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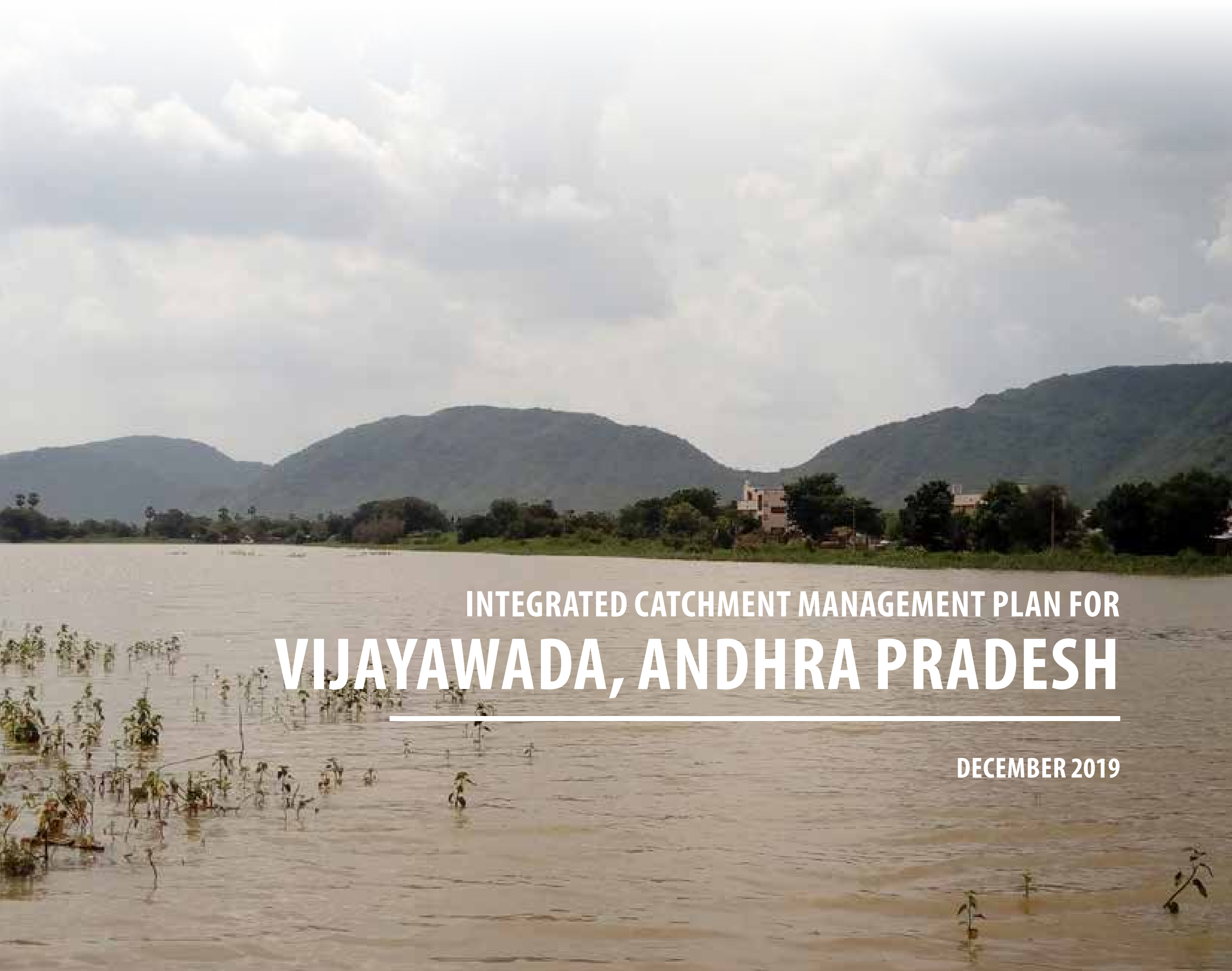

INTEGRATED CATCHMENT MANAGEMENT PLAN FOR VIJAYAWADA, ANDHRA PRADESH

DECEMBER 2019

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1 Introduction

As defined by UN-Water, water security is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. It is an increasingly important development issue in Asia and the Pacific regions, where growing populations and rapid urbanization have expanded demand and competition for, as well as driven reallocation of the finite water resources[1].

Although 70% of the earth is water, nearly 97% is in the oceans. Ocean water is too salty for drinking, manufacturing and farming. Therefore, the fresh water available for us to use is about 3% of the earth's water supply. However, this 3% of the earth's water supply has been depleting or deteriorating due to impacts of climate change, increased pollution and increased human demand and overuse of water, thereby leading us to a situation of water scarcity. While there are difficulties accessing fresh surface water either due to physical or economic water scarcity, people have been getting better at accessing ground water over the years. However, it is important to understand that groundwater gets accumulated in aquifers over millenia, and it will take millenia for it to fill back up. Hence groundwater should only be considered as a savings account which is used when absolutely necessary, like during droughts.

The approach to addressing water scarcity must focus on effective ways of utilizing the fresh surface water available by optimizing demand. Currently water is used in wasteful ways all around the world. For example, in India, sugarcane which is a water intensive crop is grown in Maharashtra - one of the driest regions in the country. A lot of water demand management programs around the world focus on optimizing water demand for personal/household uses. However, personal water use accounts for only 8% of total water usage per year, while 70% and 22% of water is being consumed for agricultural and industrial uses respectively. Therefore, the water demand management programs should increasingly focus on optimizing demand across all water uses. Competing water uses must be critically analysed and prioritised to be able to efficiently allocate the scarce fresh water resources across all uses judiciously. While we have acknowledged physical water scarcity, we also need to address economic water scarcity which is the result of poor management of the available water resources. According to the United Nations Development Programme, the latter is found more often to be the cause of countries or regions experiencing water scarcity.

A composite index called Water Security Index (WSI) quantifies on a scale of 1 to 5, the access of the population across countries/regions to the various sub-indicators of the following five key dimensions of water security:

- Household water security
- Urban water security

[1] https://qz.com/africa/1272589/how-cape-town-delayed-its-water-disaster-at-least-until-2019/

- Environmental water security
- Economic water security
- Resilience to water related disasters

India has a very low National Water Security Index of 1.6, even though piped water access at household and urban level, and presence of water treatment facilities in India are comparatively higher compared to other major South Asian countries. 10% of India's rural population and 3% of India's urban population lack improved access to water. Compared to other South Asian and South East Asian countries, India also has poor access to renewable water resources. Water security concerns in the South and South East Asian countries emerge from a host of factors that are attributed to growing populations, urbanization, industrial development and the nascent climate change induced threats . Since water security issues are increasingly becoming potent, affecting the sustainable livelihoods of human and cattle population as well as the survival of the environmental and ecosystems, it is all the more important that the countries concerned be highly sensitive and responsive in terms of mainstreaming the local governance, institutions and community based activities as well as other local development agencies for protecting and conserving the water resource system.

Climate variability has a huge impact on the hydrology and availability of water resources all over the world. Changes in temperature and precipitation patterns as consequence of the increase in concentrations of greenhouse gases will affect the hydrology process, availability of water resources, and water use for agriculture, population, and mining industry, aquatic life in rivers and lakes, and hydropower. Climate change will accelerate the global hydrological cycle, with increase in the surface temperature, changes in precipitation patterns, and evapotranspiration rate. The change in the intensity and frequency of precipitation will affect the magnitude and frequency of stream flows, thereby leading to increased intensity of floods and droughts.

The average annual per capita water availability in India is expected to decline from 1545 m3 in 2011 to as low as 1140 m3 per year in 2050. India is expected to reach a state of water stress i.e. availability falls below 1700 m3 per capita in the recent future as a result of combined effects of population growth and climate change. As per the Indian Meteorological Department, the number of days on which it rains have been coming down, making extreme rainfall events more likely, leading to floods. The overall monsoon rainfall is expected to increase in India, due to climate change, but the variability between monsoon seasons is also likely to increase, leading to volatile rainfall characterized by flooded cities or parched fields, both increasing in severity and frequency. It has been observed that changes in cropping and land use pattern, over-exploitation of water storage, and changes in irrigation and drainage in the Gangetic basin has led to reduction in the Ganges discharge by 60% over 25 years, which has in turn led to 50% drop in water availability in surface water resources, drop in groundwater table, and generation of new surface features having different thermal properties. More studies have to be conducted in different basins, aquifers, and agro-climatic regions of India to assess the response to climate change.

1.1 About the project

The catchment management plan for Solapur city is developed by ICLEI South Asia in partnerships with Athena Infonomics LLC, 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. 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 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.

1.2 Methodology – IAdapt Framework

To develop the catchment management plan for the selected micro-catchment area, the study used the IAdapt Framework toolkit developed through the project. 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. 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 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 bring 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, institutions, etc. 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 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, waste water and storm water sector
- Priority sectors identified for improvement

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

Outcome:

- List of prioritized solutions, sustainable financial models for prioritized strategies.

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 the transparency and sustainability.

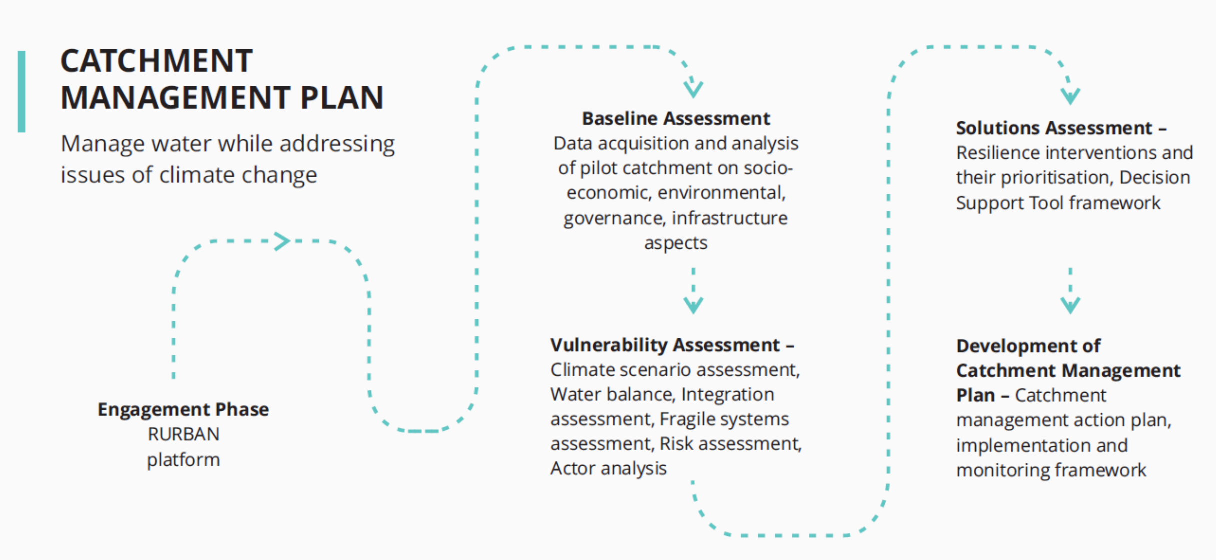


Figure 1.1 CMP Framework

2 IAdapt implementation in Vijayawada

Vijayawada is the interim capital of the state of Andhra Pradesh. Located in the Krishna District, it enjoys the benefits from the Krishna river flowing across the city. The city is known for its agricultural and industrial activities. A detailed and systematic Catchment Management Plan has been formulated in accordance with the IAdapt framework. It is a holistic plan considering the current and prospectus water demand between all the user groups in the catchment area. A robust RURBAN Platform has been institutionalized in the district, with representations from both urban and rural decision makers as well as user group organisations. Extensive consultations with the field has paved way for identification and prioritization of the resilience and adaptation strategies.

2.1 Selection of the micro catchment

To initiate the preparation of the CMP, the first step was to delineate the geographic boundaries of the catchment area. The catchments were delineated using hydrological modeling tool of GIS software. The catchment mapping exercise was carried out to identify the different micro catchments lying within the study area for Vijayawada using Digital Elevation Models (DEM).

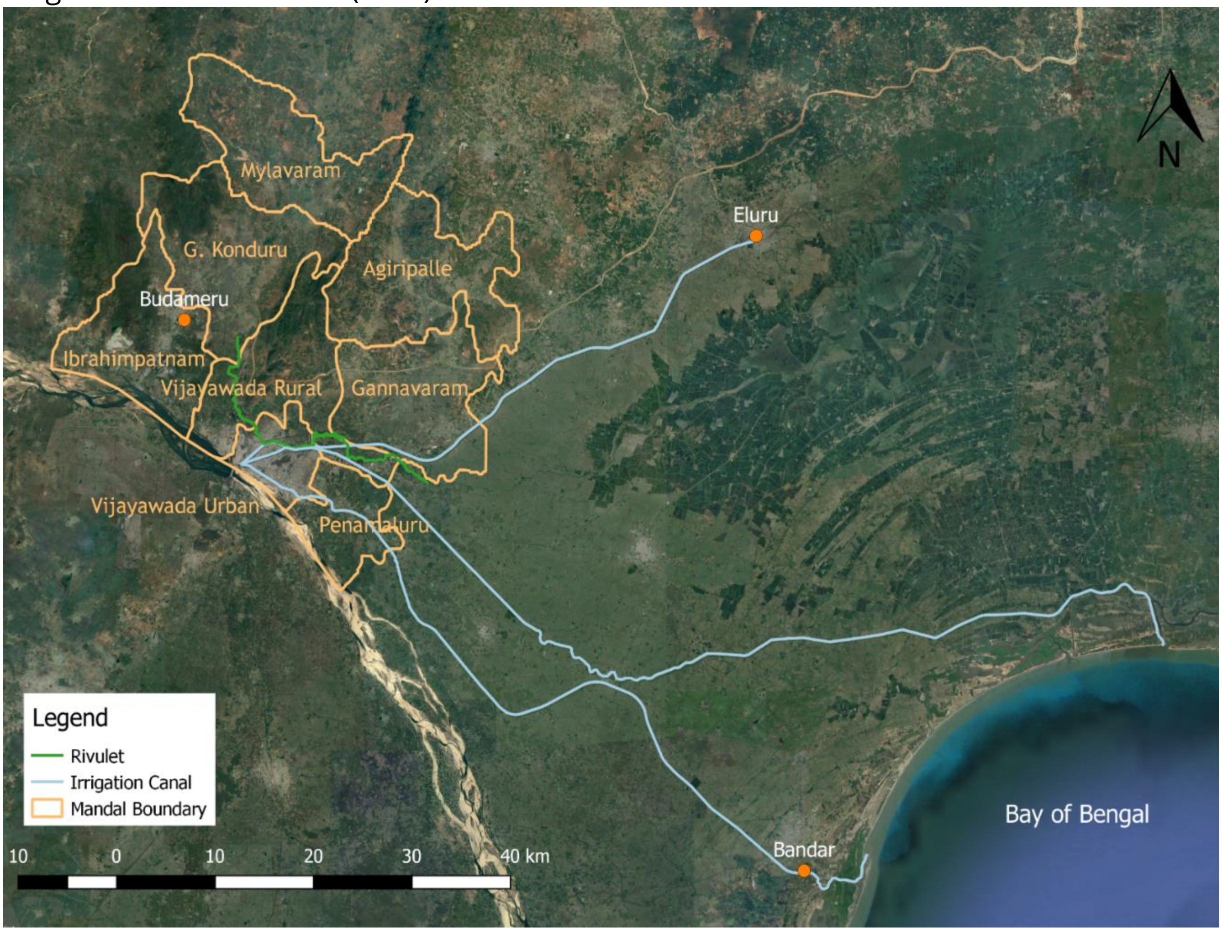


Figure 2.1 Catchment area delineation in Vijayawada

The following parameters were considered for the catchment delineation:

- Flow accumulation’
- Alignment of irrigation canals
- Future expansion plans of the municipal corporation
- Alignment of storm water drains
- Natural sinks

The outcome from the study was the following map, depicting various micro catchment with unique features. Out of the seven delineated micro-catchments, SWOT Analysis was conducted only in four, since the remaining three are located within the city boundary and do not support the rural –urban characteristics that is an essential component for the project. The SWOT Analysis revealed that micro-catchment V3 is most suitable for the implementation of the project.

The Micro-catchment V1 suffers from poor drinking water quality that compels households to purchase drinking water from RO plants. There is limited drinking water supply in few areas of the micro-catchment including hilly areas. *Pattiseema* project is being implemented in this region to meet the water demand for irrigation. This micro-catchment ranked 2nd on the SWOT Analysis. The micro-catchment V2 faces shortage of surface water for irrigation leading to overexploitation of ground water by farmers. There is a proposal to lay new water supply lines reducing loss in transmission in some urban areas of the micro-catchment. Also 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. This micro-catchment also ranked 2nd. Micro-catchment V3 covers peri-urban areas of Vijayawada therefore agriculture is practiced by a few households living in the urban areas due to their proximity to peri-urban agricultural lands and irrigation canals. There are 4 Sewage Treatment Plant (STP) in the rural and urban areas of 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. The micro-catchment ranked 1st. The micro-catchment V4 has 2 Sewage Treatment Plants (STP) in the industrial estate of the city and agriculture is the dominant occupation, with many practicing fishing as another means of livelihood. 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 hence an underground sewage system is proposed. The micro catchment ranked 3rd in the overall scoring.

The micro catchment V3 has been selected for the implementation of the project activities in Vijayawada.

Ranking Based on SWOT Analysis for Vijayawada Micro-catchments								
Micro-catchment	**Strength**	**Weakness**	**Opportunities**	**Threats**	**Positive Score**	**Negative Score**	**Total sore**	**Rank**
Micro-catchment V1	2	-7	4	-3	6	-10	-4	2
Micro-catchment V2	4	-9	5	-4	9	-13	-4	2
Micro-catchment V3	6	-9	6	-4	12	-13	-1	1
Micro-catchment V4	4	-7	3	-5	7	-12	-5	3

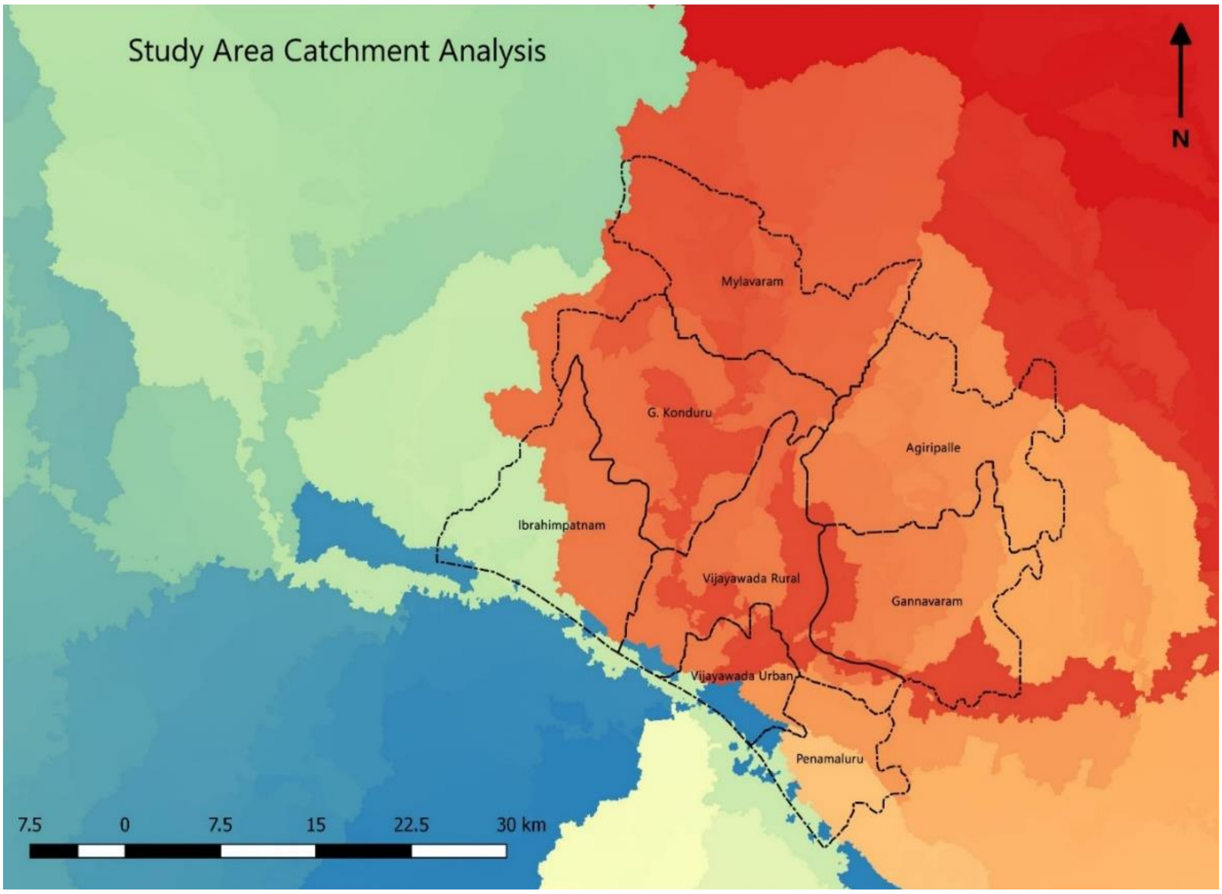


Figure 2.2 Micro catchments in Vijayawada

2.2 Pilot catchment: Overview

The selected micro catchment spans across an area of 284 sq.km and has 12 wards and 8 villages. Spread across 3 *mandals* i.e., Vijayawada urban, Vijayawada rural and Gannavaram, the pilot catchment area was then subjected to studies of the likes of baseline and vulnerability assessments.

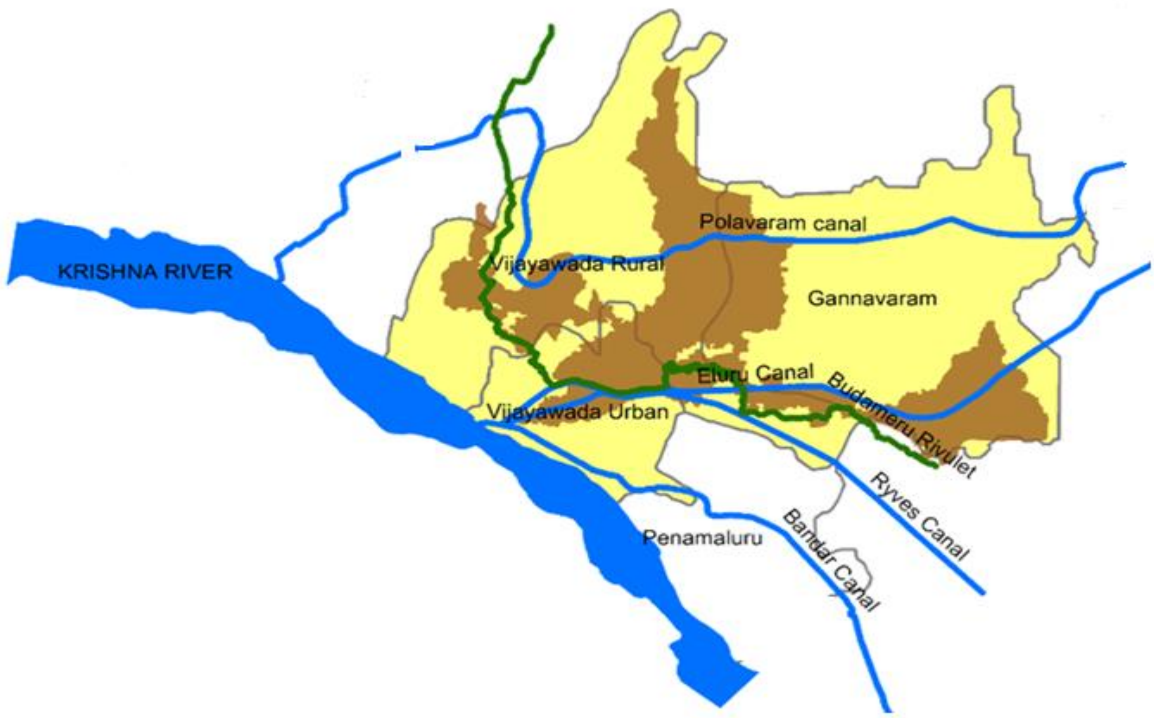


Figure 2.3 Identified pilot catchment

The catchment is located on the banks of Krishna River with a population of around 12 lakhs and with average density of 5910 persons per acre of which the city alone has a density of 16462 persons per acre. Population explosion is a major concern in Vijayawada, as the city has become part of the capital region thereby leading to an increase in migration during the recent years. The predominant agrarian economy is transforming into a service and industrial hub in order to serve the capital region of Amaravati.

