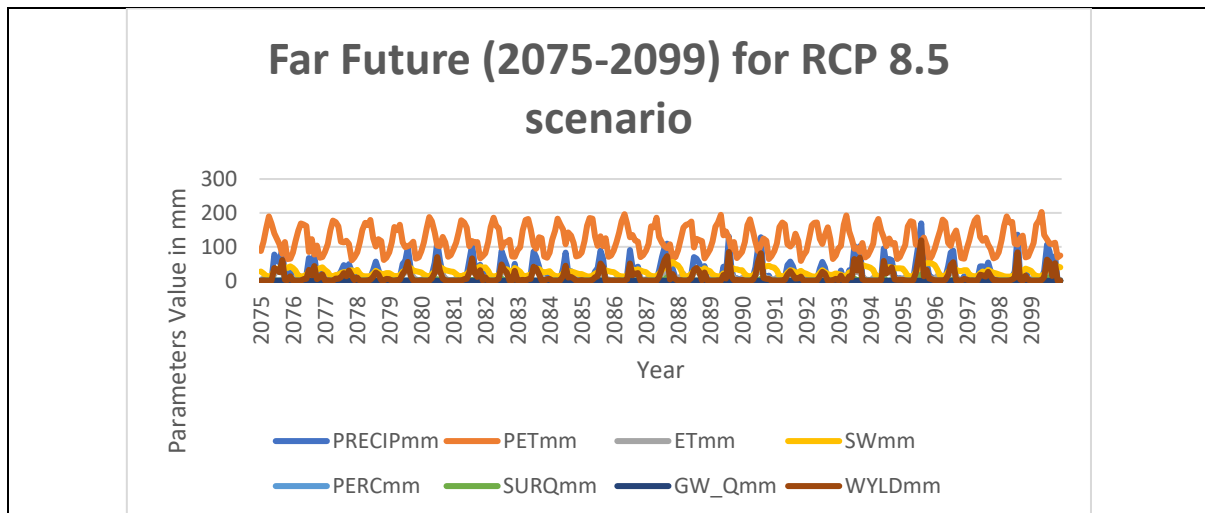


Figure 8.155: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

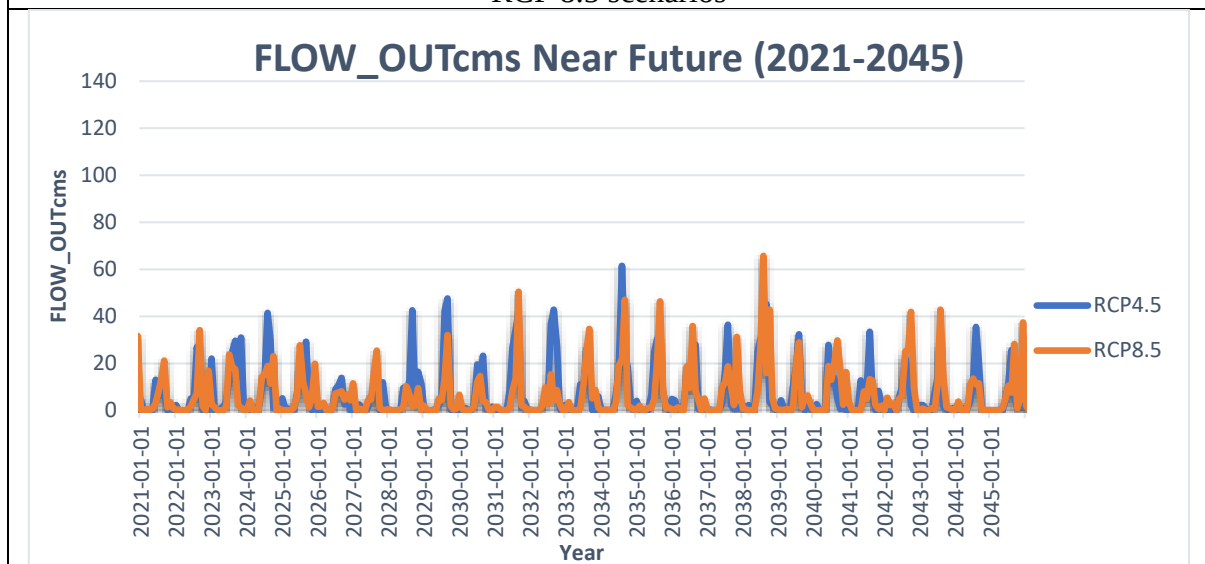


Figure 8.156: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

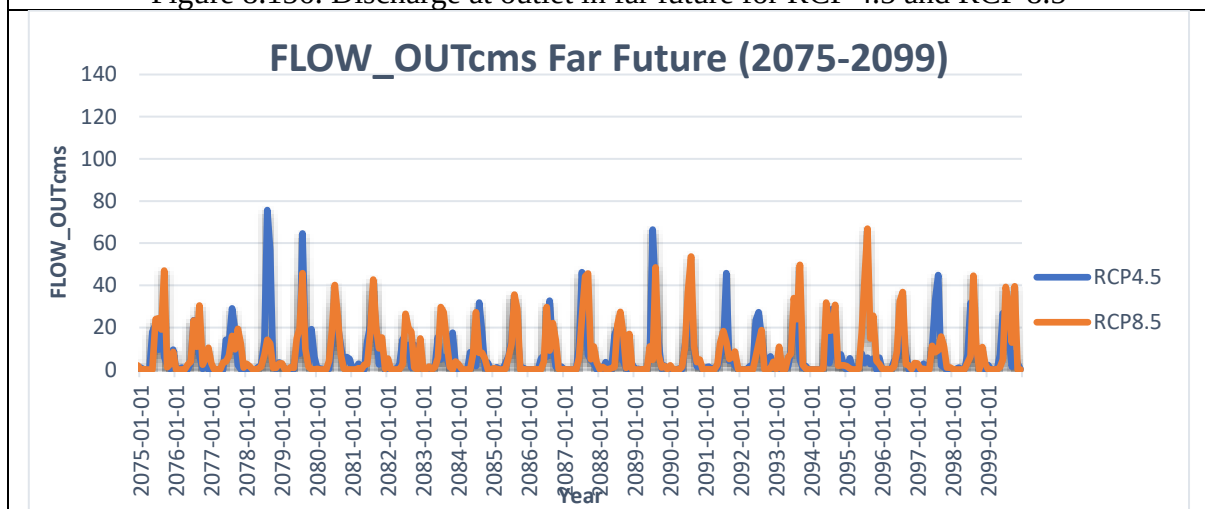


Figure 8.157: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

8.2.18 SWAT Model 18 of AID

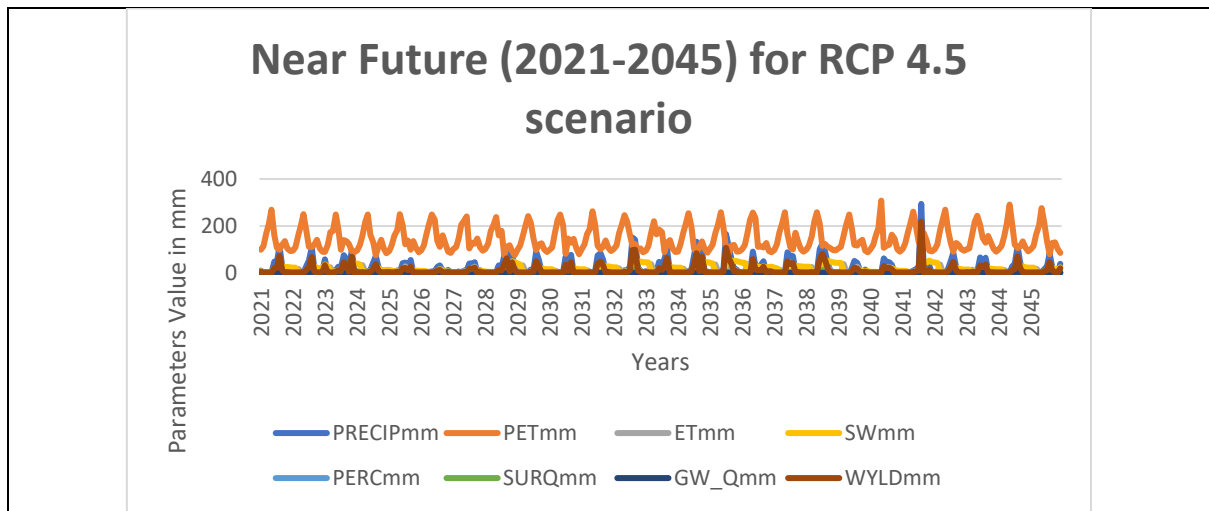


Figure 8.158: Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 4.5 scenarios

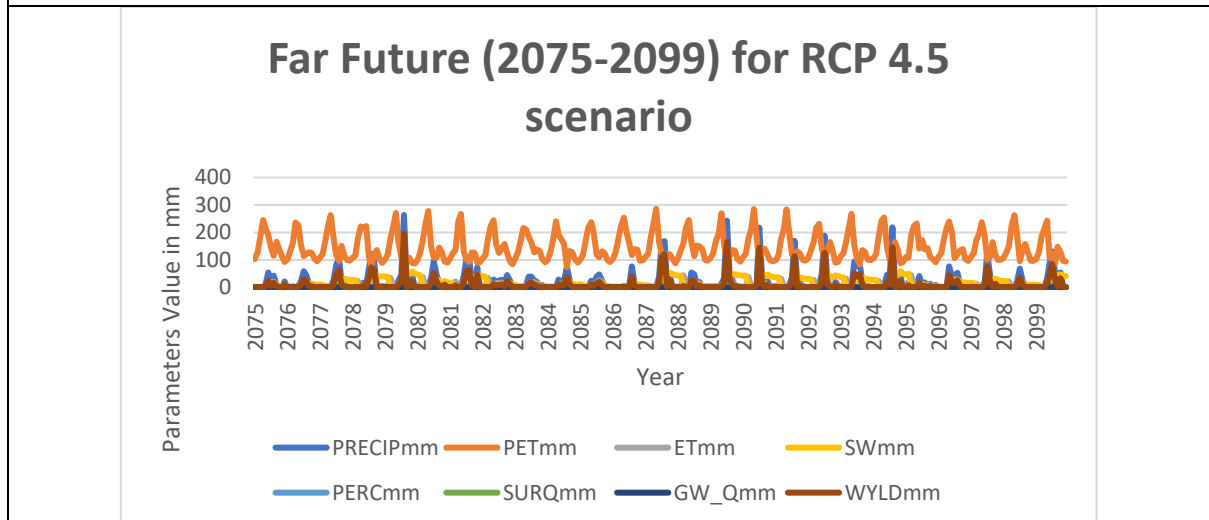


Figure 8.159: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 4.5 scenarios

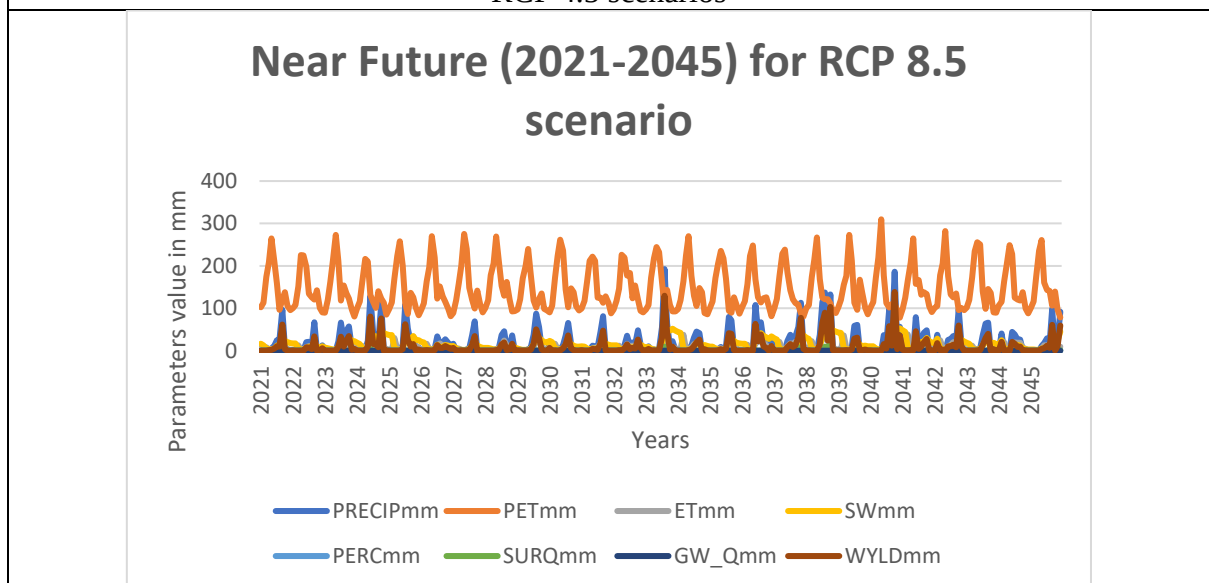


Figure 8.160 Hydrological parameters for outlet subbasin in Near Future (2021-2045) for RCP 8.5 scenarios

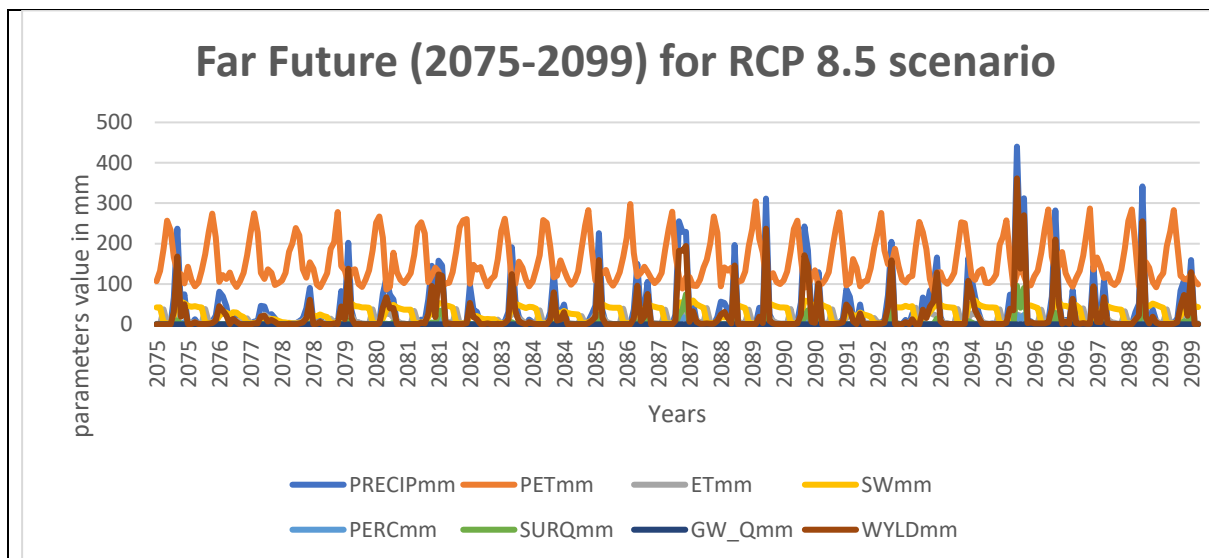


Figure 8.161: Hydrological parameters for outlet subbasin in Far Future (2075-2099) for RCP 8.5 scenarios

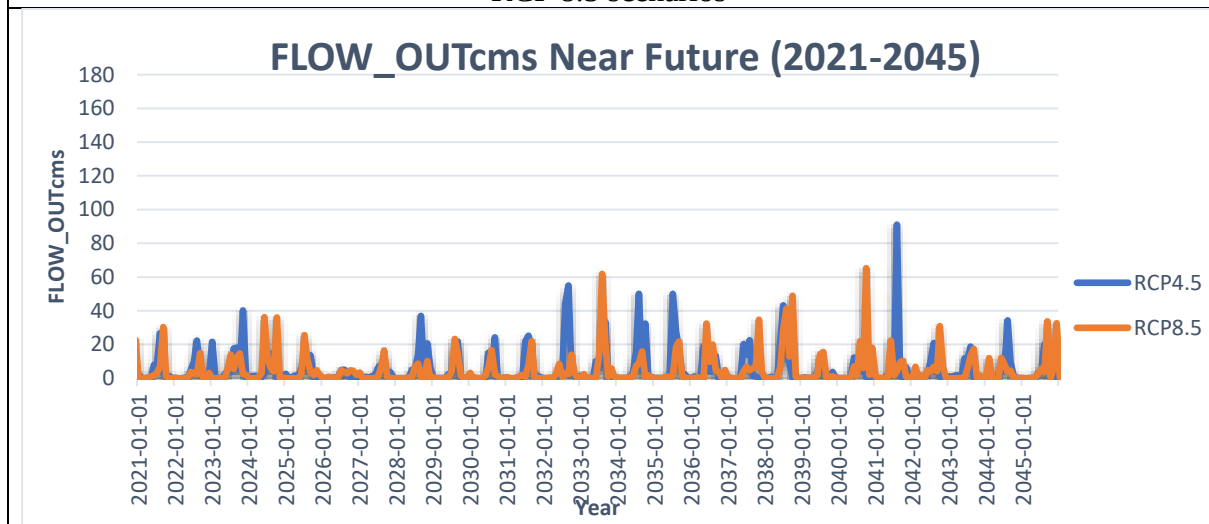


Figure 8.162: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

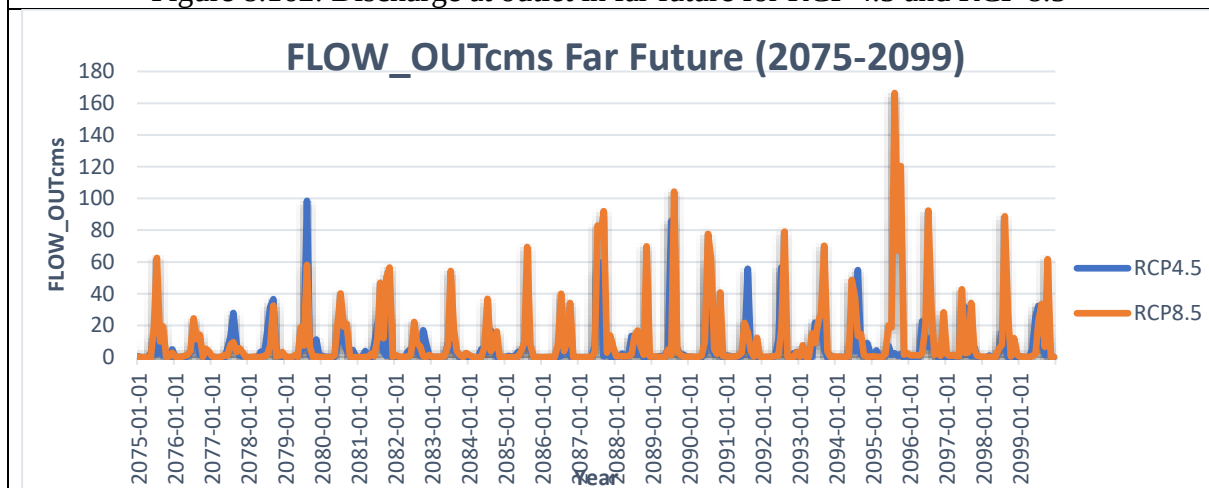


Figure 8.163: Discharge at outlet in far future for RCP 4.5 and RCP 8.5

Results

AID SWAT Model 1

Average annual precipitation (Precip) value was estimated as 485.2 mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase by 79.90mm in the near future, and in the far future, it will increase by 86.80mm in RCP 4.5. In the near future, precipitation will be increase by 32.20mm, and in the far future, precipitation will increase by 65.30mm in the RCP 8.5 scenario. Average annual surface runoff (SURQ) in baseline was estimated as 58.01mm. Compared to the baseline period, the surface runoff will increase by 27.55mm in the near future, and it will increase by 26.82mm in the RCP 4.5 scenario. In the near future, it will increase by 6.48mm and in the far future, it will increase by 27.27mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1234.5 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), it will increase by 2.8mm in the near future, and it will increase by 2.2mm in the far future of RCP 4.5 scenario. It will increase by 18.2mm in the near future, and It will increase by 92.3mm in far future of the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 355.6 mm in the baseline (1985-2005). Compared to the baseline period, ET will increase by 14.2mm in the near future and 20.9mm in the far future of RCP 4.5 scenario. It will increase by 10.4 mm in the near future and 12.3mm in the far future of RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 18.85 mm in the baseline period (1985-2005).. SW will increase by 2.42mm in the near future and it will increase by 2.49mm in the far future in the RCP 4.5 scenario compared to the baseline period, SW value in the near future will increase by 1.32mm, and in the far future, it will increase by 3.41mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 71.45 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 32.01mm in the near future and 33.52mm in the far future of RCP 4.5 scenario. PERC value in the near future PERC will increase by 9.65mm, and in the far future, it will increase by 20.68mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 119.21mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 55.09mm in the near future, and it will increase by 56.05mm in the far future of RCP 4.5 scenario. It will increase by 13.36mm in the near future, and it will increase by 42.94mm in the far future of RCP 8.5 scenario.

AID SWAT Model 2

Average annual precipitation (PRECIP) value was estimated as 321.3mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 52.3mm, and in the far future, it will increase by 72.2mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 31.8mm, and in the far future, it will increase by 71.5mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 10.21 mm. Compared to the baseline period, the surface runoff will

increase by 7.57mm in the near future, and it will increase by 12.42mm in the RCP 4.5 scenario. In the near future surface, it will increase by 5.2mm, and in the far future, it will increase by 15.03mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1351.1 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), It will increase by 7.9mm in the near future, and It will increase by 12.2mm in the far future of RCP 4.5 scenario. It will increase by 29.6mm in the near future, and it will increase by 99.4mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 280.3 mm in the baseline (1985-2005). Compared to the baseline period, it will increase in the near future by 10.1mm, and in the far future, it will increase by 18.7mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, it will increase by 7.4mm, and in the far future, it will increase by 17.9mm in the RCP 8.5 scenario. The average annual water hold capacity in the soil profile (SW) was estimated value as 21.68 mm in the baseline period (1985-2005). SW will increase by 3.8mm in the near future compared to the baseline period and it will increase by 3.29mm in the far future of RCP 4.5 scenario. SW value in the near future will increase by 2.09mm, and in the far future, It's value will increase by 4.77mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 31.02 mm in the baseline period (1985-2005). Compared to the baseline period it will increase by 30.92mm in the near future and increase by 37.64mm in the far future of the RCP 4.5 scenario. It will increase by 14.76mm in the near future and in the far future, It will increase by 35.21mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 27.24 mm in the baseline period (1985-2005). Compared to baseline period, It will increase by 32.22mm in the near future, and it will increase by 44.16mm in the far future of RCP 4.5 scenario. Compared to the baseline period it will increase by 15.54mm in the near future, and it will increase in the far future by 42.19mm in the RCP 8.5 scenario.

AID SWAT Model 3

Average annual precipitation value was estimated as 252.1mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 46.2mm, and in the far future, it will increase by 50.5mm in the RCP 4.5 scenario. While it will increase by 23.9mm in the near future, and it will increase by 75.3mm in the far future of RCP 8.5 scenario. Average annual surface runoff in baseline period was estimated as 5.14 mm. Compared to the baseline period, It will increase by 6.31mm in the near future and it will increase by 7.13mm in the near future of RCP 4.5 scenario. It will increase by 5.93mm in the near future and in the far future, it will increase by 14.53mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1439.4 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 10.7mm in the near future, and it will increase by 32.2mm in the far future of RCP 4.5 scenario. It will increase by 41.7mm in the near future, and it will increase by 128mm in the far future of RCP 8.5 scenario. Average

annual evapotranspiration (ET) was estimated as 237 mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 15.2mm, and in the far future, it will increase by 20.3mm in the RCP 4.5 scenario. While, it will increase by 5.4mm in the near future and in the far future, it will increase by 28 in the RCP 8.5 scenario. The average annual water hold capacity in the soil profile (SW) was estimated as 18.7 mm in the baseline period (1985-2005). SW will increase by 8.43mm in the near future and increase by 8.04mm in the far future in the RCP 4.5 scenario compared to the baseline period. While, it will increase by 4.6mm in the near future and it will increase by 28mm in the far future of RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 9.83 mm in the baseline period (1985-2005). Compared to the baseline period, PERC value in the near future will increase by 21.65mm, and in the far future, it will increase by 20.51mm in the RCP 4.5 scenario. While in the near future it will increase by 8.85mm and in the far future it will increase by 29.19mm of the RCP 8.5. The average annual water yield (WYLD) was estimated as 8.58 mm in the baseline period (1985-2005). Compared to baseline period, WYLD will increase by 16.28mm in the near future and it will increase by 17.01mm in the far future of the RCP 4.5 scenario. It will increase by 7.27mm in the near future and it will increase in the far future by 26.65mm of the RCP 8.5 scenario.

AID SWAT Model 4

Average annual precipitation (PRECIP) value estimated as 184.2mm in the baseline period (1985-2005). Compared to the baseline period, precipitation will increase in the near future by 46.8mm and it will increase by 38.7mm in the far future of RCP 4.5 scenario. While in the near future, compared to the baseline period, it will increase by 24.2mm and in the far future, it will increase by 104mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 1.86 mm. Compared to the baseline period, the surface runoff will increase by 5.56mm in the near future, and it will increase by 5.66mm in the far future of RCP 4.5 scenario. While in the near future it will increase by 3.75mm and in the far future, it will increase by 22.13mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated at 1437.6 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 13.22mm in the near future and it will increase by 37.4mm in the far future of RCP 4.5 scenario. It will increase by 47.7mm in the near future and it will increase by 120mm in the far futures compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 184.2 mm in the baseline (1985-2005). Compared to the baseline period in the near future, ET will increase by 28.2mm, and in the far future, ET will increase by 21.4 in the RCP 4.5 scenario. It will increase by 12.2mm in the near future and it will increase by 56.3mm in the far future of RCP 8.5 scenario.

The average annual water hold in the soil profile (SW) was estimated at 10.42 mm in the baseline period (1985-2005). SW will increase by 7.04mm in the near future compared to the

baseline period and increase by 7.13mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 4.35mm, and in the far future, SW will increase by 11.55mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 1.7 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 8.11mm in the near future and increase by 7.43mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 3.47mm, and in the far future, PERC will increase by 19.85mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 3.16 mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 6.95mm in the near future, and WYLD will increase by 7.2mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 4.04mm in the near future, and WYLD will increase in the far future by 28.45mm in the RCP 8.5 scenario.

AID SWAT Model 5

Average annual precipitation (PRECIP) value was estimated as 152.4mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 49.5mm, and in the far future, it will increase by 39.2mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 25.6mm, and in the far future, precipitation will increase by 106.5mm in the RCP 8.5 scenario. Average annual surface runoff in baseline estimated 0.58 mm. Compared to the baseline period, the surface runoff will increase by 3mm in the near future, and the surface runoff will increase by 3.09 in the RCP 4.5 scenario. In the near future, the surface runoff will increase by 1.65mm, and in the far future, the surface runoff will increase by 13.9mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1623.8 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 17.1mm in the near future, and PET will increase by 51.5mm in the far future in the RCP 4.5 scenario. PET will increase by 55.6mm in the near future, and PET will increase by 127.3mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 154.6 mm in the baseline (1985-2005). ET will be 190.2 mm in the near future, and far future ET will be 180.1 mm in the RCP 4.5 scenario. ET will be 168.7 mm in the near future, and the far future ET will be 222.9 mm in the RCP 8.5 scenario. Compared to the baseline period, ET will increase in the near future by 35.6mm, and in the far future, ET will increase by 25.5mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 14.1mm, and in the far future, ET will increase by 68.3mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated at 7.27 mm in the baseline period (1985-2005). SW will increase by 8.75mm in the near future compared to the baseline period and increase by 8.68mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 5.19mm, and in the far future, SW

will increase by 15.83mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 0.1 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 6.24mm in the near future and increase by 6.17mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 3.23mm, and in the far future, PERC will increase by 18.2mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 1.55 mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 3.87mm in the near future, and WYLD will increase by 3.88mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 2.06mm in the near future, and WYLD will increase in the far future by 18.15mm in the RCP 8.5 scenario.

AID SWAT Model 6

Average annual precipitation (PRECIP) value estimated 157.14mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 63.6mm, and in the far future, it will increase by 58.3mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 35.8mm, and in the far future, precipitation will increase by 159.5mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 2.26 mm. Compared to the baseline period, the surface runoff will increase by 3.3mm in the near future, and the surface runoff will increase by 5.46mm in the RCP 4.5 scenario. In the near future, the surface runoff will increase by 2.2mm, and in the far future, the surface runoff will increase by 19.13mm in the RCP 8.5. The average annual potential evapotranspiration (PET) was estimated at 1714 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 18.4mm in the near future, and PET will increase by 56.9mm in the far future in the RCP 4.5 scenario. PET will increase by 55.8mm in the near future, and PET will increase by 132.7mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 157 mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 39mm, and in the far future, ET will increase by 28.9mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 18.6mm, and in the far future, ET will increase by 71.2mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 8.83 mm in the baseline period (1985-2005). Compared to the baseline period, SW value in the near future will increase by 17.14mm, and in the far future, SW will increase by 18.19mm in the RCP 4.5 scenario. It will increase by 8.76mm in the near future and it will increase by 26.17mm in the far future of RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 8.76 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 15.64mm in the near future and increase by 18.64mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 8.48mm

and in the far future, PERC will increase by 61.22mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 2.26 mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 5.76mm in the near future, and WYLD will increase by 8.28mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 8.48mm in the near future, and WYLD will increase in the far future by 61.22mm in the RCP 8.5 scenario.

AID SWAT Model 7

Average annual precipitation (PRECIP) value estimated 356.2mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 60mm, and in the far future, it will increase by 56.8mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 21.9mm, and in the far future, precipitation will increase by 49.7mm in the RCP 8.5 scenario. Average annual surface runoff in baseline estimated 15.99 mm. Compared to the baseline period, the surface runoff will increase by 16.72mm in the near future, and the surface runoff will increase by 13.69mm in the RCP 4.5 scenario. In the near future, the surface runoff will increase by 5.53mm and in the far future, the surface runoff will increase by 17.71mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1249 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 8.9mm in the near future, and it will increase by 9.7mm in the far future in the RCP 4.5 scenario. PET will increase by 26.6mm in the near future, and PET will increase by 102.2mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 342.9 mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 27.7mm, and in the far future, ET will increase by 30.6mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 8.1mm, and in the far future, ET will increase by 16.8mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 10.61 mm in the baseline period (1985-2005). Compared to the baseline period, SW value in the near future will increase by 4.39mm, and in the far future, SW will increase by 3.39mm in the RCP 4.5 scenario. SW value in the near future will increase by 2mm, and in the far future, SW will increase by 4.98mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated 3.16 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 8.14mm in the near future and increase by 6.1mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 1.04mm, and in the far future, PERC will increase by 7.43mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 17.41mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 20.44mm in the near future, and WYLD will increase by 16mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by

5.17mm in the near future, and WYLD will increase in the far future by 22.7mm in the RCP 8.5 scenario.

AID SWAT Model 8

Average annual precipitation (PRECIP) value was estimated as 253.9mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 51.8mm and in the far future, it will increase by 52.6mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 35.6mm, and in the far future, precipitation will increase by 61.9mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 2.74 mm. Compared to the baseline period, the surface runoff will increase by 3.66mm in the near future, and the surface runoff will increase by 3.37mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 2.58mm and in the far future, the surface runoff will increase by 5.14mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated as 1365.1 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 4.7mm in the near future, and PET will increase by 10.9mm in the far future in the RCP 4.5 scenario. PET will increase by 31.1mm in the near future, and PET will increase by 98.9mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 241.5 mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 19.3mm and in the far future, ET will increase by 24.5mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 16.5mm, and in the far future, ET will increase by 27.5mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 17.78 mm in the baseline period (1985-2005). SW will increase by 4.19mm in the near future compared to the baseline period and increase by 3.36mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 2.35mm, and in the far future, SW will increase by 4.34mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 11.14 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 24.43mm in the near future and increase by 20.98mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 11.56mm and in the far future, PERC will increase by 25.3mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 5.88mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 20.15mm in the near future, and WYLD will increase by 17.04mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 8.15mm in the near future, and WYLD will increase in the far future by 21.8mm in the RCP 8.5 scenario.

AID SWAT Model 9

Average annual precipitation (PRECIP) value estimated 213.1mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 39.9mm, and in the far future, it will increase by 35.3mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 26.5mm, and in the far future, precipitation will increase by 43.6mm in the RCP 8.5 scenario.

Average annual surface runoff in baseline was estimated as 1.46 mm. Compared to the baseline period, the surface runoff will increase by 1.91mm in the near future, and the surface runoff will increase by 1.38mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 1.63mm, and in the far future, the surface runoff will increase by 2.36mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated at 1546.6 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 6.4mm in the near future, and PET will increase by 13.5mm in the far future in the RCP 4.5 scenario. PET will increase by 39.5mm in the near future, and PET will increase by 112.8mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 212.6mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 24.8mm, and in the far future, ET will increase by 24.1mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 16.5mm, and in the far future, ET will increase by 30.6mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 11.71 mm in the baseline period (1985-2005). SW will increase by 7.91mm in the near future compared to the baseline period and increase by 5.37mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 2.78mm, and in the far future, SW will increase by 5.44mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 1.88 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 8.58mm in the near future and increase by 5.72mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 2.86mm and in the far future, PERC will increase by 6.03mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 2.28mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 2.48mm in the near future, and WYLD will increase by 1.85mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 1.79mm in the near future, and WYLD will increase in the far future by 2.94mm in the RCP 8.5 scenario.

AID SWAT Model 10

Average annual precipitation (PRECIP) value estimated 226.7mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 39.9mm, and in the far future, it will increase by 34.3mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 23.8mm, and in the far future, precipitation

will increase by 41.9mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 1.21 mm. Compared to the baseline period, the surface runoff will increase by 2.04mm in the near future, and the surface runoff will increase by 1.33mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 1.64mm, and in the far future, the surface runoff will increase by 2.54mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated as 1430.6 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 6.4mm in the near future, and PET will increase by 12.3mm in the far future in the RCP 4.5 scenario. PET will increase by 33.2mm in the near future, and PET will increase by 103.5mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 223.2mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 20.6mm, and in the far future, ET will increase by 20.7mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 12.7mm, and in the far future, ET will increase by 25.4mm% in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 14.52 mm in the baseline period (1985-2005). SW will increase by 8.68mm in the near future compared to the baseline period and increase by 5.57mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 2.75mm and in the far future, SW will increase by 6.65mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 3.73 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 12.79mm in the near future and increase by 8.43mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 4.33mm, and in the far future, PERC will increase by 9.69mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 2.57mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 3.94mm in the near future, and WYLD will increase by 2.64mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 1.88mm in the near future, and WYLD will increase in the far future by 3.73mm in the RCP 8.5 scenario.

AID SWAT Model 11

Average annual precipitation (PRECIP) value estimated 185mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 53.1mm, and in the far future, it will increase by 46.9mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 37.9mm, and in the far future, precipitation will increase by 170.6mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 2.16 mm. In the near future (2021-2045), Compared to the baseline period, the surface runoff will increase by 6.62mm in the near future, and the surface runoff will increase by 7.28mm in the RCP 4.5 scenario. In the near future, the surface runoff will increase

by 5.74mm, and in the far future, the surface runoff will increase by 35.56mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated as 1567.3 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 11.1mm in the near future, and PET will increase by 28.5mm in the far future in the RCP 4.5 scenario. PET will increase by 43.2mm in the near future, and PET will increase by 112.6mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 181.7mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 30.2mm, and in the far future, ET will increase by 21mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 20.1mm, and in the far future, ET will increase by 60.8mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated at 11.07 mm in the baseline period (1985-2005). SW will increase by 11.53mm% in the near future compared to the baseline period and increase by 12.86mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 6.53mm, and in the far future, SW will increase by 20.19mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 2.04 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 11.79mm in the near future and increase by 14.31mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 6.5mm, and in the far future, PERC will increase by 48.2mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 3.62mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 7.89mm in the near future, and WYLD will increase by 9.28mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 6.37mm in the near future, and WYLD will increase in the far future by 59.18 in the RCP 8.5 scenario.

AID SWAT Model 12

Average annual precipitation (PRECIP) value estimated 212.8mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 54.7mm and in the far future, it will increase by 53mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 37.6mm, and in the far future, precipitation will increase by 157.2mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 3.34mm. Compared to the baseline period, the surface runoff will increase by 6.74mm in the near future, and the surface runoff will increase by 8.63mm in the RCP 4.5 scenario. In the near future surface runoff will increase by 6.1mm, and in the far future, the surface runoff will increase by 38.11mm in the RCP 8.5 scenario. The average annual potential evapotranspiration (PET) was estimated at 1506.3 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 9.4mm in the near future, and PET will increase by 21.9mm in the far future in the RCP 4.5 scenario. PET will increase by 38.6mm

in the near future, and PET will increase by 110.6mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 205.4mm in the baseline (1985-2005) Compared to the baseline period, ET will increase in the near future by 23.6mm and in the far future, ET will increase by 17.5mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 17.9mm, and in the far future, ET will increase by 48.2mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated at 16.13 mm in the baseline period (1985-2005). SW will increase by 12.95mm in the near future compared to the baseline period and increase by 13.57mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 6.83mm, and in the far future, SW will increase by 15.85mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 6.16 mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 19.19mm in the near future and increase by 22.02mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 8.22mm, and in the far future, PERC will increase by 63.23mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 7.46mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 9.14mm in the near future, and WYLD will increase by 13.83mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 6.48mm in the near future, and WYLD will increase in the far future by 78.58mm in the RCP 8.5 scenario.

