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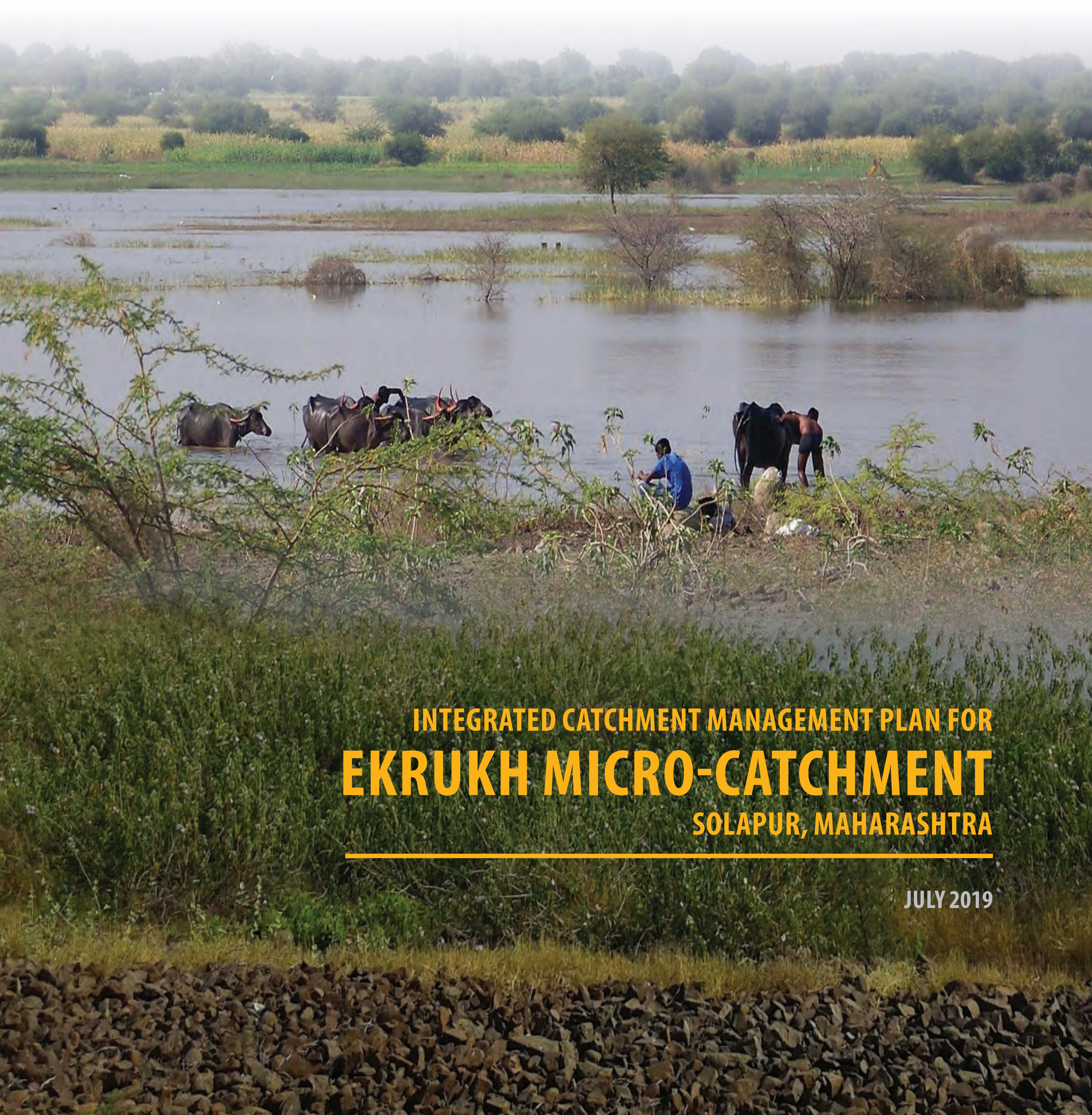

INTEGRATED CATCHMENT MANAGEMENT PLAN FOR EKRUKH MICRO-CATCHMENT

SOLAPUR, MAHARASHTRA

JULY 2019

Title

Integrated Catchment Management Plan for Ekrukh Micro-Catchment, Solapur, Maharashtra

Under the Project

Integrated Rural Urban Water Management for Climate Based Adaptations in Indian Cities (IAdapt)

Supported by

International Development Research Centre (IDRC), Canada

Project Consortium

- ICLEI – Local Governments for Sustainability, South Asia
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Disclaimer

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Abbreviations

ACCCRN	-	Asian Cities Climate Change Resilience Network
AMR	-	Automatic Meter Reading
AMRUT	-	Atal Mission for Rejuvenation and Urban Transformation
BAU	-	Business As Usual
BCM	-	Billion Cubic Meters
BGL	-	Below the Ground Level
BOD	-	Biological Oxygen Demand
CMP	-	Catchment Management Plan
COD	-	Chemical Oxygen Demand
DEWATS	-	Decentralised Wastewater Treatment Systems
GHG	-	Greenhouse Gas
GIS	-	Geographical Information Systems
GoI	-	Government of India
GWB	-	Ground Water Board
IAdapt	-	Integrated Rural Urban Water Management for Climate Based Adaptations in Indian Cities
IAM	-	Integration Assessment Matrix
IAP	-	ICLEI ACCCRN Process
ICT	-	Information and Communications Technology
IEC	-	Information Education Communication
IMD	-	India Meteorological Department
IPCC	-	Intergovernmental Panel on Climate Change
IUWM	-	Integrated Urban Water Management
IWRM	-	Integrated Water Resource Management
lpcd	-	Litres per capita per day
MIDC	-	Maharashtra Industrial Development Corporation
MLD	-	Million Litres per Day
MPL	-	Minimum Permissible Limit
MW	-	Megawatts
NGO	-	Non-Governmental Organisation
NRW	-	Non Revenue Water
PHED	-	Public Health Engineering Department
RURBAN	-	Rural Urban
RWH	-	Rain Water Harvesting
SCADA	-	Supervisory Control and Data Acquisition
SLDs	-	Shared Learning Dialogues
SMC	-	Solapur Municipal Corporation
SUDS	-	Sustainable Urban Drainage Systems
SWOT	-	Strengths, Weaknesses, Opportunities, and Threats
T&D	-	Transmission and Distribution
TEEB	-	The Economics of Ecosystems and Biodiversity
WEAP	-	Water Evaluation And Planning

1. Executive Summary

Integrated Water Resource Management (IWRM) is an approach that considers water management and planning at catchment level taking into account the water demand and supply gap and the interactions of water sector with wastewater, storm water as well as other related sectors like solid waste, groundwater systems, land use and livelihood. Climate impacts on the existing water resources can also greatly alter available resources. In this context, a climate adaptive integrated Catchment Management Plan (CMP) has been developed for the Ekrukh Micro-Catchment in Solapur, Maharastra, covering the city of Solapur and three villages – Tale Hipparga, Haglur and Ekrukh-Taratgaon.

To develop the catchment management plan, the IAdapt Framework toolkit has been used, which assists rural and urban local governments to come together and formulate micro-catchment level water management plans guided by the principles of integrated water resource management and giving due consideration to climate change.

Solapur district is located in a drought-prone area of Maharashtra. The district faces water stress due to increasing water demand from urban centers and the agriculture sector. The plan focuses on the vulnerability of residential areas, the efficiency and adequacy of the water infrastructure and considers the demand from agriculture as well. Due to the jurisdictional limitations for the city and village local authorities in decision making, two core teams were developed – one each at the urban level and one at the rural levels – to proceed with the implementation of the framework. A RURBAN platform was formulated, where both rural and urban stakeholders were brought together to discuss the common issues. The resilience interventions for water management were formulated, keeping in mind the jurisdictional restrictions.

Using a GIS software based hydrological model, four micro-catchments were delineated and out of these, one micro-catchment was selected through assessment of information and data on various social, environmental, economic and ecological parameters using Focus Group Discussions, quadrat studies and key personnel interviews. The Micro-catchment S3 (Ekrukh micro-catchment) was selected through this process.

Baseline data on various parameters like demography, socio-economics, basic services and water resources has been collected at the catchment level from both villages and Solapur city.

As per the 2011 Census, the population in Ekrukh Catchment was 9,59,997 (three villages and one city) There were approximately 1,659 households in three villages with a population of 8,439 as per the 2011 Census, while Solapur city had a population of 9,51,558, as of 2011. The economic base of the region is grounded in the textile industry. The cooperative sugar factory, brick factories and *beedi* factory also contribute to the city economy. The region is considered to be drought-prone, but the major cash crop is sugarcane, which is a water-intensive crop. All these industries and agriculture

Ekrukh Lake is the largest artificial lake, located in Tale Hipparga village, close to Solapur city. The reservoir has a total capacity of 3,330 M.Cu.Ft. The total catchment area of the reservoir is 411.81 sq.km. Besides water for irrigation and domestic use in villages, Ekrukh Lake supplies drinking water to Solapur city and is one of the city's major water resources. The entire Solapur district is part of the Bhima and Sina river basins. Ekrukh and Hotagi are the two major lakes located outside the Solapur city boundary, while there are three major lakes within the city.

The baseline assessment identified issues with both the water quality and the water availability in the micro-catchment. Climate risks are important factors that will exacerbate these issues.

The climate change vulnerability of the Ekrukh micro-catchment was assessed to understand the impacts of precipitation and temperature variations on systems like water supply, wastewater, solid waste, agriculture and health. The main climate risks considered for the purposes of this CMP, based on the detailed city specific study conducted by IIT Madras and based on the observations of the RURBAN Platform members, are:

- Climate risk 1: Increased temperature;
- Climate risk 2: Decreased rainfall and changing rainfall patterns, leading to more droughts

A water balance exercise was conducted in the Ekrukh micro-catchment (urban and rural areas) to assess the existing water demand and supply gap. This helped to identify alternative pathways to reduce the demand-supply gap and to move towards a balanced approach for using water resources without or with little additional water abstraction.

The existing average water supply of Solapur city is 168 MLD (including bulk usage and groundwater) against the demand of 224 MLD, resulting in a 56 MLD demand-supply gap, which increases to 84 MLD in peak summer (because only one source out of three is perennial). Considering the population growth trends, in 2031, the demand-supply gap will be 36 MLD even after considering a new water supply line of about 80 MLD from Ujjani Dam (that was already approved by state government at the time of the study). The average water abstraction from the 3 villages is around 698.18 KLD against the demand of 646.13 KLD, resulting in 52050 litres/day of surplus abstraction. This surplus abstraction is mainly because of operating procedures like continuous and prolonged abstraction as per the availability of electricity, storage in open wells leading to evaporation and percolation losses, and transmission and distribution losses. A business-as-usual scenario, coupled with the population trends, suggests that by 2031, these villages will face an average demand-supply gap of about 70 KLD.

The Integration Assessment Matrix (IAM) was used to assess the existing level of integration among various departments and sectors related to water. The results are given below.

Integration Assessment Matrix (IAM) Summary

IAM Final Score	23
Existing status of integration in the city (Excellent, Good, Average, Poor, Critical)	Average
Weaknesses	Water portfolio, water pollution, water resources, climate change, capacity building
Strengths	Wastewater strength, SWM
Quick Improvement Areas	Wastewater management, Solid waste
Focus Issues	Water and Energy, Wastewater Management, Stormwater/ Natural Drainage System, Holistic Solid Waste Management and Agriculture

The fragile systems that have been identified through the IAM were then assessed in detail to understand their existing fragility and possible impacts due to the above-identified climate risks. The fragile systems and their climate fragility statements, were assessed for their likelihood and consequence to get their risk assessment for both urban and rural areas. Finally, the vulnerable areas and populations impacted by this fragility are identified for a climate vulnerability assessment. The results of the assessment are given below.

Urban System Analysis

System	Fragility Statement	Climate Fragility Statement
Water Supply	Water supply in the city is unable to meet the demand, because of a poor distribution system, physical leakages, and high NRW, particularly in extension areas. In villages, the water supply comes from the Ekrukh lake that faces water pollution from sewage/sullage/ industrial waste (textiles), impacting health. Water conservation practices are poor, impacting available resources.	Decreased precipitation could result in greater stress on available water resources in future. Sudden high-intensity rainfall can damage old and weak distribution systems and lead to more losses that can reduce amount of water available for use.
		Higher temperatures create greater stress on water resources.
Wastewater	The wastewater system is under renovation and does not cover the entire city. Villages have no centralised wastewater management systems, resulting in the pollution of the lake water.	Lower rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm the plants and lead to overflow and failure of treatment system, impacting health of citizens.
		Higher temperatures can reduce efficiency of plants, and lead to odour and health issues.
Stormwater Drainage	Stormwater drainage in villages is blocked, while in cities, the nallahs are linked to the rivers, causing pollution.	Sudden high-intensity rainfall can cause overflow in stormwater drains, can dilute pollutants, cause greater runoff without recharge, and lead to waterlogging.
		Higher temperatures can lead to reduced water availability for animals in open wells.
Solid Waste Management	Solid waste management is poor in the villages, and can cause water pollution as well as issues in stormwater drainage.	With higher temperatures and drier climate, openly dumped waste can spread in the area, causing littering
Agriculture	The major crop is water intensive and creates great stress on the resource.	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity
		Less rainfall and higher temperatures can create greater demand for water, which will impact crop production and reduce water available for drinking, impacting rural economy.
Health	The water quality of the lake is impacted due to release of wastewater and effluents, and this can cause health issues.	Short-duration high-intensity rainfall can dilute pollutants and improve water quality in the lake, reducing negative health impacts
		Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health

The vulnerability assessment details of the rural and urban areas are given in tables below:

Vulnerability Assessment – Rural

Urban Systems	Climate Fragility Statement	Vulnerable Area			Vulnerable Actors
		Hipparge	Haglur	Ekrukh	
Water Supply	Decreased precipitation could result in greater stress on available water resources in future. Sudden high-intensity rainfall can damage old and weak distribution systems and lead to more losses that can reduce amount of water available for use. Risk - Medium	The pipeline in wards 1, 2 and 3 is more than 30 years old. In ward 4, Gadhar Nagar, Samata Nagar, Manthalkar Basti, Dalaway Nagar, Swami Samarth Nagar and Balgargi Nagar have no water supply	Ward 3; area with number 40	Jahangir Colony, Patel Gali	Farmers Poor people Children Elderly Gram panchayat Collector's office Zila Parishad/ Panchayat Samiti Irrigation department Horticulture Animal rearers
	Higher temperatures put greater stress on water resources Risk - Extreme			Jamadar Colony, Hodkar Gali	

Urban Systems	Climate Fragility Statement	Vulnerable Area			Vulnerable Actors
		Hipparge	Haglur	Ekrukh	
Wastewater	Higher temperatures can reduce efficiency of plants, and lead to odour and health issues. Risk - High	Ward 1- Joshi Gali, Ekta Nagar and near Sonawe Batta; ward 2-Bhiku Udan Shive	Junction of areas with number 2, 4 5, 176, 177		Residents in low-lying areas - poor people Women (washing clothes) Gram Panchayat Zila Parishad
Stormwater Drainage	Higher temperatures can lead to reduced water availability in open wells for animals. Risk - Extreme		Junction of areas with number 2, 4 5, 176, 177		Gram panchayat, elderly, women, animals
Solid Waste Management	With higher temperatures and drier climate, openly dumped waste can spread in the area, causing littering Risk - High			Javed Molani Chowk	Gram panchayat, children, elderly, women
Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity Risk - Medium Higher temperatures can cause greater demand for water, which will impact crop production and increase drinking water shortage, impacting rural economy Risk – Extreme	All farmlands	All farmlands	All farmlands	Farmers Poor people children elderly Gram panchayat Collector's office Zila Parishad/ Panchayat Samiti Irrigation department Horticulture Animal rearers
Health	Short-duration high-intensity rainfall can dilute pollutants and improve water quality in the lake, reducing negative health impacts Risk – Medium Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health Risk – Extreme	Ward 2- Ekta Nagar; ward 5- Manthalkar Basti		Dalit Basti	Poor people, elderly, children, gram panchayat

Vulnerability Assessment – Urban

Urban Systems	Climate Fragility Statement	Areas	Actors
Water supply	Decreased precipitation could result in greater stress on available water resources in future. Sudden high-intensity rainfall can damage old and weak distribution systems and lead to more losses that can reduce amount of water available for use. Risk – Medium	7, 8, 34, 35, 36, city extension areas	Slum dwellers, poor people, irrigation department, PHE, SMC, women
	Higher temperatures create greater stress on water resources. Risk - Medium	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	
Wastewater	Lower rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm plants and lead to overflow and failure of treatment system, impacting health Risk – Medium	8,13,14,33,15, 25, 24 (wastewater drains are silted), 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2 (no wastewater drains)	SMC, urban poor, slum dwellers

Urban Systems	Climate Fragility Statement	Areas	Actors
	Higher temperatures can reduce efficiency of plants, and lea`d to odour and health issues. Risk - High	41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2	
Storm water drainage	Sudden high-intensity rainfall can cause overflow in stormwater drains, dilute pollutants, cause greater runoff without recharge, and lead to waterlogging. Risk – High		
	Higher temperatures can lead to less availability of water in open wells for animals. Risk – High		
Solid Waste Management	Higher temperatures and drier climate can cause openly dumped waste to spread in the area, causing littering Risk – Low	City extension areas	SMC, slum dwellers, urban poor, children, elderly
Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity Risk – Low Lower rainfall and higher temperatures can cause greater demand for water, which will impact crop production and reduce drinking water availability, impacting rural economy. Risk – High	City extension areas- Basleswar Nagar, Degaon, Dehetne, Soregoan, Kegaon, 10, 48, 3, 9	Agriculture dept., APMC, farmers, urban poor

A list of interventions has been identified based on IUWM and climate resilience indicators to address and reduce the vulnerability of the water sector, particularly for the vulnerable areas and actors identified above. Solution assessment includes strategies best suited to address all identified vulnerable sectors, actors and areas, to build resilience and achieve sustainability in the catchment.

The resilience potential of the interventions were assessed in terms of their ability to increase the redundancy and flexibility of the water system, improve the ability of the system to respond to climate stresses and improve access to information on climate impacts and responses to climate stress. The IWRM potential of each intervention was assessed in terms of their potential to integrate all parts of the water cycle, consider various requirements for water, and take into account the local context and requirements of all stakeholders. Each of the interventions were also analysed in terms of their technical, socio- political and financial feasibility, as well as their timeframe. Both the duration in which the impact of the intervention can be felt and the criticality of the intervention in reducing water stress was assessed.

The potential list of interventions for Ekrukh micro-catchment, along with their overall prioritisation score, techno-economic feasibility, and impact in terms of time required for implementation and criticality, and tentative cost estimates is listed in table below:

List of Interventions

Interventions and Solutions	Vulnerable places	Target populations	Overall Prioritisation Score	Feasibility T - Technical P - Political F – Financial (high/ medium/ low)	Impact – Timeframe (short/ medium/long term)	Impact - Criticality (high/ medium/ low)	Tentative Cost Estimate
URBAN							
Water							
Leak detection systems to reduce T&D losses	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Citizens of extension areas, PHE, SMC, women	5	T – High P – High F – Low	1 to 5 years Medium Term	High	20,00000-50,00000/ ward
Construction of RWH pits in waterlogged areas	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Urban poor people, PHE, SMC, women	8	T – High P – High F – Medium	Within one year-Short Term	Medium	500000-1000000/ RWH Pit
Recharge local borewells through rainwater harvesting	city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Urban poor people, PHE, SMC, women	8	T – High P – High F – Medium	1 to 5 years Medium Term	High	Cost between Rs 2,0000 to Rs 5,00,000 for buildings of about 200 sq. m area.
Awareness generation programmers through IEC activities and documentary films by involving youth, NGOs and local institutes	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Slum dwellers, poor people, PHE, SMC, women	6	T – High P – High F – High	Within one year-Short Term	Medium	10,000-50,000/ ward Depending upon number of households
Waste Water							
Reuse of treated wastewater for local parks	Ward 8,13,14,33,15, 25, 24 (wastewater drains are silted),	SMC, urban poor, slum dwellers	7	T – Medium P – High F – Low	Short term	High	20,00000-50,00000/ ward
Community-level DEWATS systems	Ward 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2	SMC, urban poor, slum dwellers	6	T – High P – High F – Medium	Medium term	High	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Promotion of urban agricultural through grey water reuse	Ward 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2 (no wastewater drains)	SMC, urban poor, slum dwellers, urban farmers, migrant population	6	T – Medium P – Low/Medium F – Low	Long term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Stormwater Drainage							
Sustainable urban drainage systems: (SUDS)-based systems for a Integration of natural sponges in city design	Ward 8,13,14,33,15, 25, 24 (wastewater drains are silted)	SMC, urban poor, slum dwellers, urban farmers, migrant population	5	T – High P – Medium F – Medium	Long term	High	160822.2 to 210000 (based on type of system /sources)
Stormwater runoff storage and diversion to local ponds /park,	City extension areas, old Solapur (near Siddeshwar Lake)	SMC, urban poor, slum dwellers, local Residents and local business men	6	T – Medium P – Medium F – Medium	Long term	High	

Interventions and Solutions	Vulnerable places	Target populations	Overall Prioritisation Score	Feasibility T - Technical P - Political F – Financial (high/ medium/ low)	Impact – Timeframe (short/ medium/long term)	Impact - Criticality (high/ medium/ low)	Tentative Cost Estimate
Revival of streams using RWH and bio filters, to reuse water for urban greenery	City extension areas, old Solapur (near Siddeshwar Lake)	SMC, urban poor, slum dwellers, local Residents and local business men	4	T – High P – Low/Medium F – Medium	Medium term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Solid Waste Management							
Improve the institutional capacity and management for 100 % waste collection	City	SMC, local contractors	4	T – High P – High F – Low	Short Term	Medium	20,00000-50,00000/ ward
Decentralized plastic waste collection for revenue	Javed Molani Chowk	SMC, Local slum dwellers	0	T – Medium P – Medium F – Low	Short Term	Low	100000-500000/ ward Depending upon number of households
Health							
Management plan for heat strokes and awareness activities to reduce the impacts	City	SMC, Local slum dwellers, Industrial workers	2	T – High P – Medium F – Low	Short Term	Low	20,0000, 50,0000/ ward
Identification of "hot spots" and development of a Heat Action Plan for the city	City	SMC, Local slum dwellers, Industrial workers	2	T – High P – Medium F – Low	Short Term	Low	20,0000, 50,0000/ ward
Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes ('Catch them young')	City	SMC, Local slum dwellers, Industrial workers	7	T – High P – Medium F – Low	Short Term	Medium	20,0000, 50,0000/ ward
Institutional wisdom: Building Institutional wisdom at local level to ensure integration across sectors in future by training Municipal Engineers in using modernized systems of water and wastewater management	City	SMC, Local slum dwellers, Industrial workers	8	T – High P – High F – Medium	Short Term	Medium	40,0000, 60,0000/ ward
RURAL							
Water Supply							
Groundwater recharge through rainwater harvesting,	Local Borewell, Wells	Framers, Poor,	8	T – High P – High F – Medium	Medium term	High	Approximate cost between Rs 2,0000 to 5,00,000 for buildings of about 200 sq. m.
One water ATM at a school or panchayat ghar in each village	Tale Hipparaga, Haglur, Ekrukh		1	T – High P – Medium F – Low	Short Term	Medium	300000 to 500000/ machine

Interventions and Solutions	Vulnerable places	Target populations	Overall Prioritisation Score	Feasibility T - Technical P - Political F – Financial (high/ medium/ low)	Impact – Timeframe (short/ medium/long term)	Impact - Criticality (high/ medium/ low)	Tentative Cost Estimate
Wastewater							
Construction of soak pits to reuse wastewater for secondary purposes	Hipparaga (Ekta Nagar, Samata Nagar, Joshi Galli, Manthalkar Wasti, Datt Nagar), Haglur(Ward No. 1, 2, 3) Ekrukh (Jahangir colony, Patel Galli, Holkar Galli, Jawed Mulani Chowk, Jamadar Galli)	Poor, Dalit	8	T – High P – Medium F – Low	Medium term	Medium	Approximately 20,000 to 50,000 /pit, based on material and filter technology used
Promotion of eco-sa nitation			2	T – High P – Medium F – Medium	Medium term	Low	Approximately 50,000 to 200000 / toilet
Stormwater							
Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ek rukh	Hipparaga (Ekta Nagar, Samata Nagar, Joshi Galli, Manthalkar Wasti, Datt Nagar), Haglur (Ward No. 1, 2, 3) Ekrukh(Jahangir Colony, Patel Galli, Holkar Galli, Jawed Mulani Chowk, Jamadar Galli)	Poor People, Dalit	7	T – High P – Low/Medium F – Medium	Medium term	Medium	160822.2 to 210000 (based on type of system /sources)
Revival of streams using RWH and bio filters, to reuse water for urban greenery	Ekta Nagar, Joshi Galli, Near to Bhikha Udanshiuve House, Ward No(1, 2) Jahangir Colony, Jawed Mulani Chowk	Poor, Children,	4	T – High P – Low/Medium F – Medium	Medium term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Bio-remediation at inlet points around the Ekrukh lake			7	T – Medium P – Low/Medium F – Low/Medium	Long term	Medium	5,00000 to 1500000 depending upon bio filtration method and number of constructed wetlands
Identification of potential borewells for aquifer recharging	Near to Ekrukh Lake	Farmers	6	T – High P – High F – Low	Medium term	High	160822.2 to 210000 (based on type of system /sources)
Solid Waste Management							
Implementation of segregated waste collection system.	In Tale Hipparaga, Haglur, Ekrukh Villages	BPL	4	T – High P – High F – Medium	Medium term	low	58,000 to 70,000 depending upon number of households and density of population
Decentralized composting in villages			3	T – High P – High F – Low	Short Term	low	15000 to 25000/ compost bed - vermicomposting

Interventions and Solutions	Vulnerable places	Target populations	Overall Prioritisation Score	Feasibility T - Technical P - Political F – Financial (high/ medium/ low)	Impact – Timeframe (short/ medium/long term)	Impact - Criticality (high/ medium/ low)	Tentative Cost Estimate
Agriculture							
Water-efficient pu mps	All farmlands	Farmers, Poor	5	T – High P – High F – Medium	Short Term	Medium	Approximately 1,80,000 to 4,00,000/piece (solar pumps)
Decentralized wastewater treatment and use of treated wastewater for agriculture	All farmlands	Farmers, Poor	5	T – High P – Medium F – Low	Medium term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Low water-intensive crops to improve agriculture production	All farmlands	Farmers, Poor	5	T – Medium P – Medium F – Medium	Long term	High	Depending upon the seed quality and availability

The action plan for Ekrukh micro-catchment needs to be monitored during implementation and evaluation. This is possible by using the RURBAN Platform members, who would ensure an integrated implementation as both rural and urban stakeholders are present in the Platform.

The RURBAN Platform stakeholders can monitor the effectiveness of the plans in achieving their stated objectives and in delivering the outcomes that will underpin the rationale for the action plan. A monitoring procedure will include reporting on the plan and updates on the implementation of the action plan. It is proposed that the reporting should be done by a nodal officer at the rural level and the urban local authority who is responsible for implementation of water-related work in the region. If needed, a team may be formulated in the rural and urban local authorities for such reporting.

An annual discussion with the RURBAN Platform is proposed to understand the impact and effect of the implementation.

2. Introduction

Changes in key climate variables, such as temperature, precipitation and humidity, may have significant long-term implications for the quality and quantity of water. In addition, with increasing population and urbanisation, there is immense stress on water utilities. India, with a population of over 1.2 billion people (more than 17% of the world population), of which 31.16% (377 million)[1] live in urban areas, is increasingly facing water scarcity. Estimates by the Planning Commission state that India has a total utilisable water potential of 1,123 Billion Cubic Meters (BCM) (out of a total of 1869 BCM[2], which appears as average annual potential flow in rivers, only 1123 BCM is utilizable water due to topographic constraints and distribution-related factors)[3]. Out of the total utilisable water, 690 BCM (61.44%) is from surface water sources and 433 BCM is available in the form of groundwater (38.5%)[4].

The average annual per capita water availability in 2001 and 2011 was assessed at 1,820 cubic meters and 1,545 cubic metres, and projections are that this could reduce further to touch 1,341 cubic meters and 1,140 cubic meters by 2025 and 2050, respectively. Indian cities are under ever-increasing pressure to ensure the availability and quality of drinking water supply. By 2050, the total demand for water in India is expected to rise from 937BCM to 1,180 BCM. Agriculture (70%), followed by households (9%) and industries (7%) will claim the maximum shares of the projected demand[5].

Hence, protecting the water resources and ensuring sustainable supply is one of the priority development agendas at the national and local levels. The management and protection of the water catchments from where the water is drawn and promoting a water nexus should be at the heart of all smart city planning and regional development plans. But, currently, water management remains limited to the treatment of wastewater and 24*7 water supplies in the government's smart cities strategy. With the changing climate scenarios and demographic profiles of urban areas, a catchment-based approach is needed to ensure that maladaptation is avoided. No city or village can be considered in isolation, and therefore, a collaborative approach should be adopted while planning and designing water schemes.

Integrated Water Resource Management (IWRM) is an approach that considers water management and planning at catchment level considering the integration of water demand and supply and considers the water sector along with its interactions with wastewater, stormwater as well as other related sectors like solid waste, groundwater systems, land use and livelihood. Climate impacts on the existing water resources can also greatly alter available resources. In this context, an integrated Catchment Management Plan has been developed for the Ekrukh Micro-Catchment in Solapur, Maharastra, covering the city of Solapur and three villages – Tale Hipparga, Haglur and Ekrukh-Taratgaon.

2.1. About the Project

The catchment management plan for Solapur city has been developed by ICLEI South Asia in partnership with Athena Infonomics LLC, International Water Management Institute (IWMI) and Indian Institute of Technology, Madras (IITM), under the aegis of the Integrated Rural Urban Water Management for Climate-based Adaptations in Indian Cities (IAdapt) Project. The project is funded by International Development Research Centre, Canada (IDRC). The overall objective of the project is to institutionalise climate change adaptation in

1. Census of India 2011 (a), available at http://censusindia.gov.in/2011census/censusinfodashboard/index.html, accessed in July 2014
2. For precipitation, including snowfall, this is the availability from surface and ground water
3. Report on the Expert Group on Ground Water Management and Ownership, 2007, Planning Commission, Government of India, available at http://planningcommission.nic.in/reports/genrep/rep_grndwat.pdf, accessed in July 2014
4. Annual Report, 2016-2017, Central Water Commission , Ministry of Water Resources, River Development and Ganga Rejuvenation
5. Central Water Commission (CWC) – Ministry of Water Resources, River Development and Ganga Rejuvenation

water resource planning and catchment-level policies by implementing climate-adaptive Integrated Urban Water Management approaches through participatory planning, simple decision support tools and catchment management plans. Cities are not closed systems and the Catchment Management Plan (CMP) is an initiative to bring rural and urban authorities and communities together to manage and secure their common water resources.

2.2. Methodology – IAdapt Framework

To develop the catchment management plan for the selected micro-catchment area, the IAdapt Framework toolkit has been used. The IAdapt Framework is designed to assist rural and urban local governments to come together and formulate micro-catchment level water management plans, guided by the principles of integrated water resource management and considering climate risks. The IAdapt framework is based on the ICLEI Asian Cities Climate Change Resilience Network (ACCCRN) Process or IAP toolkit, the Adopting Integrated Urban Water Management toolkit (AdoptIUWM toolkit) and The Economics of Ecosystems and Biodiversity (TEEB) methodology for ecosystem assessment. The full framework is attached as Annex 1.

The IAdapt framework promotes an integrated approach to ensure water security, by looking at the interactions and interdependencies among water, wastewater and stormwater with other sectors such as health, agriculture, solid waste and industry. It brings together different administrative, planning and regulatory systems by creating a RURBAN platform that includes both rural and urban stakeholders at various levels, such as local authorities as well as civil society.

IAdapt Framework has five stages:

Phase 1 Engagement Phase – In this phase, local authorities can gain necessary political and administrative support by forming a RURBAN Platform that includes stakeholders from both rural and urban local governments, as well as other stakeholders such as civil society, media and institutions. A core team is also formed to be able to carry out the activities under the study.

Outcome

- RURBAN platform is formed
- Core team is set up

Phase 2 Baseline Assessments – In this phase, basic information about the micro-catchment like socio-economic characteristics, agricultural resources, water resources, land use, basic service provision and governance are identified through extensive data collection that is verified later through Shared Learning Dialogues or SLDs conducted with the core team and the RURBAN platform formulated earlier.

Outcome

- Identification of priority issues relating to water in the micro-catchment

Phase 3 Vulnerability Assessments – In phase 3, a climate change and socio economic vulnerability assessment is conducted to understand the challenges that may be faced by the water resources in the micro-catchment due to climate change. A water balance study is conducted to understand the demand-supply gap in current and future scenarios and an assessment is done to identify the strengths and weaknesses of the water sector and its level of integration with other sectors. Through SLDs, vulnerable areas and actors are identified and all data collected so far is verified.

Outcome

- Identification of vulnerable sectors, vulnerable areas and actors
- Level of integration among water, wastewater and stormwater sectors
- Priority sectors identified for improvement

Phase 4 Solution Assessment – In this phase, a set of potential interventions are identified to address the vulnerabilities, and prioritised based on various aspects of IWRM and climate resilience. Future scenarios are developed through Water Evaluation And Planning (WEAP) modeling and a decision support tool is used to identify measures to make the interventions more climate-adaptive. The interventions are also linked to existing plans of the government.

Outcome

- List of prioritised solutions.

Phase 5 Development of Catchment Management Plan and Monitoring Framework – An integrated micro-catchment management action plan is developed along with a monitoring framework to ensure transparency and sustainability.

Outcome

- Catchment Management Plan and Monitoring Framework

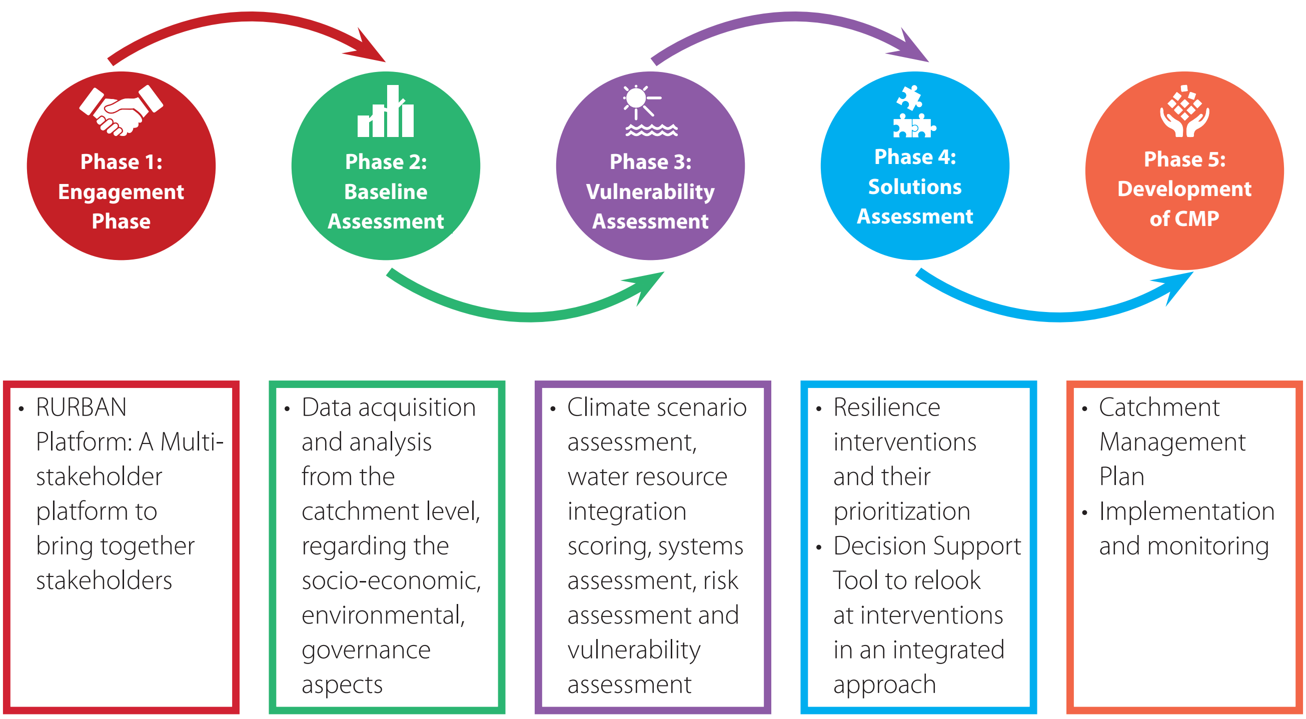

Figure 1: IAdapt Framework

3. IAdapt implementation in Ekrukh Micro-Catchment, Solapur

Solapur district is located in a drought- prone area of Maharashtra. The district faces water stress due to increasing water demand from urban centers and the agriculture sector. The Catchment Management Plan focuses on the vulnerability of residential areas, the efficiency and adequacy of the water infrastructure and considers the demand from agriculture as well. Due to the jurisdictional limitations for the city and village local authorities in decision making, two core teams were developed – one each at the urban level and one at the rural levels – to proceed with the implementation of the framework. A RURBAN platform was formulated, where both rural and urban stakeholders were brought together to discuss the common issues. The resilience interventions for water management were formulated, keeping in mind the jurisdictional restrictions.

3.1. Selection of Ekrukh Micro-Catchment

To initiate the preparation of the CMP, the first step was to delineate the geographic boundaries of the catchment areas in and around Solapur city. The catchments were delineated using a GIS software based hydrological model. The catchment-mapping exercise was carried out to identify the different micro-catchments lying within the study area for Solapur, using Digital Elevation Models (DEM). The watershed basin analysis was carried out on the GRASS GIS programme to identify potential micro-catchments.

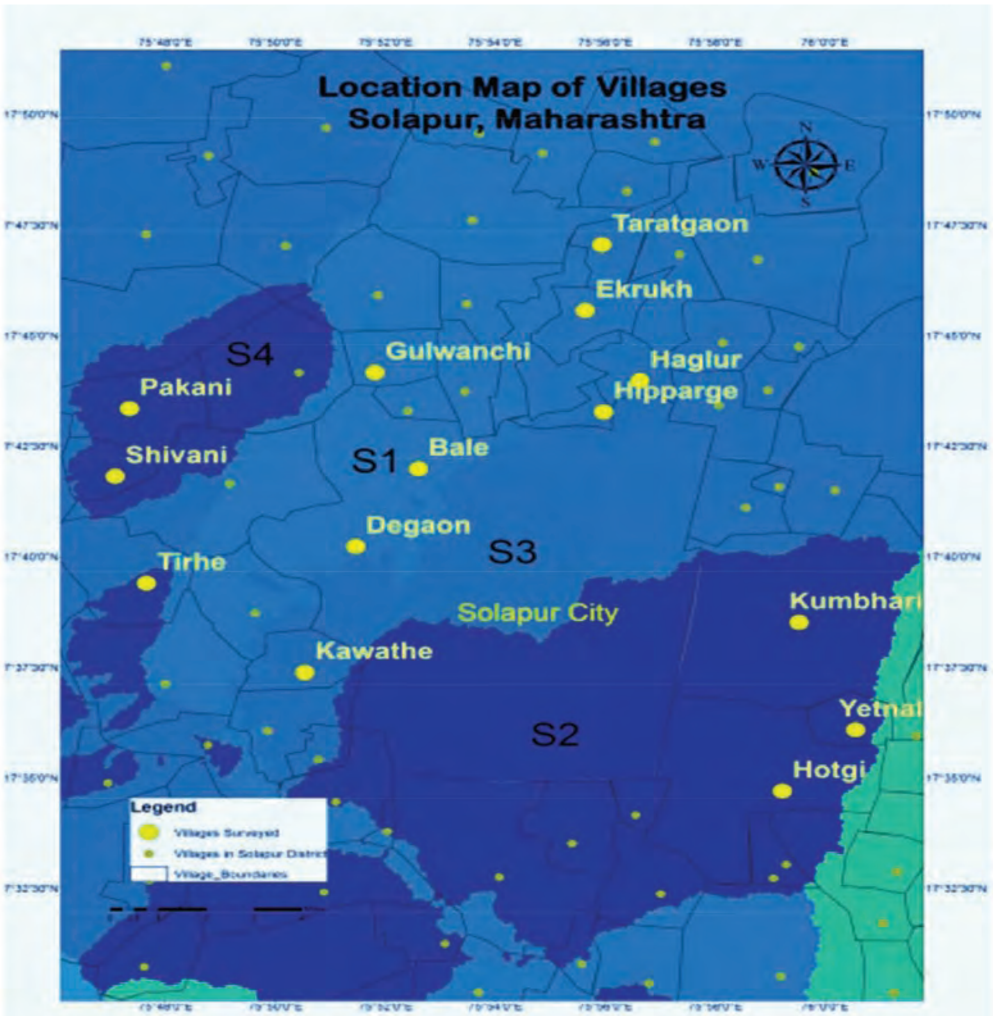

Figure 2: Delineation of Micro Catchment in Solapur

The following parameters were considered for the catchment delineation:

- The urban jurisdiction areas covered by the existing water supply system.
- The additional areas from which stormwater is likely to enter the city and the natural sinks that receive the stormwater from the city (ponds, lakes, tanks etc.).
- The potential peri-urban and rural agricultural areas that use wastewater from the city for irrigation, with complete mapping of the canals carrying wastewater, the area irrigated and the crops.
- The agricultural areas (villages) and peri-urban areas that consume groundwater.

The outcome from the study was a basin map, with four major micro-catchments containing unique identifiers for each watershed basin within the study area.

To select one micro-catchment area for the study, Focus Group Discussions, quadrat studies and key personnel interviews were conducted to collect information and data on various social, environmental, economic and ecological parameters from the villages and the city within the delineated four micro-catchments. The team visited about 14 villages in the four micro-catchment areas. The data collected for all the delineated micro-catchments in Solapur included local profile, demography, land tenure and land use, livelihood patterns, socio-economic conditions, environmental aspects, water resources, basic services and climatic and socio-environmental changes over the years. Community perceptions and requirements for micro-catchment conservation, the community attitude to such work (willingness to participate, capacity to participate etc.) were also assessed. Information on water management and governance issues, watershed services and ecosystem services, vulnerable population and exposure to natural calamities was also analysed. The details of the process of selection of the micro-catchment is provided in Annex 2.

Based on the information collected, a SWOT Analysis on the ranking method was conducted in all the micro-catchments (Table 1). The strengths, weaknesses, opportunities and threats are identified for each delineated catchment area. Each micro-catchment was provided a score on the basis of SWOT parameters - a positive score based on the number of strengths and opportunities and a negative score for the number of threats and weakness. The catchment areas are finally ranked based on the overall negative and positive scoring.

Table 1: Ranking Based on SWOT Analysis for Solapur Micro-catchments

Micro-catchment	Strength	Weakness	Opportunities	Threats	Positive Score	Negative Score	Total score	Rank
Micro-catchment S1	4	-5	1	-2	5	-7	-2	3
Micro-catchment S2	3	-5	2	-4	5	-9	-4	4
Micro-catchment S3	9	-4	2	-1	11	-5	6	1
Micro-catchment S4	3	-3	2	-1	5	-4	1	2

Micro-catchment S3 (Ekrukh micro-catchment) got the highest score and was selected for the preparation of the CMP under the project. Three villages have been selected for the study – Tale Hipparga, Haglur and Ekrukh Village. Solapur city is also included within this micro-catchment boundary. Tale Hipparga, Haglur and Ekrukh villages have been selected within the micro-catchment as they are in close proximity (within 5 km) to the lake. These three villages have high impact on the quality and quantity of the water available in the lake due to the location. Solapur city is the only urban area within the micro-catchment and is located 8 km from Ekrukh Lake, which is the major water body in this micro-catchment.