The pilot catchment has a climate with very hot summers and pleasant winters. The maximum temperature ranges from 30°C to 39°C whereas the minimum temperature ranges from 24°C to 30°C. The catchment receives rainfall mostly in the months of June to October which constitutes around 82% of the total rainfall, with Vijayawada city receiving an annual average rainfall of 982 cm. The city of Vijayawada, due to its geographical position, high rainfall variability and topography is prone to flooding. Historically, unprecedented rainfall at the end of the monsoon season has caused flooding in the outskirts of the city predominantly due to increased man-made activities such as encroachment. The Krishna river enters the city from the north leading into Budameru canal, whose networks are used to discharge excess/flood waters. The low-lying areas along the river in the city experience water logging, particularly during retreating monsoon (due to the depressions and cyclones), when reservoirs are almost at full capacity. The carrying capacity of Budameru canal has also reduced due to silting of drains, developments and encroachments over the years. Due to various flood control measures in upstream areas, overall flood risk for the city of Vijayawada has been reduced over the years. From historical flood data, it can be observed that flood occurrence has been on the fall in Vijayawada. Even the flood that occurred in 2009 might be attributed to the cumulative effect of above average rainfall over the previous 6 years leading to exceeding the storage capacity of the aquifer. The depletion of ground water table is also a major concern in the pilot catchment due to the increased industrial activities and over exploitation of ground water in the area. Vijayawada Urban has the ground water table at a depth of 9 m which is very less when compared to the water table depth of 21.6 m and 11.8 m at Vijayawada Rural *mandal* and Gannavaram *mandal* respectively.

2.3 Formulation of RURBAN platform

A RURBAN Platform has been institutionalized in the Krishna district, with representations from both urban and rural decision makers as well as user group organisations. This multi-stakeholder platform enables dialogue between the otherwise silo departments and empowers decision making towards integrated water management.

The RURBAN platform was constituted as part of the project to bring together rural and urban stakeholders in the catchment to share existing knowledge regarding water management and to make decisions in collaboration, considering the needs of different stakeholders. The primary challenge the RURBAN platform aims to address is the existing institutional silos of governance of water across boundaries. The expected outcome of the development of the RURBAN platform is the participatory management of water resources through an integrated governance mechanism. The RURBAN platform consists of key individuals from the state, district, and city departments, and ministries representing urban and rural authorities, who are responsible for interactions and discussions on integrated water management strategies and actions. The members of the RURBAN platform have the responsibility of development of water strategies and actions at the administrative and community level, and they also provide support for the implementation of water sector related actions at different levels.

Members of RURBAN Platform include:

- District Magistrate and Collector, Krishna
- Commissioner, Vijayawada Municipal Corporation
- Joint Collector, Krishna
- CEO, Zilla Parishad
- Chief Engineer, Vijayawada Municipal Corporation
- Superintending Engineer, Rural Water and Supply and Sanitation
- Engineer in Chief, Water Resources Department
- District Panchayat Officer, Krishna
- General Manager, DIC
- Joint Director, Agriculture

This District RURBAN Steering Committee has been formed under the chairpersonship of the District Collector and has been instrumental in conducting several meetings and stakeholder consultations towards integrated water management in Vijayawada.

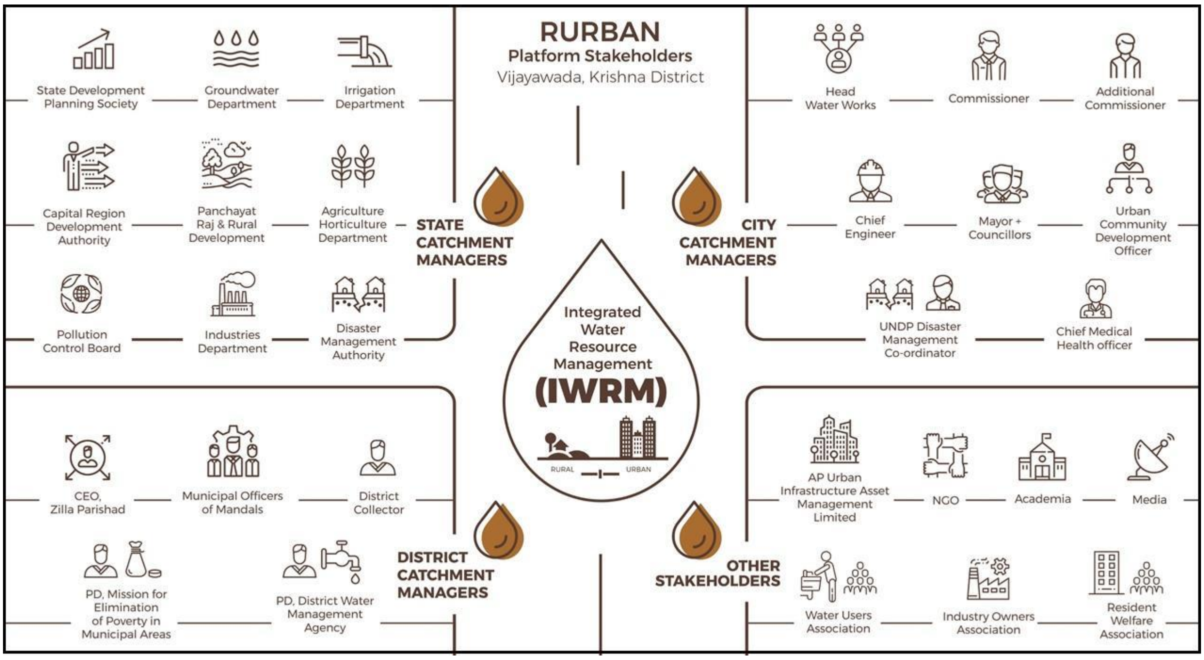


Figure 2.4 Stakeholder mapping for RURBAN Platform in Vijayawada

2.4 Baseline Assessment

A thorough and an extensive baseline assessment was carried out for the micro catchment in Vijayawada and the following represents a summary of the same:

The selected micro-catchment V3 covers 12 villages (Ambapuram, Chegireddipadu, Done Atkuru, Haveli Mutyalampadu, Jakkulenekkelam, Narasayagudem, Nunna, Phiryadi Nainavaram, Ramachandrapuram, Surampalle, Vedurupavuluru, Velageru) and Vijayawada city area. The total area covered by the 12 villages is approximately 16451.3 hectares whereas the city covers an area of about 61.88 km^2. The micro-catchment has approximately 12081 households (rural) and 231759 HH (Urban). The total rural population in the micro-catchment is approximately 42246 whereas the urban population is about 263,998 .

Ground water, Budameru river and agricultural canals carrying Krishna's fresh water are the primary water sources within the micro-catchment.

Based on an analysis of historical data, Vijayawada City witnessed several storms ranging from Tropical Depressions (31 – 61 km/hr) to very strong storms (88-117 km/hr). In the 137-year period between 1877 and 2013, 33 cyclonic disturbances passed within 150 km of Vijayawada City, an average of one cyclone in five years . However, most of the cyclones have weak effects. Exceptions to this rule are found in the May 1990 super cyclone with winds up to 117 kmph and the November 1977 cyclone with winds up to 183 kmph. Besides the overflowing of banks of Krishna River, Vijayawada city also experiences floods (mainly water logging) due to flows from Budameru river. The low-lying areas along the river in the city experience the water logging particularly during retreating monsoon (due to the depressions and cyclones), when reservoirs are almost at the full capacity. Our baselines assessment indicated that wards around Budameru River (drain) area are having a high incidence of water borne diseases (typhoid, jaundice and diarrhea). The quality of water supply in coastal regions is at risk from rising sea level and changes in precipitation. Rising sea level and the occurrence of drought can increase the salinity of both surface water and ground water through salt water intrusion.The micro-catchment receives rainfall mostly in the months of June to October which constitutes around 82% of the total rainfall, with Vijayawada city receiving an annual average rainfall of 982 cm. The city of Vijayawada, due to its geographical position, high rainfall variability and topography is prone to flooding. Historically, unprecedented rainfall at the end of the monsoon season has caused flooding in the outskirts of the city predominantly due to increased man-made activities such as encroachment.

The Krishna river enters the city from the north leading into Budameru canal, whose networks are used to discharge excess/flood waters. The carrying capacity of Budameru canal has also reduced due to silting of drains, developments and encroachments over the years. Due to various flood control measures in upstream areas, overall flood risk for the city of Vijayawada has been reduced over the years. From historical flood data, it can be observed that flood occurrence has been on the fall in Vijayawada. Even the flood that occurred in 2009 might be attributed to the cumulative effect of above average rainfall over the previous 6 years leading to exceeding the storage capacity of the aquifer.

The depletion of ground water table is also a major concern in the micro-catchment due to the increased industrial activities and over exploitation of ground water in the area. Vijayawada Urban has ground water table at a depth of 9 m which is very less when compared to the water table depth of 21.6 m and 11.8 m at Vijayawada Rural *mandal* and Gannavaram *mandal* respectively.

As per Vijayawada Municipal Corporation and Rural Water Supply and Sewerage, Krishna, it can be observed that the urban micro-catchment has 62.7% coverage of water supply distribution network with 85% households having access to piped water supply while approximately 35% households have access to piped water supply in the rural micro catchment. As on date, 36% of the households are connected to sewage distribution networks in the urban micro-catchment. Out of the 150 MLD waste water generated in the city per day, 120 MLD is treated while the rest is let out into the agricultural canals. Slums pockets are seen to have poor sewerage facilities and water supply facilities.

2.5 IAdapt Phase 3: Climate Change Vulnerability Assessment

For Vijayawada, climate scenario assessment as per the IAdapt Framework indicates that there are observed changes in temperature and rainfall. Even though the number of cyclone disturbances is expected to decrease, the cyclonic systems is expected to increase. A marginal increase in storm surge level is also expected. The sea level along the coast is found to be rising at a rate of 1.3mm/year on an average. Krishna district have had exposure to floods and cyclones, mainly due to their geographic location and the influence of parameters like deviation of rainfall and exposure to oceanic disturbances. Also, some *mandals* in Krishna district have indicated a significant decline in ground water. With a prediction of 20% reduction in water yield over the years, Krishna's abundant surface water supply is expected to be stressed.

A summary of the findings from the study for the catchment is given below:

Changing Climate Conditions	Assessments	Climate Scenario Summary Statements
Precipitation change	Regional Assessments	There is a high level of confidence of an expected change of 858±10mm to 1280±16 mm in the mean annual rainfall in the East Coastal region by the year 2030.
	Supplementary Assessments	There is a suggestion of a projected mean southwest monsoon rainfall in the range from 2-16 mm/day during 2050s and 2-18 mm/day during 2080s. There is a suggestion of a projected mean northeast monsoon rainfall ranges from 1.0- 4.0 mm/day for 2050s and 1.5-4.5 mm/day in 2080s. Also, there is a suggestion where Krishna district is projected to have a mean rainfall of 4-6 mm/day.
Temperature change	Regional Assessments	There is an expected increase from 28.7±0.6oC to 29.3±0.7oC in the annual air temperature of the East Coastal region in 2030s with respect to the 1970s.
	Supplementary Assessments	There is a suggestion that the mean annual predicted temperature varies from 26oC to 32.5oC in 2050s with further rise in range of temperature from 27oC to 33.5oC in 2080s
Extreme events		Temperature: It is expected that the change in minimum temperature along the eastern coastal region will be in the range from 2.0oC to 4.5oC. Likewise, it is expected that the change in maximum temperature in 2030s with respect to 1970s will range between 1oC to 3.5oC Precipitation: It is expected that in the eastern coast, the number of rainy days is likely to decrease by 1-5 days. Also, it is expected that the intensity of rainfall

		is likely to increase between 1mm/day and 4mm/day Storm: There is an expected increase of 100-year return levels of storm from 2.53±0.08 (1961-1990) to 2.94±0.08 (2071-2100) Cyclone: It is expected that even though cyclonic disturbances in 2030s is likely to decrease with respect to 1970s, the cyclonic systems might be more intense in 2030s
Sea level rise		The expected mean sea level rise trend along the Vishakhapatnam coast is 1.09 mm/yr

2.5.1 Water balance

The water balance modelling was done using Water Evaluation and Planning System (WEAP), which is a microcomputer tool for integrated water resources planning that provides a user-friendly framework for policy analysis. In WEAP, the water supply-demand gap is calculated by the software once the water consumption and supply details are entered for the various demand and supply nodes. In the water balance model for the catchment area which consists of 8 *mandals*, the following data which was collected from different government departments, has been input in the model:

i. Krishna river headflow
ii. Annual activity level and annual water use rate for the demand nodes (Urban and rural population, livestock, agriculture, industries and power plants)
iii. Initial storage, maximum withdrawal, natural recharge etc. for groundwater
iv. Maximum diversion for Prakasam barrage
v. Inflows to tanks
vi. Sewage treatment plant capacity

The water balance was calculated for the micro-catchment area through the WEAP model and it was estimated that there is a current unmet demand of 8 MCM in the catchment which is estimated to increase to 142.5 MCM by 2041, considering the current population growth rate.

Water quality in the micro-catchment has been identified as a focus issues and hence the impact of water quality on the water balance in the catchment is analysed using the Decision Support Tool. As per the CPCB water quality standards, drinking water sources after conventional treatment and disinfection should have a maximum BOD concentration of 3 mg/L only. If the CPCB standards are applied to the water supply in Vijayawada city, it can be observed that the unmet demand will increase because most of the groundwater abstracted by the urban population is of lower quality. The major source of water for Vijayawada city is Prakasam Barrage, and the water supplied from the barrage meets the CPCB water quality standards. But in rural areas, the BOD concentration in the water used is significantly higher, and doesn't meet the CPCB water quality standards, and hence the unmet demand increases steeply under a scenario where water supply is restricted based on CPCB quality standards.

The water balance has incorporated the future scenarios and investment scenarios such as high population growth, climate change, demand side quality restrictions, waste water reuse and 24 x 7 water supply (leakage reduction).

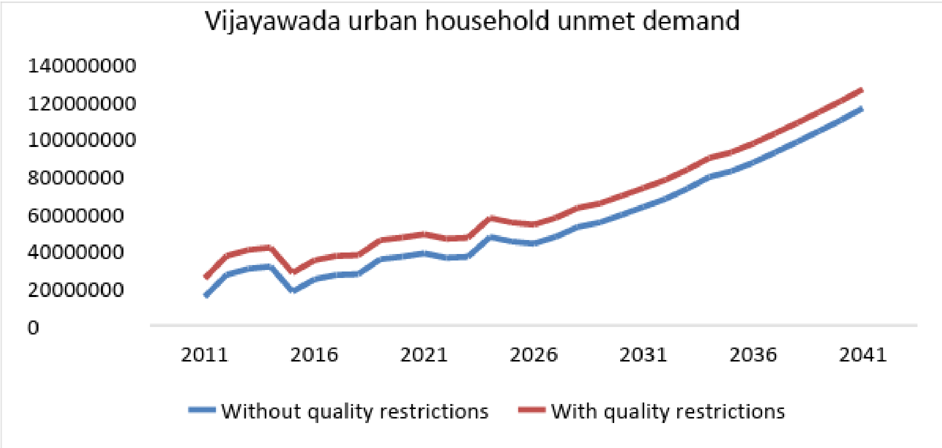


Figure 2.5 Vijayawada Urban Household Unmet Water Demand

Urban Water Balance: Existing and Future Demand-Supply gap

Parameter	Value (MCM)						
	Existing Scenario	Future Scenario					
		Business as usual	High population growth	Climate change (RCAP 4.5)	Demand side quality restrictions	Wastewater reuse	24X7 water supply (Leakage reduction)
Household demand	50.35	163.30	289.18	163.30	163.30	163.30	163.30
Household supply	45.95	46.83	46.83	46.83	10.18	46.83	58.34
Household demand supply gap	4.40	116.48	242.36	116.48	153.12	116.48	104.96
Demand for bulk uses	41.05	41.05	41.05	41.05	41.05	41.05	41.05
Supply for bulk uses	37.16	36.29	36.29	36.29	35.85	36.44	36.33
Demand-supply Gap for bulk uses	3.89	4.76	4.76	4.76	5.20	4.61	4.72
Total water demand	91.40	204.35	330.23	204.35	204.35	204.35	204.35
Total water supply	83.11	83.11	83.11	83.11	46.03	83.26	94.67
Demand and	8.29	121.24	247.12	121.24	158.32	121.09	109.68

Parameter	Value (MCM)						
	Existing Scenario	Future Scenario					
		Business as usual	High population growth	Climate change (RCAP 4.5)	Demand side quality restrictions	Wastewater reuse	24X7 water supply (Leakage reduction)
supply gap							

Rural Water Balance: Existing and Future Demand-Supply gap

Parameter	Value (MCM)						
	Existing Scenario	Future Scenario					
		Business as usual	High population growth	Climate change (RCAP 4.5)	Demand side quality restrictions	Wastewater reuse	24X7 water supply (Leakage reduction)
Household demand	7.56	17.41	17.41	17.41	17.41	17.41	17.41
Household supply	7.48	7.48	7.48	7.48	1.02	7.48	7.48
Household demand supply gap	0.09	9.93	9.93	9.93	16.39	9.93	9.93
Demand for bulk uses	57.79	57.57	81.16	57.57	57.57	57.57	57.57
Supply for bulk uses	55.80	55.59	55.59	55.59	43.07	55.53	55.59
Demand-supply Gap for bulk uses	1.99	1.99	25.57	1.99	14.51	2.04	1.99
Total water demand	65.36	74.98	98.57	74.98	74.98	74.98	74.98
Total water supply	63.28	63.06	63.06	63.06	44.08	63.01	63.06
Demand and supply gap	2.08	11.92	35.50	11.92	30.89	11.97	11.92

2.5.2 Vulnerability assessment

Based on the IAdapt Framework, climate vulnerability of the sectors were analysed. Vulnerability assessment for the four systems viz. water supply, water pollution, urban flooding, river flooding were discussed in detailed in the context of climate change. Expected changes on the systems were identified with respect to temperature and rainfall changes. Once the climate fragility of the systems was identified discussions were held to measure the likelihood and consequences of these climate fragilities of each system to conduct a climate risk assessment of the fragile systems. A score was assigned from 1 to 5 based on the likelihood of each risk occurring and related consequences. For each system, the likelihood and consequence score were multiplied to get the final risk score. Critical systems identified during the discussions were water supply, ground water, pollution and urban flooding due to waste water, storm water drainage overflows.

Based on the climate fragility statement, actors across rural and urban areas in the micro-catchment were identified and their adaptive capacity to organise and respond, access to resources and access to information was assessed and ranked. We identified that Vijayawada Municipal Corporation, Water Resources Department, Andhra Pradesh State Disaster Management Authority had higher levels of adaptive capacity and could be engaged in the proposed interventions. The user groups such as Water Users Association, Resident Welfare Associations, Gram panchayats and Self Help Groups were identified to have low adaptive capacity and would need to be specifically targeted in the resilience interventions.