AID SWAT Model 13

Average annual precipitation (PRECIP) value estimated 169.8mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 69.6mm, and in the far future, it will increase by 60.8mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 43.5mm, and in the far future, precipitation will increase by 204.6mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 2.29mm. Compared to the baseline period, the surface runoff will increase by 9.15mm in the near future, and the surface runoff will increase by 9.22mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 5.84mm, and in the far future, the surface runoff will increase by 52.36 in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated as 1622.4 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 13.5mm in the near future, and PET will increase by 43.9mm in the far future in the RCP 4.5 scenario. PET will increase by 49.3mm in the near future, and PET will increase by 117mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 166.6mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 37mm, and in the far future, ET will increase by 27.4mm

in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 20.1mm, and in the far future, ET will increase by 71.9mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 11.8 mm in the baseline period (1985-2005). SW will increase by 14.18mm in the near future compared to the baseline period and increase by 13.92mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 8.51mm, and in the far future, SW will increase by 19.5mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 2.56mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 17.75mm in the near future and increase by 18.76mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 10.67mm, and in the far future, PERC will increase by 72.45mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 3.87mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 12.6mm in the near future, and WYLD will increase by 12.15mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 6.7mm in the near future, and WYLD will increase in the far future by 100.7mm in the RCP 8.5 scenario.

AID SWAT Model 14

Average annual precipitation (PRECIP) value estimated 235.6mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 55.2mm, and in the far future, it will increase by 52.1mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 38.7mm, and in the far future, precipitation will increase by 144.2mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 4.77mm. Compared to the baseline period, the surface runoff will increase by 8.47mm in the near future, and the surface runoff will increase by 10.47mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 8.5mm, and in the far future, the surface runoff will increase by 41.06mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated as 1545.6 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 5.7mm in the near future, and PET will increase by 14.1mm in the far future in the RCP 4.5 scenario. PET will increase by 34mm in the near future, and PET will increase by 106.7mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 219.1mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 18mm, and in the far future, ET will increase by 13.5mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 16.1mm and in the far future, ET will increase by 39.4 in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 19.53 mm in the baseline period (1985-2005). SW will increase by 11.23mm in the near future compared to the baseline period

and increase by 11.42mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 7.05mm, and in the far future, SW will increase by 13.46mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated 10.01mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 24.64mm in the near future and increase by 24.22mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 9.69mm, and in the far future, PERC will increase by 58.61mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 9.49mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 13.53mm in the near future, and WYLD will increase by 16.69mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 7.94mm in the near future, and WYLD will increase in the far future by 76.93mm in the RCP 8.5 scenario.

AID SWAT Model 15

Average annual precipitation (PRECIP) value was estimated as 163.7mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 72mm, and in the far future, it will increase by 66.4mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 42.9mm, and in the far future, precipitation will increase by 203.1mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 1.08mm. Compared to the baseline period, the surface runoff will increase by 5.66mm in the near future, and the surface runoff will increase by 7.17mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 3.32mm, and in the far future, the surface runoff will increase by 34.13mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated as 1687.4 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 15mm in the near future, and PET will increase by 52mm in the far future in the RCP 4.5 scenario. PET will increase by 49.9mm in the near future, and PET will increase by 126.2mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) was estimated as 162mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 39.4mm, and in the far future, ET will increase by 29.4mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 20.7mm, and in the far future, ET will increase by 71mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated at 11.74mm in the baseline period (1985-2005). SW will increase by 18.31mm in the near future compared to the baseline period and increase by 19.79mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 9.93mm, and in the far future, SW will increase by 24.36mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) was estimated as 3.03mm in the baseline period (1985-2005).. Compared

to the baseline period PERC will increase by 20.97mm in the near future and increase by 24.43mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 12.32mm, and in the far future, PERC will increase by 88.72mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated as 2.74mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 9.45mm in the near future, and WYLD will increase by 11.04mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 4.51mm in the near future, and WYLD will increase in the far future by 93.17mm in the RCP 8.5 scenario.

AID SWAT Model 16

Average annual precipitation (PRECIP) value was estimated as 221.6mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 43.1mm, and in the far future, it will increase by 41mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 26.2mm, and in the far future, precipitation will increase by 67.9mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 1.65mm. Compared to the baseline period, the surface runoff will increase by 3.13mm in the near future, and the surface runoff will increase by 2.45mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 3.36mm, and in the far future, the surface runoff will increase by 6.81mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated at 1379.9 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 9.7mm in the near future, and PET will increase by 28mm in the far future in the RCP 4.5 scenario. PET will increase by 38.3mm in the near future, and PET will increase by 110.2mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 217mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 20.4mm, and in the far future, ET will increase by 22.2mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 10.1mm, and in the far future, ET will increase by 35mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated at 15.23mm in the baseline period (1985-2005). SW will increase by 11mm in the near future compared to the baseline period and increase by 8.18mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 5.71mm, and in the far future, SW will increase by 12.51mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 4.29mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 16.05mm in the near future and increase by 13.16mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 8.4mm, and in the far future, PERC will increase by 22.07mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 4.82mm in the

baseline period (1985-2005). Compared to baseline, WYLD will increase by 5.65mm in the near future, and WYLD will increase by 5.72mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 3.6mm in the near future, and WYLD will increase in the far future by 10.33mm in the RCP 8.5 scenario.

AID SWAT Model 17

Average annual precipitation (PRECIP) value estimated 217.8mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 42.3mm, and in the far future, it will increase by 37.9mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 26.3mm, and in the far future, precipitation will increase by 63.8mm in the RCP 8.5 scenario. Average annual surface runoff in baseline estimated 1.68mm. Compared to the baseline period, the surface runoff will increase by 2.73mm in the near future, and the surface runoff will increase by 12mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 2.99mm, and in the far future, the surface runoff will increase by 5.5mm in the RCP 8.5 scenario of SWAT model 4 of AID. The average annual potential evapotranspiration (PET) was estimated at 1394.2 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 13.7mm in the near future, and PET will increase by 30.6mm in the far future in the RCP 4.5 scenario. PET will increase by 40.5mm in the near future, and PET will increase by 109.8mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 217mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 22.9mm, and in the far future, ET will increase by 23mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 11.6mm, and in the far future, ET will increase by 37.2mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 14.47mm in the baseline period (1985-2005). SW will increase by 10.84mm in the near future compared to the baseline period and increase by 7.02mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 5.21mm, and in the far future, SW will increase by 11.13mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 3.52mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 13.68mm in the near future and increase by 10.16mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 7.53mm, and in the far future, PERC will increase by 17.75mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 3.57mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 3.31mm in the near future, and WYLD will increase by 3.6mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 2.9mm in the near future, and WYLD will increase in the far future by 7.05mm in the RCP 8.5 scenario.

AID SWAT Model 18

Average annual precipitation (PRECIP) value was estimated as 175.3mm in the baseline period (1985-2005). Compared to baseline, precipitation will increase in the near future by 67.7mm, and in the far future, it will increase by 61.8mm in the RCP 4.5 scenario. In the near future, compared to the baseline period, precipitation will increase by 47.5mm, and in the far future, precipitation will increase by 214mm in the RCP 8.5 scenario. Average annual surface runoff in baseline was estimated as 2.48mm. Compared to the baseline period, the surface runoff will increase by 9.18mm in the near future, and the surface runoff will increase by 9.04mm in the RCP 4.5 scenario. In the near future surface, the runoff will increase by 6.78mm, and in the far future, the surface runoff will increase by 54.04mm in the RCP 8.5 scenario of SWAT model 4 of AID.

The average annual potential evapotranspiration (PET) was estimated as 1770.4 mm in the baseline (1985-2005). Compared to the baseline period (1985-2005), PET will increase by 12.4mm in the near future, and PET will increase by 37.6mm in the far future in the RCP 4.5 scenario. PET will increase by 51.9mm in the near future, and PET will increase by 124.6mm compared to the baseline period in the RCP 8.5 scenario. Average annual evapotranspiration (ET) estimated 171.5mm in the baseline (1985-2005). Compared to the baseline period, ET will increase in the near future by 34.6mm, and in the far future, ET will increase by 25.6mm in the RCP 4.5 scenario. Compared to the baseline period in the near future, ET will increase by 22.3mm, and in the far future, ET will increase by 68.4mm in the RCP 8.5 scenario. The average annual water hold in the soil profile (SW) was estimated as 11.84mm in the baseline period (1985-2005). SW will increase by 17.26mm in the near future compared to the baseline period and increase by 18.89mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, SW value in the near future will increase by 10.47mm, and in the far future, SW will increase by 25.42mm in the RCP 8.5 scenario. Average annual percolation out of soil profile (PERC) estimated 2.32mm in the baseline period (1985-2005). Compared to the baseline period PERC will increase by 18.61mm in the near future and increase by 21.82mm in the far future in the RCP 4.5 scenario. Compared to the baseline period, PERC value in the near future PERC will increase by 12.2mm, and in the far future, PERC will increase by 83.51mm in the RCP 8.5 scenario. The average annual water yield (WYLD) was estimated at 4.32mm in the baseline period (1985-2005). Compared to baseline, WYLD will increase by 11.25mm in the near future, and WYLD will increase by 11.88mm in the far future in the RCP 4.5 scenario. Compared to the baseline period WYLD will increase by 8.02mm in the near future, and WYLD will increase in the far future by 106.87mm in the RCP 8.5 scenario.

Chapter 9: Crop water requirement for major crop

9. Introduction

The largest state in the country, Rajasthan covers about 10% geographical area, 5% population, 19% livestock and 14% cultivable area of the country. But Rajasthan has only 1.16% of the country's surface water. Its 14 river basins are reported to yield about 16.06 BCM of surface water at 50% dependability and another 17.78 BCM is available as state's shares in trans-boundary river waters under inter-state agreements. The irrigable land available in the state is about 15.7 million hectares requiring 75-100 BCM of water which is not there. Water availability is thus a serious constraint on food production potential of the state. Paradoxically, irrigation efficiencies of the existing projects in the state are reported be very low varying between 13-35 % of the usable water which are much below the national average. To cope with the water-shortage, it is necessary to adopt water saving agriculture counter measures as efficient use of irrigation water is becoming increasingly important. The primary objective of irrigation is to apply water to maintain crop Evapotranspiration (ET_c) when precipitation is insufficient. It is defined crop water requirements as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Each and every crop has individual water requirements. Evapotranspiration is the sum of evaporation and transpiration.

9.1 Objectives of the study

The adopted Methodology for the estimation of ET₀ is FAO-56 Penman-Monteith Method and for the CWR tool used is CROPWAT 8.0.for calculation of eff. rainfall we used USDA SC method.

The FAO Penman-Monteith method to estimate ET₀ is given in Eq.(9.1)

$$ET_0 = \frac{.408\Delta(R_n - G) + \gamma \left(\frac{900}{T + 273} \right) u_2 (e_s - e_a)}{u_2 (e_s - e_a)} \quad (9.1)$$

$$ET_c = K_c (ET_0) \quad (9.2)$$

Where,

ET_0 = Reference Evapotranspiration [mm/day]

R_n = Net Radiation at the Crop Surface [MJ/ m²day]

G = Soil heat flux density [MJ/m²day]

T = Mean daily air temperature at 2 m height [°C]

u_2 = Wind speed at 2 m height [m/s]

e_s = Saturation vapour pressure [kPa]

e_a = Actual vapour pressure [kPa]

$e_s - e_a$ = Saturation vapour pressure deficit [kPa]

Δ = slope vapour pressure curve [kPa /°C]

γ = Psychrometric constant [kPa /°C]

CROPWAT 8.0 – CropWat is a decision support system developed by FAO, having as main functions:

Table 9.1 CropWat decision support system main function

To calculate	Reference evapotranspiration, crop water requirements, crop irrigation requirements;
To develop	Irrigation schedules under various management conditions, Scheme water supply;

CROPWAT modules -

In Program structure, there are 5 Input modules and 3 are Calculation modules.

- The Input modules are
 1. Climate/ ET_0
 2. Rain
 3. Crop
 4. Soil
 5. Crop Pattern
- The Calculation modules

1. CWR
2. Schedule
3. Scheme

9.2 RESULTS AND DISCUSSION

This section deals with the result obtained in the study by following the program modules data entries and discussion on the crop water requirement for all five districts of Mahi region in Rajasthan so that an average estimation of crop water requirement can be analyzed for the districts.

9.2.1. Banswara

Crop water requirement (CWR)

Crop water requirement, effective rain and irrigation requirement values obtained for historical climatic year 2000 to 2019 for Maize crop and graph has been plotted between ET_c, Effective rain and IR v/s Years. The avg. ET_c for 20 years is 806.93 mm/dec, avg. Eff. rainfall is 349.365 mm/dec, avg. Irr. Req. is 501.215 mm/dec, avg. rain efficiency is 79.565%, vg. yield reduction is 15.08 % The graph trend shows that CWR lies between 680-944.8 mm/dec for the crop period of 125 days. Irrigation requirement also lies between 212-690 mm/dec for the all 20 years.

Table 9.2 CropWat water requirement for Banswara

CWR					
Years	ET _c (mm/dec)	Eff. Rainfall (mm/dec)	Irr. Req. (mm/dec)	Rain efficiency (%)	Yield reduction (%)
2000	779.6	331.1	494	81.2	10.4
2001	694	435.6	319.5	60.6	0
2002	944.8	328.1	643.2	94.2	17.7
2003	946	264.6	689.1	100	24.8
2004	821.6	259.2	609.5	85.9	21.6
2005	756.9	332.3	478.8	70.2	15.7
2006	769.9	271.4	528.9	92.7	16.5
2007	736.1	396.3	396.1	68.1	0.9
2008	801.4	359.1	480.1	78.5	0
2009	812.7	363.8	501.5	77.1	9.4
2010	816.8	353.2	518.5	70.9	22.3
2011	811.9	301.1	529.5	87.6	25.6

2012	822.3	333.1	539.9	75.5	23.6
2013	681.7	521.7	211.9	67	0
2014	949.7	390	622.2	73.9	27
2015	807.5	290.3	554.9	89.2	27.5
2016	819.6	342	505.1	86.1	19.5
2017	766.3	336.2	477.2	78.5	16.2
2018	819.7	385.8	488.3	71.5	17.8
2019	780.1	392.4	436.1	82.6	5.1
Avg.	806.93	349.365	501.215	79.565	15.08

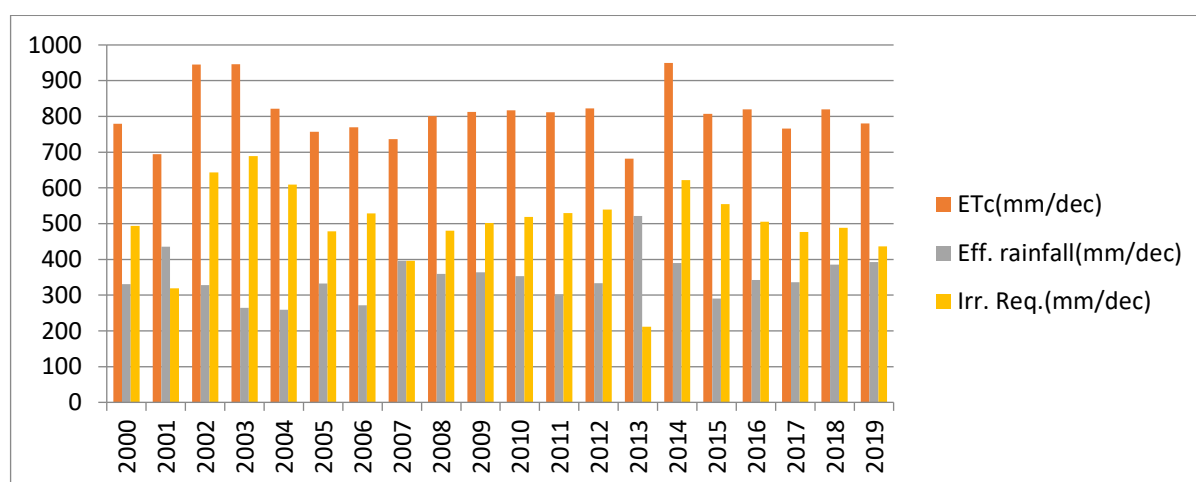


Figure 9.1: Graph between ETC, Effective Rain and IR V/S YeaEers (2000-2019)

Table 9.3 : Crop pattern for selected crops for Banswara

Crops Names	Plantation date	Harvesting Date	%Area
Maize	20/04	22/08	40
soyabean	10/05	02/08	5
wheat(winter)	01/10	28/05	27

Scheme Supply

Table 9.4: Precipitation deficit for major crops in Banswara

MONTHS/ CROPS	MAIZE	SOYABEAN	WINTER WHEAT
JAN	0	0	136.7
FEB	0	0	170.3
MAR	0	0	252.6
APR	30.4	0	307.3

MAY	144.3	103.6	195
JUN	160.5	160.6	0
JUL	59.1	41.6	0
AUG	3.2	4.9	0
SEP	0	0	0
OCT	0	0	66.9
NOV	0	0	81.3
DEC	0	0	102.6

Table 9.5: Net Scheme Irrigation Required in Banswara

Irr.req.	in mm/day	in mm/month	in l/s/h
JAN	1.2	36.9	0.14
FEB	1.6	46	0.19
MAR	2.2	68.2	0.25
APR	3.2	95.7	0.37
MAY	3.8	118.5	0.44
JUN	2.5	75.4	0.29
JUL	0.9	26.9	0.1
AUG	0.1	1.6	0.01
SEP	0	0	0
OCT	0.6	18.1	0.07
NOV	0.7	22	0.08
DEC	0.9	27.7	0.1

So, by adding all month's irrigation required we get yearly irrigation required which is 537 mm per year for Banswara district.

9.2.2. Dungarpur

Crop water requirement (CWR)

Crop water requirement, effective rain and irrigation requirement values obtained for historical climatic year 2000 to 2019 for Maize crop and graph has been plotted between ET_c, Effective rain and IR v/s Years. The avg ET_c for 20 years is 804.94 mm/dec, Eff. rainfall is 324.53 mm/dec, Irr. Req. is 521.63 mm/dec, rain efficiency is 84.68%, yield reduction is 12.95 % The graph trend shows that CWR lies between 680-960 mm/dec for the crop period of 125 days. Irrigation requirement also lies between 320-650 mm/dec for the all 20 years.

Table 9.6: Crop water requirement in Dungarpur

CWR					
Year s	ETc(mm/dec)	Eff. rainfall(mm/de c)	Irr. Req.(mm/dec)	Rain efficiency(%)	Yield reduction(%)
2000	797.5	304.3	529.5	87.3	14.5
2001	688.8	425.5	321.8	63.5	0
2002	910.4	301.5	631.6	100	15.4
2003	799.5	255.5	569	91.1	23.1
2004	822.4	241.3	622.7	94.6	22.6
2005	754	323.1	482.8	71.9	16.4
2006	760.2	260.1	529.5	92.3	17.2
2007	746.8	381.9	421	71.5	1.9
2008	753.9	342	470.3	77.6	0.7
2009	836.3	348.7	534.4	87.5	10.3
2010	820.2	334.4	539.3	78.5	16.5
2011	837.2	288.3	566.2	96.4	20.1
2012	825.8	313.4	555.6	83.5	17.7
2013	698.2	348.5	401.2	75.4	2.8
2014	960.3	372.6	647.1	81.1	21.6
2015	824.2	276.2	579.1	94.2	19.8
2016	844.7	328.4	535.4	93.9	13.5
2017	766.8	306	502.5	81.3	13.2
2018	838.1	374.1	511.3	79.1	11.4
2019	813.6	364.8	482.3	93	0.4
Avg.	804.945	324.53	521.63	84.685	12.955

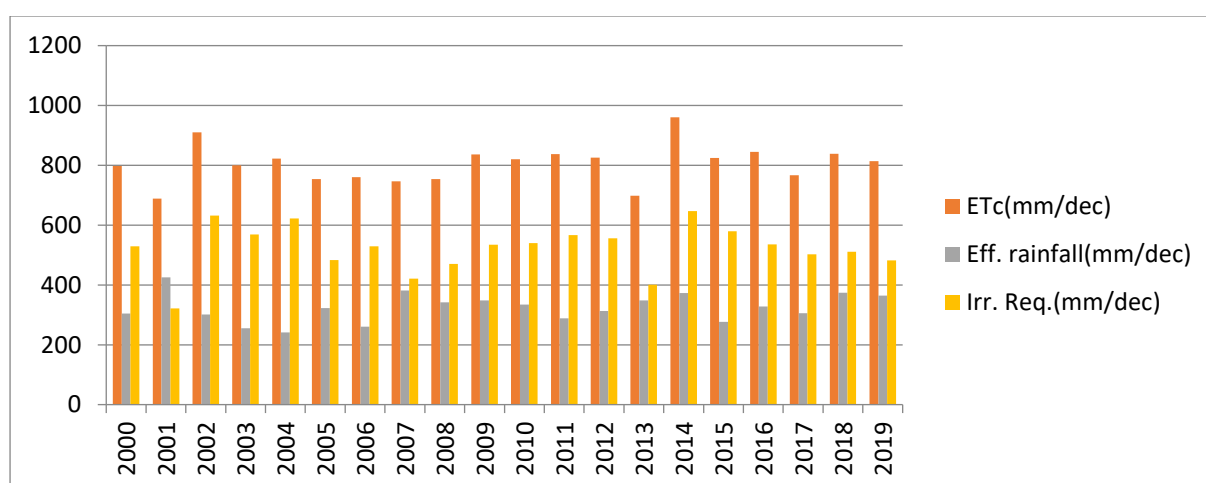


Figure 9.2: Graph between ETc, Effective Rain and IR V/S Years (2000-2019)

Table 9.7: Crop pattern

Crops Names	Plantation date	Harvesting Date	%Area
Maize	20/04	22/08	38
pulses	10/05	02/08	7
wheat(winter)	01/10	28/05	22

Scheme Supply

Table 9.10: Precipitation deficit for major crops in Dungarpur

MONTHS/ CROPS	MAIZE	PULSES	WINTER WHEAT
JAN	0	0	138.8
FEB	0	0	173.1
MAR	0	0	258.3
APR	31.3	0	316.1
MAY	155.8	98	205.2
JUN	243.8	150.3	0
JUL	73.9	66.7	0
AUG	3.3	5	0
SEP	0	0	0
OCT	0	0	71.8
NOV	0	0	82.8
DEC	0	0	104.4

Table 9.11: Net Scheme Irrigation Required in Dungarpur

MONTHS/ IRR. REQ.	in mm/day	in mm/month	in l/s/h
JAN	1	30.5	0.11
FEB	1.4	38.1	0.16
MAR	1.8	56.8	0.21
APR	2.7	81.4	0.31
MAY	3.6	111.2	0.42
JUN	3.4	103.2	0.4
JUL	1.1	32.7	0.12
AUG	0.1	1.6	0.01
SEP	0	0	0
OCT	0.5	15.8	0.06
NOV	0.6	18.2	0.07
DEC	0.7	23	0.09

So, by adding all month's irrigation required we get yearly irrigation required which is 512.5 mm per year or 1.96 L/s/h for Dungarpur district for above selected crops.

9.2.3. Pratapgarh

Crop water requirement (CWR)

Crop water requirement, effective rain and irrigation requirement values obtained for historical climatic year 2000 to 2019 for Maize crop and graph has been plotted between ET_c, Effective rain and IR v/s Years. The avg ET_c for 20 years is 807.075 mm/dec, Eff. rainfall is 327.43 mm/dec, Irr. Req. is 524.47 mm/dec, rain efficiency is 81.9%, yield reduction is 13.545 % The graph trend shows that CWR lies between 690-950 mm/dec for the crop period of 125 days. Irrigation requirement also lies between 320-650 mm/dec for the all 20 years.

Table 9.12 Crop water requirement in Pratapgarh

years	CWR				
	ET _c (mm/dec)	Eff. rainfall(mm/dec)	Irr. Req.(mm/dec)	rain efficiency(%)	yield reduction(%)
2000	787.8	245.3	579.2	86.8	22.6
2001	692.3	412.1	338.1	67.9	0
2002	951.8	306.5	673.2	100	18.5
2003	816.5	294.3	565.8	80.5	23
2004	842.8	235	652.3	93.7	26.2
2005	775.1	330.6	493.9	74.7	14.9
2006	777.6	288.9	528.8	89	14.1
2007	747.1	396.7	407.2	68.6	0.3
2008	730.2	361.2	426.9	67.3	0.2
2009	809.6	355	499	86.8	7.6
2010	826.7	341.8	537.8	77.5	15.6
2011	808.4	301.5	542	83.9	20.5
2012	845.5	315.3	576.5	83.9	20
2013	761.2	355.9	454.6	76.1	4.6
2014	952.3	367.8	644.1	80.4	21.9
2015	817.7	272.8	577.1	93	18.9
2016	809.4	330.6	510.1	85.2	13.4
2017	775.1	302	525	79.5	16
2018	825.6	375.4	501.8	72.6	11.9
2019	788.2	359.9	456	90.6	0.7
Avg.	807.045	327.43	524.47	81.9	13.545

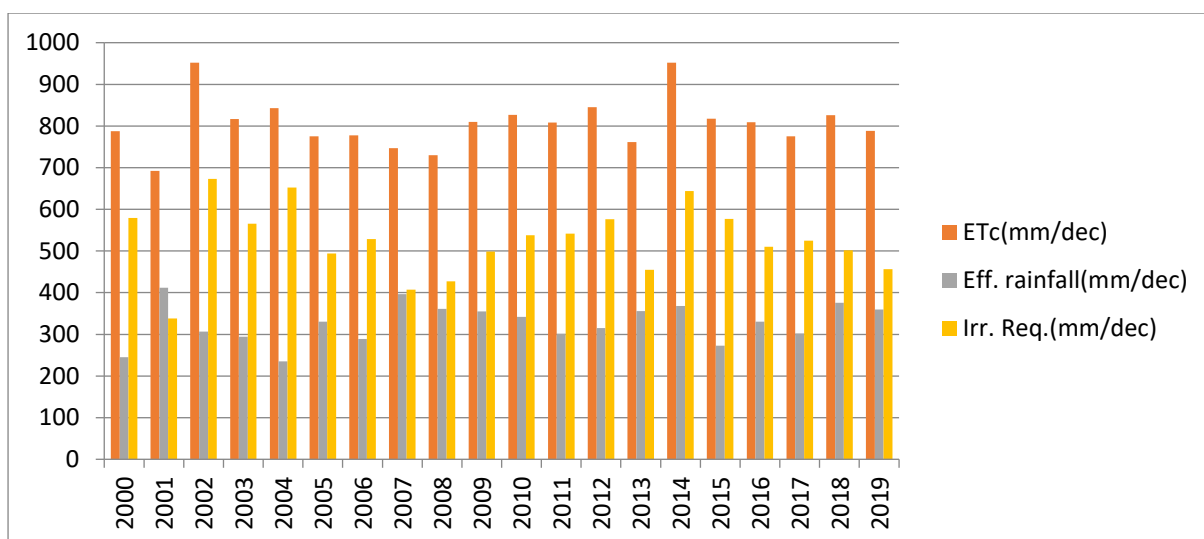


Figure 9.3: Graph between ETc, Effective Rain and IR V/S Years (2000-2019)

Crop pattern

Table 9.13: Crop pattern for selected crops in Pratapgarh

Crops Names	Plantation date	Harvesting Date	%Area
Maize	20/04	22/08	21
soyabean	10/05	02/08	37
wheat(winter)	01/10	28/05	19

Scheme Supply

Table 9.14: Precipitation deficit for major crops in Pratapgarh

MONTHS/ CROPS	MAIZE	SOYABEAN	WINTER WHEAT
JAN	0	0	136.9
FEB	0	0	169
MAR	0	0	257.5
APR	30.7	0	311.8
MAY	153.4	111.8	202.3
JUN	239	235.5	0
JUL	74.3	53.2	0
AUG	3.2	5.2	0
SEP	0	0	0
OCT	0	0	65.7
NOV	0	0	74.7
DEC	0	0	94.9

Table 9.15: Net Scheme Irrigation Required in Pratapgarh

MONTHS/ IRR. REQ.	in mm/day	in mm/month	in l/s/h
JAN	0.8	26	0.1
FEB	1.1	32.1	0.13
MAR	1.6	48.9	0.18
APR	2.2	65.7	0.25
MAY	3.6	112	0.42
JUN	4.6	137.3	0.53
JUL	1.1	35.3	0.13
AUG	0.1	2.6	0.01
SEP	0	0	0
OCT	0.4	12.5	0.05
NOV	0.5	14.2	0.05
DEC	0.6	18	0.07

So, by adding all month's irrigation required we get yearly irrigation required which is 504.6 mm per year or 1.92 L/s/h for Pratapgarh district for above selected crops.

9.2.4. Chittorgarh

Crop water requirement (CWR)

Crop water requirement, effective rain and irrigation requirement values obtained for historical climatic year 2000 to 2019 for Maize crop and graph has been plotted between ET_c, Effective rain and IR v/s Years. The avg ET_c for 20 years is 803.295 mm/dec, Eff. rainfall is 320.08 mm/dec, Irr. Req. is 526.82 mm/dec, rain efficiency is 83.27%, yield reduction is 17 %. The graph trend shows that CWR lies between 690-950 mm/dec for the crop period of 125 days. Irrigation requirement also lies between 350-680 mm/dec for all 20 years.

Table 9.16 Crop water requirement in Chittorgarh

Crop Water Rrequirements					
years	ET_c(mm/dec)	Eff. rainfall(mm/dec)	Irr. Req.(mm/dec)	rain efficiency (%)	yield reduction (%)
2000	799.3	305.3	524.8	89.8	15.9
2001	696.7	399.7	355.1	74.3	1.7
2002	954	316.9	664.5	100	19.6
2003	830.4	285.6	584.5	84.8	27.6
2004	850.5	217	677.2	92.2	33.3
2005	778.7	314.9	504.3	80.2	19.4
2006	776.1	296.6	523.5	87.5	16.8

2007	753.5	380.3	429.3	74.6	4.2
2008	714.4	344.5	426.3	72.1	2.6
2009	813.3	351.7	500.4	90.6	11
2010	826.1	314.2	564	80.1	22
2011	790.3	307.4	523.4	77.9	23.3
2012	855.4	287.3	611.3	84.5	26.2
2013	704.8	346.5	415.9	72.4	7
2014	943.4	354.9	644.4	81.4	26.5
2015	818.1	258.7	585.4	93	23.6
2016	802.9	317.9	519.8	83.6	19.4
2017	753	289	518.3	75.3	20.6
2018	817	365.4	502.2	77	14.9
2019	788	347.8	461.8	94.1	4.4
Avg.	803.295	320.08	526.82	83.27	17

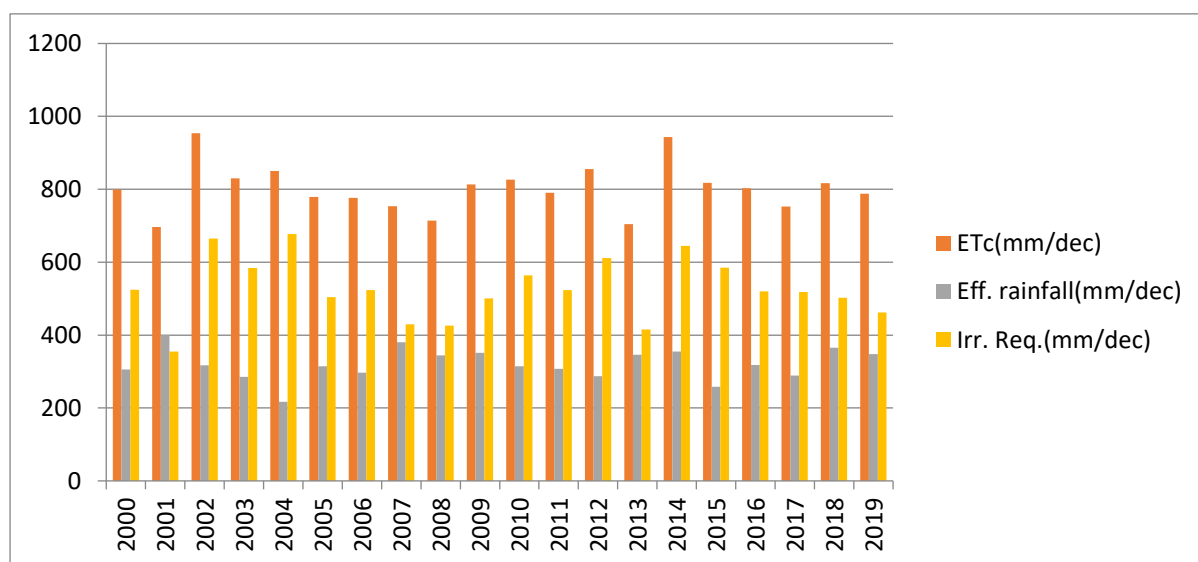


Figure 9.4: Graph between ETc, Effective Rain and IR V/S Years (2000-2019)

Crop pattern

Table 9.17 Crop pattern for selected crops Chittorgarh

Crops Names	Plantation date	Harvesting Date	%Area
Maize	20/04	22/08	27
soyabean	10/05	02/08	21
wheat(winter)	01/10	28/05	18

Scheme Supply

Table 9.18 Precipitation deficit for major crops in Chittorgarh

MONTHS/ CROPS	MAIZE	SOYABEAN	WINTER WHEAT
JAN	0	0	122.5
FEB	0	0	158.9
MAR	0	0	246.8
APR	29.9	0	305.5
MAY	149.2	108.6	196.8
JUN	242.6	238.8	0
JUL	86.7	62.3	0
AUG	3.3	5.3	0
SEP	0	0	0
OCT	0	0	67.8
NOV	0	0	72
DEC	0	0	88.4

Table 9.19: Net Scheme Irrigation Required in Chittorgarh

MONTHS/ IRR. REQ.	in mm/day	in mm/month	in l/s/h
JAN	0.7	22.1	0.08
FEB	1	28.6	0.12
MAR	1.4	44.4	0.17
APR	2.1	63.1	0.24
MAY	3.2	98.5	0.37
JUN	3.9	115.7	0.45
JUL	1.2	36.5	0.14
AUG	0.1	2	0.01
SEP	0	0	0
OCT	0.4	12.2	0.05
NOV	0.4	13	0.05
DEC	0.5	15.9	0.06

So, by adding all month's irrigation required we get yearly irrigation required which is 452 mm per year or 1.74 L/s/h for Chittorgarh district for above selected crops.

9.2.5. Udaipur

Crop water requirement (CWR)

Crop water requirement, effective rain and irrigation requirement values obtained for historical climatic year 2000 to 2019 for Maize crop and graph has been plotted between ET_c, Effective

rain and IR v/s Years. The avg ETc for 20 years is 778.79 mm/dec, Eff. rainfall is 323.98 mm/dec, Irr. Req. is 499.92 mm/dec, rain efficiency is 82.18 %, yield reduction is 14.41 %. The graph trend shows that CWR lies between 680-1024 mm/dec for the crop period of 125 days. Irrigation requirement also lies between 350-730 mm/dec for the all 20 years.