3.2. Overview Ekrukh Micro-Catchment

Ekrukh Lake is the largest artificial lake and the most important water body in Solapur. It is located in Tale Hipparga village, close to Solapur city, around 8 km away towards the north east. The Ekrukh water reservoir is a historical and one of the largest man-made lakes in Maharashtra. It has a total capacity of 3,330 M.Cu.Ft. The reservoir, formed by an earthen dam on the Adela River is 7,200 feet long and 72 feet high, has three canals. The reservoir commands a gross area of 17,152 acres with maximum height of the dam being 21.45m. The total catchment area of the reservoir is 411.81 sq.km. Besides water for irrigation and domestic use in villages, Ekrukh Lake supplies drinking water to Solapur city and is one of the city's major water resources.

Figure 3: Location of Ekrukh Lake in Solapur

Over the years, due to changing patterns of precipitation, temperature, urbanization and a high siltation rate, the capacity of Ekrukh Lake has decreased by more than 50% (earlier 25MLD was provided to Solapur city and now only 10 to 11 MLD water is available in the monsoon period). In the selected study area, the three villages (Ekrukh,Tale Hipparga, Haglur) and Solapur City are directly dependent on the lake for their drinking water or irrigation water supply. The pressure on Ekrukh Lake has grown immensely over the last few decades due to increasing sewage and sullage population in the micro-catchments, polluting economic activities specially textiles and brick-making, and unsustainable agricultural practices such as the cultivation of sugarcane in a drought-prone area.

3.3. Formulation of RURBAN Platform

A multi-stakeholder RURBAN Platform was formulated at the beginning of the study to enable rural and urban stakeholders to exchange information, promote collaborative actions, and formulate and design plans for improved water management in the selected micro-catchment..

Members of RURBAN Platform included:

- District Collector
- Mayor, Solapur
- Municipal Commissioner, Solapur
- PHED Chief Engineer, Solapur Municipal Corporation (SMC)
- Agriculture Officer
- Chief Executive Officer, Zilla Parishad, Solapur
- Resident Deputy Collector,
- Sub-regional officer
- Maharashtra Pollution Control Board Head, Solapur Division,
- Maharashtra Jivan Pradhikaran,
- Block Development Officer, Head, Solapur Division
- Senior Scientist, Water Resource Department ,
- Groundwater Survey and Development Agency, Solapur.

The Platform is responsible for interactions and discussions on integrated water management strategies and actions. Through SLDs, the members of the RURBAN Platform interacted at every stage of the IAdapt Process for engagement, training, capacity building, planning and monitoring.

Figure 4: RURBAN Stakeholders of Solapur

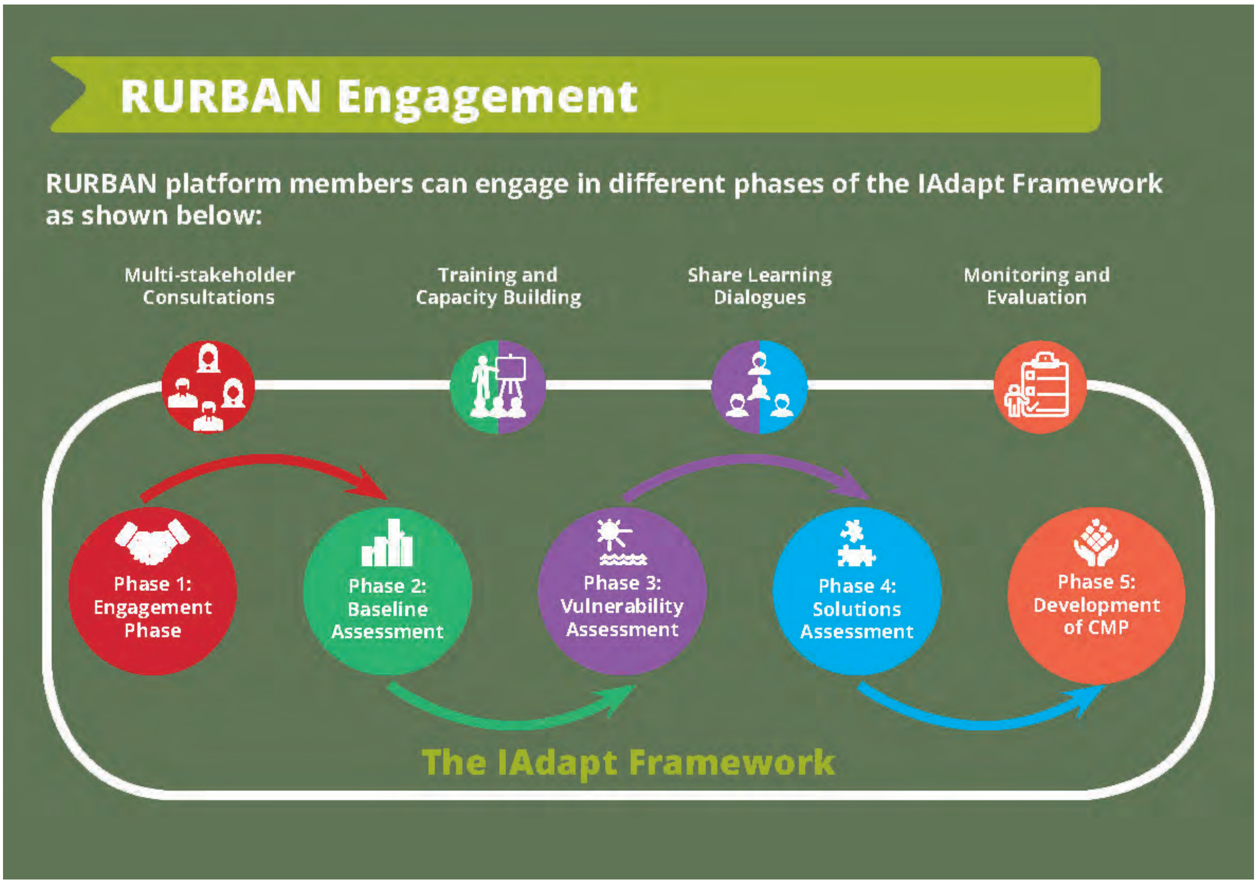

Figure 5: Engagement of RURBAN Stakeholder in IAdapt Framework

3.4. Baseline Assessment

Baseline data on various parameters like demography, socio-economics, basic services and water resources has been collected at the catchment level from both villages and Solapur city. With a population of nearly 1 million as per the 2011 Census, Solapur has a total water supply of approximately 110 MLD. Ekrukh Lake, located in its immediate catchment area, provides around 10 MLD to the city and is one of its major water resources. With nearly 40% NRW, the per capita supply to the city has declined. This has impacted the water supply in the city (water is received on alternate days; during summer, water is supplied once in 4-5 days) and in the villages (dependent on Ekrukh Lake for irrigation purposes and drinking water through bore-wells within the lake area).

3.4.1. Demography

As per the 2011 Census, the population in Ekrukh Catchment was 9,59,997 (three villages and one city) There were approximately 1,659 households in three villages with a population of 8,439 as per the 2011 Census, while Solapur city had a population of 9,51,558, as of 2011. The population is nearly 1.1 million today, comprising more than 98 % of the total population within the micro-catchment.

According to the National Census, Solapur's population increased from 8, 72,478 in 2001 to 9, 51,558 in 2011. The decadal growth rate of Solapur city was much lower than that of Solapur district (12.16%) and Maharashtra State (15.99%). The city is expected to have a daily floating population of approximately 19,450 (SMC, City Sanitation Plan, 2012). The gross population density of Solapur city and district were 5329 persons/km and 290 persons/km2, respectively, in 2011. The decadal growth rates for the last few decades have been more than 20%, with the highest rate of 38% being recorded in the 1981-1991 period. The city recorded its lowest growth rate of 9% in the 2001-2011 period. The sudden decrease in the growth rate can be attributed to the decline in industrial growth of the city, which used to attract migrant labourers from other states.

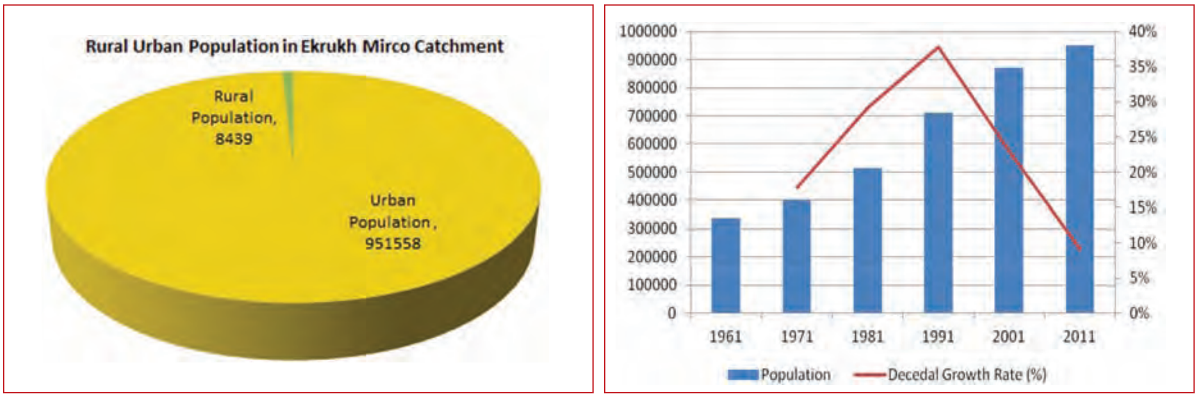

Figure 6: Percentage of Rural Urban Population share within the Micro catchment

Only 67% of the total population is engaged in agricultural activities in the micro-catchment. Approximately 4% of the total population in these villages are marginal workers (of which 42% are female). With the growing population, the stress on water resources is also increasing. This will also increase the pressure on urban utilities that provide regular water supply.

3.4.2. Economic Activities

The economic base of the region is grounded in the textile industry. Solapur, once called the textile capital, has been a hub for trade & commerce in textiles since the British reign. The textile units based in the Solapur Maharashtra Industrial Development Corporation (MIDC), along Akkalkot Road, employ more than 7000 persons in 615 factories. Although the water treatment facilities are provided by the big textile unit owners, the small units are still discharging water into local drains, contributing majorly to water pollution. The cooperative sugar factory, brick factories and beedi factory also contribute to the city economy. The Beedi industry is the second-most important industry in Solapur. Nearly 115 units and six major beedi factories employ 70,000 women workers and 1,725 factory workers at the district level. Although these industries are the major livelihood providers in the region, they are also major water polluters and consumers in the catchment.

Table 2: Industrial areas in Solapur District

Industrial area (Solapur District)	Category
Chincholi	Major industrial area
Karmala	Growth centre
Kurduwadi (Madha)	Mini industrial area
Managlwedha	Growth centre
Solapur (Akkalkot Road MIDC)	Major industrial area
Tembhurni	Growth centre

Source: City Development Plan, Solapur, 2006

3.4.3. Agriculture

Agriculture is one of the biggest contributors to the economy of the region, contributing approximately 25.08% of the net income of Solapur district. The sector is growing because of the Ujjani dam and other irrigation projects in the area. Nearly 9.1 lakh hectare (62% of the district area) of land is under agriculture. Solapur region grows both kharif and rabi crops, but the area under rabi crops is larger in the district. The region is considered to be drought-prone, but the major cash crop is sugarcane, which is a water-intensive crop. This is due to the fixed rate of the sugarcane market. Other major cash crops are pomegranate, lime/sweet lime, grapes, ber, mango, soyabean, sunflower seeds and pulses. Farmers extract groundwater extensively for irrigation, impacting the groundwater level in the region. Droughts and drought-like situations are very common in summers.

3.4.4. Water Resource

An assessment was conducted in the Ekrukh catchment to understand the water availability and resources. The entire Solapur district is part of the Bhima and Sina river basins. Nira, Mann and Bhogawati rivers are its tributaries. Ekrukh and Hotagi are the two major lakes located outside the Solapur city boundary, while there are three major lakes within the city: Siddheshwar, Kambar and Soregaon lakes. The major water resources for the SMC are outlined below:

Ekrukh Lake: The Ekrukh lake is the largest artificial lake in the district. The scheme was prepared in 1863 and sanctioned in 1866. It comprises a reservoir formed by an earthen dam 7,200 feet long and 72 feet high and three canals. The lake serves a population of around 10 million and is used for irrigation purposes.

Bhima River: Ujjani Dam, also known as Bhima Dam or Bhima Irrigation Project is the major water source for Solapur city. The length of the Bhima River passing through Solapur district is around 289 km. The project provides multipurpose benefits of irrigation water, hydroelectric power, drinking and industrial water supply and fisheries development to Solapur region and also other cities such as Pimpri Chinchwad. Two irrigation canals (Ujjani right-bank canal and Ujjani left-bank canal) have been provided from the dam for irrigation. In case of Bhima River at Takli, the irrigation department has to release nearly 10 to 15 times more water to ensure 0.2 TMC water reaches the tapping point, as farmers along the way use the water for irrigation. The SMC lifts at 75MLD of water at Takali, and 80 MLD at Ujjani dam.

Ground Water: Groundwater is the major source of water supply for drinking and irrigation purposes within the micro-catchment. The groundwater availability varies across the city due to lack of continuity in groundwater flow at greater depths and the hard rock terrain. Recharging of the upper shallow aquifers takes place during the monsoon only. At present, there are public bore-wells (22% of the total bore-wells) as well as private bore-wells (78% of the total bore-wells), some of them fitted with electric pumps, in the city. As per municipal records, up to 2001, 2195 bore-wells were drilled in the city and the water table ranged between 100 and 150 metres. There are roughly 10,000 bore-wells in the city, of which about 60% are said to be seasonal with low discharge (about 200 to 500 litres/day), nearly 30% have medium discharge (about 500 to 2000 litres/day) and nearly 10% discharge more than 2500 litres/day. It is estimated that approximately 3 to 4.5 MLD is made available through groundwater resources. During summer, nearly 20% of the bore-wells become defunct[6].

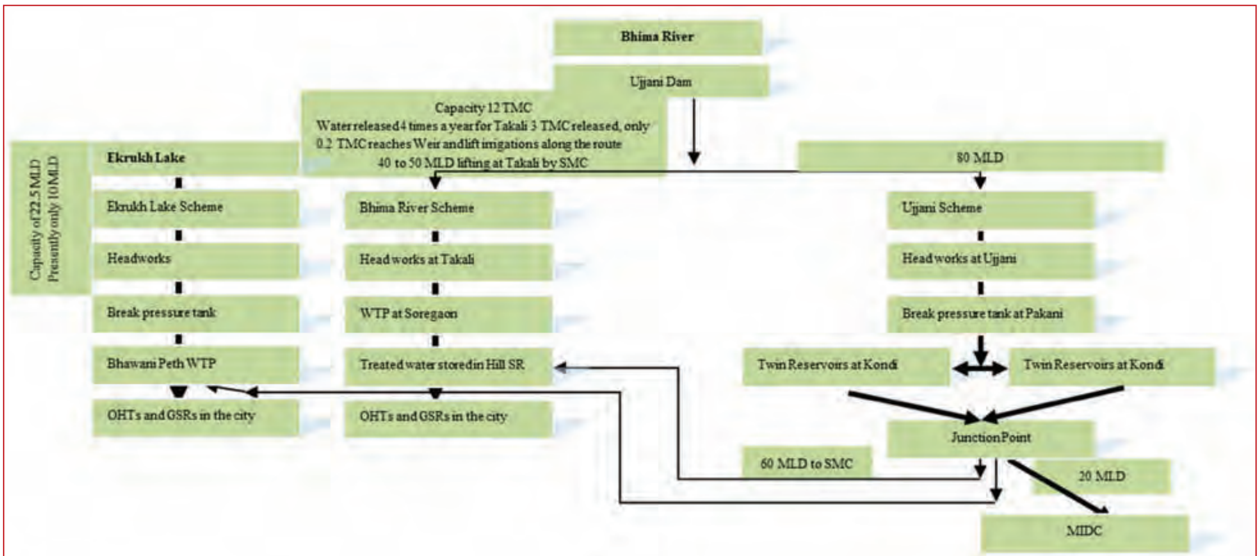

Figure 7: Water supply System in Solapur City

3.4.5. Water-related Issues in Solapur

The baseline assessment identified the following water-related issues in the SMC and surrounding areas:

Water Availability: Solapur region is a drought-prone area as declared by the government of Maharashtra. In the micro-catchment, the major sources of water supply for the city are Ujjani Dam, Ekrukh Lake, Bhima River and groundwater. For the villages in the study area, groundwater and water from Ekrukh Lake are the major water resources. Both rural and city areas face water scarcity during summer.

6. As per 'Augmentation & Improvements in Solapur Water Supply Scheme (DPR – Augmentation of Bulk water supply)', SMC under proposal

Groundwater is an important source of water in this micro-catchment. The pre-monsoon depth of the water ranges from ground level to 12.80 metres in the district. At present, the water level is depleting at an alarming rate due to excessive abstraction. As per the Ground Water Board (GWB) report 2017-18, most of the stations were dry during the pre-monsoon season, indicating that the water level has gone roughly 9m below the ground level (BGL) as a majority of the wells are having a depth range between 8 and 16m BGL, except a few observation wells where it is more than 16m BGL. There is also a drastic reduction in the amount of water availability in Ekrukh Lake due to siltation. The basaltic rocks, due to poor storage and transmission capability, get fully saturated during the monsoon, but a situation of rejected recharge results in the post monsoon and early summer months. These aquifers also drain naturally due to the high water table gradient, formed by the sloping and undulating topography.

Water Quality: The groundwater present in Solapur district is mainly affected by nitrate concentration above the minimum permissible limit (MPL) (Maharashtra Ground Water Board, 2016-17). High pH values are also recorded in some areas. The main reason is the use of inorganic fertilizers and animal manure in agricultural areas.

There are also a number of small-scale textile units in Solapur city, which discharge wastewater directly into open drains.

The lack of a wastewater drainage system and sanitation facilities in the rural areas are also affecting the water quality of the lake directly.

For the study, a water quality analysis of five samples collected from various sources (groundwater, surface water, wastewater) at different locations in the city and at Ekrukh Lake was conducted. The results shows that most of the parameters like pH, COD and alkalinity are within permissible limits. However, the BOD levels in domestic wastewater is 450mg/l, which is quite high as per the limit of 350mg/l. Similarly, in groundwater samples (hand pump), the BOD is 12 mg/l (limit 2mg/l) and in surface water samples, the BOD is 320 mg/l, which is much higher than the permissible limits. The main reason for such a high level of BOD in the region is the open drains in the city and near the lake, and the lack of sanitation.

Climate Risks: With the changing patterns of temperature and precipitation, the district is facing issues related to heat stress, droughts and water-logging. As per the hydrological and climate modeling analysis conducted for the catchment dry spells are predicted to increase by 2030, resulting in more droughts in the region. Due to change in the intensity of the precipitation received in the area, the surface runoff will also increase, impacting the percolation rate, and hence resulting in low groundwater recharge. The adverse effects of an increase in temperature include a shortened crop-growing season.

3.5. IAdapt Phase 3: Climate Change Vulnerability Assessment

The climate change vulnerability of the Ekrukh micro-catchment was conducted to understand the impacts of precipitation and temperature variations on systems like water supply, wastewater, stormwater, solid waste, agriculture and health. A water balance exercise was conducted for the micro-catchment and the integration levels among different sectors assessed using the Integration Assessment Matrix (IAM) tool. The fragile systems facing climate threats were identified and prioritised according to their risk status. The vulnerability of different areas in the city and the villages in the study area as well as local stakeholders were analyzed to identify the key areas and actors at risk. Climate scenarios were formulated based on secondary and primary studies to predict and analyse the future impacts of climate change on water resources and the different systems. The analysis identifies potential climate risks of higher temperatures and decreased but high-intensity rainfall of shorter durations, and also considers the vulnerability of the region to extreme events like floods, heat waves and drought. The assessments from the 'Climate Change and India: A 4x4 Assessment' prepared by the Government of India[7] and the information on the climatic trends projected for the Western Ghats region for the period till 2030 has been referred to verify results. The city-level study conducted by IIT Madras as part of this study was also used to understand possible temperature and rainfall projections.

The main impacts of climate change faced by the communities are discussed through SLDs with the RURBAN platform and in interactions with the rural and urban local authorities for ground truthing purposes.

3.5.1. Climate Trends and Scenario Assessment

Solapur city falls in the semi-arid category with a history of scanty to medium rainfall.

For the climate analysis, meteorological data was obtained from IMD and any missing or erroneous data was filled based on temporal interpolation and statistical properties. The analysed climatic data comprised monthly and annual rainfall for the 1971-2005 period. The analysed climatic data for temperature comprised monthly and annual average maximum and minimum temperatures for the period of 1969-2009. Once a time series was obtained, trend analysis was done on a monthly basis using Student t-test. Three variables were considered: monthly rainfall, monthly maximum temperature, and monthly minimum temperature. The null hypothesis is, the slope of the trend is 0, i.e. there is no net change in the pattern. This gave the trend of rainfall and temperature in the region.

For climate projections, the General Circulation Models (GCM) variable was downscaled using the change factor method. In this approach, for rainfall, multiplicative change factor is used, and for temperature, the additive change factor has been used. These change factors were recalculated based on the change in the mean monthly value of the variable. Based on the change factor calculated, the projection for the variables was made using the same factor for the historical data of the study area. Different RCP scenarios were considered to get rainfall and temperature projections.

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

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

The detailed climate assessment conducted by IIT Madras for the purposes of the study is attached in Annex 3.

Rainfall

Table 3 shows the percentage change in monthly rainfall in the next 60 years. From the figures given above, it can be predicted that overall rainfall is going to decrease. In all the RCPs, the annual average rainfall is decreasing by 40 mm, which is maximum for RCP 8.5. Drought events are also going to be more frequent, with almost 25-30 events in the next 60 years. The magnitude of the droughts will reach a very low level of 200 to 300 mm, and the flood magnitude will reach a very high level of 1500 mm.

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7. Indian Network for Climate Change Assessment. 2010. Climate Change and India: A 4X4 Assessment - A sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Government of India.http://www.metoffice.gov.uk/media/pdf/c/a/GOM_brochure_for_web.pdf

Table 3: Percentage change in monthly rainfall for all RCPs for Solapur

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

Maximum Temperature

Table 4 shows the increase in the monthly maximum temperature for all the RCP scenarios. It is evident that if RCP 2.6 follows, the minimum temperature will rise by about 1ºC. From 2020 to 2049, the change in temperature for RCP 4.5 and RCP 6.0 is around 1ºC, which will rise to 1.5ºC in 2050-2079. RCP 8.5 is the extreme case, where in the first 30 years, the rise is more than 1ºC; but in the next 30 years, the rise will be around 2ºC. For a few months, it may rise by 2.3ºC also.

Table 4: Increase (°C) in monthly maximum temperature for all RCPs for Solapur

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2049	Jan	0.9	1.2	1.0	1.3
	Feb	1.0	1.1	1.0	1.2
	Mar	0.6	0.8	0.7	1.0
	Apr	0.9	1.0	0.9	1.1
	May	0.9	1.1	0.9	1.2
	Jun	0.9	1.1	1.0	1.2
	Jul	0.9	1.1	0.9	1.1
	Aug	1.0	1.0	1.0	1.1
	Sep	0.9	1.0	0.9	1.1
	Oct	0.8	1.0	1.0	1.0

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

Minimum Temperature

Table 5 shows the increase in monthly minimum temperature for all the RCP scenarios. It is evident that if RCP 2.6 follows, the minimum temperature will rise by about 1ºC. From 2020 to 2049, the change in temperature for RCP 4.5 and RCP 6.0 is around 1ºC, which will rise to touch 1.5ºC in 2050-2079. RCP 8.5 is the extreme case where in the first 30 years, the rise is more than 1ºC; but in the next 30 years, the rise will be around 2ºC. The pattern of minimum temperature is the same as that of maximum temperature.

Table 5: Increase (°C) in monthly minimum temperature for Solapur

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

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
	Sep	1.0	1.5	1.4	2.1
	Oct	0.9	1.4	1.4	2.1
	Nov	1.0	1.4	1.4	2.2
	Dec	0.9	1.5	1.5	2.2

The analysis of secondary information from regional and national studies also suggests that, in terms of temperature, there is an expected increase of 1.7ºC to1.8ºC in the temperature of the Western Ghats region with respect to the 1970s. There is a projected increase in temperature over the entire Maharashtra region for the monsoon season, with a range between 1.5ºC and 3ºC. The humidity is in the range of 51-82% and the average evaporation is 7.6 mm/day

3.5.2. Climate Scenario Statements

Climate scenario statements were formulated for the Ekrukh micro-catchment region based on the IIT Madras studies and secondary regional studies. The statements developed were discussed with the RURBAN platform stakeholders to ratify them through general observations in the region. The stakeholders mentioned that the temperature seems to be increasing over the years, whereas the rainfall seems to be decreasing. It is possible that the shift in the monsoon, as evidenced by the trend analysis, is leading to this perception of decreased rainfall since the usual rainfall months are not seeing enough rain.

The observations match perfectly with the projections of the IIT Madras study. However, regional studies, such as the INCCA report of Government of India suggests that there would be a projected rise in the intensity of the monsoon rainfall in the Western Ghats by the year 2030 and along the coast of Maharashtra. This discrepancy could be because of the larger area that is considered in the INCCA report.

The climate scenario statements, as per each of the studies considered in this assessment, are summarised below:

Table 6: Summary of Climate Scenario Statements

Changing Climate Conditions	Assessments	Climate Scenario Summary Statements
Precipitation Change	**Regional Assessments:** Indian Network for Climate Change Assessment. 2010. Climate Change and India: A 4X4 Assessment - A sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Government of India	There is a high level of confidence of an expected change of 935±185.33mm to 1794±247mm in the mean annual rainfall in the Western Ghats region by the year 2030
	Regional Assessments: The Met Office Hadley Centre, TERI and Government of Maharashtra. 2012. Climate change in Maharashtra- A pioneering adaptation strategy. Met Office, The Energy and Resources Institute and The Government of Maharashtra	There is a suggestion of a projected rise in the intensity of monsoon rainfall, particularly along the coast of Maharashtra and the Western Ghats. The number of days with 'high' or 'very high' rainfall (greater than 25 mm per day) is projected to increase over the Maharashtra region.

Changing Climate Conditions	Assessments	Climate Scenario Summary Statements
	Local Assessment: Study conducted by IIT Madras	The overall rainfall is going to decrease. In all the RCPs, the annual average rainfall is decreasing by 40 mm, which is maximum for RCP 8.5. Drought events will also be more frequent, with almost 25-30 events in the next 60 years. The magnitude of the droughts will reach a very low level of 200 to 300 mm, and the flood magnitude will reach a very high level of 1500 mm.
Temperature Change	**Regional Assessments:** Indian Network for Climate Change Assessment. 2010. Climate Change and India: A 4X4 Assessment - A sectoral and regional analysis for 2030s. Ministry of Environment and Forests, Government of India.	There is an expected increase in temperature of 1.7ºC to 1.8ºC in the Western Ghats region, with respect to the 1970s.
	Regional Assessments: The Met Office Hadley Centre, TERI and Government of Maharashtra. 2012. Climate change in Maharashtra- A pioneering adaptation strategy. Met Office, The Energy and Resources Institute and The Government of Maharashtra.	There is a projected increase in temperature of 1.5ºC to 3ºC over the entire Maharashtra region for the monsoon season.
	Local Assessment: Study conducted by IIT Madras	The monthly maximum and minimum temperatures for all the RCP scenarios will rise. RCP 8.5 is the extreme case for both maximum and minimum temperatures, where in the first 30 years, the rise is more than 1ºC, but in the next 30 years, the rise will be around 2ºC.

The main climate risks considered for the purposes of this CMP, based on the detailed city specific study conducted by IIT Madras and on the observations of the RURBAN platform stakeholders, are:

- **Climate risk 1:** Increased temperature;
- **Climate risk 2:** Decreased rainfall and changing rainfall patterns, leading to more droughts

3.5.3. Water Balance

A water balance exercise was conducted in the Ekrukh micro-catchment (urban and rural areas) to assess the existing water demand and supply gap. This helped to identify alternative pathways to reduce the demand-supply gap and to move towards a balanced approach for using water resources without or with little additional water abstraction.

For the ease of calculation, urban and rural areas were considered separately for the water supply and demand gap analysis.

Urban Water Supply and Demand Gap: TThe existing average water supply of Solapur city is 168 MLD (including bulk usage and groundwater) against the demand of 224 MLD, resulting in a 56 MLD demand-supply gap, which increases to 84 MLD in peak summer (because only one source out of three is perennial)[8]. Considering the population growth trends, in 2031, the demand-supply gap will be 36 MLD even after considering a new water supply line of about 80 MLD from Ujjani Dam (that was already approved by state government at the time of the study). Wastewater treatment is limited to about 70 MLD and the same will increase to 102.5 MLD after completion of ongoing work for upgradation of the sewerage network. SMC plans to sell about 75 MLD of recycled wastewater to the National Thermal Power Corporation's plant near Solapur. The same is not considered under this water balance as the water will be out of city's water cycle, although it will generate revenue for SMC. In addition to this, SMC plans to recycle 5 MLD of wastewater for industrial usage within the city till the year 2031. The runoff potential and present and future groundwater recharge efforts of SMC have been also considered, which shows that groundwater recharge will increase to 2 ML per year from present 0.1 ML per year. However, the city has to work a lot to minimise its transmission and distribution losses throughout the water supply network.

Rural Drinking Water Demand and Supply Gap: The average water abstraction from the 3 villages is around 698.18 KLD against the demand of 646.13 KLD, resulting in 52050 litres/day of surplus abstraction[9]. This surplus abstraction is mainly because of operating procedures like continuous and prolonged abstraction as per the availability of electricity, storage in open wells leading to evaporation and percolation losses, and transmission and distribution losses. A business-as-usual scenario, coupled with the population trends, suggests that by 2031, these villages will face an average demand-supply gap of about 70 KLD. In rural areas, grey water is being discharged without any treatment, while black water is being discharged after partial low-cost treatment like septic tanks. Most of the agricultural fields and livestock are given groundwater or water directly pumped from Ekrukh Lake. Depending on the crop variety and crop area, the quantity of water abstracted fluctuates, for which data is not available.

Water Quality Assessment: A water quality assessment was conducted at five locations, considering various sources like domestic wastewater, industrial water, grey water, groundwater (from hand pumps, and taps) and surface water from local drains. The quality of water was tested on 22 different parameters like pH, COD, BOD, MH, TH, TDS, TSS, TS, chloride colour and alkalinity. Table 7 showcases five main parameters to develop the basic profile of the catchment.

Table 7: Water Quality analysis

Domestic waste-water			Ground water			Surface drain water		Industrial water	
Parameters	Limits as per IS: 10500	Results	Limits as per IS: 10500	Ground water (Hand pump)	Ground water (Tap)	Limits as per IS: 10500	Results	Limits as per IS: 10500	Results
pH	5.5-9	6.96	6.5-8.5	6.99	7.84	5.5-9	6.9	5	6.85
DO mg/L	NS	0.89	6	1.3	1.07	NS	0.96	NS	1

8. Water supply related data was collected from Solapur Municipal Corporation (urban area).Transmission and distribution (T&D) losses were also considered while calculating the water demand and supply gap. Since the region face issues related to water scarcity in summer; this has been included as an additional indicator for urban water balance exercise. Future water balance for the year 2031 has been also calculated based on ongoing works in water sector and population projections for both urban and rural areas.
9. For rural areas in absence of water meters, information about pumps, operating hours, bore-wells, open wells, storage tanks and population data was collected to calculate water demand and supply. Agriculture areas of few villages' falls under different village's jurisdictions and hence only domestic and commercial water usage are considered at present.

Domestic waste-water			Ground water			Surface drain water		Industrial water	
Parameters	**Limits as per IS: 10500**	**Results**	**Limits as per IS: 10500**	**Ground water (Hand pump)**	**Ground water (Tap)**	**Limits as per IS: 10500**	**Results**	**Limits as per IS: 10500**	**Results**
Turbidity (NTU)	NS	255	5	23.6	0.89	5	5670	40	92.7
Alkalinity (mg/L)	NS	30	200	15	5	200	40	NS	60
BOD (mg/L)	350	450	2	12	28	30	320	2100	85
COD (mg/L)	NS	560	NS	19.2	64	250	480	30	1632

3.5.4. Identification of Focus Sectors and Issues

The Integration Assessment Matrix (IAM) was used to assess the existing level of integration among various departments and sectors related to water. This self-assessment tool consists of 12 indicators, each with a number of criteria that have scores to assess its contribution to sectoral integration in the city. The matrix for Solapur study area and scoring sheet is provided in Annex 4.

The result of the IAM for the Ekrukh micro-catchment suggests that the existing status of integration among various sectors (water and its allied sectors, as well as other sectors like land use, agriculture, and health) is limited. The catchment received an IAM score of 21 points and falls in the average category of the IAM index.

The key weakness of the Ekrukh micro-catchment is the lack of awareness among the residents on water conservation. Being a drought-prone region, the absence of water recharging options and water recycling strategies might impact the future water security plans for the villages and the city. A high dependence on groundwater, lack of involvement of officials in treating wastewater and water pollution, improper management of wastewater and solid waste are some of the key issues identified in the micro-catchment.

Table 8: Integration Assessment Matrix Scores of Ekrukh (Rural and Urban)

IAM Final Score	23
Existing status of integration in the city (Excellent, Good, Average, Poor, Critical)	Average
Weaknesses	Water portfolio, water pollution, water resources, climate change, capacity building
Strengths	Waste-water strength, SWM
Quick Improvement Areas	Wastewater management, Solid waste
Focus Issues	Water and Energy, Wastewater Management, Stormwater/ Natural Drainage System, Holistic Solid Waste Management and Agriculture

The key strength of the micro-catchment is the potential to recycle wastewater in both city and the rural areas. At present, in rural areas the wastewater is discharged into the lake, whereas in Solapur city, there are three wastewater treatment plants. But many peripheral areas are still not connected to the drainage system. This makes the wastewater sector a quick improvement area.

3.5.5. Fragile Systems Assessment

The fragile systems that have been identified through the IAM (as the Focus issues or Weaknesses or Quick Improvement Areas) were then assessed in detail to understand their existing fragility and possible impacts due to future climate risks identified earlier. The fragility analysis was conducted for the Ekrukh micro-catchment through rigorous discussions in the SLDs for the systems listed below:

i. Water Supply

ii. Wastewater

iii. Stormwater

iv. Solid Waste Management

v. Health

vi. Agriculture

The fragility of the systems were analysed in terms of their flexibility and diversity, redundancy and safe failure based on the information from the baseline assessment that was conducted as well as information shared in the SLD by the stakeholders from rural and urban areas.

For each of the systems, the impacts of the likely temperature and rainfall changes were analysed to produce climate fragility statements for each system.

Table 9: Climate Fragility Analysis of Local Systems

System	Why is it critical or fragile?	What are the existing and anticipated problems caused by the fragility of this system?	Responsibility	Fragility Statement	Climate Fragility Statement
Water Supply	Water for urban areas is sourced from Ekrukh lake, Bhima river near Takali village and Ujjani Dam. **1. Ekrukh lake** - 26 km in circumference; 27.5 MLD designed capacity, in use since 1940; most economical source of water because it can be sourced by gravity; heavily silted due to agricultural activities in the lake area;, MI tanks in between has blocked the flow of water into the lake from the catchment area, reducing recharge of the lake. The current capacity is 5-10MLD in the rainy season; it is shut down in summer. **2. Ujjani dam** - In use since 1998; requires pumping over long distances and is a costly option; the transportation line is old and has several leakages; AMRUT funds are being used to rejuvenate 5.5km of the pipeline. **3. Takli gaon** - Bhima river, 30km away, is being used as a source since 1968; total designed capacity is 108 MLD; currently, it is supplying 80 MLD. A majority of the villages are using groundwater and water from Ekrukh Lake. There are different sources of water, but Ekrukh lake is the best option. The lake's water quality is better than that of the dam water, and requires less energy and money. The lake is silted up and has suffered a drastic reduction in water availability. The summer season sees regular shortage of water. The Ujjani dam and Bhima river are far away and pumping is needed to get water. The groundwater level is going down due to excessive abstraction.	In urban areas, the entire water supply system has 30% leakage losses, which results in 57% NRW, but this is being addressed through AMRUT funds. There is a demand of 190 MLD in the city, but the supply is about 150-155 MLD. The city boundary has increased from 36 sq.km to 178 sq.km; the distribution system is absent in the extension region and tankers are used. A 110 MLD pipeline from Ujjaini dam is being sanctioned and will increase the supply, but the distribution system needs to be set up. The already existing demand-supply gap will increase in future as demand increases and climatic challenges reduce water resources. **Villages:** A majority of the water is sourced from Ekrukh lake and groundwater. The region experiences water pollution caused by 10-12 lakh people who come during pilgrim festivals, as well as from the textile industry. The water quantity is affected due to excessive sugarcane farming that requires a lot of water, and due to the neglect of water conservation.	SMC, Gram Panchayat	Water supply in the city is unable to meet the demand, because of a poor distribution system, physical leakages, and high NRW, particularly in extension areas. In villages, the water supply comes from the Ekrukh lake that faces water pollution from sewage/sullage/ industrial waste (textiles), impacting health. Water conservation practices are poor, impacting available resources.	Decreased precipitation could result in greater stress on available water resources in future. Sudden high intensity rainfall can damage old and weak distribution systems and lead to more losses, reducing the amount of water available for use. Higher temperatures create greater stress on water resources.

System	Why is it critical or fragile?	What are the existing and anticipated problems caused by the fragility of this system?	Responsibility	Fragility Statement	Climate Fragility Statement
Wastewater	There are 3 sewage treatment plants for the city, which work throughout the year. But they do not cover the entire city. Untreated waste goes into the local streams. In villages, the wastewater and sewage is released directly into the lake.	**Solapur City:** All untreated water goes falls into Sina river. The city is catered by 3 sewage treatment plants - Pratapnagar 15 MLD, Kumtha 12.5 MLD, and Degaon 75 MLD. There are 13 wastewater zones; 8 zones are fully covered by sewage pipelines and work is ongoing in 2 more zones. Once they are all commissioned, the collection system will collect 90-95 MLD of sewage from the city and treat it in the different plants. But this is still not enough for the city. **Villages:** Wastewater from villages is released directly into surface lakes. Currently there are no plans or funding available for sewage management. The toilets, where they exist, have septic tanks, but the tanks are not cleaned, and if they are filled, they are bypassed, letting wastewater out into the lake. Open defecation is also prevalent, that is also washed into the lake water.	SMC, Gram Panchayat	The wastewater system is under renovation and does not cover the entire city. Villages have no centralised wastewater management systems, resulting in the pollution of the lake water.	Less rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm the plants and lead to overflow and failure of the treatment system, impacting the health of citizens. Higher temperatures can reduce the efficiency of plants, and lead to odour and health issues.
Stormwater Drainage	Most of the places do not have stormwater disposal systems. Two *nallahs* transport water from the city to the nearby rivers. The stormwater from the villages dumps wastewater into the lake.	Two *nallahs* in the city transport water from upstream and downstream regions to the nearby rivers. *Shilagi nallah* falls into Sina river, which falls the Bhima river. There is no wastewater collection system in villages; it falls into open drains or ditches that run into the lake.	SMC, Gram Panchayat	Stormwater drainage in villages is blocked, while in cities, the *nallahs* are linked to the rivers, causing pollution.	Sudden high intensity rainfall can cause overflow in stormwater drains, dilute pollutants, cause greater runoff without recharge, and lead to waterlogging. Higher temperatures can lead to reduced water availability for animals in open wells.

System	Why is it critical or fragile?	What are the existing and anticipated problems caused by the fragility of this system?	Responsibility	Fragility Statement	Climate Fragility Statement
Solid Waste Management	Segregation is not practiced and open dumping is common. There is only one treatment and processing facility in the region, which caters to the waste from the city.	**Solapur City:** City has established a treatment and processing facility using biomethanation, producing gas and energy. No segregation of waste at source is practiced. **Villages:** No system of SWM in rural areas. Open dumping is practiced.	SMC, Gram Panchayat	Solid waste management is poor in the villages, and can cause water pollution as well as issues in stormwater drainage.	Higher temperatures can lead to more degradation and in drier climate, openly dumped waste can spread in the area, causing littering.
Agriculture	The villages are largely dependent on agriculture.	Millets and vegetables are the common food crops. Sugarcane is the major economic crop in the region, impacting groundwater. Earlier, Degaon grew grass using wastewater from the nallah that is used by milch buffaloes, and the milk quality was impacted. The sugarcane industry in the district gets sugarcane supplies from villages and city areas.	SMC, Gram Panchayat	The major crop is water intensive and creates great stress on the resource.	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity Less rainfall and rising temperatures can raise the demand for water, which will impact crop production and reduce the drinking water availability, impacting rural economy.
Health	There are no PHCs in the villages; villagers use city hospitals that are nearby. There are no Primary Health Centres in the villages. Recently, a PHC was sanctioned for Haglur. The existing PHC is 10 km away; while the city hospitals are nearer.	There have been water quality-related epidemics (cholera and gastroenteric diseases in 2009). Quality monitoring takes place in treatment plants, but the wastewater released from villages falls into Ekrukh Lake, which is taken consumed by the city, causing health issues. The TDS of Ekrukh lake is 150, while that of Ujjani and Bhima rivers are more than 400. Ekrukh lake has good quality water, but the quantity is insufficient. The practice of open defecation is prevalent; the panchayat samiti has built toilets, but they are not used properly.	SMC, Gram Panchayat	The water quality of the lake is impacted due to release of wastewater and effluents, and this can cause health issues.	Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health.

3.5.6. Risk Assessment of the systems

The climate fragility of these systems was discussed at a SLD with the RURBAN platform stakeholders in terms of their likelihood and consequences, to conduct a climate risk assessment of all the fragile systems.

The fragile urban systems and fragility statements with the highest risks as per the assessment were investigated further. The total risk score for each climate fragility statement is defined as a combination of the likelihood of an event to occur and the consequences faced if the event occurred, both of which were given a score from 1 to 5, 1 being the lowest. The assessment was conducted for rural and urban areas separately, since each region faces different consequences from the same event. The details of the risk assessment is given in Table 10.

In Ekrukh urban, wastewater, stormwater and agriculture received the highest scores in terms of impacts due to changing precipitation and temperature. In rural areas, on the other hand, all six sectors received a high score in terms of impact due to higher temperatures that will create greater stress on water resources and related sectors. The agriculture sector received a high score in terms of impacts of temperature variations, as the rising temperatures can cause greater demand for water resources, which will impact crop production and increasing deprivation of water resources for drinking, impacting the rural economy.

Table 10: Risk Assessment

Urban Systems	Climate fragility statement	Region	Likelihood (l)	Consequence (c)	Risk Score (lxc)	Risk Status
Water Supply	Decreased precipitation could result in greater stress on available water resources in future. Sudden high intensity rainfall can damage old and weak distribution systems and lead to more losses, reducing the amount of water available for use.	Urban	3	2	6	Medium
		Rural	3	3	9	Medium
	Higher temperatures create greater stress on water resources.	Urban	3	2	6	Medium
		Rural	5	5	25	Extreme
Wastewater	Less rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm the plants and lead to overflow and failure of the treatment system, impacting the health of citizens.	Urban	3	3	9	Medium
	Higher temperatures can reduce the efficiency of plants, and lead to odour and health issues.	Urban	4	3	12	High
		Rural	4	4	16	High
Stormwater Drainage	Sudden high intensity rainfall can cause overflow in stormwater drains, dilute pollutants, cause greater runoff without recharge, and lead to waterlogging.	Urban	3	4	12	High
	Higher temperatures can lead to reduced water availability for animals in open wells.	Urban	4	3	12	High
		Rural	5	4	20	Extreme
Solid Waste Management	Higher temperatures can lead to more degradation and in drier climate, openly dumped waste can spread in the area, causing littering.	Urban	2	2	4	Low
		Rural	4	4	16	High

Urban Systems	Climate fragility statement	Region	Likelihood (l)	Consequence (c)	Risk Score (lxc)	Risk Status
Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity.	Urban	2	2	4	Low
		Rural	2	3	6	Medium
	Less rainfall and rising temperatures can raise the demand for water, which will impact crop production and reduce the drinking water availability, impacting rural economy.	Urban	4	4	16	High
		Rural	5	4	20	Extreme
Health	Short-duration high-intensity rainfall can dilute pollutants and improve water quality in the lake, reducing negative health impacts.	Urban	2	2	4	Low
		Rural	3	3	9	Medium
	Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health.	Urban	2	2	4	Low
		Rural	5	5	25	Extreme

3.5.7. Vulnerability Assessment and Mapping

In order to build resilience, there is a need to understand the extent of vulnerability within the micro-catchment to climate change. As defined by The Intergovernmental Panel on Climate Change (IPCC, 2007)[10], vulnerability involves a function of three parameters - character, magnitude, and rate of climate variation - to which a system is exposed, its sensitivity, and its adaptive capacity. Vulnerability assessment consists of:

1. Identification of areas vulnerable to the identified climate risks
2. Identification of vulnerable actors for all the prioritised climate fragility statements of the fragile urban systems and,
3. Analysis of the adaptive capacities of the actors and the fragile systems.