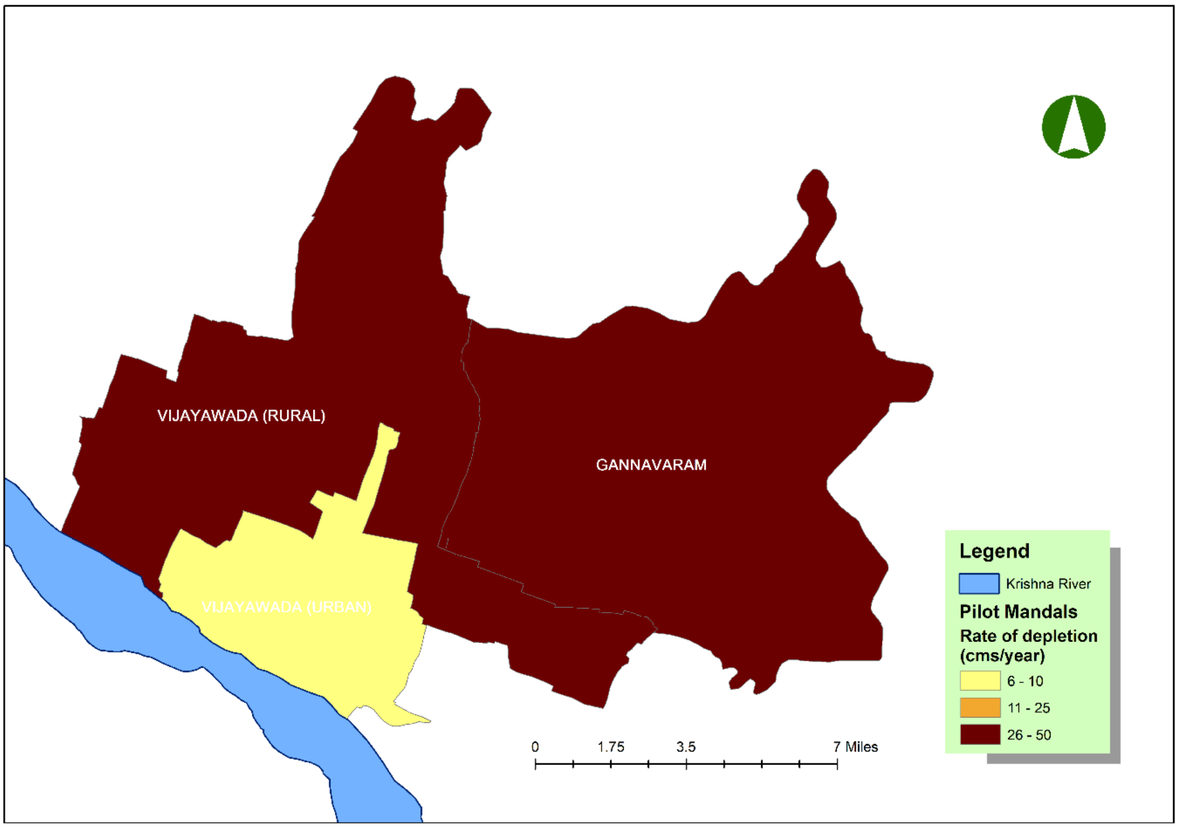


Figure 2.6 Pilot catchment groundwater depletion rates

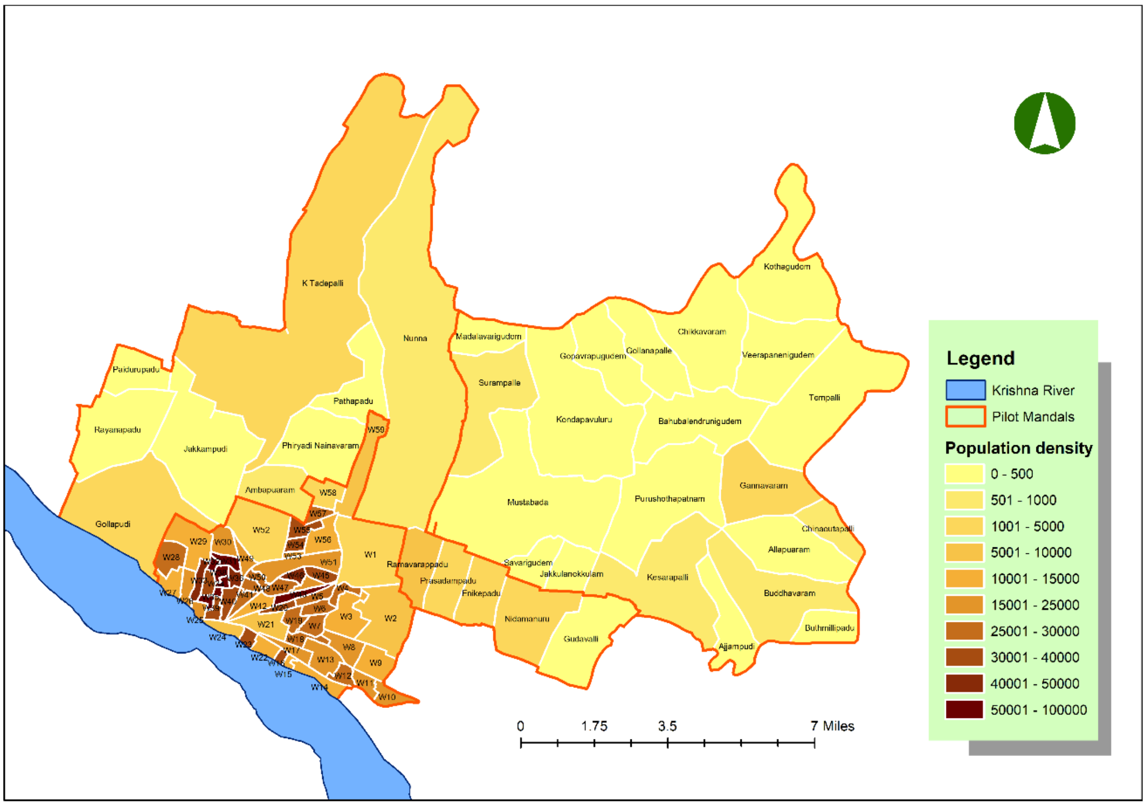


Figure 2.7 Pilot catchment population density

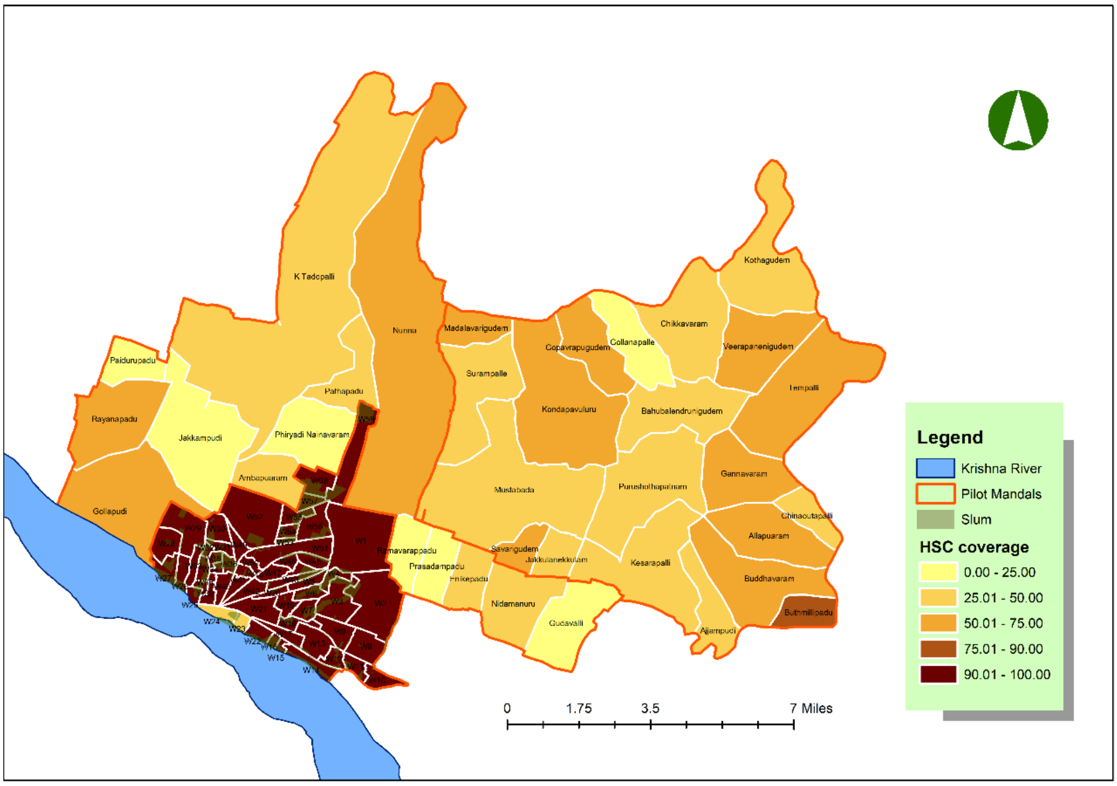


Figure 2.8 Pilot catchment Household Water Supply Coverage

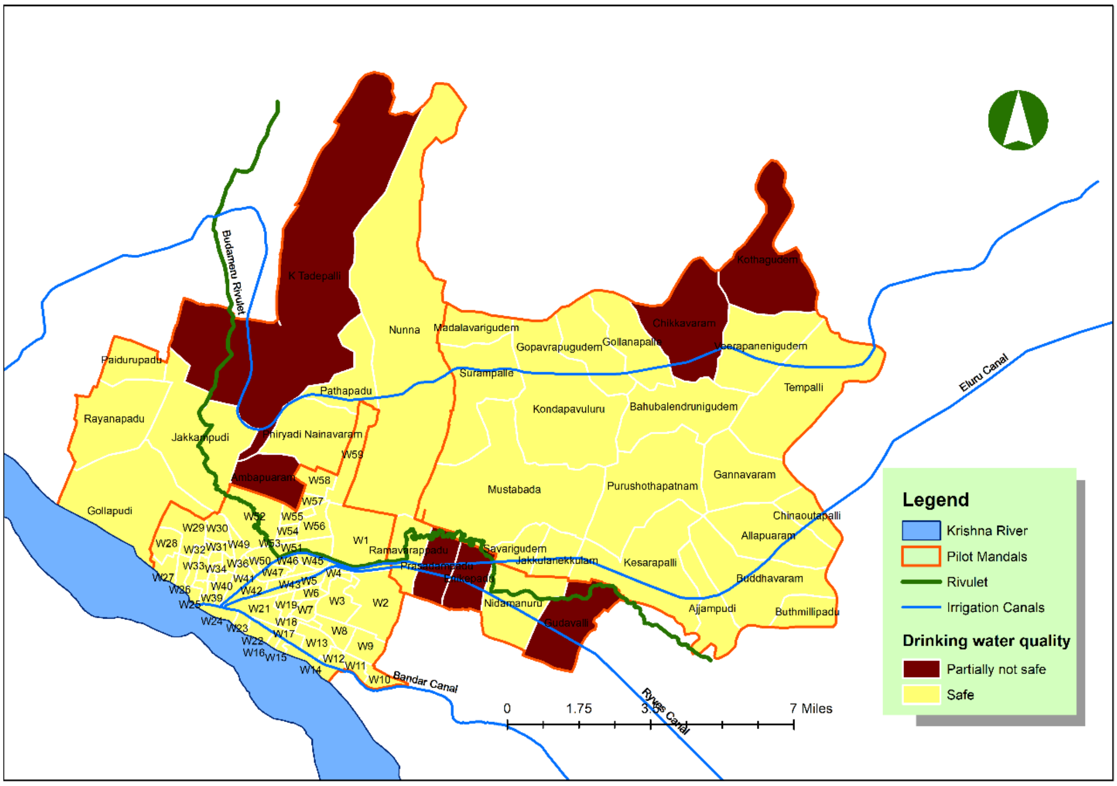


Figure 2.9 Pilot catchment Water Quality

2.6 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 have been identified, a Water Evaluation and Assessment Planning tool is employed to help in the decision making and adaptation finalizations.

2.6.1 Group discussions on CMP adaptations

The objective of the group discussions was to ratify about the focus areas and problems identified as part of the IAdapt framework along with discussing the solutions that are feasible in the context of micro-catchment with various stakeholders who are involved in water management. The feasible solutions as prioritised by stakeholders will be recommended towards catchment-based approaches in water management.

A total of four group discussions were conducted involving officials from AP state water resource department, Rural water supply and sanitation, Vijayawada Municipal corporation, Mandal parishad and gram panchayats, Agriculture department and farmers.

On the first day, discussions were held with the officials of the Andhra Pradesh state water resources department and Rural water supply and sanitation department of Krishna district. It has come to the notice that water bodies have been abused by the residents of the city and water quality of the canals is pathetic with ammonia content. Since the source of drinking water for rural settlements is ground water, officials from RWSS state that the water supplied from PWS scheme is portable which contradicts with ground reality as most percentage of population still buy on the water from RO plants. In the discussion we also came to know that the water which is drawn from the ground for drinking purposes should be passed through the sand filters, for which the sand filters have to cleaned on regular basis to remove the silt and sediments but this is not happening due to the truncated financial status of the Gram panchayats. There is no mechanism for treatment of water before supplying for drinking purposes. The sewerage and sanitation sector have been a neglected in the rural areas. There were no steps taken yet to lay underground drainage system till date in the rural areas. Water resource department mainly concerned about the allocation of water for drinking and agricultural purposes and post flood mitigation measures. There were no steps taken in advance to mitigate the flood. Some issues related to usage of water which are connected to the people stigma need a behavioural change.

On the second day, discussions were held with the officials from Vijayawada Municipal corporation, the main challenge in the urban water supply is supply of drinking water to the slums/encroachments in the slum areas and most of the wards with slum pockets do not have sewerage facilities and sanitation facilities. While the VMC is working on this issue to provide for better water supply infrastructure and management. As the water coming into this canal has been polluted by the city inhabitants letting domestic water and littering solid waste this water is only being used for irrigation purposes. The VMC had come up with a pilot project 'Recycling of wastewater from canals' includes establishing the Onsite treatment plants and send it to Main pumping stations which carry to the STPs. This project will encourage the use of surface water for drinking purposes and increase in the crop yield. The exploitation of ground water both for irrigation and drinking water purposes in the rural settlements is identifiable.

On the final day, the discussions were held with MPDOs, Panchayat secretaries, Farmers and residents of the Villages. When we are discussing with MPDOs we came to know that there is lack of co-ordination between RWSS and Panchayats since the statements contradict when we ask questions about the drinking water supply and its quality. As stated previously there is no mechanism for treatment of water before supplying for drinking purposes. No storm water drains or pits to conserve the rainwater, even the sewage water, solid waste is let into the roadside kuccha drains. During the monsoons these drains overflow where the stagnated water come out and spill out on roads leading for outbreak of diseases.
The focus areas, problems and micro catchment solutions were discussed with respective participants and their responses were collected. The following tables provide the insights of the participated stakeholders on each solution and problem area.

FGD 1 – Discussions with officials of the Andhra Pradesh state water resources department and Rural water supply and sanitation department of Krishna district

Focus areas and problems					
		Members			
Focus areas	***Fragility statements***	**Sai nath, SE, RWSS**	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
Water supply	Old piped network leading to 40% physical losses due to leaks	No (only upto 10%)	No (only upto 10%)	-	-
	Lack of water supply in hilly slum areas of the city	-	-	-	-
	Only 50% of the households are connected to the water supply system in the city	No (around 25 - 30%)	No (above 50%)	-	-
	Excessive dependence on groundwater; No restriction on borewell digging.	Yes	Yes	Not in delta areas	Not in delta areas
	Additional financial burden on individual households to purchase water from water tankers during summers	Yes	Yes	Yes	Yes
Water pollution	Only 60% of the city is connected by underground sewerage drainage	UGD facilities are not yet available in the Villages	UGD facilities are not yet available in the Villages	-	-
	Industrial effluents and household sewage is therefore discharged into	household sewage mostly ends up in the soak pits and fields near by	household sewage mostly ends up in the soak pits and fields near by	Yes	Yes

Focus areas and problems					
		Members			
Focus areas	***Fragility statements***	**Sai nath, SE, RWSS**	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
	the irrigation canals and rivulet				
	The polluted water in the irrigation canal is used for irrigation and drinking purposes in the villages	No	No	-	-
	Surface run-off leads the fertilisers used for agriculture being washed off into canals and water bodies	Yes	Yes	Yes	Yes
	The fertilisers also seep into the ground water and pollute the groundwater	Depends on the available ground water levels of that area	-	-	-
	There is a practice of dumping solid waste into canals by Households	No	No	Yes	Yes
	The open dumping sites in the villages used by the city corporation cause pollution of ground water through seepage	Depends on the available ground water levels of that area		Yes	Yes
	Usage of polluted water for agriculture and household purpose is impacting the	No	No	Yes	Yes

Focus areas and problems					
		Members			
Focus areas	***Fragility statements***	**Sai nath, SE, RWSS**	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
	produce and health respectively				
	Residents are buying RO water due to poor quality of water supply	Portable water is supplied through PWS scheme	Due to panchayat raj inability to Sand filters, the stigma prevailed in the residents do not use supplied water	Yes	Yes
Urban flooding (stormwater flooding)	There is low connectivity of storm water drains and hence the storm water is accumulated in the canals and rivulet	Yes	Yes	Yes	Yes
	The canal networks and rivulets are also used to discharge excess/flood waters from the reservoir	-	-	Not beyond the design capacity	Not beyond the design capacity
	Low lying areas experience water logging from the canals and rivulet during retreating monsoon due to depression and cyclones when reservoirs are almost at full capacity	Yes	Yes	No	No
	The carry	Yes	Yes	Yes	Yes

Focus areas and problems					
Focus areas	***Fragility statements***	**Members**			
		Sai nath, SE, RWSS	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin , AE, APSWRD**
	capacity of the canals and rivulets has reduced due to silting, encroachment				
	Water logging is causing outbreak of vector borne diseases	Not in identifiable proportion	-	No	No
River flooding and cyclone	Heavy rainfall in the upper reaches of catchment in Western Ghats region is a major cause of flooding in the lower Krishna basin which is caused by monsoon depressions	-	-	Yes (During the monsoons)	Yes (During the monsoons)
	Vijayawada is located on the line which separated the delta and irrigated land	-	-	Yes	Yes
	The flooding is primarily caused by unauthorized settlements along the river	-	-	Yes	Yes
	Breaking of bunds for public private development creates backwater	-	-	-	-
	This flooding results in loss of	-	-	Yes	Yes

Focus areas and problems					
Focus areas	***Fragility statements***	**Members**			
		Sai nath, SE, RWSS	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin , AE, APSWRD**
	property, livelihood, assets, health and at times lives				

Micro-catchment solutions					
Focus area and fragility statement	***Micro-catchment solutions***	**Members**			
		Sainath, SE, RWSS	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
Water supply: There is irregular supply of water supply to residents causing them to rely on other unsustainable sources of water supply and creating a financial burden on the people	Maximise coverage of water supply network	Yes (already being done)	Yes (already being done)	Yes	Yes
	Replace old pipes with new pipes to reduce loss of water during transmission	Yes (already being done)	Yes (already being done)	Yes	Yes
	Conduct awareness to reduce water consumption among users	Yes	Yes	Yes	Yes
	Subsidies encouraging water efficient fixtures in residential units	Enforcement rather subsidies	Enforcement rather subsidies	Yes	Yes
	Introduce pricing/metering to improve the efficiency of water use	Yes	Yes	Yes	Yes
	Encourage selling of recycled water to other users	Yes	Yes	Yes	Yes
	Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management practices to determine water use efficiency and develop recommendations for improving it	Yes	Yes	Yes	Yes
	Encourage water efficient irrigation systems	Yes	Yes	Yes	Yes
	Make Rain water harvesting systems	Yes	Yes	Yes	Yes

Micro-catchment solutions					
Focus area and fragility statement	***Micro-catchment solutions***	**Members**			
		Sainath, SE, RWSS	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
	mandatory across the city				
Water quality: The irrigation canals flowing through the city are polluted due to disposal of sewage and waste into the canals and the run off fertilizers from the agricultural fields. The ground water is getting polluted from fertilizer percolation and dumping ground percolation. This water which is used for agriculture and household purposes is creating health problems and forcing residents to buy water for drinking purpose from RO plants	Enhance capacity of Sewage Treatment Plans (STP)	Yes	Yes	Yes	Yes
	Conduct awareness to reduce water consumption among users + Subsidies encouraging water efficient fixtures in residential units + Introduce pricing/metering to improve the efficiency of water use – to reduce waste water generation and to reduce investment on STPs	Yes	Yes	Yes	Yes
	Design decentralized waste water treatment system for local reuse	Yes	Yes	Yes	Yes
Urban flooding: Due to poor storm	Encourage paddy cultivation to reduce run off	Yes	Yes	Yes	Yes

Micro-catchment solutions					
		Members			
Focus area and fragility statement	***Micro-catchment solutions***	**Sainath, SE, RWSS**	**Sujatha, AE, RWSS**	**K.V.L.N.P Chowdary, SE, APSWRD**	**Azamuddin, AE, APSWRD**
water drain network, water logging in the irrigation canals and rivulet is causing urban flooding leading to loss of assets and outbreak of vector borne diseases	from rural catchments				
	Develop /filter strips / swales / bio retention area / rain garden / filter drains and trenches/ permeable pavements / detention basin / infiltration basins / water retention ponds as part of Sustainable Drainage system	Yes	Yes	Yes	Yes
River flooding: Due to the reduction of river bed and heavy rains caused by monsoon depressions, Krishna river gets flooded and there is loss of property, assets, and livelihoods, health and at times lives	Develop hazard maps for low lying areas outlining areas at risk for flooding – awareness programs on possible impact, safety concerns, potential risk and appropriate responses	Yes	Yes	Yes	Yes

FGD 2 – Discussions with officials from Vijayawada Municipal corporation

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		Rama krishna, SE, VMC	**Basivi Reddy, AE, HWW VMC**	**Rama koteswararao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
Water supply	Old piped network leading to 40% physical losses due to leaks	Around 15 - 20%	-	-	-
	Lack of water supply in hilly slum areas of the city	80% of the slums are taken care	-	-	-
	Only 50% of the households are connected to the water supply system in the city	More than 80% covered	-	-	-
	Excessive dependence on groundwater; No restriction on borewell digging.	Not in the city	Not in the city	Not in the city	Not in delta areas
	Additional financial burden on individual households to purchase water from water tankers during summers	No, Fixed tariff	No, Fixed tariff	-	Yes
Water pollution	Only 60% of the city is connected by underground sewerage drainage	Yes	Yes	Yes	-
	Industrial effluents and household sewage is therefore discharged into the irrigation canals and rivulet	Onsite treatment plants are being proposed	-	-	Yes
	The polluted water in the irrigation canal is used for irrigation and drinking purposes in the villages	-	-	-	Yes
	Surface run-off leads the fertilisers used for agriculture being washed off into canals and water	-	-	-	-

Focus areas and problems					
Focus areas	***Fragility statements***	**Members**			
		Rama krishna, SE, VMC	**Basivi Reddy, AE, HWW VMC**	**Rama koteswararao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
	bodies				
	The fertilisers also seep into the ground water and pollute the groundwater	Depends on the available ground water levels of that area	-	-	Yes
	There is a practice of dumping solid waste into canals by Households	Fencing has been provided	-	Fencing has been provided	Yes
	The open dumping sites in the villages used by the city corporation cause pollution of ground water through seepage	Depends on the available ground water levels of that area	-	-	Yes
	Usage of polluted water for agriculture and household purpose is impacting the produce and health respectively	-	-	-	Yes
	Residents are buying RO water due to poor quality of water supply	Depends on the affordability. VMC supplied drinking water meets the required standards	Depends on the affordabilit y. VMC supplied drinking water meets the required standards	-	Yes
Urban flooding (stormw ater flooding)	There is low connectivity of storm water drains and hence the storm water is accumulated in the canals and rivulet	No	-	-	Yes
	The canal networks and rivulets are also used to discharge excess/flood waters from the reservoir	-	-	-	Not beyond the design capacity

Focus areas and problems					
Focus areas	***Fragility statements***	**Members**			
		Rama krishna, SE, VMC	**Basivi Reddy, AE, HWW VMC**	**Rama koteswararao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
	Low lying areas experience water logging from the canals and rivulet during retreating monsoon due to depression and cyclones when reservoirs are almost at full capacity	Yes	-	-	No
	The carry capacity of the canals and rivulets has reduced due to silting, encroachment	Yes	-	-	Yes
	Water logging is causing outbreak of vector borne diseases	Not in identifiable proportion	-	-	Yes
River flooding and cyclone	Heavy rainfall in the upper reaches of catchment in Western Ghats region is a major cause of flooding in the lower Krishna basin which is caused by monsoon depressions	-	-	-	Yes (During the monsoons)
	Vijayawada is located on the line which separated the delta and irrigated land	-	-	-	Yes
	The flooding is primarily caused by unauthorized settlements along the river	-	-	-	Yes
	Breaking of bunds for public private development creates backwater	-	-	-	-
	This flooding results in loss of property, livelihood, assets,	-	-	-	Yes

Focus areas and problems					
Focus areas	***Fragility statements***	**Members**			
		Rama krishna, SE, VMC	**Basivi Reddy, AE, HWW VMC**	**Rama koteswararao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
	health and at times lives				

Micro-catchment solutions					
		Members			
Focus area and fragility statement	***Micro-catchment solutions***	**Rama krishna, SE, VMC**	**Basivi Reddy, AE, HWW VMC**	**Rama koteswara rao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
Water supply: There is irregular supply of water supply to residents causing them to rely on other unsustainable sources of water supply and creating a financial burden on the people	Maximise coverage of water supply network	Yes (already being done)	Yes (already being done)	Yes	Yes
	Replace old pipes with new pipes to reduce loss of water during transmission	Yes (already being done)	Yes (already being done)	Yes	Yes
	Conduct awareness to reduce water consumption among users	Yes	Yes	Yes	Yes
	Subsidies encouraging water efficient fixtures in residential units	Yes	Yes	Yes	Yes
	Introduce pricing/metering to improve the efficiency of water use	Yes	Yes	Yes	Yes
	Encourage selling of recycled water to other users	Yes	Yes	Yes	Yes
	Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management	Yes	Yes	Yes	Yes