Table 9.20 Crop water requirement in Udaipur

CWR					
years	ETc (mm/dec)	Eff. rainfall(mm/dec)	Irr. Req.(mm/dec)	rain efficiency(%)	yield reduction(%)
2000	770.8	316.8	494	85.1	12.7
2001	688.4	394.2	351.7	74.9	1.5
2002	1024.9	323.4	726.3	100	24.9
2003	794.2	297.4	540.5	79.4	23.8
2004	811	218.3	640.2	90.1	29.9
2005	757.7	319.6	479.4	80.4	15.4
2006	751.1	305.9	490.5	87.7	14.7
2007	730	386.1	401.7	73.9	2.3
2008	699.5	355.4	402	72.1	1.3
2009	769.4	356.2	454.3	86.1	6
2010	785.7	321.3	516.9	81.5	14.6
2011	786.3	307.4	518.1	80.3	21.3
2012	808.5	287.3	564.8	84.6	22.5
2013	688.2	346.5	401.3	72.3	5.2
2014	907.9	354.9	607.2	81.4	23.3
2015	773.5	258.7	542.9	92.8	20.4
2016	775.1	317.9	490.6	82.9	16.8
2017	711.1	289	479.6	69.6	18.6
2018	778	365.4	463.9	75.6	11.6
2019	764.5	357.9	432.5	92.9	1.4
Avg.	778.79	323.98	499.92	82.18	14.41

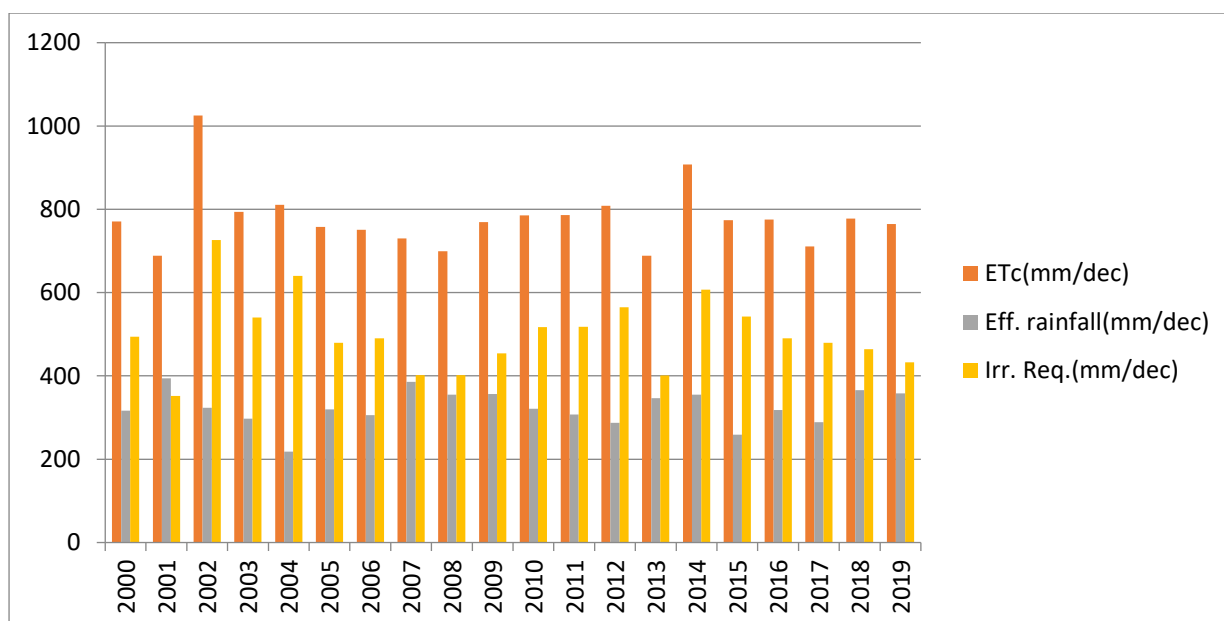


Figure 9.5: Graph between ETc, Effective Rain and IR V/S Years (2000-2019)

Crop pattern

Table 9.21: Crop pattern for selected crops in Udaipur

Crops Names	Plantation date	Harvesting Date	%Area
Maize	20/04	22/08	50
Sorghum	03/03	30/06	2
wheat(winter)	01/10	28/05	21

Scheme Supply

Table 2.22: Precipitation deficit for major crops in Udaipur

MONTHS/ CROPS	MAIZE	SORGHUM (GRAIN)	WINTER WHEAT
JAN	0	0	124.5
FEB	0	0	163.4
MAR	0	66.5	252.2
APR	29.4	199.1	303.4
MAY	144.4	339.7	191.5
JUN	222.8	128.2	0
JUL	79.5	0	0
AUG	3.2	0	0
SEP	0	0	0
OCT	0	0	65.3

NOV	0	0	72.9
DEC	0	0	88

Table 9.23: Net Scheme Irrigation Required Udaipur

MONTHS/ IRR. REQ.	in mm/day	in mm/month	in l/s/h
JAN	0.8	26.2	0.1
FEB	1.2	34.3	0.14
MAR	1.8	54.3	0.2
APR	2.7	82.4	0.32
MAY	3.8	119.2	0.45
JUN	3.8	113.9	0.44
JUL	1.3	39.8	0.15
AUG	0.1	1.6	0.01
SEP	0	0	0
OCT	0.4	13.7	0.05
NOV	0.5	15.3	0.06
DEC	0.6	18.5	0.07

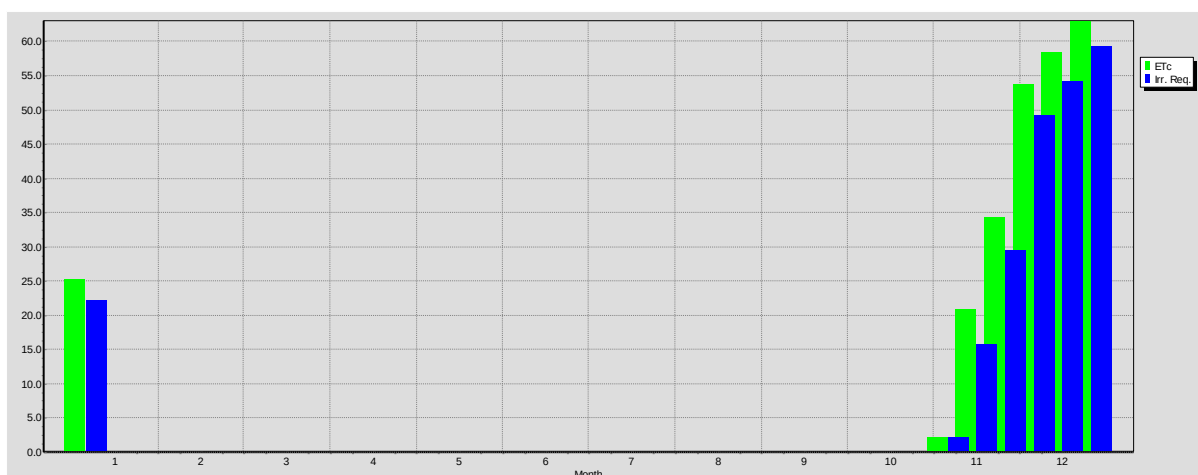
So, by adding all month's irrigation required we get yearly irrigation required which is 519.2 mm per year or 1.99 /s/h for Udaipur district for above selected crops

9.2.6. Area of Inland drainage

Crop water requirement (CWR) - Crop water requirement, effective rain and irrigation requirement values obtained for the historical climatic year 2000 to 2019 for Mustard crop and graph has been plotted between ET_c, IR v/s monthsthe in field. The avg ET_c for 20 years is 257.7 mm/dec, avg. Eff. rainfall is 25.2 mm/dec, avg Irr. Req. is 232.4 mm/dec.

Table 9.24: ET_c, ER, IR values for mustard (historical)

Month	Decade	Stage	Kc	ET _c	ET _c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.35	2.2	2.2	0.5	2.2
Nov	2	Deve	0.35	2.08	20.8	5.1	15.8
Nov	3	Deve	0.61	3.43	34.3	4.8	29.5
Dec	1	Mid	1.01	5.38	53.8	4.5	49.3
Dec	2	Mid	1.15	5.84	58.4	4.3	54.1
Dec	3	Late	1.13	5.73	63	3.7	59.3
Jan	1	Late	0.63	3.16	25.3	2.4	22.3
					257.7	25.2	232.4



Crop pattern -

Crops Names	Plantation date	Harvesting Date	%Area
Mustard	10/11	8/01	45

Scheme Supply -

Table 9.25: Precipitation deficit for major crop

Month / Crop	mustard
Jan	22.3
Feb	0
Mar	0
Apr	0
May	0
Jun	0
Jul	0
Aug	0
Sep	0
Oct	0
Nov	47.5
Dec	162.7

Table 9.26: Net Scheme Irrigation Required

Net scheme irr. req.	mm/day	mm/month	l/s/h
Jan	0.3	10	0.04
Feb	0	0	0
Mar	0	0	0
Apr	0	0	0

May	0	0	0
Jun	0	0	0
Jul	0	0	0
Aug	0	0	0
Sep	0	0	0
Oct	0	0	0
Nov	0.7	20.4	0.08
Dec	2.0	62.2	0.27

Total irrigation required for mustard crop in desert area is 92.6 mm/year.

CWR (ET_o, ET_c, IR) for near and far future at RCP 4.5 scenarios

Table 9.27: ET_o Values with climatic parameters (2030-2040)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ET _o
	°C	°C	%	m/s	hours	MJ/m ² /day	mm/day
January	10	27.1	31	3	9.9	16.4	4.81
February	14.2	30.9	28	3.1	10.3	19.3	6.03
March	19.7	34.5	24	3.1	10.9	23	7.53
April	23.8	38.4	22	3.7	11.5	26.2	9.78
May	26.9	41.7	28	5.1	12.1	28	12.32
June	27.7	39.9	39	5.4	9.2	23.9	10.99
July	26.9	37.9	52	5.2	5.9	18.8	8.52
August	26.7	37.5	58	4.4	6	18.3	7.29
September	24.5	36.9	51	3.5	9.6	21.8	7.42
October	19.6	33.5	33	2.6	10.9	20.8	6.34
November	13.4	29.1	28	2.6	10.4	17.4	5.14
December	10	26.1	30	2.8	9.5	15.2	4.49
Average	20.3	34.5	35	3.7	9.7	20.8	7.55

Table 9.18: ET_o Values with climatic parameters (2080-2090)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ET _o
	°C	°C	%	m/s	hours	MJ/m ² /day	mm/day
January	12.2	29.7	31	3	9.9	16.4	5.14
February	17.3	33.1	28	3.1	10.3	19.3	6.4
March	22	36.8	24	3.1	10.9	23	7.93
April	25.9	41.6	22	3.7	11.5	26.2	10.39
May	28.9	42.9	28	5.1	12.1	28	12.72
June	28.7	40.2	39	5.4	9.2	23.9	11.11
July	27.6	38.5	52	5.2	5.9	18.8	8.65
August	26.7	38.6	58	4.4	6	18.3	7.48

September	23.6	36.5	51	3.5	9.6	21.8	7.36
October	17.9	32.5	33	2.6	10.9	20.8	6.18
November	12.7	28.6	28	2.6	10.4	17.4	5.03
December	10.5	27.2	30	2.8	9.5	15.2	4.57
Average	21.2	35.5	35	3.7	9.7	20.8	7.75

Table 9.29: ET_c, ER, IR values for mustard (2030-2040)

Month	Decade	Stage	Kc	ET _c	ET _c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.35	1.94	1.9	0.3	1.9
Nov	2	Deve	0.35	1.82	18.2	2.1	16.1
Nov	3	Deve	0.61	3	30	1.7	28.3
Dec	1	Mid	1.01	4.66	46.6	1.3	45.3
Dec	2	Mid	1.15	5.04	50.4	0.9	49.6
Dec	3	Late	1.13	5.11	56.2	0.9	55.3
Jan	1	Late	0.63	2.96	23.7	0.7	22.8
					227.1	7.8	219.3

Table 9.30: ET_c, ER, IR values for mustard (2080-2090)

Month	Decade	Stage	Kc	ET _c	ET _c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.35	1.9	1.9	0.4	1.9
Nov	2	Deve	0.35	1.78	17.8	4.1	13.8
Nov	3	Deve	0.61	2.98	29.8	3	26.7
Dec	1	Mid	1.01	4.69	46.9	1.6	45.2
Dec	2	Mid	1.15	5.14	51.4	0.6	50.8
Dec	3	Late	1.13	5.3	58.2	0.6	57.7
Jan	1	Late	0.63	3.12	24.9	0.5	24.3
					231	10.8	220.4

Scheme Supply

Table 9.31: Precipitation deficit for used crop

Month / Crop	Near future	Far future
Jan	22.8	24.3
Feb	0	0
Mar	0	0
Apr	0	0
May	0	0
Jun	0	0
Jul	0	0

Aug	0	0
Sep	0	0
Oct	0	0
Nov	46.3	42.4
Dec	150.3	153.7

Table 9.32: Net scheme Irrigation required

Irr. req.	Near Future (2030-40)			Far future (2080-90)		
	mm/day	mm/month	l/s/h	mm/day	mm/month	l/s/h
Jan	0.3	10.3	0.04	0.4	11	0.04
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0
May	0	0	0	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	0	0	0	0	0	0
Oct	0	0	0	0	0	0
Nov	0.7	20.8	0.08	0.6	19.1	0.07
Dec	2.2	67.7	0.25	2.2	69.2	0.26

CWR (ET_o, ET_c, IR) for near and far future at RCP 8.5 scenarios

Table 9.33: ET_o Values with climatic parameters (2030-2040)

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m ² /day	ET _o mm/day
January	10.1	27.2	31	3	9.9	16.5	4.84
February	14.4	30.8	28	3.1	10.3	19.4	6.04
March	19.6	34.4	24	3.1	10.9	23.1	7.53
April	24	39	22	3.7	11.5	26.2	9.88
May	27	41.9	28	5.1	12.1	28	12.35
June	28.3	40.6	39	5.4	9.2	23.9	11.15
July	27.2	38.3	52	5.2	5.9	18.8	8.6
August	26.8	37.8	58	4.4	6	18.3	7.34
September	24.7	37.2	51	3.5	9.6	21.9	7.47
October	19.6	33.4	33	2.6	10.9	20.9	6.34
November	14	29.2	28	2.6	10.4	17.5	5.17
December	10.3	26.3	30	2.8	9.5	15.2	4.53
Average	20.5	34.7	35	3.7	9.7	20.8	7.6

Table 9.34: ETo Values with climatic parameters (2080-2090)

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	14.3	30.7	31	3	9.9	16.5	5.31
February	19.4	34.6	28	3.1	10.3	19.4	6.65
March	23.9	38.7	24	3.1	10.9	23.1	8.26
April	27.9	43.7	22	3.7	11.5	26.2	10.83
May	31	44.6	28	5.1	12.1	28	13.2
June	30.6	42.2	39	5.4	9.2	23.9	11.63
July	28.9	39.5	52	5.2	5.9	18.8	8.87
August	28.6	39.6	58	4.4	6	18.3	7.67
September	25.4	37.9	51	3.5	9.6	21.9	7.62
October	20.8	33.9	33	2.6	10.9	20.9	6.43
November	15.6	30.4	28	2.6	10.4	17.5	5.31
December	13.1	29.1	30	2.8	9.5	15.2	4.86
Average	23.3	37.1	35	3.7	9.7	20.8	8.05

Table 9.35: ETc, ER, IR values for mustard (2030-2040)

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	1	Init	0.35	1.95	1.9	0.5	1.9
Nov	2	Deve	0.35	1.83	18.3	4.3	14
Nov	3	Deve	0.61	3.02	30.2	4	26.3
Dec	1	Mid	1.01	4.71	47.1	3.7	43.3
Dec	2	Mid	1.15	5.1	51	3.3	47.6
Dec	3	Late	1.13	5.15	56.7	2.6	54.1
Jan	1	Late	0.63	2.98	23.9	1.2	22.3
					229	19.7	209.6

Table 9.36: ETc, ER, IR values for mustard (2080-2090)

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	1	Init	0.35	1.99	2	0.6	2
Nov	2	Deve	0.35	1.88	18.8	6.2	12.6
Nov	3	Deve	0.61	3.15	31.5	4.6	26.8
Dec	1	Mid	1.01	4.97	49.7	2.5	47.2
Dec	2	Mid	1.15	5.47	54.7	1	53.7
Dec	3	Late	1.13	5.57	61.3	1.1	60.2

Jan	1	Late	0.63	3.25	26	1.1	24.6
					244	17.2	227

Scheme Supply

Table 9.37: Precipitation deficit for used crop

Month / Crop	Near future	Far future
Jan	22.3	24.6
Feb	0	0
Mar	0	0
Apr	0	0
May	0	0
Jun	0	0
Jul	0	0
Aug	0	0
Sep	0	0
Oct	0	0
Nov	42.2	41.4
Dec	145.1	161

Table 9.38: Net scheme Irrigation required

Irr. req.	Near Future (2030-40)			Far future (2080-90)		
	mm/day	mm/month	l/s/h	mm/day	mm/month	l/s/h
Jan	0.3	10	0.04	0.4	11.1	0.04
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0
May	0	0	0	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	0	0	0	0	0	0
Oct	0	0	0	0	0	0
Nov	0.6	19	0.07	0.6	18.6	0.07
Dec	2.2	69.5	0.24	2.3	72.5	0.27

9.3 Historic Drought and Flood validation with Standardised Precipitation Index (SPI)

9.3.1 Introduction

SPI (Standardised Precipitation Index) is used to calculate the flood and drought in the area by point or grid precipitation data. The SPI value varies between +2.5 to –2.5 which defines extreme wet and extreme dry conditions respectively.

9.3.2 Data Used

The precipitation dataset of upper Mahi basin areis collected from India WRIS (Water Resource Information System) portal.

Also, Gauge dataset of different gauges like Rangeli, Dhariyawad, Paderdibadi, Mataji and Chakaliya are used.

9.3.2 Methodology

In SPI calculation the precipitation data is distributed by gamma function.

The R Programming language and ‘SPEI’ programming package is used to calculate various monthly SPI values.

The SPI values are calculated 24 time ranging from 1-Monthly to 24-Monthly.

After that the observed discharge dataset from the collected observation data standardised and compared with the SPI values.

So, the two values of SPI (Standardised Precipitation Index) and SDI (Standardised Discharge Index) is compared and the co-relation co-efficient is calculated.

The below table shows the R^2 value for different monthly SPI and SDI values.

The SPI index is used to perform the historic drought and flood validation.

Table 9.24 Correlation Table for (SDI vs. SPI)

Monthly SPI	R-square
1	0.1776
2	0.2291
3	0.2744
4	0.3321
5	0.4066
6	0.4936
7	0.5678
8	0.6736
9	0.7281
10	0.7986
11	0.8643
12	0.8709
13	0.8823
14	0.8882
15	0.8918

16	0.8949
17	0.8983
18	0.9003
19	0.9021
20	0.9044
21	0.906
22	0.9081
23	0.9113
24	0.9122

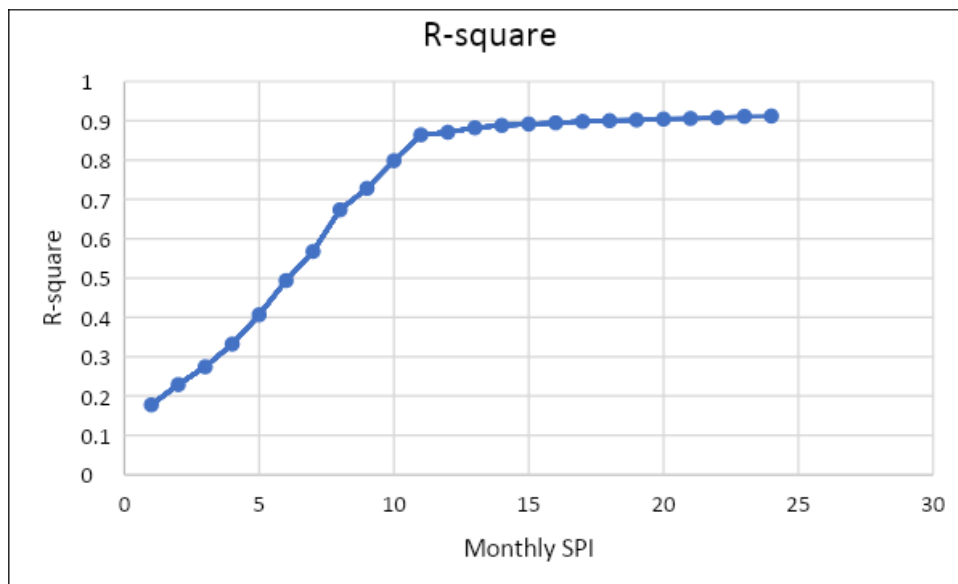


Figure 8.1: R-square plot (Monthly SPI vs. R-square)

9.3.4 Results

As shown in above table the SPI values from 12-Month to 24-Month have shown the highest correlation coefficient.



Figure 8.2: SPI Plot (12-Monthly)

To validate the historic flood and drought dataset the information from the newspaper and reports are scrutinised.

The plot showing the drought in 2001, flood in 2006, 2013 and 2020 are validated by the newspaper and reports of various government agencies.

Chapter 10: Ground water recharge under different RCP scenarios

10. Introduction

People have known for a long time that climate change could affect water resources, but there hasn't been much research done on groundwater (IPCC,2001). When it comes to groundwater, climate change research has mostly been about figuring out what the likely direct effects of changing rainfall and temperature patterns will be. A lot of research has been conducted on the impact of climate change on surface water bodies. However, relatively little study has been conducted on the possible consequences of climate change on groundwater, even though groundwater is the primary supply of drinking water in most of the globe and plays an important role in preserving an area's bioactivity.

10.1 Ground water Recharge in different climate scenarios

Groundwater recharge will be affected by many things, such as changes in rainfall and temperature patterns, coastal flooding, urbanisation and surface sealing, the creation of new forests, changes in cropping and rotation, and so on. Throughout most places, the direct effects of the climate scenarios are bigger than the effects of the socio-economic scenarios. The socio-economic scenarios do lead to changes in the region in small watershed and the effects of the socio-economic scenarios can be very big where they lead to big changes in how land is used in region. Climate scenarios was derived from an ensemble of 4 climate simulations provided by 4 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) driven by RCP4.5 and RCP8.5 future greenhouse gas concentrations.

The climate scenario simulation process was constrained by SWAT hydrological model for hydrological water balance components (Surface runoff, Ground water recharge ...etc) and climate variables (temperature and precipitation) between the 1981–2010 period and the 2011–2100 period for scenario 4.5 and 8.5. Ground water recharge for both scenario RCP 4.5 and RCP8.5 computed, and results are presented based on the HRUs in all sub basins of the Mahi River. The simulation period was divided into two period Near Future (2021-2045) and Far future (2075-2100), the reference period taken for comparison 1985-2005.

The simulations showed both increases and decreases in Ground Water Recharge in the future, hence noticeably increasing the range of possible future conditions from those simulated in the reference period. The analysis of monthly recharge allowed major shifts in the intra-annual changes in future GWR to be identified. The results show that GWR could significantly increase due to climate change and lead to an earlier annual GWR peak in the sites of Mahi River basin.

These outcomes were most likely made achievable by the employment of a single model throughout the area and a thorough understanding of previous dynamics in the Ground water recharge. Understanding the features of various locations to address the link between climate change and the depletion of fresh groundwater recharge. Future climate change may have a greater effect on emerging countries such as India, whose economy is heavily reliant on agriculture and is already stressed owing to present population growth and accompanying needs for energy, freshwater, and food.

Spatial distribution of mean annual precipitation represents that during the historical period (1981-2005) it was 843.23mm . According to MME projections it will increase by 117.33 mm in NF and 211.59 mm in FF under RCP4.5 scenario. These changes in RCP8.5 scenario is less as compared to RCP4.5 due to high warming in RCP8.5. Spatial distribution of mean annual maximum temperature (Tasmax) represents that during the historical period it was 41.52°C. According to MME projections it will increase by 0.75°C in NF and 1.41°C in FF under RCP4.5 scenario. The annual mean increase in NF of both RCPs are like each other but in FF of RCP8.5 it is projected to increase by more than two times of increase in RCP4.5 scenario. In mahi River Basin annual minimum temperature is projected to increase more as compared to annual maximum temperature in both RCPs. This represents that in the coming years the warming rate in the nights will be more as compared to in day time.

Future projections of MME represent that mean annual precipitation changes will spatially vary between 18.56mm to 191.56mm in RCP4.5 scenario while it will be between -7.22 to 250.38mm in RCP8.5 scenario. In RCP8.5 scenario, North-East regions of Area of Inland Drainage (AID) will have decreasing rainfall in this century. But the south-western part of AID will be highly vulnerable to increase in rainfall (around 250mm). In AID mean annual maximum temperature was 42.26°C during historical period which is projected by MME to increase by 1.23°C and 1.41°C in NF of RCP4.5 and RCP8.5 scenario. It will increase by 4.56°C in FF under RCP8.5 scenario which is more than two times of increase in RCP4.5

scenario. The areas near to border will be more affected due to major rise in temperature. It will affect the specially affect for soldiers of army working on border. Mean annual minimum temperature of AID was 4.77°C during historical period which is projected to increase by 1.00°C in NF and 2.21°C in FF of RCP4.5 and RCP8.5 scenario, respectively. Maximum increase will be in the central regions of AID where minimum temperature can increase more than 5°C in FF of RCP8.5. For all the SWAT model sub basin of AID showing drastically increase in PET and PET for future period. Most of the AID SWAT model shows decrease the Groundwater component in AID area.

Table 10.1: Average ground water recharge in different basin area

Basin Area	Historical	Near Future (2021 - 2045)		Far future (2075 - 2099)	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bajaj Sagar	7.52	8.76	7.82	9.44	8.61
Mataji	8.16	9.63	8.54	10.24	9.36
Kadana	6.16	7.95	6.72	8.67	8.02
Paderdibadi	3.66	4.62	3.86	5.07	4.52
Rangeli	4.19	5.33	4.42	5.86	5.25
Panam	6.48	8.15	7.10	8.28	8.93
Khanpur	6.34	7.99	7.22	9.00	8.23
Dhariyabad	5.39	6.52	5.54	7.02	6.26
Chakaliya	5.90	7.05	6.24	7.64	6.93
AID	0.31	0.84	0.49	0.85	1.08

The ground water recharge varies due to climate change has been summarized in table 10.1 Changes in different climate scenarios compared to historical period has been analysed. Both increase and decrease in GW recharge has been found for future scenarios. For all the sub basins consistent GW recharge has been found in the historical period. In the near future, period, it will be increased and in the far future it will be decreased. In near future the RCP 4.5 has shown more GW recharge compared to RCP 8.5 scenarios in Mahi River basin area. But for AID, has significantly low GW recharge compared to Mahi River basin area. Also, the GW recharge rate will be increased in future for both the scenarios. But the RCP 4.5 shows almost equal increase in near and far future. In far future RCP 8.5 GW recharge will be increased more compared to near future RCP 8.5. Monthly variation in GW recharge for different basin areas has been shown in figures' below. GW recharge mainly happened in monsoon season when there is a good amount of precipitation.

10.2 Graphical representation of the ground water recharge in different climate change scenario

Mataji station basin area

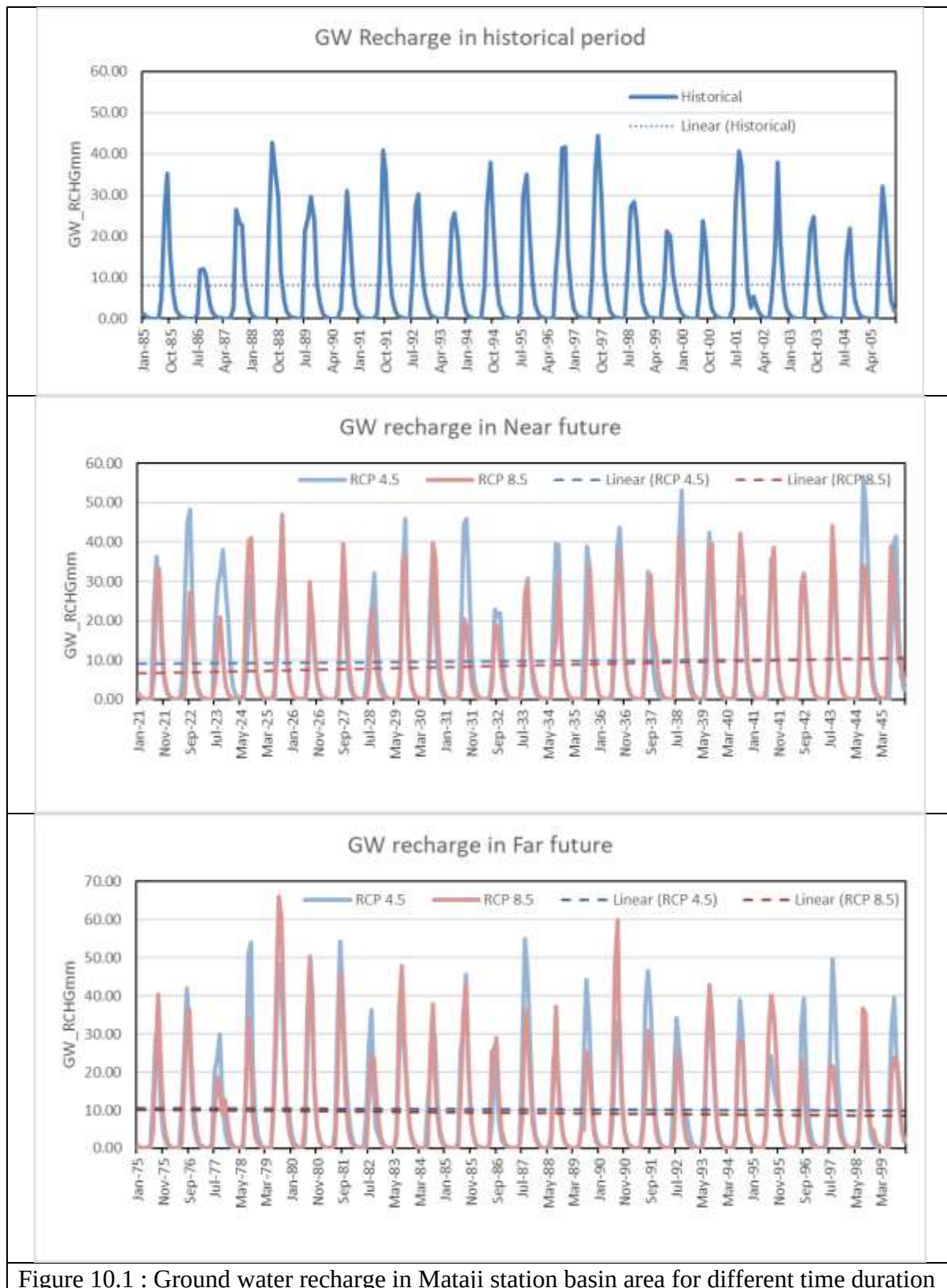


Figure 10.1 : Ground water recharge in Mataji station basin area for different time duration

Bajaj Sagar station basin area

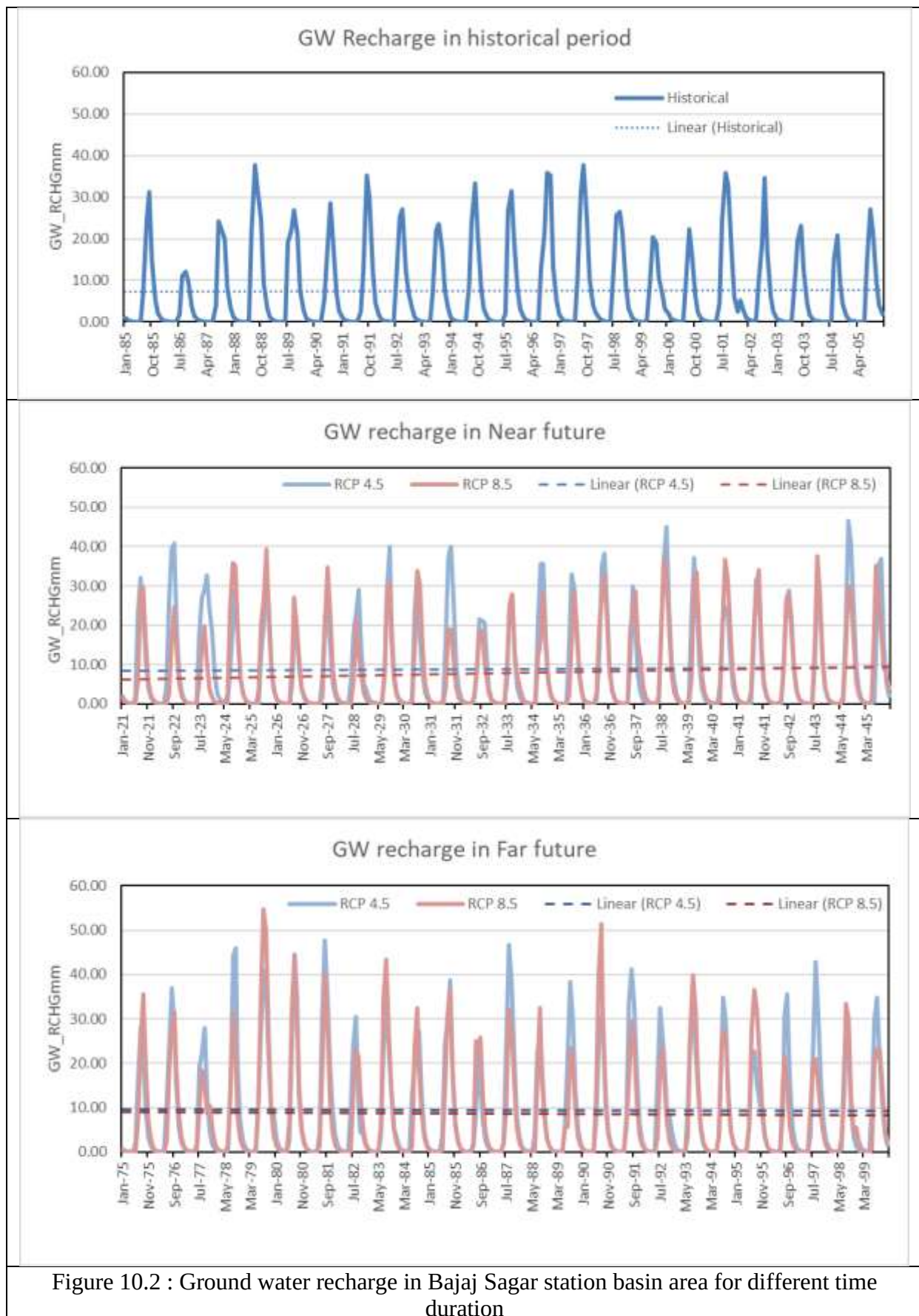


Figure 10.2 : Ground water recharge in Bajaj Sagar station basin area for different time duration

Kadana station basin area

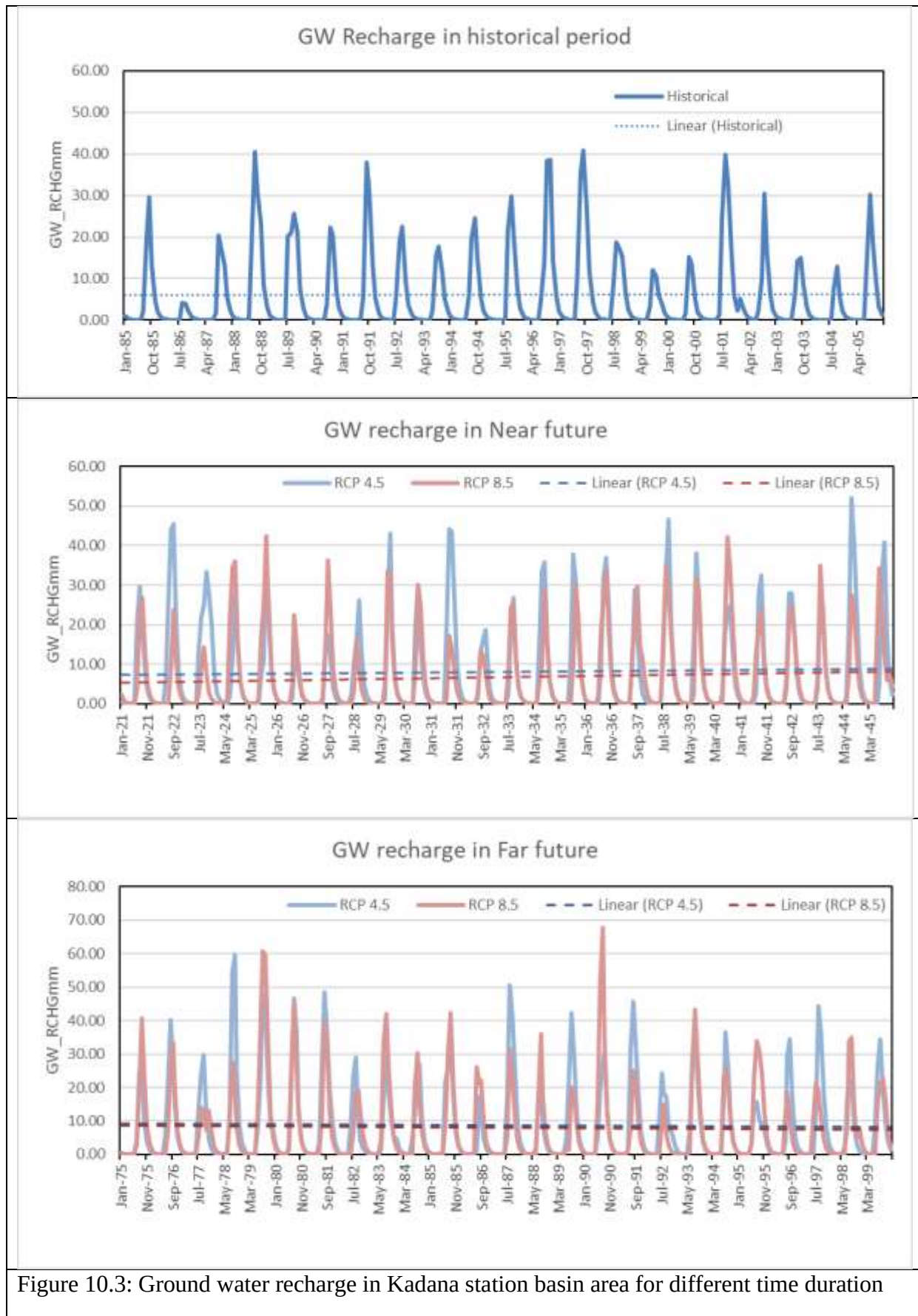
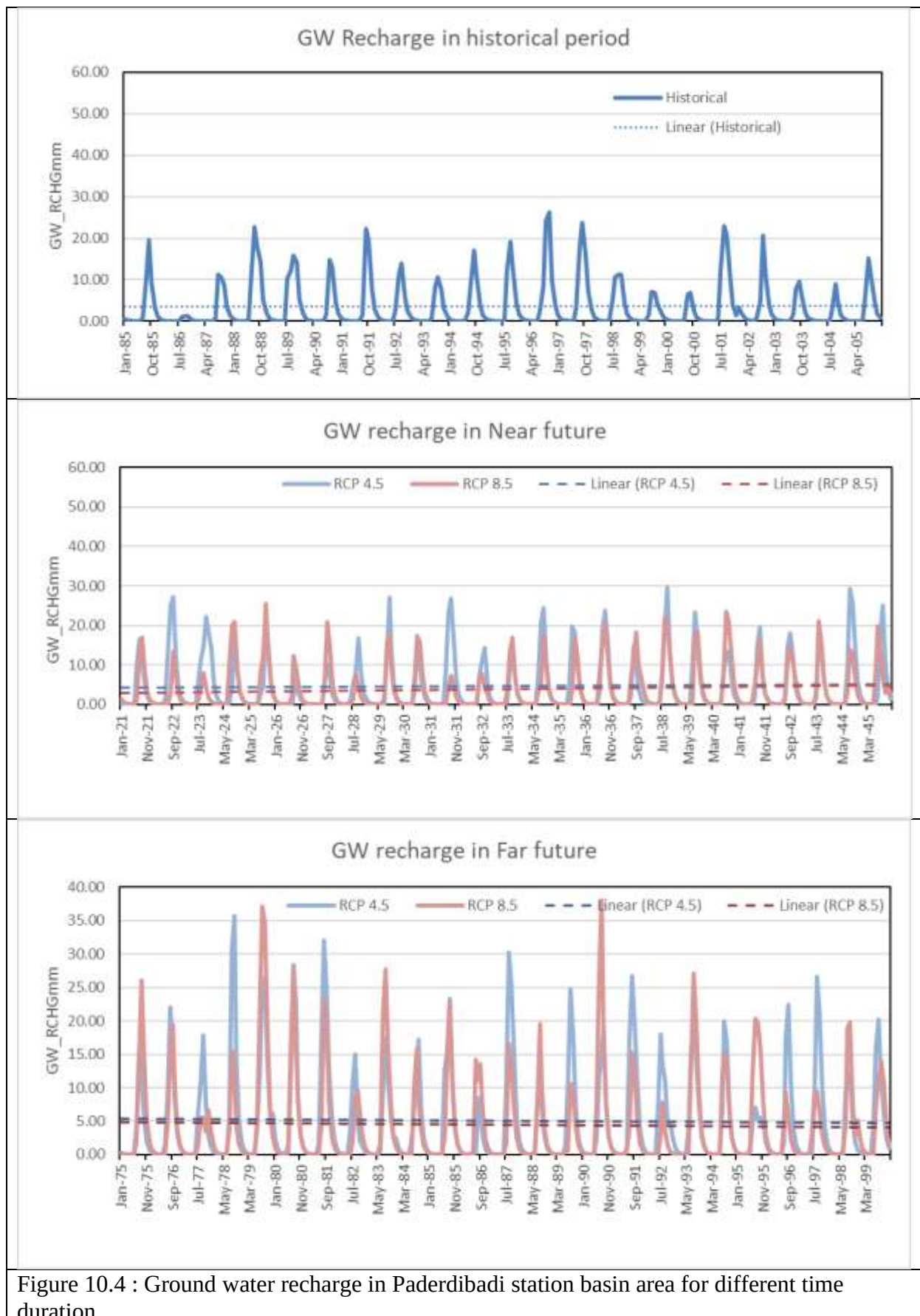