The SLD discussions on the climate fragility statements for various sectors helped to identify the vulnerable actors and areas most likely to be affected. For urban areas, ward-wise locations were identified as vulnerable to the identified climate risks, while in rural areas, the locations affected by each of the identified climate risks within the villages were marked.

The figures below and the tables 11 and 12 show the vulnerable areas and vulnerable actors in the rural and urban areas for each of the fragile systems that have been identified to be at high/extreme climate risk.

10. IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Annex I., M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

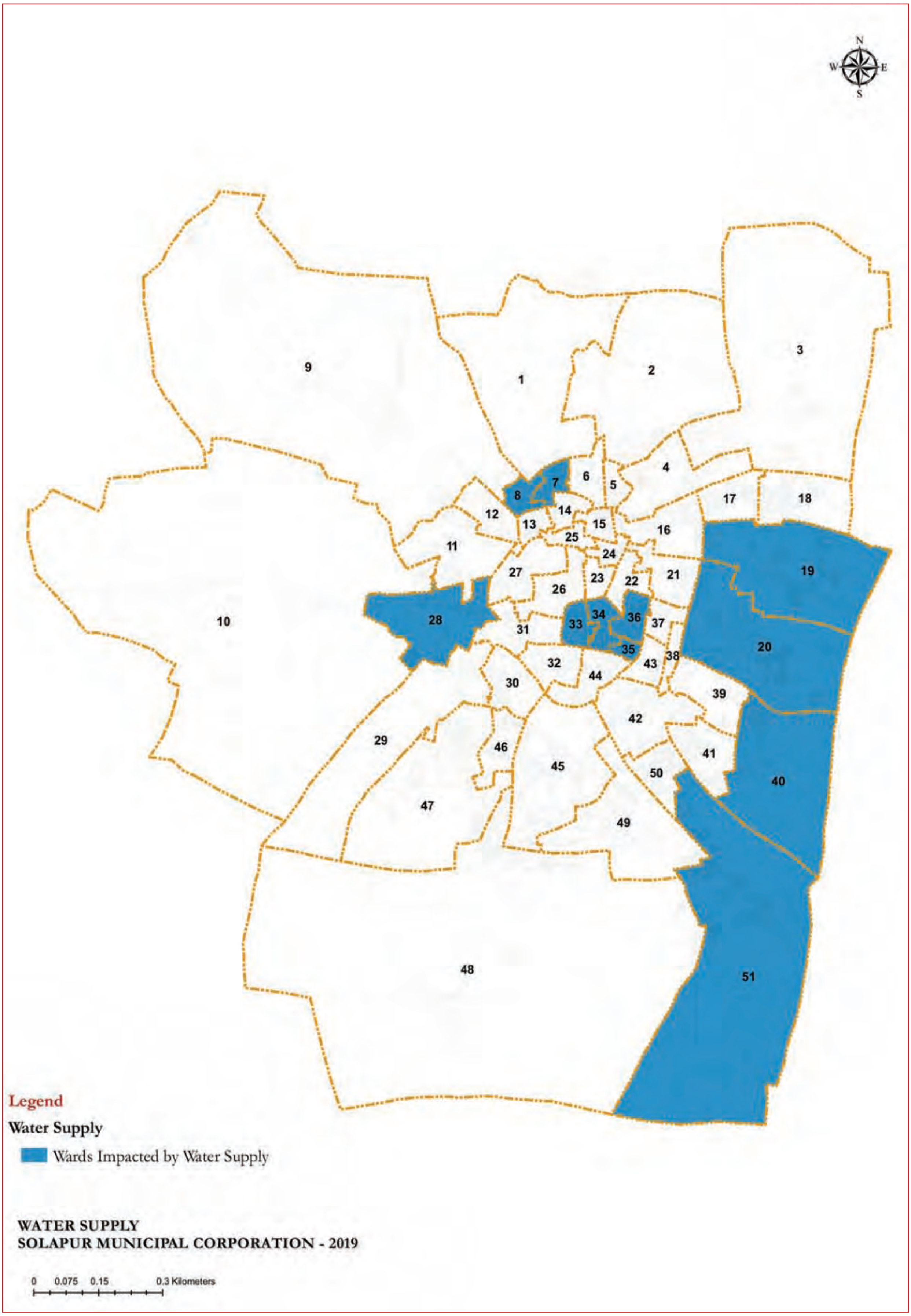

Figure 8: Water Supply Urban

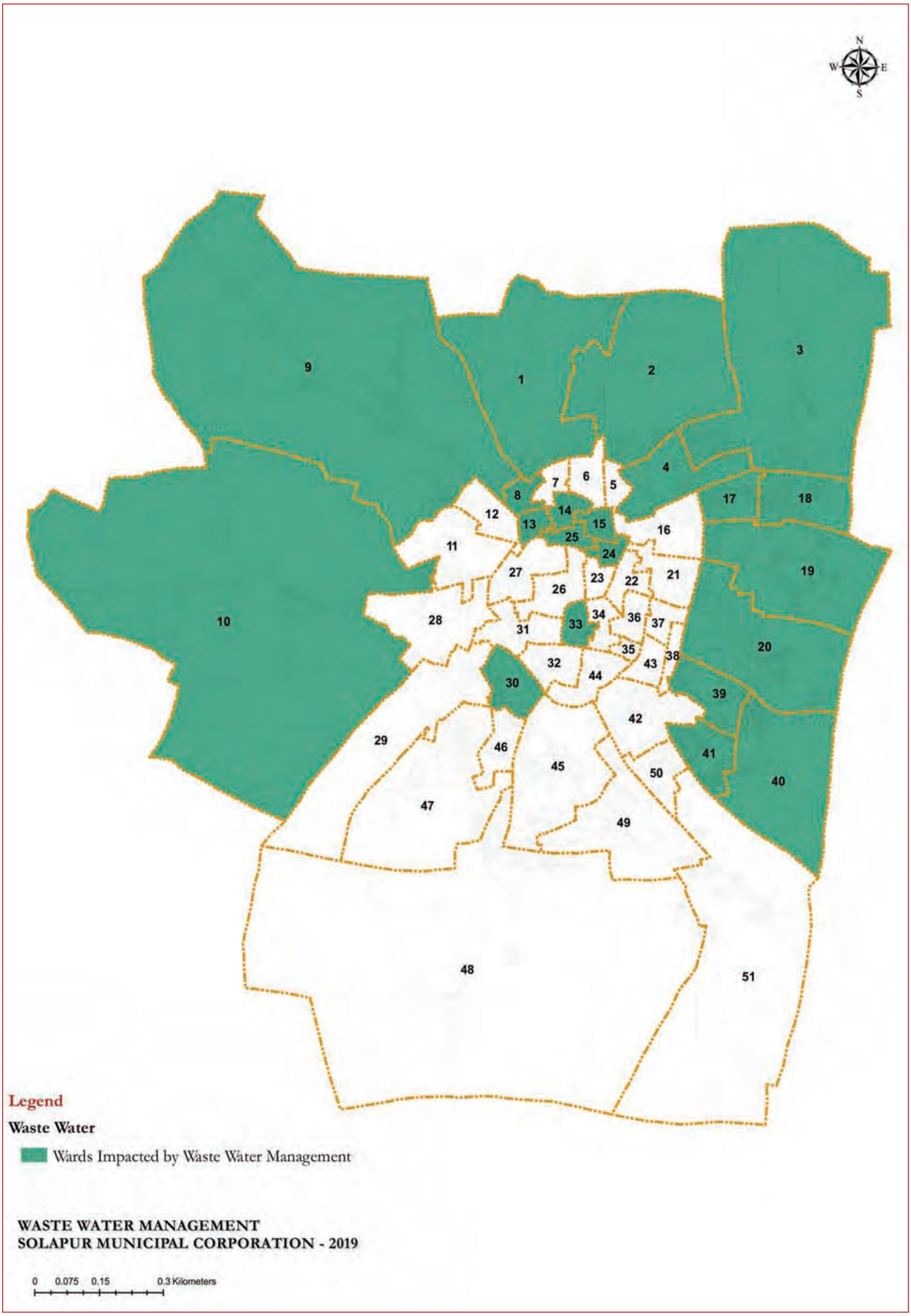

Figure 9: Wastewater Urban

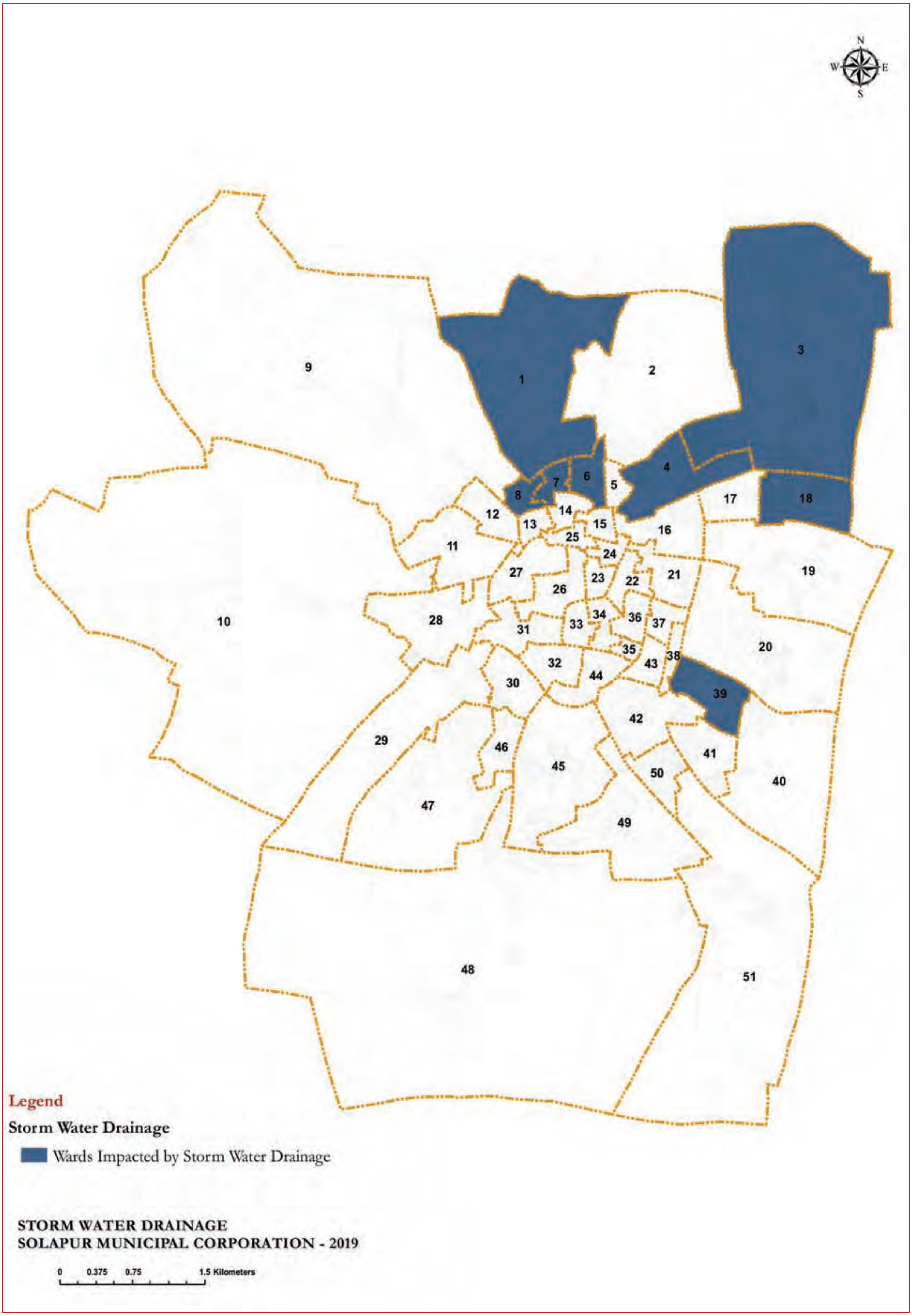

Figure 10: Stormwater Drainage Urban

Figure 11: Solid Waste Management Urban

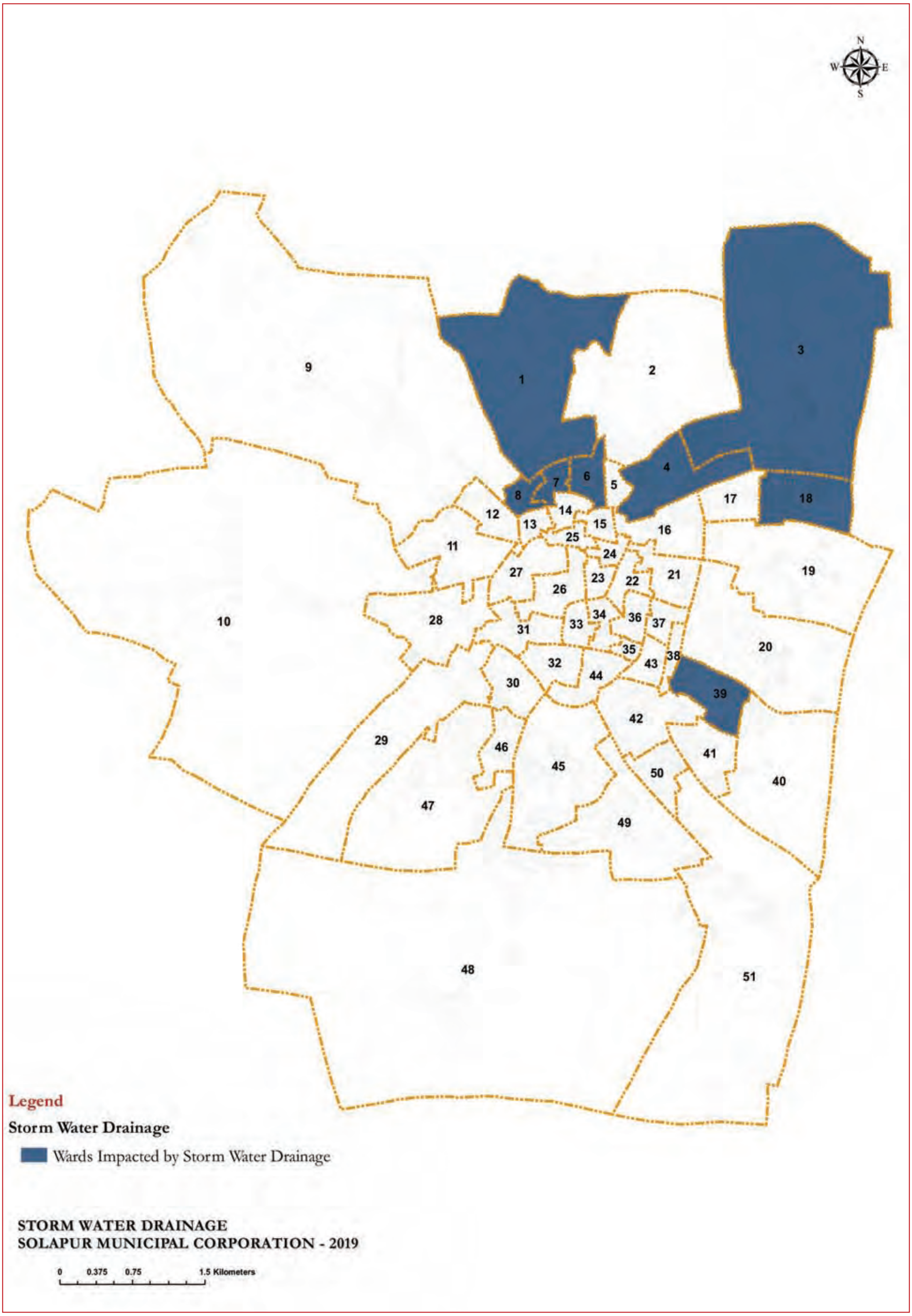

Figure 12: Stormwater Drainage Urban

Figure 13: Stormwater Drainage Urban

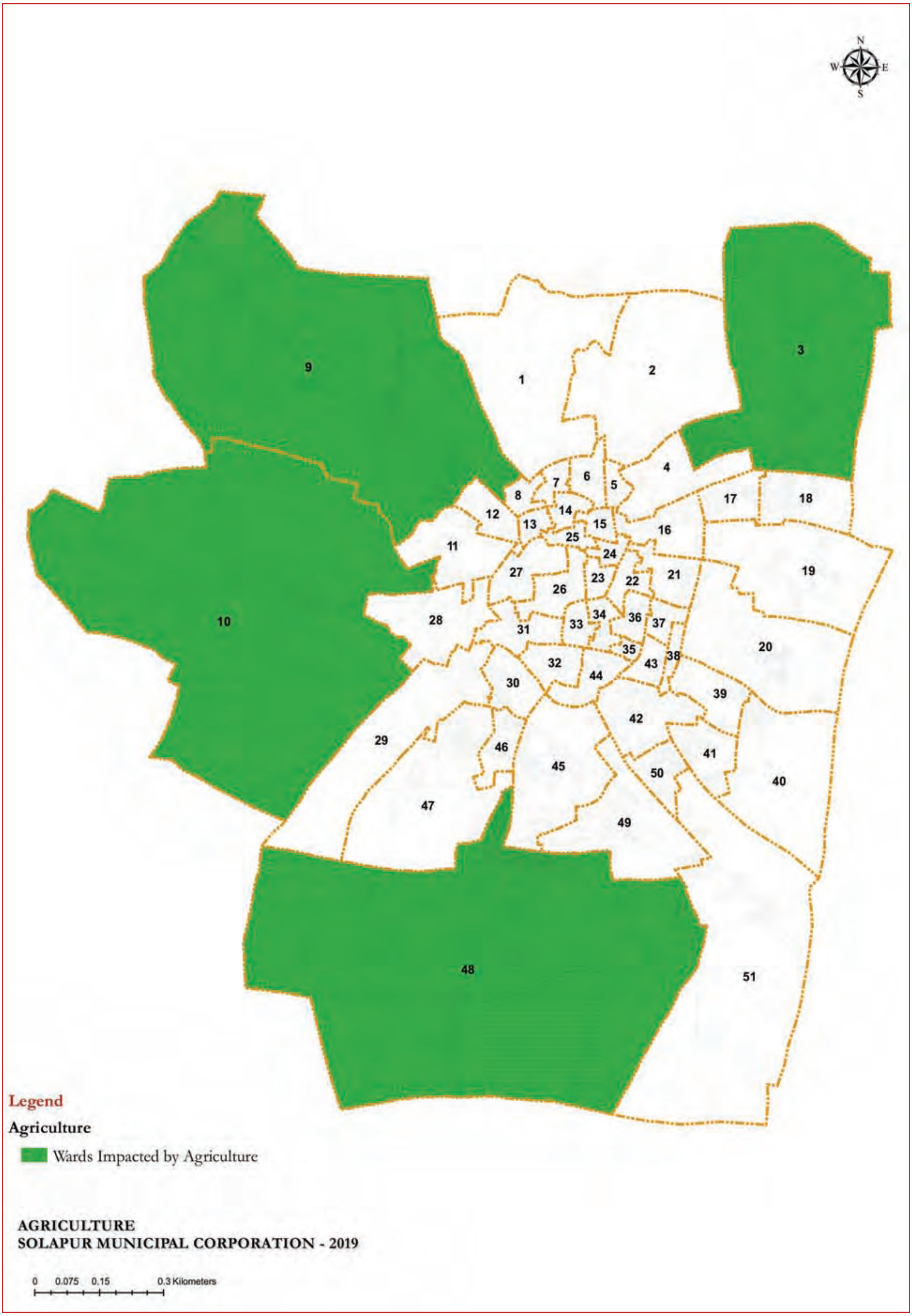

Figure 14: Stormwater Drainage Urban

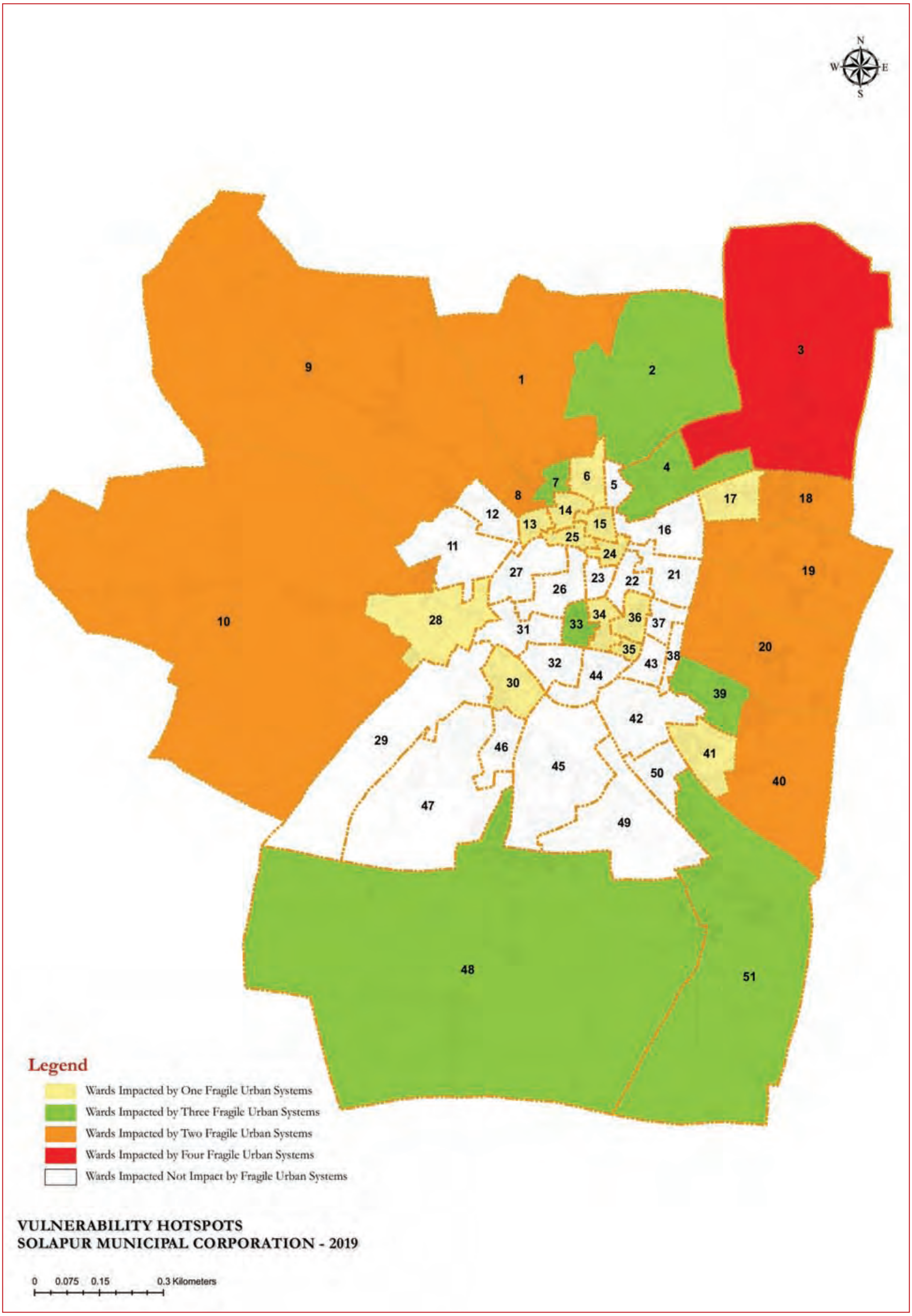

Figure 15: Vulnerability Hotspots - Urban

Table 11: Vulnerability Assessment – Rural

Urban Systems	Climate Fragility Statement	Area - Hipparge	Area - Haglur	Area - Ekrukh	Actors
Water Supply	Decreased precipitation could result in greater stress on available water resources in future. Sudden high intensity rainfall can damage old and weak distribution systems and lead to more losses, reducing the amount of water available for use.	The pipeline in wards 1, 2 and 3 is more than 30 years old. In ward 4, Gadhar Nagar, Samata Nagar, Manthalkar Basti, Dalaway Nagar, Swami Samarth Nagar and Balgargi Nagar have no water supply	Ward 3; area with number 40	Jahangir Colony, Patel Gali	Farmers Poor people Children Elderly Gram Panchayat Collector's office Zila Parishad/ Panchayat Samiti Irrigation department Horticulture Animal rearers
	Higher temperatures create greater stress on water resources.			Jamadar Colony, Hodkar Gali	
Wastewater	Higher temperatures can reduce the efficiency of plants, and lead to odour and health issues.	Ward 1- Joshi Gali, Ekta Nagar and near Sonawe Batta; ward 2-Bhiku Udan Shive	Junction of areas with number 2, 4 5, 176, 177		Residents in low lying areas - poor people Women (washing clothes) Gram Panchayat Zila Parishad
Stormwater Drainage	Higher temperatures can lead to reduced water availability for animals in open wells.		Junction of areas with number 2, 4 5, 176, 177		Gram panchayat, elderly, women, animals
Solid Waste Management	Higher temperatures can lead to more degradation and in drier climate, openly dumped waste can spread in the area, causing littering.			Javed Molani Chowk	Gram panchayat, children, elderly, women
Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity.	All farm lands	All farmlands	All farmlands	Farmers Poor people Children Elderly Gram Panchayat Collector's office Zila Parishad/ Panchayat Samiti Irrigation department Horticulture Animal rearers
	Less rainfall and rising temperatures can raise the demand for water, which will impact crop production and reduce the drinking water availability, impacting rural economy.				
Health	Short-duration high-intensity rainfall can dilute pollutants and improve water quality in the lake, reducing negative health impacts.	Ward 2- Ekta Nagar; ward 5- Manthalkar Basti		Dalit Basti	Poor people Elderly Children Gram Panchayat
	Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health.				

Table 12: Vulnerability Assessment – Urban

Urban Systems	Climate Fragility Statement	Areas	Actors
Water supply	Decreased precipitation could result in greater stress on available water resources in future. Sudden high intensity rainfall can damage old and weak distribution systems and lead to more losses, reducing the amount of water available for use.	7, 8, 34, 35, 36, city extension areas	Slum dwellers, poor people, irrigation department, PHE, SMC, women
	Higher temperatures create greater stress on water resources.	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	
Wastewater	Less rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm the plants and lead to overflow and failure of the treatment system, impacting the health of citizens.	8,13,14,33,15, 25, 24 (wastewater drains are silted), 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2 (no wastewater drains)	SMC, urban poor, slum dwellers
	Higher temperatures can reduce the efficiency of plants, and lead to odour and health issues.	41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2	
Stormwater drainage	Sudden high intensity rainfall can cause overflow in stormwater drains, dilute pollutants, cause greater runoff without recharge, and lead to waterlogging.	8,13,14,33,15, 25, 24, 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2	SMC, urban poor, slum dwellers
Solid Waste Management	Higher temperatures can lead to more degradation and in drier climate, openly dumped waste can spread in the area, causing littering.	City extension areas	SMC, slum dwellers, urban poor, children, elderly
Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity. Less rainfall and rising temperatures can raise the demand for water, which will impact crop production and reduce the drinking water availability, impacting rural economy.	City extension areas- Basleswar Nagar, Degaon, Dehetne, Soregoan, Kegaon, 10, 48, 3, 9	Agriculture department, APMC, farmers, urban poor

Based on the analysis of vulnerable areas, vulnerability maps were developed to show the distribution of the high climate risks across the micro-catchment in rural and urban areas. Vulnerability maps are prepared with the precise location of sites where people, the natural environment or property are at risk due to a potential climate-related disaster.

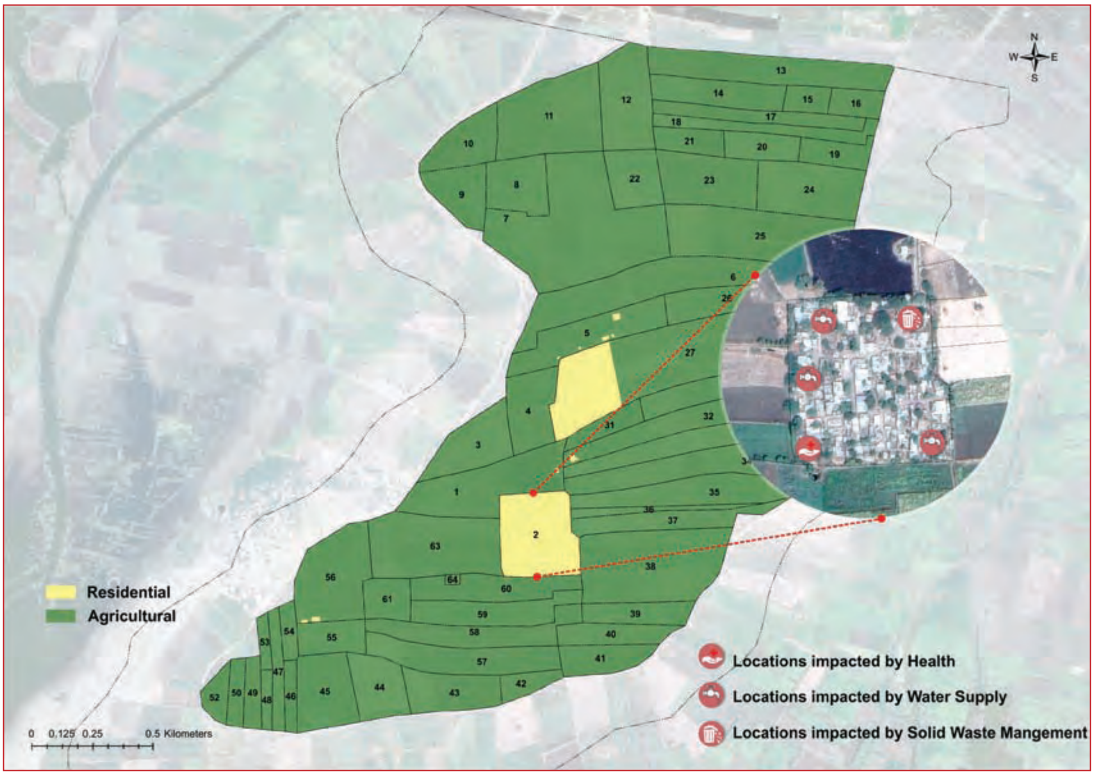

Figure 16: Vulnerability Hotspots of Ekrukh Village

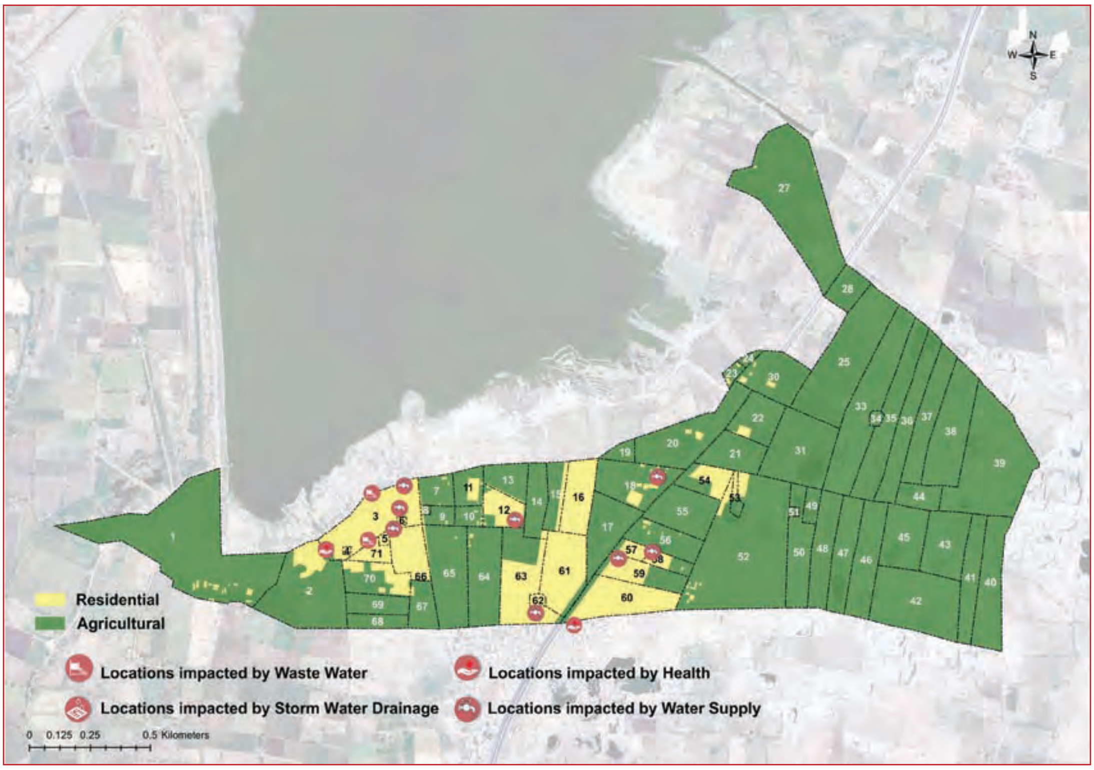

Figure 17: Vulnerability Hotspots of Hipparage Village

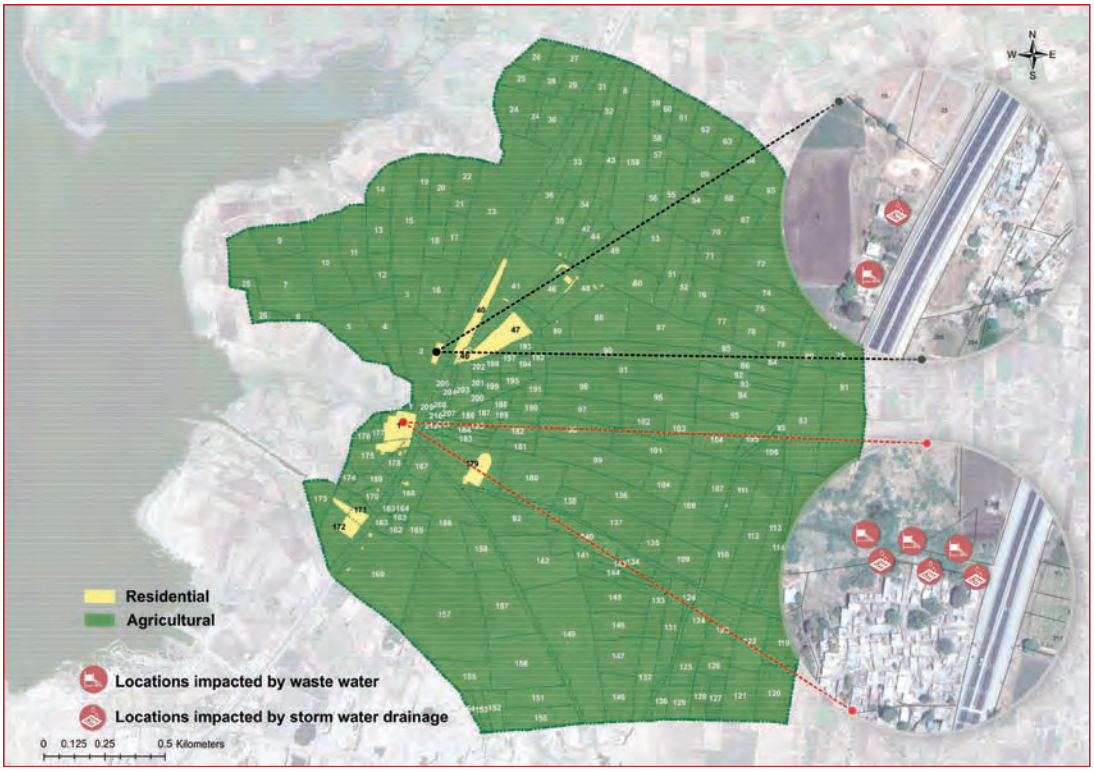

Figure 18: Vulnerability Hotspots of Haglur Village

The actors were analysed on the basis of their ability to organise and respond to climate and water related disasters, access to financial and technical resources and access to information on climate risks and disasters to understand their inherent adaptive capacities. The actors with the lowest adaptive capacities are the most vulnerable, and the ones with higher capacities could potentially be used to support the resilience of the water sector through relevant interventions identified in the next stages. The adaptive capacity assessment of the actors are given in the table below:

Table 13: Adaptive Capacity of the Actors

Actors	Capacity to respond (a)	Resources available (b)	Capacity to access information (c)	Adaptive capacity score (a*b*c)
Poor people	1	1	1	1
Children	1	1	1	1
Elderly	1	1	1	1
Gram Panchayat	1	2	2	4
Collector's office	3	3	3	27
Zila Parishad/ Panchayat Samiti	2	2	2	8
Irrigation department	2	2	2	8
Horticulture	2	2	3	12
Animal rearers	1	1	1	1
Residents in low lying areas - poor people	1	1	1	1
Women	2	1	1	2
Gram Panchayat	2	2	2	8
Zila Parishad	2	2	3	8

Actors	Capacity to respond (a)	Resources available (b)	Capacity to access information (c)	Adaptive capacity score (a*b*c)
SMC	3	3	3	27
Urban poor	1	1	2	2
Slum dwellers	1	1	1	1
PHE	3	3	3	27
Agriculture Department	2	2	3	12
APMC	2	2	1	4
Farmers	2	2	1	4
Children	1	1	1	1

3.6. IAdapt Phase 4: Solutions Assessment

In the fourth phase, a list of interventions is identified based on IUWM and climate resilience indicators to address and reduce the vulnerability of the water sector, particularly for the vulnerable areas and actors identified above. Solution assessment includes strategies best suited to address all identified vulnerable sectors, actors and areas, to build resilience and achieve sustainability in the catchment. Once these solutions were identified, a Water Evaluation and Assessment Planning tool was used to test various scenarios on the climate adaptive IUWM strategies for water management to select the ones with maximum impact. Finally, a decision support tool was used to identify climate-adaptive measures that could be incorporated into these interventions. The selected interventions were further linked with existing plans and policies of the government. All the information was then assimilated into an action plan for the micro-catchment.

3.6.1. Identification of interventions for Catchment-level Water Resource Management

Each locality or community experiences climate change in unique ways, depending upon topography, geographic location, features of the local ecosystem, along with social, urban and economic factors. Therefore, the adaptive responses of each community will be individual. However, collectively, many communities have already identified responses to particular climate exposures, and this can be useful information for a city that is starting out on the process.

For each Climate Fragility Statement, a list of possible interventions was compiled, specifically keeping in mind the vulnerable actors and how the intervention would benefit them and the adaptive capacity of the urban system under consideration. The potential list of intervention for Ekrukh micro-catchment is listed in Table 14.

Table 14: Micro-Catchment Solutions

Sr No.	Vulnerable Sectors	Climate Fragility Statements	Actors		Micro-Catchment Solutions
			Vulnerable Actors	Supporting Actor	
1	Water	Decreased precipitation could result in greater stress on available water resources in future. Sudden high intensity rainfall can damage old and weak distribution systems and lead to more losses, reducing the amount of water available for use.	Urban poor, women, slum dwellers, children	SMC, PHE	1. Leak detection systems to reduce T&D losses 2. Construction of RWH pits in water logged areas 3. Recharge local bore-wells through rain water harvesting 4. Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes
		Higher temperatures create greater stress on water resources.	Farmers, women children elderly	Gram Panchayat, Collector's Office, Irrigation Department	1. Ground water recharge through rain water harvesting, 2. Water ATMs at a school or panchayat ghar in each village
2	Wastewater	Less rainfall can result in STPs operating below capacity. Sudden, high-intensity rainfall can overwhelm the plants and lead to overflow and failure of the treatment system, impacting the health of citizens.	Urban poor, women, slum dwellers, children	SMC, PHE	1. Reuse of treated wastewater for local parks 2. Community level DEWATS systems 3. Promotion of urban agriculture using grey water
		Higher temperatures can reduce the efficiency of plants, and lead to odour and health issues.	Farmers, women, children, elderly	Gram Panchayat, Collector's Office, Water Sanitation Board	1. Construction of soak pits to reuse wastewater for secondary purposes 2. Promotion of eco-sanitation toilets
3	Natural drainage/ stormwater	Sudden high intensity rainfall can cause overflow in stormwater drains, dilute pollutants, cause greater runoff without recharge, and lead to waterlogging. Higher temperatures can lead to reduced water availability for animals in open wells.	Urban poor, women, slum dwellers, children, farmers, elderly	SMC, PHE Gram Panchayat, Collector's Office, Irrigation Department	1. Sustainable urban drainage systems (SUDS) for integration of natural sponges in city design 2. Stormwater runoff storage and diversion to local ponds /park 3. Revival of streams using RWH and bio filters to reuse water for urban greenery 4. Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ekrukh 5. Bio remediation at inlet points around the Ekrukh lake 6. Identification of potential bore-wells for aquifer recharging
4	Solid waste	Higher temperatures can lead to more degradation and in drier climate, openly dumped waste can spread in the area, causing littering.	Urban poor, women, slum dwellers, children	SMC, PHE Gram Panchayat, Collector's Office, Irrigation Department	1. Improve institutional capacity and management for 100 % waste collection 2. Decentralized plastic waste collection for revenue 3. Implementation of segregated waste collection system. 4. Decentralized composting in villages

Sr No.	Vulnerable Sectors	Climate Fragility Statements	Actors		Micro-Catchment Solutions
			Vulnerable Actors	Supporting Actor	
5	Agriculture	Short-duration and high-intensity rainfall does not ensure rainfall during proper phases of agriculture and can be harmful to crops and productivity.	Urban poor, women, slum dwellers, children	SMC, PHE	1. Water efficient pumps 2. Diversification of water portfolio to conserve water (recycling, recharge and reuse) 3. Decentralized wastewater treatment and use of treated wastewater for agriculture 4. Promotion of urban agriculture 5. Low water-intensive crops to improve agriculture production
		Less rainfall and rising temperatures can raise the demand for water, which will impact crop production and reduce the drinking water availability, impacting rural economy.	Farmers, women, children, elderly	Gram Panchayat, Collector's Office	
6	Heath	Short-duration high-intensity rainfall can dilute pollutants and improve water quality in the lake, reducing negative health impacts. Higher temperatures in summer and increased water demand can lead to heat strokes, impacting health.	Urban poor, women, slum dwellers, children, farmers, women, elderly	SMC, PHE Gram Panchayat	1. Management plan for heat strokes and awareness activities to reduce the impacts 2. Identification of "hot spots" and development of a Heat Action Plan for the city 3. Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes ('Catch them young') 4 Building institutional wisdom at local level to ensure integration across sectors in future, by training municipal engineers in using modernized systems of water and wastewater management

3.6.2. WEAP Scenario Analysis

A Water Evaluation And Planning (WEAP) model is used to analysis the unmet demand in the city and the rural areas. The impact of IUWM/IWRM intervention was analyzed on the overall water balance in the city as well as in the rural areas. Three scenarios were considered:

1. **Business As Usual Scenario (BAU):** Where the water is consumed as per the current rate and water conservation strategies are minimal. This, however, includes the proposed plans by the city and rural authorities.
2. **Climate change impact in case of BAU:** The impact on overall water availability in case of predicted changes in precipitation.
3. **IUWM scenario:** Impact on the water balance in case of implementation of IUWM-based interventions like water harvesting, leakage detection and recycling of water.