Micro-catchment solutions					
		Members			
Focus area and fragility statement	***Micro-catchment solutions***	**Rama krishna, SE, VMC**	**Basivi Reddy, AE, HWW VMC**	**Rama koteswara rao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
	practices to determine water use efficiency and develop recommendations for improving it				
	Encourage water efficient irrigation systems	Yes	Yes	Yes	Yes
	Make Rain water harvesting systems mandatory across the city	Yes	Yes	Yes	Yes
Water quality: The irrigation canals flowing through the city are polluted due to disposal of sewage and waste into the canals and the run off fertilizers from the agricultural fields. The ground water is	Enhance capacity of Sewage Treatment Plans (STP)	Yes	Yes	Yes	Yes
	Conduct awareness to reduce water consumption among users + Subsidies encouraging water efficient fixtures in residential units + Introduce pricing/metering to improve the efficiency of water use – to reduce waste water generation	Yes	Yes	Yes	Yes

Micro-catchment solutions					
Focus area and fragility statement	***Micro-catchment solutions***	**Members**			
		Rama krishna, SE, VMC	**Basivi Reddy, AE, HWW VMC**	**Rama koteswara rao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
getting polluted from fertilizer percolation and dumping ground percolation. This water which is used for agriculture and household purposes is creating health problems and forcing residents to buy water for drinking purpose from RO plants	and to reduce investment on STPs				
	Design decentralized waste water treatment system for local reuse	Yes	Yes	Yes	Yes
Urban flooding: Due to poor storm water drain network, water logging in the irrigation canals and	Encourage paddy cultivation to reduce run off from rural catchments	-	-	-	Yes
	Develop /filter strips / swales / bio retention area / rain garden / filter drains and trenches/	-	-	-	Yes

Micro-catchment solutions					
		Members			
Focus area and fragility statement	***Micro-catchment solutions***	**Rama krishna, SE, VMC**	**Basivi Reddy, AE, HWW VMC**	**Rama koteswara rao, CCS, STP, VMC**	**Gopinath, DEE, Prakasam Barrage, APSWRD**
rivulet is causing urban flooding leading to loss of assets and outbreak of vector borne diseases	permeable pavements / detention basin / infiltration basins / water retention ponds as part of Sustainable Drainage system				
River flooding: Due to the reduction of river bed and heavy rains caused by monsoon depressions, Krishna river gets flooded and there is loss of property, assets, and livelihoods, health and at times lives	Develop hazard maps for low lying areas outlining areas at risk for flooding – awareness programs on possible impact, safety concerns, potential risk and appropriate responses	-	-	-	Yes

FGD 3 – Discussions with MPDOs and Panchayat secretaries

Focus areas and problems				
Focus areas	***Fragility statements***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
Water supply	Old piped network leading to 40% physical losses due to leaks	-	-	-
	Lack of water supply in hilly slum areas of the city	-	-	-
	Only 50% of the households are connected to the water supply system in the city	Around 70%	Around 70%	Around 70%
	Excessive dependence on groundwater; No restriction on borewell digging.	Yes	Yes	Yes
	Additional financial burden on individual households to purchase water from water tankers during summers	Burden on Panchayats not on residents	Burden on Panchayats not on residents	Burden on Panchayats not on residents
Water pollution	Only 60% of the city is connected by underground sewerage drainage	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages
	Industrial effluents and	household sewage mostly	household sewage mostly	household sewage mostly end up in

Focus areas and problems				
Focus areas	***Fragility statements***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
	household sewage is therefore discharged into the irrigation canals and rivulet	end up in the soak pits and fields near by	end up in the soak pits and fields near by	the soak pits and fields near by
	The polluted water in the irrigation canal is used for irrigation and drinking purposes in the villages	No	No	No
	Surface run-off leads the fertilisers used for agriculture being washed off into canals and water bodies	Yes	Yes	Yes
	The fertilisers also seep into the ground water and pollute the groundwater	-	-	-
	There is a practice of dumping solid waste into canals by Households	No	No	No
	The open dumping sites in the villages used by the city corporation	No	No	No

Focus areas and problems				
Focus areas	***Fragility statements***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
	cause pollution of ground water through seepage			
	Usage of polluted water for agriculture and household purpose is impacting the produce and health respectively	No	No	No
	Residents are buying RO water due to poor quality of water supply	Yes, This due to miscordination between RWSS and Panchayats to supply safe drinking water.	Yes, This due to miscordination between RWSS and Panchayats to supply safe drinking water.	Yes, This due to miscordination between RWSS and Panchayats to supply safe drinking water.
Urban flooding (stormwater flooding)	There is low connectivity of storm water drains and hence the storm water is accumulated in the canals and rivulet	No stormwater drains in villages	No stormwater drains in villages	No stormwater drains in villages
	The canal networks and rivulets are also used to discharge excess/flood waters from the reservoir	-	-	-
	Low lying	Yes	Yes	Yes

Focus areas and problems				
Focus areas	***Fragility statements***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
	areas experience water logging from the canals and rivulet during retreating monsoon due to depression and cyclones when reservoirs are almost at full capacity			
	The carry capacity of the canals and rivulets has reduced due to silting, encroachment	Yes	Yes	Yes
	Water logging is causing outbreak of vector borne diseases	Not in identifiable proportion	Not in identifiable proportion	Not in identifiable proportion
River flooding and cyclone	Heavy rainfall in the upper reaches of catchment in Western Ghats region is a major cause of flooding in the lower Krishna basin which is caused by monsoon depressions	-	-	-
	Vijayawada is located on the	-	-	-

Focus areas and problems				
Focus areas	***Fragility statements***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
	line which separated the delta and irrigated land			
	The flooding is primarily caused by unauthorized settlements along the river	-	-	-
	Breaking of bunds for public private development creates backwater	-	-	-
	This flooding results in loss of property, livelihood, assets, health and at times lives	-	-	-

Micro-catchment solutions				
Focus area and fragility statement	***Micro-catchment solutions***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
Water supply: There is irregular supply of water supply to residents causing them to rely on other unsustainable sources of water supply and creating a financial burden on the people	Maximise coverage of water supply network	Yes (already being done)	Yes (already being done)	Yes (already being done)
	Replace old pipes with new pipes to reduce loss of water during transmission	Yes (already being done)	Yes (already being done)	Yes (already being done)
	Conduct awareness to reduce water consumption among users	Yes	Yes	Yes
	Subsidies encouraging water efficient fixtures in residential units	Yes	Yes	Yes
	Introduce pricing/metering to improve the efficiency of water use	Yes	Yes	Yes
	Encourage selling of recycled water to other users	Yes	Yes	Yes
	Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management practices to determine water use efficiency and develop recommendations for improving it	Yes	Yes	Yes
	Encourage water efficient irrigation systems	Yes	Yes	Yes
	Make Rain water harvesting systems mandatory across the city	Yes	Yes	Yes
Water quality: The irrigation canals flowing through the city are polluted due to disposal of sewage and waste into the	Enhance capacity of Sewage Treatment Plans (STP)	Yes	Yes	Yes
	Conduct awareness to reduce water consumption among users + Subsidies encouraging water efficient fixtures in	Yes	Yes	Yes

Micro-catchment solutions				
Focus area and fragility statement	***Micro-catchment solutions***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
canals and the run off fertilizers from the agricultural fields. The ground water is getting polluted from fertilizer percolation and dumping ground percolation. This water which is used for agriculture and household purposes is creating health problems and forcing residents to buy water for drinking purpose from RO plants	residential units + Introduce pricing/metering to improve the efficiency of water use – to reduce waste water generation and to reduce investment on STPs			
	Design decentralized waste water treatment system for local reuse	Yes	Yes	Yes
Urban flooding: Due to poor storm water drain network, water logging in the irrigation canals and rivulet is causing urban flooding leading to loss of assets and outbreak of vector borne diseases	Encourage paddy cultivation to reduce run off from rural catchments	-	-	-
	Develop /filter strips / swales / bio retention area / rain garden / filter drains and trenches/ permeable pavements / detention basin / infiltration basins / water retention ponds as part of Sustainable Drainage system	-	-	-
River flooding: Due to the reduction of river bed and	Develop hazard maps for low lying areas outlining areas at risk for flooding –	-	-	-

Micro-catchment solutions				
Focus area and fragility statement	***Micro-catchment solutions***	**Members**		
		Ankama rao, MPDO, Gannavaram	**Satya sai babu, PS, Allapuram**	**Vijaya Kumari, PS, Purushottapatnam**
heavy rains caused by monsoon depressions, Krishna river gets flooded and there is loss of property, assets, and livelihoods, health and at times lives	awareness programs on possible impact, safety concerns, potential risk and appropriate responses			

FGD 4 - Discussions with Farmers and residents

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
Water supply	Old piped network leading to 40% physical losses due to leaks	-	-	-	-	-
	Lack of water supply in hilly slum areas of the city	-	-	-	-	-
	Only 50% of the households are connected to the water supply system in the city	-	-	-	-	-
	Excessive dependence on groundwater; No restriction on borewell digging.	Yes	Yes	Yes	Yes	Yes
	Additional financial burden on individual households to	Yes	Yes	Yes	Yes	Yes

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	purchase water from water tankers during summers					
Water pollution	Only 60% of the city is connected by underground sewerage drainage	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages	UGD facilieties are not yet availlable in the Villages
	Industrial effluents and household sewage is therefore discharged into the irrigation canals and rivulet	household sewage mostly end up in the soak pits and fields near by	household sewage mostly end up in the soak pits and fields near by	household sewage mostly end up in the soak pits and fields near by	household sewage mostly end up in the soak pits and fields near by	household sewage mostly end up in the soak pits and fields near by
	The polluted water in the irrigation canal is used for irrigation and drinking purposes in the	Yes	Yes	Yes	Yes	Yes

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	villages					
	Surface run-off leads the fertilisers used for agriculture being washed off into canals and water bodies	Yes	Yes	Yes	Yes	Yes
	The fertilisers also seep into the ground water and pollute the groundwater	-	-	-	-	-
	There is a practice of dumping solid waste into canals by Households	No	No	No	No	No
	The open dumping sites in the villages used by the city corporati	No	No	No	No	No

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	on cause pollution of ground water through seepage					
	Usage of polluted water for agriculture and household purpose is impacting the produce and health respectively	No	No	No	No	No
	Residents are buying RO water due to poor quality of water supply	Yes	Yes	Yes	Yes	Yes
Urban flooding (stormwater flooding)	There is low connectivity of storm water drains and hence the storm	No stormwater drains in villages	No stormwater drains in villages	No stormwater drains in villages	No stormwater drains in villages	No stormwater drains in villages

Focus areas and problems						
		Members				
Focus areas	***Fragility statements***	**M. Narendra Babu, MPEO**	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	water is accumulated in the canals and rivulet					
	The canal networks and rivulets are also used to discharge excess/flood waters from the reservoir	-	-	-	-	-
	Low lying areas experience water logging from the canals and rivulet during retreating monsoon due to depression and cyclones when reservoirs are almost at full capacity	Yes	Yes	Yes	Yes	Yes
	The carry capacity	Yes	Yes	Yes	Yes	Yes

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	of the canals and rivulets has reduced due to silting, encroachment					
	Water logging is causing outbreak of vector borne diseases	Not in identifiable proportion	Not in identifiable proportion	Not in identifiable proportion	Not in identifiable proportion	Not in identifiable proportion
River flooding and cyclone	Heavy rainfall in the upper reaches of catchment in Western Ghats region is a major cause of flooding in the lower Krishna basin which is caused by monsoon depressions	Yes	Yes	Yes	Yes	Yes
	Vijayawada is	-	-	-	-	-

Focus areas and problems						
Focus areas	***Fragility statements***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	located on the line which separated the delta and irrigated land					
	The flooding is primarily caused by unauthorized settlements along the river	Yes	Yes	Yes	Yes	Yes
	Breaking of bunds for public private development creates backwater	Yes	Yes	Yes	Yes	Yes
	This flooding results in loss of property, livelihood, assets, health and at times lives	Yes (2009 flood)	Yes (2009 flood)	Yes (2009 flood)	Yes (2009 flood)	Yes (2009 flood)

Micro-catchment solutions						
Focus area and fragility statement	***Micro-catchment solutions***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
Water supply: There is irregular supply of water supply to residents causing them to rely on other unsustainable sources of water supply and creating a financial burden on the people	Maximise coverage of water supply network	Yes	Yes	Yes	Yes	Yes
	Replace old pipes with new pipes to reduce loss of water during transmission	Yes	Yes	Yes	Yes	Yes
	Conduct awareness to reduce water consumption among users	Yes	Yes	Yes	Yes	Yes
	Subsidies encouraging water efficient fixtures in residential units	Yes	Yes	Yes	Yes	Yes
	Introduce pricing/metering to improve the efficiency of water use	Yes	Yes	Yes	Yes	Yes
	Encourage selling of recycled water to other users	Yes	Yes	Yes	Yes	Yes
	Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management practices to determine water use efficiency and	Yes	Yes	Yes	Yes	Yes

Micro-catchment solutions						
Focus area and fragility statement	***Micro-catchment solutions***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	develop recommendations for improving it					
	Encourage water efficient irrigation systems	Yes	Yes	Yes	Yes	Yes
	Make Rain water harvesting systems mandatory across the city	Yes	Yes	Yes	Yes	Yes
Water quality: The irrigation canals flowing through the city are polluted due to disposal of sewage and waste into the canals and the run off fertilizers from the agricultural fields. The ground water is getting polluted from fertilizer percolation and dumping	Enhance capacity of Sewage Treatment Plans (STP)	Yes	Yes	Yes	Yes	Yes
	Conduct awareness to reduce water consumption among users + Subsidies encouraging water efficient fixtures in residential units + Introduce pricing/metering to improve the efficiency of water use – to reduce waste water generation and to reduce investment on STPs	Yes	Yes	Yes	Yes	Yes

Micro-catchment solutions						
Focus area and fragility statement	***Micro-catchment solutions***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
ground percolation. This water which is used for agriculture and household purposes is creating health problems and forcing residents to buy water for drinking purpose from RO plants	Design decentralized waste water treatment system for local reuse	Yes	Yes	Yes	Yes	Yes
Urban flooding: Due to poor storm water drain network, water logging in the irrigation canals and rivulet is causing urban flooding leading to loss of assets and outbreak of vector borne diseases	Encourage paddy cultivation to reduce run off from rural catchments	Paddy is the major crop cultivated here	Paddy is the major crop cultivated here	Paddy is the major crop cultivated here	Paddy is the major crop cultivated here	Paddy is the major crop cultivated here
	Develop /filter strips / swales / bio retention area / rain garden / filter drains and trenches/ permeable pavements / detention basin / infiltration basins / water retention ponds as part of Sustainable	Yes	Yes	Yes	Yes	Yes

Micro-catchment solutions						
Focus area and fragility statement	***Micro-catchment solutions***	**Members**				
		M. Narendra Babu, MPEO	**K. Rajasekhar, Farmer**	**P. Mallikarjun, Farmer**	**K. Eshwara Rao, Farmer**	**B. Satyam Naryana, Farmer**
	Drainage system					
River flooding: Due to the reduction of river bed and heavy rains caused by monsoon depressions, Krishna river gets flooded and there is loss of property, assets, and livelihoods, health and at times lives	Develop hazard maps for low lying areas outlining areas at risk for flooding – awareness programs on possible impact, safety concerns, potential risk and appropriate responses	-	-	-	-	-

2.6.2 Prioritization matrix for the shortlisted interventions

Prioritizing resilience interventions - Vijayawada

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/Re-organisation (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)	Considers requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
Maximise coverage of water supply network – dual plumbing and replace old pipes with new pipes to reduce loss of water during transmission	1	0	1	1	1	1	1	1	7
Set up helium leak detectors or flowmeters to trace leakages in pipe lines	1	1	1	1	0	0	1	1	6
SCADA system – complaint register aid in locating potential leaks in residential units or commercial units.	1	1	1	1	1	0	1	1	7
Introduce pricing/metering to improve the efficiency of water use	1	1	0	1	1	1	1	1	7
Make Rain water harvesting systems mandatory across the	1	1	1	1	1	1	1	1	8

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/Re-organisation (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)**	**Considers requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High**
city and reuse for non-potable uses at household level									
Sell recycled water to industries	1	1	0	1	1	1	1	1	7
Design decentralized waste water treatment system for local reuse (DEWATS)	1	1	1	1	1	1	1	1	8
Digitize the rural water supply not only at household level but also at community level	1	1	0	0	1	1	1	0	5
Provide rural households with water wheels to reduce the strain on women during water collection	1	1	1	1	0	1	1	1	7
Repair existing but unused water structures	1	0	1	1	0	1	1	1	6
Encourage water efficient irrigation systems such as micro irrigation (drip irrigation)	1	1	1	1	1	1	0	1	7
Lining irrigation ditches to prevent leakage,	1	1	1	1	1	1	1	1	8

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/Re-organisation (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)	Considers requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
covering irrigation ditches to prevent evaporation									
Practice rain water harvesting and aquifer recharging	1	1	1	1	1	1	1	1	8
Behavioural Change and Communication campaigns to users to encourage judicial water consumption and reuse of recycled water	1	1	1	1	1	1	1	1	8
Subsidies encouraging water efficient fixtures in residential units	1	1	0	1	0	0	1	1	5
Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management practices to determine water use efficiency and develop recommendations for improving it.	1	1	0	1	1	0	0	1	5
Incentivise farmers using solar pumps to sell excess power back	1	1	1	0	0	1	1	1	6

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/Re-organisation (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)	Considers requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
to the grid. The guaranteed buy-back scheme produces a triple win; farmers gain income, the state gains electricity reserves, and the water source is conserved by curbing usage									
Involve local entrepreneurial water operators selected by the community to operate, maintain and manage water supply systems based on a contract signed with the communities	1	1	0	1	0	0	1	1	5
Apply effective pricing systems that permit sufficient cost recovery to support capital, operation and maintenance costs, informed by sustainable development principles	1	1	0	1	1	1	1	1	7
Enhance capacity of Sewage Treatment	1	1	1	1	1	1	1	1	8

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/Re-organisation (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)**	**Considers requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High**
Plans (STP) and enhance coverage of UGDs									
Onsite waste water recycling where primary treated water is sent to main pumping stations which carry them to STP for secondary treatment.	1	1	1	1	1	1	1	1	8
Use of low-cost nano-ceramic membrane to remove pollutants from irrigation canals	0	1	1	1	1	1	1	1	7
Strengthen water quality monitoring and surveillance systems – Increase no of water monitoring stations – Use of T sensors in the water bodies to monitor and manage water quality. Integrate ground water quality and quality in decision making	1	1	0	1	1	1	1	1	7
Curb water withdrawal beyond sustainable levels from ground	1	0	1	1	0	1	1	1	6

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/Re-organisation (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)	Considers requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
water sources									
Behavioural Change and Communication (BCC) campaigns to users against littering, discharge of household sewage into irrigation canals / Krishna river	1	1	0	1	1	1	1	1	7
BCC campaigns towards farmers to use organic manure for agriculture – Encourage use of dried sludge from STPs as manure	1	1	1	1	1	1	1	0	7
Affordable water filter to remove resistant viruses from water such as Procleanse water filtration system (Zero maintenance, low cost water filtration bucket) at rural household level	1	1	1	1	1	1	1	1	8
Develop training campaigns for practitioners and provide technical assistance for the effective	1	0	1	1	1	1	1	1	7

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	Flexibility (yes/no)	Responsiveness/Re-organisation (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)	Considers requirement of various stakeholders (yes/no)	1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High
implementation of best practices to address water pollution									
Develop /filter strips / swales / bio retention area / rain garden / filter drains and trenches/ permeable pavements / detention basin / infiltration basins / water retention ponds / storm water tree trench / storm water planter as part of Sustainable Drainage system and thereby develop a sponge city. These green infrastructure building techniques may be incorporated in public and private buildings, parks and public spaces	1	1	1	1	1	1	1	1	8
Enhance network of urban drainage system in the city	1	0	1	1	1	1	1	1	7
Desilting and cleaning of drains with using	1	0	1	1	1	0	1	1	6

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/Re-organisation (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)**	**Considers requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High**
Robots									
Raised ridges upto 10 m wide to be alternated with shallow canals to channel water, either harvested rain or deviated river water.	0	1	1	1	1	1	1	1	7
Incentivise residents to create an eco-roof/green roof in exchange for an increase in a building's allowable area	1	1	1	1	1	0	1	1	7
Develop hazard maps for low lying areas outlining areas at risk for flooding – Forbid buildings in the floodplain. Integrate flood zone maps in all spatial maps and plans such as development plans/master plans	1	1	1	1	1	1	1	1	8
Develop a system of micro-dams with a dual purpose of attenuating floods and retaining refuse.	0	1	1	1	1	1	1	1	7

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/Re-organisation (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)**	**Considers requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High**
Clear the river bed of waste and dredge to restore natural drainage capacity	1	1	1	1	1	1	1	1	8
Awareness programs on possible impact, safety concerns, potential risk and appropriate responses	1	1	0	1	1	1	1	1	7

Prioritising interventions based on feasibility and impact - Vijayawada

Interventions and Solutions	**Feasibility**			**Impact – Timeframe**
	Technical (high/medium/ low)	**Political (high/medium/ low)**	**Financial (high/medium/ low)**	**(short/medium/ long term)**
Maximize coverage of water supply network – dual plumbing and replace old pipes with new pipes to reduce loss of water during transmission	*Medium*	*Low*	*Low*	*Long*
Set up helium leak detectors or flowmeters to trace leakages in pipe lines	*Medium*	*Low*	*Medium*	*Short*
SCADA system – complaint register aid in locating potential leaks in residential units or commercial units.	*Medium*	*Medium*	*Medium*	*Short*
Introduce pricing/metering to improve the efficiency of water use	*High*	*Low*	*High*	*Medium*
Make Rain water harvesting systems mandatory across the city and reuse for non-potable uses at household level	*Medium*	*Medium*	*Medium*	*Long*
Sell recycled water to industries	*Medium*	*Medium*	*Medium*	*Medium*
Design decentralized waste water treatment system for local reuse (DEWATS)	*Medium*	*Low*	*Medium*	*Medium*
Digitize the rural water supply not only at household level but also at community level	*Medium*	*Medium*	*Medium*	*Medium*
Provide rural households with water wheels to reduce the strain on women during water collection	*High*	*High*	*High*	*Short*
Repair existing but unused water structures	*High*	*Medium*	*Medium*	*Medium*
Encourage water efficient irrigation systems such as micro irrigation (drip irrigation)	*Low*	*Medium*	*Medium*	*High*
Lining irrigation ditches to prevent leakage, covering irrigation ditches to prevent evaporation	*High*	*Medium*	*Medium*	*Medium*
Practice rain water harvesting and aquifer recharging	*Low*	*Low*	*Low*	*Long*
Behavioural Change and Communication campaigns to users to encourage judicial water consumption and reuse of recycled water	*Low*	*Medium*	*Medium*	*Long*
Subsidies encouraging water efficient fixtures in residential units	*Low*	*High*	*Low*	*Long*
Conduct water audits on a regular basis to assess water using hardware, fixtures, equipment and management practices to determine water use efficiency and develop recommendations for improving it.	*Low*	*Low*	*Medium*	*Medium*
Incentivise farmers using solar pumps to sell excess power back to the grid. The guaranteed buy-back scheme produces a triple win; farmers	*Medium*	*Medium*	*Medium*	*Medium*