Figure 10.3: Ground water recharge in Kadana station basin area for different time duration

Paderdibadi station basin area



Rangeli station basin area

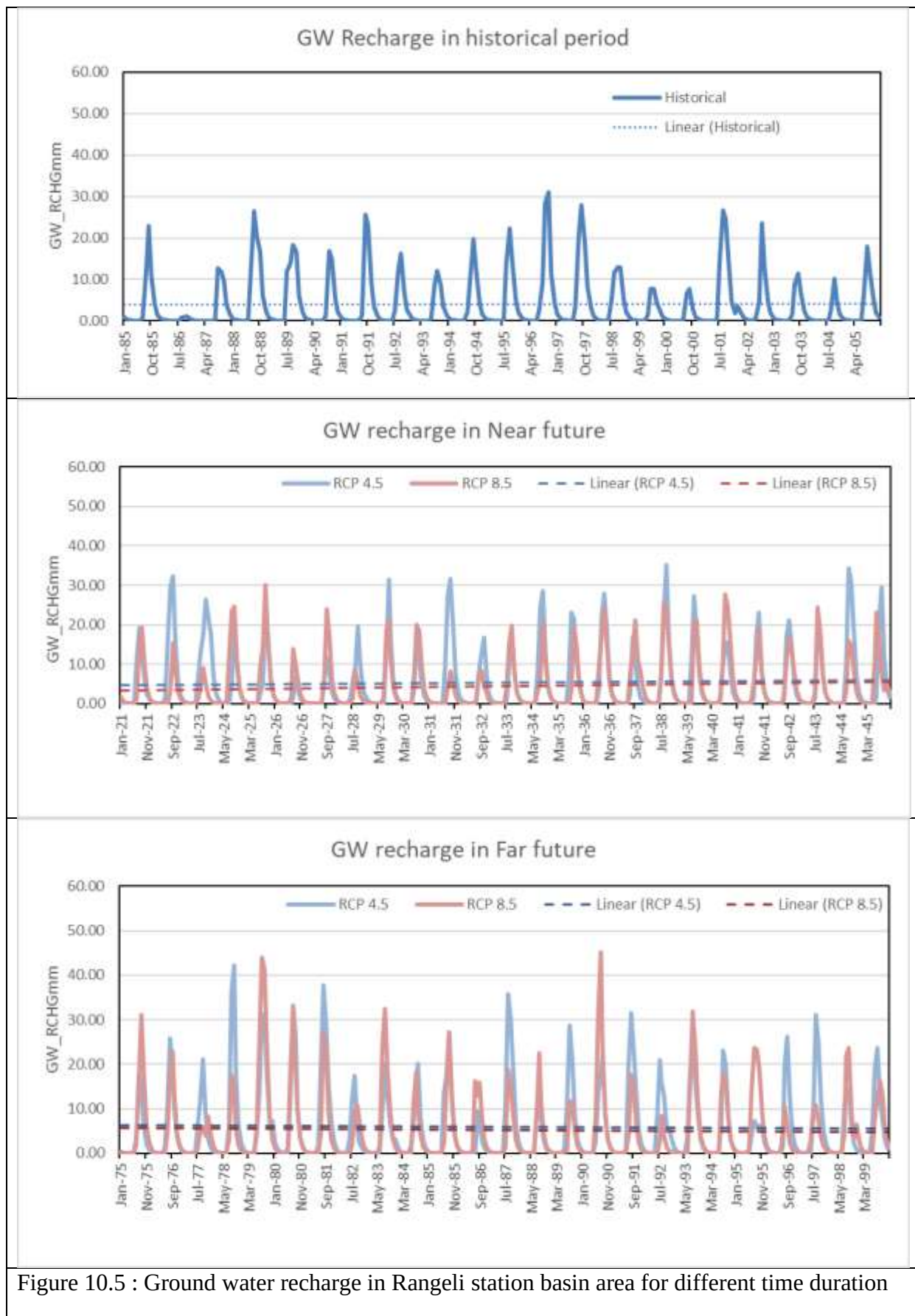


Figure 10.5 : Ground water recharge in Rangeli station basin area for different time duration

Panam station basin area

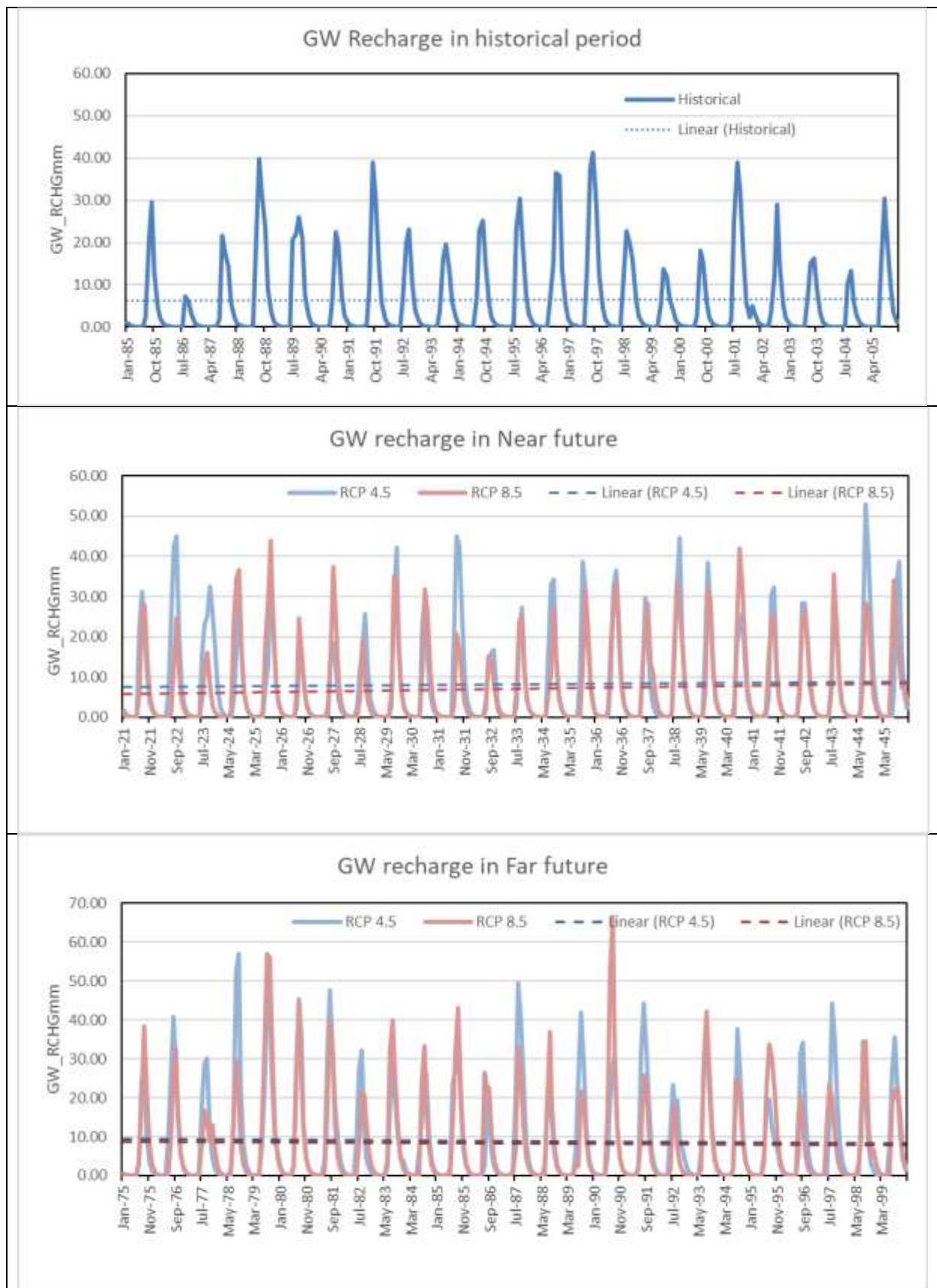


Figure 10.6 : Ground water recharge in Panam station basin area for different time duration

Khanpur station basin area

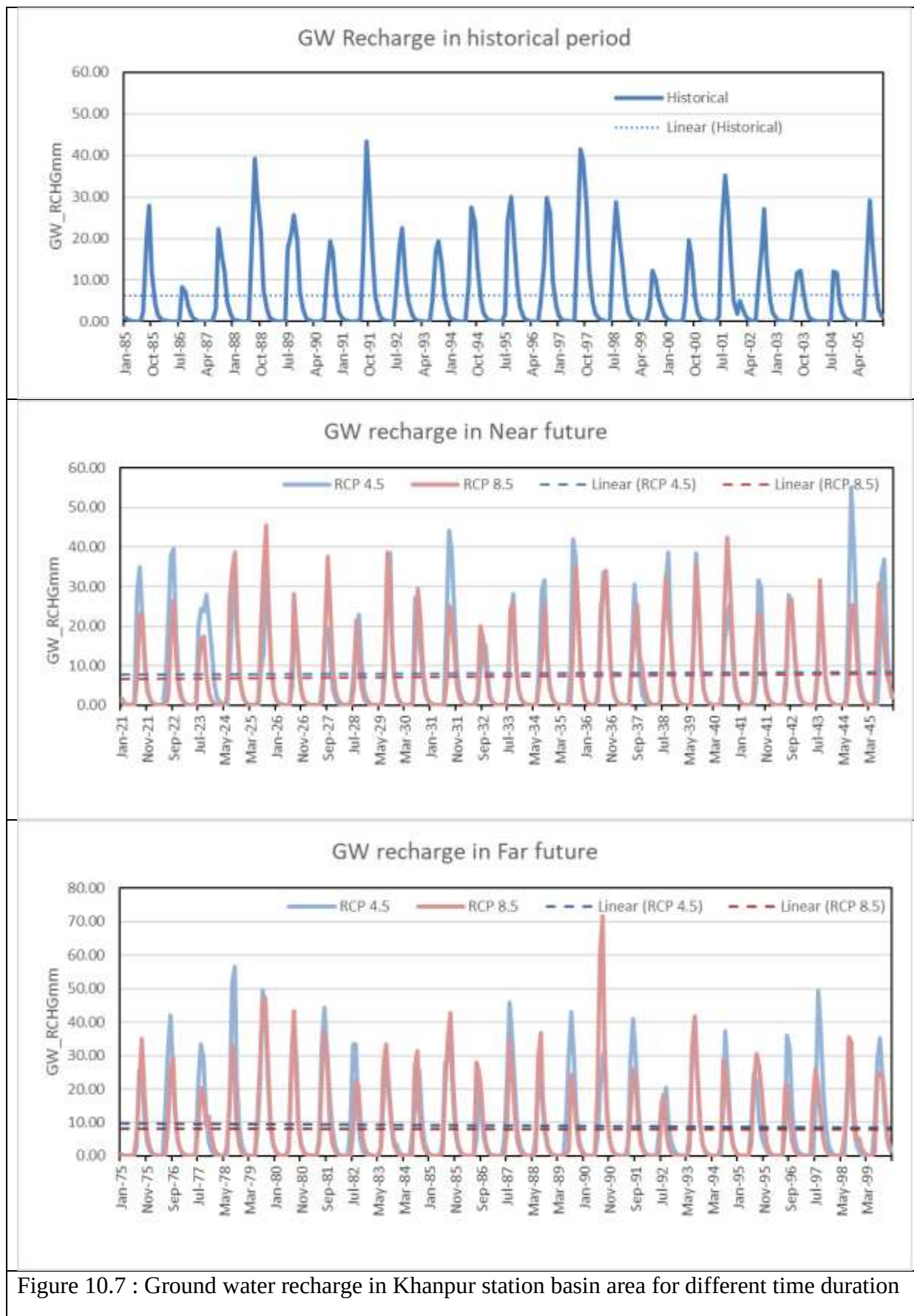


Figure 10.7 : Ground water recharge in Khanpur station basin area for different time duration

Dhariyabad station basin area

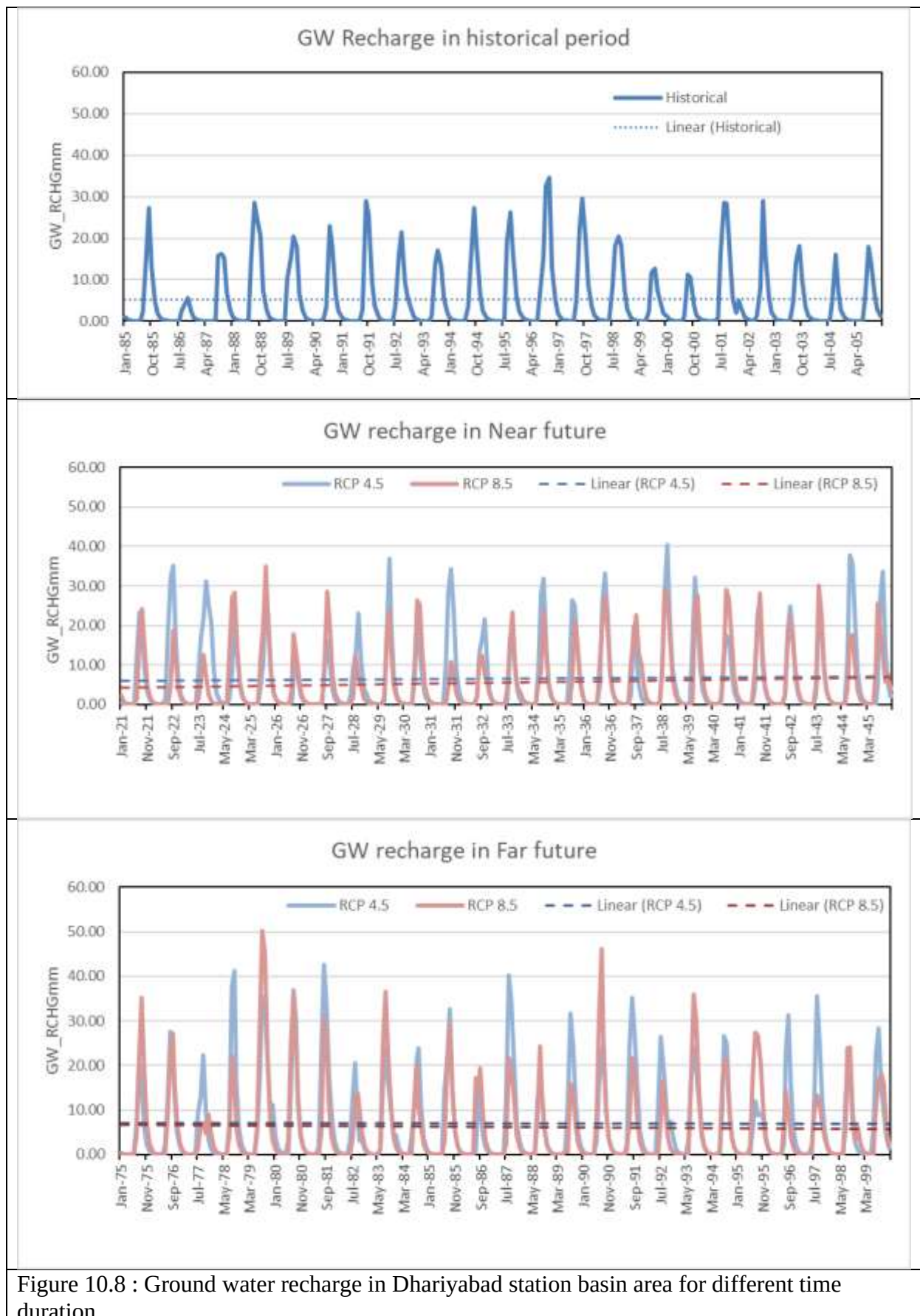


Figure 10.8 : Ground water recharge in Dhariyabad station basin area for different time duration

Chakaliya station basin area

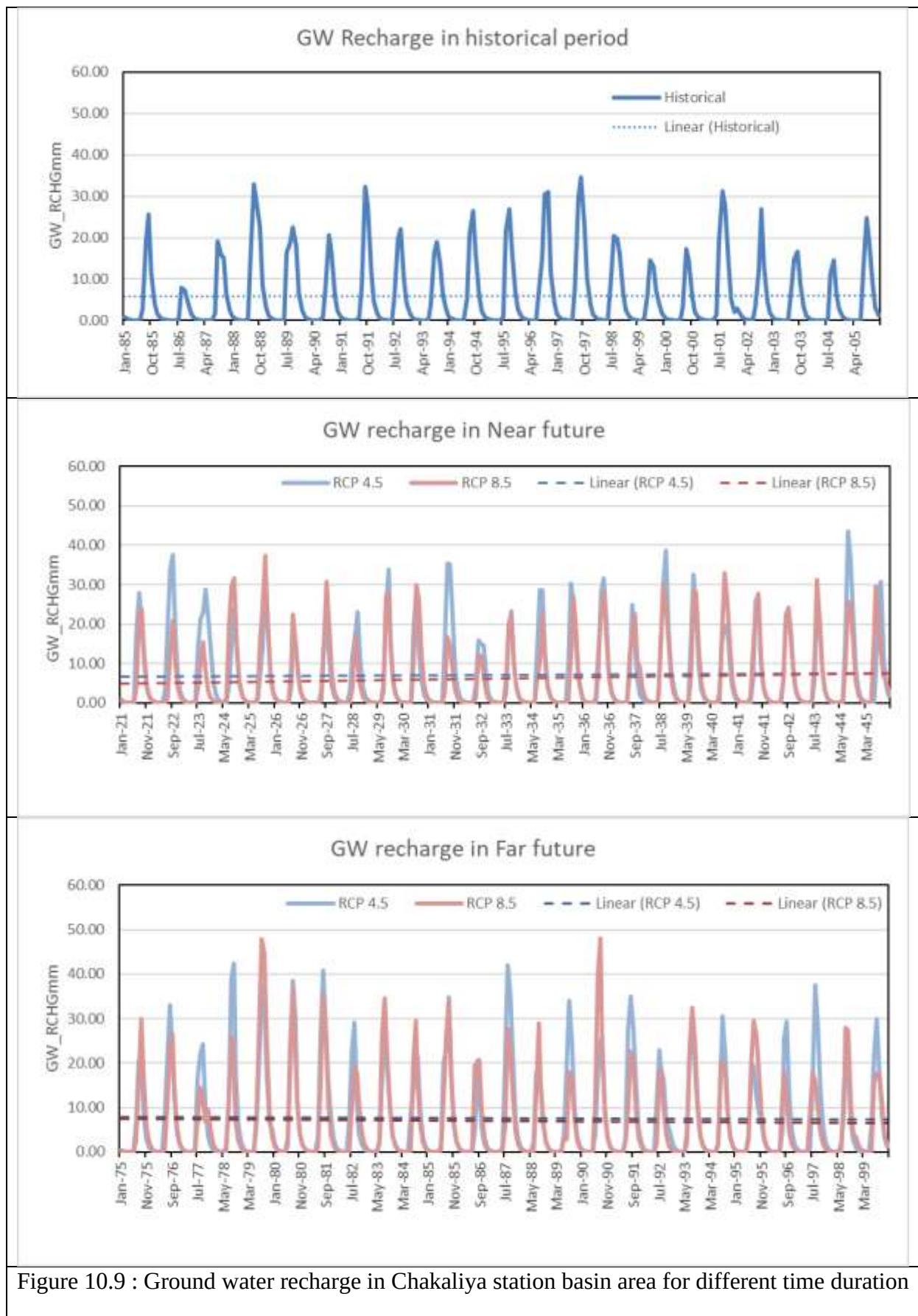


Figure 10.9 : Ground water recharge in Chakaliya station basin area for different time duration

Area of Inland drainage

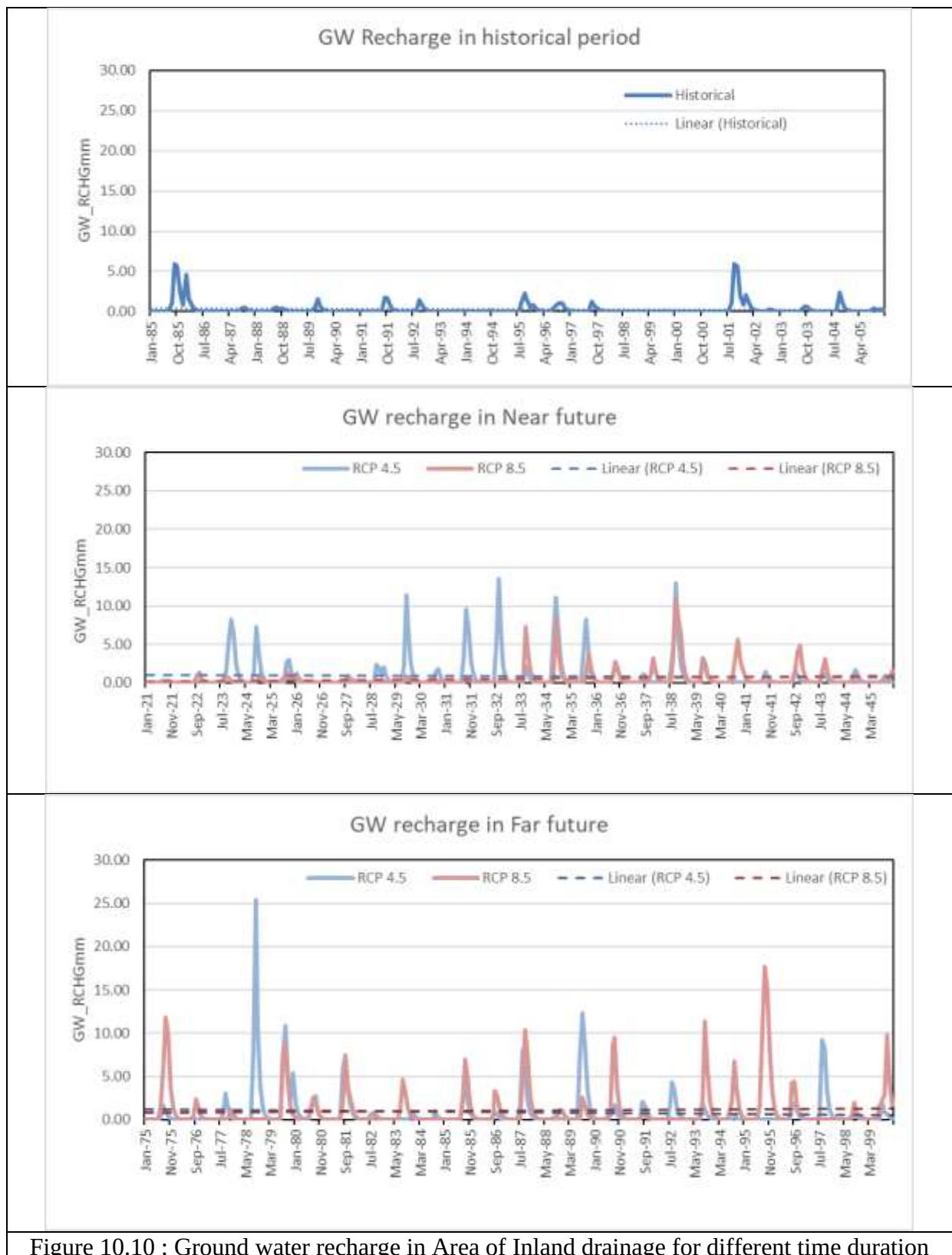


Figure 10.10 : Ground water recharge in Area of Inland drainage for different time duration

Chapter 11: Optimal water allocations

11.1 Optimal water allocations/use involving different sources and users under different climate change scenarios

11.1.1 End of month storage levels under RCP 4.5 & RCP 8.5 near future (2021-2044) and far future (2075-2099)

End of month storage levels of all the three reservoirs under RCP 4.5 and RCP 8.5 with near future (2021-2044) and far future (2075-2099) resulted from the simulation model is given below.

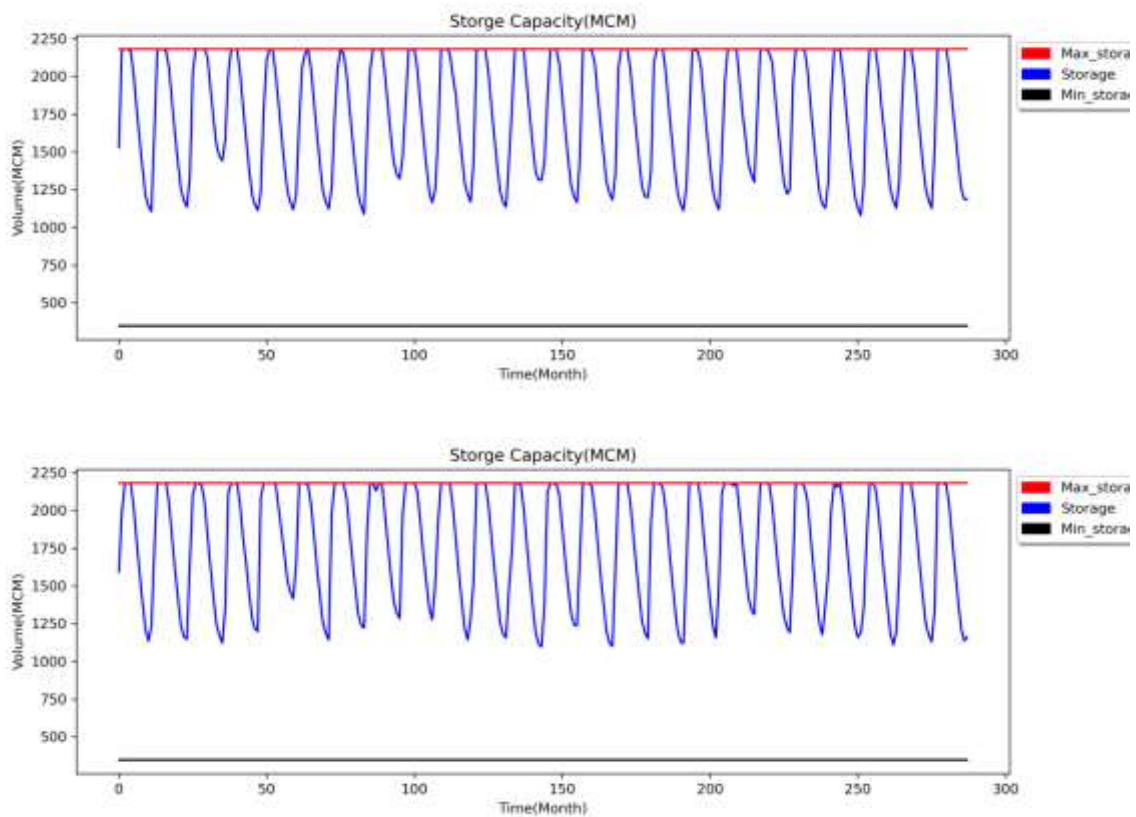


Figure. 11.1: Resulted final storage levels in Mahi reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From Figure 11.1 it has been observed that Mahi reservoir maintain maximum reservoir level during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So there is spillage during monsoon season.

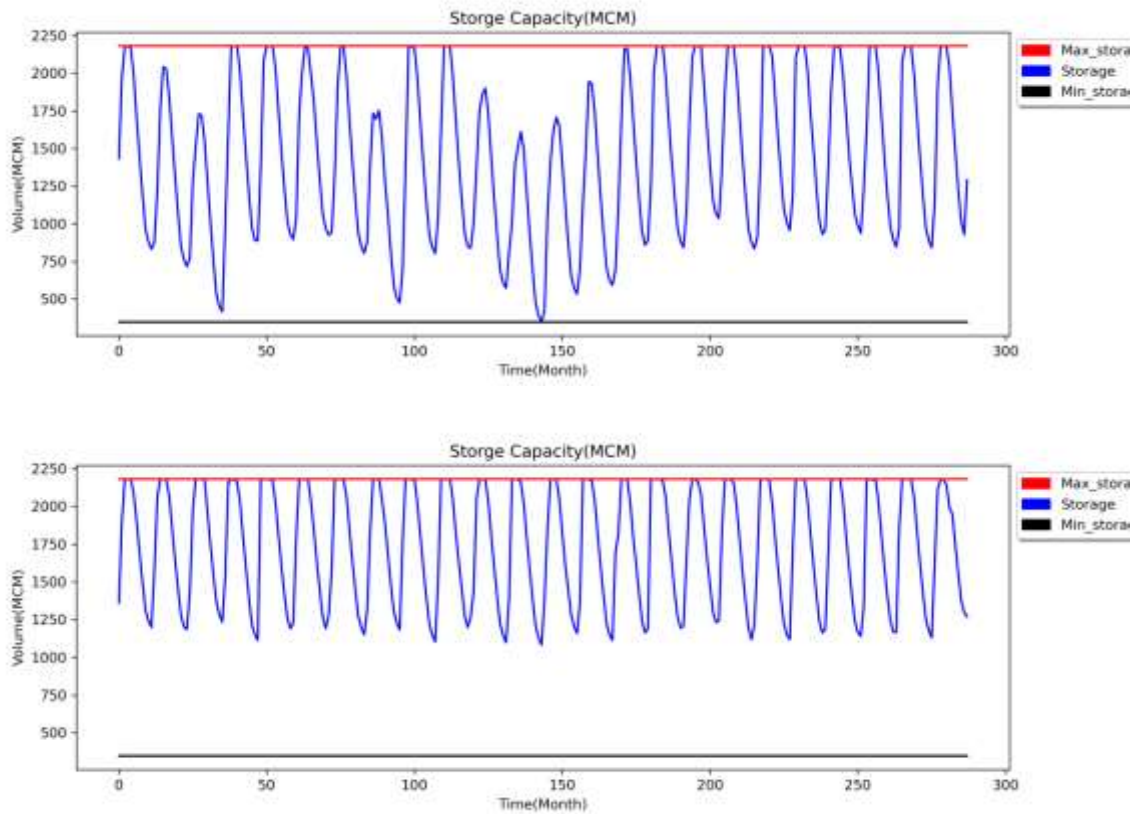
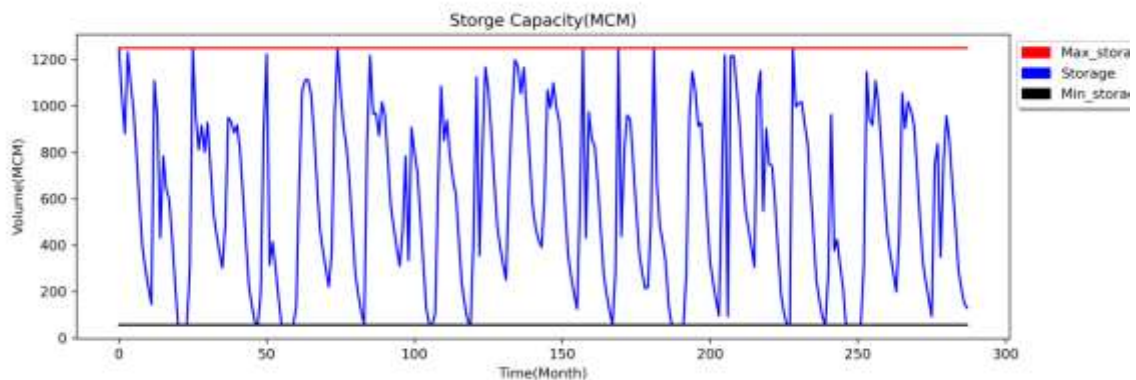


Figure 11.2: Resulted final storage levels in Mahi reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.2 it has been observed that Mahi reservoir maintain maximum reservoir level during all the time period under RCP 8.5 far future (2075-2099) except RCP 4.5 near future (2021-2044). In this case, reservoir touches minimum reservoir level which may cause deficit in next month. But for RCP 8.5 far future (2075-2099), there is spillage during monsoon season.



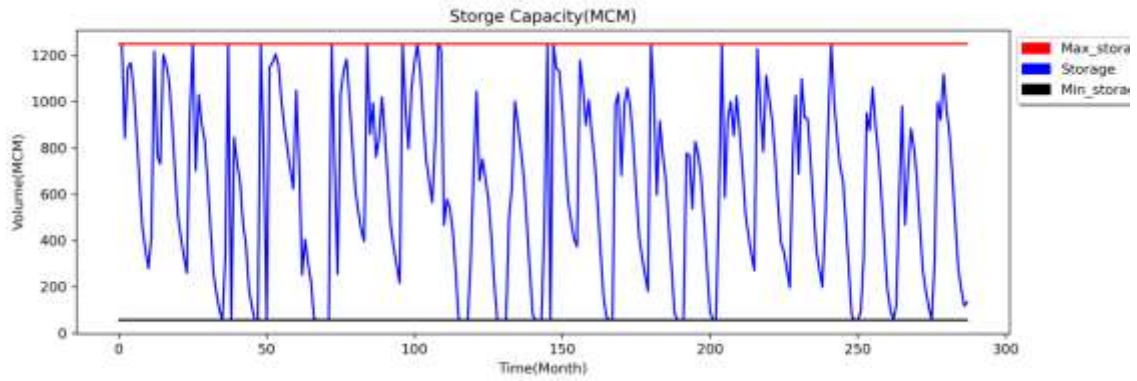


Figure 11.3: Resulted final storage levels in Kadana from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.3 it has been observed that Kadana reservoir touches minimum reservoir level several times during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So there are some deficit months during all the time period.

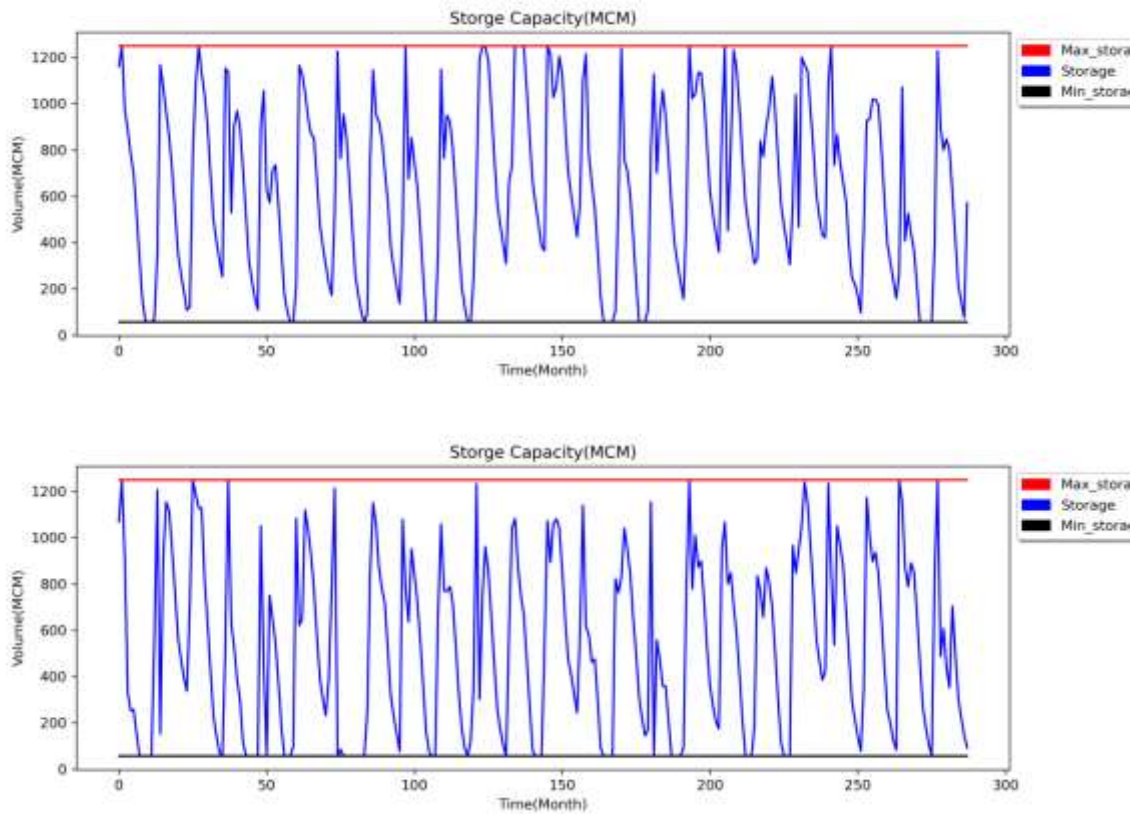


Figure 11.4 Resulted final storage levels in Kadana from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.4 it has been observed that Kadana reservoir touches minimum reservoir level several times during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So, there are some deficit months during all the time period.