The analysis shows that in case of a business as usual scenario, the unmet demand in all the sectors in the catchment area will increase by 60 to 65 MLD. In case of climate change impacts on the BAU scenario, the overall unmet demand will increase to 70 MLD. The unmet demand can be reduced to 10 to 20%, if the IUWM interventions are implemented in the city. Similarly, the overall availability of the water supply will improve in case of the IUWM scenario.

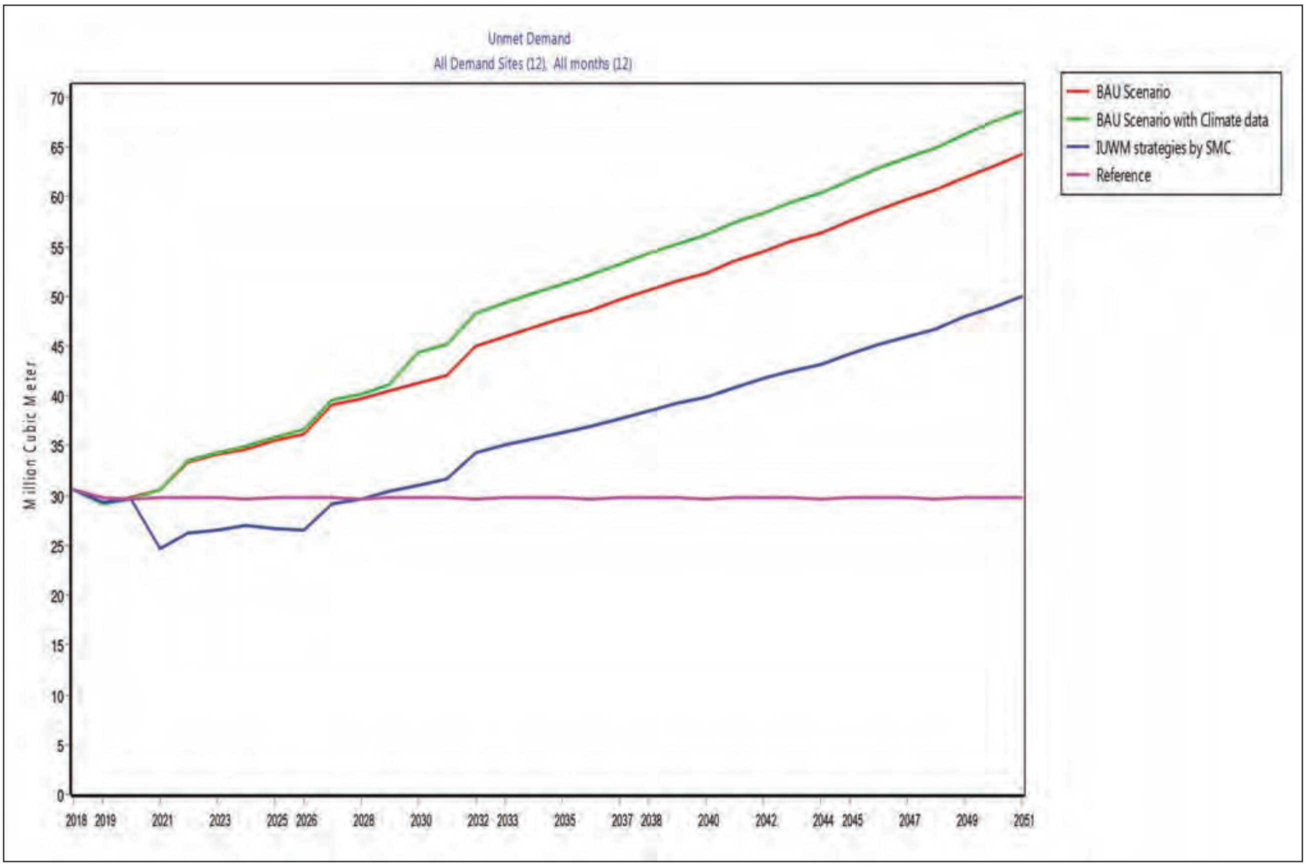

Figure 19: Outcomes of the WEAP Model Analysis – Unmet Demand

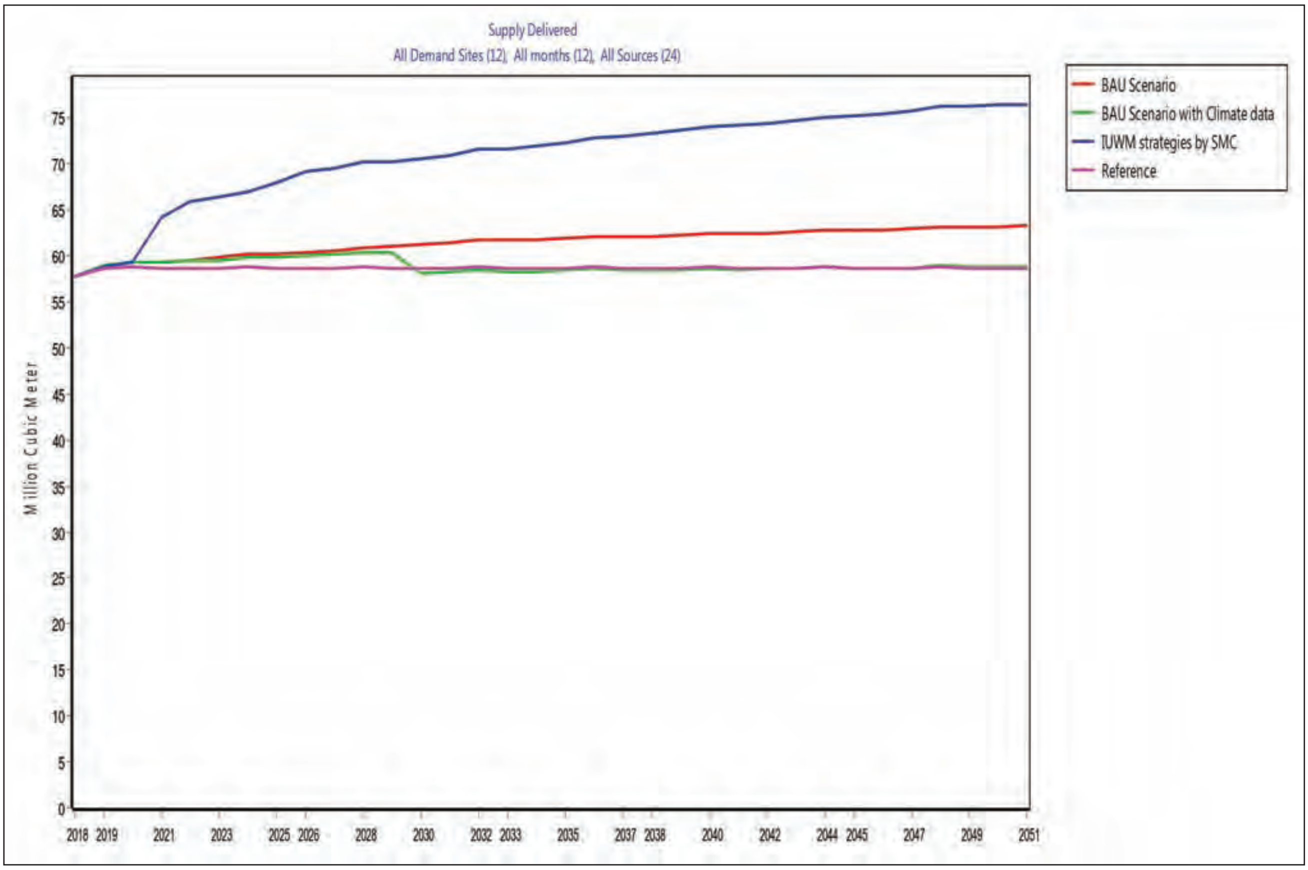

Figure 20: Outcomes of the WEAP Model Analysis – Supply Delivered

3.6.3. Project Prioritization Tool

The Project Prioritisation Matrix tool was used in an SLD to collaboratively assess the resilience and IUWM potential of identified projects to prioritise projects that would constitute the Action Plan for the micro-catchment area. A participatory approach is adopted for prioritisation of potential interventions to ensure social and environmental benefits, economic feasibility and community involvement. The resilience potential of the interventions were assessed in terms of their ability to increase the redundancy and flexibility of the water system, improve the ability of the system to respond to climate stresses and improve access to information on climate impacts and responses to climate stress. The IWRM potential of each intervention was assessed in terms of their potential to integrate all parts of the water cycle, consider various requirements for water, and take into account the local context and requirements of all stakeholders.

The prioritisation has been presented in Table 15.

Table 15: Prioritisation of Resilience Water Management Interventions

Prioritising resilience interventions									
Interventions and Solutions	**Resilience Indicators**				**IWRM Indicators**		**Overall Prioritisation**		
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/ Reorganisation (yes/no)**	**Access to Information (yes/no)**	**Consider all parts of the water cycle (yes/no)**	**Consider various requirements for water (yes/no)**	**Consider the local context (yes/no)**	**Consider requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – Average 7-8 yes – High**
URBAN									
Water									
Leak detection systems to reduce T&D losses	1	0	0	1	1	1	1	0	5
Construction of RWH pits in water logged areas	1	1	1	1	1	1	1	1	8
Recharge local bore-wells through rain water harvesting	1	1	1	1	1	1	1	1	8
Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes	1	1	0	1	1	0	1	1	6
Institutional wisdom: Building Institutional wisdom at local level to ensure integration across sectors in future by training Municipal Engineers in using modernized systems of water and wastewater management	1	1	1	1	1	1	1	1	8
Wastewater									
Reuse of treated wastewater for local parks	1	1	1	1	1	1	1	0	7
Community-level DEWATS systems	1	1	1	1	0	0	1	1	6
Promotion of urban agriculture through grey water reuse	1	0	0	1	1	1	1	1	6

Prioritising resilience interventions									
Interventions and Solutions	**Resilience Indicators**				**IWRM Indicators**		**Overall Prioritisation**		
	Redundancy (yes/no)	**Flexibility (yes/ no)**	**Responsiveness/ Reorganisation (yes/no)**	**Access to Information (yes/no)**	**Consider all parts of the water cycle (yes/no)**	**Consider various requirements for water (yes/no)**	**Consider the local context (yes/no)**	**Consider requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – Average 7-8 yes – High**
Stormwater									
Sustainable urban drainage systems (SUDS) based systems for an integration of natural sponges in city design	1	1	1	1	0	0	1	0	5
Stormwater runoff storage and diversion to local ponds /park	1	1	1	1	0	1	1	0	6
Revival of streams using RWH and bio filters, to reuse water for urban greenery	1	0	0	1	1	0	1	0	4
Solid Waste Management									
Improvement of institutional capacity and management for 100 % waste collection	1	1	0	1	0	0	1	1	5
Implementation of segregated waste collection system.	0	0	1	1	1	0	0	1	4
Decentralized plastic waste collection for revenue	0	0	0	0	0	0	0	0	0
Agriculture									
Promotion of urban agriculture	0	0	0	0	0	0	1	1	2
Health									
Management plan for heat strokes and awareness activities to reduce the impacts	1	0	0	0	0	0	1	0	2
Identification of "hot spots" and development of a Heat Action Plan for the city	1	0	0	0	0	0	1	0	2
RURAL									
Water									
Ground water recharge through rain water harvesting,	1	1	1	1	1	1	1	1	8
One water ATM at a school or village-level office (Panchayat ghar) in each village	0	0	0	1	0	0	0	0	1

Prioritising resilience interventions									
Interventions and Solutions	Resilience Indicators				IWRM Indicators		Overall Prioritisation		
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/ Reorganisation (yes/no)	Access to Information (yes/no)	Consider all parts of the water cycle (yes/no)	Consider various requirements for water (yes/no)	Consider the local context (yes/no)	Consider requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – Average 7-8 yes – High
Wastewater									
Construction of soak pits to reuse wastewater for secondary purposes	1	1	1	1	1	1	1	1	8
Promotion of Eco sanitation	1	0	0	1	0	0	0	0	2
Stormwater									
Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ekrukh	1	1	1	1	1	1	1	0	7
Bio remediation at inlet points around the Ekrukh lake	1	1	1	1	1	1	1	0	7
Identification of potential bore-wells for aquifer recharging	1	1	1	0	1	1	1	0	6
Solid Waste Management									
Decentralised composting in villages	0	0	1	1	0	0	0	1	3
Agriculture									
Water-efficient pumps	1	0	0	0	1	1	0	0	3
Decentralized wastewater treatment and use of treated wastewater for agriculture	1	1	1	0	1	1	0	0	5
Low water-intensive crops to improve agriculture production	1	0	0	1	1	1	1	0	5
Diversification of water portfolio (recycling, recharge and reuse)	1	1	1	1	1	1	1	1	8

Each of the interventions were also analysed in terms of their technical, socio- political and financial feasibility, as well as their timeframe. Both the duration in which the impact of the intervention can be felt and the criticality of the intervention in reducing water stress was assessed. The feasibility analysis is given in Table 16.

Table 16: Feasibility and Impact Analysis

Interventions and Solutions	Feasibility			Impact – Timeframe (short/medium/long term)	Impact - Criticality (high/medium/ low)	Cost
	Technical (high/ medium/ low)	Political (high/medium/ low)	Financial (high/medium/ low)			
URBAN						
Water						
Leak detection systems to reduce T&D losses	High	High	Low	1 to 5 years Medium Term	High	20,00000-50,00000/ward
Construction of RWH pits in water logged areas	High	High	Medium	Within one year-Short Term	Medium	500000-1000000/RWH Pit
Recharge local bore-wells through rain water harvesting	High	High	Medium	1 to 5 years Medium Term	High	Cost between Rs 2,0000 to Rs. 5,00,000 for buildings of about 200 sq. m. area
Awareness generation programmers through IEC activities and documentary films by involving youth, NGOs and local institutes	High	High	High	Within one year-Short Term	Medium	10,000-50,000/ward Depending upon number of households
Institutional wisdom: Building Institutional wisdom at local level to ensure integration across sectors in future by training Municipal Engineers in using modernized systems of water and wastewater management	High	High	Medium	Short Term	Medium	40,0000, 60,0000/ward
Wastewater						
Reuse of treated wastewater for local parks	Medium	High	Low	Short term	High	20,00000-50,00000/ward
Community-level DEWATS systems	High	High	Medium	Medium term	High	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Promotion of urban agricultural through grey water reuse	Medium	Low/Medium	Low	Long term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Stormwater						
Sustainable urban drainage systems (SUDS) based systems for a Integration of natural sponges in city design	High	Medium	Medium	Long term	High	160822.2 to 210000 (based on type of system / sources)
Stormwater runoff storage and diversion to local ponds /park,	Medium	Medium	Medium	Long term	High	
Revival of streams using RWH and bio filters to reuse water for urban greenery	High	Low /Medium	Medium	Medium term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately

Interventions and Solutions	Feasibility			Impact – Timeframe	Impact - Criticality	Cost
	Technical (high/ medium/ low)	Political (high/medium/ low)	Financial (high/medium/ low)	(short/medium/long term)	(high/medium/ low)	
Solid Waste Management						
Improve the institutional capacity and management for 100 % waste collection	High	High	Low	Short Term	Medium	20,00000-50,00000/ward
Implementation of segregated waste collection system.	High	High	Medium	Medium term	Low	58,000 to 70,000 depending upon number of households and density of population
Decentralized plastic waste collection for revenue	Medium	Medium	Low	Short Term	Low	100000-500000/ward Depending upon number of households
Health						
Management plan for heat strokes and awareness activities to reduce the impacts	High	Medium	Low	Short Term	Low	20,0000, 50,0000/ward
Identification of "hot spots" and development of a Heat Action Plan for the city	High	Medium	Low	Short Term	Low	20,0000, 50,0000/ward
Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes ('Catch them young')	High	Medium	Low	Short Term	Medium	20,0000, 50,0000/ward
RURAL						
Water						
Ground water recharge through rain water harvesting,	High	High	Medium	Medium term	High	Approximately Cost between Rs 2,0000 to 5,00,000 for buildings of about 200 sq. m.
One water ATM at a school or panchayat ghar in each village	High	Medium	Low	Short Term	Medium	300000 to 500000/ machine
Wastewater						
Construction of soak pits to reuse wastewater for secondary purposes	High	Medium	Low	Medium term	Medium	Approximately 20,000 t0 50,000 /pit based on material and filter technology used
Promotion of eco-sanitation	High	Medium	Medium	Medium term	low	Approximately 50,000 to 200000 /toilet

Interventions and Solutions	Feasibility			Impact – Timeframe (short/medium/long term)	Impact - Criticality (high/medium/ low)	Cost
	Technical (high/ medium/ low)	Political (high/medium/ low)	Financial (high/medium/ low)			
Stormwater						
Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ekrukh	High	Low/Medium	Medium	Medium term	Medium	160822.2 to 210000 (based on type of system / sources)
Bio-remediation at inlet points around the Ekrukh lake	Medium	Low/Medium	Medium/Low	Long term	Medium	5,00000 to 1500000 depending upon bio filtration method and number of constructed wetlands
Revival of streams using RWH and bio filters to reuse water	Medium	Low/Medium	Medium/Low	Long term	Medium	Approximately 13765550.00 to 48179425.00 depending on the level of contaminants in relation to the local discharge regulations
Identification of potential bore-wells for aquifer recharging	High	High	Low	Medium term	High	160822.2 to 210000 (based on type of system / sources)
Solid Waste Management						
Implementation of segregated waste collection system.	High	High	Medium	Medium term	Low	58,000 to 70,000 depending upon number of households and density of population
Decentralized composting in villages	High	High	Low	Short Term	Low	15000 to 25000/compost bed - vermi-composting
Agriculture						
Water efficient pumps	High	High	Medium	Short Term	Medium	Approximately 1,80,000 to 4,00,000/piece (solar pumps)
Diversification of water portfolio (recycling, recharge and reuse)	High	Low	Low	Long term	High	10,0000 to 25,0000 depending upon the level of interventions
Decentralized wastewater treatment and use of treated wastewater for agriculture	High	Medium	Low	Medium term	Medium	8-10 KLD capacity -Rs. 2.5-3 lakhs approximately
Low water-intensive crops to improve agriculture production	Medium	Medium	Medium	Long term	High	Depending upon the seed quality and availability

3.7. IAdapt Phase 5: Resilience Strategy for the Catchment - An Action Plan

Without significant and well-planned adaptation efforts, climate change is predicted to have a marked effect on livelihood and water security in the Ekrukh micro-catchment. However, there is considerable potential to adapt to climate change, particularly through enhanced focus on improved land and water management, the establishment of appropriate policies, capacity building of institutions and individuals, and the promotion of investments in land and water management with the use of catchment management approach, as seen in the sections above. Based on the results and analysis of the IAdapt framework, a set of strategies were identified for each vulnerable sector. A robust list of interventions was prepared from this assessment for further strategic prioritisation and discussed with the RURBAN Platform stakeholders. These projects are included in the IUWM Action Plan. A participatory approach was adopted for prioritisation of potential interventions to ensure social benefits, environmental benefits, economic feasibility and community involvement.

An action plan has been developed consisting of the prioritised interventions identified through discussions at an SLD. The prioritised strategies were linked with ongoing programmes and projects of the government (national, state, and local). Wherever possible, climate resilience interventions are linked with, or built into, existing departmental work plans to make them an integral part of the local development process. The action plan is a way of strengthening the resilience of local plans to achieve catchment-level results, rather than a standalone intervention. This helps to make the action plan sustainable without the need for separate budget decisions or funding from alternative sources.

Table 16 shows the Ekrukh micro-catchment action plan, indicating possible integration with existing plans and policies, the vulnerable areas and populations that it would improve and impact and the time-frame in which the intervention could be taken up.

Table 17: Action Plan for Ekrukh Micro-Catchment

Sector	Recommended Resilience Interventions	Vulnerable Areas	Target Actors	Relevant Programmes	Ongoing/upcoming/ Planned strategies under the programme	Time frame Short Term-0-1 year Medium Term-1 to 5 years Long Term more than 5 years
Urban						
Water	Leak detection systems to reduce T&D losses	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Citizens of extension areas, PHE, SMC, women	Smart City Mission, AMRUT	Ongoing, 1 Installation of universal metering for the selected area shall also be included.2.Project for source augmentation from Ujjani dam (perennial source) is proposed to be taken up under AMRUT. Physical components for pan city solution are: 1. SCADA systems 2. AMR Meters 3. GIS-based asset management systems 4. Other ICT hardware	Medium Term
	Construction of RWH pits in water logged areas	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Urban poor people, PHE, SMC, women	National Lake Conservation Plan, AMRUT	Strengthening stormwater management in the city Steps for Kambar lake (Sambhaji lake) conservation	Medium Term
	Recharge local bore-wells through rain water harvesting	City extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Urban poor people, PHE, SMC, women	AMRUT	Ongoing, 1 Recharge of 200 bore-wells in Solapur city	Medium Term
	Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes	Neelam Nagar, city extension areas, 40, 51, 19, 20, 28 (v high leakages), 33 (v high leakages), Nitin Nagar	Slum dwellers, poor people, PHE, SMC, women	Smart City Mission, AMRUT	Ongoing, 1 Installation of universal metering for the selected area shall also be included. 2. Project for source augmentation from Ujjani dam (perennial source) is proposed to be taken up under AMRUT. Physical components for pan city solution are : 1. SCADA systems 2. AMR Meters 3. GIS-based asset management systems 4. Other ICT hardware	Within one year-Short Term

Sector	Recommended Resilience Interventions	Vulnerable Areas	Target Actors	Relevant Programmes	Ongoing/upcoming/ Planned strategies under the programme	Time frame Short Term-0-1 year Medium Term-1 to 5 years Long Term more than 5 years
Wastewater	Reuse of treated wastewater for local parks	Ward 8,13,14,33,15, 25, 24 (wastewater drains are silted),	SMC, urban poor, slum dwellers	Smart City Mission	Efficient wastewater recycling and reuse (strengthening sewage collection network, tertiary treatment plant)	Short term
	Community level DEWATS systems	Ward 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2	SMC, urban poor, slum dwellers	AMRUT	E-toilets	Long Term
					Solapur	
	Promotion of urban agricultural through grey water reuse	Ward 41,40, 39, 20, 19, 18, 17, 4, 1, 9, 10, 30, 3, 2 (no wastewater drains)	SMC, urban poor, slum dwellers,urban farmers, migrant population	NA	NA	Long term
Stormwater drainage	Sustainable urban drainage systems	Ward 8,13,14,33,15, 25, 24 (wastewater drains are silted)	SMC, urban poor, slum dwellers,urban farmers, migrant population	Smart City Mission	Efficient use of public spaces (Development of stadium, akhada, Siddheshwar Lake, light and sound show, night market, gardens and parks)	Medium term
	(SUDS) based systems for an integration of natural sponges in city design					Medium term
	Stormwater runoff storage and diversion to local ponds /park,	City extension areas, old Solapur (near Siddeshwar Lake)	SMC, urban poor, slum dwellers, local Residents and local business men			Medium Term
	Revival of streams using RWH and bio-filters to reuse water for urban greenery					Medium Term
Solid Waste	Improve the institutional capacity and management for 100 % waste collection	City	SMC, local contractors	SBM	Clean city - 100% waste management. (primary waste collection and transportation. street sweeping waste transfer station E-toilets)	Short Term
	Decentralized plastic waste collection for revenue	Javed Molani Chowk	SMC, Local slum dwellers	SBM	Private partner is being engaged to collect, segregate and transport 100% of waste which will ensure 100% collections and treatment of waste in the city. 2 Waste-to-Energy (Thermophilic Bio-methanation) Plant of three megawatt (MW) capacity on PPP basis which is operational since last three years	Short Term

Sector	Recommended Resilience Interventions	Vulnerable Areas	Target Actors	Relevant Programmes	Ongoing/upcoming/ Planned strategies under the programme	Time frame Short Term-0-1 year Medium Term-1 to 5 years Long Term more than 5 years
Health	Management plan for heat strokes and awareness activities to reduce impacts	City	SMC, Local slum dwellers, Industrial workers	City	NA	Short Term
	Identification of "hot spots" and develop a Heat Action Plan for the city					Short Term
	Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes ('Catch them young')					Short Term
	Institutional wisdom: Building institutional wisdom at local level to ensure integration across sectors in future, through programme to train municipal engineers in using modernized systems of water and wastewater management					Short Term
Rural						
Water	Groundwater recharge through rainwater harvesting,	Local Bore-well, Wells	Framers, Poor,	Jalyukt Shivar Yojana, NREGA, MREGS,14 Vitt Aayog	Wells, Bore-wells of farmers in farm	Medium Term
	One water ATM at a school or panchayat ghar in each village	Tale Hipparaga, Haglur, Ekrukh		14 Vitt Aayog, NAREGA	In school or panchayat of three villages,	Short Term

Sector	Recommended Resilience Interventions	Vulnerable Areas	Target Actors	Relevant Programmes	Ongoing/upcoming/ Planned strategies under the programme	Time frame Short Term-0-1 year Medium Term-1 to 5 years Long Term more than 5 years
Wastewater	Construction of soak pits to reuse wastewater for secondary purposes	Hipparaga (Ekta Nagar, Samata Nagar, Joshi Galli, Manthalkar Wasti, Datt Nagar), Haglur(Ward No. 1, 2, 3)	Poor, Dalit	NREGA, 14 Vitt Aayog, Thakkar Bappa Adivasi, Paradhi Samaj Yojana, Sant Gadegababa Grampanchyat Yojana	Ongoing	Medium Term
		Ekrukh(Jahangir colony, Patel Galli, Holkar Galli, Jawed Mulani Chowk, Jamadar Galli)				
	Promotion of Eco sanitation				NA	Medium Term
Stormwater drainage	Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ekrukh	Hipparaga (Ekta Nagar, Samata Nagar, Joshi Galli, Manthalkar Wasti, Datt Nagar), Haglur (Ward No. 1, 2, 3)	Poor People, Dalit ,	14 Vitt Aayog, NREGA, Thakkar Bappa Adivasi Sudhar Yojana	NA	Medium Term
		Ekrukh(Jahangir Colony, Patel Galli, Holkar Galli, Jawed Mulani Chowk, Jamadar Galli)				
	Bio-remediation at inlet points around the Ekrukh lake				NA	Long Term
	Revival of streams using RWH and bio-filters to reuse of water	Ekta Nagar, Joshi Galli, Near to Bhikha Udanshiuve House,	Poor, Children,	14 Vitt Aayog, NREGA, National Watershed Development Projects,	NA	Long Term
		Ward No(1, 2)				
		Jahangir Colony, Jawed Mulani Chowk				
	Identification of potential bore-wells for aquifer recharging	Near to Ekrukh Lake	Farmers	Jalyukt Shivar Yojana, NREGA, MREGS,	Ongoing	Medium Term
Solid Waste	Implementation of segregated waste collection system.	In Tale Hipparaga, Haglur, Ekrukh Villages	BPL	NREGA	NA	Medium Term
	Decentralized composting in villages				NA	Short Term

Sector	Recommended Resilience Interventions	Vulnerable Areas	Target Actors	Relevant Programmes	Ongoing/upcoming/ Planned strategies under the programme	Time frame Short Term-0-1 year Medium Term-1 to 5 years Long Term more than 5 years
Agriculture	Water efficient pumps	All farmlands	Farmers, Poor	PMKSY, Drip Irrigation, NABARD	In all villages generally used the drip irrigation system for the crops.	Short Term
	Diversification of water portfolio (recycling, recharge and reuse)			14 Vitt Aayog, NREGA	NA	Long Term
	Decentralized wastewater treatment and use of treated wastewater for agriculture				NA	Medium Term
	Low water-intensive crops to improve agriculture production (Sorghum, Dragon Fruit, Pulses)			NREGA, Paramparagat Krishi Vikas Yojana, Rashtriya Krishi Vikas Yojana	Sugarcane is a cash crop, but needs a large amount of water. Crops like Dragon fruit, Sorghum, Pulses don't need a large amount of water.	Long Term

4. Monitoring and Evaluation Framework

The action plan for Ekrukh micro-catchment needs to be monitored during implementation and evaluation. This is possible by using the RURBAN Platform members, who would ensure an integrated implementation as both rural and urban stakeholders are present in the Platform.

The RURBAN Platform stakeholders can monitor the effectiveness of the plans in achieving their stated objectives and in delivering the outcomes that will underpin the rationale for the action plan. A monitoring procedure will include reporting on the plan and updates on the implementation of the action plan. It is proposed that the reporting should be done by a nodal officer at the rural level and the urban local authority who is responsible for implementation of water-related work in the region. If needed, a team may be formulated in the rural and urban local authorities for such reporting.

An annual discussion with the RURBAN Platform is proposed to understand the impact and effect of the implementation. After the completion of one project, the project prioritisation tool should be assessed and new projects could be selected.

The table below gives the monitoring framework for the prioritised water management interventions:

Intervention	Implementing Agency	Indicator	Responsibility of monitoring	Method/ tool of monitoring	Frequency of monitoring
Leak detection systems to reduce T&D losses	Public Health Engineering Department, SMC	Reduction in number of leaks in distribution system	Engineering Department, SMC	Complaints regarding leaks addressed	Monthly
Construction of RWH pits in water logged areas	Public Health Engineering Department, Public Works Department, SMC	Reduction in number of days of water logging	Public Health Engineering Department,	Time interval and frequency of water logging	Yearly
Recharge local bore-wells through rain water harvesting	Public Health Engineering Department, SMC, Ground water survey and development agency (GSDA)	Ground water level of various seasons and draft (usage)	Public Health Engineering Department, SMC	Water level indicators	Before and after monsoon, winter (3 times in a year)
Awareness generation programmes through IEC activities and documentary films by involving youth, NGOs and local institutes ('Catch them young')	Public Health Engineering Department, Smart City Cell, Education Department SMC, NULM, SMC	Number of events	Public Health Engineering Department, SMC	Target audience/ number of participants	Quarterly
Reuse of treated wastewater for local parks	Public Health Engineering Department, SMC	Litres of wastewater reused	Public Health Engineering Department, SMC	Litres of freshwater saved	Half yearly
Community level DEWATS systems	Public Health Engineering Department, SMC	Number of DEWATS systems	Public Health Engineering Department, SMC	Litres of wastewater treated	Half yearly
Promotion of urban agricultural through grey water reuse	Public Health Engineering Department, SMC, Horticulture Department	Area of agriculture under grey water irrigation	Public Health Engineering Department, SMC,	Litres of grey water used for urban agriculture	Quarterly
Sustainable urban drainage systems	Public Health Engineering Department, Public Works Department, SMC	Length of SUDS	Public Health Engineering Department, Public Works Department, SMC	In comparison with length of roads	Yearly (before monsoon)
SUDS-based systems for an Integration of natural sponges in city design	Public Health Engineering Department, Public Works Department, Town Planning Department, SMC	Number/length of SUDS	Public Health Engineering Department	Water level and quality	Half yearly
Stormwater runoff storage and diversion to local ponds /park,	Public Health Engineering Department, Public Works Department, SMC	Litres of water stored/diverted	Public Health Engineering Department,	Litres of fresh water saved	Half yearly
Revival of streams using RWH and bio filters to reuse of water for urban greenery	Public Health Engineering Department, Public Works Department, Horticulture Department, SMC	Area of urban greenery	Public Health Engineering Department	Quality of water flowing through streams	Quarterly
Improve institutional capacity and management for 100 % waste collection	Solid Waste Management Department, Health Department, SMC	Collection of waste	Solid Waste Management Department	Solid waste collection coverage and efficiency	Quarterly

Intervention	Implementing Agency	Indicator	Responsibility of monitoring	Method/ tool of monitoring	Frequency of monitoring
Decentralized plastic waste collection for revenue	Solid Waste Management Department, Health Department, SMC	Weight of plastic waste colleciton	Solid Waste Management Department,	Total revenue collected	Quarterly
Management plan for heat strokes and awareness activities to reduce the impacts	Disaster Management Department, Education Department, NULM, SMC	Number of activities	Disaster Management Department,	Reduced cases of heat stocks	Yearly
Identification of "hot spots" and develop a Heat Action Plan for the city	Disaster Management Department, SMC	Heat Action Plan and its implementation	Disaster Management Department, SMC	Reduced cases of people affected by heat waves	Yearly
Building Institutional wisdom at local level to ensure integration across sectors in future through programme to train Municipal Engineers to in using modernized systems of water and wastewater management	Public Health Engineering Department and General Administration Department	Number of events per year	Public Health Engineering Department	Number of events per year	Yearly
One water ATM at a school or panchayat in each village	Public Health Engineering Department, Education Department, SMC, Village Panchayat and Zillha Parishad	Number of water ATMs	Public Health Engineering Department, SMC and Village Panchayat	Number of people served	Quarterly
Construction of soak pits to reuse wastewater for secondary purposes	Individual Households, Village Panchayat and District Water and Sanitation Mission Cell, Zillha Parishad	Number of soak pits	Village Panchayat	Number of households without soak pit/sewage connection	Yearly
Promotion of Eco sanitation	Public Health Engineering Department, SMC, Village Panchayat and District Water and Sanitation Mission Cell, Zillha Parishad	Number of locations having eco-sanitation	Public Health Engineering Department, SMC, Village Panchayat	People served	Half yearly
Brown field site or retrofitting SUDS in existing settlement to improve water availability for Ekrukh	Irrigation/Water Resource Department, District Authority, Village Panchayat, District Water and Sanitation Mission Cell, Zillha Parishad	Number of SUDs or length	Irrigation/Water Resource Deparmtent, Village Panchayat	Water level of Ekrukh lake	Pre and post monsoon
Bio-remediation at inlet points around the Ekrukh lake	Irrigation/Water Resource Department, Village Panchayat, Zillha Parishad and District Authority	Number of bio-remediation plants	Irrigation/Water Resource Department	Water quality of Ekrukh lake	Quarterly

Intervention	Implementing Agency	Indicator	Responsibility of monitoring	Method/ tool of monitoring	Frequency of monitoring
Revival of streams using RWH and bio filters for reuse of water	Village Panchayat, District Water and Sanitation Mission Cell, Zillha Parishad and District Authority	Water quality	District Water and Sanitation Mission Cell, Zillha Parishad	Litres of water reused	Half yearly
Identification of potential bore-wells for aquifer recharging	Ground water survey and development agency (GSDA), District Water and Sanitation Mission Cell, Zillha Parishad	Number of bore-wells used for recharge	Groundwater survey and development agency (GSDA),	Ground water level	Water levels of pre and post monsoon and winter
Implementation of segregated waste collection system.	Village panchayat, District Water and Sanitation Mission Cell, Zillha Parishad	Weight of segregated waste collection	District Water and Sanitation Mission Cell, Zillha Parishad	Waste collection coverage and efficiency	Quarterly
Decentralized composting in villages	Village Panchayat, District Water and Sanitation Mission Cell, Zillha Parishad	Number of composting plants	Village Panchayat	Weight of waste treated in composting plant	Quarterly
Water efficient pumps	Public Health Engineering Department, Mechanical Department, SMC, Village Panchayat, District Water and Sanitation Mission Cell, Zillha Parishad	Number of water efficient pumps	Public Health Engineering Department, SMC, Village Panchayat	Water delivered through such pumps	Half yearly
Diversification of water portfolio (recycling, recharge and reuse)	Public Health Engineering Department, SMC, District Water and Sanitation Mission Cell, Zillha Parishad, Irrigation/Water Resource Department	Number of sources	Public Health Engineering Department, SMC, District Water and Sanitation Mission Cell, Zillha Parishad, Irrigation/ Water Resource Department	% of water delivered from various sources	Quarterly
Decentralized wastewater treatment and use of treated wastewater for agriculture	District Water and Sanitation Mission Cell, Zillha Parishad, Agriculture Department	Area of agriculture under irrigation (treated wastewater)	District Water and Sanitation Mission Cell, Zillha Parishad	Litres of wastewater treated	Quarterly
Low water intensive crops to improve agriculture production	Agriculture Department	Area of agriculture under low water intensive crop	Agriculture Department	Litres of water saved	Yearly
De-siltation of Ekrukh	Water resource department	Increase in capacity	Water resource department	Capacity enhancement	Yearly

Annexure 1: IAdapt Framework

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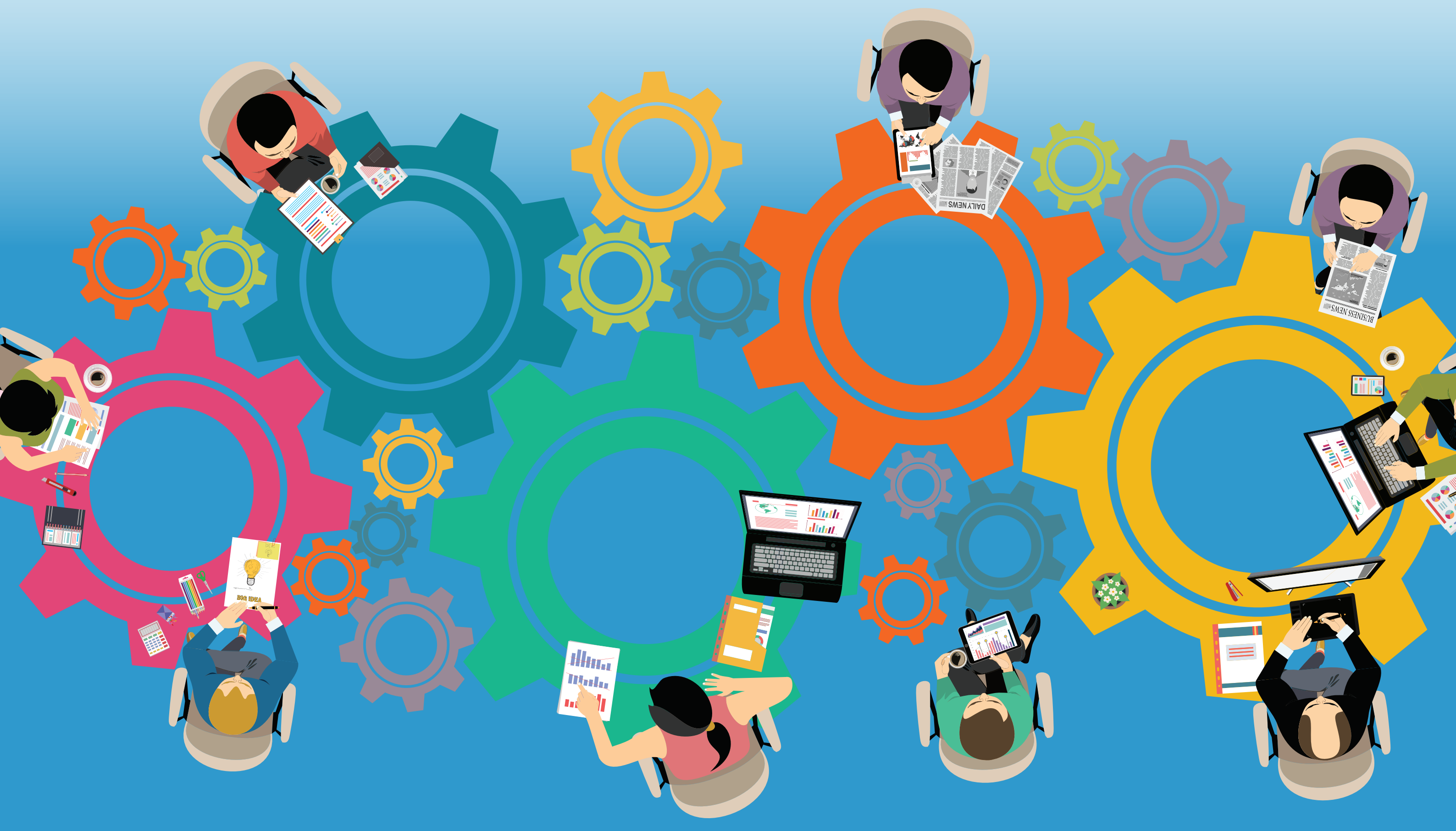
IADAPT FRAMEWORK FOR DEVELOPMENT OF CATCHMENT MANAGEMENT PLANS



Title

IAdapt Framework for Development of Catchment Management Plans

Under the Project

Integrated Rural Urban Water Management for Climate Based Adaptations in Indian Cities (IAdapt)

Supported by

International Development Research Centre (IDRC), Canada

Project Consortium

- ICLEI – Local Governments for Sustainability, South Asia
- Athena Infonomics LLC Pvt. Ltd.
- International Water Management Institute (IWMI)
- Indian Institute of Technology, Madras (IITM)

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Abbreviations

ACCCRN	-	Asian Cities Climate Change Resilience Network
CMP	-	Catchment Management Plan
GHG	-	Greenhouse Gas
GIS	-	Geographical Information Systems
GoI	-	Government of India
IAdapt	-	Integrated Rural Urban Water Management for Climate Based Adaptations in Indian Cities
IAM	-	Integration Assessment Matrix
IAP	-	ICLEI ACCCRN Process
IITM	-	Indian Institute of Technology, Madras
IPCC	-	Intergovernmental Panel on Climate Change
IUWM	-	Integrated Urban Water Management
IWMI	-	International Water Management Institute
IWRM	-	Integrated Water Resource Management
lpcd	-	Litres per capita per day
MLD	-	Million Litres per Day
NRW	-	Non Revenue Water
RURBAN	-	Rural Urban
TEEB	-	The Economics of Ecosystems and Biodiversity

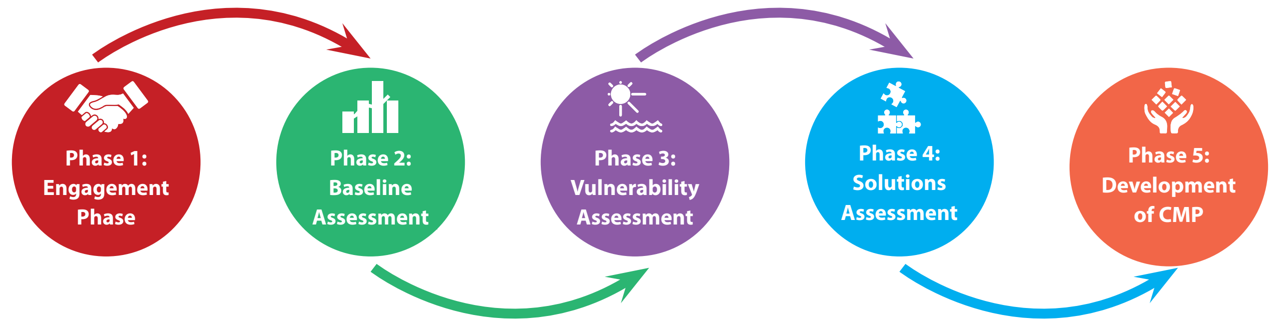
1. Introduction

Changes in key climate variables, such as temperature, precipitation and humidity, may have significant long term implications on the quality and quantity of water. Besides this, with increasing population and urbanization, there is an immense stress on water utilities.

Protecting water resources and ensuring sustainable supply is one of the priority development agendas in India, both at national and local level. Management and protection of catchments from where the water is drawn and promoting water nexus is at the heart of all smart city and regional planning. With changing climate scenarios and demographic profiles of urban areas, a catchment based approach is needed to ensure that mal-adaptation is avoided. No city or village can be considered in isolation, and therefore, a collaborative approach should be adopted while planning and designing water schemes.

ICLEI – Local Governments for Sustainability, South Asia, in partnership with Athena Infonomics LLC Pvt. Ltd., International Water Management Institute (IWMI) and Indian Institute of Technology, Madras (IITM) under the aegis of Integrated Rural Urban Water Management for Climate Based Adaptations in Indian Cities (IAdapt) Project has developed a framework to prepare catchment level water management plans. The project is funded by International Development Research Centre, Canada (IDRC). The overall objective of the project is to institutionalize climate change adaptation in water resource planning policies by implementing climate adaptive, integrated water management approaches through participatory planning, simple decision support tools and catchment management plans.