Interventions and Solutions	**Feasibility**			**Impact – Timeframe**
	Technical (high/medium/ low)	**Political (high/medium/ low)**	**Financial (high/medium/ low)**	**(short/medium/ long term)**
gain income, the state gains electricity reserves, and the water source is conserved by curbing usage				
Involve local entrepreneurial water operators selected by the community to operate, maintain and manage water supply systems based on a contract signed with the communities	*Low*	*High*	*Low*	*Short*
Apply effective pricing systems that permit sufficient cost recovery to support capital, operation and maintenance costs, informed by sustainable development principles	*Medium*	*Low*	*High*	*Medium*
Enhance capacity of Sewage Treatment Plans (STP) and enhance coverage of UGDs	*High*	*High*	*Medium*	*Long*
Onsite waste water recycling where primary treated water is sent to main pumping stations which carry them to STP for secondary treatment.	*Medium*	*Medium*	*Low*	*Long*
Use of low-cost nano-ceramic membrane to remove pollutants from irrigation canals	*Medium*	*High*	*Medium*	*Short*
Strengthen water quality monitoring and surveillance systems – Increase no of water monitoring stations – Use of T sensors in the water bodies to monitor and manage water quality. Integrate ground water quality and quality in decision making	*Medium*	*Medium*	*Medium*	*Long*
Curb water withdrawal beyond sustainable levels from ground water sources	*Low*	*Low*	*Medium*	*Long*
Behavioural Change and Communication (BCC) campaigns to users against littering, discharge of household sewage into irrigation canals / Krishna river	*Low*	*Medium*	*Medium*	*Long*
BCC campaigns towards farmers to use organic manure for agriculture – Encourage use of dried sludge from STPs as manure	*Low*	*Medium*	*Medium*	*Long*
Affordable water filter to remove resistant viruses from water such as Procleanse water filtration system (Zero maintenance, low cost water filtration bucket) at rural household level	*Medium*	*High*	*Medium*	*Short*
Develop training campaigns for practitioners and provide technical assistance for the effective implementation of best practices to address water pollution	*Low*	*Low*	*Low*	*Long*
Develop /filter strips / swales / bio retention area / rain garden / filter	*Medium*	*Medium*	*Medium*	*Long*

Interventions and Solutions	Feasibility			Impact – Timeframe
	Technical (high/medium/ low)	Political (high/medium/ low)	Financial (high/medium/ low)	(short/medium/ long term)
drains and trenches/ permeable pavements / detention basin / infiltration basins / water retention ponds / storm water tree trench / storm water planter as part of Sustainable Drainage system and thereby develop a sponge city. These green infrastructure building techniques may be incorporated in public and private buildings, parks and public spaces				
Enhance network of urban drainage system in the city	*Medium*	*Medium*	*Low*	*Long*
Desilting and cleaning of drains with using Robots	*Medium*	*Medium*	*Medium*	*Medium*
Raised ridges upto 10 m wide to be alternated with shallow canals to channel water, either harvested rain or deviated river water.	*High*	*Medium*	*High*	*Medium*
Incentivise residents to create an eco-roof/green roof in exchange for an increase in a building's allowable area	*Low*	*Low*	*Medium*	*Long*
Develop hazard maps for low lying areas outlining areas at risk for flooding – Forbid buildings in the floodplain. Integrate flood zone maps in all spatial maps and plans such as development plans/master plans	*Medium*	*Medium*	*Medium*	*Long*
Develop a system of micro-dams with a dual purpose of attenuating floods and retaining refuse.	*High*	*Medium*	*Medium*	*Long*
Clear the river bed of waste and dredge to restore natural drainage capacity	*High*	*Medium*	*Medium*	*Medium*
Awareness programs on possible impact, safety concerns, potential risk and appropriate responses	*Low*	*Medium*	*Medium*	*Long*

2.6.3 Decision Support Tool: Structure

The DST model selected for the integrated rural urban water management in Vijayawada consists of the following components:

- WEAP model: Water Evaluation and Planning (WEAP) is a computer tool developed by the Stockholm Environment Institute's U.S. Centre for integrated water resources planning, which provides a comprehensive, flexible, and user-friendly framework for development of water balances, scenario generation, planning, and policy analysis.
- Adaptation module: The outcome from WEAP is linked to a meta set of interventions, and based on the constraints identified by the RURBAN platform members, it further shortlists interventions and presents a prioritized set of actions to the RURBAN platform to discuss and integrate into the proposed project.

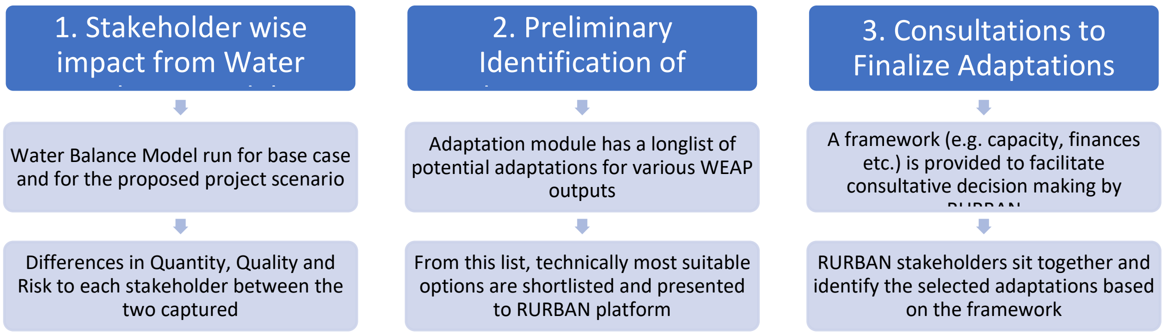
2.6.4 Decision Support Tool: Application

The Decision Support Tool can be used by the catchment managers to identify future integrated water management projects/interventions or to modify the existing projects/interventions to adhere to integrated water management concepts. In the current context, the Decision Support Tool has several potential entry points:

- Needs assessment: Evaluation of most critical areas across stakeholders in the RURBAN platform, based on current and future demand-supply assessment
- Intervention review: Review of ongoing/already designed projects to introduce adaptations/augmentations for greater sustainability and better balance of stakeholder interests
- Intervention design: Design of projects/interventions through assessment of options on economic, social, environmental, and other costs and benefits

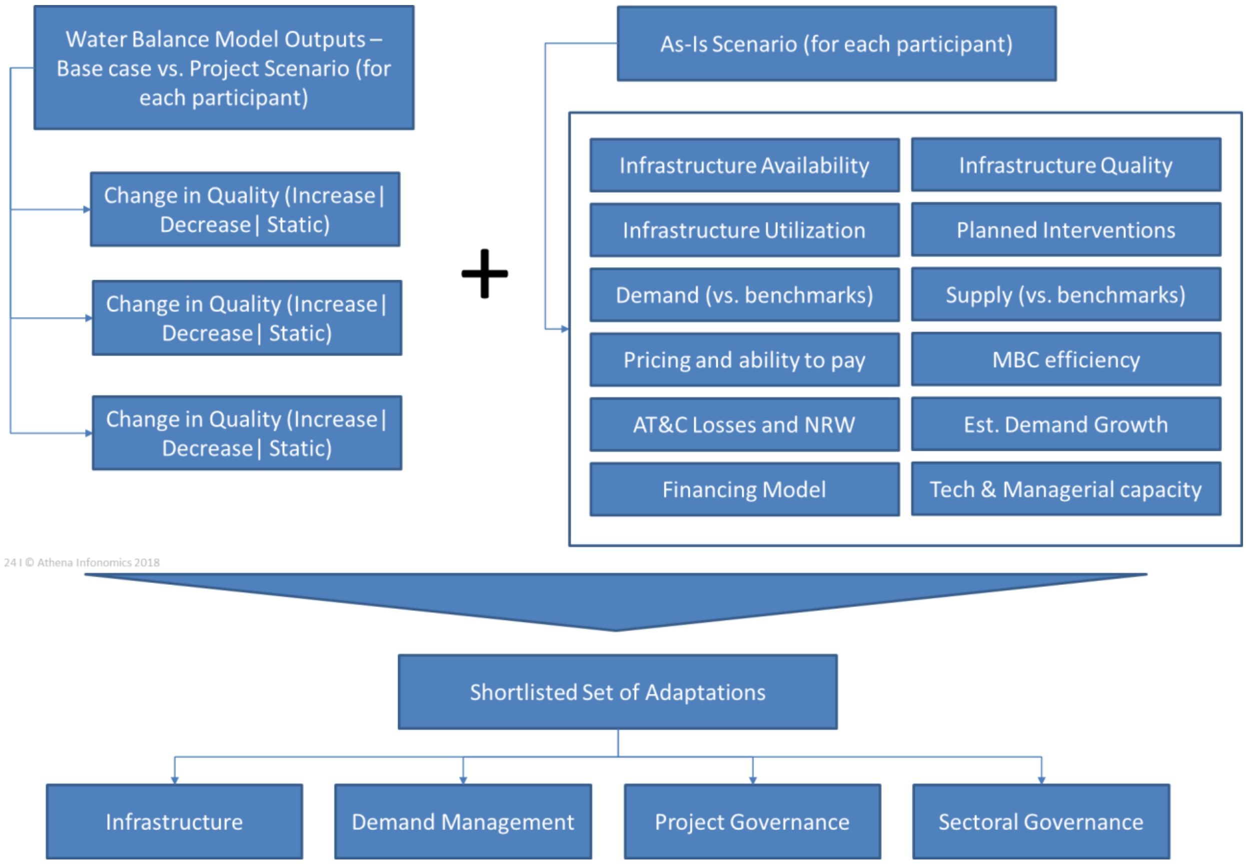
The evaluation of the most critical areas for interventions across stakeholders is done with the help of a Catchment Management Plan, through an assessment of economic, social, environmental, and financial benefits. The catchment under consideration is evaluated for critical areas, and the interventions to manage the critical areas, are identified based on a climate fragility statement, and an integration matrix. The areas which require urgent attention have to be identified, and shortlisted from the list of all interventions proposed in the catchment. The interventions/projects that are to be implemented can be shortlisted after analyzing the impacts of all the proposed interventions in the catchment area using the Decision Support Tool.

The Decision Support Tool can also be used to modify proposed or ongoing/already designed projects to adhere to integrated water management concepts. The different water management projects/interventions in the catchment area can be analyzed using the Decision Support Tool (WEAP) to assess their impact. The interventions can be assessed under different scenarios to evaluate how they perform under different environmental, economic, and social conditions. Upon evaluation of the impacts under different scenarios, the interventions are then evaluated with an Adaptation set, which will help in identifying the gaps in the project w.r.t. to integrated water management concepts. The adaptation set is a multi-level list of potential intervention options that can be used to evaluate the adherence to IWRM concepts, and suggest possible interventions. The adaptation set will help in identifying the components to be added to a particular water management project for it to adhere to IWRM concepts. The members of the RURBAN platform will review the set of adaptation options to check for implementability, and suggest changes if required. Using the adaptation set, interventions for each proposed/ongoing project are identified, which are to be reviewed by the members of the RURBAN platform for implementatbility and sustainability. The final set of interventions are shortlisted after the review by the RURBAN platform, upon which pilot projects for the selected interventions will be implemented.



In the Adaptation module, we will take the demand and supply side inputs, and project the overall water balance, which will basically reflect the allocation of the available grades of water (supply) among the various users (demand). The proposed project data points will then be added to the existing water balance model and the impacts it has on meeting the water demand, water quality will be analysed after which mitigation measures will be curated and proposed for integration into the interventions themselves. This will be done through a lookup module, which will compile all potential responses to a variety of projects, along with rules for selection of the most appropriate subset for a model output, based on a combination of suitability factors

Illustration of process of shortlisting adaptation interventions



A set of 40 broad adaptations has been drawn up across four areas

- Infrastructure: Infrastructure oriented adaptations fall into four categories – changing infrastructure specifications of a proposed project, upgradation and retrofitting of existing infrastructure, increasing utilization of existing infrastructure and creation of new infrastructure (in that order of preference). Infrastructure interventions will be sensitive to the nature of the issue and will span the value chain (bulk sourcing, transmission, distribution and treatment)
- Demand management: Adaptations around demand management are primarily directed at two user groups – rural (Agriculture) and urban households. These adaptations are in the areas of decreasing demand through IEC/BCC campaigns, through supporting low water footprint products and technologies, through pricing nudges, through support for accelerating structural change (e.g. cropping patterns, industries) and by reallocating grades of supply across demand nodes
- Project Governance: Project adaptations are usually the easiest to implement since the DST is applied at the formative stage of project interventions. Such adaptations range from expanding project stakeholder groups and sharing information, to more structural changes on project scope and financing. It should be remembered that such adaptations are

not necessarily focused on increasing project costs. In many cases where there are positive externalities from the project, a share of these can be monetized and help support project viability

- Sectoral Governance: These include adaptations which are out of scope of the project, since they go beyond the project mandate, and/or require resources which cannot be raised within the project

Annex 1

IADAPT FRAMEWORK FOR MICRO-CATCHMENTS

The IAdapt Framework will consist of five phases and will assist in developing the Catchment Management Plan for the selected micro-catchment in the city-regions of Solapur and Vijayawada. The five phases consist of the following:

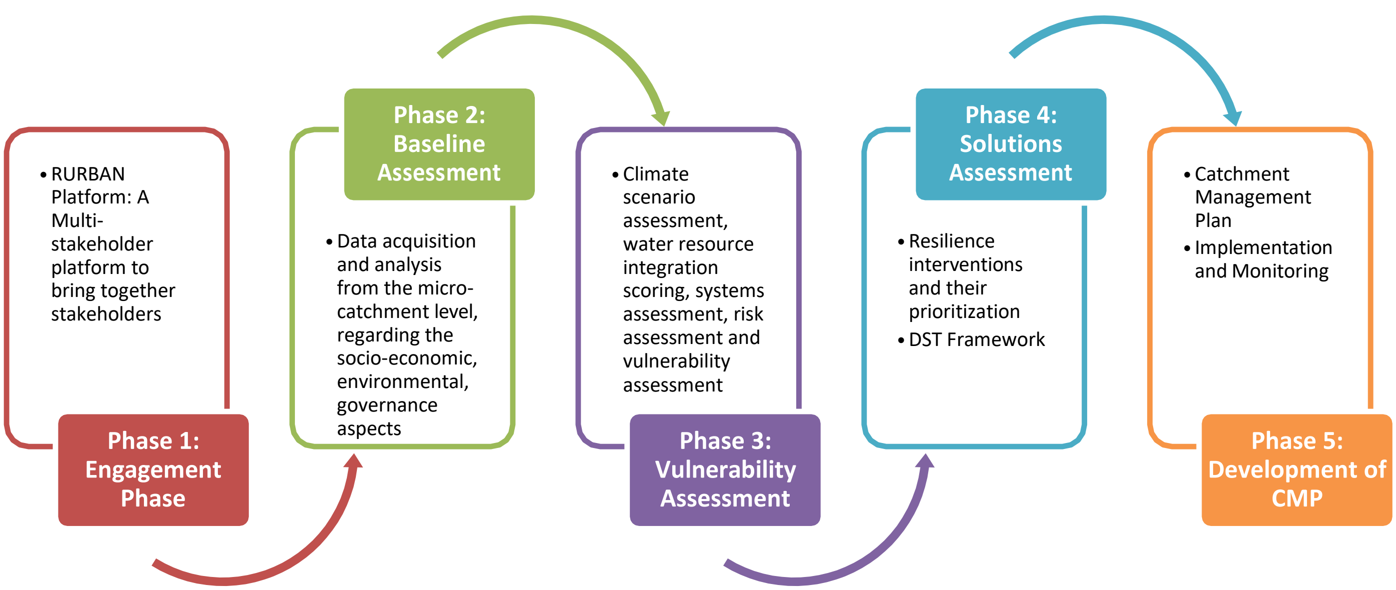
Phase 1: Engagement Phase – This phase includes formation of the Core Team and formation of the RURBAN platform and engaging with both.

Phase 2: Baseline Assessment – This phase involves collection of data from the micro-catchment level, regarding the socio-economic, environmental, governance aspects.

Phase 3: Climate Vulnerability of Water Resources – This phase includes climate scenario assessment, water resource integration scoring, systems assessment, risk assessment and vulnerability assessment. It will help to select the particular sector/issue which can be focused on for developing integrated solutions for water management.

Phase 4: Solutions Assessment – This phase includes selection of resilience interventions and their prioritization.

Phase 5: Development of CMP – This phase describes the structure of the Catchment Management Plan.



1. Phase 1: Engagement Phase

1.1 Formation of Core Team

The identification of the Core Team members is a very crucial process as the Core Team will be responsible for driving the process. The Core Team may consist of representatives from 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. It is important to identify a Project Nodal Officer at the rural and urban level who can be the focal point for the process in the city. It is also important to provide for senior management support to the Core Team, to ensure that staff members working on the IADAPT Process are directly supported in their day-to-day work by 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
- Attend and participate in the IADAPT workshops to guide the programs, strategies and expected outputs (tools, materials, reports)
- Lead the city government's efforts to participate in the programme
- Ensure the IADAPT Process is followed in its entirety
- Secure the participation of multiple contacts across the city government in the programme
- Support in organizing 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.
- Support internal institutional capacity building to effectively fulfill the long-term climate resilience plan requirements.

2 Project Nodal Officers – urban and rural – for the Core Team also needs to be identified who can act as the focal point for the process. The main responsibilities of the Project Nodal Officer would be the coordination and smooth implementation of the tasks of the Core Team in implementing the IAdapt Framework. Responsibilities may include:

- Organize meetings of the Core Team as per the agreed schedule
- Facilitate communication and consultation with the stakeholder group
- Track the progress on IAdapt Process and inform the Core Team regarding completed and upcoming tasks as laid out.
- Facilitate data collection from various departments and other sources

Table 1: IAdapt Core Team

Name	Position	Responsibility

1.2 Formation of RURBAN Platform

The IAdapt Core Team and the state officials will formulate a RURBAN Platform involving key individuals (from the district departments, core team member and officials from State departments and Ministries representing urban and rural authorities), that will be responsible for interactions and discussions on integrated water management strategies and actions.

Table 2: RURBAN Platform

Characteristics of RURBAN Committee	Govt. (local, city, block , state)	Local NGOs / CBOs	Academia	Community Representatives	Private Sectors	Any other imp stakeholder
Have the ability to develop water strategies and actions at the community level						
Have 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 these actions developed						

Once the members of the RURBAN Platform have been identified, an organizational framework needs to be decided upon.

Vision

The Core Team along with the RURBAN Platform members should develop a vision, which states how it 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; now, considering the various elements, 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 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 term.
- The RURBAN members will meet minimum **twice in a year** to review and to get updates on the status of the project. The meeting must be held at the concerned State head offices. Meetings can be rescheduled or reorganized 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 schedule for the meetings, time of day, location and maximum length of the meeting should be determined beforehand.

- At the meeting, the following shall preside -
  - The national and state government representatives
  - Two core team members representing the urban and rural areas
  - Collector or block representative who is for the time being designated under to represent (nodal officer)
- 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 2 shall be members who are state officers and at least 4 core team members.
- The nodal officer will be responsible for providing the project updates and status of the project to the RURBAN Platform. The Project Nodal Officer can be in-charge for ensuring the reporting and thereby monitoring the project. The report will be finalized after the approval of RURBAN committee. The comments and suggestions from the committee should be incorporated before the submission of the report.
- Every question or other matter for decision or determination at a meeting shall be decided or determined by a majority of votes of the members present and entitled to vote and, in the event that voting is equally divided, the National government representative or State member presiding at the meeting shall have a casting vote.

Outcome of Phase 1:

- Identification of the nodal officer
- Formulation of the core team
- RURBAN platform

2. Phase 2: Baseline Assessment

The baseline assessment will enable collection of baseline situational information from the micro-catchment area. It will have generic information from the villages and the parts of the city included in the micro-catchment area.

Table 3: Micro-Catchment baseline questionnaire

Category	Unit	Data	Source of Data
Micro-Catchment Level Information			
No 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*		
Fresh Water for drinking purposes	*Yes/No*		
Medicinal Resources: plants used as traditional medicines or raw materials for the pharmaceutical industry	*Yes/No*		
Regulating Services from water resources in the region	*Yes/No*		
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*		
Waste-water 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 fishes 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 requirement, if possible	*Percentage*		

Water resources for the micro-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 ground water 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 fertilizers, pesticides, and industrial effluents, etc*		
Demographics in micro-catchment			
Population			
Total population in micro-catchment (village wise)	*Number*		
Total population in city			
Sex Ratio (village wise and for city)			
No 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 AAY families	*Number*		
Number of BPL families	*Number*		
Health			
Disease			
Total number of deaths from calamities/ extreme climate events/ disasters (number/year) (village wise)	*Number/year*		
Total no. of incidences of the water borne diseases in the city in last year (village wise)			
Total no. of incidences of the vector borne diseases in the city in last 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	*Area of different land uses, with map*		
Topography	*Topographic map with ward/zone/area*		
Infrastructure			
Water supply			
Number of wells/hand pumps/community taps (village wise)			

[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

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 authorized residential connections	*Number of ward/zone/area wise distribution*		
Number of authorized 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 fresh water for the city	*Names and capacity in ML*		
Distance from the city for each source	*k.m*		
Water treatment plant(s)	*Number, capacity, location, ward/zone/area covered*		
Micro-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 waste water generated per day	*MLD*		
Volume of waste water collected	*MLD*		
Volume of waste water 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*		

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			
Storm water drainage			
Drainage distribution network	*Map with ward/zone/area*		
Total length of covered network	*Kms*		
Total length of uncovered network	*Kms*		
Areas prone to water logging 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 actions among rural and urban administrative counterparts?	*Yes/No/Partly*		

Outcome Phase 2

- Detailed baseline data for the catchment
- Weakness and Strengths of the catchment
- Prioritized issues

3. Phase 3: Climate Vulnerability of Water Resources

3.1 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 climate, 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						
	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'*** *i.e. degree of certainty***>**... of a...**<***insert information from* ***'amount of expected change'*** *i.e. the range***>**...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'***>."

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		

3.2 Water Balancing

Core Team should undertake the Water Balance Exercise. This exercise helps demonstrate an alternative pathway to reduce the demand-supply gap and move towards a demand-supply balance based approach without any additional water abstraction by using the IWRM principles. Since Indian cities face issues related to water scarcity in summer, this has been included as an additional indicator for urban water balance exercise.

The exercise has 3 steps:

a. 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 micro-catchment – agriculture, industries, etc. The existing supply of water can be assessed from a random sample survey of the population in the micro-catchment and other data that is available at the water resource department at the state level. The other data that is available at the water resource department at the state level and Ground Water Board can be also be used (if available).
   Water demand urban areas: total population *135 LPCD Water demand rural areas: Total population *40 LPCD
b. Similar information will be calculated for future population scenarios based on the future population estimates (upto 2030) assessed in above exercise. For sections where data is not available, realistic estimates can be used. Future population can be calculated 1) arithmetical increase method, 2) geometrical progression method) 3) graphical method.
   Example: Arithmetical increase method
   It is assumed that the population is increasing at constant rate. Hence, dP/dt = C i.e., rate of change of population with respect to time is constant. Therefore, Population after nth decade will be Pn= P + n.C (1) Where, Pn is the population after 'n' decades and 'P' is present population.
c. The Core Team will assess the existing and future Demand-Supply Gap.