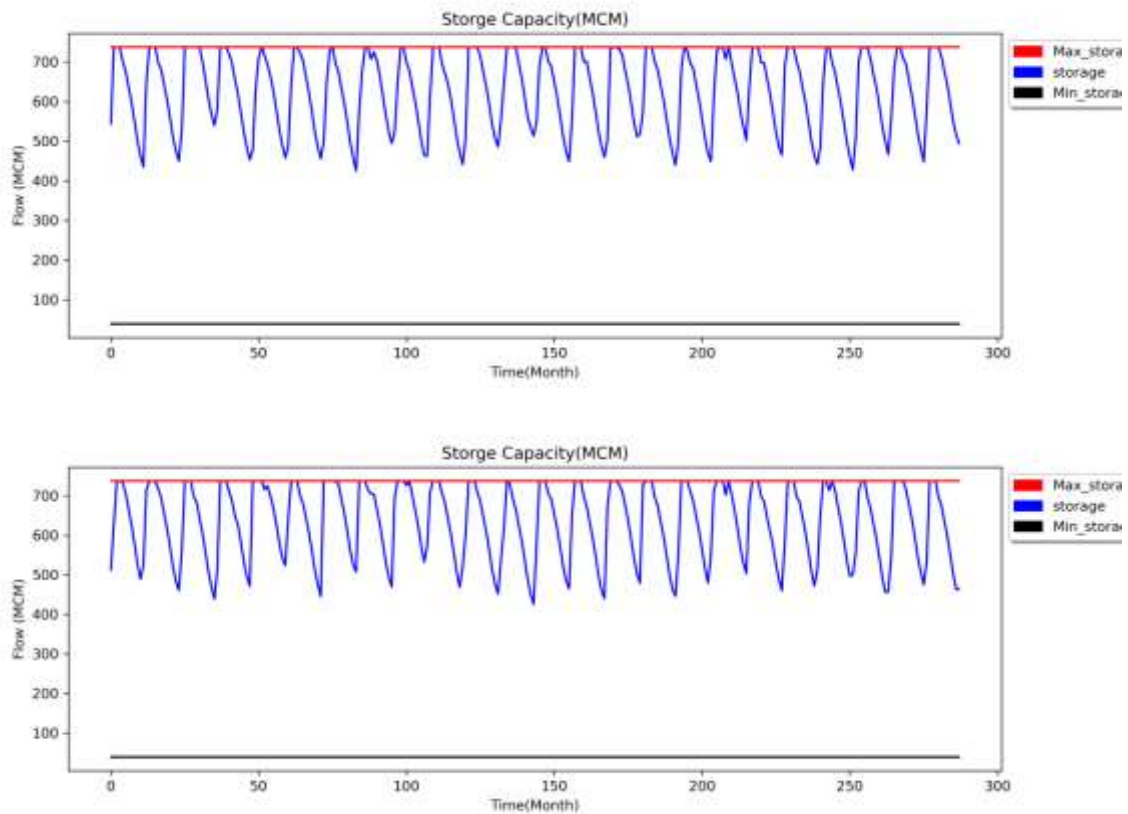
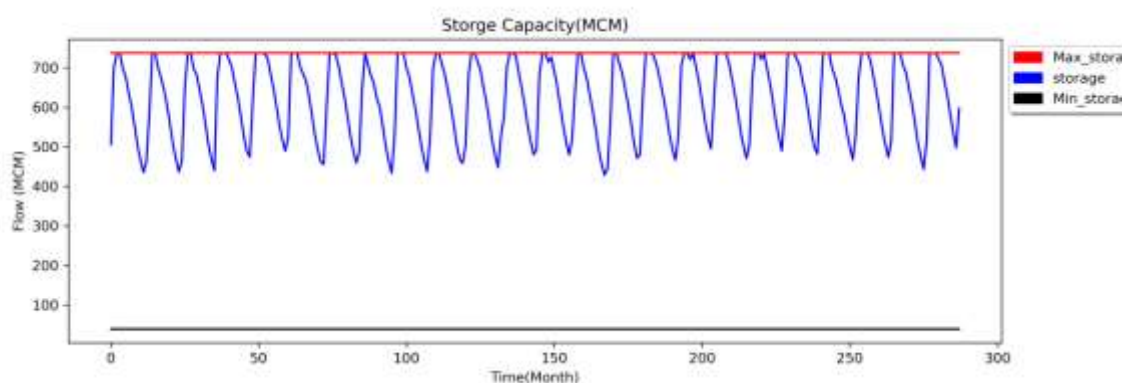


Figure 11.5 Resulted final storage levels in Panam reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)



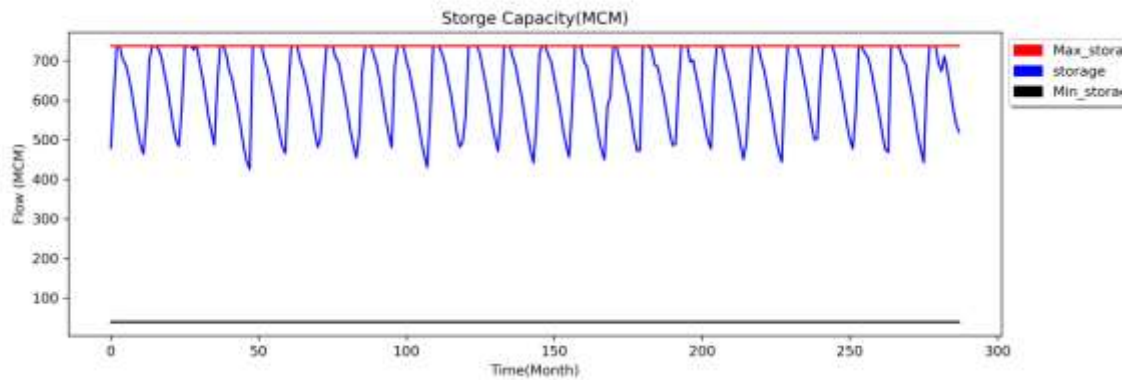


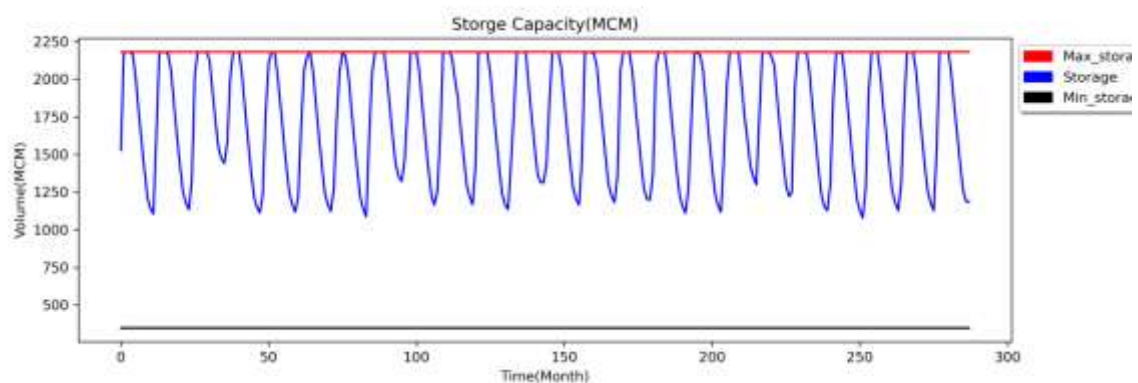
Figure 11.6 Resulted final storage levels in Panam reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure11.5 it has been observed that Panam reservoir maintain maximum reservoir level during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So, there is spillage during monsoon season.

From the Figure11.6 it has been observed that Panam reservoir maintain maximum reservoir level during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So, there is spillage during monsoon season.

10.1.2 End of month storage levels

End of month storage levels of all the three reservoirs under RCP 4.5 and RCP 8.5 with near future (2021-2044) and far future (2075-2099) resulted from the simulation model is given below.



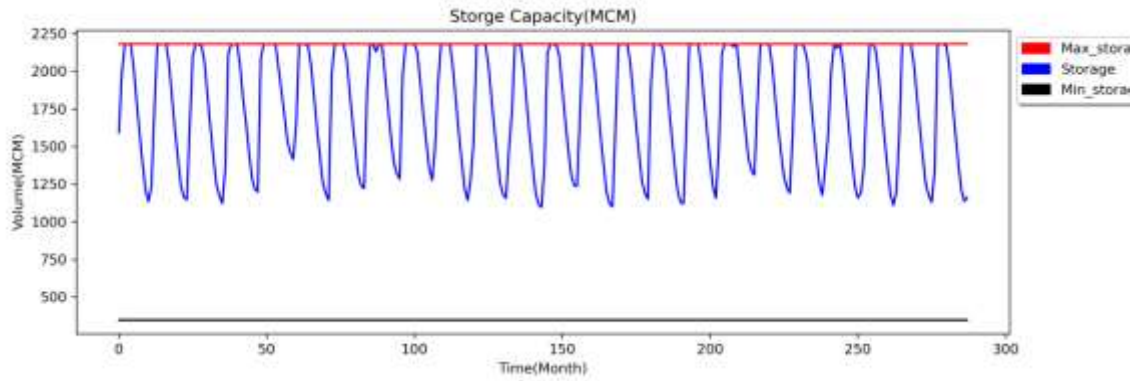


Figure 11.7 Resulted final storage levels in Mahi reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.7 it has been observed that Mahi reservoir maintain maximum reservoir level during all the period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So, there is spillage during monsoon season.

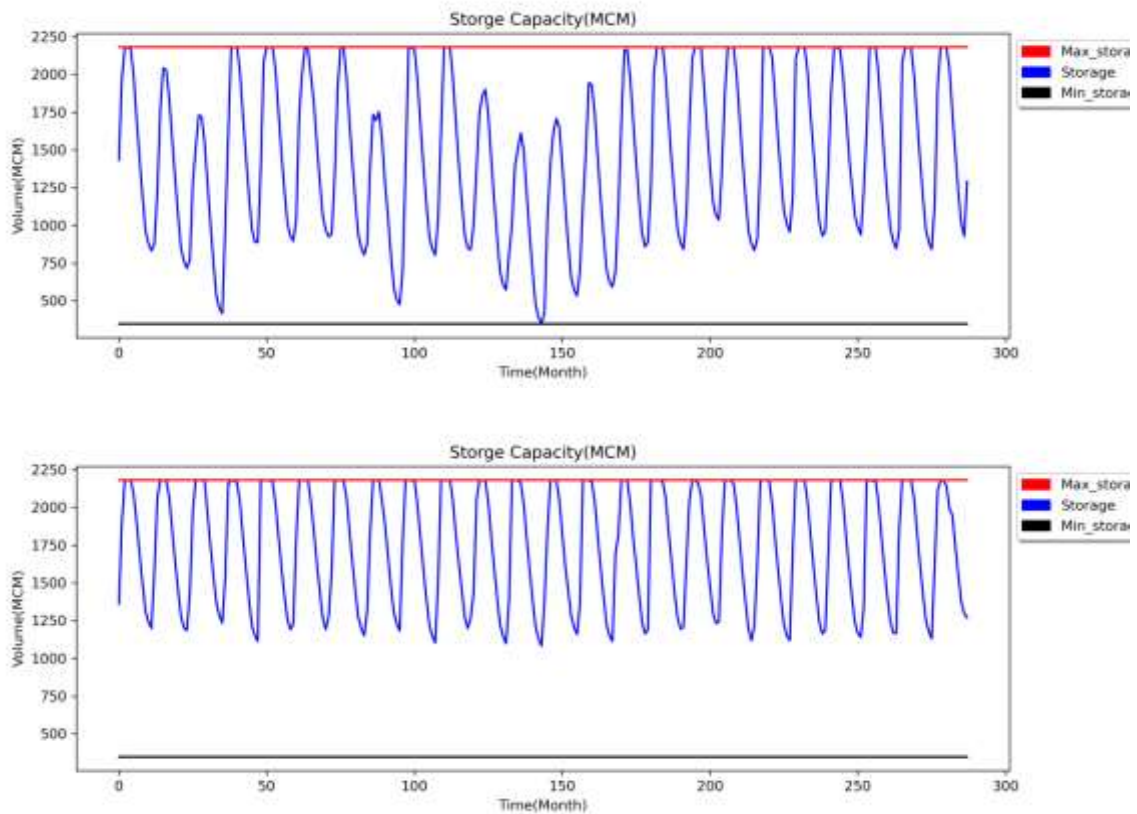


Figure 11.8 Resulted final storage levels in Mahi reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.8 it has been observed that Mahi reservoir maintain maximum reservoir level during all the time period under RCP 8.5 far future (2075-2099) except RCP 4.5 near future (2021-

2044). In this case, reservoir touches minimum reservoir level which may cause deficit in next month. But for RCP 8.5 far future (2075-2099), there is spillage during monsoon season.

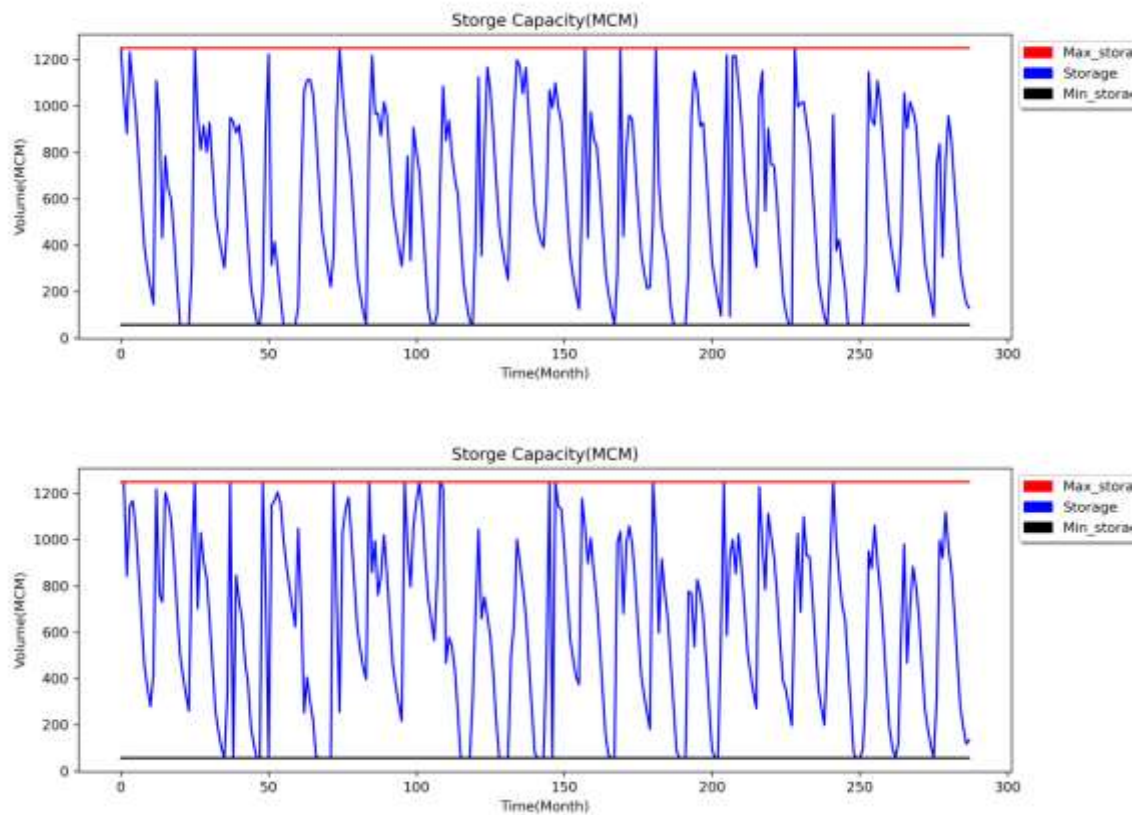
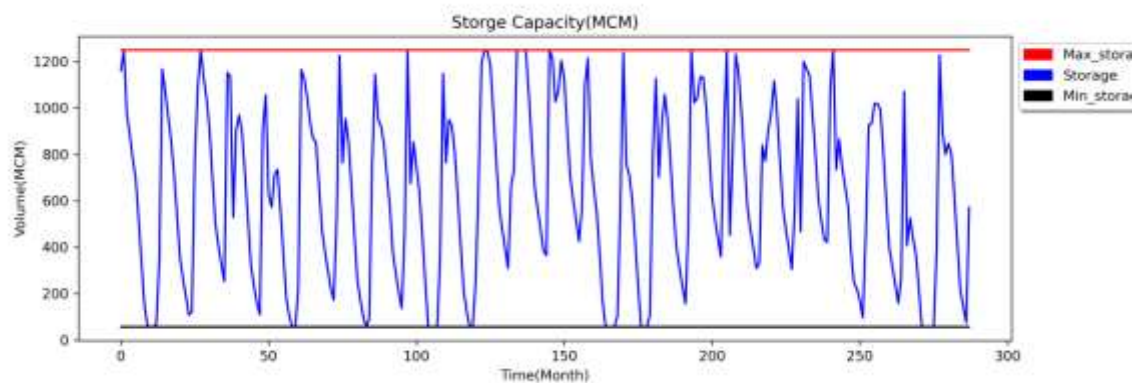


Figure 11.9 Resulted final storage levels in Kadana from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.9 it has been observed that Kadana reservoir touches minimum reservoir level several times during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So there are some deficit months during all the time period.



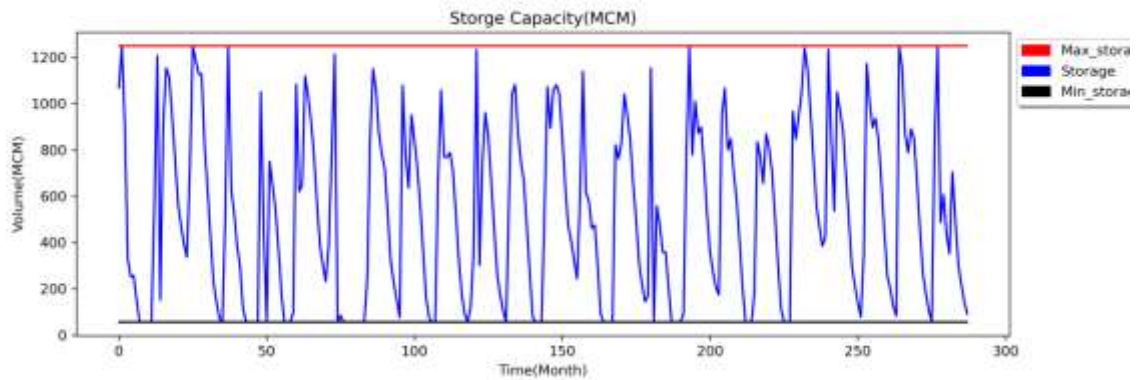


Figure 11.10: Resulted final storage levels in Kadana from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.10 it has been observed that Kadana reservoir touches minimum reservoir level several times during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So there are some deficit months during all the time period.

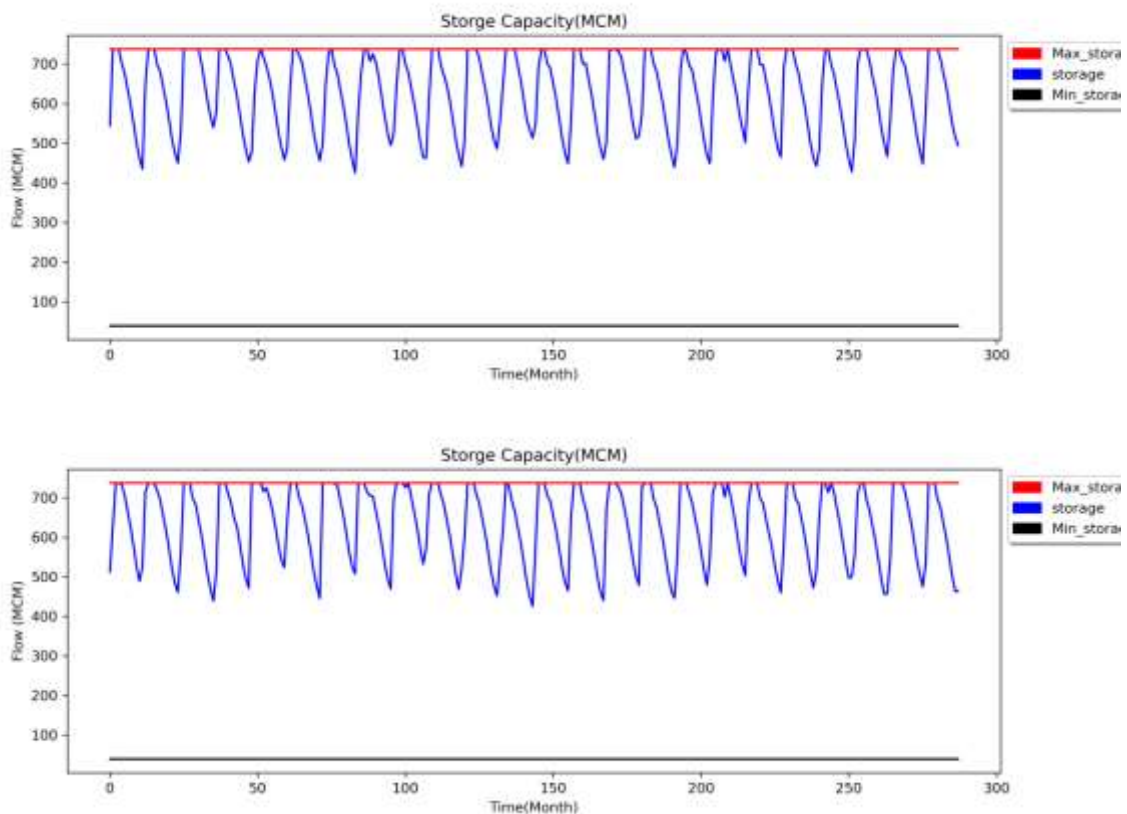


Figure 11.11: Resulted final storage levels in Panam reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.11 it has been observed that Panam reservoir maintain maximum reservoir level during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So, there is spillage during monsoon season.

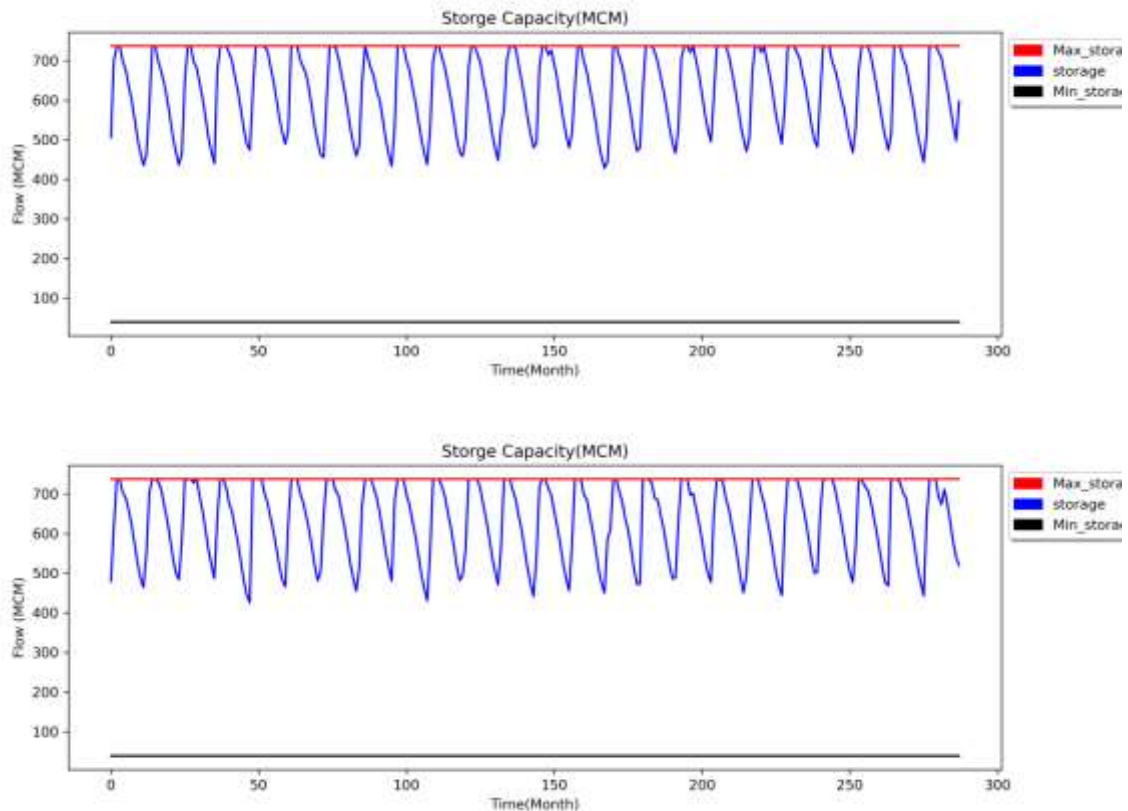


Figure 11.12: Resulted final storage levels in Panam reservoir from the simulation model under RCP 4.5 near future (2021-2044) and far future (2075-2099)

From the Figure 11.12 it has been observed that Panam reservoir maintain maximum reservoir level during all the time period under RCP 4.5 near future (2021-2044) and far future (2075-2099). So there is spillage during monsoon season.

Irrigation Release

The monthly irrigation releases to all the canals in Mahi Bajaj Sagar reservoir system is resulted from simulation model is showing in the given below. The simulation is done under two climate change scenarios RCP4.5 and RCP8.5 with near future (2021-2044) and far future (2075-2099) time period. Initial month for simulation is taken as June as this is month from which water year is calculated in India. Figure 11.13 and Figure 11.14 shows the demand, inflow and releases from the reservoir for RCP 4.5 and RCP 8.5.

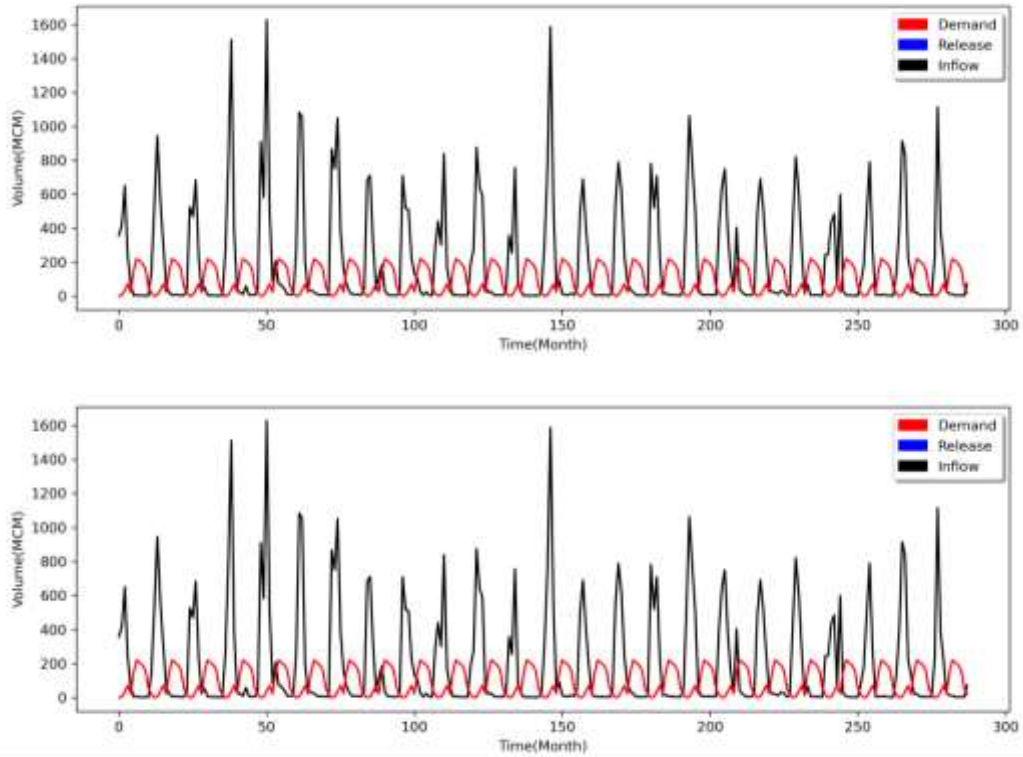


Figure 11.13: The values of inflow, demand and released water of the Mahi reservoir in operation by SOP under RCP 4.5 near future (2021-2044) and far future (2075-2099)

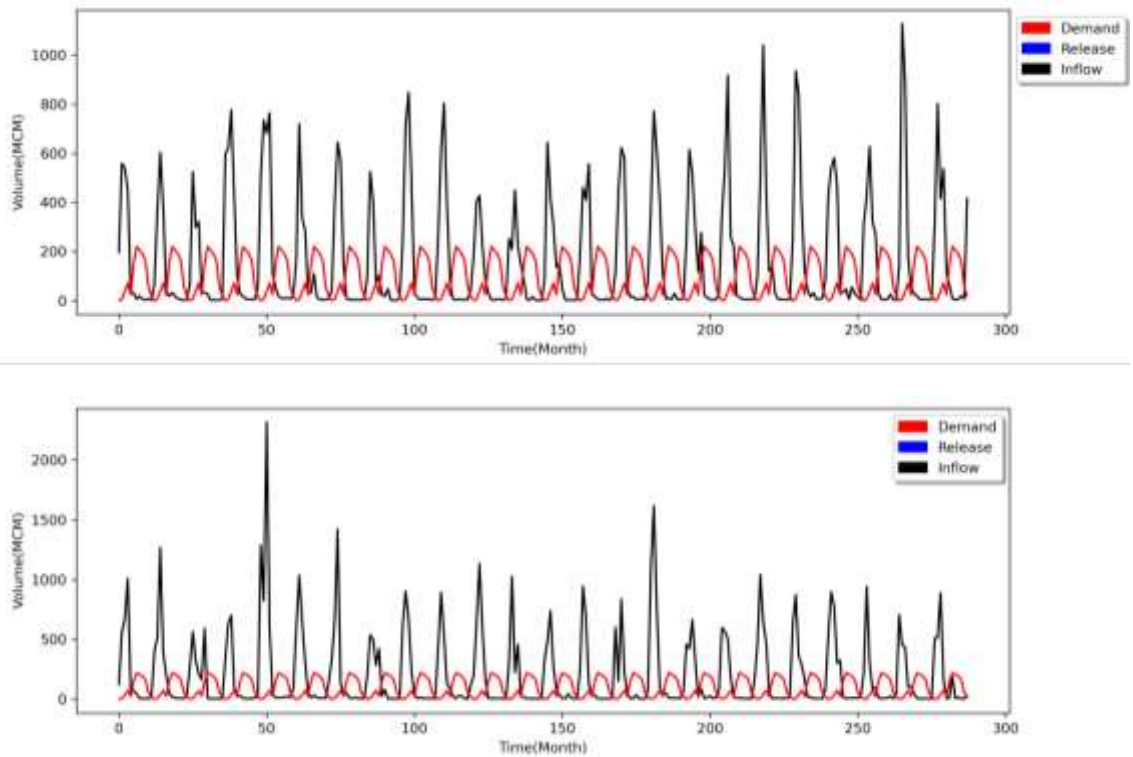


Figure 11.14: The values of inflow, demand and released water of the Mahi reservoir in operation by SOP under RCP 8.5 near future (2021-2044) and far future (2075-2099)

The monthly irrigation releases to all the canals in Kadana reservoir system is resulted from simulation model is showing in the given below. The simulation is done under two climate change scenarios RCP4.5 and RCP8.5 with near future (2021-2045) and far future (2075-2099) time period. Initial month for simulation is taken as June as this is month from which water year is calculated in India. Figure11.15 and Figure11.16 shows the demand, inflow and releases from the reservoir for RCP 4.5 and RCP 8.5.

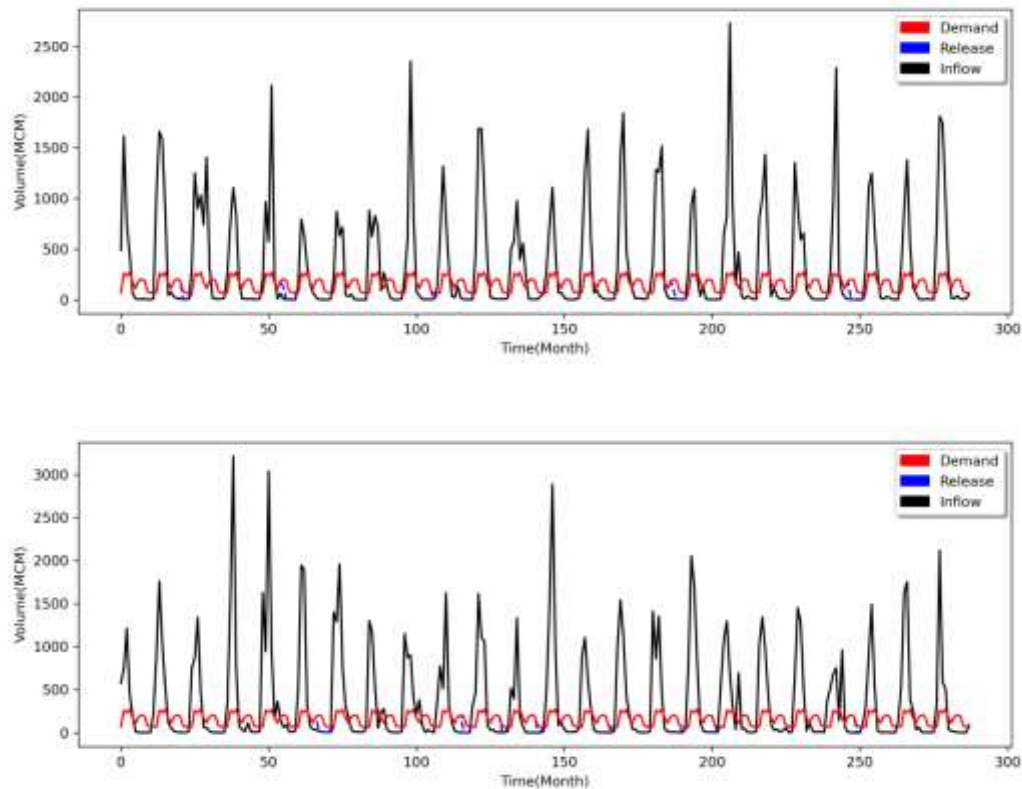
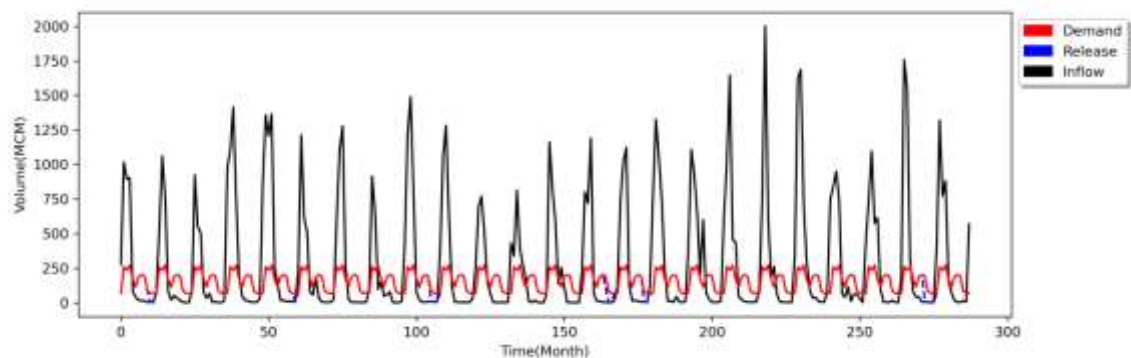


Fig. 11.15 The values of inflow, demand and released water of the Kadana reservoir in operation by SOP under RCP 4.5 near future (2021-2044) and far future (2075-2099)



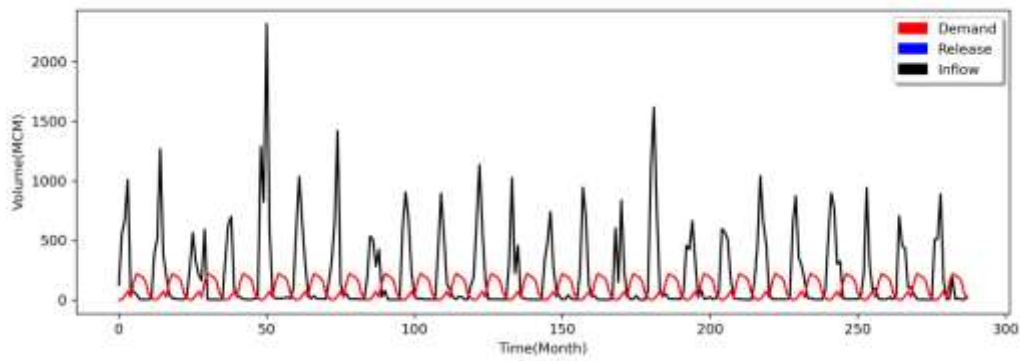


Figure 11.16: The values of inflow, demand and released water of the Kadana reservoir in operation by SOP under RCP 8.5 near future (2021-2044) and far future (2075-2099)

The monthly irrigation releases to all the canals in Panam reservoir system is resulted from simulation model is showing in the given below. The simulation is done under two climate change scenarios RCP4.5 and RCP8.5 with near future (2021-2044) and far future (2075-2099) time period. Initial month for simulation is taken as June as this is month from which water year is calculated in India. Figure 11.17 and Figure11.18 shows the demand ,inflow and releases from the reservoir for RCP 4.5 and RCP 8.5.