To help formulate catchment management plans (CMP), the project has developed the IAdapt Framework Toolkit. The IAdapt Framework is based on the ICLEI Asian Cities Climate Change Resilience Network (ACCCRN) Process or IAP toolkit, the Adopting Integrated Urban Water Management toolkit (AdoptIUWM toolkit) and The Economics of Ecosystems and Biodiversity (TEEB) methodology for ecosystem assessment.



Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
• RURBAN Platform: A Multi-stakeholder platform to bring together stakeholders	• Data acquisition and analysis from the catchment level, regarding the socio-economic, environmental, governance aspects	• Climate scenario assessment, water resource integration scoring, systems assessment, risk assessment and vulnerability assessment	• Resilience interventions and their prioritization • Decision Support Tool to relook at interventions in an integrated approach	• Catchment Management Plan • Implementation and monitoring

The Framework is designed to assist rural and urban local governments to come together and formulate catchment level water management plans guided by the principles of integrated water resource management. It promotes an integrated approach to ensuring water security, by looking at the interactions and interdependencies among water, waste water and storm water with other sectors such as health, agriculture, solid waste, industry, etc. It brings together different administrative, planning and regulatory systems by creating a RURBAN platform that includes both rural and urban stakeholders at various levels such as local authorities as well as civil society.

The IAdapt Framework consists of five phases and will assist in developing the Catchment Management Plan for selected catchments in the city-regions. The five phases are:

Phase 1: Engagement Phase

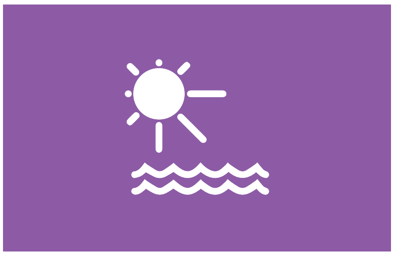
This phase includes formation of the core team and the RURBAN platform and engagements with both entities.

Phase 2: Baseline Assessment

This phase involves collection of socio-economic, environmental and governance data at the catchment level.

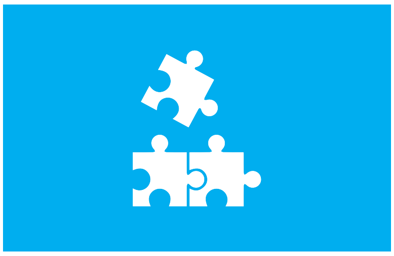
Phase 3: Climate Vulnerability of Water Resources

This phase includes climate scenario assessment, scoring of water resource integration, systems assessment and risk assessment, besides vulnerability assessment. It will help to select the particular sector/ issue for developing integrated solutions for water management.



Phase 4: Solutions Assessment

This phase includes selection of resilience interventions and their prioritisation.



Phase 5: Development of Catchment Management Plan (CMP)

This phase describes the structure of the Catchment Management Plan.

2. Phase 1: Engagement Phase

This phase outlines the institutional mechanisms that need to be established and defines the tools to identify and engage with all stakeholders in rural and urban areas.

2.1. Formation of Core Team

The identification of the core team members is a very crucial step as they will be responsible for driving the process. The core team may consist of representatives from city departments who have responsibilities for, or impact on, development planning, water use, pollution and waste, besides food security, water security, public health and local economic development, as well as infrastructure, and agricultural development. It is important to provide senior management support to the core team, to ensure that staff members working on the IAdapt Framework are directly supported in their day-to-day work by the management.

The core team is not a fixed body and new members can be added as and when required. Given below are a set of suggested responsibilities that the core team should commit to:

- Serve as representatives for their city government's divisions or sectors
- Lead the city government's efforts to participate in the programme
- Attend and participate in workshops to guide the IAdapt Framework implementation
- Ensure the IADAPT Process is followed in its entirety
- Secure the participation of multiple contacts in the city government in the programme
- Support in organising and delivering workshops and stakeholder consultations at different stages of the project, to gather relevant information from them and incorporate their suggestions and inputs as appropriate
- Coordinate the necessary communication and collaboration with all relevant departments and other stakeholders.

Two Project Nodal Officers – urban and rural – for the core team, who can act as the focal point for the process, also need to be identified. The main responsibilities of the Project Nodal Officers would be coordination and smooth execution of the tasks of the core team for implementing the IAdapt Framework. The officers' responsibilities may include:

- Organising meetings of the core team as per the agreed schedule.
- Facilitating communication and consultation with the core team.
- Tracking the progress of the IAdapt Process and informing the core team about completed and upcoming tasks.
- Facilitating data collection from various departments and other sources.
- A list should be prepared as per Table 1 identifying the core team members and their primary roles.

Table 1: IAdapt Core Team

Name	Position	Responsibility

2.2. Formation of RURBAN Platform

The IAdapt core team should formulate a Rural Urban (RURBAN) Platform involving key individuals from the district departments, state departments and officials representing urban and rural authorities, which will be responsible for interactions and discussions on integrated water management strategies and actions. This platform is a larger body who facilitates collaboration and participation from both rural and urban counterparts and prepares the CMP together with the Core Team and provides advisory services to the Core Team.

The RURBAN Platform is an active cross-sectoral network to facilitate inter-agency collaboration and participatory decision making on water management. It consists of decision makers and practitioners from relevant government departments and civil society. This unique platform brings together rural and urban stakeholders to plan for integrated water management.

The RURBAN Platform facilitates

- Exchange of information
- Collaborative Actions
- Formulation and design of plans

The members of the Platform should be identified using the characteristics outlined in Table 2 below.

Table 2: RURBAN Platform

Characteristics of the RURBAN Committee	Government (local, city, block , state)	Local NGOs / CBOs	Academia	Community Representatives	Private Sector	Any other important stakeholder
Has the ability to develop water strategies and actions at the community level						
Has the ability to develop water strategies & actions at the administrative level						
Whose support will be essential to implement water sector-related actions at different levels (e.g. community, city level)						
Those most affected by water related issues						

Once the members of the RURBAN Platform have been identified, an organisational framework needs to be decided upon. This includes formulating a vision and setting the terms and conditions of the Platform.

Vision

The core team along with the RURBAN Platform members should develop a vision, which states how they would like the region to be in the future, regarding water resource management (e.g. in 5 – 10 or 20 years). This vision could be guided by an existing vision statement of the city: first, note the various elements of the desired vision; then, discuss and formulate the Vision Statement. For example: *"By 2030 ….. micro-catchment area would have water infrastructure and systems that ensure the equitable provision of basic service to all and are climate resilient…."*

Terms and conditions of the RURBAN Platform

- The members of the RURBAN Platform shall be appointed for the period of the project duration. A member may resign his/her office by giving at least one month's notice in writing to the committee members, if he/she is completing his/her official term before the conclusion of the project. The core team can appoint a substitute official for the remaining period.
- The RURBAN members will meet at least twice in a year to review and receive updates on the status of the project. Meetings can be rescheduled or reorganised in case of emergency or any unforeseen event.
- A meeting of the RURBAN Platform members may be convened by the state office /district collectorate. The meeting's schedule, time, venue and maximum duration should be determined beforehand.
- At the meeting, the following shall preside -
  - The national and state government representatives
  - Two core team members, representing urban and rural areas
  - Collector or block representative
- The frequency of meetings should be based on the project plan.
- The quorum for the meeting of the RURBAN Platform members shall be at least half of the members of the committee, of whom at least two shall be state officers and at least four will be core team members.
- The nodal officer will be responsible for providing the project updates and status to the RURBAN Platform. The nodal officer can be responsible for ensuring the reporting and thereby monitoring of the project. The report will be finalised after the approval of the RURBAN committee. The comments and suggestions from the committee should be incorporated before the submission of the report.
- Every question or matter for decision or determination at a meeting shall be decided or determined by a majority of votes of the members present. In the event of a tie, the national government representative or state member presiding at the meeting shall have a casting vote.

2.3. Outcomes of Phase 1

- Identification of nodal officers
- Formulation of the core team
- Development of the RURBAN platform

3. Phase 2: Baseline Assessment

The baseline assessment will enable the collection of baseline situational information from the catchment area. It will have generic information from the villages and the parts of the city included in the catchment area. Table 3 provides an exhaustive list of data that should be collected as baseline. The Core Team and Nodal Officers should try to collect as much data from this list as possible.

Table 3: Micro-Catchment Baseline Questionnaire

Category	Unit	Data	Source of Data
Catchment level information			
Number of villages	Number		
Part of city included in the micro-catchment	Area		
Ecosystems / Biodiversity			
Area under green cover	Sq.km		
Types of ecosystems available (wetlands, riverine, forest etc.)	Number / area		
Provisioning services from water resources in the region			
Food: such as support to agro-ecosystems, freshwater systems, forests (wild foods from forests)	Yes/No		
Raw Materials: such as wood, biofuels and plant oils that are directly derived from wild and cultivated plant species	Yes/No		
Freshwater for drinking purposes	Yes/No		
Medicinal Resources: plants used in traditional medicines or as raw materials by the pharmaceutical industry	Yes/No		
Regulating services from water resources in the region			
Local Climate and Air Quality: temperature control, precipitation	Yes/No		
Carbon Sequestration and Storage: through water resources or trees	Yes/No		
Moderation of extreme events such as through wetlands, mangroves, trees	Yes/No		
Wastewater treatment	Yes/No		
Erosion prevention and maintenance of soil fertility	Yes/No		
Pollination	Yes/No		
Habitat or supporting services from water resources in the region			
Habitat for fish or birds that are important locally or as support to ecosystems	Yes/No		
Maintenance of genetic diversity through support to habitats of varied species	Yes/No		
Cultural services from water resources in the region			
Recreation and mental and physical health	Yes/No		
Tourism/economy	Yes/No		
Aesthetic or spiritual benefits	Yes/No		
Agricultural resources			
Total area of agricultural land	Sq.km		
Regional crop seasons	Months		
Primary crop	Names		
Secondary crop	Names		
Contribution to local economy, if possible	Percentage of total GDP		
Contribution to local food requirements, if possible	Percentage		

Category	Unit	Data	Source of Data
Water resources for the catchment			
Number of water bodies	Number, sq.km		
Major source of water supply (village wise)	List		
Classification of water bodies (ponds, lakes, rivers)	Number, sq.km, list		
Depth of groundwater table (village wise)	Metres, list		
Water quality (village wise)	As per pollution control board categories		
Major known water pollutants in micro-catchment	Info from FGDs – consider agricultural fertilisers, pesticides, and industrial effluents, etc.		
Demographics in catchment			
Population			
Total population in micro-catchment (village wise)	Number		
Total population in city			
Sex Ratio (village wise and for city)			
Number of households (village wise)	Number		
Average size of household	Number		
Floating/itinerant population[1]	Number		
Rate of annual inward migration, if possible	Persons/ year		
Rate of annual outbound migration, if possible	Persons/ year		
Employment			
Employment rates (%)	Percentage		
Nature of occupation	List		
Primary occupation	Percentage from list		
Secondary occupation	Percentage from list		
Informal sector[2]: numbers, categories			
Literacy			
Average literacy rate	Percentage		
Vulnerable groups			
Number of slums	Number		
Population living in slums	Number		
Population of minority groups	Number		
Number of Antyodaya Anna Yojana (AAY) families	Number		
Number of Below Poverty Line (BPL) families	Number		
Health			
Total number of deaths from calamities/ extreme climate events/ disasters (number/year) (village wise)	Number/year		
Total number of incidences of water-borne diseases in the city in the previous year (village wise)			
Total number of incidences of vector-borne diseases in the city in the previous year (village wise)			
Existing and proposed schemes or plan for the healthcare system	List		
Land			
Total area of micro-catchment (calculate from map)	Sq.km		
Zoning/ land use	Land use map with area		
Topography	Topographic map with ward/ zone/area		

1. a group of people who reside in a given population for a certain amount of time and for various reasons, but are not generally considered part of the official census count
2. The informal sector or informal economy is that part of an economy that is not taxed, monitored by any form of government or included in any gross national product (GNP), unlike the formal economy

Category	Unit	Data	Source of Data
Infrastructure			
Water supply			
Village Information			
Number of wells/hand pumps/community taps (village wise)			
Number of households (village wise) with piped water supply			
City Information			
Water supply distribution network	Maps to scale, with ward/zone/ area wise breakup; % coverage of network		
Number of authorised residential connections	Number of ward/zone/area wise distribution		
Number of authorised commercial connections	Number of ward/zone/area wise distribution		
Households with piped water supply	Number, percent		
Per capita supply [(total supply in MLDx10,00,000)/ population]	(lpcd)		
Households having water meters	Number, percent		
Taps, hand pumps, tube wells, tankers	Number		
Total amount of water supply (zone wise)	MLD		
Total amount of water demand (zone wise)	MLD		
Total non-revenue water (NRW) / unaccounted for water (UFW) (zone wise)	MLD		
Sources of freshwater for the city	Names and capacity in ML		
Distance from the city for each source	Kms		
Water treatment plant(s)	Number, capacity, location, ward/zone/area covered		
Catchment Information			
Existing and proposed schemes/plans from water supply			
Source of supply in the proposed scheme			
Sewage			
Sewage distribution network	Map with location of pumping stations and STPs and % coverage		
Total length of sewage network pipes	Ward/zone/area wise distribution		
Total length of underground sewage pipes	Kms		
Average age of network pipes	Years		
Volume of wastewater generated per day	MLD		
Volume of wastewater collected	MLD		
Volume of wastewater treated	MLD		
Volume of treated water reused	MLD		
Sewage treatment plant(s)	Number, capacity, location, ward/zone/area covered		
Outfall of main sewer lines	Place , distance from the city		
Level of treatment achieved at outfall (primary, secondary, tertiary)	type of treatment		
Households connected to sewage	Number, percent		
Households with septic tanks	Number, %coverage,		
Process of septage management	Collection, transportation, treatment and disposal process		

Category	Unit	Data	Source of Data
Coverage of pockets of urban poor by sewerage network and/or septic tank provision	Number, percent		
Existing and proposed schemes/plans for sewerage / septic tank or septage management			
Solid Waste Management			
Solid waste generated per day	TPD		
Amount of waste collected	TPD		
Amount of waste treated	TPD		
% of door-to-door collection			
% of waste segregation at the household level			
Solid waste treatment facility	Number, capacity, location, ward/zone/area covered		
Scientific landfills	Number, capacity, location, ward/zone/area covered		
Open dump sites	Number, capacity, location, ward/zone/area covered		
Existing and proposed schemes/plans for SWM			
Stormwater drainage			
Drainage distribution network	Map with ward/zone/area		
Total length of covered network	Kms		
Total length of uncovered network	Kms		
Areas prone to waterlogging in the city	Location, area, coverage in %		
Existing and proposed schemes/plans for drainage			
Governance			
What is the regional environmental plan or policy?	Name, year		
What is the regional disaster management plan or policy?	Name, year		
What is the regional climate change policy or plan?	Name, year		
Any policies, plans, guiding statements that are used to direct actions to reduce energy use and pollution?	Name, year		
What is the regional water management policy or plan?	Name, year		
Is there engagement and collaborative action among rural and urban administrative counterparts?	Yes/No/Partly		

3.1. Outcomes of Phase 2

- Detailed baseline data for the catchment
- Tentative priority sectors that need more exploration

4. Phase 3: Climate Vulnerability of Water Resources

In this phase, the core team, in consultation with the RURBAN Platform members, identify the climate risks to the fragile systems in the catchment. The water balance of the catchment along with the vulnerable areas and vulnerable populations are also assessed here.

4.1. Climate Scenario Assessment

This step helps to collate and analyse climate change data and generate at least one climate exposure scenario, or projection. Ideally, local climate data should be used; however, if this is not available, other sources can be used for conducting the analysis. An in-depth secondary study is conducted to identify how the climate is already changing, as well as how it is expected to change in the future due to changes expected in climatic factors such as average temperature, precipitation, sea-level rise and extreme events in the area.

Climate data collection

For each climate change condition, as much information as possible should be collected and put in the table below:

Table 4: Climate Data Summary

Changing Climate Condition	Assessments	Amount of Expected Change (Include baseline and planning horizon years)	Geographical area	Greenhouse Gas Emissions Scenario	Extent of variability	Level of confidence	Sources
Precipitation Change	Regional Assessments	*Example: 1268±225.2 mm to 1604±175.2 mm*	*Himalayan Region (Western Himalayas constituting of Jammu and Kashmir, Uttarakhand and Himachal Pradesh)*	*A1B scenario, IPCC*	*Overall increase in rainfall. June, July, August, September - 12mm January, February - 5mm October, November and December*	*High*	*4x4 Assessment report by GoI*
	Supplementary Local Assessments						
Temperature Change							
Extreme events							
Sea Level Rise							

Climate Scenario Statements

If there are both regional and local assessments, the data can be analysed to determine whether there is a consistent set of projections. If the results for a particular 'changing climate condition' are consistent for both the regional and local assessments, a single Climate Scenario Summary Statement can be written for that climate condition. However, if there are significant variations in the projections, you may need to develop two separate Climate Scenario Summary Statements for each of the assessments. Some specialist assistance may also be required for this process.

A Scenario Statements can be framed in the following manner:

"There is a... **<insert information from 'level of confidence'>**... degree of certainty of a...**<insert information from 'amount of expected change' i.e. the range>**... change in the...**<insert information from 'changing climate condition'>**...in the...**<insert information from 'geographical area'>**...by the year...**<insert information on the planning horizon year from 'amount of expected change' column>**. The projected change is expected to...**<insert information from 'extent of variability'>**."

The summary statements can be noted down in the table below.

Table 5: Summary of Climate Scenario Statements

Changing Climate Conditions	Assessments	Climate Scenario Summary Statements
Precipitation Change	Regional Assessments	
	Supplementary Local Assessments	
Temperature Change		
Extreme events		
Sea Level Rise		

From the scenario statements, the major climate risks for the catchment should be identified and listed by the team for use in subsequent steps.

4.2. Water Balancing

The core team will undertake the Water Balance Exercise. The water balance exercise identifies the demand-supply gap and helps to demonstrate alternative pathways to reduce this gap. It helps the catchment to move towards a demand-supply balanced approach without any additional water abstraction. Since Indian cities face issues related to water scarcity in summer, summer water balance is an additional indicator to be assessed for the water balance exercise.

The exercise has three steps:

1. The core team collects data for demand and supply related to existing scenarios of water sectors. The existing demand of water can be calculated on an average from the population and other bulk uses of water in the catchment – agriculture, industries, etc. The existing supply of water can be assessed from a random sample survey of the population in the catchment and other data that is available with the state water resource department or Groundwater Board.
   - Water demand urban areas: total population *135 lpcd[3]
   - Water demand rural areas: Total population *40 lpcd[3]

3. http://cgwa-noc.gov.in/LandingPage/Guidlines/NBC2016WatRequirement.pdf

2. The demand supply gap will be calculated for future population scenarios based on future population estimates. For sections where data is not available, realistic estimates can be used. Future population can be calculated as follows (arithmetic method):
   Average rate of change of population with respect to time, $C = dP/dt$, where dP is the change in population and dt is the change in time. Population after nth decade will be $P_n = P + n.C$ (1) Where, P_n is the population after 'n' decades and 'P' is present population.
3. The core team will assess the existing and future demand-supply gap and add the information in Table 6.

Table 6: Water Balance: Existing and Future Demand-Supply Gap

Parameter	Value (MLD)	
	Existing Scenario	Future Scenarios
Household Supply		
Total water supply		
Total water demand		
Demand and supply gap		
Alternative water use		
Supply for bulk uses		
Demand for bulk uses		
Demand-supply gap for bulk uses		
Total demand-supply bulk gap		
Summer water supply		
Summer water demand		
Summer: demand-supply gap		

Once the demand and supply gap is known, there is a need to look at options to reduce this gap using the principles of IWRM so as to achieve water balance in the catchment. The IWRM principles demand that the demand-supply gap be reduced using alternate approaches/options to meet the increasing water demand, without resorting to additional abstraction. Future scenarios need to be assessed to enable a transition from addressing demand-supply gaps to achieving demand-supply balance. Six key approaches for achieving the balance are:

1. Wastewater reuse
2. Stormwater reuse/recharge
3. NRW loss reduction
4. Per capita supply reduction
5. Revival of traditional practices (for water conservation) and local water bodies
6. Service provision, particularly to poor and marginalised

After using these key approaches for integration, the reduction in the demand and supply gap will provide us the Integration Value. These values can be used to calculate the demand-supply balance (refer Table 7).

Table 7: Water Balance: Demand-Supply Balance

Parameters	Business as Usual Scenario Value (MLD)	After Integration Value (MLD)	Business as Usual Scenario Value (MLD)	After Integration Value (MLD)
	Existing Scenario		Future Scenario	
Total supply available for household use				
Total supply available for bulk uses				
Demand-supply balance: household supply				
Demand-supply balance: bulk uses				
Total demand-supply balance				

Example

Water supply

A. Drinking: 30 MLD
B. Industries: 40 MLD
C. Green area/parks: 20 MLD

Total Water Supply, S: A+B+C = 90 MLD

Water demand

Population, P: 10000
Per capita consumption, C: 120 lpcd
Total Water Demand, D: PxC = 12000000 = 120 MLD

Water Supply Demand Gap: D-S = 30 MLD

Scenario after intervention

Integration solution of IUWM Approach: Wastewater reuse
Available water for reuse after treatment: 20 MLD
Integration Value is 20 MLD

Total water supply = water supply+ integration value: 90 + 20=110 MLD
Demand: 120 MLD
Water Supply Demand Gap: 10 MLD

Thus there is a reduction of 20 MLD in the supply demand gap.

4.3. Identification of Focus Sectors and Issues

For integrated water management, an analysis of water and its allied sectors is needed to understand existing situation and improvement needs. This can be done using the Integration Assessment Matrix (IAM). It is a self-assessment tool that contains questions, based on principles of IWRM, to assess the existing status of integration of water and allied sectors. It assesses the different water sources and uses in the micro-catchment and identifies whether different quality of water is used for different uses. The tool provides different indicator questions that tries to estimate the level of integration among water and its allied sectors. For each indicator question, possible responses are selected based on the situation in the catchment. Each possible response has been given a score in the matrix and the sum total of these scores give the total integration score.

The core team should discuss and assign a score to each indicator, based on the options best suited to the catchment. For indicators where accurate data is not available, the core team can use broad estimates that best depict the existing situation. The matrix is given in Table 9.

This tool will give:

a. Existing status of integration through an integration score for the catchment, which is a measurement of the extent to which different quality of water is used for different uses. This score should be compared with the Scoring Table below to get the existing status of integration across water sectors in the catchment.

Table 8: Scoring Table

Score	Status
Above 30	Excellent
Between 25-30	Good
Between 20 – 25	Average
Between 15 – 20	Poor
Less than 15	Critical

b. Strengths, Weaknesses and Quick Improvement Areas: The tool shows that:
   - All indicators with a high score are the strengths of the catchment.
   - Indicators with a medium score are the quick improvement areas, where with minimal intervention, improvements in the level of integration can be made.
   - Indicators with a low score would correspond to weaknesses of the catchment. These are critical areas that the city should focus on.

c. Focus issue based on Integration Assessment Matrix: The tool will indicate the issue/s that score low that should be addressed by the city on priority basis.

Table 9: Integration Assessment Matrix

<table>
<tr><th rowspan="2">Sr. No</th><th rowspan="2">Integration Indicators</th><th colspan="3">Criteria Scoring</th></tr>
<tr><th>Criteria/sub criteria</th><th>Scale</th><th>Selected Score</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Location of major water source(s) in the micro catchment</td><td>Main source(s) within micro-catchment boundary</td><td>3</td><td></td></tr>
<tr><td>Main source(s) located at district level</td><td>2</td><td></td></tr>
<tr><td>Main source(s) located outside district</td><td>1</td><td></td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Existing participatory process for integration of water sectors</td><td>All stakeholders and water sector departments are involved throughout planning and implementation (through stakeholder consultations)</td><td>3</td><td></td></tr>
<tr><td>No direct stakeholder involvement, comments invited after preparation of final plan</td><td>2</td><td></td></tr>
<tr><td>No involvement, plans prepared internally by government departments</td><td>1</td><td></td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Water portfolio for supply</td><td>Practicing Reuse, Recycle and Recharge - Traditional rainwater harvesting (RWH) structures and systems or new policies to recycle reuse</td><td>3</td><td></td></tr>
<tr><td>Water security plans using different sources of water (groundwater, surface water, pond)</td><td>2</td><td></td></tr>
<tr><td>No plan for water security, but supplies assured through single source (for next 10 to 20 years)</td><td>1</td><td></td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Water pollution</td><td>Water quality (surface and groundwater) within permissible limits</td><td>2</td><td></td></tr>
<tr><td>Polluted pockets are being confined; no mitigation plan/ measures yet</td><td>1</td><td></td></tr>
<tr><td>Critical level of surface water pollution (Coliform, BOD, DO level, eutrophication, etc.) and critical level of groundwater pollution (fluoride, arsenic, etc.) – no plans for mitigation</td><td>0</td><td></td></tr>
</table>

Sr. No	Integration Indicators	Criteria Scoring		
		Criteria/sub criteria	Scale	Selected Score
5	Link between water and energy	Link is realised and measures are taken (like use of renewable energy, energy efficiency, land use etc.)	2	
		Link is realised but measures are not taken	1	
		Link not recognised and no measures are planned	0	
6	Climate change and water resources	Impacts of climate change on water resources are recognised and adaptation measures are taken up	2	
		Need is recognised but no measures being taken	1	
		Need is recognised but no measures being taken	0	
7	Instances of water or vector-borne diseases (malaria, typhoid, jaundice, hepatitis, etc.	Not common	2	
		Occasional occurrence in some areas	1	
		Water-borne diseases leading to fatality and outbreak of epidemic in recent past	0	
8	Capacity (skills, resources, awareness, willingness) of administrative staff and other stakeholders	Capacity-related constraints are limited, addressed regularly	2	
		Addressed only in extreme cases	1	
		Capacity-related constraints not addressed at all	0	
9	Solid Waste Management	Segregated waste collection, treatment and disposal available; no impact on water quality or drainage	3	
		Simple collection without segregation, treatment and disposal available; low impact on water quality or drainage	2	
		Simple collection without segregation, no treatment, only disposal; medium impact on water quality or drainage	1	
		Open dumping, without collection or treatment; high impact on water quality or drainage	0	
10	Wastewater	Treatment system available to treat wastewater at least to secondary level, and septage management system available	3	
		Part sewer connection, and/or septage management available	2	
		No sewer connection, and septage management available	1	
		No sewers and no septage, link to open or natural drains	0	
11	Stormwater	Waterlogging due to encroachment of natural drains is frequent	1	
		Waterlogging due to encroachment of natural drains is infrequent	3	
12	Ecosystems	More than 50% green cover and supports at least 3 types of ecosystem services	4	
		Between 35-50% green cover and supports at least 2 types of ecosystem services	3	
		Between 20-35% green cover and supports at least 2 types of ecosystem services	2	
		Less than 20% green cover and supports 1 or no ecosystem service	1	
	Total Score			

The core team should prepare a summary sheet from the integration assessment matrix as per Table 10.

Table 10: Summary Sheet for Integration Assessment Matrix

Total Score	
Existing status of integration in the city (Excellent, Good, Average, Poor, Critical)	
Weaknesses	
Strengths	
Quick Improvement Areas	
Focus systems	

4.4. Fragile Systems Assessment

This exercise helps to analyse the fragile systems that have been identified through Table 10 as the focus issues or weaknesses or quick improvement areas. The systems may include 'core systems', such as water and food, essential for survival, and 'secondary systems' such as education and social services, which rely on the core services. This step helps to do the following:

1. Analyse of fragile systems i.e. the systems or services that are already weak or under great pressure, by looking at them through a water lens.
2. Assess the impact of climate change on these fragile systems.

The fragility of these systems are identified in terms of the characteristics of resilient systems - flexibility and diversity, redundancy and safe failure. This information can be obtained largely from the baseline questionnaire that collects information on these systems and through discussions in meetings with the RURBAN Platform and core team members.

Flexibility and Diversity – whether the sector is able to provide a mix of multiple options, so that key assets and functions are distributed or decentralised, and not all affected by a single event, and can function under a variety of conditions.

Example: A variety of water sources are used for water supply, rather than one centralised water treatment facility.

Redundancy – whether the system has alternatives / back-up systems / contingency plans, capacity for contingency situations, multiple pathways and options for service delivery in case one or several options fail.

Example: If the water treatment facility fails, tankers can be used to provide water for essential services.

Safe Failure – whether the system has the ability to absorb sudden shocks or slow onset stress so as to avoid catastrophic failure.

Example: Dikes are designed so that if their capacity is exceeded, they fail in predictable ways, channelling flooding away from populated areas.

The systems are also analysed in terms of the impacts of this fragility on other systems and services and the overall responsibility of these systems. The information is then collated to formulate a Fragility Statement for the system to define concisely why the system is considered fragile in the catchment.

Table 11: Fragile Systems Assessment

System	Why is it critical or fragile?	What are the existing and anticipated problems caused by the fragility of this system?	Responsibility	Fragility Statement
Example: Water Supply	*Flexibility & Diversity:* *Traditional water sources have been lost due to urbanisation and the city depends on centralized pumping systems that transport water from significant distances to the city. Supply cannot meet the growing demand* *Redundancy: Alternatives usually include water supplied by tankers (trucks). This is an expensive and polluting fallback option* *Safe failure: in case of a disruption in water supply, individual households have to fend for themselves.*	■ *Disruption of water supply to citizens* ■ *Additional financial burden on individual households to purchase water from water tankers* ■ *Increased pollution and emissions from the plying of water tankers*	*Shared with the Irrigation & Public Health Department*	*The water supply system in the city is old and largely dependent on transporting water over large distances, whereby even minor disruptions cause significant shortages in the city in the face of an ever growing demand; alternatives are not cost effective or sustainable*

To assess the impacts of climate change on the fragile systems identified in the table above, the core team should develop a Climate Fragility Statement for each fragile system. To do this, the core team should look at the climate risks (identified through the climate scenario assessment in Table 5) and consider the possible impacts of such risks on the fragility of these systems. This should be outlined in Table 12.

Table 12: Climate Fragility Statements

Urban System	Fragility Statement	Climate fragility statement Climate Risk 1: increased precipitation	Climate fragility statement Climate Risk 2: Increased temperatures
Example: Water Supply	*The water supply system in the city is old and largely dependent on transporting water over large distances, whereby even minor disruptions cause significant shortages in the city in the face of an ever-growing demand; alternatives are not cost-effective or sustainable*	*Increased precipitation disrupts / damages water supply infrastructure*	*Increased temperatures will lead to increased demand for water, thereby posing additional stress on the supply system*

4.5. Risk Assessment of Climate Fragility Statements

After the climate fragility statements for the fragile systems are identified, these should be prioritised on the basis of the likelihood of its occurrence and the consequence, if such a risk occurs. It is recommended that the core team conducts a workshop to assess the risk status. It is important to incorporate the views of all stakeholder groups as well. The Risk Assessment exercise should be undertaken jointly with the stakeholders as part of a consultation process through group exercises in the workshop. Every group can present their results and debate and finalise together the final scores of the exercise.

To assess the climate risks, the core team needs to score the likelihood and consequence of each climate fragility statement of each of the systems.

The likelihood of each risk can be assigned a score from 1 to 5 as per the table below. It is recommended that you refer back to the 'Level of Confidence' that has been assigned to each of the identified climate change conditions in Table No 4, which indicates whether the likelihood of occurrence is higher or lower.

Table 13: Likelihood Rating and Scoring

Likelihood Rating	Description	Score
Almost certain	Is highly likely to occur, could occur several times per year; Likelihood probably greater than 50%	5
Likely	Reasonable likelihood, may arise once per year; Likelihood 50-50 chance	4
Possible	May occur, perhaps once in 10 years; Likelihood less than 50%, but still quite high	3
Unlikely	Unlikely but should still be considered, may arise once in 10 to 25 years	2
Rare	Likelihood probability significantly greater than zero. Unlikely in foreseeable future – negligible probability	1

Next, for each climate risk, assess the consequence or impact, if the risk does occur. Consequences can be assigned a score from 1 to 5, where 5 is Catastrophic and 1 is Insignificant. Table 14 shows how to assess the different consequence rating, using "Impact on the System" and "Impact on the City Government" as measures. It is necessary to consider the impacts on both, the system as well as the poor and vulnerable, while deciding on the consequence ratings.

Table 14: Table 14: Consequence Rating and Scoring

Consequence Rating	Impact on System	Impact on poor and vulnerable and city government	Score
Catastrophic	System fails completely and is unable to deliver critical services; may lead to failure of other connected systems	Severe impact on poor and vulnerable groups in the city, leading to situations of extreme destitution	5
Major	Serious impact on the system's ability to deliver critical services; however, not a complete system failure	Loss of confidence and criticism in city government; ability to achieve city vision and mission seriously affected Significant impact on poor and vulnerable groups in the city that seriously affects their lives and livelihoods	4
Moderate	System experiences significant problems, but still able to deliver some degree of service	Moderate impact on the lives and livelihoods of the poor and vulnerable groups in the city	3
Minor	Some minor problems experienced, reducing effective service delivery, possibly affecting certain other systems or groups	Minor impact on the lives and livelihoods of the poor and vulnerable groups in the city	2
Insignificant	Minimal impact on system – may require some review or repair, but still able to function	Minimal impact on the lives and livelihoods of the poor and vulnerable groups in the city	1

The likelihood and consequence scores can be multiplied to get the Risk Score. The Risk Score can be compared to the Risk Matrix (see Table 15) to assess the Risk Status. This can be outlined in Table 16.

Risk Score = Likelihood x Consequence

Table 15: Risk Matrix

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium (RS=5)	Medium (RS=10)	High (RS=15)	Extreme (RS=20)	Extreme (RS=25)
Likely	Low (RS=4)	Medium (RS=8)	High (RS=12)	High (RS=16)	Extreme (RS=20)
Possible	Low (RS=3)	Medium (RS=6)	Medium (RS=9)	High (RS=12)	High (RS=15)
Unlikely	Low (RS=2)	Low (RS=4)	Medium (RS=6)	Medium (RS=8)	Medium (RS=10)
Rare	Low (RS=1)	Low (RS=2)	Low (RS=3)	Low (RS=4)	Medium (RS=5)

RS=Risk Score

Table 16: Prioritisation of Climate Risks

Climate Risk Statements	Likelihood	Consequence	Risk Score (Likelihood X Consequence)	Risk Status
Increased precipitation disrupts/ damages water supply infrastructure	4	4	16	High

The climate risk statements with high or extreme risks should be given priority during the solutions assessment in the later stages.

4.6. Vulnerability Assessment

In a workshop conducted by the core team with the RURBAN Platform members, vulnerability assessment should be carried out for the region, to identify the areas prone to the climate risks identified above and the social groups/communities/ stakeholders who are impacted by these risks in these areas.

Maps showing the distribution of the high priority climate risks across the catchment area are produced. This can be done using hard copies of the catchment map showing different village boundaries and city wards. Different colours representing different climate risk statements can be put in the areas that the core team perceives to be at greatest risk. The vulnerable areas for each sector can be identified on separate maps. Superimposing all the maps will create the vulnerability hotspot map indicating which area is vulnerable to most issues so that interventions can be targeted to these areas.

The core team should then identify the actors (i.e. individuals, households and public/private sector organisations) that can play a critical role towards building urban resilience. Their ability to contribute to water resilience is broadly dependent on the following three key capacities:

a. **Capacity to organise and respond** – whether the actor has the capacity to organise and re-organise in response to threat or disruption.

b. **Access to Resources** – whether the actor has access to the resources necessary to respond to stress (manpower, technology, funds).

c. **Access to information** – whether the actor can avail data and information necessary to develop effective plans and actions and to improve responses to disruptions.

The combination of these three characteristics would help to determine the adaptive capacity of each of the urban actors.

Adaptive Capacity Score = Capacity to organise and respond x Access to Resources x Access to Information

Table 17: Actors' Capacities Rating and Scoring

Key Capacities of Actors	Score
Capacity to Organise and Respond - in response to threat or disruption	
Low capacity	1
Medium capacity	2
High capacity	3
Access to Resources - necessary to respond (manpower, technology, funds)	
Low access	1
Medium access	2
High access	3
Access to Information – to develop effective plans for better responses to disruptions	
Low access	1
Medium access	2
High access	3

Table 18: Levels of Adaptive Capacity of Urban Actors

Adaptive Capacity Score	Level of Adaptive Capacity
1-8	Low
9-17	Medium
18-27	High

Adaptive Capacity Score for each actor is obtained by multiplying the scores allocated to each of the 3 characteristics. Actors having a 'Low' or 'Medium' level of adaptive capacity would be those that would need to be specifically targeted in the actions (or resilience strategies) that are undertaken in the catchment management plan. Actors with a 'High' level of adaptive capacity can be engaged in the proposed actions as they have the capacity to effectively respond to the impacts of the fragile systems. The information can be listed in Table 19.

Table 19: Actor Analysis

Climate Fragility Statements	Area/ward/ village	Actors	Capacity to Organise & Respond (A)	Resources (B)	Access to Information (C)	Adaptive Capacity Score (A)*(B)*(C)	Supporting Notes
Example: Contamination of water supply due to flooding made worse by lack of alternative sources	*Village Name*	*Slum dwellers*	*1*	*1*	*1*	*1 (low)*	*Dependent on shallow aquifers that are easily contaminated; access to water tankers too expensive; no information on water purification techniques*
		Private Sector	*2*	*3*	*2*	*12 (medium)*	
		RWA	*2*	*2*	*1*	*4 (low)*	
		Water Authority	*2*	*3*	*3*	*18 (High)*	
		NGO	*2*	*1*	*3*	*6 (low)*	

4.7. Outcomes of Phase 3

- Water balance of the catchment
- Climate scenarios and climate risks to the catchment
- List of fragile sectors in the catchment
- Vulnerable areas in the catchment
- Vulnerable populations in the catchment

5. Phase 4: Solutions Assessment

In this phase, the core team will use the information and analysis from Phases 2 and 3 to develop a list of possible interventions that will support integrated water resource management. These interventions will be screened and prioritised, linked to existing city plans, and assembled into a Catchment Management Plan.

5.1. Identification of Interventions for Catchment Water Resources

This step should be conducted by the core team and verified by the RURBAN Platform. All the climate fragility statements should be listed along with their vulnerable areas (villages, or city wards) and vulnerable actors (social groups) as identified through above exercises. Based on these, interventions and solutions will be identified and listed in Table 20. While selecting the interventions, it is important to remember to:

- Focus on the most vulnerable groups, sectors, neighbourhoods
- Develop measures to address current issues and to prevent future problems
- Aim for a mix of "hard" (e.g. infrastructure related) and "soft" (e.g. policy changes, capacity building) solutions
- Consider links with other existing plans and processes to facilitate implementation of the Catchment Management Plan.

Table 20: List of Interventions

Climate Fragility Statements	Vulnerable Sectors	Urban Actors		Micro-Catchment Solutions
		Vulnerable Actors	Supporting Actors	
Example: Contamination of water supply due to flooding made worse by lack of alternative sources	*Water, wastewater etc.*	■ *Slum Dwellers* ■ *Resident Welfare Association* ■ *NGOs*	■ *Private sector* ■ *Water Authority*	■ *Rooftop water harvesting and safe storage* ■ *Capacity building on hygiene and sanitation* ■ *Provision of low-cost, effective water purifiers*

5.2. Prioritisation of Interventions and Solutions

Once the interventions are selected, they are first assessed for their contributions to climate resilience using a set of resilience indicators and their contribution to integrated water management through a set of integration indicators. They are then assessed for their feasibility and impact.

The resilience indicators to be used for assessing the selected interventions include:

- **Redundancy:** The intervention should support redundancy and enable the system to work in a variety of ways. A resilient system can function and achieve results through multiple paths, so that if one path fails, the others still function. In contrast, a "single best solution" is not resilient because if this single option fails, the system collapses. Back-up systems, or decentralised nodes for service delivery in a linked network, are preferable.

- **Flexibility and diversity:** The intervention should enable the system to function in different conditions and work in spite of climate stresses and shocks. Essential systems should be able to work under a variety of conditions and not be rigid or designed only for one specific situation.
- **Re-organisation and responsiveness:** Under extreme conditions, the intervention should enable the systems to respond and change to meet unexpected shocks. This requires access to different kinds of resources (information, skills, equipment, knowledge and experience) and high level of coordination among departments.
- **Access to information:** The interventions should enable the system to measure all impacts of climate change. Resilient systems have mechanisms to learn from and build on experience, so that past mistakes are not repeated and lessons from other cities can be integrated into planning. This requires procedures for monitoring and evaluating that can be shared among different departments.

The contribution of the interventions to the principles of IWRM are also assessed to analyse their priority for the region. The primary concepts of IWRM are considered:

- **Consider all parts of the water cycle:** Whether the intervention helps to include different sources and forms of water into the water resources for the region.
- **Consider various requirements for water:** Whether the intervention helps to assign different quality of water for different uses.
- **Consider the local context:** Whether the intervention is locally relevant and addresses pertinent local issues
- **Considers requirement of various stakeholders:** Whether the intervention addresses requirements of different stakeholders in the region.

The core team should count and calculate the number of instances when these indicators are addressed (i.e., marked Yes). The overall prioritization score is calculated as per the number of instances where "Yes" occurs. The score is ranked as low, medium, average or high based on the rating given below:

- if yes occurs 1-2 times then the score is **"Low"**
- if yes occurs 3-4 times then the score is **"Medium"**
- if yes occurs 5-6 times then the score is **"Average"**
- if yes occurs 7-8 times then the score is **"High"**

Table 21: Prioritising resilience interventions – Example and exercise

Interventions and Solutions	Resilience Indicators (yes/no)				IWRM Indicators (yes/no)				Overall Prioritisation Score
	Redundancy	Flexibility	Responsiveness/Re-organisation	Access to Information	Considers all parts of the water cycle	Considers various requirements for water	Considers the local context	Considers requirement of various stakeholders	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
Example: Roof-top water harvesting to be made mandatory to deal with water stress due to anticipated increase in temperatures and decrease in precipitation	*Yes Supports a higher degree of self-sufficiency at the household level*	*Yes System allows for water to be channelised towards recharging groundwater as well*	*Yes In case of shutdown of the city's water supply system, households have stored rainwater for use*	*No City helplines exist, but responsibility lies with individual households*	*Yes Considers rainwater as a resource*	*Yes Assigns different quality of water to different uses*	*Yes Addresses local water scarcity*	*Yes All stake-holders can benefit*	*7*

Apart from building resilience, interventions should be checked for their feasibility and expected impact.

Feasibility can be assessed using the following criteria:

- **Technical:** The region has the necessary technical expertise to implement the project, or can access the required skills; the project is implementable, realistic and suitable to the local conditions.
- **Political:** The intervention will be seen as acceptable to city leaders and the community, and is consistent with the city's values and vision.
- **Financial:** The cost is within the capacity of the region, or the region will be able to access the required funds from the state or the central government, and the anticipated benefits of the action will justify the cost; any low hanging fruits that can be implemented quickly with minimal efforts and costs.

Impact can be assessed using:

- **Timeframe:** most actions should be completable within a short or medium timeframe.
- **Criticality or overall impact:** The proposed intervention should have a significant and measurable impact on the targeted climate risk

For each of these parameters, the core team should discuss and decide a scoring, such as low or medium or high for each intervention or solution. On the basis of these scores, a prioritised list of interventions and solutions will be developed for the catchment. The information should be listed in Table 22.

Table 22: Feasibility and Impact

Interventions and Solutions	Feasibility			Impact – Timeframe	Impact - Criticality
	Technical (high/ medium/ low)	Political (high/medium/ low)	Financial (high/medium/ low)	(short/medium/ long term)	(high/medium/ low)
Example: *Roof-top water harvesting to be made mandatory to deal with water stress due to anticipated increase in temperatures and decrease in precipitation*	*High (technology is easily available)*	*Medium (would require a change in building by- laws and building codes)*	*High (not an expensive option to implement with substantial results)*	*Short term (can be completed in a short time)*	*High (Can help to deal with water stress areas with immediate focus)*

5.3. Verification and Ratification

The interventions and solutions selected should be discussed in the RURBAN Platform to get their opinions and suggestions. Once they are discussed and ratified by the RURBAN Platform they can be integrated into the Catchment Management Plan for implementation and eventual evaluation. The District Collector and the Municipal Commissioner should be present in the meeting to discuss potential immediate actions.