Table 6: Urban 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 an integrated approach that will include the principles of IWRM so as to achieve water balance in the micro-catchment. The demand- supply gap can be reduced if the micro-catchment works towards achieving this integration through the identification of alternate approaches/options to meet the increasing water demand, without resorting to additional abstraction. Future scenarios will be assessed to enable a transition from addressing demand - supply gaps to achieving demand-supply balance. Six key approaches for this integration are:

1. Wastewater reuse
2. Storm water 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 values that are arrived at for reducing 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 Balance

Water supply: 100 MLD

- Drinking: 30
- Industries: 50
- Green area/parks: 20

Water demand: 150 MLD
Water supply demand GAP: 50 MLD

Integration solution

- IUWM Approach: **Wastewater**

reuse Available water for reuse after

treatment: 20 MLD **Integration Value**

(MLD) is 20 MLD

Scenario after intervention
Water Supply+ integration value: 100
+20=120 Total water supply: 120
Demand: 150
Water supply demand gap**: 30**

3.3 Identification of Focus Sectors and Issues

The Integration Assessment Matrix is a self-assessment tool that contains questions, based on principles of IWRM, to assess the existing status of integration of different water resources and consumption patterns in the micro-catchment. The different integration indicators are provided with possible responses that can reflect the situation in the city and each possible response has been given a score.

The Core Team should discuss and assign a score to each indicator, based on the options best suited to the city. For indicators where accurate data is not available, the Core Team can use broad estimates that best depict the existing situation.

This tool will give:

a. Existing status of integration: Tool will give the total integration score for the micro-catchment. This score should be compared with the Scoring Table below to get the existing status of integration across water sectors in the micro- catchment.

Table 8: Scoring Table

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 micro-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 micro-catchment. These are critical areas that the city should focus on.

d. Focus issue based on Integration Assessment Matrix: The Tool will indicate the issue/s that score low that should be taken up by the city on priority.

Table 9 Integration Assessment Matrix

Sr. 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	
		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	
		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	
		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	
		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.)	2	
		Link is realized but measures are not taken	1	
		Link not recognized and no measure are planned	0	
6	Climate change and water resources	Impacts of climate change on water resources are recognized and adaptation measures are taken up	2	
		Need is recognized but no measures being taken	1	
		Need is recognized 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	Capacity related constraints are limited, addressed regularly	2	
		Addressed only in extreme cases	1	
		Capacity related constraints not addressed at all	0	

	other stakeholders			
9	SWM	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	2	

Sr. No	Integration Indicators	Criteria Scoring		
		Criteria/sub criteria	Scale	Selected Score
		drainage		
		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	
		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	
		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	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 services	1	

Table 10 Summary Sheet for Integration Assessment Matrix

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

3.4 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 the survival, and ‘secondary systems’ such as education and social services, which rely on the core services. The step helps to do the following:

1. Analysis of “fragile systems” i.e. the systems or services which are already weak or under great pressure, by looking at them through a water lens.

2. Assessment of the impact of climate change on these fragile systems.

The tool analyses the causes of the fragility 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.

Flexibility and diversity - mix of multiple options, key assets and functions are distributed or decentralised, not all affected by a single event

Example: A network of hospitals rather than a single, central hospital

Redundancy - 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: Hospitals and emergency communications facilities have shared or linked backup electrical generators

Safe failure – 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 as shown in table below.

Table 11: Analyse Fragile Urban Systems based on information from baseline questionnaire

System	Why is it critical or fragile?	What are the existing and anticipated problems caused by the fragility of this system?	Responsibility	Fragility Statement
Water Supply	Flexibility & Diversity: Traditional water sources have been lost due to the urbanisation process 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). Given the mountainous region this limits access of these trucks in addition to them being an expensive and polluting fallback option Safe failure: in case of a disruption in water supply, individual	Disruption of water supply to citizens • Additional financial burden on individual households to purchase water from water tankers • Water shortage adversely impacts the tourism industry • 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

	households have to fend for themselves. One of the systems is over a 100 years old			

To assess the impacts of climate change on the fragile systems identified in the table above, we have to develop a Climate Fragility Statement for each fragile system, considering the climate scenario summaries and the possible impacts of these climatic changes on the fragile systems.

Table 12: Climate Fragility Statements

Urban System	Fragility Statement	Climate fragility statement	**Climate fragility statement**
		Climate Risk 1: increased precipitation	Climate Risk 2: Increased Temperatures
Water Supply	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
		Increased precipitation can cause water to freeze in the pipelines	

3.5 Risk Assessment of Climate Fragility Statements

After the climate fragility statements for the fragile systems are identified, these can be prioritized on the basis of their likelihood and consequence. 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 group 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 outputs of the exercise.

To assess the climate risks, we need to assess 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, which indicates if 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 below 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: Consequence Rating and Scoring

Consequence Rating	Impact on System	Impact on poor and vulnerable	Score
Catastrophic	System fails completely and is unable to deliver critical services,, may lead to failure of other connected systems	Severe impacts 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 complete system failure;	Loss of confidence and criticism in city government; ability to achieve city vision and mission seriously affected; Significant impacts 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 impacts 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 impacts 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 impacts 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 to assess the Risk Status.

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

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

Table 16: Prioritization 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

3.6 Vulnerability assessment

The workshop conducted by the Core Team will further conduct the vulnerability assessment. The vulnerability assessment will include identification of vulnerable areas that are prone to the climate risks identified above and the social groups or stakeholders who are impacted by these risks in these areas.

Maps showing the distribution of the high priority climate risks across the micro-catchment area are produced. This can be done using hard copies of the micro-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 Core Team will 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 resilience and adaptation is broadly dependent on the following three key capacities:

- Capacity to organise and respond - the capacity to organise and re-organise in response to threat or disruption.
- Resources – access to the resources necessary to respond (manpower, technology, funds).
- Access to information – availability of data and information necessary to develop effective plans and actions and to improve responses to disruptions.

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

Table 17: Actors' Capacities Rating and Scoring

Key Capacities of Actors	**Score**
Capacity to Organize and Respond - to organise and re-organise in response to threat or disruption	
Low capacity	1
Medium capacity	2
High capacity	3
Resources - necessary to respond (manpower, technology, funds)	
Low access	1
Medium access	2
High access	3
Access to Information – data and 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

The score for each capacity can be multiplied to get the total score for the adaptive capacity of the actors. 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 to reduce the fragility of the identified fragile system. 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.

Table 19: Actor Analysis

Climate Fragility Statements	Area/ward/ village	Actors	Capacity to Organize & Respond (A)	Resources (B)	Access to Information (C)	Adaptive Capacity Score (A)*(B)*(C)	Supporting Notes
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)	

Outcome Phase 3

- Water Balance
- Climate scenarios
- Vulnerable sectors, areas and populations

4. 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 adaptation actions, or "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.

4.1 Identification of interventions for Catchment Water Resources

The exercise will 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 the vulnerable actors (social groups) as identified through above exercises. Based on these, interventions and solutions will be identified to address these issues by the Core Team together as part of a workshop. 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.

Climate Fragility Statements	Vulnerable Sectors	Urban Actors		Micro-Catchment Solutions
		Vulnerable Actors	Supporting Actor	
e.g.: Contamination of water supply due to flooding made worse by lack of alternative sources	*Water, waste water 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*

4.2 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 of the interventions and solutions can be measured if they are able to build in the following resilience characteristics into the fragile system:

- Redundancy: 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: 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, systems should be able 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: 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.

Table 20 Prioritizing resilience interventions – Example and exercise

Interventions and Solutions	Resilience Indicators				IWRM Indicators				Overall Prioritisation Score
	Redundancy (yes/no)	**Flexibility (yes/no)**	**Responsiveness/ Re-organisation (yes/no)**	**Access to Information (yes/no)**	Consider al l parts of the water cycle **(yes/no)**	Consider various requirements for water **(yes/no)**	Consider the local context **(yes/no)**	**Considers requirement of various stakeholders (yes/no)**	**1-2 yes – Low 3-4 yes – Medium 5-6 yes – average 7-8 yes – High**
Roof top water harvesting to be made mandatory to deal with water stress due to anticipated increasing temperatures and decreasing precipitation	*Yes Supports a higher degree of self sufficiency at the household level*	*Yes System allows for water to be channelized 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 stakeholders 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 required funds from the state or central

government, and the anticipated benefits of the action will justify the cost; any low hanging fruits for early implementation

Impact can be assessed using:

- Timeframe – most actions should be able to be completed within a short or medium timeframe.
- Criticality or Overall impact - the proposed intervention will 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 prioritized list of interventions and solutions will be developed for the micro-catchment.

Table 21: Feasibility and Impact

	Feasibility			**Impact – Timeframe**	**Impact - Criticality**
Interventions and Solutions	**Technical (high/medium/ low)**	**Political (high/medium/ low)**	**Financial (high/medium/ low)**	**(short/medium/long term)**	**(high/medium/ low)**
e.g. Roof top water harvesting to be made mandatory to deal with water stress due to anticipated increasing temperatures and decreasing 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)*

4.3 Verification and Ratification

The interventions and solutions selected will 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.

Outcome Phase 4

- List of solutions for catchment water resources
- Scoring and Prioritization of the solutions on the basis of resilience, IWRM principal
- Feasibility and impact assessment of the prioritized solutions
- Ratification at the RURBAN platform
- Pilot project

5. Phase 5: CMP Formulation

Structure of Catchment Management Plan

The catchment management plan should be developed while keeping the overall fragility and vulnerability of the resources and the community. To prepare an integrated catchment management plan following steps need to be followed.

Introduction: Introduces the concept of integration (IWRM, IUWM), the rationale of conducting an integrated catchment management and adopting integrated approaches to assess the vulnerability to climate change. Methodology and approaches used to develop catchment management plan.

1. What are IUWM and IWRM?
2. What are the principles to adopt these approaches?
3. Benefits of adopting these approaches while developing catchment management plan, explain the socio- economic and environmental benefits.
4. **Methodology of assessment**
   a Explanation of the different steps of the IADAPT
   Process b Possible annexes and tools
      i. List of members of RURBAN Platform and the
      ii. List of members of core team
      iii. Public communications from the core team (for instance, minutes of meeting, newspaper cuttings, memos, etc)
      iv. Tools of IUWM, IAP &TEEB

Catchment profile:

Location of the catchment:

This will include the information about main Rivers and its 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:

a. Number of villages and urban centers
b. Population data – general v/s urban poor
c. Population projections

Socio-economic profile
a. Information on population, number of households, number of slums, marginalized groups, urban poor
b. Information on economic profile of the population, major livihood activities and other development activities within the catchment
c. Urbanization pattern and percentage

Climate pattern and geomorphology of the catchment
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

Planning and designing of an integrated micro catchment management plan

The catchment plan will includes four phases

1. **Engagement phase**: In this phase various stakeholders from rural and urban areas within the micro catchments will come together and discuss the issues, develop strategies to overcome the challenges and implement best possible solutions.
   a) **Formation of core teams** representatives from 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. It is important to identify a **Project Nodal Officer** at the rural and urban level who can be the focal point for the process in the city
   b) **Formation of RURBAN platform** for timely discussion and privatization of the strategies in the main agenda. Core Team and the state officials to formulate a **RURBAN committee**. The committee will involve key individuals (from the district departments, core team member and officials from State departments and Ministries representing urban and rural authorities). The committee will be responsible for developing the RURBAN platform for interactions and discussions on integrated water management strategies and actions.

2. **Baseline assessment:** Data and information on micro catchment level. Water resources (water availability, water supply and water management), waste water, storm water and solid waste will be collected. Demographic data within the micro catchment including population characteristics and composition, health, exposure to disasters, bio diversity and ecosystem services of various resources within the micro catchment will be collected. The ongoing or proposed policies and programs for integration at basin level or micro catchment level will also be studied.

3. **Assessing the climate vulnerability:** In this phase a water balance will be calculated to understand the present and future stress on water resources due to urbanization, population growth and other economic development activities. The benefits of integrated approaches will be calculated based on demand and supply data and water balance calculations. Focus sectors will be selected on the basis of integration matrix. Vulnerability assessment of the water and allied sectors, develop climate statements and analyze the fragile rural-urban system and impact of climate change on these system. In the end list of most vulnerable systems will be prepared.

4. **Solution assessments**: A list of solutions will be prepared to combat all the issues/ vulnerability of the specific sector. Responses by one or more of the approaches will be listed for each of the Water and Climate Risk Statements. An exercise on resilience scoring will help in identifying the gaps present in the availability of data for each fragile urban system. This will help in determining the need for detailed sector wise studies that need to be undertaken for each of these urban systems. Based on that list of projects/ strategies/projects will be developed and projects will be prioritized for implementation. And an action plan will be developed to implement the solutions/strategies/projects with specific objectives and outcomes.

5. **Monitoring and evaluation framework**: RURBAN committee 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 that will underpin the rationale for the need for the plan. A monitoring procedure will include reporting on the plan and to update the

implementation of action plan. Cumulative responsibilities of RURBAN committee and core team require regular reviews the plans. it is proposed that reporting should be done by nodal officer and the core team. Yearly discussion with the core team and local residents to understand the impact and effect of the implementation. After the completion of one project the project prioritization tool will be re implemented and new projects will be selected.

Table 22: Monitoring Framework

Monitoring and Evaluation Framework					
Intervention	**Implementing Agency**	**Indicator**	**Responsibility of monitoring**	**Method/ tool of monitoring**	**Frequency of monitoring**

Table 23: CMP Implementation Monitoring Table

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

Outcome Phase 5

- Catchment management plan

Annex 2

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

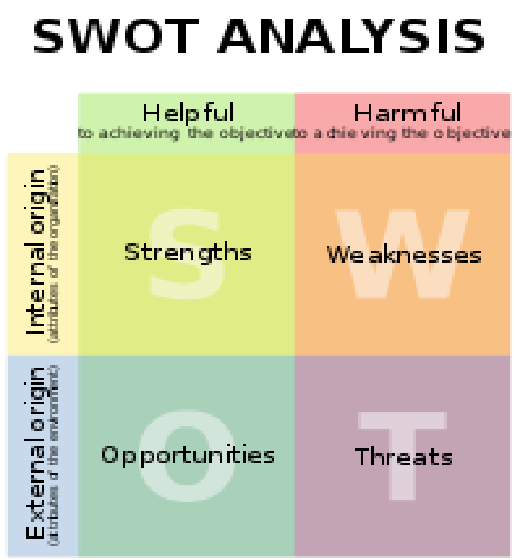


Figure 1: SWOT Analysis Method

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

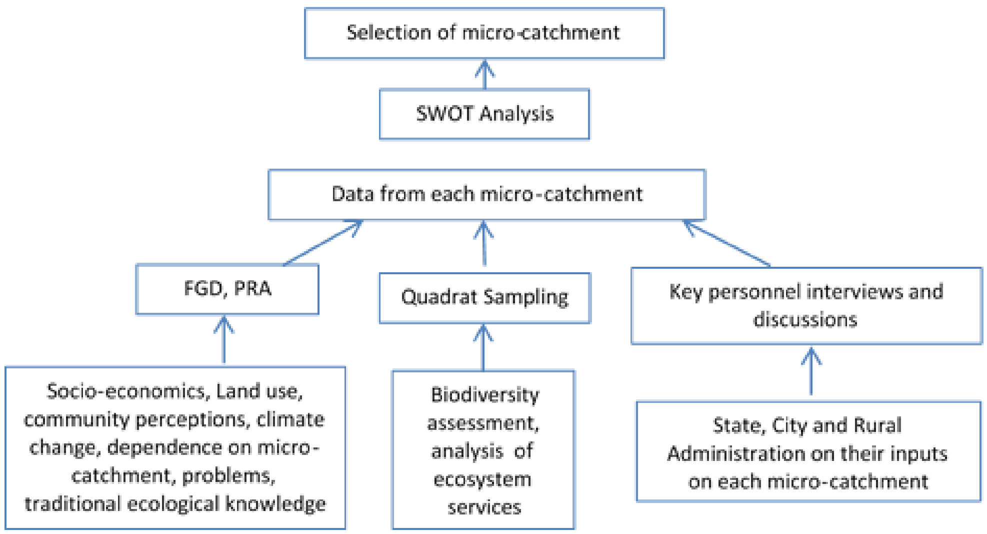


Figure 2: Inputs from various activities which were used for the SWOT analysis

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	• 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.

weirs to recharge ground water under various schemes of government and CSR activities of industries	• 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 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	• 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 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.

(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.	
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	• Increased industrial and infrastructural development along with climate change will put additional stress on

reduce pollution of water resources	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

<table>
<tr><td colspan="2">Micro catchment V1:</td></tr>
<tr><td>Strengths</td><td>Weaknesses</td></tr>
<tr><td>

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

</td><td>

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

</td></tr>
<tr><td>Opportunities</td><td>Threats</td></tr>
<tr><td>

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 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)

</td><td>

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
Budgetary constraint is preventing the ULB from constructing more STPs. The proposed no. of treatment plants is not enough to hold the capacity of

</td></tr>
</table>

and to prevent salinity creep.	Vijayawada's sewage and storm water in the future years

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

<table>
<tr><th colspan="2">Micro catchment V2:</th></tr>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>

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.

</td><td>

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

</td></tr>
</table>

	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	• Due to shortage of surface water, irrigation canals are filled only during the Kharif season. This shortage of surface water for irrigation leads to

the NTR Sujala Scheme • The micro-catchment has a significantly high Shannon diversity and high species abundance. • Agriculture is practiced by few 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	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. • 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 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-

- 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 (prevent discharge of surplus water from Prakasham barrage to the sea) and to prevent salinity creep.	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 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 drains • Few sewage pumping stations have been proposed in the urban area of the micro-catchment	• 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. • 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

Annex 3

Hydrological and Climate Modeling of Vijayawada

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CHAPTER 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:

1. Expanding an existing IUWM framework to catchment area while addressing challenges presented by climate change for improved water security at the catchment level
2. 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.
3. 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
4. Capacity building of stakeholders on various aspects of IUWM, climate change, scientific decision making, and project financing.
5. 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:

1. To estimate the runoff from the watersheds/ sub-watersheds of both the cities and to study its variability over the years.
2. 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.
3. To develop strategies for adaptation to climate change vulnerability.

Chapter 2

METHODOLO

GY

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

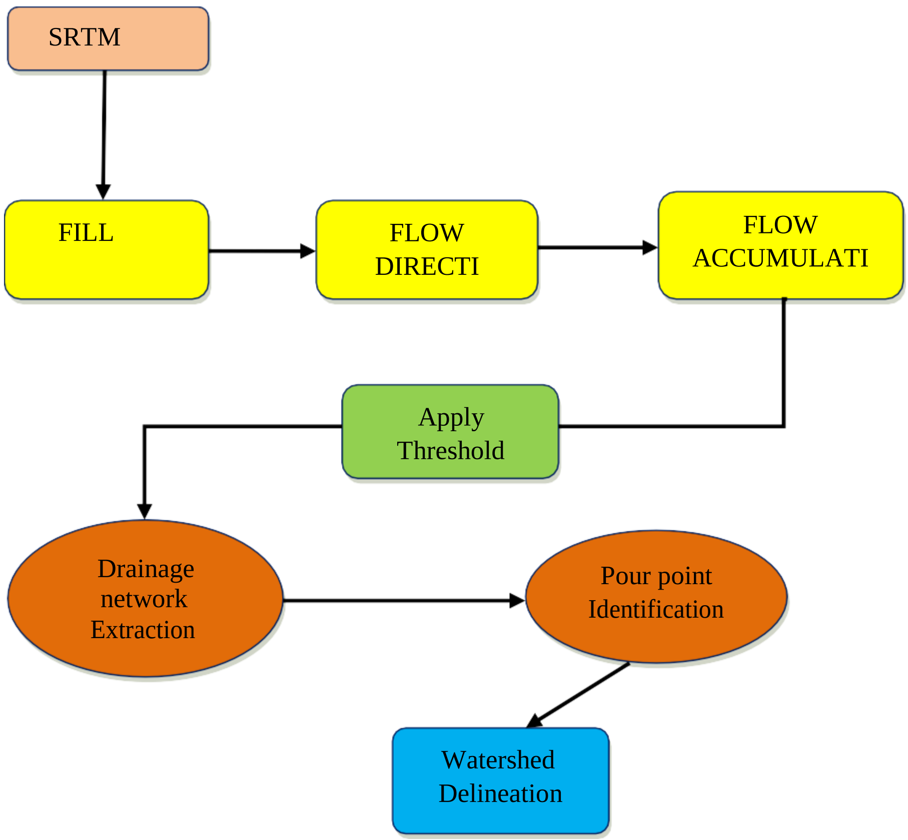


Fig. 2.1 Flow Chart for Delineation of Watershed

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).

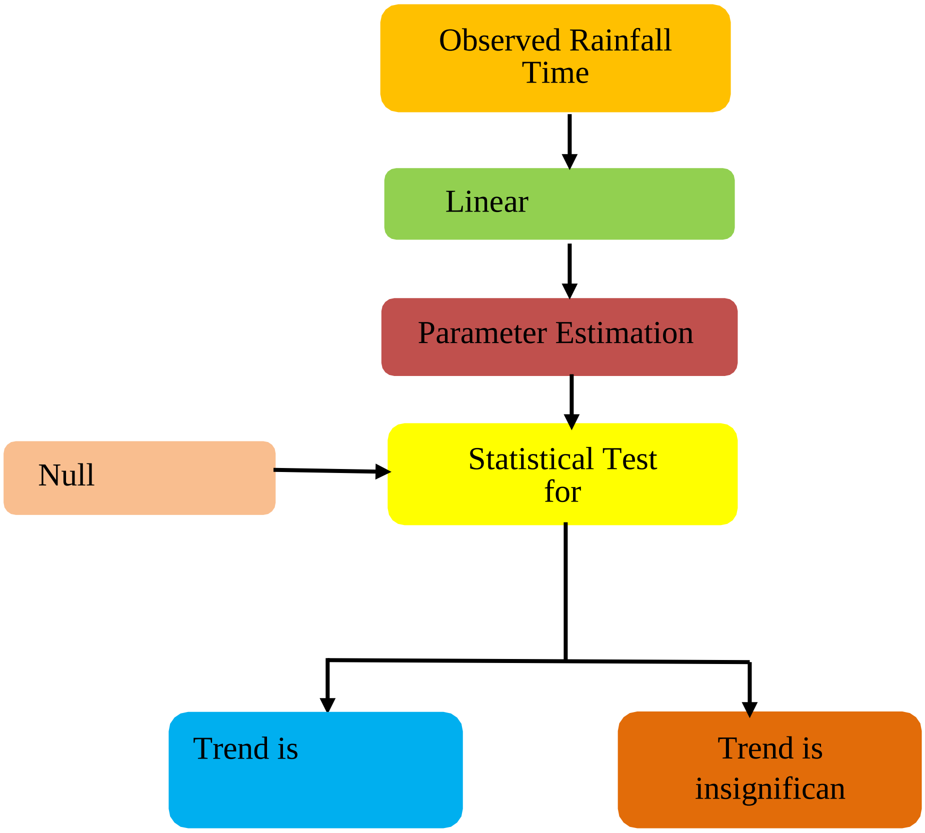


Fig 2.2 Flow chart for Trend analysis

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).