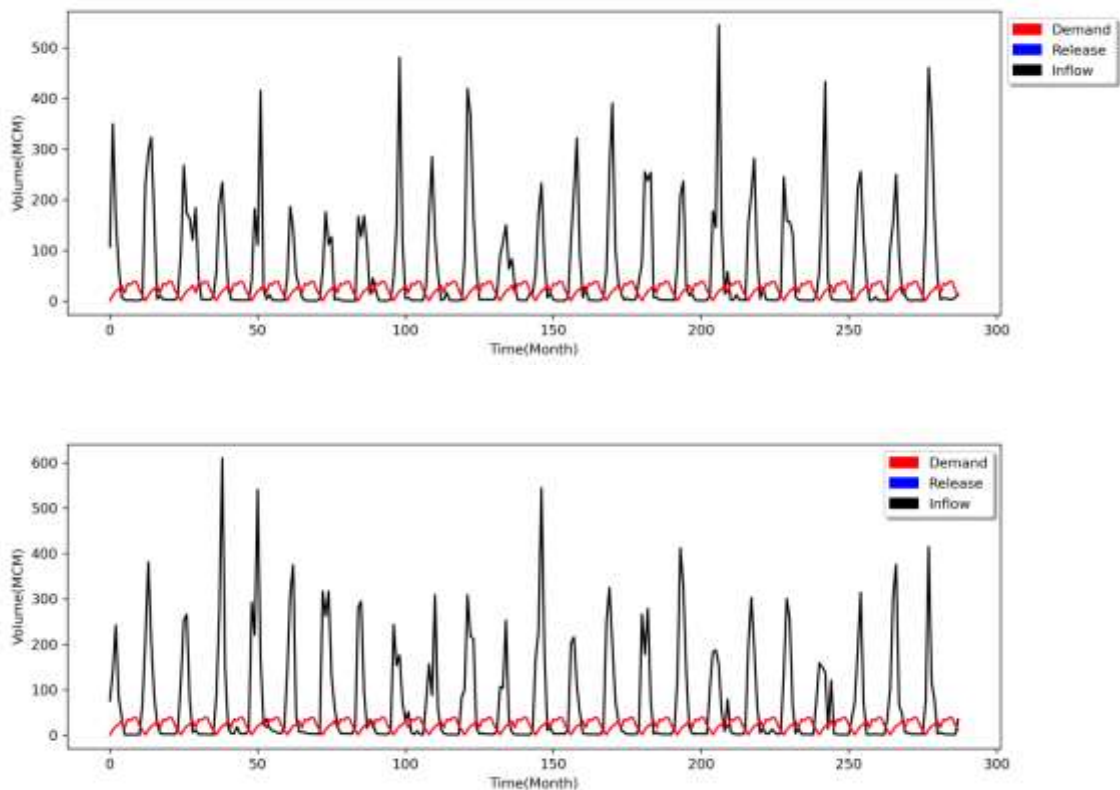


Figure 11.17: The values of inflow, demand and released water of the Panam reservoir in operation by SOP under RCP 4.5 near future (2021-2044) and far future (2075-2099)

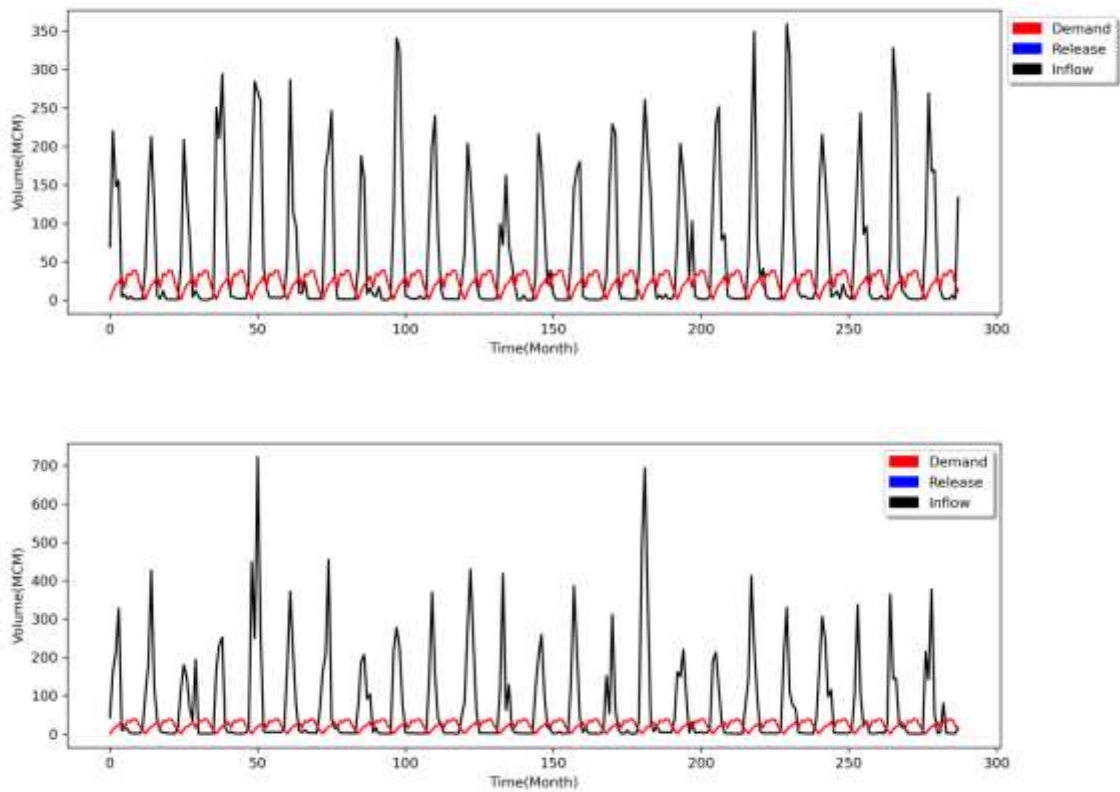


Figure 11.18: The values of inflow, demand and released water of the Panam reservoir in operation by SOP under RCP 8.5 near future (2021-2044) and far future (2075-2099)

10.2 Operational policies for multi-reservoir operation

Operational policies for future scenarios were framed for various combinations of resource enhancement and demand management strategies. Resource enhancement strategy through reallocation of reservoir storage capacity encompasses increasing the conservation storage volume at the expense of flood control storage volume for reservoirs. Again, relatively small storage reallocation seems to be viable, keeping in view the uncertainty in the occurrence of extreme rainfall events and the risk associated with a loss in flood control storage capacity, particularly with an extreme flood event. Analysis of historical records revealed that Mahi Bajaj Sagar Dam and Kadana Dam spills are moderately high every year during monsoon months. For Panam reservoir, it was not so frequent.

The operational policies used for the presented study are narrated below for the sake of ready reference:

Operational Policy 1: Simulation of the operation of the system with future inflow data, historical average water demand data

Operational Policy 2: Simulation of the operation of the system with future inflow data with 10% increase in historical average water demand data

Operational Policy 3: Simulation of the operation of the system with future inflow data with 20% increase in historical average water demand data

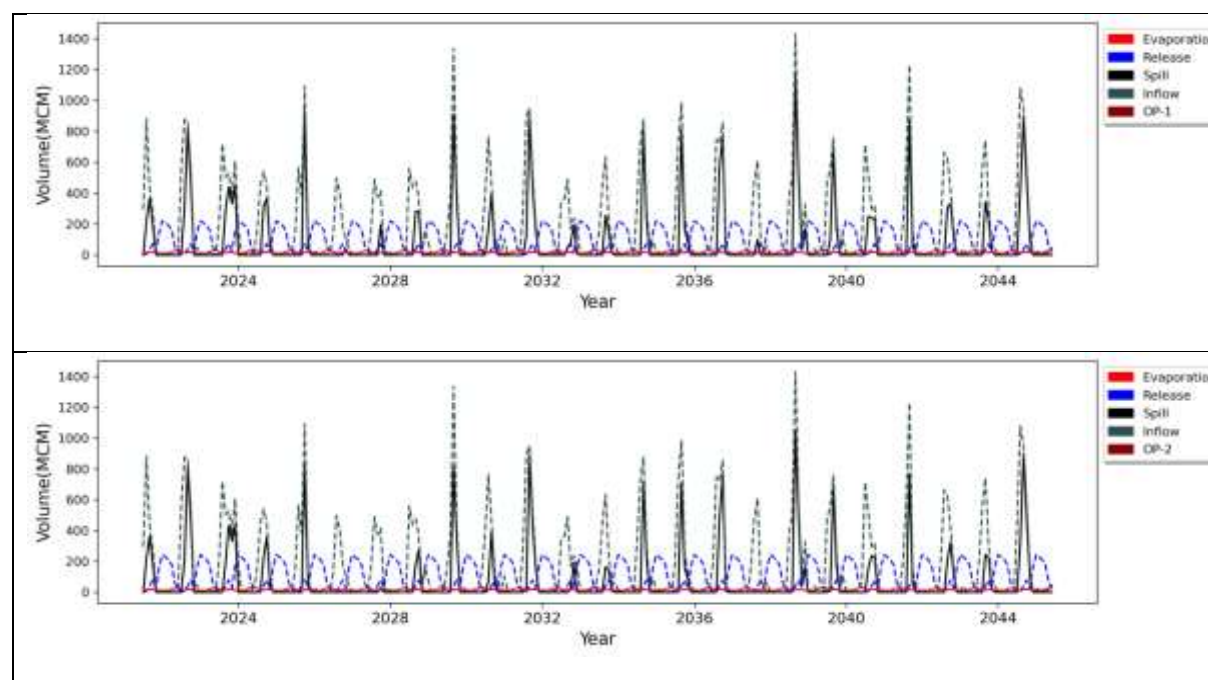
Operational Policy 4: Simulation of the operation of the system with future inflow data with 30% increase in historical average water demand data

Operational Policy 5: Simulation of the operation of the system with future inflow data with 40% increase in historical average water demand data

Operational Policy 6: Simulation of the operation of the system with future inflow data with 50% increase in historical average water demand data

Table 11.1: Assumed water demand scenarios agricultural demands in the future, relative to historical conditions

	Operation Policy 1	Operation Policy 2	Operation Policy 3	Operation Policy 4	Operation Policy 5	Operation Policy 6
Change in Agriculture Demand	No Change	+10%	+20%	+30%	+40%	+50%



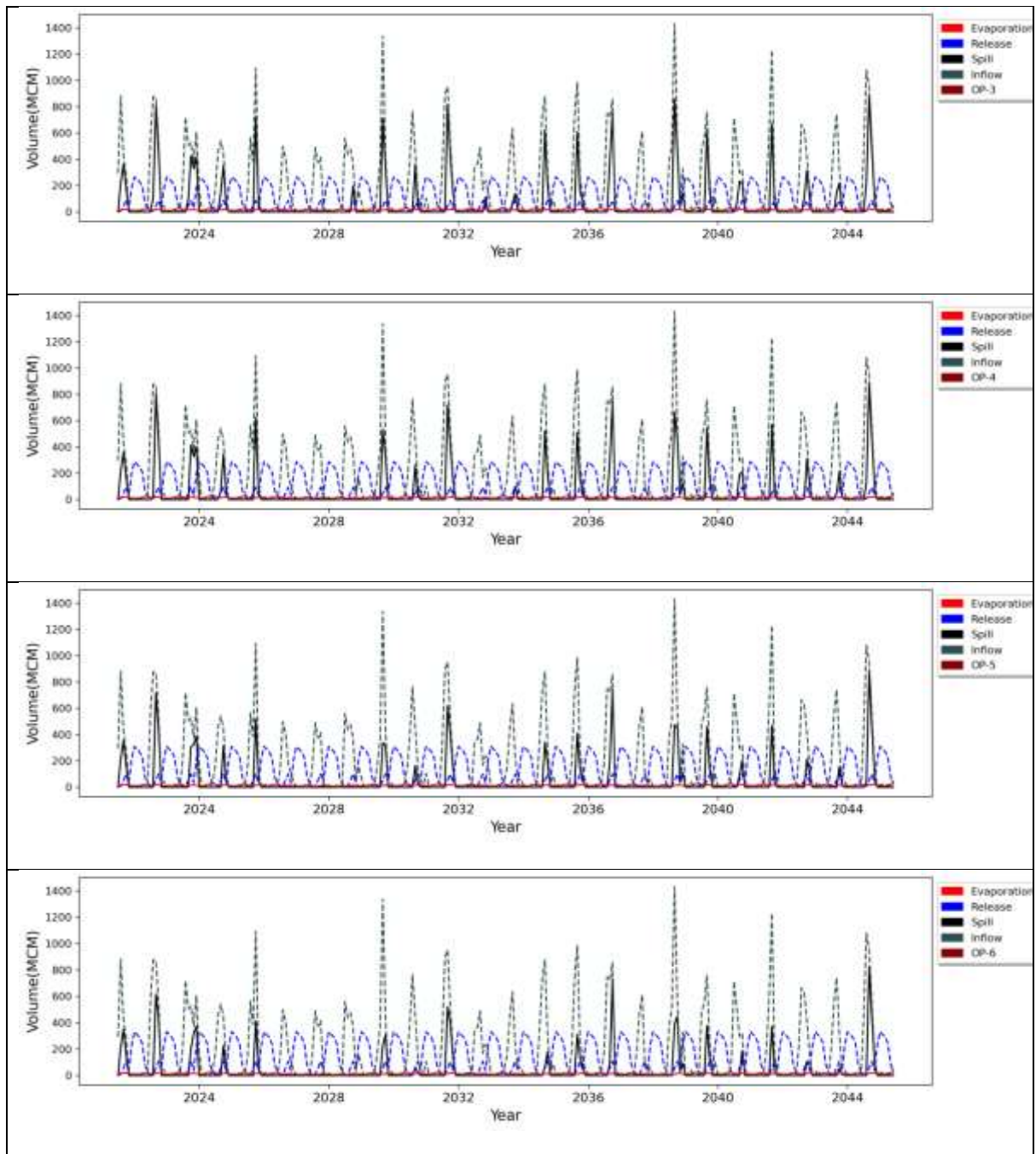
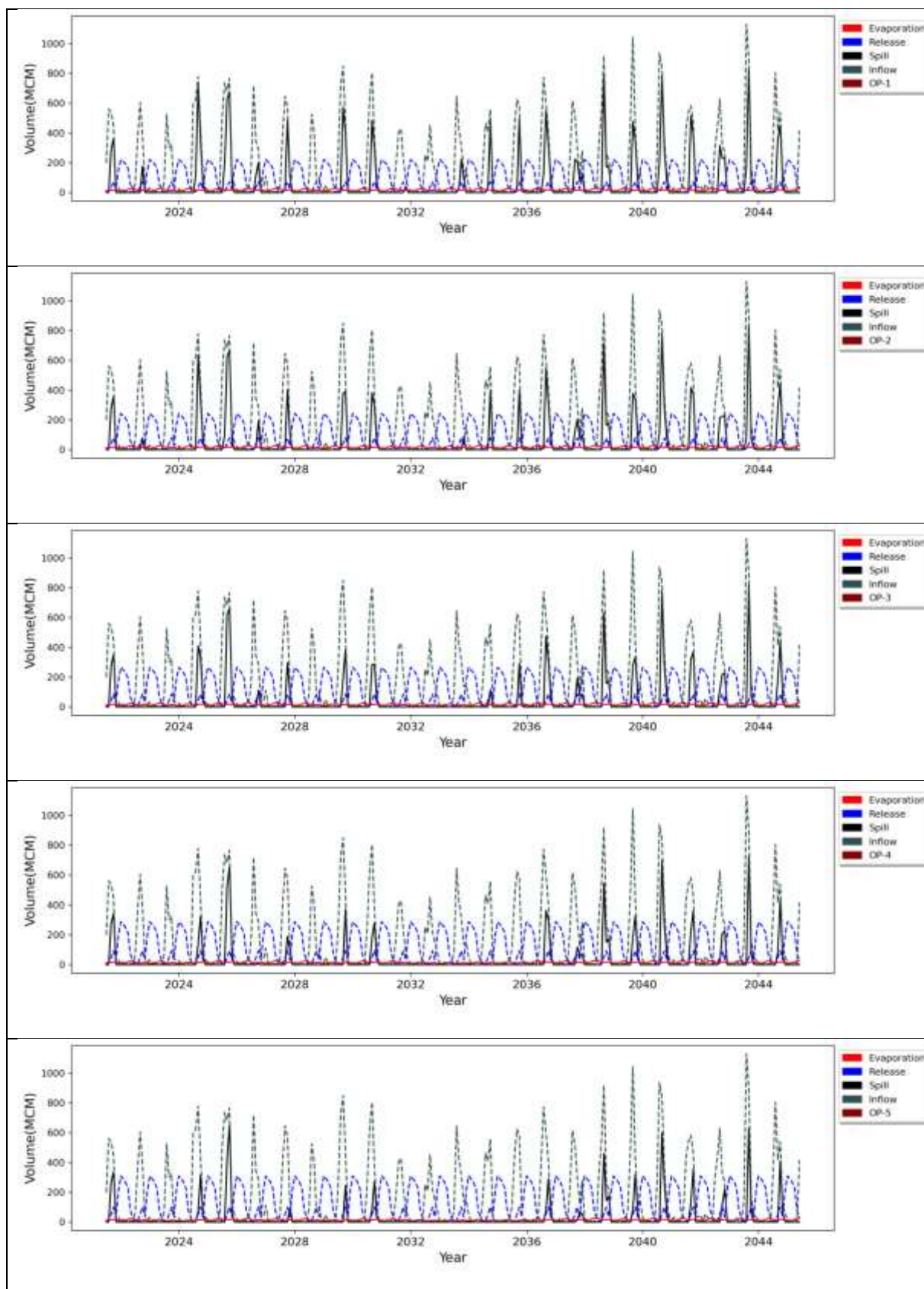


Figure 11.19: The values of inflow, spillway release, irrigation release and evaporation losses of the Mahi Bajaj Sagar reservoir under different operation policies for near future(2021-2044) RCP 4.5 climate change scenario



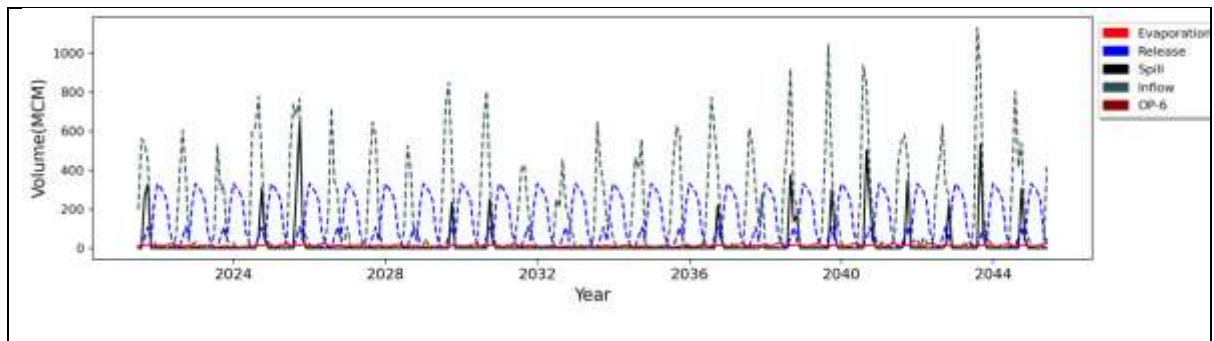
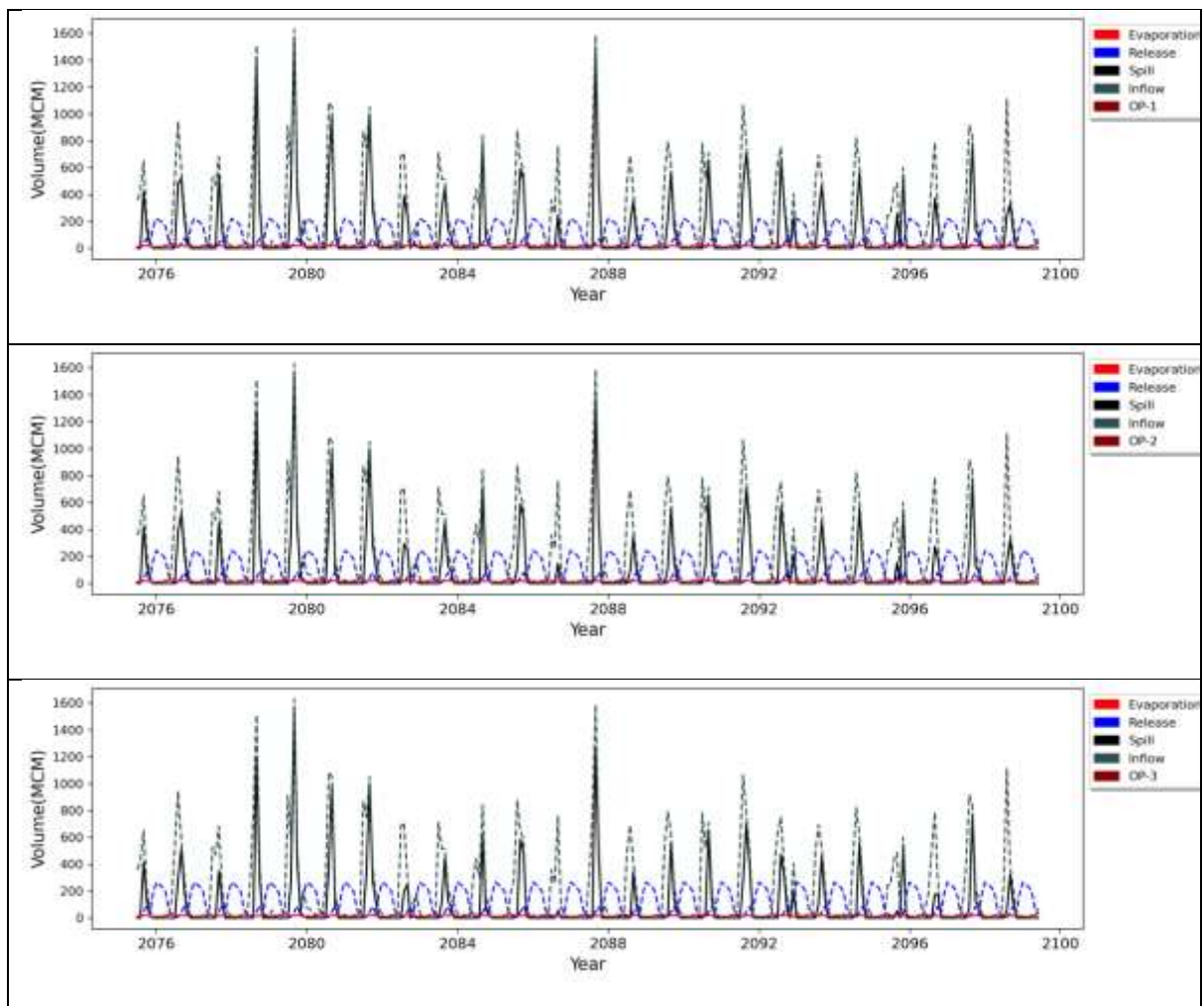


Figure 11.20: The values of inflow, spillway release, irrigation release and evaporation losses of the Mahi Bajaj Sagar reservoir under different operation policies for near future(2021-2044) RCP 8.5 climate change scenario



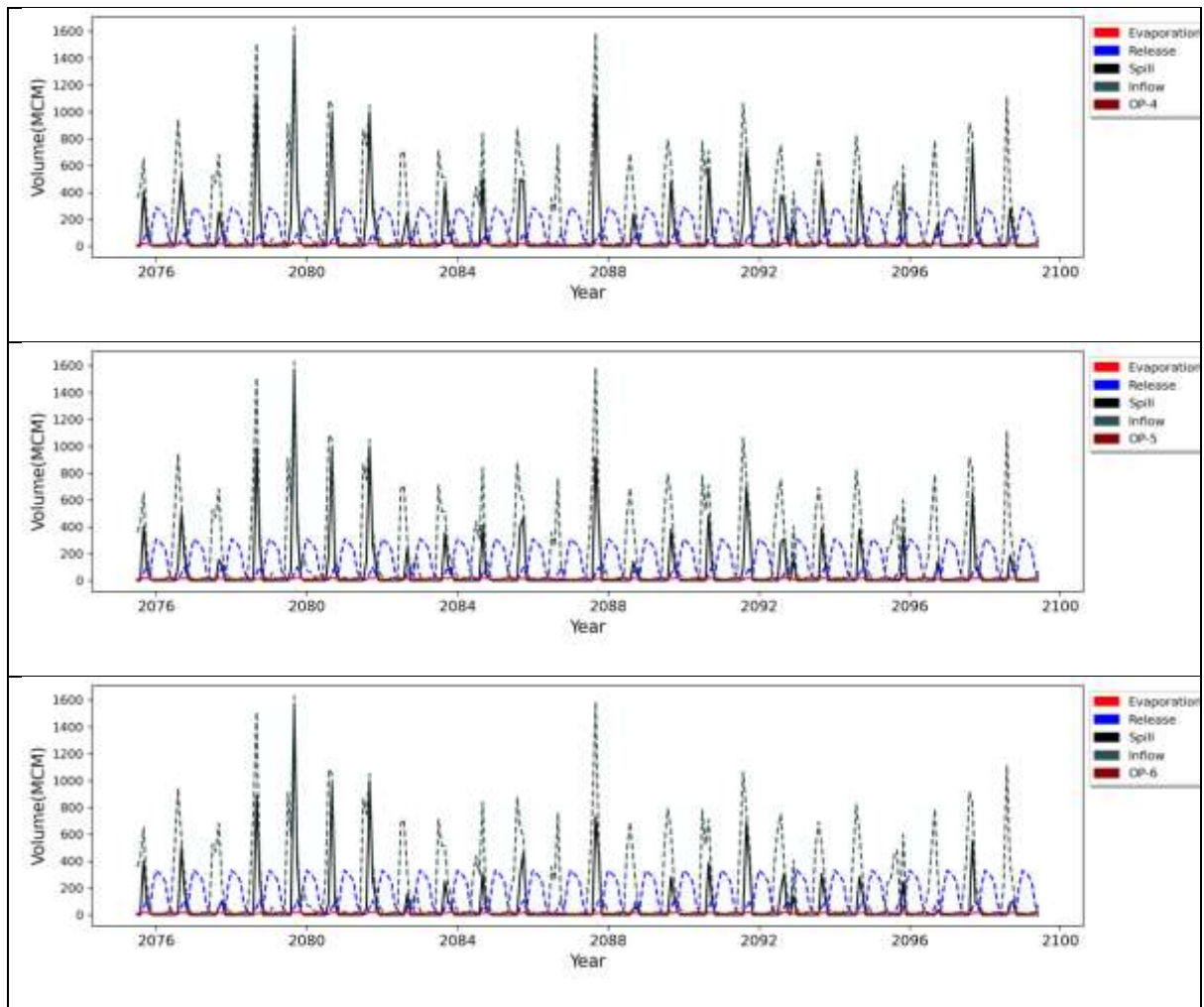
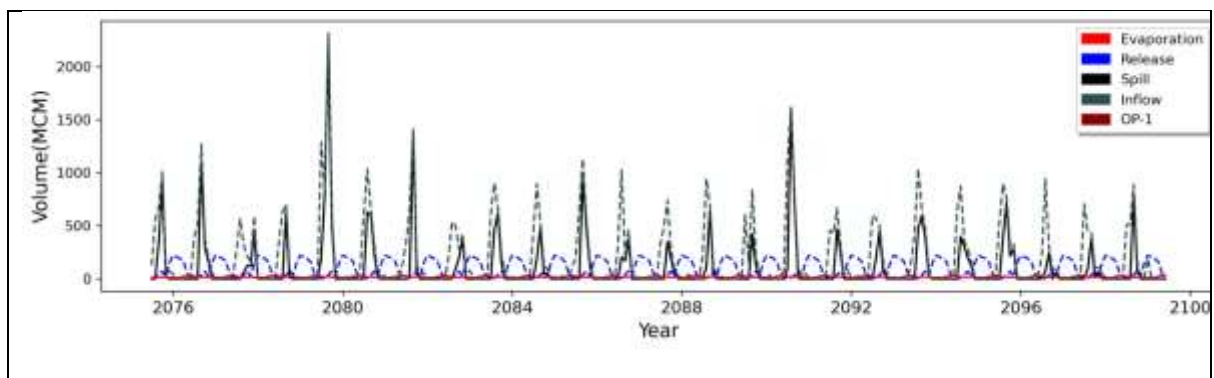
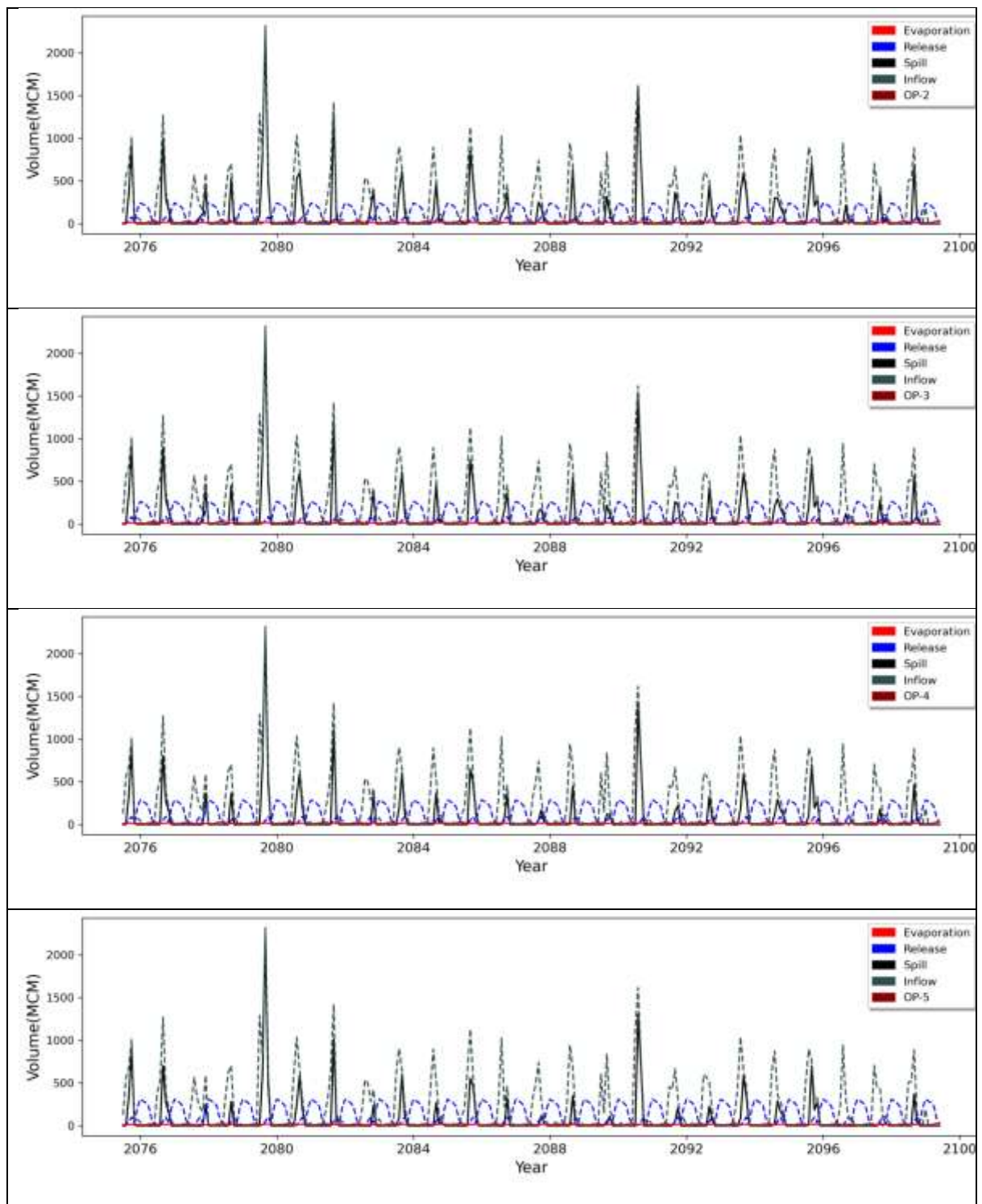


Figure 11.21: The values of inflow, spillway release, irrigation release and evaporation losses of the Mahi Bajaj Sagar reservoir under different operation policies for far future(2075-2099) RCP 4.5 climate change scenario





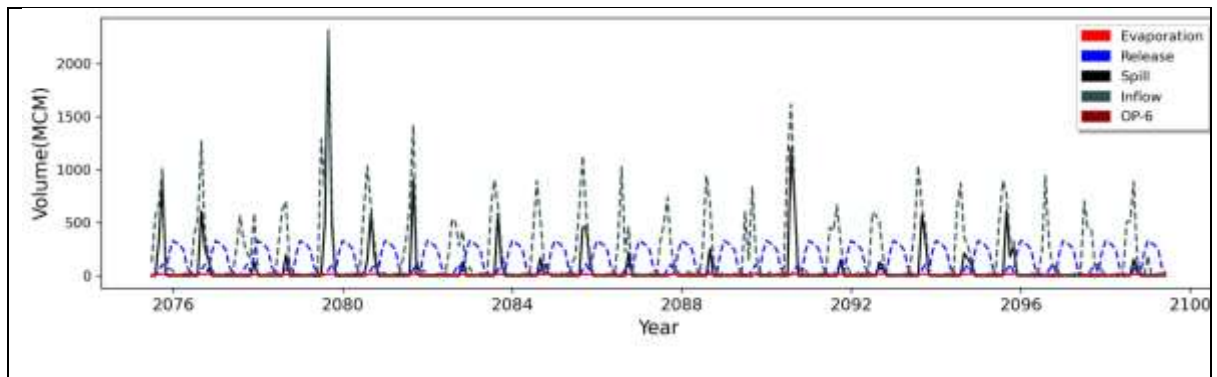
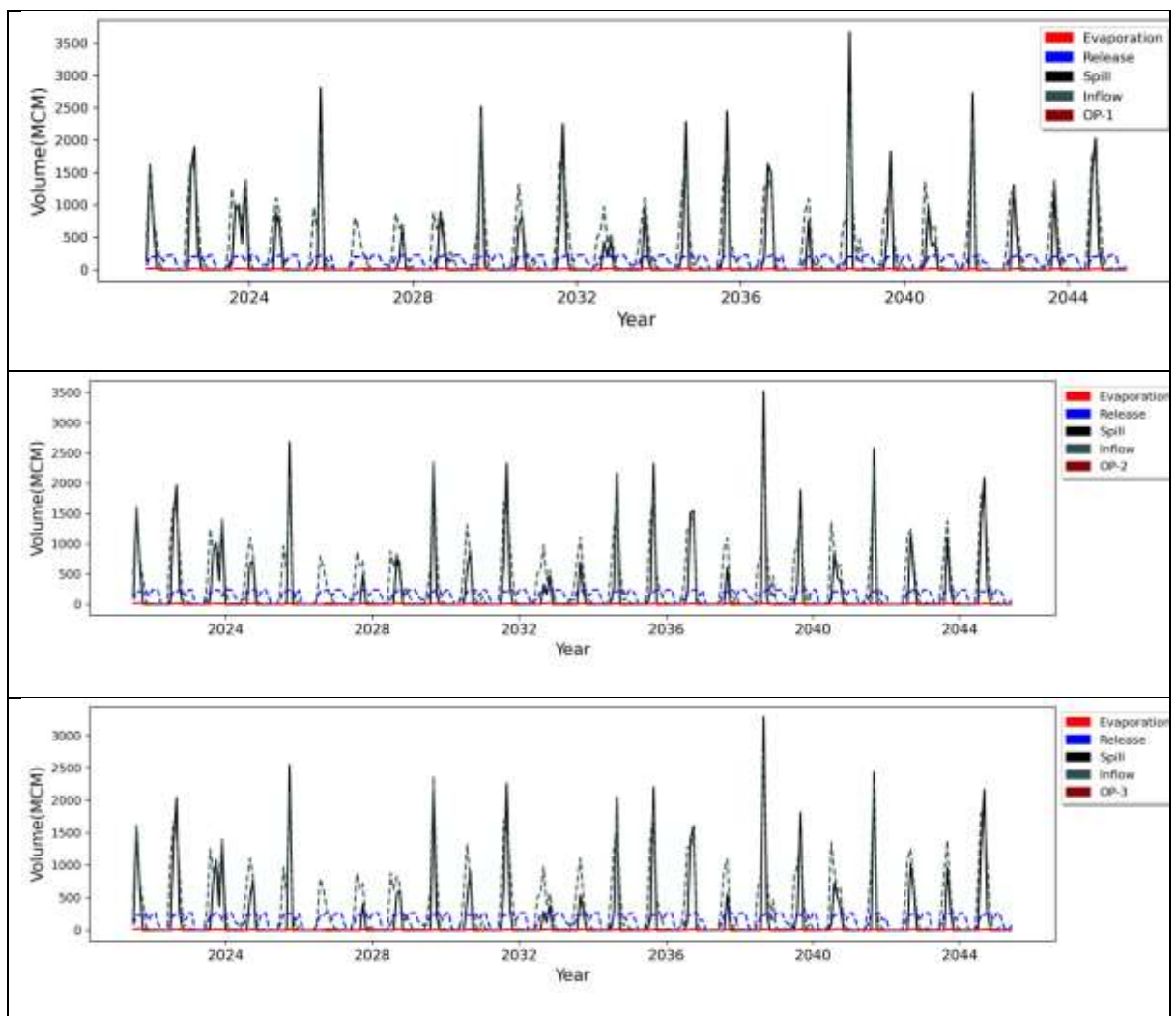


Figure 11.22: The values of inflow, spillway release, irrigation release and evaporation losses of the Mahi Bajaj Sagar reservoir under different operation policies for far future(2075-2099) RCP 8.5 climate change scenario