5.4. Outcomes of Phase 4

- List of interventions for catchment water resources.
- Scoring and prioritisation of the interventions on the basis of resilience and IWRM principles.
- Feasibility and impact assessment of the prioritised interventions.
- Ratification by the RURBAN platform.
- Quick win projects selected from the list of interventions.

6. Phase 5: Catchment Management Plan (CMP) Formulation

This is the final phase which helps to collate all information from previous phases to develop the catchment management plan. A monitoring tool is also provided to facilitate implementation and regular evaluation of the plan.

6.1. Structure of the Catchment Management Plan (CMP)

The catchment management plan (CMP) should be developed while keeping in mind the overall fragility and vulnerability of the resources and the community. A typical structure of the integrated catchment management plan consists of the following sections:

Introduction: This section introduces the concept of integrated water resource management (IWRM, IUWM), the rationale of conducting a catchment management and reasons of adopting integrated approaches to assess the vulnerability to climate change. Methodology and approaches used to develop catchment management plan are also defined here.

1. What are the IUWM and IWRM principles applied to the catchment?
2. Benefits of adopting these approaches while developing catchment management plan, including the socio- economic and environmental benefits for the catchment.
3. Methodology of assessment
   a. Explanation of the different steps of the IAdapt Framework followed.
   b. Possible annexes and tools
      i. List of members of RURBAN Platform;
      ii. List of members of core team;
      iii. Public communications from the core team (for instance, minutes of meeting, newspaper cuttings, memos, etc).

Catchment profile: This section describes the nature and existing situation of the catchment for which the management plan is being developed and could have the following information:

- **Location of the catchment:** This will include the information about the main rivers and their tributaries and basins, information on area, number of water sources within the catchment and potential of the catchment area, location, number and capacity of dams within the catchment etc.
- **Demography:** This will include:
  a. Number of villages and urban centers;
  b. Population data – general v/s urban poor;
  c. Population projections.
- **Socio-economic profile:** This will include:
  a. Information on population, number of households, number of slums, marginalized groups, urban poor;
  b. Information on economic profile of the population, major livelihood activities and other development activities within the catchment;
  c. Urbanization pattern and percentage.

- **Climate pattern and geomorphology of the catchment:** This will include
  a. General climatic pattern of the city.
  b. Seasonal information on temperature, precipitation.
  c. Information on soil, slope and forest cover.
  d. Past events in the catchment – droughts, floods, cyclones etc.
     i. Date of occurrence of event;
     ii. Details of the event (for instance, reasons of occurrence of the event, details of the event);
     iii. Impacts of the event on life and livelihood of the citizens, urban systems, and environment;
     iv. Measures undertaken by the city or regional government to mitigate impacts of the event;
     v. Actions or measures undertaken by the city or regional government to address such occurrences in future, if any.

Integrated catchment management plan: This section provides information of the entire methodology of using the IAdapt Framework to develop the catchment management plan.

1. **Engagement phase:** This section describes the engagement with various stakeholders from rural and urban areas within the catchments to discuss the issues, develop strategies to overcome the challenges and implement best possible solutions. It should define:

   a. Formation of core teams from representatives of city departments who have responsibilities for, or an impact on, development planning, water use, pollution, waste, food security, water security, public health, local economic development, infrastructure, and agricultural development.

   b. Identification of Project Nodal Officer at the rural and urban level who can be the focal point for the process in the city.

   c. Formation of RURBAN platform for advice, discussion and prioritization of strategies identified by the core team and state officials. It should involve key individuals from the district departments, core team member and officials from State departments and Ministries representing urban and rural authorities.

2. **Baseline assessment:** This section outlines all data and information collected at the catchment level on water resources (water availability, water supply and water management), waste water, storm water and solid waste. All data collected on demography, including population characteristics and composition, health, exposure to disasters, as well as information on bio diversity and ecosystem services of various resources within the catchment is presented. Ongoing or proposed policies and programmes for water management at catchment level is also outlined.

3. **Assessing the climate vulnerability:** The water balance for the catchment is presented in this section, presenting the current and future stress on water resources due to urbanization, population growth and other economic development activities. Information from the integration matrix, information on the climate scenarios, data on the fragile systems, their climate risks and vulnerability, hotspot maps prepared and actors identified are presented in this section.

4. **Solution assessment:** The list of solutions or interventions prepared to combat vulnerability of the fragile sectors are outlined in this section. The interventions are presented along with their resilience and IWRM integration priorities, their technical, financial and political feasibility and their criticality and timeframe are outlined. This section should also outline any financing sources that may be available for the implementation of the interventions.

5. **Monitoring and evaluation framework:** This section outlines the monitoring and evaluation processes for the CMP implementation. The RURBAN committee will ensure a regular monitoring of the CMP and will monitor the effectiveness of the plans in achieving their stated objectives and delivering the outcomes.

6.2. Monitoring and Evaluation

Monitoring and evaluation processes is vital to successful implementation of the CMP. It helps to ensure that the plan is implemented and keeps a record of all targets achieved. Ideally the RURBAN Platform will ensure a regular monitoring of the catchment management plan and will monitor the effectiveness of the plans in achieving their stated objectives and delivering the outcomes. A monitoring procedure should be developed based on reporting on the implementation of the interventions and updated at regular intervals. The framework should identify the individual with responsibility of monitoring, the methods to be used for monitoring, and the frequency of monitoring of all the activities implemented. The monitoring framework is given in Table 23.

Table 23: Monitoring Framework

Intervention	Implementing Agency	Indicator	Responsibility of monitoring	Method/ tool of monitoring	Frequency of monitoring

Once the CMP implementation begins, annual discussion with the core team and RURBAN Platform members will help to understand the impact and effect of the implementation. Any updates to the CMP based on its implementation and changing targets/outcomes, should be recorded by the core team. The implementation monitoring table is given in Table 24.

Table 24: CMP Implementation Monitoring Table

Status of Implementation of the CMP				
Phase	Outcome	Responsibility	Methodology/tools	Status

6.3. Outcome of Phase 5

- Catchment management plan with monitoring framework

7. Conclusion

The IAdapt Framework is an indicative process for developing a catchment management plan in a manner that responds to both climate challenges and water issues of the catchment. This is a flexible tool and may be adapted to suit the requirements of a large number of cities and local governments and provides a step by step guidance to develop the catchment management plan. As one works through the process, it may be discovered that there are issues and groups of stakeholders that were not identified initially. There will be points where there is a need to consult external groups and points where there is a need to report back to the regional decision makers. It is therefore essential that the engagement decisions taken as per the Framework are reviewed regularly and updated.

The prime purpose of the Catchment Management Plan or CMP developed through the IAdapt Framwork is to assist local authorities with their own water management planning and execution, with focus on the climate impacts on this sector. The CMP will provide the necessary documentation to demonstrate the planning process followed by the local authorities. In order to ensure that the CMP is judged of good quality, it should have the following characteristics:

- The CMP must showcase the engagement at rural and urban levels through the formalized RURBAN Platform
- The CMP must consider future climate scenarios and climate vulnerability of water and its allied sectors.
- The CMP must consider current and future demands on water from both urban and rural users.
- The CMP must identify a mix of hard and soft interventions, long term and short term interventions and prioritise them
- The CMP must promote future sustainability and resilience and fulfil the "Do No Harm" principle
- The CMP must include mechanisms for integration with other regional development plans and include a component of monitoring and reporting

It must be mentioned here that the development of the Catchment Management Plan is only the beginning of a long way towards a water resilient future for the region. The Framework outlines means of monitoring and evaluation of the plan and these may be employed along with the local authorities own monitoring processes to assess the success of implementation of the plan and achievement of water resilience in the region.

NOTES

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Annexure 2: Methodology of Selection of Micro-Catchment

SWOT Analysis Report

Introduction

SWOT analysis (or SWOT matrix), an acronym for *strengths*, *weaknesses*, *opportunities*, and *threats*, can be used to measure the effectiveness and requirement of a project. It helps to identify the internal and external factors that are favorable and unfavorable to achieve the project objectives. The degree to which the internal environment of the project matches with the external environment is expressed by the concept of strategic fit.

- Strengths: characteristics that are advantagoes give it an advantage over others
- Weaknesses: characteristics of the project at a disadvantage relative to others
- Opportunities: elements in the environment that the project could exploit to its advantage
- Threats: elements in the environment that could cause trouble for the project

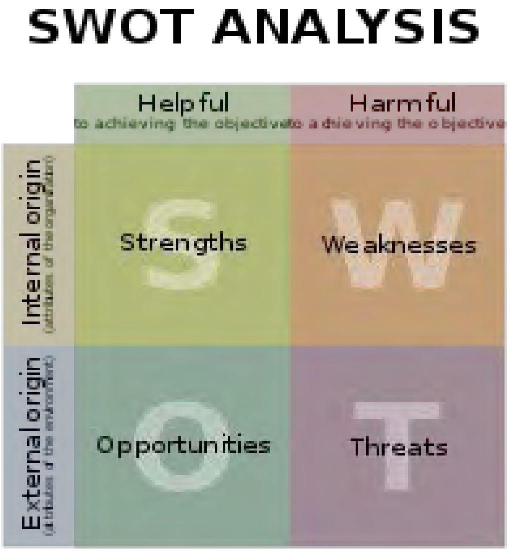

Figure 1: SWOT Analysis Method

Identification of SWOTs is important because they can inform later steps in planning to achieve the objective. SWOT analysis was used to identify the micro-catchment around each city where detailed project activities will be undertaken. The results drawn from the focus group discussions, key personnel interviews, inputs from officials and secondary data collected were used to carry out the SWOT analysis (refer Figure 2). The parameters that were used for the analysis include:

- Urban rural integration
- Biodiversity
- Pollution
- Regional significance of water bodies
- Agriculture and Economy
- Attitude of the community
- Related ongoing work

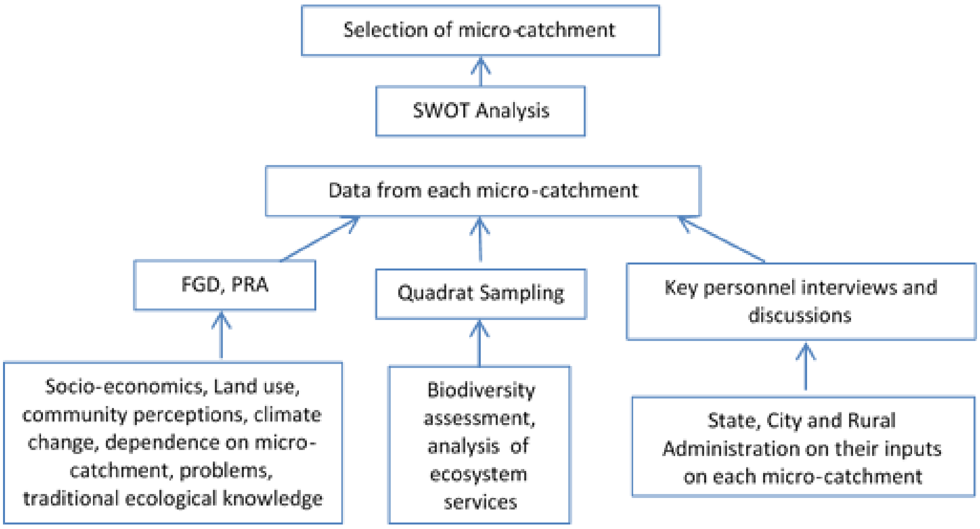

Figure 2: Inputs from various activities which were used for the SWOT analysis

SWOT Analysis of Urban-Rural Micro catchments in Solapur

Micro-catchment S1- Bale (within city), Kawathe, Degaon (within city), Gulwanchi	
Strength	**Weakness**
• Micro-catchment includes largest sewage treatment plant of Solapur Municipal Corporation. • Community has undertaken water conservation works like nallah (stream) widening, ground water recharge pits under various schemes by government. • Micro-catchment is close to Great Indian Bustard Sanctuary. • Highest Shannon Diversity.	• Untreated sewage discharged by Degaon stream and underground drainage is being used to irrigate sugarcane crop. • Issues like increased hardness of the ground water, smell, mosquito and sometimes colour in the water are very common in the villages in the micro-catchment. • Incomplete coverage of septic tanks and drainage system in the villages in the micro-catchment. • Villages in the micro-catchment close to the industrial belt are affected by pollution • High incidences of human-wildlife conflicts
Opportunity	**Threat**
• Planning is in progress to treat the wastewater till tertiary level in the sewage treatment plant and reuse for industrial purposes at National Thermal Power Corporation’s plant near Solapur, which will reduce stress on Ujani reservoir and increase water share for Solapur city.	• High levels of pollution in the water bodies can see further increase due to industries and sewage from villages. • Stress of rapid development and ignorance of villagers resulted into de-notification of some areas from wild life sanctuary

Strength 4	Weakness -5	Total -1
Opportunity 1	Threat -2	Total -1
Overall		-2

Micro-catchment S2 - Hotagi lake - Hotgi-Sawathed, Yatnal, Kumbhari	
Strength	**Weakness**
• Micro-catchment has second prominent lake in the region, serving for drinking water, irrigation and industrial uses. • Major sugarcane producing region and thus high dependency on the water supply from the lake. • Community has initiated water conservation projects like constructing weirs to recharge ground water under various schemes of government and CSR activities of industries	• High levels of pollution in lake, leading to loss of fish and related livelihoods. • Incomplete coverage of septic tanks and drainage system in the villages in the micro-catchment. • Discharge of untreated sewage and industrial wastewater have polluted nearby water bodies in the micro-catchment. • Agriculture area is reducing due to unavailability of water for irrigation. • Lowest Shannon Diversity
Opportunity	**Threat**
• Traditional practices of worship and protection of nature can be revived. • Industry and ecology co-existence can be retrieved	• High levels of pollution in the lake (Oil on water surface, odour and sometimes colour are prominent characteristics noted by community members) can see further increase due to pollution. • Villages in the micro-catchment are already facing water stress, which will further increase due to climate change • Politically and administratively sensitive area because of industries (sugar mill) • Rapidly developing micro-catchment affecting ground water quality and quantity

Strength 3	Weakness -5	Total -2
Opportunity 2	Threat -4	Total -2
Overall		-4

Micro-catchment S3 – Ekrukh lake - Tale hipparga, Haglur, Ekrukh, Tartgaon, 70% area of core city	
Strength	**Weakness**
• Close proximity of Ekrukh - major lake in the micro-catchment to city • Solapur Municipal Corporation and 10 more villages are sharing this water resource. • Community highly dependent on water from Ekrukh lake for their agricultural fields. • Community well aware of need for conservation and taking initiatives for	• Due to siltation over the period and inadequate rainfall, capacity of Ekrukh lake has reached nearly half of its original. • Unavailability of wastewater treatment plant in the neighboring villages leads to pollution of the lake due to gray water and septic tank discharge. • Solid waste treatment plant of the Solapur Municipal Corporation is

plantation, water conservation projects like constructing weirs to recharge ground water, recharge pits through various state level programs. • City government also wants this micro-catchment to be focused on to maintain quality and quantity at intake • Regional stakeholders are interested (ongoing lake conservation activities could be strengthened) • Relatively high Shannon Diversity. • Highest species abundance over time, as predicted through Rarefaction curve. • Micro-catchment also holds Sidhheashwar lake – an oldest lake of a region and pilgrim location in addition to Kambar lake - facing eutrophication issue.	defunct and leachate from this place might be adding pollution of the lake. • Severe from fertilizers and sewage discharged through runoff. Siltation and pollution may lead to eutrophication problem.
Opportunity	**Threat**
• Traditional culture of co-existence with nature can be revived. • Being a regional resource; efforts and initiatives would reach out to maximum population and set an example	• Further siltation and decreased rainfall due to climate change can lead to reduction in water supply from Ekrukh lake and increase stress on the micro-catchment.

Strength 9	Weakness -4	Total 5
Opportunity 2	Threat -1	Total 1
Overall		6

Micro-catchment S4 – Pakani, Shivani, Tirhe	
Strength	**Weakness**
• Micro-catchment harbours agriculture zones and industries. • Micro-catchment includes water treatment plant (80 MLD) of Solapur Municipal corporation on Ujani water supply scheme • Community has undertaken water conservation works like construction of weirs, widening of streams, recharge of open well, recharge pits and plantations various schemes by government and NGOs.	• Sinna river, a river in this micro-catchment, used to be a perennial river but construction of a dam, industrial development and wastewater discharge has transformed it to a seasonal water resources. • Industrial development, wastewater discharge and increased number of consumers resulted in pollution and stress on the available water resources. • Wastewater from industrial areas resulted in colour and odour problems in the agricultural fields in the micro-catchment.

Opportunity	Threat
• Close proximity to National Highway. • Industrial co-operation for runoff management can be acquired to reduce pollution of water resources	• Increased industrial and infrastructural development along with climate change will put additional stress on the water resource in future.

Strength 3	Weakness -3	Total 0
Opportunity 1	Threat -1	Total 0
Overall		0

SWOT Analysis of Urban-Rural Micro catchments in Vijayawada

Micro catchment V1:	
Strengths	**Weaknesses**
• In the rural areas, agriculture is the dominant occupation with many practicing fishing as another means of livelihood • Water demand for irrigation is met through the *Pattiseema* project	• Limited drinking water supply in few areas of the micro-catchment including hilly areas • Irrigation water availability from *Tummalapalem* lift irrigation is dependent on upland condition • Poor drinking water quality within the micro-catchment compels households to purchase drinking water from RO plants • The storm water drains are open and mostly blocked causing bad odour, flooding of waste water and rampant breeding of mosquitos often leading to outbreak of vector-borne diseases in some of the villages/wards in the micro-catchment • Villages in the micro-catchment have had crop losses due to cyclone impact • The urban area of the micro-catchment is currently poorly connected by UGD network • Most urban households/apartments have a private borewell connection indicating disappointment over the current water supply thereby causing over exploitation of ground water
Opportunities	**Threats**
• The larger community is aware about the metrics of climate change and its likely impacts • The city is being connected by storm water drains and proposed to be connected by underground	• There is no conscious effort by the government/ community to recharge the ground water • Not every official agrees with climate change as a phenomenon which could bring about severe

sewage drains • Many sewage pumping stations have been proposed in the urban area of the micro-catchment • A barrage is being proposed near Vijayawada to allow for more storage (prevent discharge of surplus water from Prakasham barrage to the sea) and to prevent salinity creep.	harmful impacts if climate resilience and adaptation is not considered. There is very less co-ordination observed among departments in the water and sanitation sector • Budgetary constraint is preventing the ULB from constructing more STPs. The proposed no. of treatment plants is not enough to hold the capacity of Vijayawada's sewage and storm water in the future years

Strength 2	Weakness -7	Total -5
Opportunity 4	Threat -3	Total 1
Overall		-4

Micro catchment V2:	
Strengths	**Weaknesses**
• In the rural areas, the micro-catchment is observed to be harvesting multiple crops • Water demand for irrigation is met through the *Pattiseema* project • Rain water harvesting irrigation tanks exist in few rural areas of the micro-catchment • In return for utilising the old quarry area in one of the villages for the city's solid waste dumping, the village is allowed to procure drinking water from the adjacent ward which is supplied water by VMC.	• Due to shortage of surface water, irrigation canals are filled only during the Kharif season. This shortage of surface water for irrigation leads to overexploitation of ground water by farmers. Due to this over exploitation, there is drop in ground water level rendering to higher costs in pumping water from a deeper level to meet irrigation needs • Most urban households/apartments have a private borewell connection indicating disappointment over the current water supply thereby causing over exploitation of ground water. They are compelled to rely on tankers during summers • A village's households who go to the adjacent ward to collect drinking water tend to have conflicts during collection. • Post *Pattiseema* project, the water quality has become unfit for drinking thereby creating a shift towards purchasing RO drinking by households who can afford to. • Losses during transmission of water supply in the urban areas is observed to cause reduction in water supply quantity. • During rains, flooding of storm water and irrigation canals occur in several areas of the micro-catchment. • The drains are open and mostly

	blocked causing rampant breeding of mosquitos often leading to outbreak of vector-borne diseases in some of the villages/wards in the micro-catchment • Occurrence of skin diseases have also been reported due to poor quality of water used for domestic purposes. • The urban area of the micro-catchment is poorly connected by UGD network
Opportunities	**Threats**
• The city is being connected by storm water drains and proposed to be connected by underground sewage drains • There is a proposed remediation of all solid waste dumping grounds where the land may be converted into an open space thus creating a natural aquifer for ground water recharge. • There is a proposal to lay new water supply lines reducing loss in transmission in some urban areas of the micro-catchment • The larger community is aware about the metrics of climate change and its likely impacts • A barrage is being proposed near Vijayawada to allow for more storage (prevent discharge of surplus water from Prakasham barrage to the sea) and to prevent salinity creep.	• There is no conscious effort by the government/ community to recharge the ground water • Not every official agrees with climate change as a phenomenon which could bring about severe harmful impacts if climate resilience and adaptation is not considered. There is very less co-ordination observed among departments in the water and sanitation sector • The newly constructed storm water drains will be diverted to the three irrigation canals causing even more water pollution. Eluru, Bandar and Ryves canals are being used by rural communities for domestic, irrigation purposes. The polluted irrigation canals, after serving their purpose, is diverted into sea without any treatment • Budgetary constraint is preventing the ULB from constructing more STPs. The proposed no. of treatment plants is not enough to hold the capacity of Vijayawada's sewage and storm water in the future years

Strength 4	Weakness -9	Total -5
Opportunity 5	Threat -4	Total 1
Overall		-4

Micro catchment V3:	
Strengths	**Weaknesses**
• In the rural areas, agriculture is the dominant occupation • Government has subsidised RO drinking water for rural areas through the NTR Sujala Scheme • The micro-catchment has a significantly high Shannon diversity and high species abundance. • Agriculture is practiced by few	• Due to shortage of surface water, irrigation canals are filled only during the Kharif season. This shortage of surface water for irrigation leads to overexploitation of ground water by farmers. Due to this over exploitation, there is drop in ground water level rendering to higher costs in pumping water from a deeper level to meet

households living in the urban areas due to their proximity to peri-urban agricultural lands and irrigation canals • There is a fair amount of UGD coverage in the urban area of the micro-catchment • There are 4 Sewage Treatment Plant (STP) in the rural and urban areas of the micro-catchment	irrigation needs. • The drains are open and mostly blocked causing rampant breeding of mosquitos often leading to outbreak of vector-borne diseases in some of the villages/wards in the micro-catchment • Flooding of waste water is perceived to be polluting the ground water on which households depend for their domestic and drinking water use. • Poor drinking water quality from ground water is creating a shift towards purchasing RO drinking by households who can afford to. • Climate induced heat waves has led to few deaths in the rural areas of the micro-catchment • Sewage and industrial waste in the urban areas of the micro-catchment is released into Ryves, Eluru, Bandar canals – the main source of water for irrigation and its water is also used for household purposes by few locals. • Villages in the micro-catchment have had crop losses due to cyclone impact • There are households in the micro-catchments who do not have an individual water connection • Most urban households/apartments have a private borewell connection indicating disappointment over the current water supply thereby causing over exploitation of ground water
Opportunities	**Threats**
• There is a proposed capacity augmentation of the Sewage Treatment Plant (STP) in the rural area of the micro-catchment • The city is being connected by storm water drains and proposed to be connected by underground sewage drains • There is a proposal to lay new water supply lines reducing loss in transmission in some urban areas of the micro-catchment • The larger community is aware about the metrics of climate change and its likely impacts • Many sewage pumping stations have been proposed in the urban area of the micro-catchment • A barrage is being proposed near Vijayawada to allow for more storage	• There is no conscious effort by the government/ community to recharge the ground water • Not every official agrees with climate change as a phenomenon which could bring about severe harmful impacts if climate resilience and adaptation is not considered. There is very less co-ordination observed among departments in the water and sanitation sector • The newly constructed storm water drains will be diverted to the three irrigation canals causing even more water pollution. Eluru, Bandar and Ryves canals are being used by rural communities for domestic, irrigation purposes. The polluted irrigation canals, after serving their purpose, is diverted into sea without any treatment

(prevent discharge of surplus water from Prakasham barrage to the sea) and to prevent salinity creep.	• Budgetary constraint is preventing the ULB from constructing more STPs. The proposed no. of treatment plants is not enough to hold the capacity of Vijayawada's sewage and storm water in the future years

Strength 6	Weakness -9	Total -3
Opportunity 6	Threat -4	Total 2
Overall		-1

Micro catchment V4:	
Strengths	**Weaknesses**
• In the rural areas, agriculture is the dominant occupation with many practicing fishing as another means of livelihood • The micro-catchment has is observed to have the highest Shannon diversity among all micro-catchments • There are 2 Sewage Treatment Plants (STP) in the industrial estate of the city • A barrage is being proposed near Vijayawada to allow for more storage (prevent discharge of surplus water from Prakasham barrage to the sea) and to prevent salinity creep.	• Industrial pollution from Jawaharlal Nehru Autonagar Industrial Estate is discharged into Eluru and Ryves irrigation canal causing bad odour for residents in the micro-catchment as well affecting the agriculture irrigated by the canal water. • During rains, there is an occurrence of flooding of the canals causing skin diseases and other health concerns when residents come in contact with the polluted water. • The drains are open and mostly blocked causing rampant breeding of mosquitos often leading to outbreak of vector-borne diseases in some of the villages/wards in the micro-catchment • Poor drinking water quality within the micro-catchment compels households to purchase drinking water from RO plants. • In the rural area, where the dependency for drinking and domestic water is from ground water, health concerns have been reported. • The urban area of the micro-catchment is poorly connected by UGD network • Most urban households/apartments have a private borewell connection indicating disappointment over the current water supply thereby causing over exploitation of ground water
Opportunities	**Threats**
• The larger community is aware about the metrics of climate change and its likely impacts • The city is being connected by storm water drains and proposed to be connected by underground sewage	• There is no conscious effort by the government/ community to recharge the ground water • Not every official agrees with climate change as a phenomenon which could bring about severe harmful impacts if

drains • Few sewage pumping stations have been proposed in the urban area of the micro-catchment	climate resilience and adaptation is not considered. There is very less co-ordination observed among departments in the water and sanitation sector • The newly constructed storm water drains will be diverted to the three irrigation canals causing even more water pollution. Eluru, Bandar and Ryves canals are being used by rural communities for domestic, irrigation purposes. • Budgetary constraint is preventing the ULB from constructing more STPs. The proposed no. of treatment plants is not enough to hold the capacity of Vijayawada's sewage and storm water in the future years • The polluted irrigation canals, after serving their purpose, is diverted into sea without any treatment

Strength 4	Weakness -7	Total -3
Opportunity 3	Threat -5	Total -2
Overall		-5

Annexure 3: Hydrological and Climate Modeling of Solapur

Hydrological and Climate Modeling of Solapur

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1 INTRODUCTION

1.1 General

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

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

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

1.2 Climate Change and Its Impact

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

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

Evidence for rapid climate change:

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

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

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

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

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

1.3 Assessment of Water Availability

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

1.4 Sustainable Development Plan

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

1.5 Objectives

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

The specific objectives of the project include:

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

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

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

2 METHODOLOGY

2.1 General

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

2.2 Watershed Delineation

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

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

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

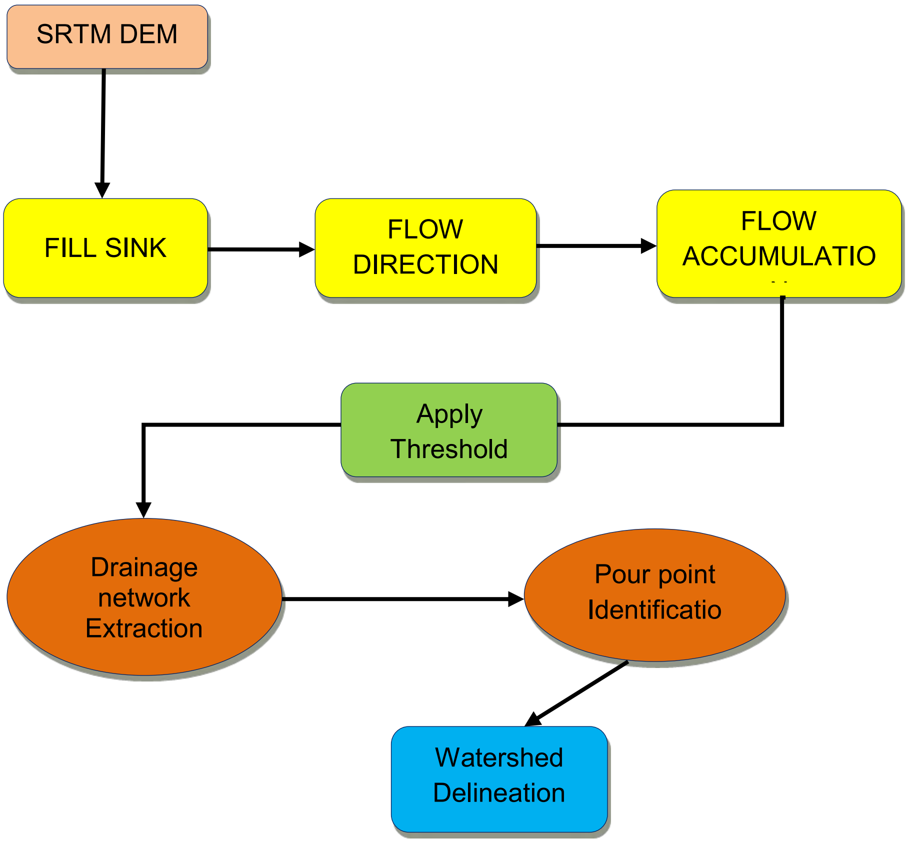

Figure 2.1: Flow Chart for Delineation of Watershed

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

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

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

2.3 Trend Analysis

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

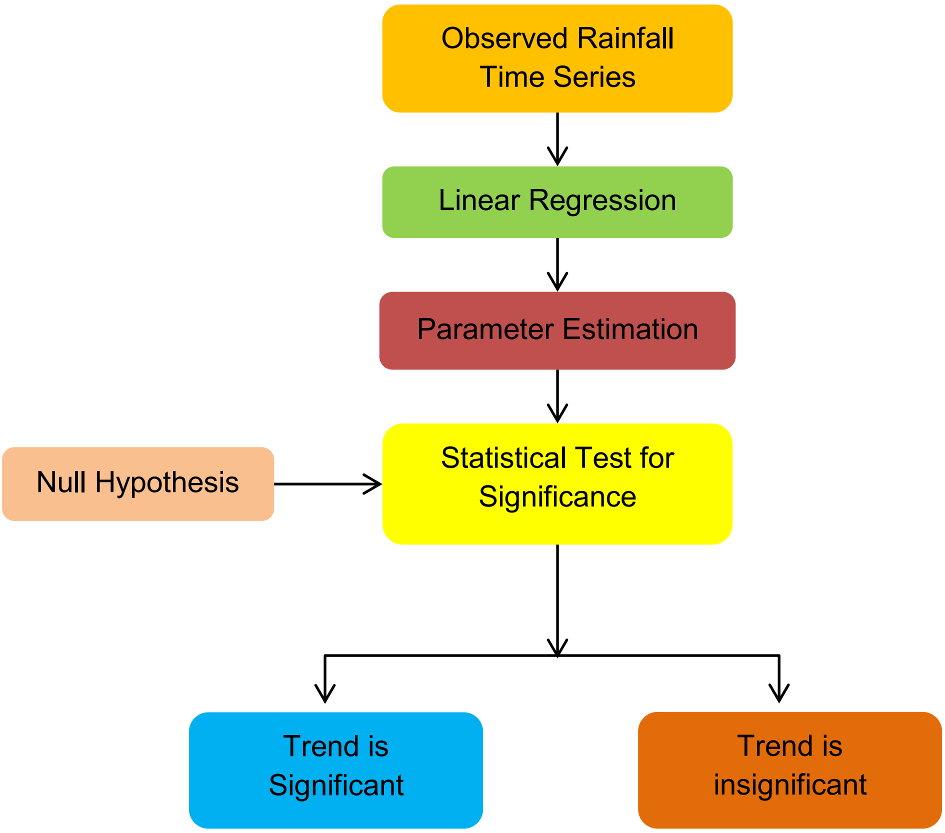

Figure 2.2: Flow chart for Trend analysis

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

2.4 Climate Change and its Assessment

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

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

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

2.4.1 General Climate Models (GCMs)

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

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

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

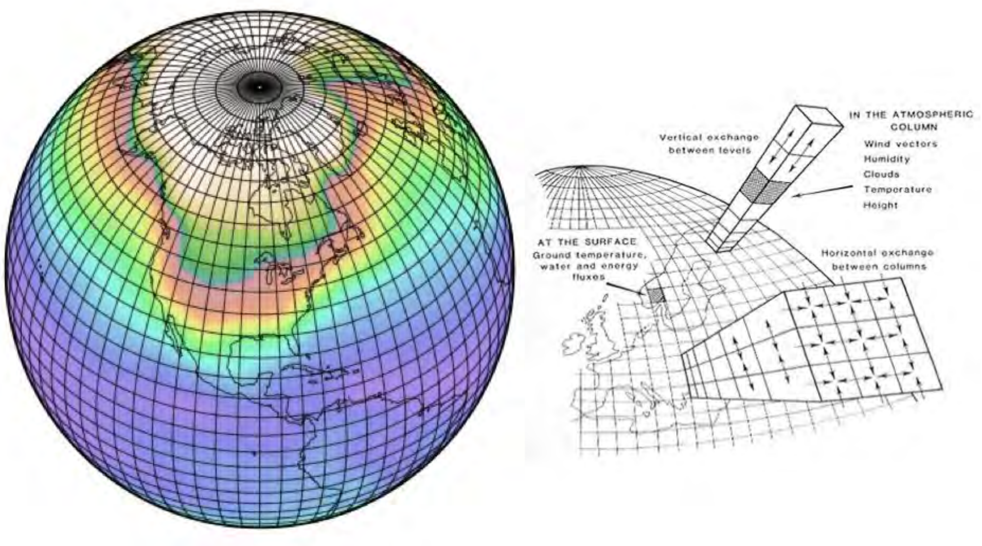

Figure 2.3: **Grid Point Model (Henderson-Sellers, 1985)**

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

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

2.4.2 Representative Concentration Pathways (RCPs)

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

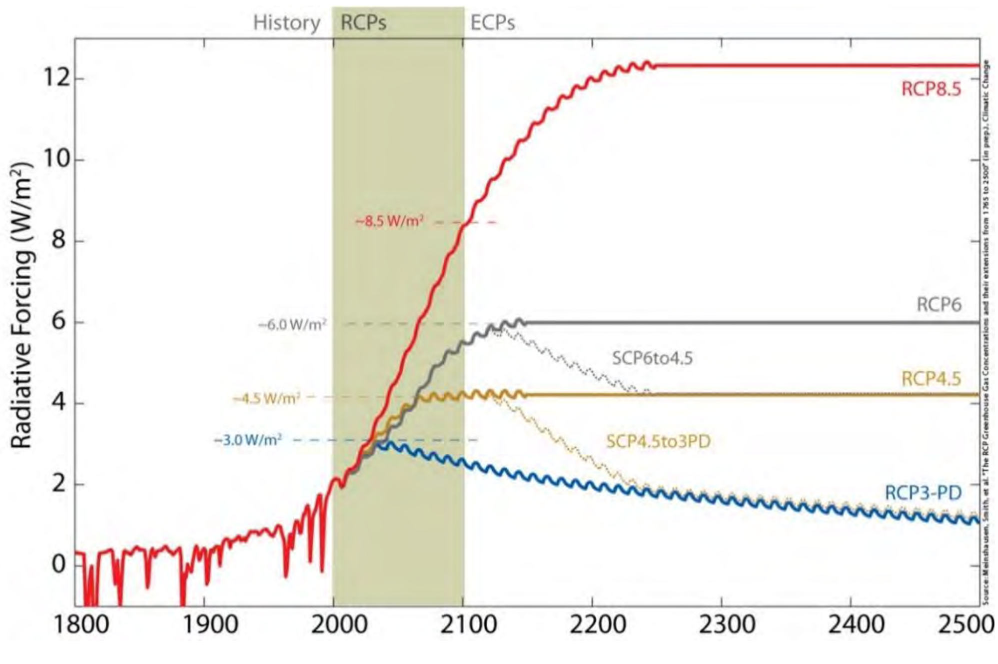

Figure 2.4: **Radiative forcing for different climate scenarios**

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

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

2.4.3 Downscaling GCM

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

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

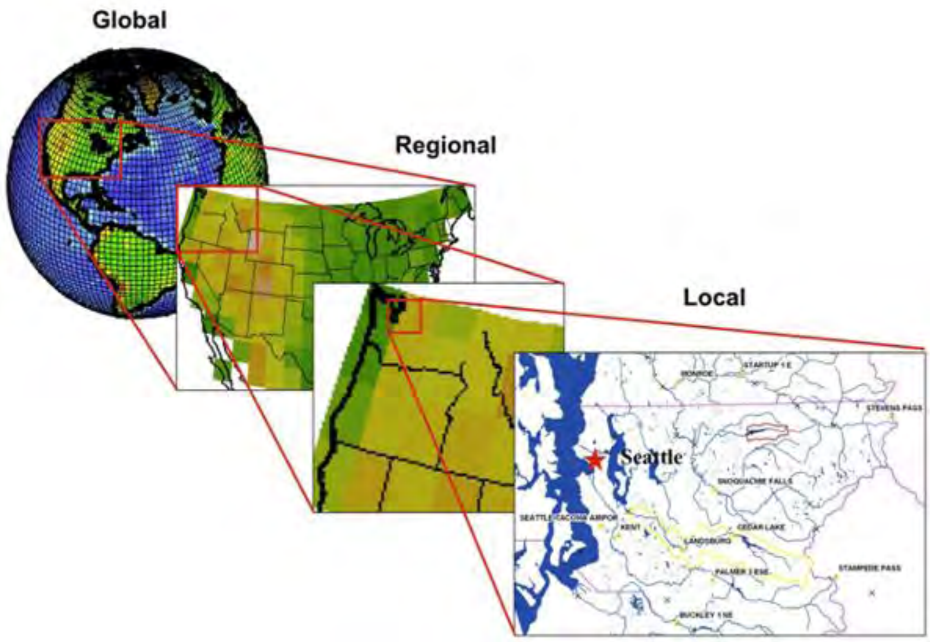

Figure 2.5: Downscaling Global Climate Model

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

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

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

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

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

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

Change factor Method (CFM)

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

$$GCMb_{mean} = \sum_{i=1}^{Nb} \frac{GCMb_i}{Nb} \tag{2.1}$$

$$GCMf_{mean} = \sum_{i=1}^{Nf} \frac{GCMf_i}{Nf} \tag{2.2}$$

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

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

$$CF_{mul} = \frac{GCMf_{mean}}{GCMb_{mean}} \tag{2.3}$$

The local scaled future values can be computed as follow,

$$LSf_i = LOb_i * CF_{mul} \tag{2.4}$$

Where LOb_i represents the observed values of the variable.