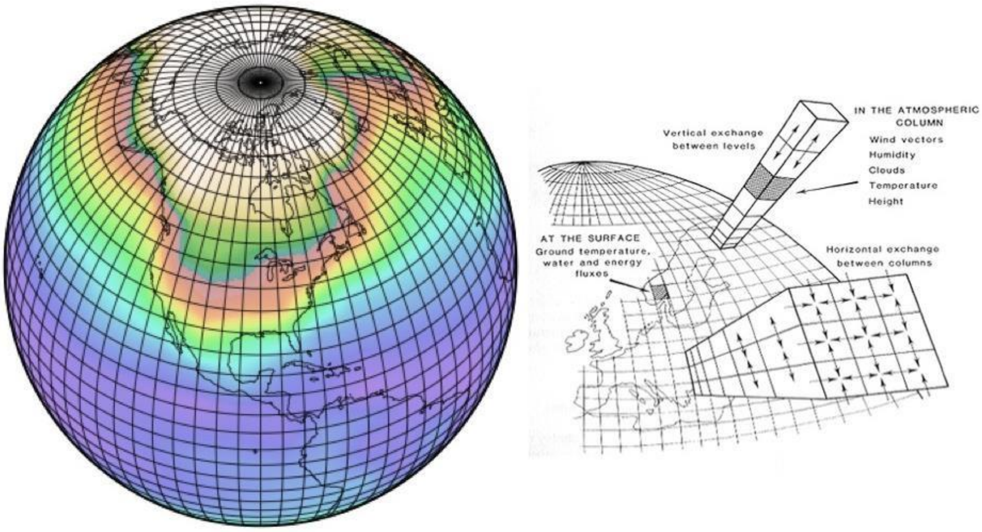


Fig. 2.3 Grid Point Model (Henderson-Sellers, 1985)

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.

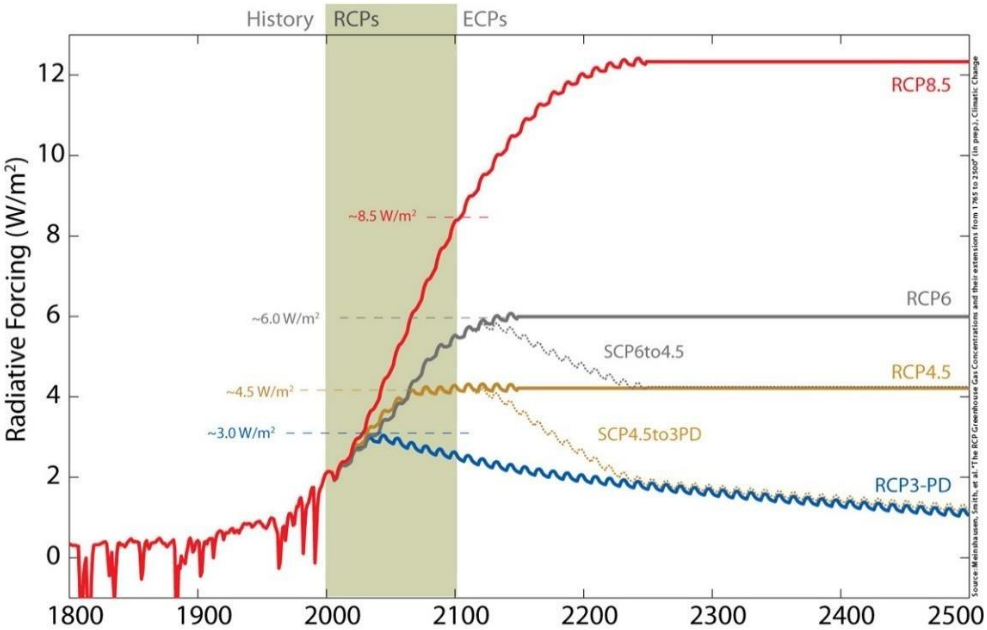


Fig. 2.4 Radiative forcing for different climate scenarios

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.

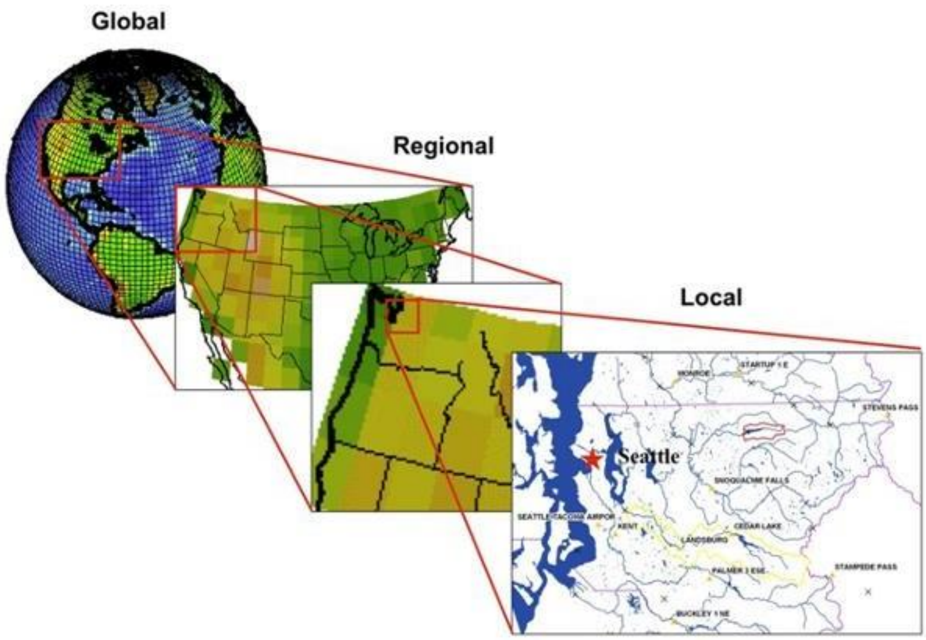


Fig. 2.5 Downscaling Global Climate Model

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.

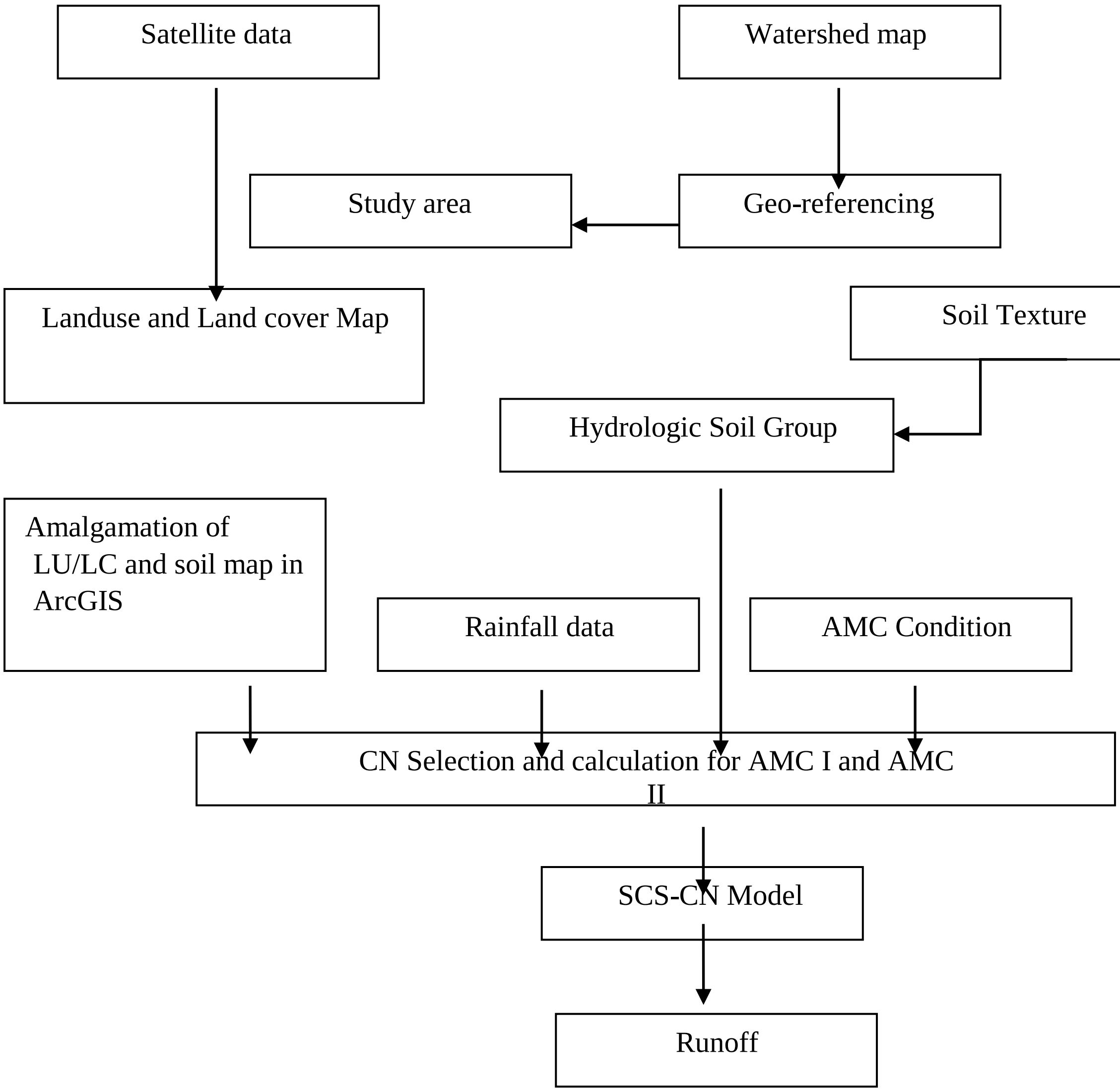


Fig. 2.6 Flow chart for SCS-CN Method

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.

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

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.

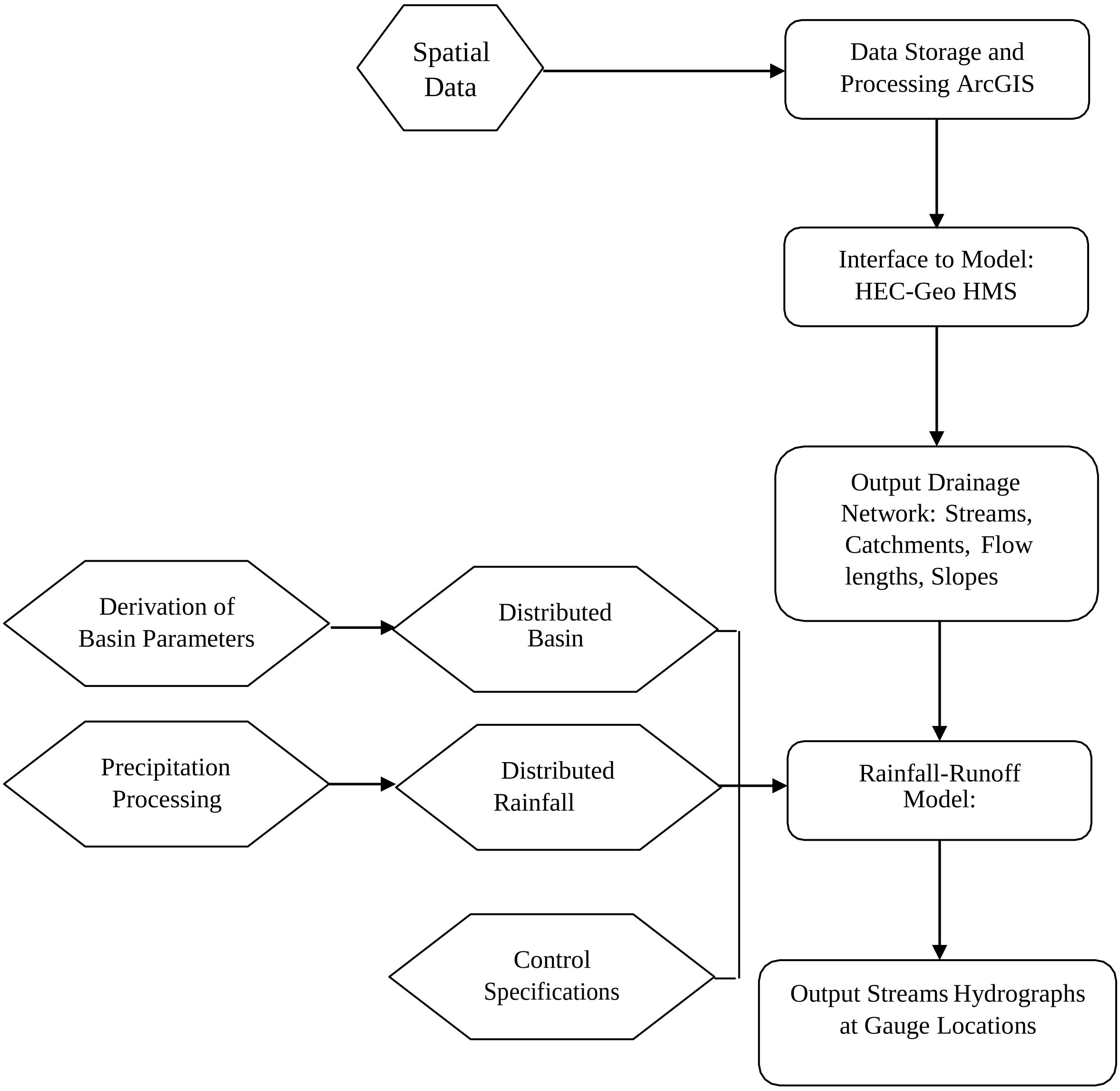


Fig. 2.7 Flow chart for HEC HMS Modelling

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:

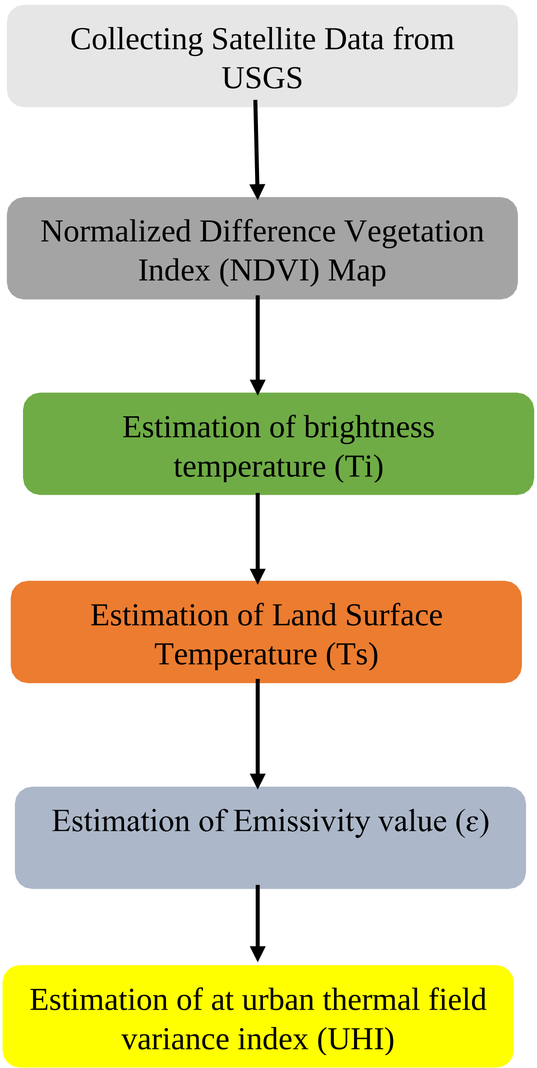
1) To determine the NDVI value
2) To determine the Brightness temperature
3) To determine the Land Surface Temperature

4) 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.

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



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.

Fig. 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.

where, L_λ = TOA spectral radiance (Watts/(m^2.srad.μm)); M_C = Band-specific multiplicative

$$L_\lambda = M_c Q_{cal} + A_L \quad (2.14)$$

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:

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

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.

Chapter 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.

4.4 Climate Modelling for Vijayawada (Gannavaram Station)

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

4.4.1 Trend

Analysis

Monthly

rainfall

Fig. 4.8 shows the variation of monthly rainfall.

Mean annual rainfall: 906.3 mm

Standard deviation: 236.1 mm

Linear regression,

$$y(t) = \hat{\alpha} + \hat{\beta}t + \varepsilon(t)$$

α = 71.75; β = 0.02(Slope of line) Null Hypothesis:

β = 0, i.e. Mean of the annual rainfall remains same

Using Student-t-test, (for a significance level of 0.05%)

T_score = 0.42 <T_critical = 1.96

Hence, the hypothesis is accepted. So, the change in the mean annual rainfall is **statistically significant**.

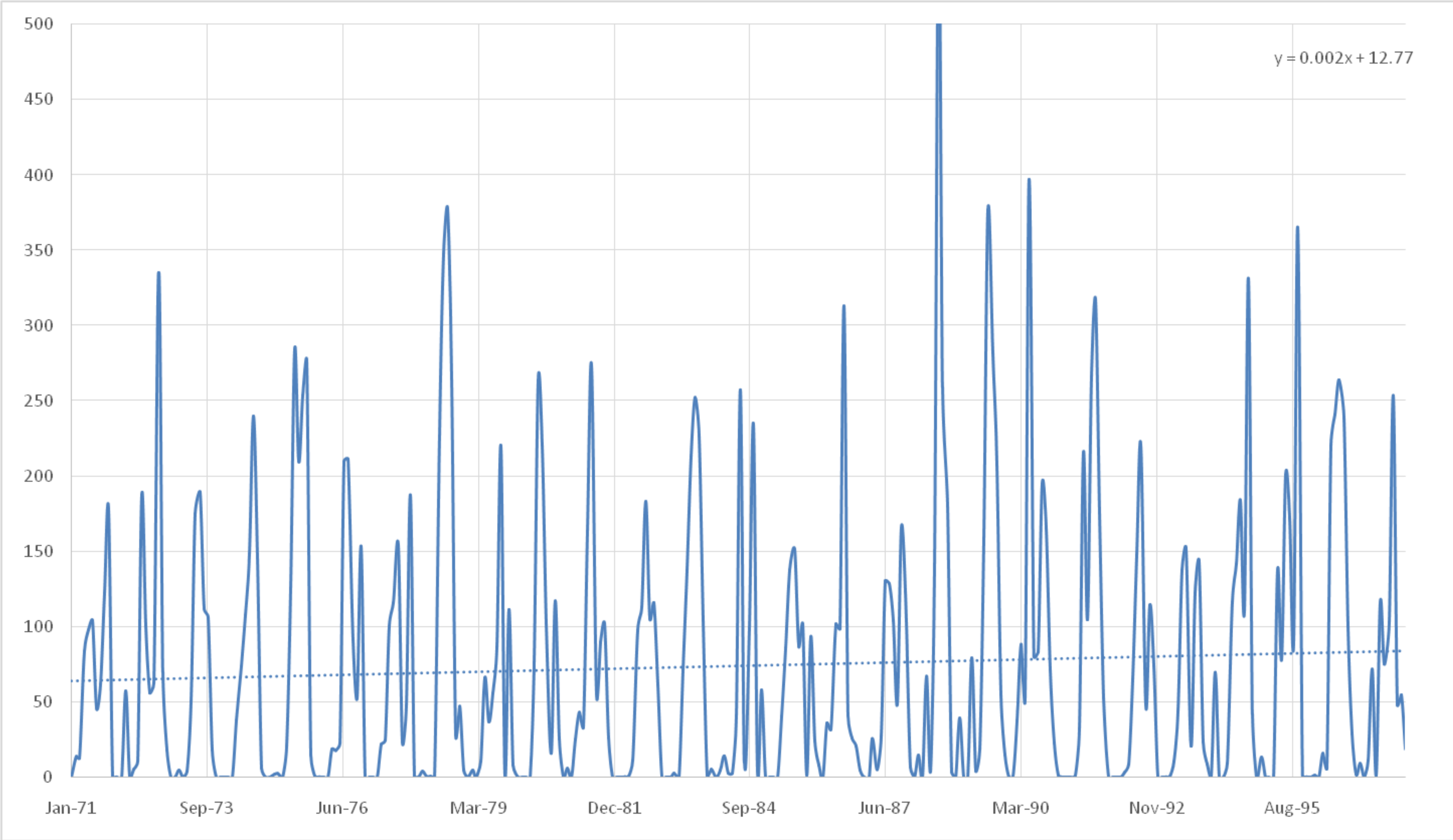


Fig. 4.8 Trend of monthly rainfall for Vijayawada

4.4.2 GCM Projections

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

RCP 2.6

Projection for Rainfall

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

Table 4.20 Number of floods and droughts as per RCP 2.6 for Vijayawada

	Global Climate Models						
	NCAR CESM1 (CAM5)	**FIO ESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NORESM1-M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	0	3	0	0	1	12	5
Severe drought	7	22	5	2	11	15	21
Moderate drought	15	10	20	18	14	8	8
Normal	16	13	15	16	16	17	15
Moderate flood	6	6	4	6	6	4	6
Severe flood	5	3	7	6	3	2	1
Extreme flood	9	1	7	10	7	0	2