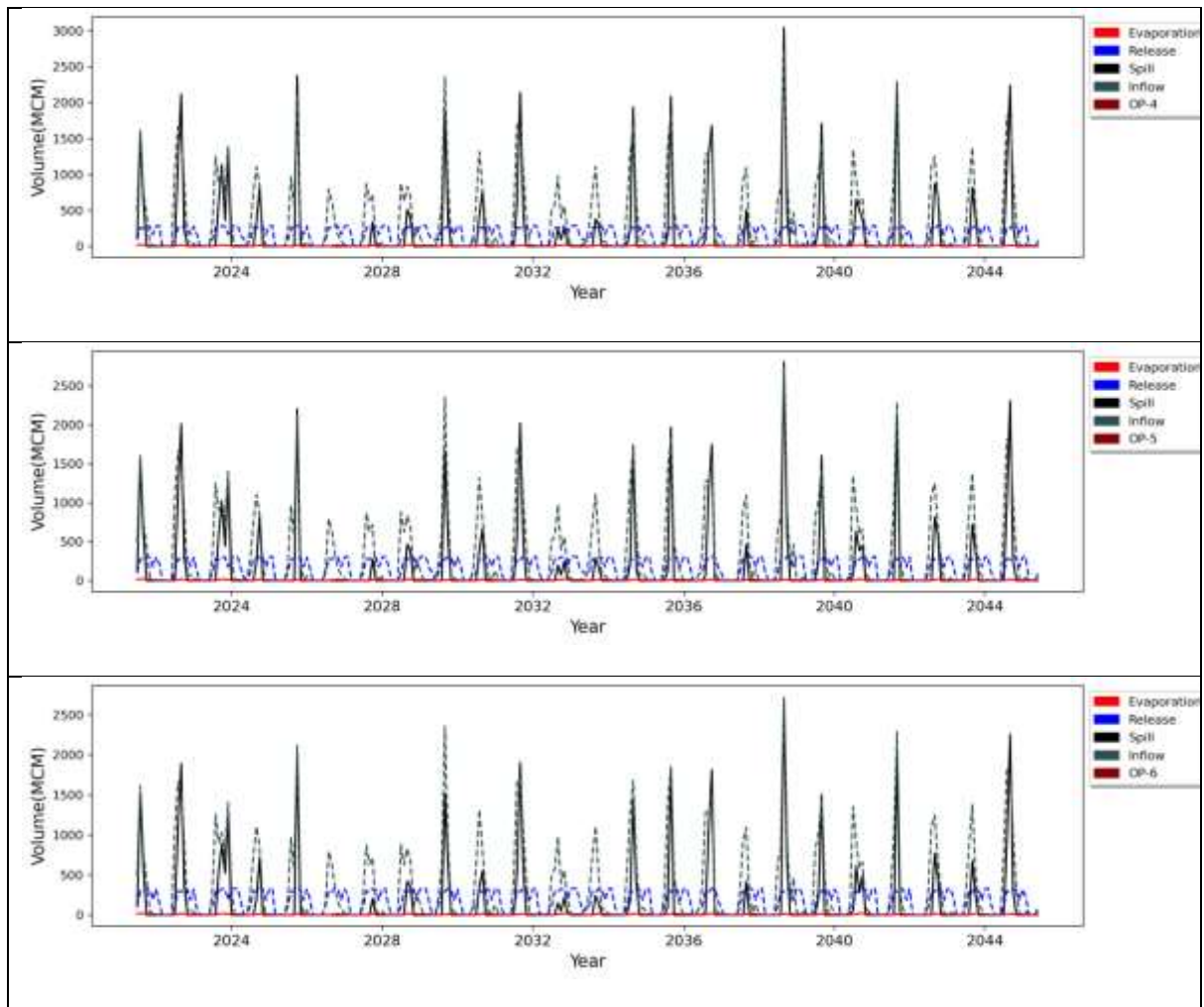
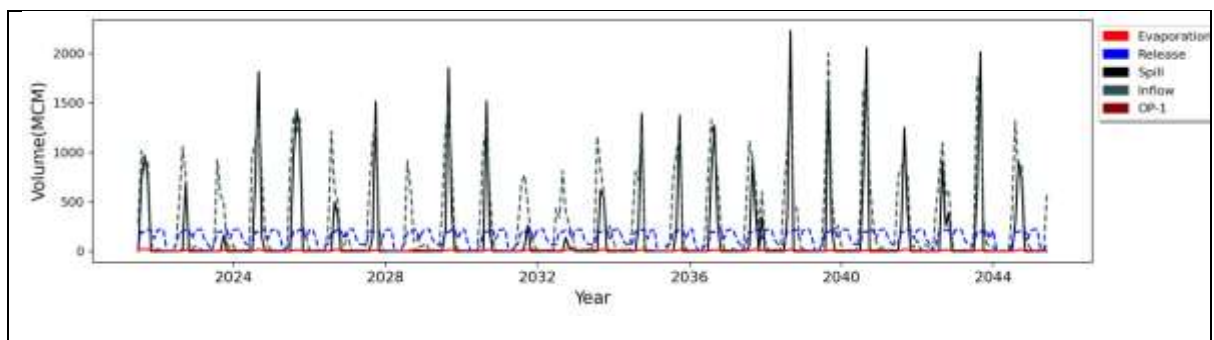


Figure 11.23: The values of inflow, spillway release, irrigation release and evaporation losses of the Kadana reservoir under different operation policies for near future(2021-2044) RCP 4.5 climate change scenario



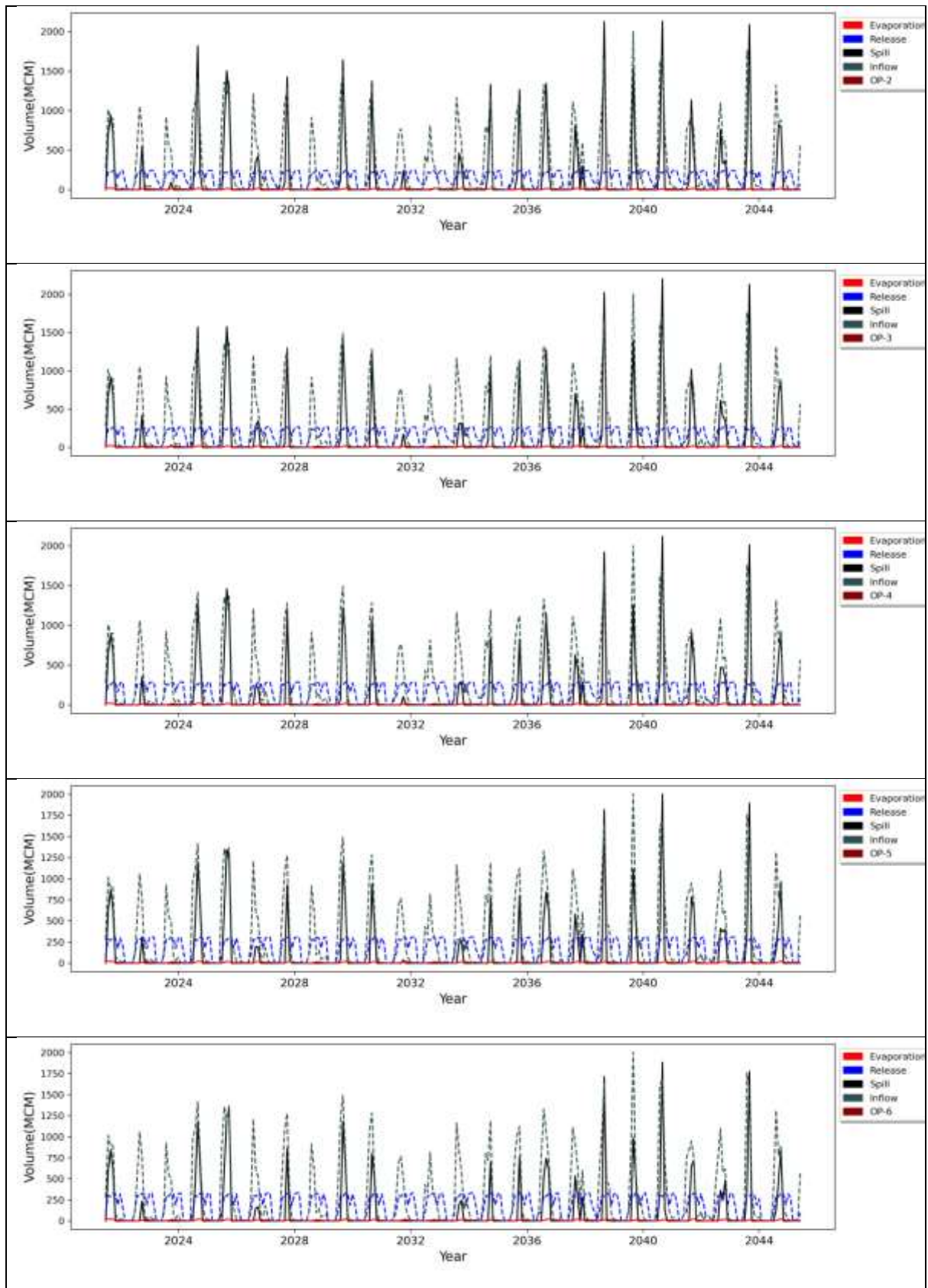
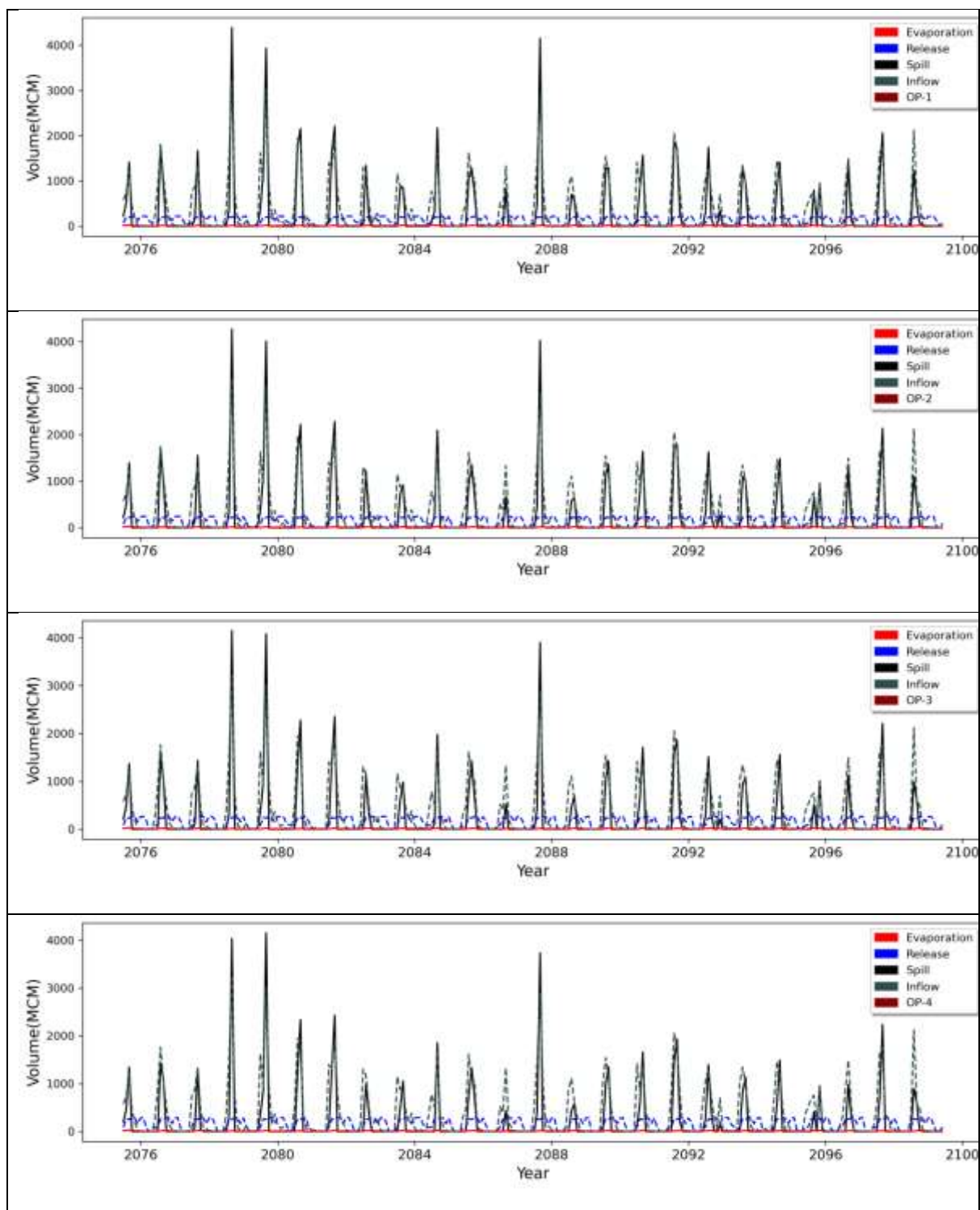


Figure 11.24: The values of inflow, spillway release, irrigation release and evaporation losses of the Kadana reservoir under different operation policies for near future(2021-2044) RCP 8.5 climate change scenario



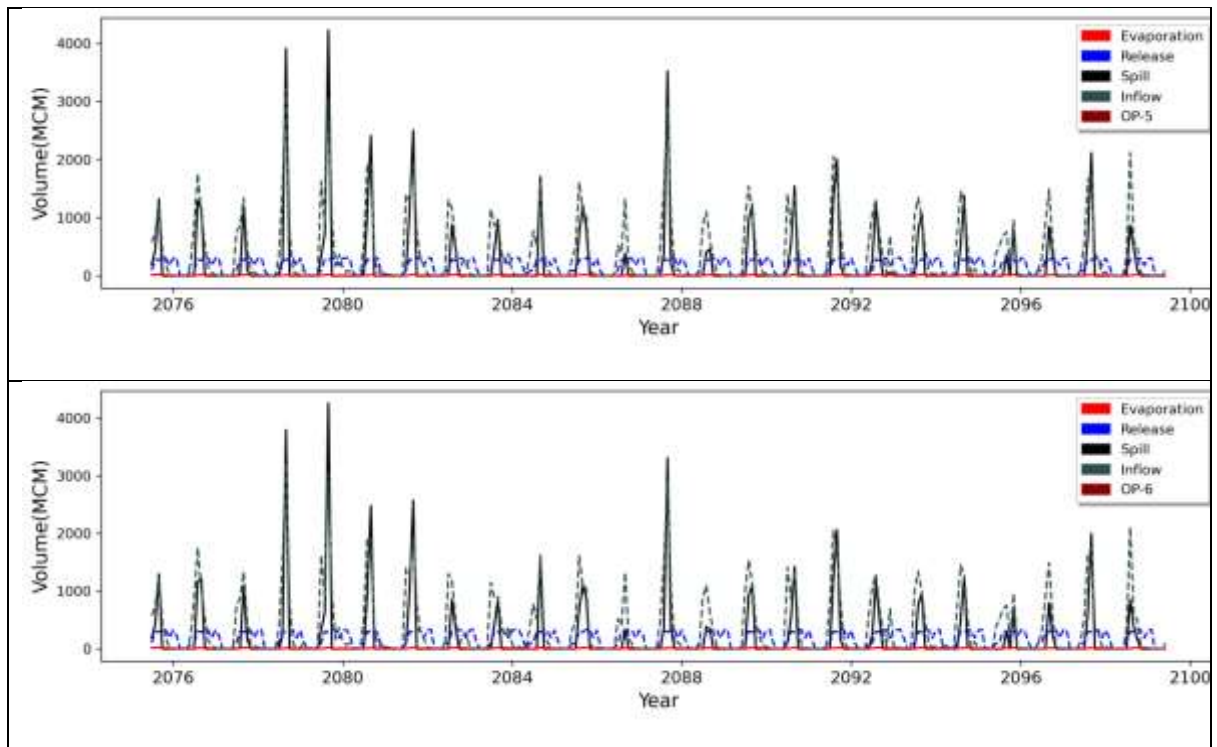
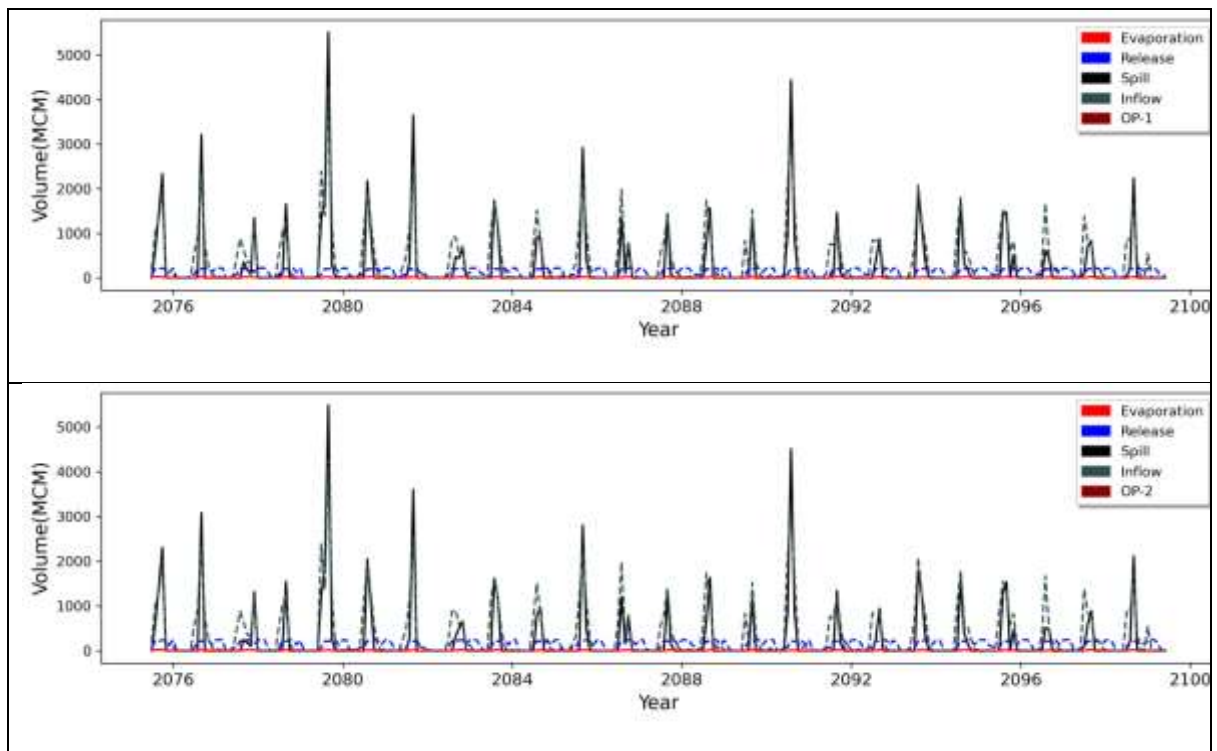


Figure 11.25: The values of inflow, spillway release, irrigation release and evaporation losses of the Kadana reservoir under different operation policies for far future(2075-2099) RCP 4.5 climate change scenario



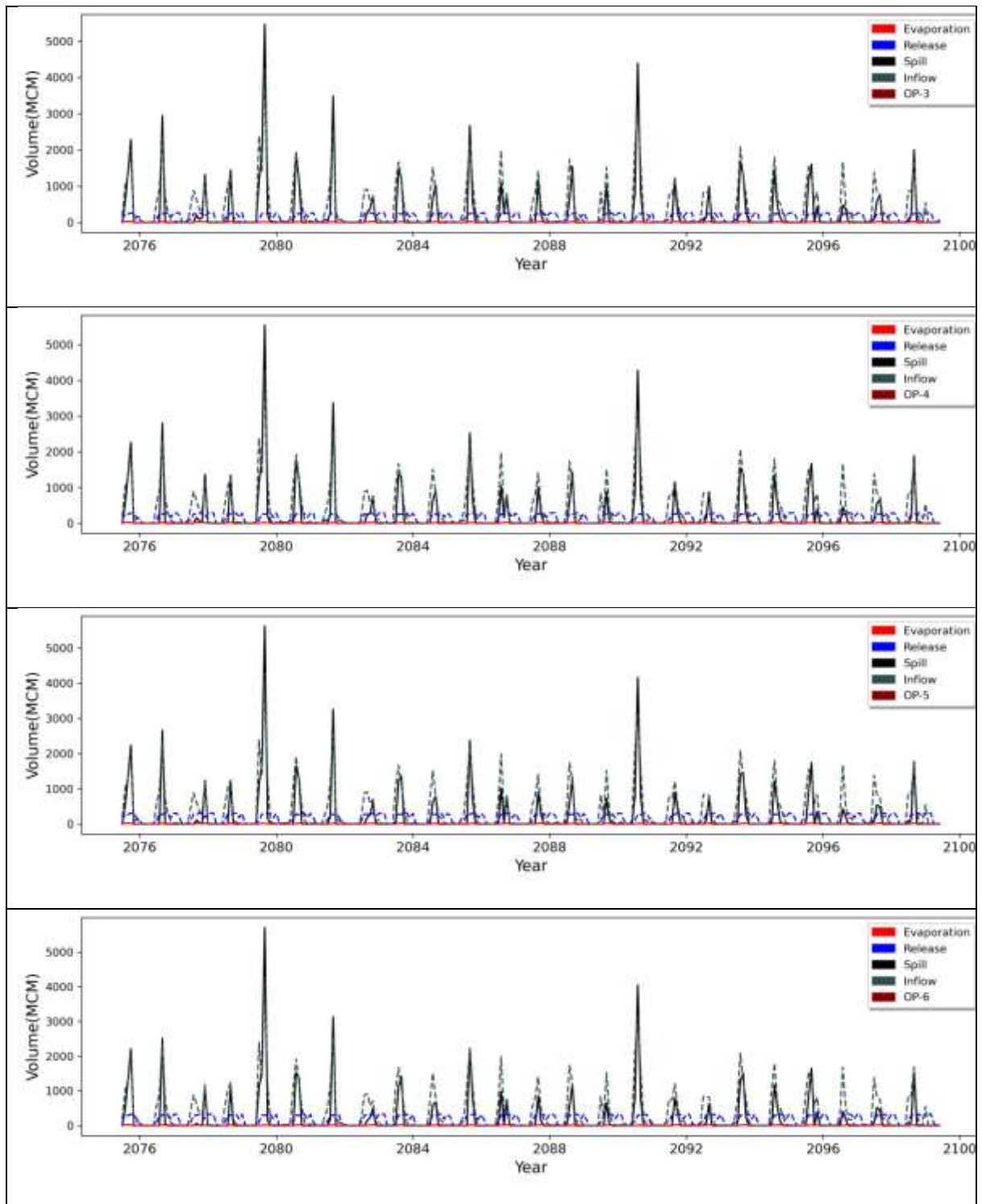
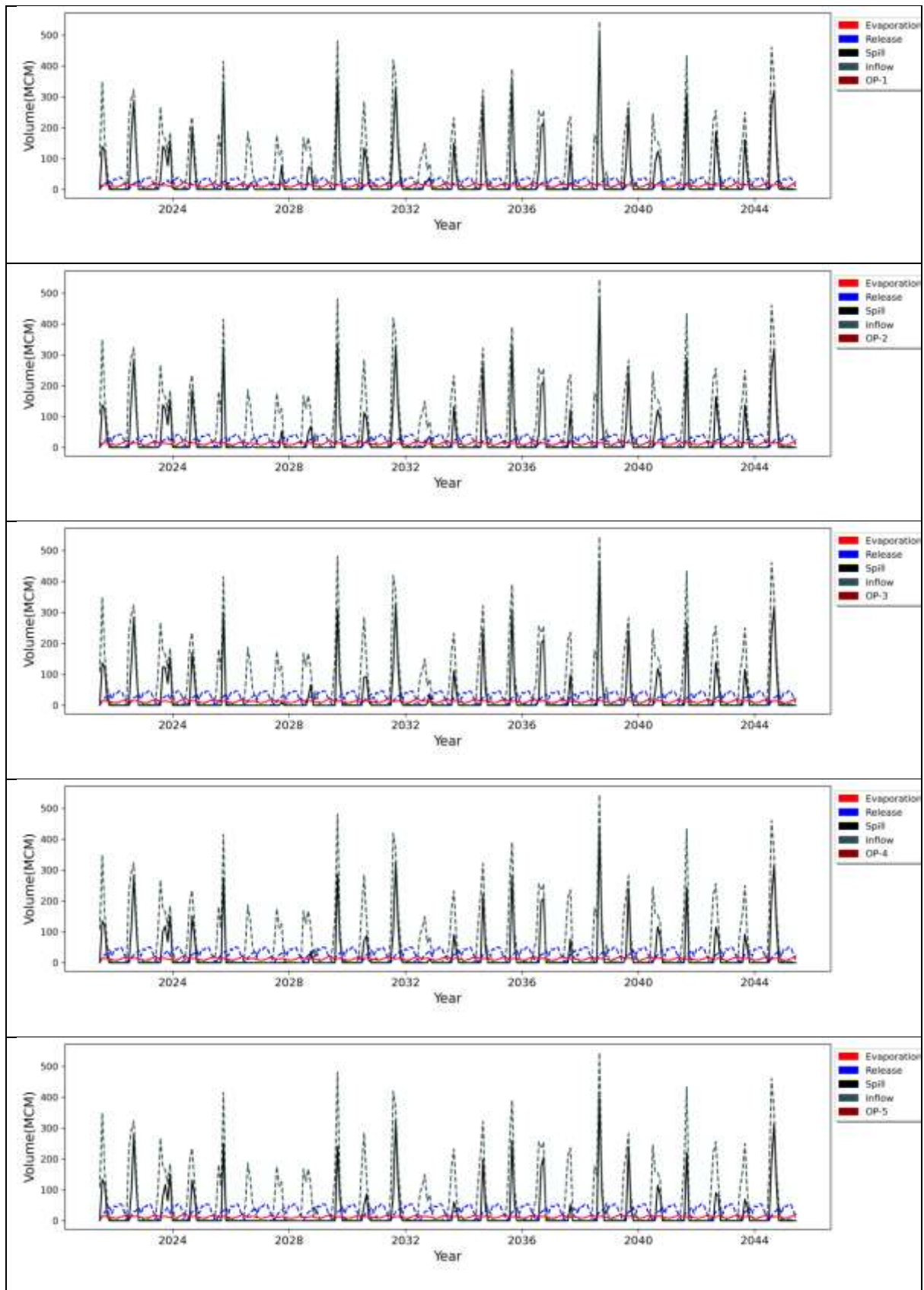


Figure 11.26: The values of inflow, spillway release, irrigation release and evaporation losses of the Kadana reservoir under different operation policies for far future(2075-2099) RCP 8.5 climate change scenario



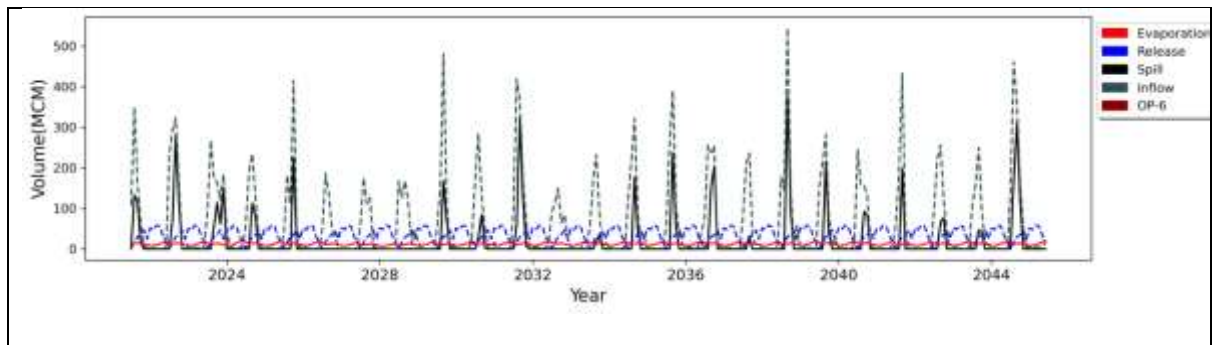
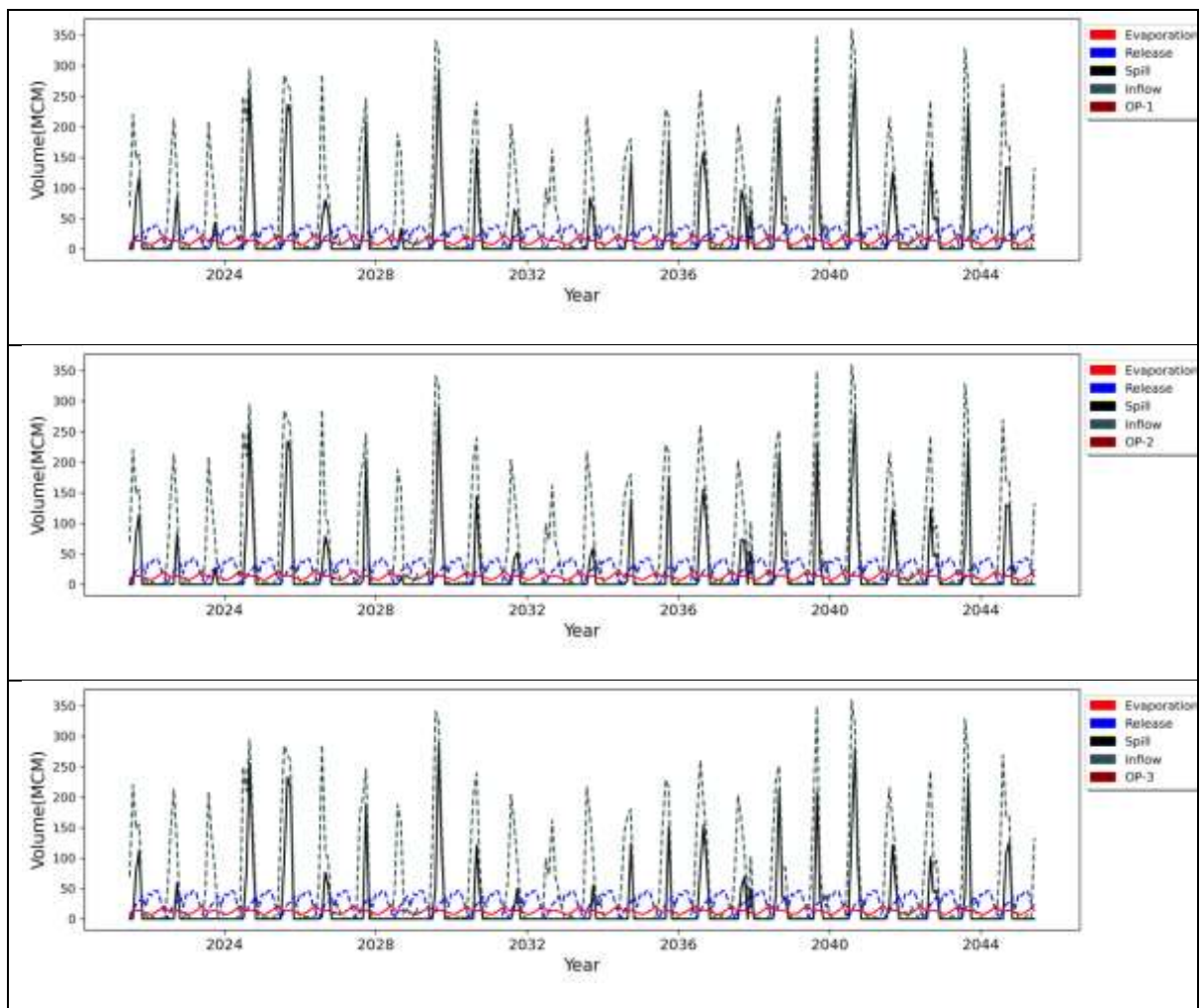


Figure 11.27: The values of inflow, spillway release, irrigation release and evaporation losses of the Panam reservoir under different operation policies for near future(2021-2044) RCP 4.5 climate change scenario



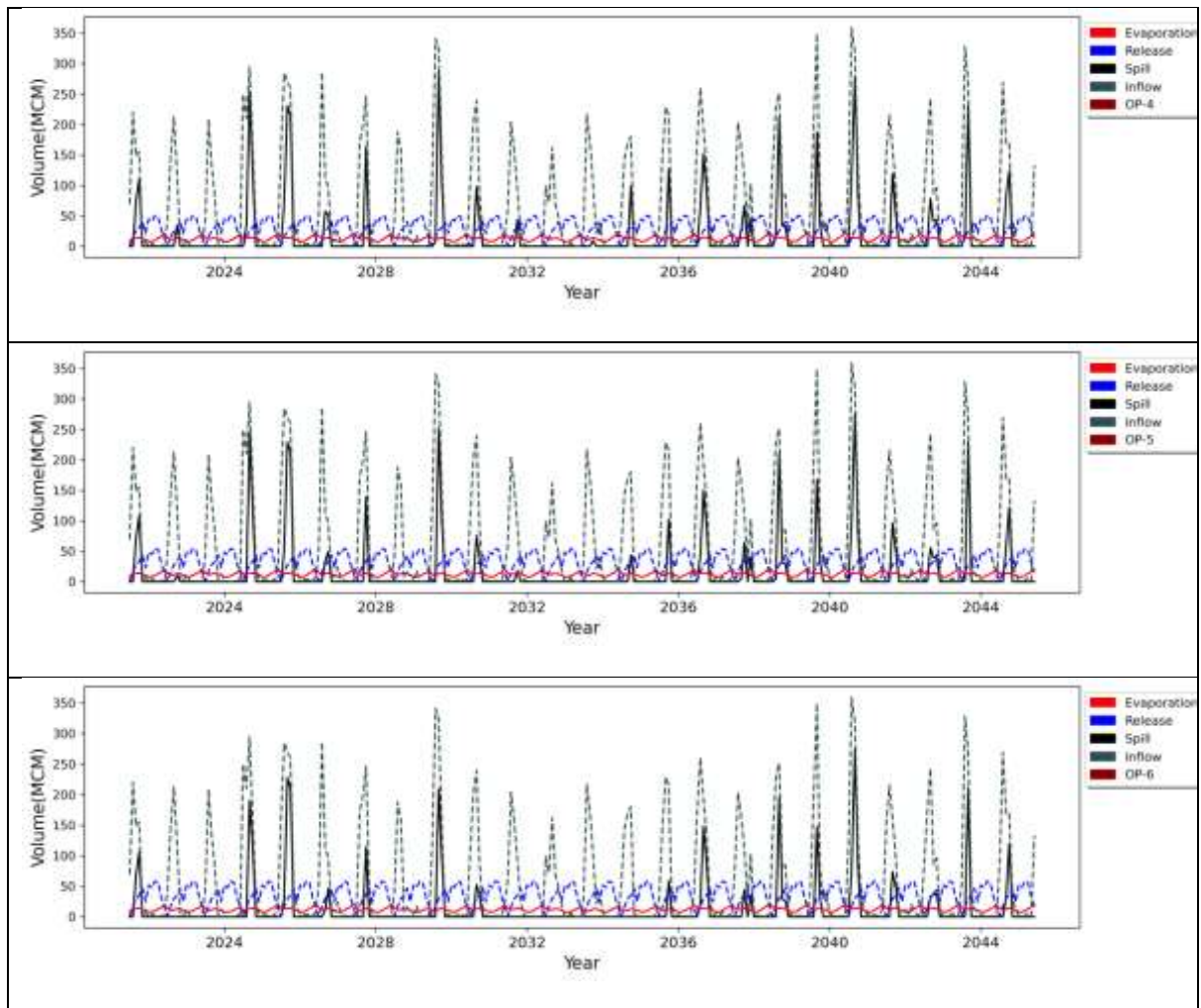
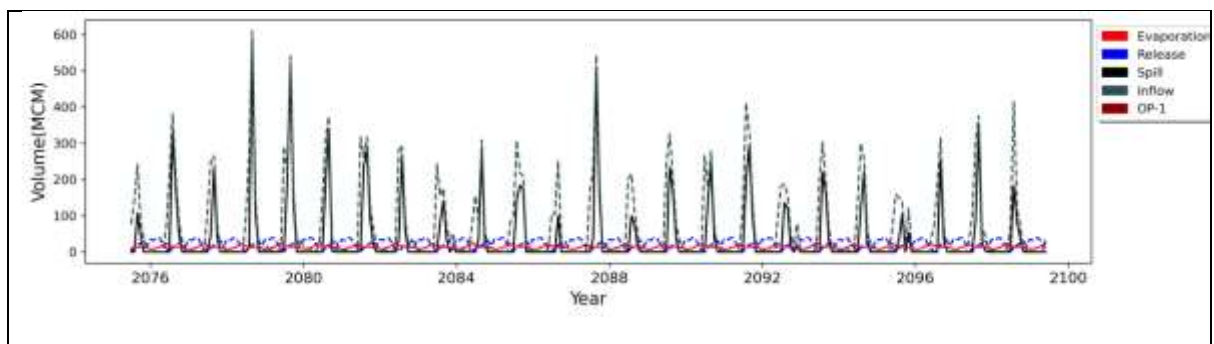


Figure 11.27: The values of inflow, spillway release, irrigation release and evaporation losses of the Panam reservoir under different operation policies for near future(2021-2044) RCP 8.5 climate change scenario