2.5 Runoff Generation Using SCS CN Method

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

$$\frac{F}{S} = \frac{Q}{P - I_a} \tag{2.5}$$

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

$$S = \frac{1000}{CN} - 10 \tag{2.6}$$

$$I_a = 0.2S \tag{2.7}$$

The final equation for runoff calculation is

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

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

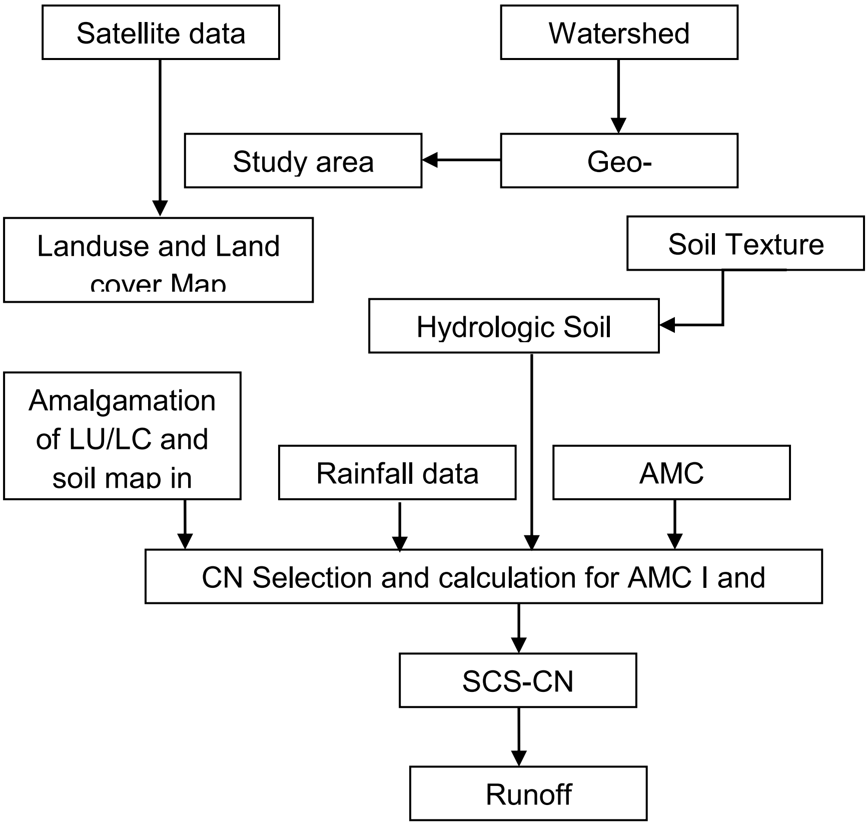

Figure 2.6: Flow chart for SCS-CN Method

Curve Number and Impervious Areas

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

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

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

Initial abstraction

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

2.6 Runoff Generation Using Empirical Formula

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

2.6.1 Inglis and Desouza Formula

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

For Ghat regions of western India usually Highlands

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

For Deccan plateau usually Plain areas

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

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

2.6.2 Indian Irrigation Department

Indian Irrigation Department uses the following equation between Rainfall and Runoff

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

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

2.7 HEC HMS Hydrologic Modelling

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

2.7.1 Reach Characteristics

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

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

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

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

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

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

Table 2-2: Guidelines for routing method selection

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

2.7.2 Running Control Parameter for Simulation

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

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

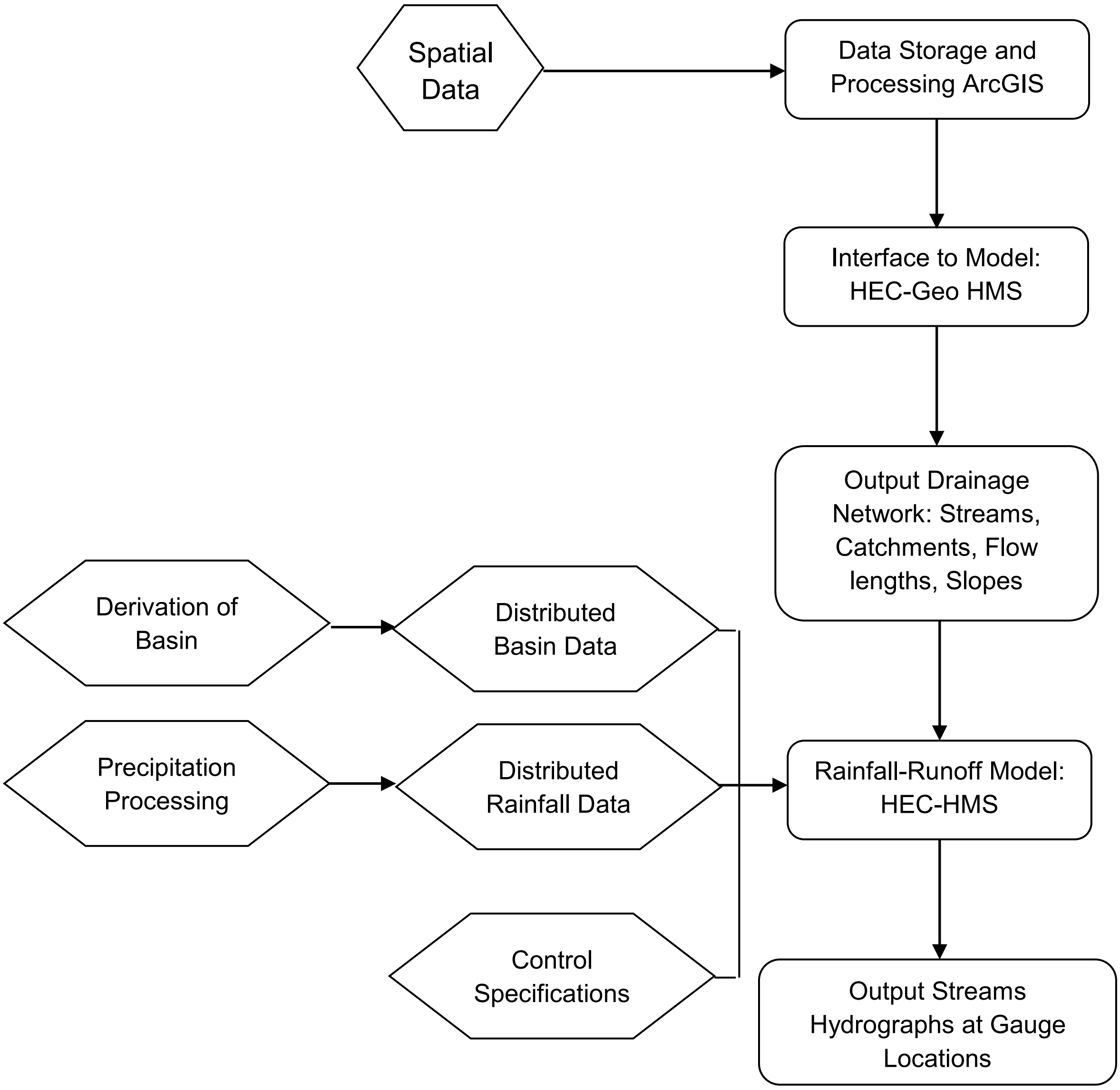

Figure 2.7: Flow chart for HEC HMS Modelling

2.8 Urban Heat Island

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

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

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

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

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

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

2.8.1 Normalized Difference Vegetation Index (NDVI)

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

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

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

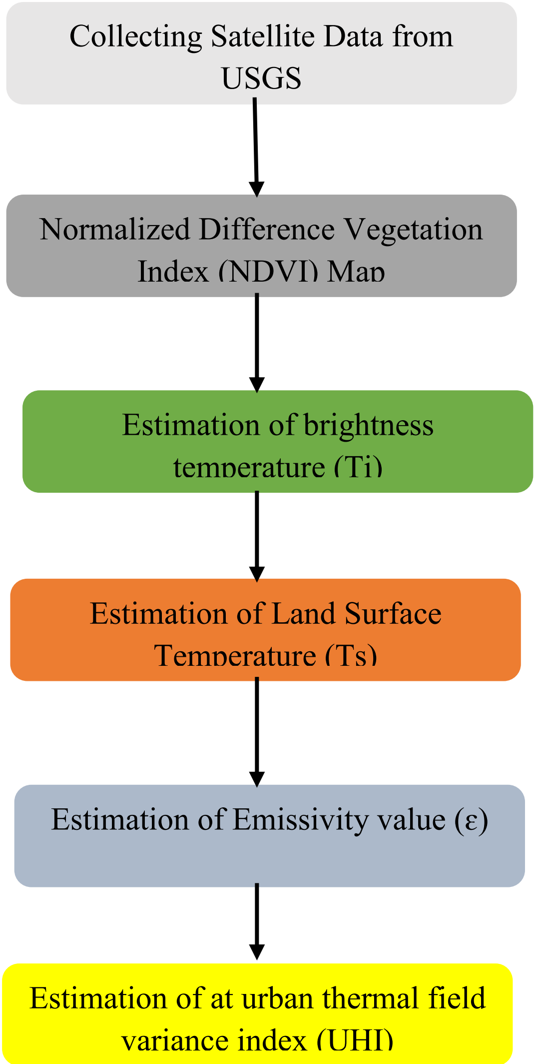

Figure 2.8: Flowchart for estimation of UHI Index

2.8.2 Brightness Temperature (T_i)

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

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

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

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

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

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

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

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

Temperature Classification	Interval of Temperature Classification
High-temperature area	$Ts > \mu + std$
Secondary high-temperature area	$\mu + 0.5std < Ts \leq \mu + std$
Medium temperature area	$\mu - 0.5std \leq Ts \leq \mu + 0.5std$
Secondary low temperature area	$\mu - std \leq Ts < \mu - 0.5std$
Low-temperature area	$Ts < \mu - std$

2.8.3 Land Surface Temperature (T_s)

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

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

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

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

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

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

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

2.8.4 LST Normalization Urban Heat Island (UHI)

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

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

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

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

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

2.9 Sustainable Management Plan and Wastewater Reuse

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

3 STUDY AREA

3.1 General

Solapur lies in the basin of river Bhima and the municipal jurisdiction of the Solapur city, encompasses an area of 164.64 km^2. Solapur is well connected by neighboring major cities in Maharashtra as well as Andhra Pradesh and Karnataka. The city is connected with Pune through national highway 9 (NH-9) which also passes through Hyderabad. The city lies centrally in the basin of river Bhima and the watershed of river Adila (a tributary of river Sina). It is located at 17°10" and 18°32" N and 74°.42" and 76°.15" E. It has an average elevation of 457 meters above mean sea level.

3.2 Solapur Climate

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

Rainfall pattern

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

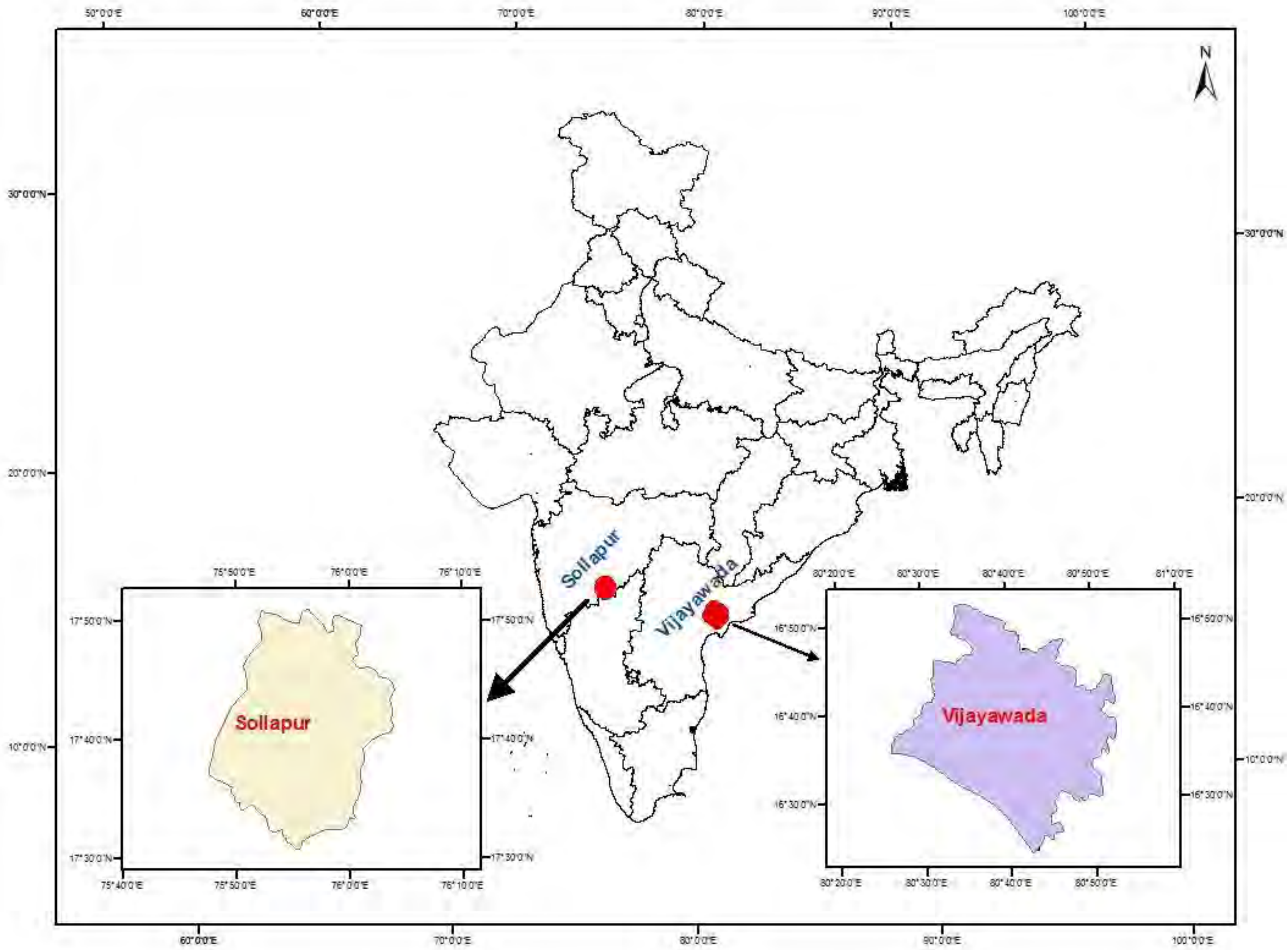

Figure 3.1: **Location of study area**

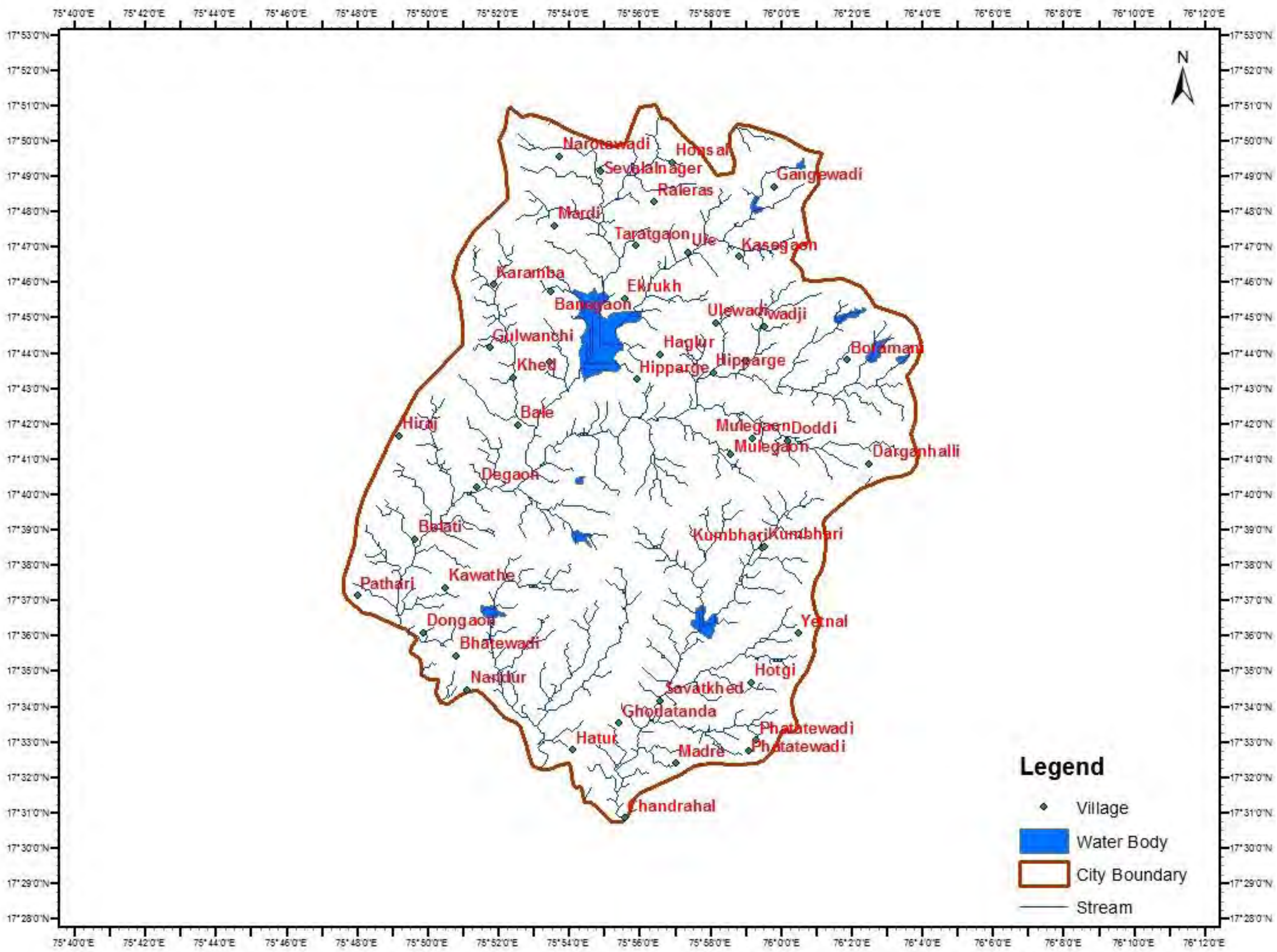

Figure 3.2: **Solapur City**

The monthly variation of rainfall for Solapur city is given in Fig. 3.3. It can be observed that the mean monthly rainfall is almost at the center of maximum and minimum rainfall for most of the months, except for August and September.

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

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

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

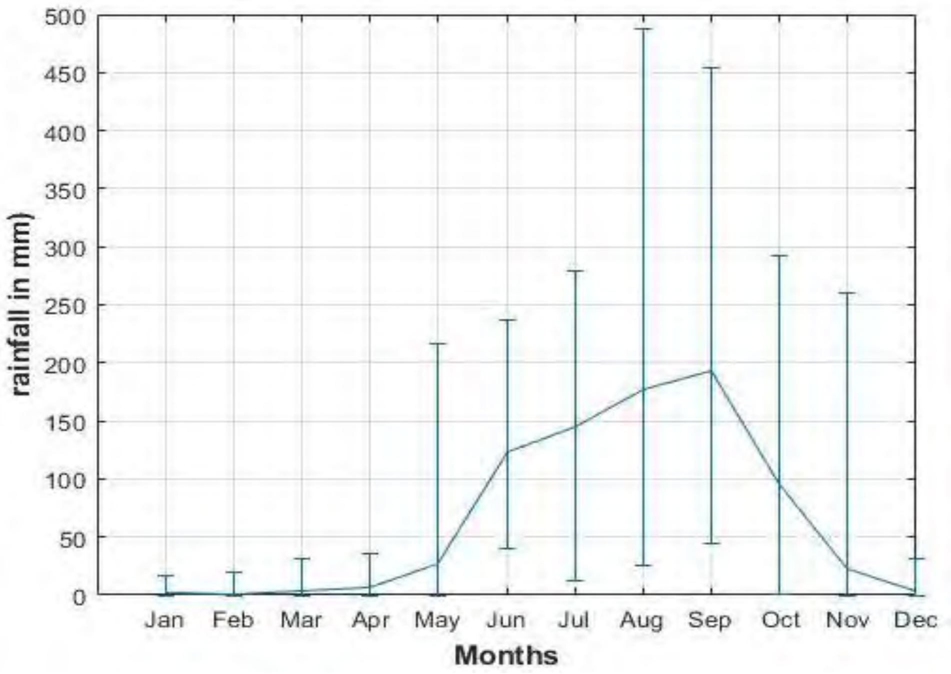

Figure 3.3: Monthly variation of rainfall in Solapur

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

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

Historical Monthly Maximum Temperature

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

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

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

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

Fig. 3.4 shows a variation of the monthly maximum temperature of Solapur. The variability in temperature is maximum in June. The mean of monthly maximum temperature lies mostly in the range of 30-40^{0}C.

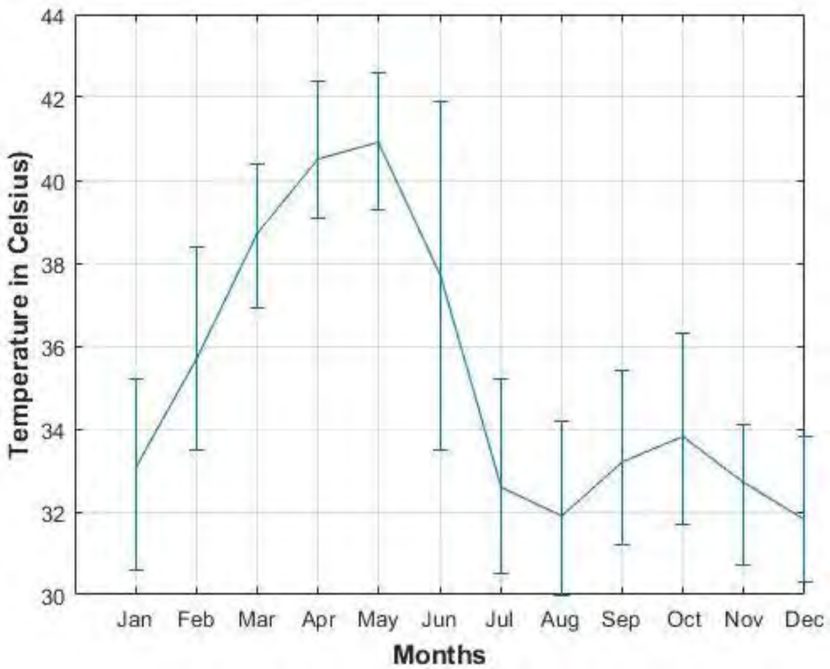

Figure 3.4: Variation of Monthly maximum temperature in Solapur

Historical Monthly Minimum Temperature

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

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

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

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

Fig. 3.5 shows a variation of monthly minimum temperature for Solapur city. The variability is comparatively high in the non-monsoon period that that in monsoon. In January, and December month, the minimum temperature has gone even below 10^{0}C.

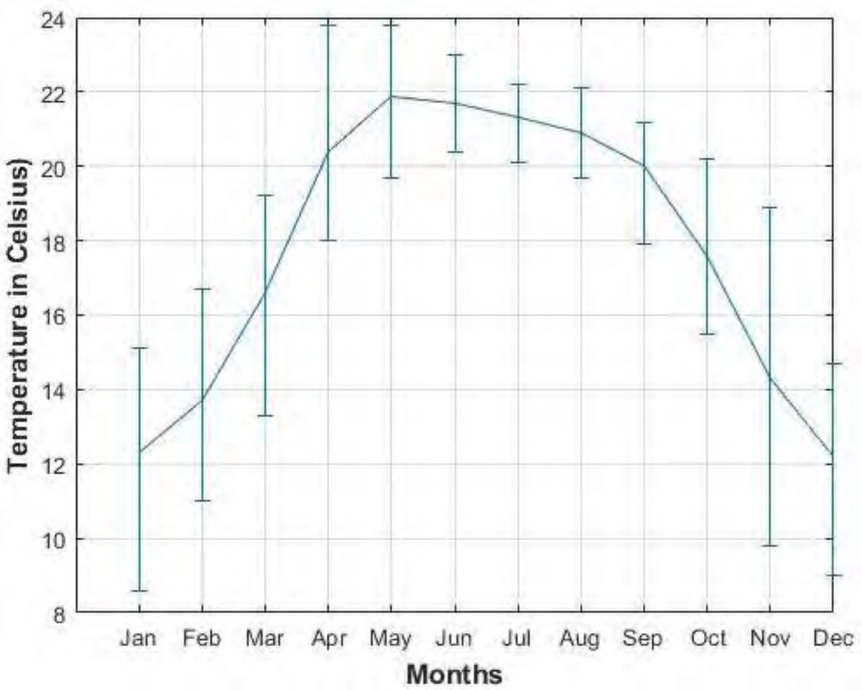

Figure 3.5: Variation of monthly minimum temperature

4 CLIMATE CHANGE MODELLING

4.1 General

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

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

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

4.2 Procedure

The methodology consists of five steps:

Step 1. Data filling and error checking

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

Step 2. Trend analysis

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

Step 3. GCM downscaling

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

Step 4. Predictions

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

Step 5. Indices

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

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

4.3 Climate Change Modelling For Solapur

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

4.3.1 Trend Analysis

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

Monthly rainfall

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

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

Monthly Maximum Temperature

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

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

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

Monthly Minimum Temperature

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

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

4.3.2 GCM Projections for Solapur

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

RCP 2.6

Projection for Rainfall

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

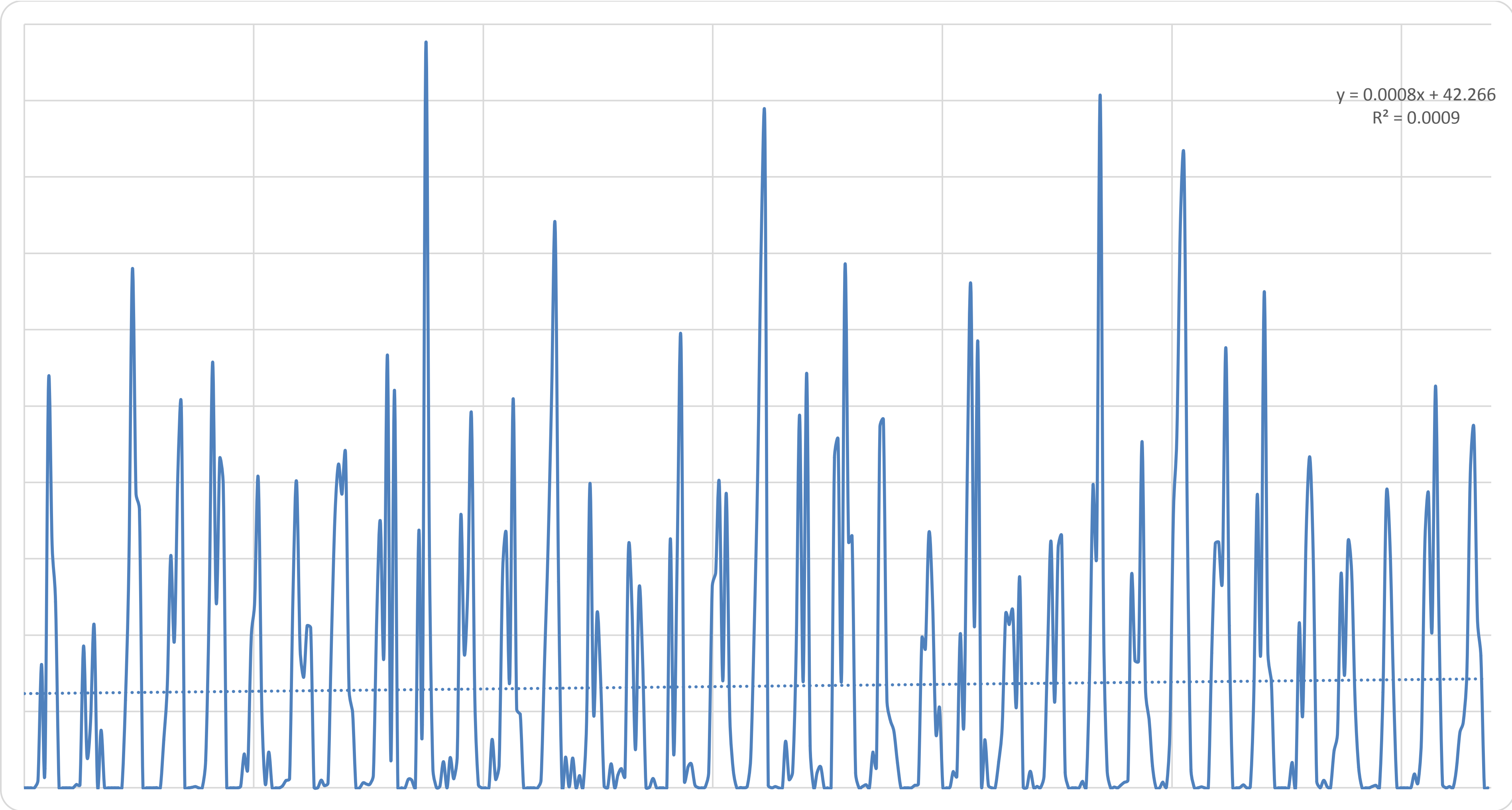

Figure 4.1: linear regression fit for monthly rainfall for Solapur

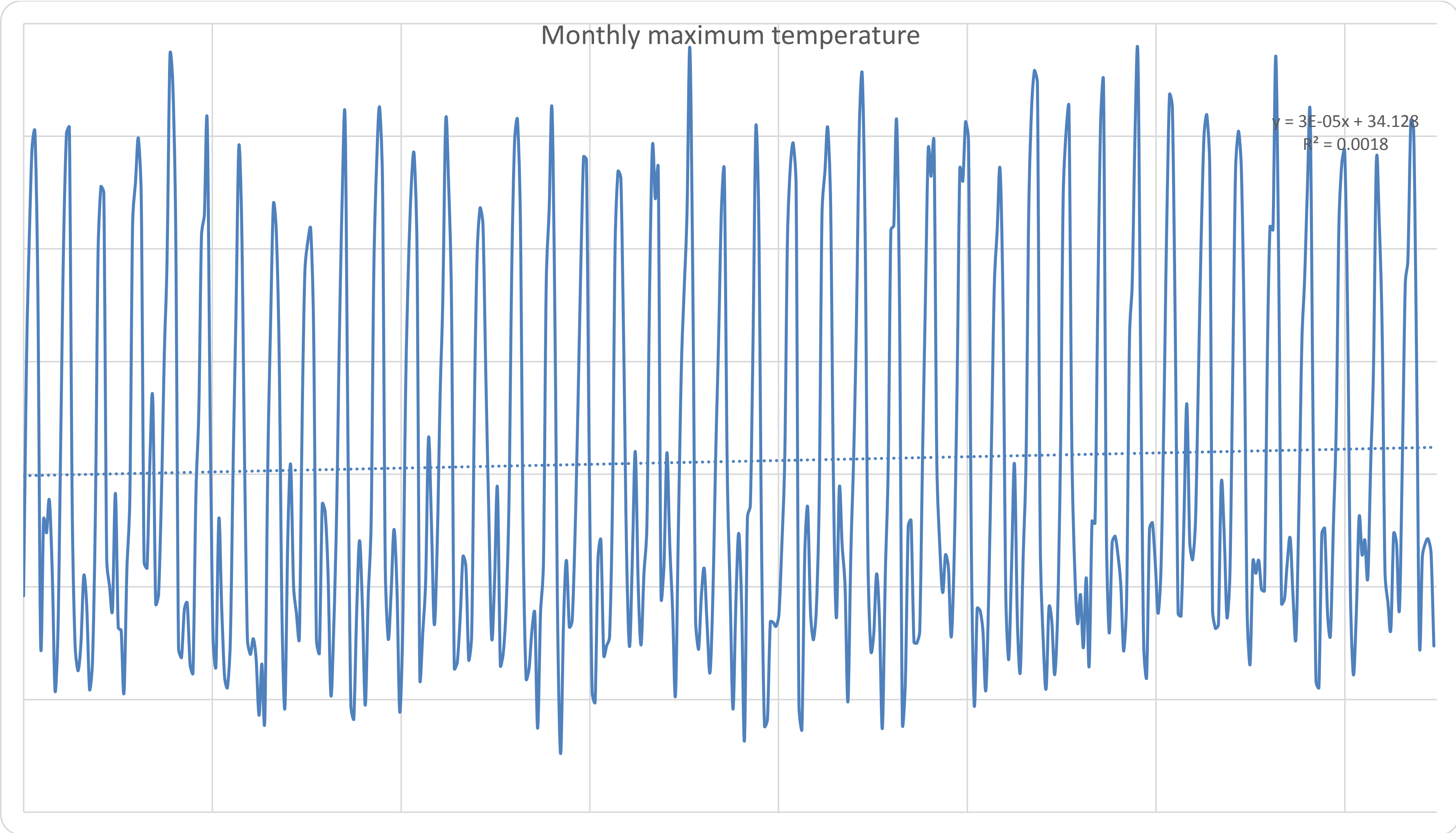

Figure 4.2: linear regression fit for monthly maximum temperature for Solapur

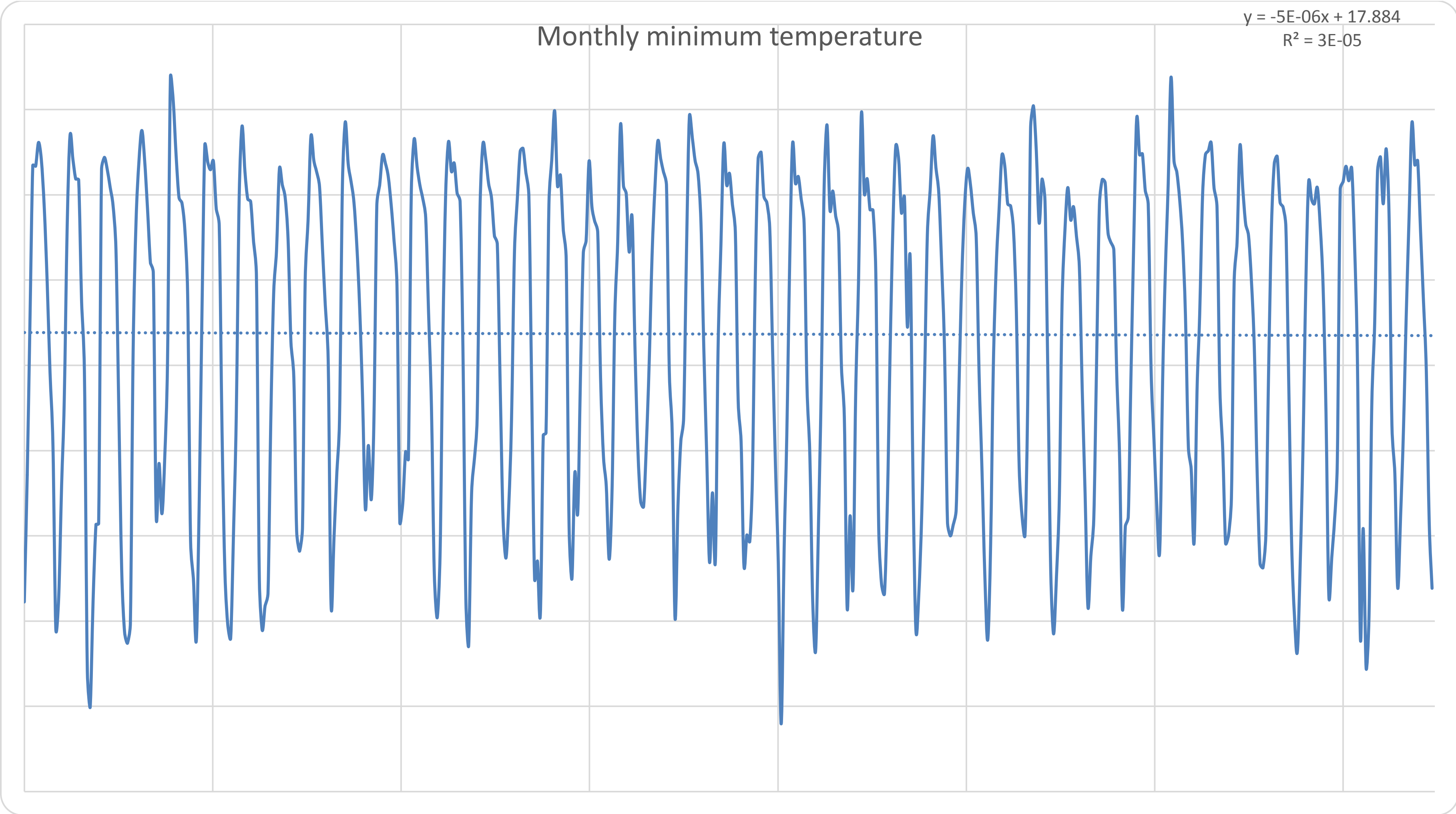

Figure 4.3: Linear regression fit for monthly minimum temperature for Solapur

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

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

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

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

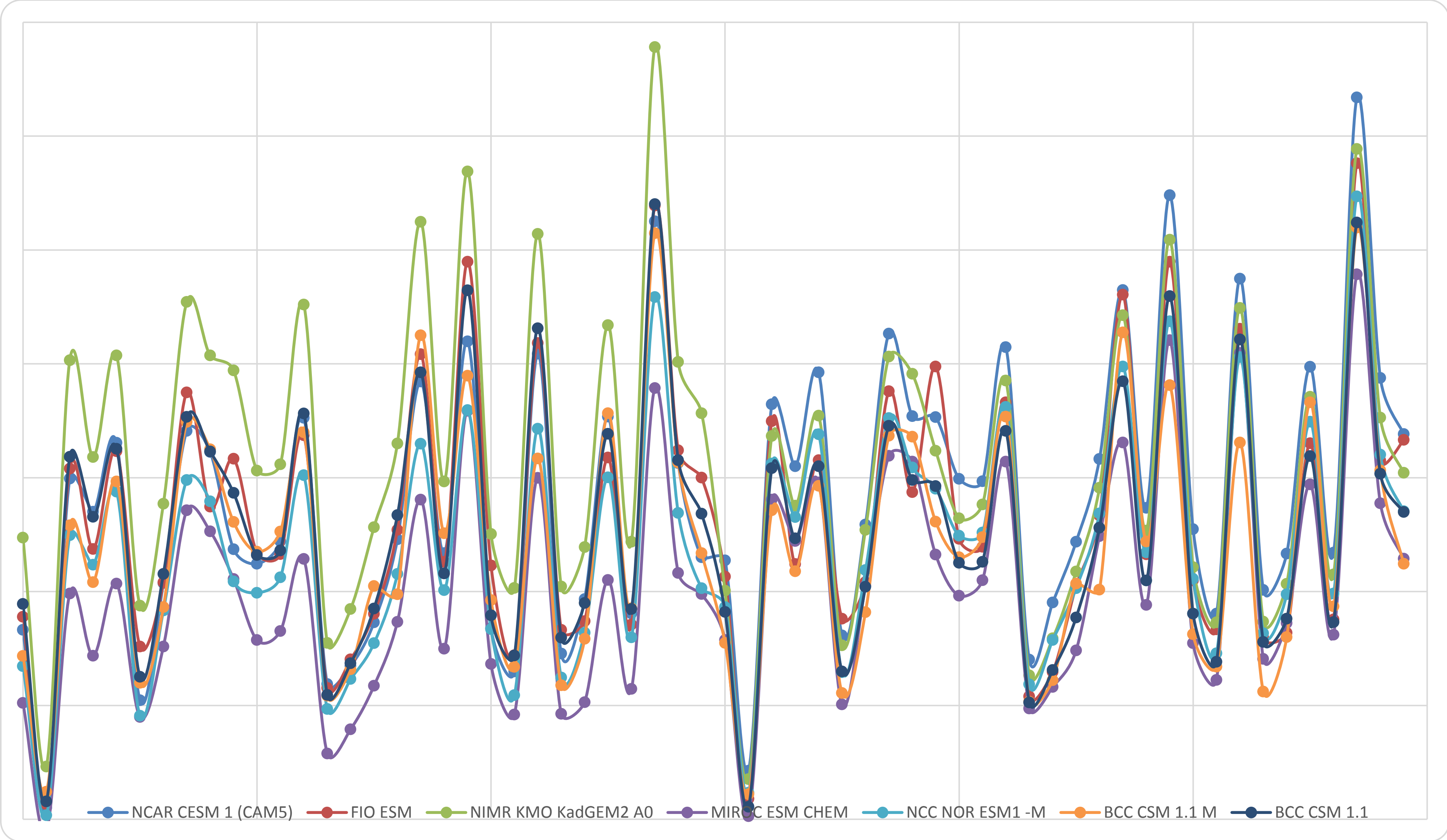

Figure 4.4: Annual rainfall projection (in mm) for RCP 2.6 scenario for Solapur

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

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

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

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

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

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

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

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

RCP 4.5

Projection for rainfall

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

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

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

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

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

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

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

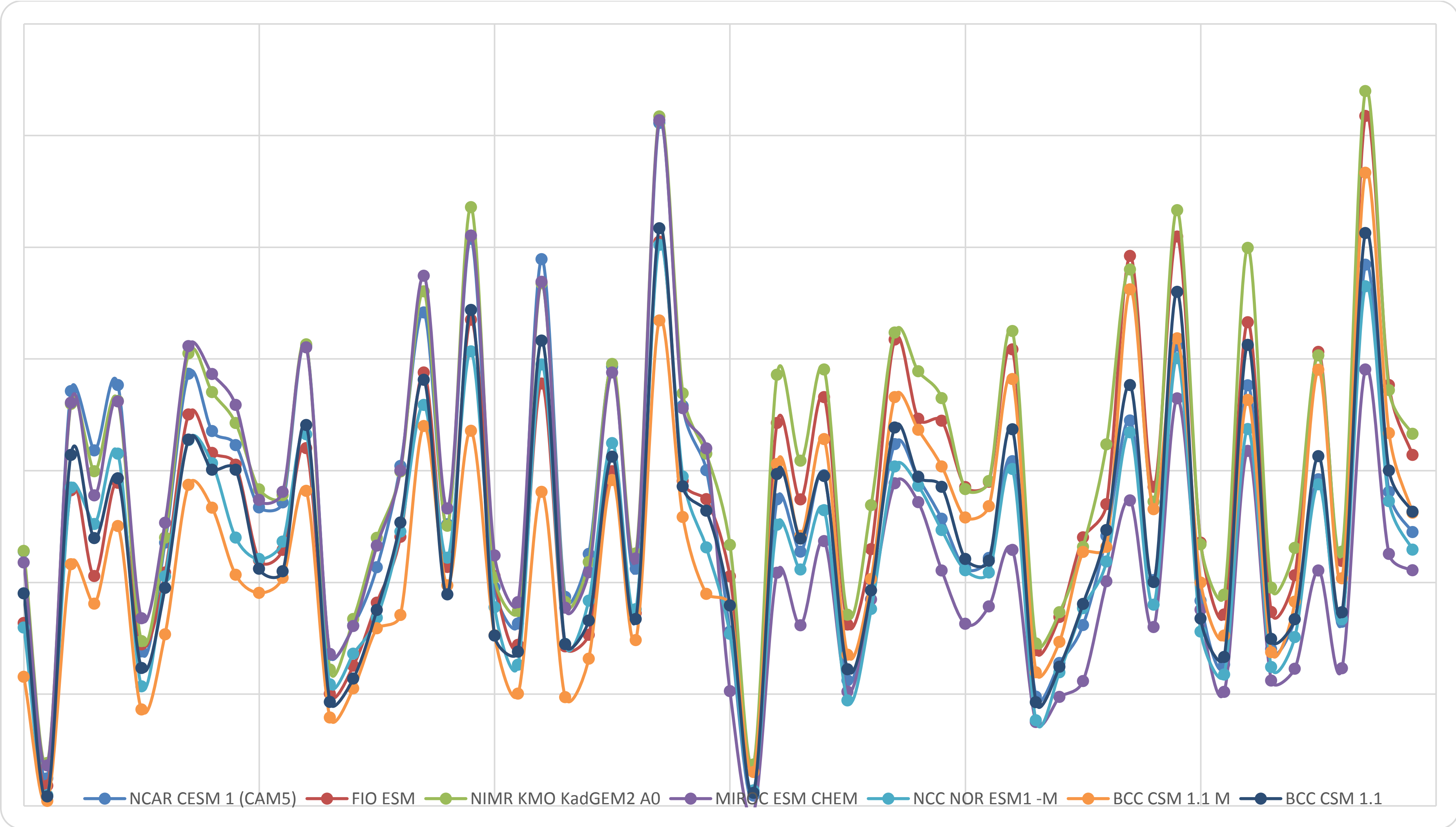

Figure 4.5: Annual rainfall projection for RCP 4.5 scenario for Solapur

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

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

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

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

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

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

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

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

RCP 6.0

Projection for Rainfall

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

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

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

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

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

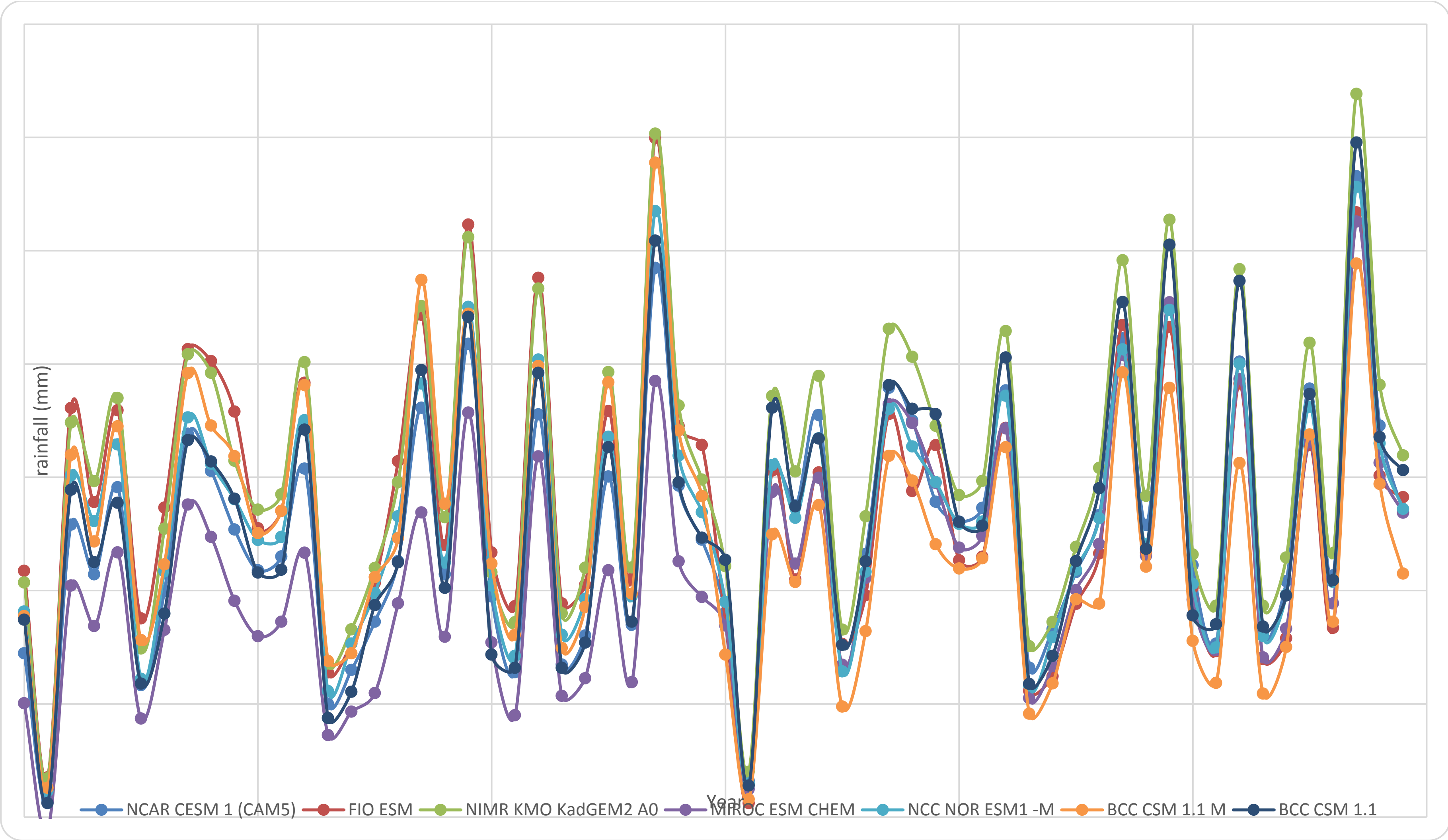

Figure 4.6: Annual rainfall projection for RCP 6.0 scenario for Solapur

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

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

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

The projection for Maximum Temperature

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

The projection for Minimum Temperature

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

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

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

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

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

RCP 8.5

Projection for Rainfall

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

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

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

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

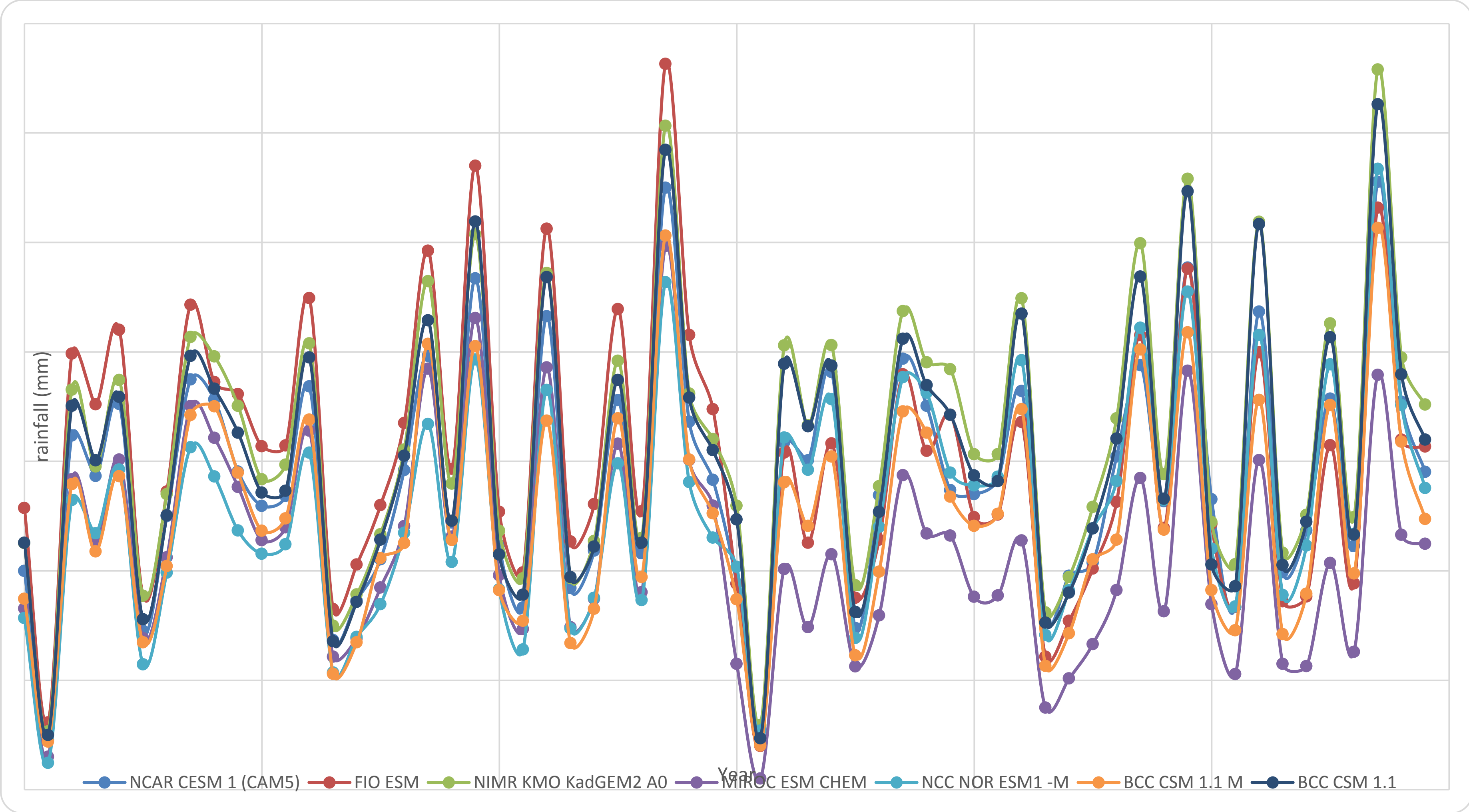

Figure 4.7: Annual rainfall projection for RCP 8.5 scenario for Solapur

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

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

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

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

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

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

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

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

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

4.3.3 Summary

Rainfall

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

Maximum Temperature

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

Minimum Temperature

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

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

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

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

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

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

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

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

5 RUNOFF ESTIMATION

5.1 CATCHMENT DELINEATION

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

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

5.1.1 Catchment Boundary

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

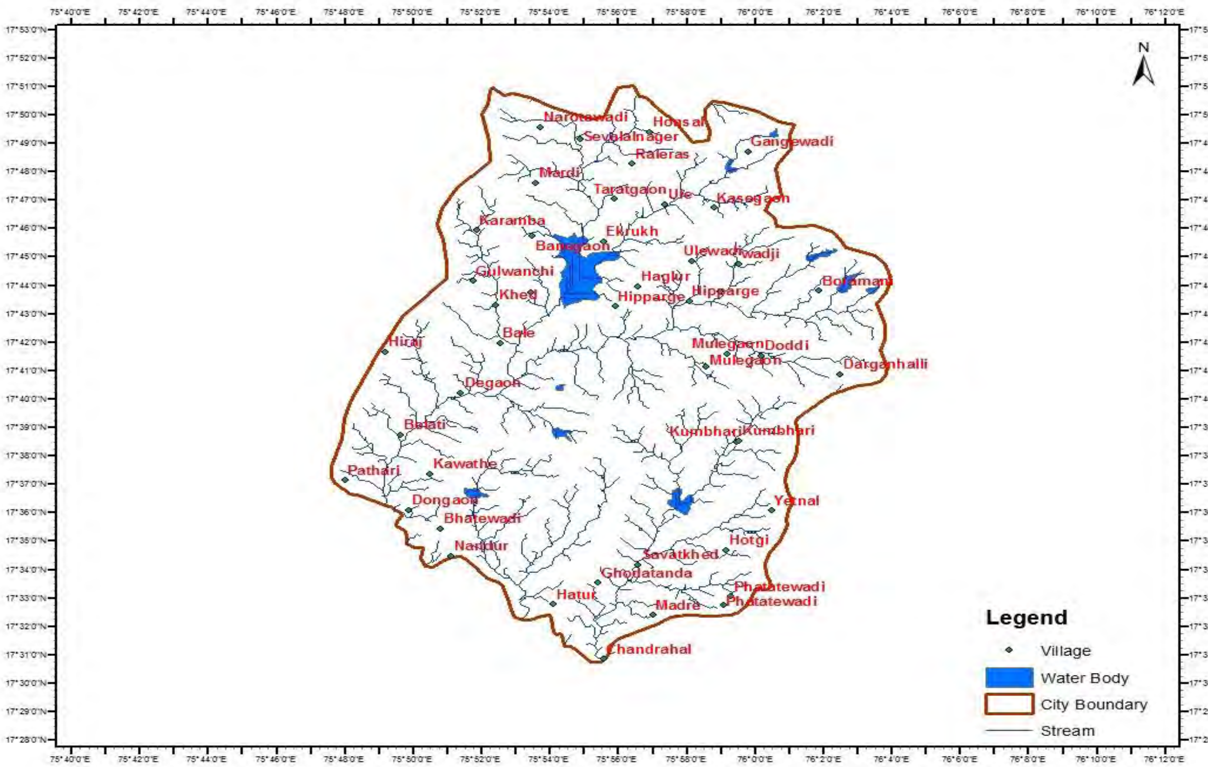

Figure 5.1: Solapur city boundary

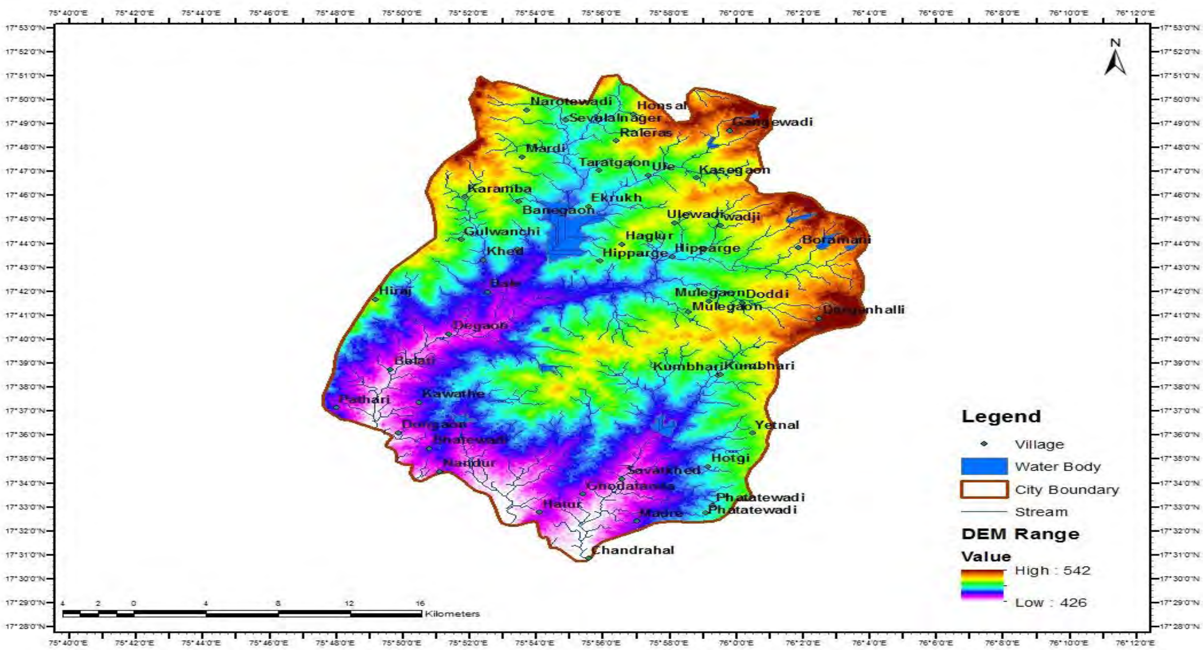

Figure 5.2: Digital Elevation Model (DEM) for Solapur city

5.1.2 Land Use Pattern

Land use map was generated from Spot-5 image satellite data from 1979-2007 with a resolution of 2.5 m. The supervised classification method with maximum likelihood clustering was employed for image classification through ArcGIS 10.1 Software. The Land use identified in the watershed is primarily urban, bare soil, agricultural and forest areas. Land use classification for Solapur is shown in Fig. 5.3.

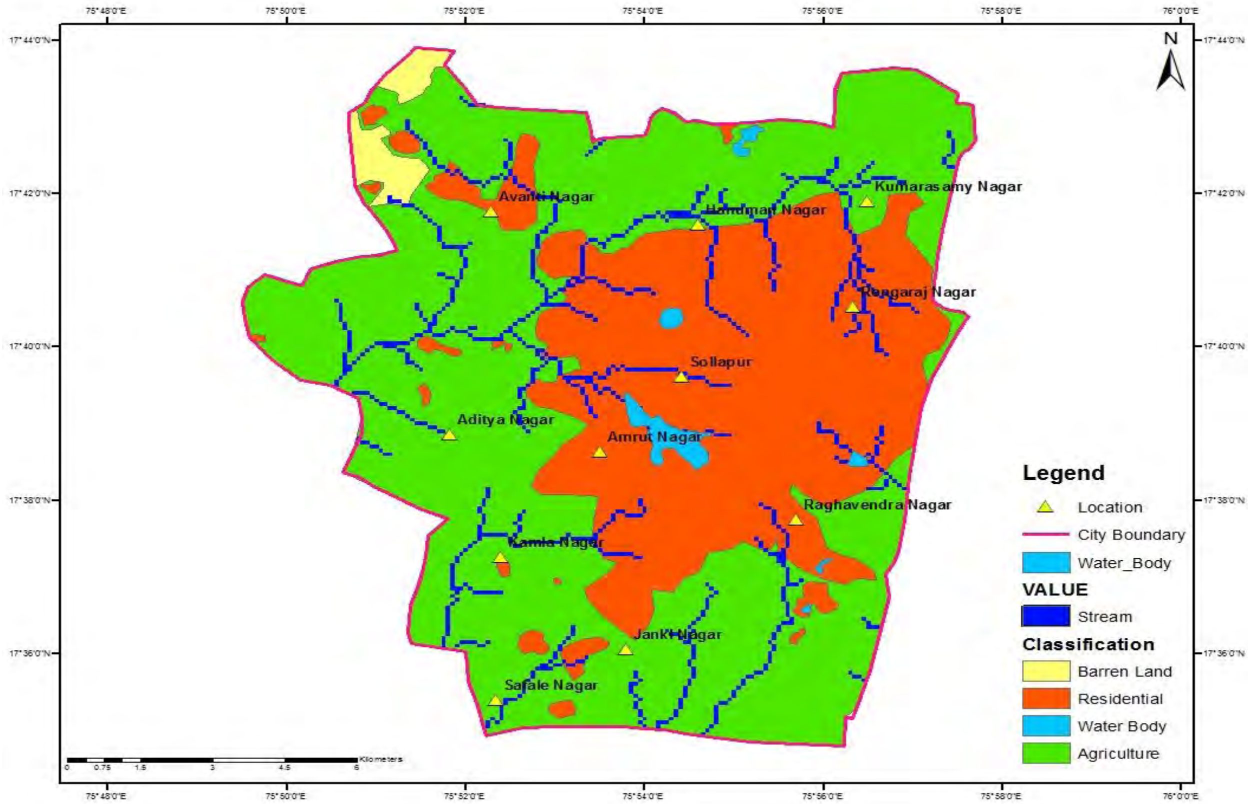

Figure 5.3: Land use map for Solapur City

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

5.1.3 Hydrologic Soil Groups Map

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

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

Table 5-1: Hydrologic soil group classification

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

5.1.4 Catchment Map

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

Fig.5.4 shows the catchment map of Solapur city sub-basin wise. Fig 5.5 shows the subbasin map of Solapur city used as an input in HEC HMS for estimation of runoff generation.

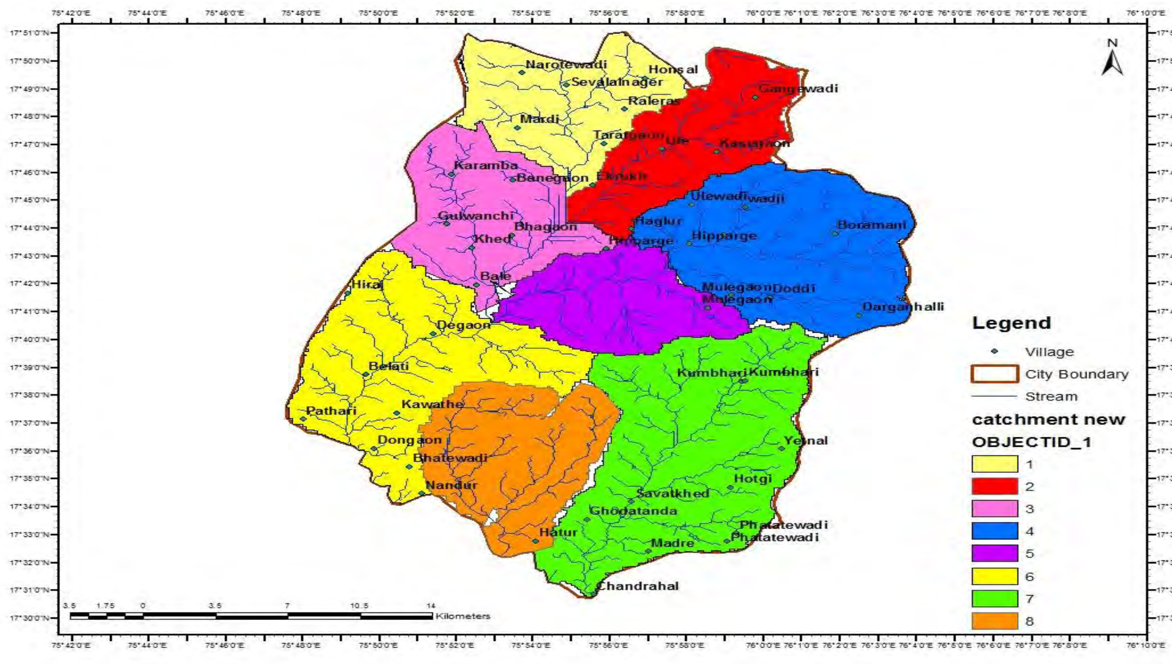

Figure 5.4: Catchment map for Solapur City

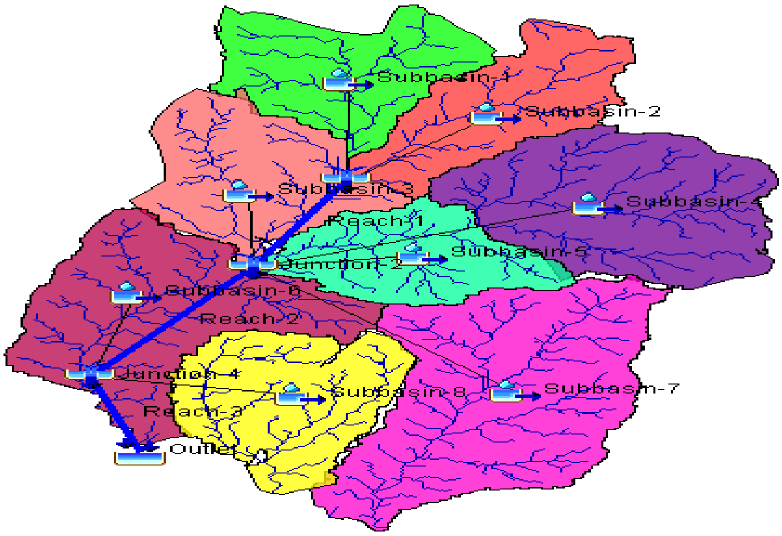

Figure 5.5: HEC-HMS input sub basin model for Solapur basin

5.1.5 Sub Basin Characteristics

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

Table 5-2: Solapur basin characteristics

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

5.2 Runoff Generation

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

5.2.1 Runoff Estimation

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

Table 5-3: Annual Runoff for Solapur Sub Basin wise (in TMC)

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

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

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

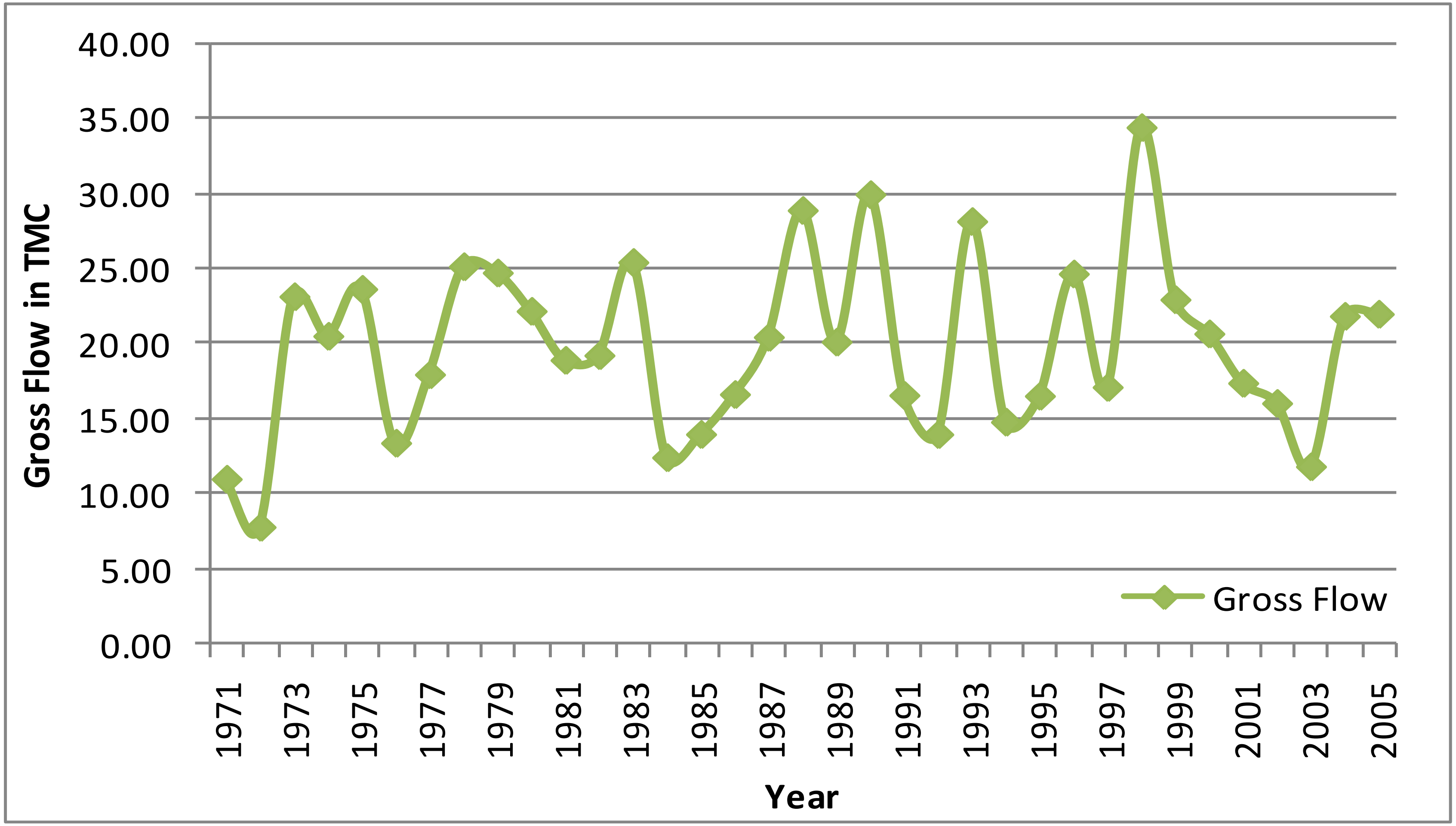

Figure 5.6: Year wise runoff using HEC-HMS model for Solapur basin

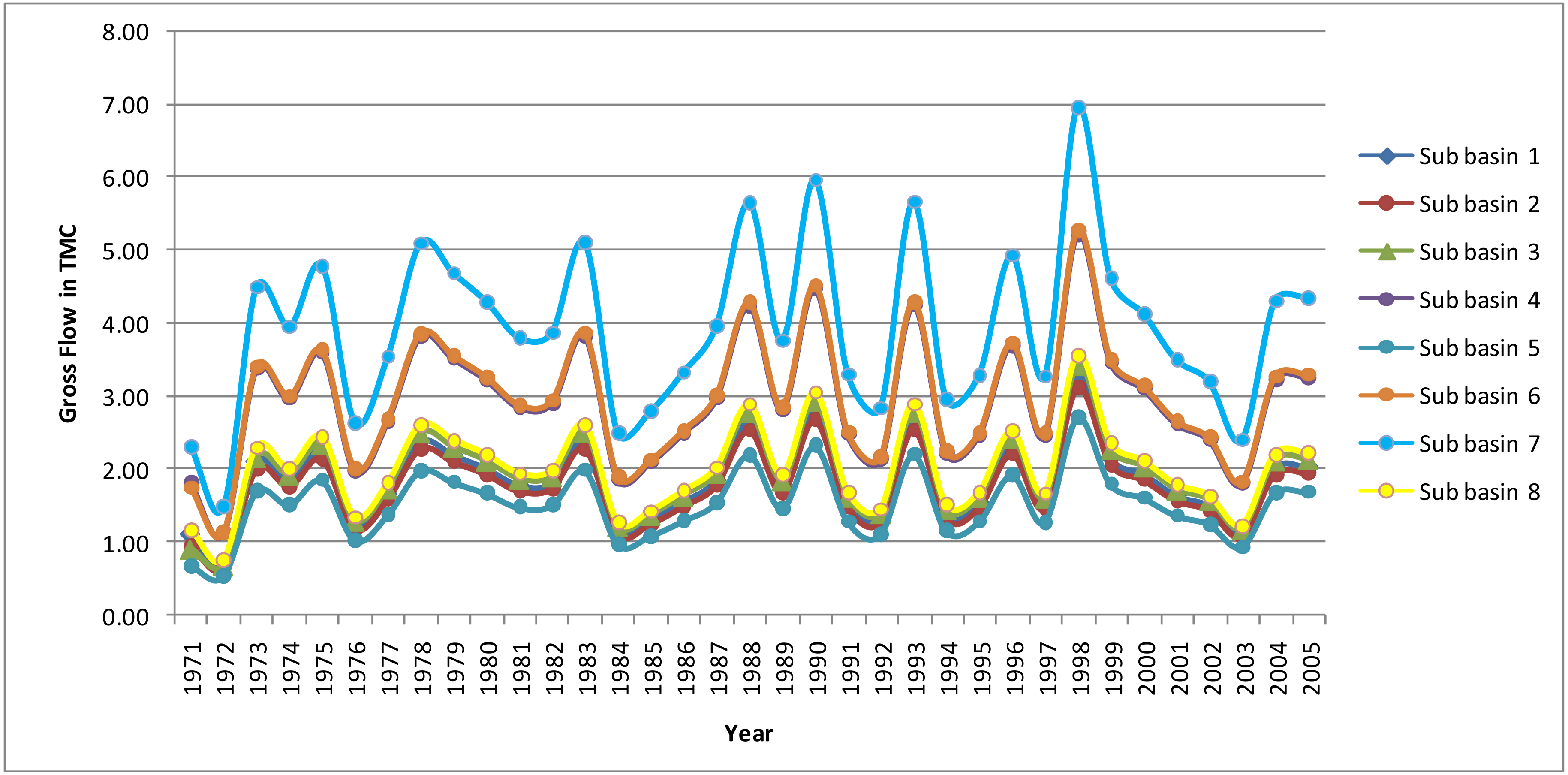

Figure 5.7: Annual Runoff Variation in each Sub basin for Solapur

6 URBAN HEAT ISLAND

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

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

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

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

6.1 Study Area

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

Table 6-1: Area of the city

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

6.2 Data available

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

Table 6-2: Details about Satellite data

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

Table 6-3: Application of satellite Band data

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

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

Study Area	NDVI Min	NDVI Max
Solapur	-1	0

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

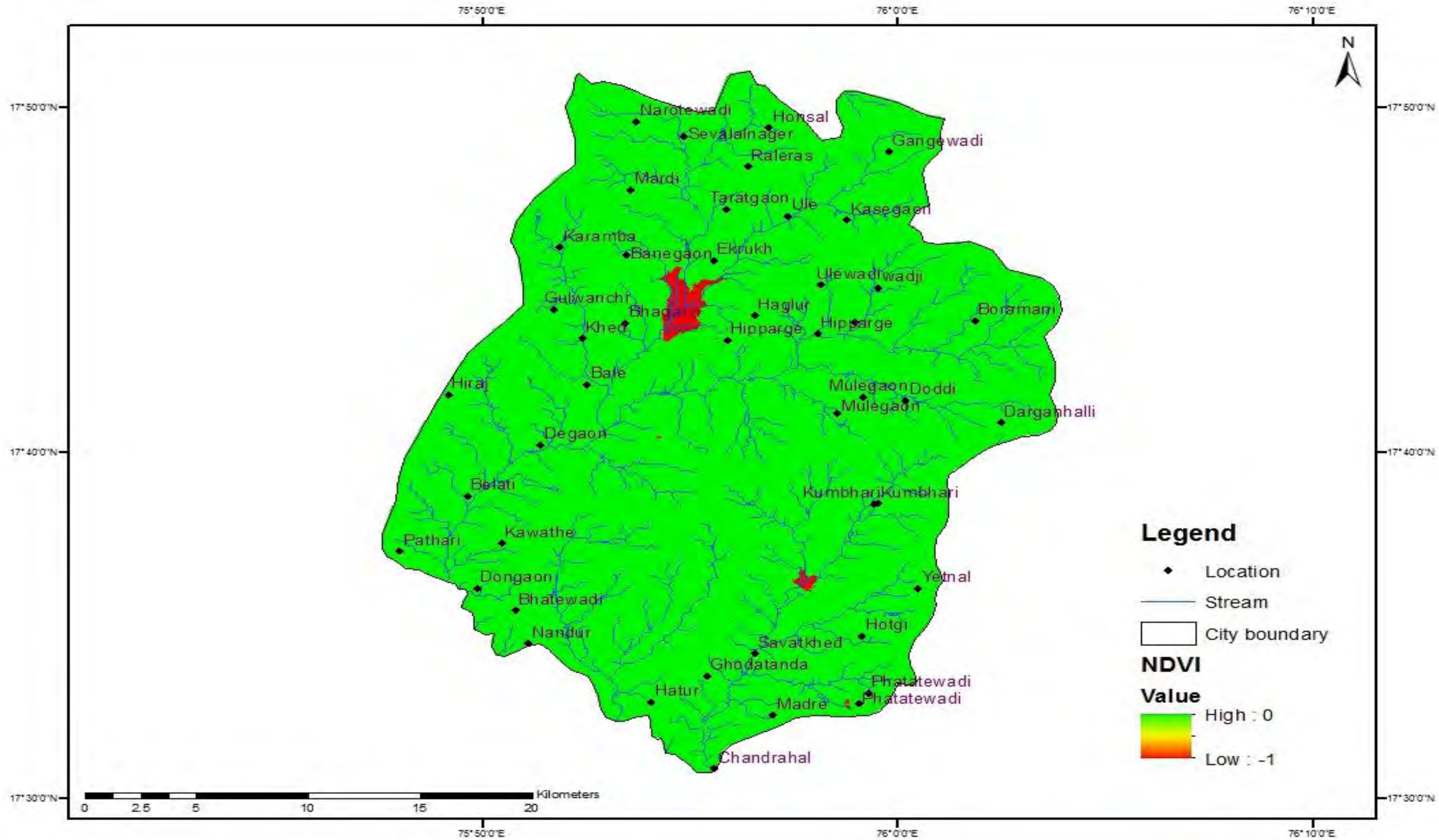

Figure 6.1: NDVI map in Solapur City

6.3 Estimation of at sensor brightness temperature Ti

Classify urban brightness temperature into low-temperature area, secondary low-temperature area, medium temperature, secondary high-temperature area, and high-temperature area. The basic principle of using Mean-Standard Deviation Method for temperature classification is shown in Table 6.5, is the average temperature, std represents the standard deviation of TB and Ts represents TB value of image pixel. Classify TB chart in the research region based on map algebra of GIS and according to Table 6.6. Using the temperature classification the range of TB for study area as shown in fig 6.2.

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

Temperature Classification	Interval of Temperature Classification
High-temperature area	$Ts>\mu+std$
Secondary high-temperature area	$\mu+0.5std<Ts\leq \mu+std$
Medium temperature area	$\mu-0.5std\leq Ts\leq \mu+0.5std$
Secondary low temperature area	$\mu-std\leq Ts< \mu-0.5std$
Low-temperature area	$Ts< \mu-std$

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

Temperature Classification	Solapur	
	Area(Km^2)	Proportion (%)
High temperature area	263.28	39.17
Secondary high temperature area	219.54	32.66
Medium temperature area	118.16	17.58
Secondary low temperature area	63.88	9.50
Low temperature area	7.32	1.09
Total	**672.18**	**100**

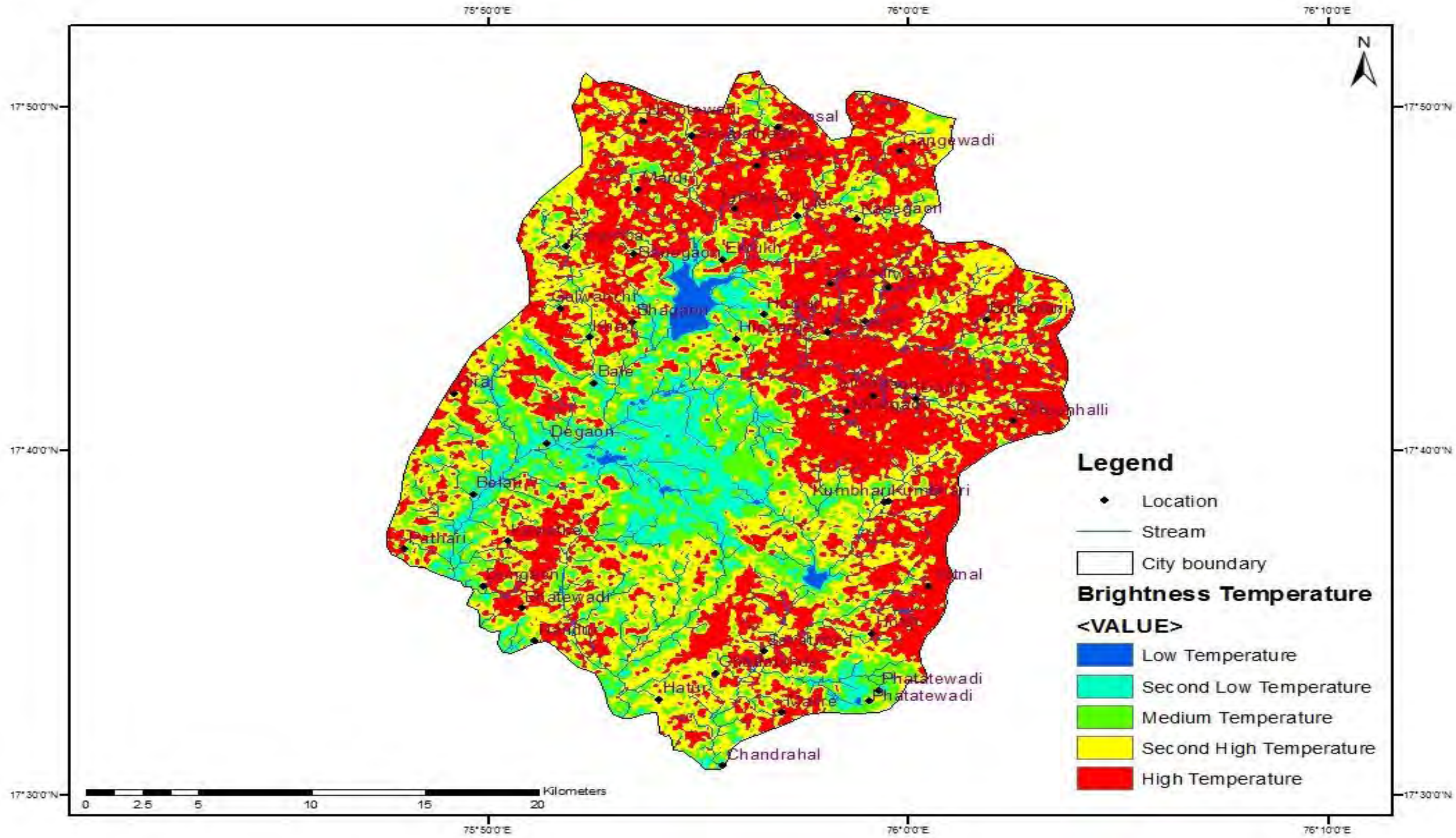

Figure 6.2: Brightness Temperature Map Solapur city

6.4 Retrieving land surface temperature (T_s)

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

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

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

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

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

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

Table 6-8: Land surface spectral emissivity range.

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

6.5 LST normalizing and obtaining urban heat island (UHI)

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

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

Where,

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

UTFVI was divided into six levels by six different ecological evaluation indices (Liu and Zhang, 2011; Zhang, 2006). Thresholds in the six UTFVI levels are shown in Table 6.9. And the Threshold values of urban thermal field variance index various range in the study area as shown in Table 6.10, The second level of LST normalization is the ecological evaluation of UHI by calculation of UTFVI at a different level as shown in Fig 6.3 displays the resulted of UHFVI range.

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

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

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

Urban Heat Island Phenomena	Solapur	
	Area(Km^2)	Proportion (%)
Very Weak	249.28	37.09
Weak	27.00	4.02
Medium	20.87	3.10
Strong	29.91	4.45
Stronger	32.93	4.90
Strongest	312.18	46.44
Total	672.18	100

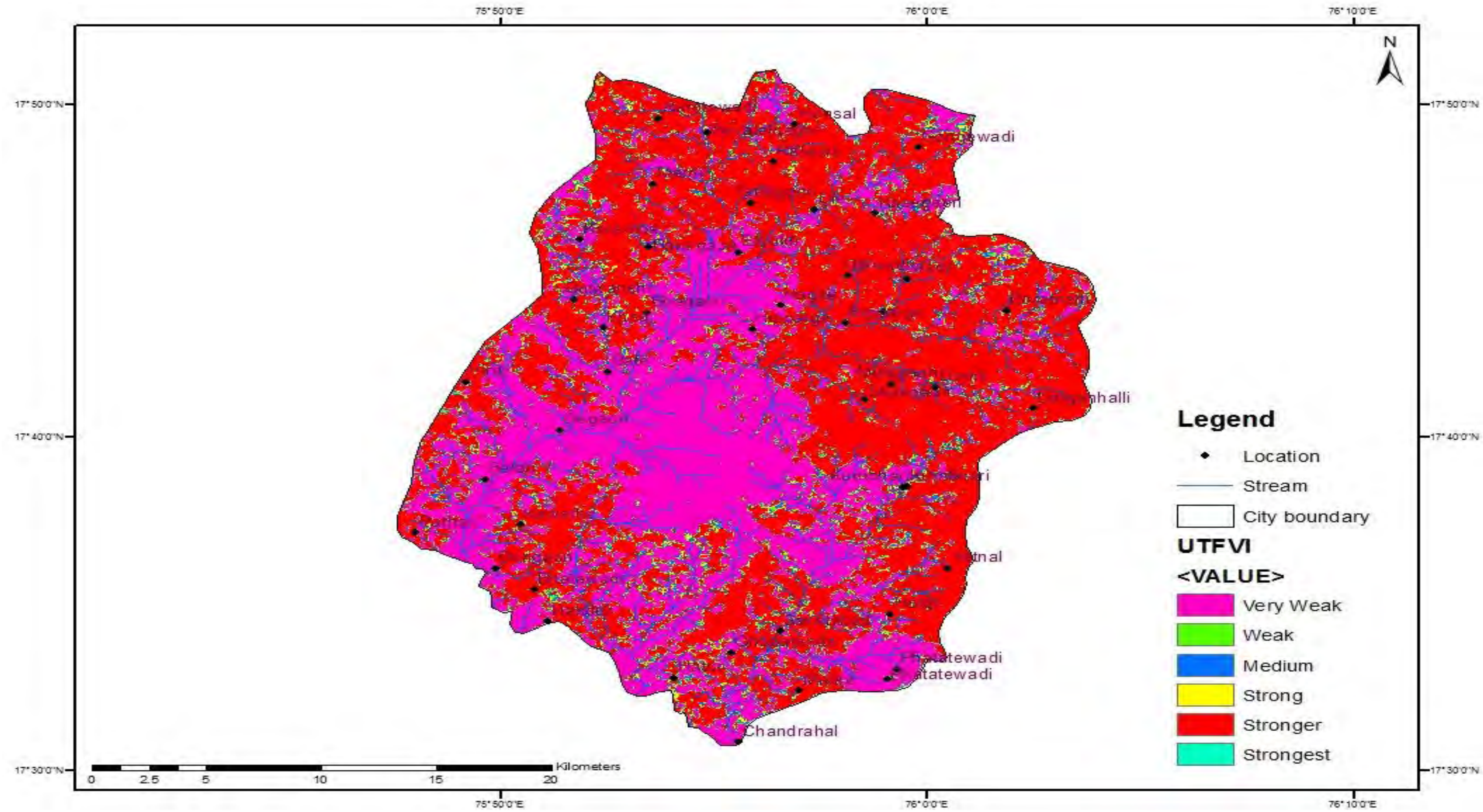

Figure 6.3: Urban Heat Island Index map for Solapur city

7 RESULT AND DISCUSSION

7.1 General

Assessment of climate change and its impact on the hydrology were made in the present work. Solapur, a city in Maharashtra, is struggling with frequent droughts. Based on the Climate change forecast and hydrological modeling, suitable sustainable management plan are made.

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

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

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

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

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

7.2 Climate Change Assessment

Solapur

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

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

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

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

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

7.3 Hydrological Modelling

The study area is delineated based on land use and land cover. Solapur city has a total area of 672.18 km^2, in that 43% is agricultural, Residential is 54% and the remaining 3% belongs to another category. Solapur has mostly loamy soil.

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

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

7.4 Urban Heat Island Map

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

Annexure 4: Integration Assessment Matrix

Integration Assessment Matrix of Solapur

S . No	Integration Indicators	Criteria Scoring		
		Criteria/sub criteria	**Scale**	**Selected Score**
1	Location of major water source(s) in the micro catchment	Main source(s) within micro-catchment boundary	**3**	2
		Main source(s) located at district level	**2**	
		Main source(s) located outside district	**1**	
2	Participatory process for integration of water sectors	All stakeholders and water sector departments are involved throughout planning and implementation (through stakeholder consultations)	**3**	2
		No direct stakeholder involvement, comments invited after preparation of final plan	**2**	
		No involvement, plans prepared internally by government departments	**1**	
3	Water Portfolio for supply	Practicing Reuse –Recycle and recharge - Traditional rain water harvesting (RWH) structures and systems or new policies to recycle reuse	**3**	1
		Water security plans using different sources of water (ground water, surface water, pond)	**2**	
		No Plan for water security but supplies assured through single source (for next 10 to 20 years)	**1**	
4	Water pollution	Water quality (surface and groundwater) within permissible limits	**2**	2
		Polluted pockets are being confined, no mitigation plan/measures yet	**1**	
		Critical level of surface water pollution (Coliform, BOD, DO level, eutrophication, etc.) and Critical level of groundwater pollution (Fluoride, Arsenic, etc.) – no plans for mitigation	**0**	
5	Link between water and energy	Link is realized and measures are taken (like use of Renewable Energy, Energy Efficiency, land use etc.)	**1**	0
		Link is realized but measures are not taken	**0**	
		Link not recognized and no measure are planned	**2**	
6	Climate change and water resources	Impacts of climate change on water resources are recognized and adaptation measures are taken up	**1**	1
		Need is recognized but no measures being taken	**0**	
		Need is recognized but no measures being taken	**2**	
7	Instances of water or vector borne diseases (Malaria, Typhoid, Jaundice, Hepatitis, etc	Not common	**1**	1
		Occasional occurrence in some areas	**0**	
		Water borne diseases leading to fatality and outbreak of epidemic in recent past	**2**	

S. No	Integration Indicators	Criteria Scoring		
		Criteria/sub criteria	**Scale**	**Selected Score**
8	Capacity (skills, resources, awareness, willingness) of administrative staff and other stakeholders	Capacity related constraints are limited, addressed regularly	**1**	3
		Addressed only in extreme cases	**0**	
		Capacity related constraints not addressed at all	**3**	
9	SWM	Segregated waste collection, treatment and disposal available; no impact on water quality or drainage	**3**	3
		Simple collection without segregation, treatment and disposal available; low impact on water quality or drainage	**2**	
		Simple collection without segregation, no treatment, only disposal; medium impact on water quality or drainage	**1**	
		Open dumping, without collection or treatment; high impact on water quality or drainage	**0**	
10	Waste water	Treatment system available to treat waste water at least to secondary level and septage management system available	**3**	3
		Part sewer connection, and/or septage management available	**2**	
		No sewer connection, and septage management available	**1**	
		No sewers and no septage, link to open or natural drains	**0**	
11	Storm water	Water logging due to encroachment of natural drains is frequent	**1**	3
		Water logging due to encroachment of natural drains is infrequent	**3**	
12	Ecosystems	More than 50% green cover and supports at least 3 types of ecosystem services	**3**	2
		Between 35-50% green cover and supports at least 2 types of ecosystem services	**2**	
		Between 20-35% green cover and supports at least 2 types of ecosystem services	**1**	
		Less than 20% green cover and supports 1 or no ecosystem services	**1**	
				23

Final Score	23
Existing status of integration in the city (Excellent, Good, Average, Poor, Critical)	Average
Weaknesses	Water portfolio, water pollution, water resources, climate change, capacity building
Strengths	Waste water strength, SWM
Quick Improvement Areas	Water and energy, ecosystems
Focus systems	