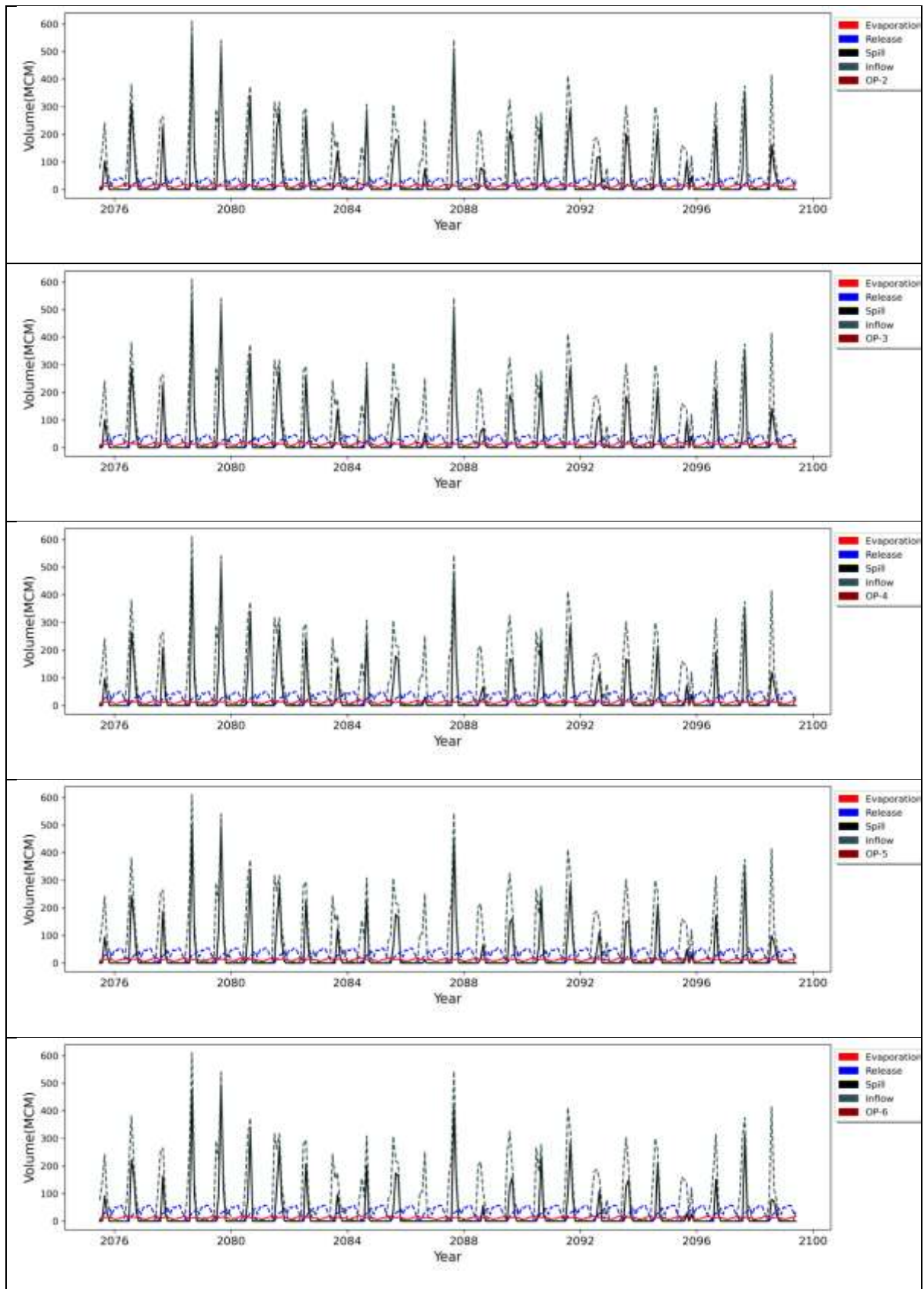
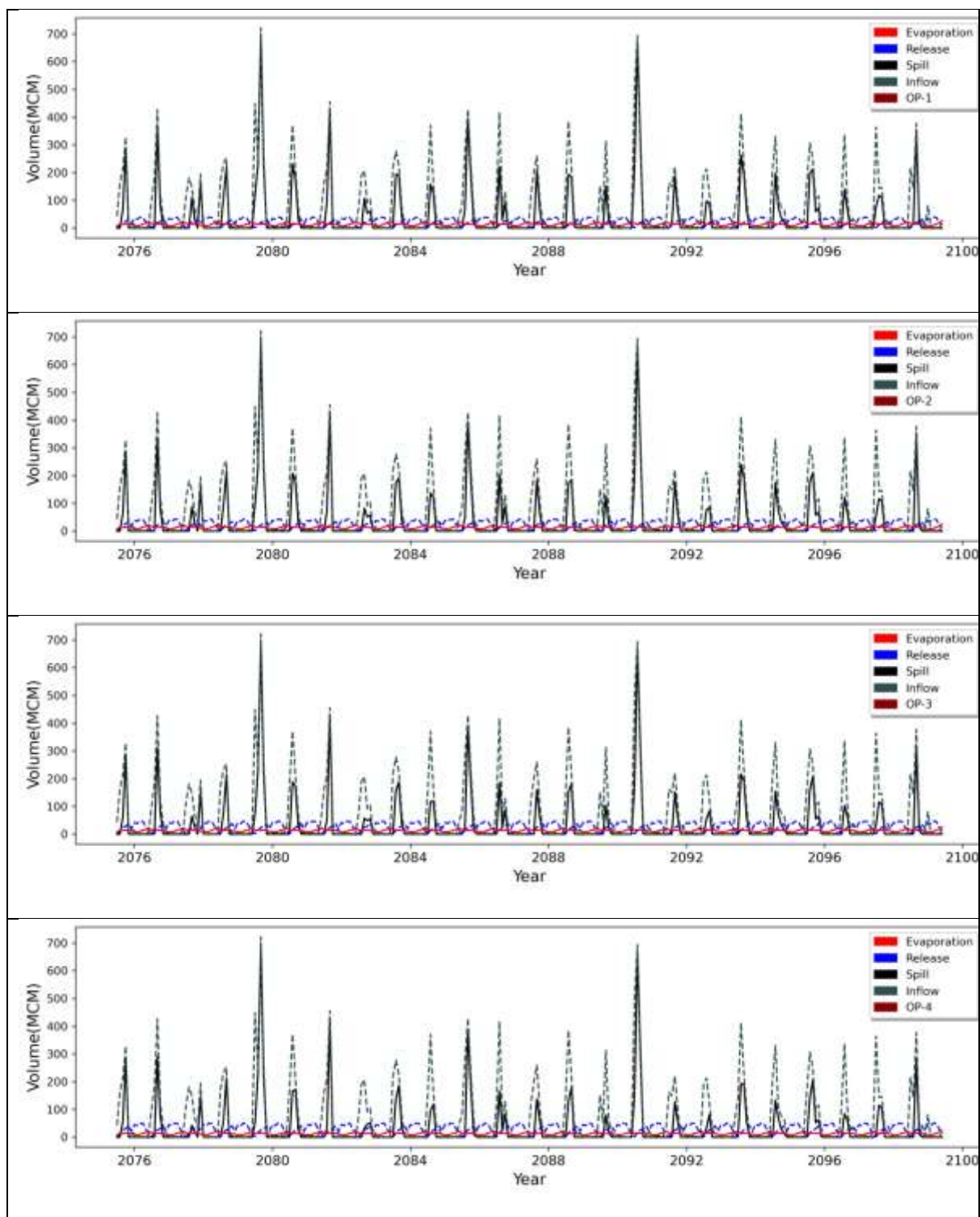
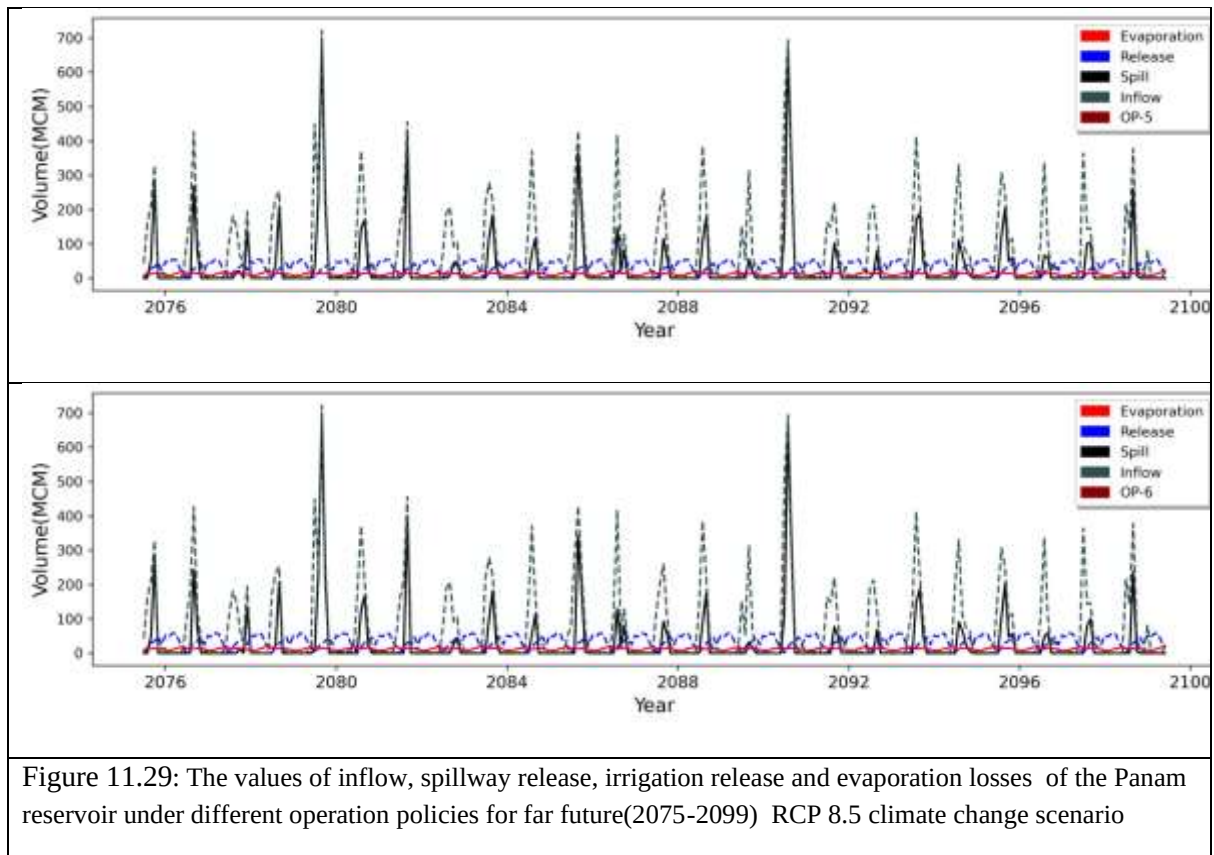


Figure 11.28: The values of inflow, spillway release, irrigation release and evaporation losses of the Panam reservoir under different operation policies for far future(2075-2099) RCP 4.5 climate change scenario





11.3 Reservoir performance

The performance of the reservoir was checked using reliability, resilience, vulnerability, shortage index and modified shortage index indices for each scenario (Table 11.1).

A 100% reliability is possible when a reservoir satisfies the target demand for its entire duration of the operation. Under all the operation policy, Mahi bajaj sagar reservoir system and Panam reservoir system meets all the possible demand under future climate scenarios. However, this is not possible for Kadana reservoir system.

The reliability of the Kadana reservoir for the current irrigable area is under operation (average irrigation demand) is varying from 93.4% to 84.5% under RCP8.5 and RCP4.5 scenarios, respectively. Similarly, resilience of nearly 26.3% to 33.3% was obtained under RCP4.5 and RCP8.5 scenarios, respectively for average irrigable area.

It can be deduced from here that the reservoir has a good capacity to satisfy the demand. However, it needs to be monitored and checked for changing demand and supply conditions.

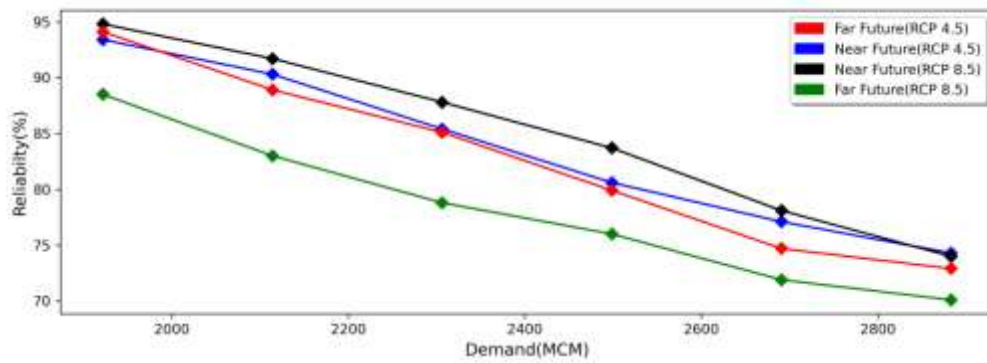


Figure 11.30: Kadana reservoir reliability for two climate change scenarios in near future and far future: RCP 4.5 and RCP8.5

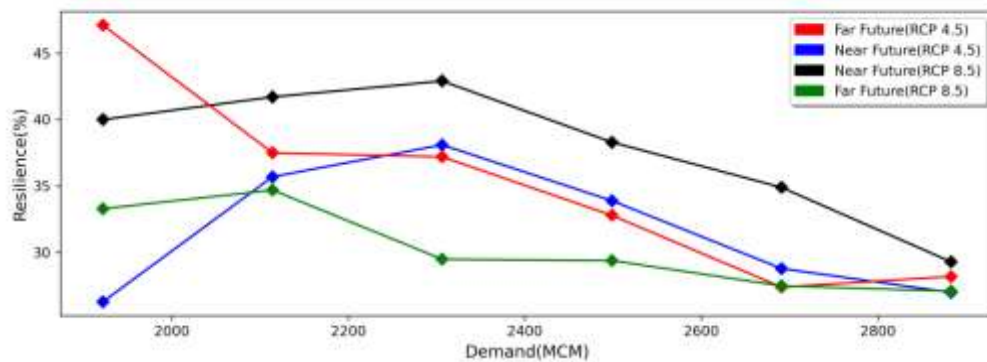


Figure 11.31: Kadana reservoir resiliency for two climate change scenarios in near future and far future: RCP4.5 and RCP8.5

In Figure 11.21 similar plots are shown with reference to vulnerability. From the plots 100% of vulnerability can be inferred, which indicates that climate change is expected to severely aggravate impacts of deficits.

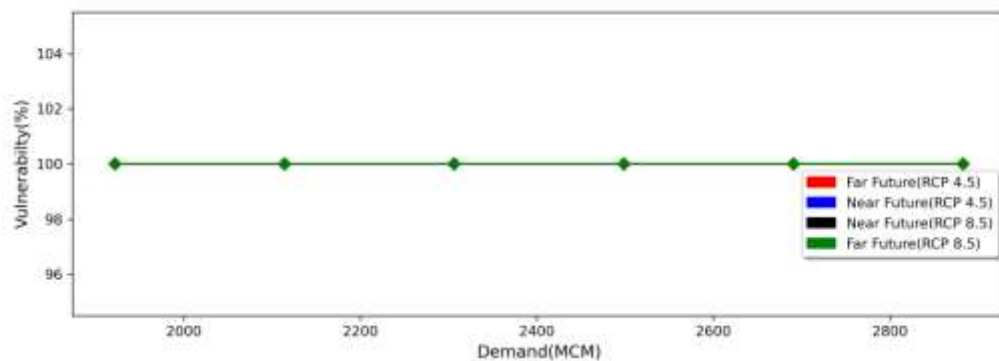


Figure 11.32: Kadana reservoir vulnerability for two climate change scenarios in near future and far future: RCP4.5 and RCP8.5

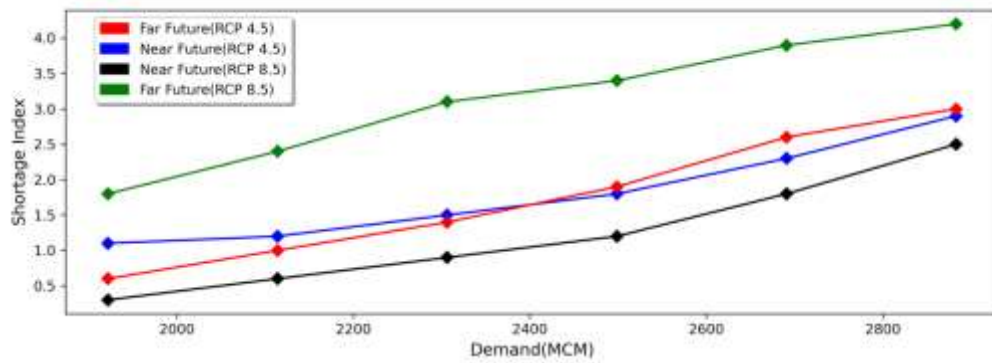


Figure 11.33: Kadana reservoir shortage index (SI) for two climate change scenarios in near future and far future: RCP4.5 and RCP8.5

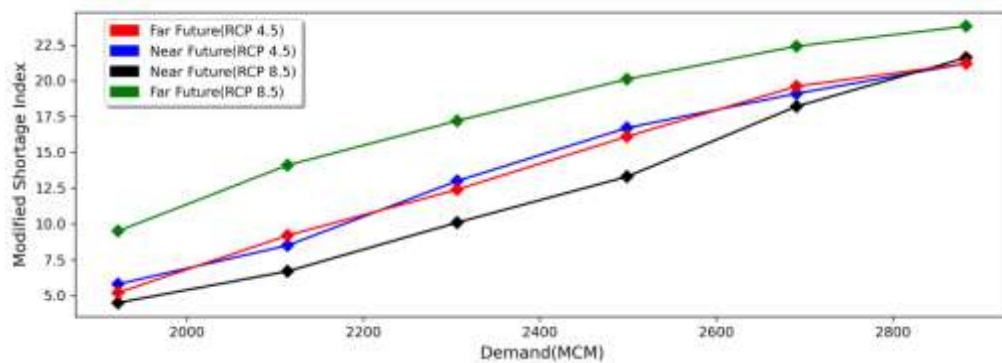


Figure 11.34: Kadana reservoir modified shortage index (MSI) for two climate change scenarios in near future and far future: RCP4.5 and RCP8.5

The above results have been synthesized in Table 11.2. Table 11.2 shows the reduction of performances for increasing demand in the future, in both RCPs and for all periods. As can be seen from Table 11.2, reliability, and resilience for Kadana reservoir is decreasing with increasing in total demand. But, for Mahi Bajaj Sagar reservoir and Panam reservoir, there no change in reliability and resilience. As seen from Table 11.2, shortage index and modified shortage index is increasing with increase in demand for future time period but there is no change for Mahi Bajaj Sagar reservoir and Panam reservoir.

Table 11.2: The reliability, resilience, vulnerability, shortage index(SI) and modified shortage index (MSI) obtained for meeting the irrigation demands for SOP for different climate change scenarios for Mahi Bajaj Sagar Dam reservoir, Kadana reservoir and Panam reservoir respectively

Climate Change Scenario	Near Future(RCP 4.5)						Near Future(RCP 8.5)						Far Future(RCP 4.5)						Far Future(RCP 8.5)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Demand Scenario no.																								
Reliability(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Resilience(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Vulnerability(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shortage Index	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Modified Shortage Index	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Climatic Change Scenario	Near Future(RCP 4.5)						Near Future(RCP 8.5)						Far Future(RCP 4.5)						Far Future(RCP 8.5)					
Demand Scenario no.	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Reliability(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Resilience(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Vulnerability(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

e Ind ex																									
Mo difi ed Sho ratg e Ind ex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cli mat e Cha nge Sce nari o	Near Future(RCP 4.5)						Near Future(RCP 8.5)						Far Future(RCP 4.5)						Far Future(RCP 8.5)						
De man d Sce nari o no.	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	
Reli abil ty(%)	93.4	90.3	85.4	80.6	77.1	74.3	94.8	91.7	87.8	83.7	78.1	74.0	94.1	88.9	85.1	79.9	74.7	72.9	88.5	83.0	78.8	76.0	71.9	70.1	
Res ilie nce(%)	26.3	35.7	38.1	33.9	28.8	27.0	40.0	41.7	42.9	38.3	34.9	29.3	47.1	37.5	37.2	32.8	27.4	28.2	33.3	34.7	29.5	29.4	27.5	27.1	
Vul nera bilt y(%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Sho rtag e	1.1	1.2	1.5	1.8	2.3	2.9	0.3	0.6	0.9	1.2	1.8	2.5	0.6	1.0	1.4	1.9	2.6	3.0	1.8	2.4	3.1	3.4	3.9	4.2	

Ind ex																								
Mo difi ed Sho ratg e Ind ex	5.8	8.5	13.0	16.7	19.1	21.2	4.5	6.7	10.1	13.3	18.2	21.6	5.2	9.2	12.4	16.1	19.6	21.2	9.5	14.1	17.2	20.1	22.4	23.8

Descriptive statistics of the Mahi Bajaj Sagar reservoir simulation result under different climate change conditions are given below in the table.

Note:all units are in million cubic meter(MCM) and power generation in million unit(MU)

	Mahi Bajaj Sagar Reservoir under RCP 4.5 near future(2020-2044)							Mahi Bajaj Sagar Reservoir under RCP 4.5 far future(2075-2099)						
Descript ive statistics	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)
count	288	288	288	288	288	288	288	288	288	288	288	288	288	288
mean	1719.5	95.4	17.9	75.9	189.0	95.4	9.5	1751.5	95.4	18.2	94.2	207.3	95.4	9.6
std	392.0	80.8	7.0	193.5	282.0	80.8	8.2	390.5	80.8	6.9	228.5	310.1	80.8	8.1
min	1074.9	0.9	10.6	0.0	2.2	0.9	0.0	1092.7	0.9	10.5	0.0	2.8	0.9	0.0
25%	1339.1	23.2	11.7	0.0	6.9	23.2	2.4	1383.7	23.2	11.7	0.0	7.1	23.2	2.4
50%	1765.0	63.5	16.3	0.0	26.8	63.5	6.3	1804.1	63.5	17.1	0.0	30.3	63.5	6.3
75%	2169.8	169.0	21.9	0.0	319.9	169.0	16.8	2180.3	169.0	22.0	24.0	312.7	169.0	16.7
max	2180.3	220.6	39.7	1155.5	1430.3	220.6	22.5	2180.3	220.6	39.5	1570.6	1627.0	220.6	22.5
	Mahi Bajaj Sagar Reservoir under RCP 8.5 near future(2020-2044)							Mahi Bajaj Sagar Reservoir under RCP 8.5 far future(2075-2099)						
Descript ive statistics	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)

count	288	288	288	288	288	288	288	288	288	288	288	288	288	288
mean	1697.9	95.4	17.7	57.4	171.6	95.4	9.5	1733.5	95.4	18.0	95.2	208.6	95.4	9.5
std	393.2	80.8	7.0	150.7	246.2	80.8	8.2	395.7	80.8	6.9	253.1	333.3	80.8	8.1
min	1052.6	0.9	10.3	0.0	1.6	0.9	0.0	1077.8	0.9	10.6	0.0	2.8	0.9	0.0
25%	1290.4	23.2	11.7	0.0	6.2	23.2	2.3	1353.2	23.2	11.7	0.0	6.5	23.2	2.4
50%	1663.3	63.5	16.0	0.0	30.8	63.5	6.1	1800.7	63.5	17.1	0.0	27.3	63.5	6.3
75%	2165.8	169.0	21.8	0.0	296.4	169.0	16.7	2180.3	169.0	21.7	16.3	317.8	169.0	16.7
max	2180.3	220.6	36.8	844.7	1128.7	220.6	22.5	2180.3	220.6	36.5	2260.0	2317.0	220.6	22.5

Descriptive statistics of the Kadana reservoir simulation result under different climate change conditions are given below in the table.

	Kadana Reservoir under RCP 4.5 near future(2020-2044)							Kadana Reservoir under RCP 4.5 far future(2075-2099)						
Descriptive statistics	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)
count	288	288	288	288	288	288	288	288	288	288	288	288	288	288
mean	509.7	144.1	8.2	185.0	332.4	160.8	25.2	512.5	143.9	8.3	224.5	368.6	160.8	27.9
std	385.4	81.0	5.1	530.8	515.3	62.7	42.2	378.5	79.7	5.3	615.2	575.9	62.7	46.3
min	57.6	0.0	0.7	0.0	0.5	63.8	0.0	57.6	0.0	0.7	0.0	1.2	63.8	0.0
25%	101.6	69.4	3.4	0.0	5.6	105.6	4.0	83.2	69.4	3.5	0.0	5.8	105.6	4.1

50%	441.1	193.2	7.8	0.0	36.1	196.7	14.1	510.8	193.2	7.7	0.0	42.0	196.7	14.0
75%	867.8	213.8	11.9	0.0	547.1	215.2	16.9	814.1	213.8	12.0	0.0	521.6	215.2	16.9
max	1249.3	221.2	21.3	3672.4	2730.4	221.2	172.5	1249.3	221.2	23.5	4389.7	3212.3	221.2	172.5

Note:all units are in million cubic meter(MCM) and power generation in million unit(MU)

	Kadana Reservoir under RCP 8.5 near future(2020-2044)							Kadana Reservoir under RCP 8.5 far future(2075-2099)						
Descript ive statistics	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)	Storage	Release	Evaporat ion	Spill	Inflow	Demand	Power Generati on(MU)
count	288	288	288	288	288	288	288	288	288	288	288	288	288	288
mean	548.0	149.4	8.9	140.8	295.7	160.8	23.5	462.1	138.5	7.3	235.7	370.4	160.8	26.8
std	393.2	76.6	5.2	388.8	436.4	62.7	37.8	381.0	83.5	5.1	674.0	615.7	62.7	45.3
min	57.6	0.0	0.8	0.0	0.4	63.8	0.0	57.6	0.0	0.6	0.0	1.2	63.8	0.0
25%	161.0	73.6	4.1	0.0	4.5	105.6	5.1	57.6	69.4	2.7	0.0	5.5	105.6	0.1
50%	516.0	193.2	8.7	0.0	47.8	196.7	15.0	397.5	193.2	6.5	0.0	37.3	196.7	14.0
75%	870.7	213.8	12.6	0.0	520.6	215.2	16.9	787.3	213.8	10.5	0.0	550.4	215.2	16.9
max	1249.3	221.2	22.8	2228.9	2001.6	221.2	172.5	1249.3	221.2	22.6	5515.0	4265.0	221.2	172.5

Descriptive statistics of the Panam reservoir simulation result under different climate change conditions are given below in the table.

	Panam Reservoir under RCP 4.5 near future(2020-2044)							Panam Reservoir under RCP 4.5 far future(2075-2099)						
Descriptive statistics	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)
count	288	288	288	288	288	288	0	288	288	288	288	288	288	0
mean	623.8	23.2	13.7	28.3	65.3	23.2	0	631.9	23.2	13.8	34.5	71.4	23.2	0
std	98.6	11.5	4.3	74.4	103.5	11.5	0	97.2	11.5	4.3	85.9	112.1	11.5	0
min	423.7	0.7	8.0	0.0	0.3	0.7	0	423.8	0.7	8.0	0.0	0.7	0.7	0
25%	537.3	15.2	9.9	0.0	1.7	15.2	0	544.6	15.2	9.9	0.0	2.1	15.2	0
50%	642.8	22.7	14.0	0.0	6.9	22.7	0	649.7	22.7	14.2	0.0	8.6	22.7	0
75%	721.4	32.5	15.3	0.0	105.8	32.5	0	737.6	32.5	15.7	4.2	102.1	32.5	0
max	737.6	38.7	26.7	500.9	545.0	38.7	0	737.6	38.7	26.1	576.8	610.3	38.7	0

Note:all units are in million cubic meter(MCM) and power generation in million unit(MU)

	Panam Reservoir under RCP 8.5 near future(2020-2044)							Panam Reservoir under RCP 8.5 far future(2075-2099)						
Descriptive statistics	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)	Storage	Release	Evaporation	Spill	Inflow	Demand	Power Generation(MU)

count	288	288	288	288	288	288	0	288	288	288	288	288	288	0
mean	620.5	23.2	13.6	21.6	58.9	23.2	0	627.9	23.2	13.7	35.9	73.1	23.2	0
std	99.4	11.5	4.3	54.2	87.9	11.5	0	97.3	11.5	4.3	91.7	121.2	11.5	0
min	427.0	0.7	8.0	0.0	0.2	0.7	0	423.7	0.7	8.0	0.0	0.8	0.7	0
25%	526.8	15.2	9.9	0.0	1.5	15.2	0	540.2	15.2	9.9	0.0	1.9	15.2	0
50%	636.3	22.7	13.7	0.0	6.2	22.7	0	645.8	22.7	14.2	0.0	6.2	22.7	0
75%	719.2	32.5	15.1	0.0	96.9	32.5	0	729.3	32.5	15.2	0.0	106.9	32.5	0
max	737.6	38.7	25.3	292.4	359.3	38.7	0	737.6	38.7	25.9	687.9	722.1	38.7	0

Chapter 12: Conclusion

Conclusions

The impact of Climate Change (CC) is being felt around the globe. In order to study the impact of CC on National Water Resources, Central Water Commission (CWC) has prepared a plan for basin level study under National Water Mission and NAPCC. The Department of Civil Engineering Malaviya National Institute of Technology (MNIT) Jaipur along with IIT Delhi and Central University of Rajasthan, Kishangarh, Ajmer proposed comprehensive research on the Areas of Inland Drainage in western Rajasthan and Mahi River Basin in the South-Eastern part of the Rajasthan. The primary objective of the project was to study the impact of Climate Change on various Hydrological parameters of a river basin using high resolution GCM outputs. This includes the analysis of climate change analysis, development of basin specific Hydrological model for quality and quantity of available water and identification of hotspots with respect to hydrological parameters. Hydrological modelling has been performed using Soil and Water Assessment Tool (SWAT) model for Mahi River basin and Area of Inland drainage.

Region 1: Mahi River Basin – The Mahi River originates in the Mahi Kanta hills in the Vindhya range, in the western part of Madhya Pradesh. The Mahi basin extends over an area of 34,842 km² which is nearly 1.1 percent of the total geographical area of the country. It lies between east longitudes 72° 15' to 78° 15' and north latitudes 22° 0' to 22° 40' N respectively. The basin lies in the States of Rajasthan, Gujarat and Madhya Pradesh.

- Spatial distribution of mean annual precipitation represent that during the historical period (1981-2005) it was 843.23mm (Spatially vary: 631.85 to 1056.2mm). According to MME projections it will increase by 117.33 mm (63.23mm) in NF and 211.59 mm (188.50mm) in FF under RCP4.5 scenario. These changes in RCP8.5 scenario is less as compared to RCP4.5 due to high warming in RCP8.5. The spatial distribution shows that south-western region (Panch Mahals and Dahod districts) of Mahi River basin will be highly vulnerable and have more than 250 mm rise in annual rainfall which can cause flooding conditions in these regions.
- Spatial distribution of mean annual maximum temperature (Tasmax) represents that during the historical period it was 41.52°C. According to MME projections it will increase by

0.75°C (0.88°C) in NF and 1.41°C (2.94°C) in FF under RCP4.5 scenario. The annual mean increase in NF of both RCPs is similar to each other but in FF of RCP8.5 it is projected to increase by more than two times of increase in RCP4.5 scenario. The spatial distribution shows that northern region (Udaipur and Chittorgarh Districts) of Mahi River basin will be highly vulnerable and have more than 1.5°C and 3°C rise in RCP4.5 and RCP8.5 scenario, respectively.

- The mean annual minimum temperature (Tasmin) will increase by 2.25°C under RCP4.5 scenario while in extreme scenario RCP8.5, it will increase by 4.87°C by the end of 21st century.
- In mahi River Basin annual minimum temperature is projected to increase more as compared to annual maximum temperature in both RCPs. This represents that in the coming years the warming rate in the nights will be more as compared to day time. Health risk due to day time heat can substantially increase if the human body does not get a break from the heat during the night. It will impact the human health and can increase the mortality and morbidity because people will not be able to get comfort even in nights after working whole day.
- There are a total 9 observing station over mahi river basin. Within those stations are Mataji, Paderdibadi, Rangeli, Khanpur, Dhariyabad, Chakaliya observe data have been collected from CWC and Bajajsagar, Kadana, Panam have been collected from State water resource department of Gujarat and Rajasthan. Observed data (Discharge) for model calibration and validation has been collected from Central Eater Commission (CWC) and State water resource department.
- Data required for the modelling are Land use land cover (LULC), Soil Texture, Digital elevation model and meteorological data. For LULC, Satellite data are collected from USGS Earth Explorer and NRSC.
- LULC map prepared for the year 1990, 1995, 2000, 2055 for kharif and rabi season with 30 m spatial resolution. Major LULC classes are Agricultural land and Barren land. There is an increasing trend for agriculture and urban area. Soil data has been collected from FAO with 1:1 km scale. ASTER 30m DEM has been used for the modelling. For meteorological data, precipitation and temperature downscaled data has been collected from IIT Bombay. Multi model ensemble has been used for the input preparation. Dynamic LULC changes is used in the model.

- Calibration and validation have been done using Swat Cup with SUFI2 algorithm. Model has been simulated for near future (2021-2045) and far future (2075-2099) for RCP 4.5 and RCP 8.5. Water Balance parameters values for Historical period have shown increased trend as compared to RCP 4.5 for both periods. Both near future and far future water balance values are decreased in RCP 4.5 compared to RCP 8.5. Discharge at outlet Near Future period will increased in Scenario RCP4.5 as compared to Scenario RCP8.5. Discharge at outlet For Far future will increases in scenario RCP8.5.

Region 2: Area of Inland Drainage- The Area of Inland Drainage (AID) extends over an area of 1,73, 869km². The area has no drainage and mostly occupied by the Thar Desert. It has an Arid Climate and slopes gently towards West – Southwest towards Indus River system. Inland drainage is surrounded by Satluj, Yamuna, Chambal and Luni River basin respectively from north, east to south. This region receives water from Indira Gandhi canal system from which water is mainly used for drinking purpose and irrigation of Rabi crops. Monsoon often fails in the region and droughts are a common phenomenon followed by heat wave.

- Future projections of MME represent that mean annual precipitation changes will spatially vary between (18.56mm to 191.56mm) in RCP4.5 scenario while it will be between (-7.22 to 250.38mm) in RCP8.5 scenario. In RCP8.5 scenario, North-East regions of Area of Inland Drainage (AID) (Panchkula, Patiala and Ambala Districts) will have decreasing rainfall in this century. But the south-western part of AID (Jaisalmer and nearby regions) will be highly vulnerable to increase in rainfall (around 250mm). It can cause the flooding conditions frequently if the proper drainage system is not provided in these regions.
- In AID mean annual maximum temperature was 42.26°C during historical period which is projected by MME to increase by 1.23°C and 1.41°C in NF of RCP4.5 and RCP8.5 scenario. It will increase by 4.56°C (3.51°C to 5.83°C) in FF under RCP8.5 scenario which is more than two times of increase in RCP4.5 scenario. The areas near to border (Ganganagar district) will be more affected due to major rise in temperature. It will affect the specially affect for soldiers of army working on border.
- Mean annual minimum temperature of AID was 4.77°C during historical period which is projected to increase by 1.00°C (1.19°C) in NF and 2.21°C(4.64°C) in FF of RCP4.5 and RCP8.5 scenario, respectively. Maximum increase will be in the central regions (Churu, Bhiwani, Jhunjhunu) of AID where minimum temperature can increase more than 5°C in FF of RCP8.5.

- Total 18 models have been prepared for the area. The area is mostly over the western part of Rajasthan part Thar desert. There does have any surface flowing river over that area. For the climate change scenario, precipitation will be increase in near future RCP 4.5 compare to RCP 8.5. But for far future, precipitation will be increase in near future RCP 8.5 compare to RCP 4.5. ET is the main components in the water balance.
- Increase of discharge observations in the all the SWAT model sub basin of AID, however we have taken care of uncertainties in precipitation data and SWAT model parameters.
- For all the SWAT model sub basin of AID showing drastically increase in PET and PET for future period. Most of the AID SWAT model underestimate the Groundwater component in AID area.

Climate Change

- The mean annual precipitation in Mahi River basin during the historical period was 843.23mm which is projected to increase in all NF and FF of both scenarios. But the mean increase in precipitation is more in RCP4.5 scenario as compared to RCP8.5. The south-east region of the Mahi basin will be more vulnerable as compared to other regions.
- Annual Maximum temperature in Mahi River basin is projected to increase by 1.41°C and 2.94°C under RCP4.5 and RCP8.5 by the end of this century.
- Annual mean temperature is projected to increase two times of annual maximum temperature. It is projected to increase up to 2.30°C (4.87°C) under FF of the RCP4.5 (RCP8.5) scenario.
- Annual mean precipitation in AID is projected to increase by 57.05mm (NF) and 61.55mm (FF) under the RCP4.5 scenario. The south-east region of AID will have a maximum rise in precipitation under the RCP8.5 scenario.
- Annual maximum temperature is projected to increase by 2.34°C (4.56°C) in the FF of RCP4.5 (RCP8.5) scenario. The upper central regions of AID will have a maximum rise in temperature. The annual minimum temperature is projected to increase by 2.21°C (4.46°C) in FF of RCP4.5 (RCP8.5) as the maximum in central regions of AID.
- Time series analysis of annual mean precipitation in the Mahi River basin and AID represents a decrease in rainfall during FF of both RCPs.

Reservoir operation policy performance evaluated using reliability, resilience, vulnerability, shortage index and modified shortage index. Here we have used six operation policy with changing the irrigation demand by increasing demand from 10% to 50%. Using the above six operation policy we have simulate the reservoir system with four climate change scenarios to analyse the performance of multi reservoir systems. Our main conclusions for multi reservoir operation are the following:

- The reliability for Mahi Bjaaj Sagar reservoir and Panam reservoir is remain 100 % for all the operational policies. But for Kadana reservoir system reliability will deteriorate from 83.6% to 64.7% in the future under all the RCP scenarios. Thus, mitigation measures become key to ensuring an adequate reservoir system's performance during the next decades.
- The resiliency for Mahi Bjaaj Sagar reservoir and Panam reservoir remains 100 % for all the operational policies. But for Kadana reservoir system resiliency will deteriorate from 38.4% to 22% in the future under all the RCP scenarios. The worst scenario among the four scenarios is RCP 8.5 in case of the resiliency of the systems.
- The above study shows that Mahi Bajaj Sagar reservoir and Panam reservoir are not vulnerable for all the all the operational policies. But for Kadana reservoir system vulnerability will remain 100% in the future under all the RCP scenarios.
- There is no shortage in terms of water allocation for both Mahi Bjaaj Sagar reservoir and Panam reservoir remains all the operational policies. But for Kadana reservoir system shortage index will deteriorate from 2.1% to 7.5% in the future under all the RCP scenarios. The worst scenario among the four scenarios is RCP 8.5 in case of the shortage index of the systems.
- There is no shortage in terms of water allocation for both Mahi Bjaaj Sagar reservoir and Panam reservoir remains all the operational policies. But for Kadana reservoir system modified shortage index will deteriorate from 13.7% to 28.9% in the future under all the RCP scenarios. The worst scenario among the four scenarios is RCP 8.5 in case of the modified shortage index of the systems
- The impacts of climate change on reservoir inflows also increase moving toward 2100, and so are the impacts on reservoir performance. These results indicate that measures for climate change adaptation should be implemented soon to avoid socio-economic impacts. The above study has been done using Standard operation policy (SOP) and we have done simulate the three reservoirs with different operation policies with four

climate change scenarios. The above results concluded that the worst scenarios are RCP 8.5 for future and RCP 8.5 near future.

13. Reference

1. Sahu, M., Lahari, S., Gosain, A.K. and Ohri, A., 2016. Hydrological Modeling of Mahi Basin Using SWAT. *Journal of Water Resource and Hydraulic Engineering*, 5, pp.68-79.
2. Chow V T, D R Maidment and L W Mays (1988), *Applied Hydrology*, Megraw Hill, 572 p
3. Ayivi, F. and Jha, M.K., 2018. Estimation of water balance and water yield in the Reedy Fork-Buffalo Creek Watershed in North Carolina using SWAT. *International Soil and Water Conservation Research*, 6(3), pp.203-213.
4. Swat Mannual, Version 2012
5. Harmonized World Soil Database v 1.2
6. Storm Water Management Model User's Manual Version 5.1, 135 p
7. U.S. Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, title 430-VI. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242 (accessed day month year).
8. <http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/en/>
9. Yacoub, C. and Foguet, A.P., 2012. Slope effects on SWAT modeling in a mountainous basin. *Journal of Hydrologic Engineering*, 18(12), pp.1663-1673.
10. Le, T., Al-Juaidi, F. and Sharif, H., 2014. Hydrologic simulations driven by satellite rainfall to study the hydroelectric development impacts on river flow. *Water*, 6(12), pp.3631-3651.