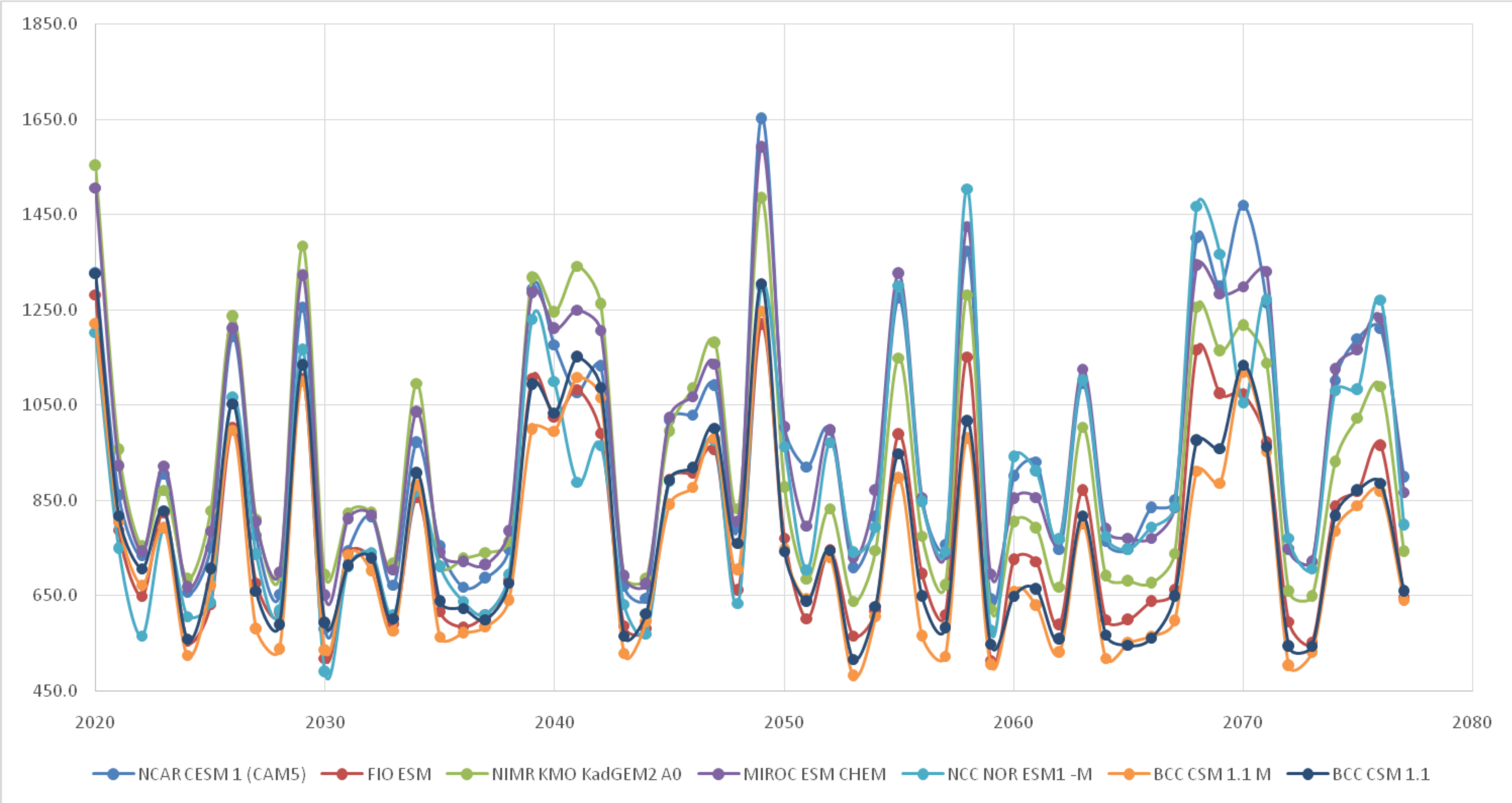


Fig 4.9 Annual rainfall projection for RCP 2.6 scenario for Vijayawada

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

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

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

RCP 4.5

Projection of rainfall

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

Table 4.21 Percentage change in monthly rainfall for the RCP 2.6 scenario for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	29.6	-19.1	28.7	18.6	-17.6	-8.6	-6.4	3.6
	Feb	12.2	34.2	-15.4	11.8	-25.4	-11.0	13.2	2.8
	Mar	15.3	-1.2	-13.1	9.5	1.9	-2.5	-0.1	1.4
	Apr	55.8	8.3	-8.2	4.1	-24.4	-8.5	23.7	7.2
	May	-39.5	-6.6	29.4	4.6	-50.7	1.7	-0.3	-8.8
	Jun	-21.7	-2.1	-2.0	-3.6	-29.7	24.8	-0.3	-5.0
	Jul	1.7	-13.9	-5.5	-5.5	14.7	-41.0	-29.7	-11.3
	Aug	-5.3	-19.4	7.5	0.8	-10.3	-28.0	-26.6	-11.6
	Sep	6.2	-23.7	31.0	13.9	-29.0	5.8	16.6	3.0
	Oct	10.9	-14.8	-12.8	0.4	-8.1	-20.6	-13.4	-8.3
	Nov	-1.6	-0.2	3.5	15.5	0.2	-33.3	-7.2	-3.3
	Dec	-5.9	-26.1	1.5	19.5	16.4	-36.5	6.5	-3.5
2049-2078	Jan	19.7	-15.5	-0.9	15.2	-29.0	-5.9	-6.2	-3.2
	Feb	-2.3	5.9	-29.6	7.5	-26.2	0.7	-3.9	-6.8
	Mar	51.7	10.9	-22.2	-0.7	12.2	-14.5	21.1	8.4
	Apr	142.5	-4.0	-22.2	-0.7	-13.2	7.5	2.2	16.0
	May	27.4	-9.7	20.0	3.3	-51.6	16.8	10.5	2.4
	Jun	11.8	-10.0	-5.5	0.6	36.2	-2.3	-23.4	1.0
	Jul	-5.5	-4.9	1.3	-7.3	20.0	-48.7	-32.1	-11.0
	Aug	18.4	-6.9	-5.8	15.7	22.7	-24.3	-25.9	-0.9
	Sep	-3.8	-26.6	5.1	29.1	-11.0	-13.5	-7.4	-4.0
	Oct	18.1	-32.7	-14.9	17.0	0.5	-23.9	-18.5	-7.8

	Nov	2.2	-7.1	8.4	16.2	-4.5	-24.9	8.1	-0.2
	Dec	-8.3	-13.5	-3.7	16.2	-15.0	-14.1	-29.3	-9.7

Table 4.22 Increase (^{0}C) in monthly maximum temperature for RCP 2.6 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIOESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1M	BCC CSM 1.1	
2020-2048	Jan	1.1	0.7	1.3	0.8	1.1	0.2	0.6	0.8
	Feb	1.2	0.7	1.1	0.8	1.1	0.1	0.6	0.8
	Mar	0.9	0.6	0.8	0.7	1	0.2	0.6	0.7
	Apr	1.3	0.7	0.7	0.8	1.2	0.8	0.8	0.9
	May	1.2	0.6	1	0.8	1.1	1.1	0.6	0.9
	Jun	1.1	0.8	1	0.9	1	1	0.7	0.9
	Jul	1.3	0.9	0.8	0.8	1.2	0.9	0.7	0.9
	Aug	1.3	0.7	1.1	1	0.9	0.8	0.6	0.9
	Sep	1.1	0.8	0.9	1.1	1.2	0.8	0.6	0.9
	Oct	1	0.7	0.7	1.1	1.4	0.8	0.7	0.9
	Nov	1	0.6	0.7	0.9	1.2	0.5	0.6	0.8
	Dec	0.9	0.6	1	1	1	0.3	0.6	0.8
2049-2078	Jan	1.5	0.9	0.9	1	1.2	0.6	0.7	1.0
	Feb	1.6	0.9	0.7	1.1	1.7	0.5	0.7	1.0
	Mar	1.7	0.7	0.8	1	1.1	0.6	0.7	0.9
	Apr	1.8	0.8	0.7	0.9	1.1	1	0.9	1.0
	May	1.9	0.9	0.7	1	1.3	1.1	0.7	1.1
	Jun	1.8	0.9	1	0.9	1.4	1	0.7	1.1
	Jul	1.5	1	0.6	1.1	1	0.8	0.7	1.0
	Aug	1.6	0.9	0.8	1.3	0.9	0.8	0.6	1.0
	Sep	1.5	0.9	0.6	1.2	1.2	1	0.6	1.0
	Oct	1.5	0.9	0.6	1.2	1.3	0.9	0.7	1.0
	Nov	1.7	0.8	0.5	1.2	1.4	0.8	0.7	1.0

	Dec	1.4	0.9	0.6	1.2	1.2	0.6	0.6	0.9

Table 4.23 Increase (^{0}C) in monthly minimum temperature for RCP 2.6 for Vijayawada

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

	Nov	1.8	0.7	0.8	1.2	2.0	1.0	0.9	1.2
	Dec	2.3	0.8	0.8	1.1	2.0	1.0	0.8	1.2

Table 4.24Number of floods and droughts as per RCP 4.5 for Vijayawada

	Global Climate Models						
	NCAR CESM1 (CAM5)	FIOESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 - M	BCC CSM 1.1 M	BCC CSM 1.1
Extreme drought	4	6	0	0	0	21	2
Severe drought	13	10	9	1	12	12	18
Moderate drought	10	15	18	11	17	11	13
Normal	17	14	13	22	11	12	14
Moderate flood	4	4	7	5	9	1	7
Severe flood	5	6	7	6	4	1	2
Extreme flood	5	3	4	13	5	0	2

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

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

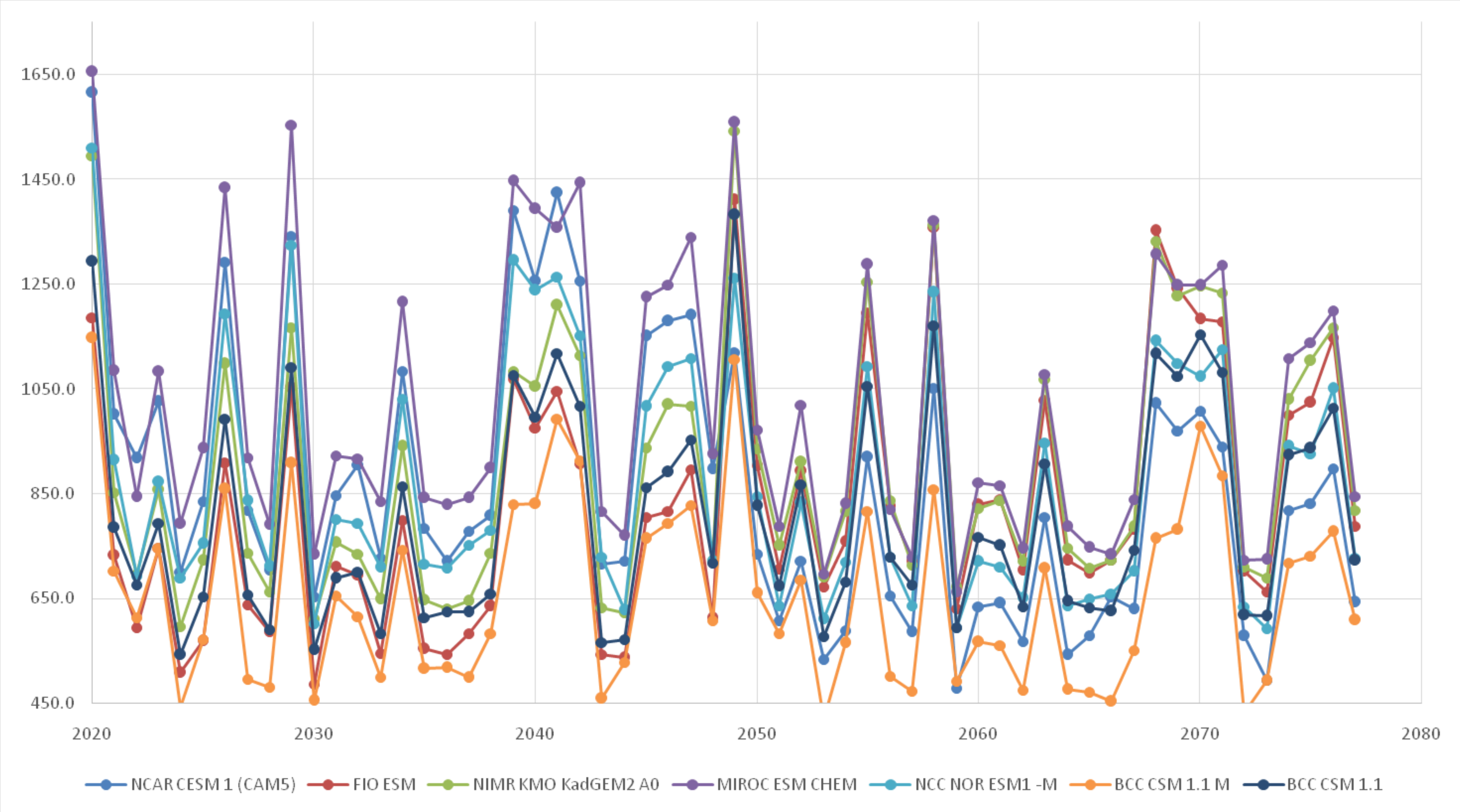


Fig 4.10 Annual rainfall projection for RCP 4.5 scenario for Vijayawada

Table 4.25 Percentage change monthly rainfall for RCP 4.5 scenario for Vijayawada

Period	Global Climate Models								Mean
	Month	NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	0.5	-18.0	24.1	14.9	-16.2	-16.5	31.4	2.9
	Feb	79.9	34.7	-22.7	20.6	-7.0	-7.8	12.1	15.7
	Mar	19.2	-2.0	-18.2	8.0	26.7	-5.5	-0.9	3.9
	Apr	132.2	3.3	-17.9	-1.6	-19.6	-9.2	33.8	17.3
	May	17.7	-4.5	22.7	-1.0	11.0	-5.0	-2.7	5.4
	Jun	-4.7	0.0	-8.9	12.2	-23.6	13.1	-8.4	-2.9
	Jul	-3.3	-14.4	-24.1	-1.6	3.3	-54.6	-30.7	-17.9
	Aug	4.5	-25.1	-10.8	31.2	25.9	-43.2	-16.9	-4.9
	Sep	15.8	-34.7	1.4	35.9	-13.9	-18.2	-5.3	-2.7
	Oct	23.4	-35.4	0.2	26.7	0.5	-17.8	-17.7	-2.9
	Nov	-9.3	-3.9	21.4	19.7	11.1	-32.7	-6.3	0.0
	Dec	-21.3	-30.4	-22.2	18.5	-6.0	-15.3	28.3	-6.9
2049-2078	Jan	9.2	-4.5	16.9	25.7	-23.6	-33.6	-26.5	-5.2
	Feb	-8.4	10.5	-15.4	10.5	21.9	0.8	16.1	5.1
	Mar	18.1	5.8	-28.0	7.6	-10.0	-7.4	14.9	0.2
	Apr	35.4	7.0	6.5	2.7	-34.3	-12.2	-7.8	-0.4
	May	-28.0	-9.8	10.1	-3.2	-21.9	-5.6	1.0	-8.2
	Jun	-22.0	1.1	-10.5	14.5	-7.1	-11.0	6.3	-4.1
	Jul	-36.7	8.6	4.1	-6.8	-23.4	-61.4	-19.9	-19.4
	Aug	7.5	3.4	2.2	0.0	2.9	-48.6	-18.0	-7.2
	Sep	-33.8	2.8	20.9	17.9	8.2	-2.0	-6.6	1.1
	Oct	-22.1	-12.6	2.0	18.8	-15.9	-26.9	-13.0	-10.0

	Nov	-9.9	19.1	16.8	18.5	5.4	-14.6	29.2	9.2
	Dec	3.1	-3.8	-14.9	14.1	4.4	-29.5	2.8	-3.4

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

Table 4.26 Increase (^{0}C) in monthly maximum temperature for RCP 4.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NOR ESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.7	0.9	1.5	1.0	1.9	1.0	0.8	1.2
	Feb	0.1	0.9	1.4	1.0	1.9	1.0	0.9	1.0
	Mar	1.0	0.8	1.2	0.9	0.8	1.0	1.0	1.0
	Apr	1.0	0.8	1.1	1.0	1.2	1.0	0.9	1.0
	May	1.3	0.8	1.3	1.0	1.5	1.0	0.9	1.1
	Jun	1.9	0.7	1.1	1.0	1.7	0.8	0.9	1.2
	Jul	2.1	0.7	1.1	1.0	1.2	0.5	0.7	1.0
	Aug	1.7	0.7	1.1	1.0	0.8	0.6	0.7	1.0
	Sep	0.6	0.6	1.2	1.1	1.1	0.8	0.9	0.9
	Oct	0.5	0.8	1.1	1.2	1.8	1.0	1.0	1.1
	Nov	1.4	0.8	1.1	1.1	1.0	1.0	1.0	1.0
	Dec	1.7	0.8	0.9	1.0	1.6	1.0	0.9	1.1
2049-2078	Jan	2.2	1.1	1.7	1.5	2.3	1.3	1.1	1.6
	Feb	2.7	1.1	1.7	1.5	2.2	1.4	1.3	1.7
	Mar	1.6	1.1	1.4	1.4	1.0	1.4	1.3	1.3
	Apr	2.5	1.1	1.4	1.5	1.9	1.4	1.3	1.6
	May	3.0	1.1	1.9	1.5	2.4	1.3	1.2	1.8
	Jun	2.6	1.2	1.8	1.5	2.0	1.1	1.1	1.6
	Jul	2.6	1.1	1.7	1.6	1.7	0.6	1.0	1.5
	Aug	2.5	1.1	1.9	1.6	1.9	0.5	1.0	1.5
	Sep	2.9	1.1	1.8	1.6	1.9	0.8	1.3	1.6
	Oct	2.1	1.1	1.9	1.7	2.2	1.2	1.4	1.7

	Nov	2.6	1.1	1.5	1.7	2.3	1.3	1.3	1.7
	Dec	2.7	1.2	1.4	1.6	1.9	1.2	1.1	1.6

Table 4.27 Increase (^{0}C) in monthly minimum temperature for RCP 4.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIOESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.4	0.8	1.6	0.9	1.5	1.0	0.8	1.1
	Feb	1.2	0.9	1.4	1.0	1.9	1.0	0.8	1.2
	Mar	1.5	0.8	1.2	0.9	1.8	1.0	1.0	1.2
	Apr	2.0	0.8	1.2	1.0	1.4	1.0	0.9	1.2
	May	1.3	0.8	1.3	1.0	1.3	1.0	0.9	1.1
	Jun	1.3	0.7	1.2	1.0	1.1	0.8	0.9	1.0
	Jul	1.4	0.7	1.1	1.0	0.4	0.5	0.7	0.8
	Aug	1.5	0.7	1.1	1.0	0.6	0.7	0.7	0.9
	Sep	1.2	0.6	1.1	1.0	1.0	0.8	0.9	1.0
	Oct	1.5	0.7	1.1	1.1	1.4	1.0	1.0	1.1
	Nov	1.1	0.7	1.0	1.1	1.1	1.0	1.0	1.0
	Dec	1.2	0.8	1.0	1.0	1.4	1.1	0.9	1.0
2049-2078	Jan	2.3	1.1	1.9	1.5	1.6	1.3	1.1	1.6
	Feb	2.7	1.1	1.6	1.5	2.5	1.4	1.3	1.7
	Mar	1.6	1.2	1.5	1.5	1.5	1.4	1.3	1.4
	Apr	2.7	1.1	1.5	1.6	1.2	1.4	1.3	1.5
	May	2.4	1.1	1.9	1.6	1.3	1.3	1.2	1.5
	Jun	1.9	1.2	1.8	1.5	1.6	1.1	1.1	1.5
	Jul	1.8	1.1	1.8	1.6	0.3	0.6	1.0	1.2
	Aug	1.8	1.1	1.9	1.6	0.8	0.5	1.0	1.2
	Sep	2.2	1.1	1.8	1.6	1.6	0.8	1.3	1.5
	Oct	1.9	1.1	1.8	1.7	1.7	1.2	1.4	1.6

	Nov	2.1	1.1	1.5	1.7	2.0	1.3	1.3	1.6
	Dec	2.2	1.2	1.6	1.6	1.8	1.2	1.1	1.5

RCP 6.0

Projection of Rainfall

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

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

Table 4.28 Number of floods and droughts as per RCP 6.0 for Vijayawada

	Global Climate Models						
	NCAR CESM1 (CAM5)	**FIOESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NOR ESM1 - M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	0	6	0	0	0	17	9
Severe drought	12	20	9	0	4	16	12
Moderate drought	16	9	18	10	23	10	15
Normal	14	15	12	23	12	10	13
Moderate flood	7	5	5	4	5	4	5
Severe flood	4	2	8	6	10	1	3
Extreme flood	5	1	6	15	4	0	1

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

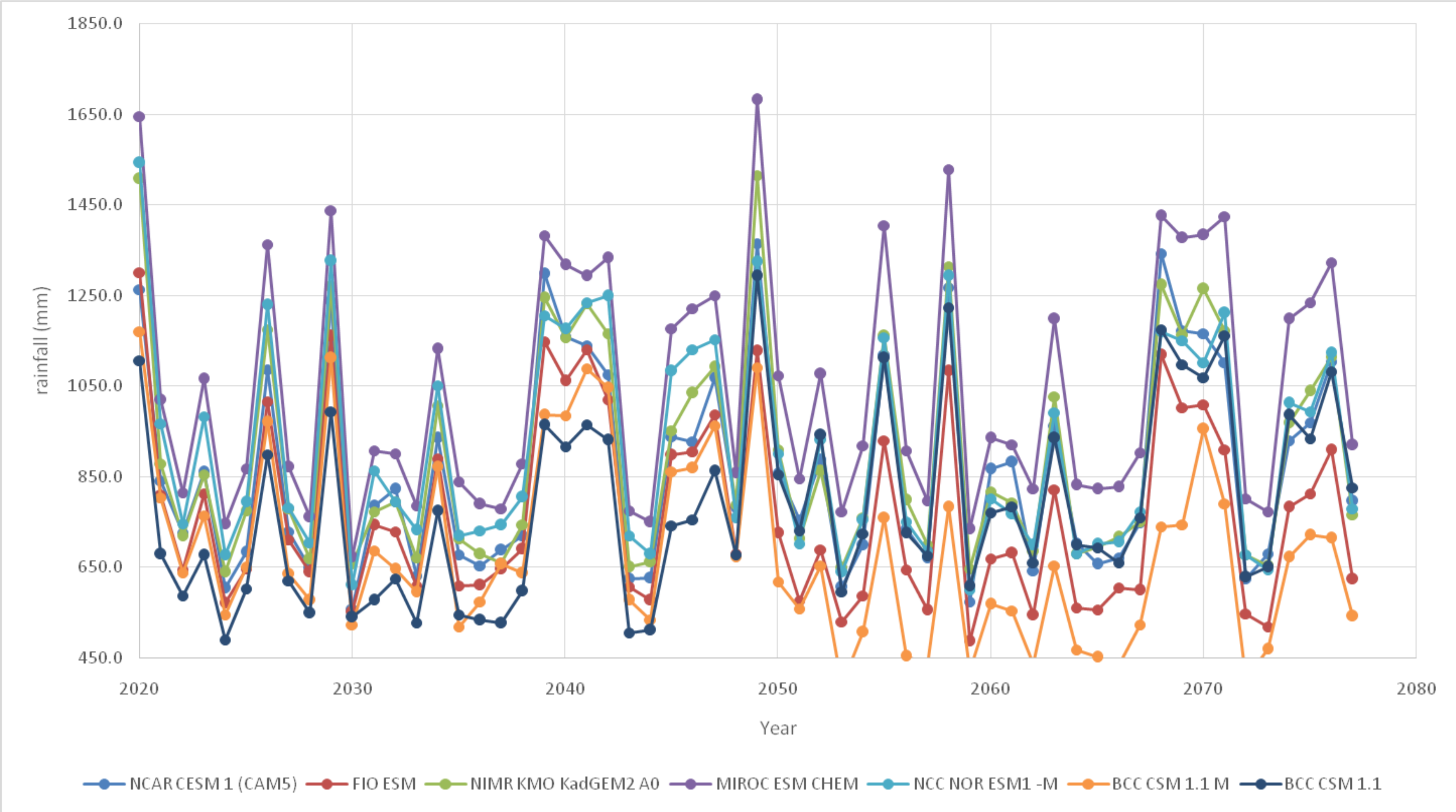


Fig 4.11 Annual rainfall projection for RCP 6.0 scenario for Vijayawada

Table 4.29 Percentage change in monthly rainfall for RCP 6.0 scenario for Vijayawada

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

	Nov	-4	-21	15	26	10	-32	20	2
	Dec	-10	-23	-1	23	22	-29	57	6

Projection for Maximum Temperature

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

Projection for Minimum Temperature

Table 4.31 shows the increase in monthly minimum temperature for RCP 6.0 scenario. Here also, out of the seven models, NCAR CESM 1 (CAM5) shows the maximum increase which is at most of 1.2^{0}C in the first 30 years and rises to 2.5^{0}C in the next 30 years. BCC CSM 1.1 shows a minimum increase in temperature. Overall the maximum temperature will rise by 1^{0}C in 2020 to 2048 and 1.5^{0}C – 1.6^{0}C in 2049-2078.

Table 4.30 Increase (^{0}C) in monthly maximum temperature for RCP 6.0 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	0.8	1	1.2	0.7	0.8	0.7	0.7	0.8
	Feb	1	0.9	1	0.7	1.5	0.5	0.5	0.9
	Mar	0.9	0.9	0.9	0.7	1.1	0.5	0.7	0.8
	Apr	1.4	0.7	0.9	0.7	1	0.9	1	0.9
	May	1.2	0.9	1.1	0.7	1.1	1.1	0.8	1.0
	Jun	1.2	0.8	1.2	0.8	1.4	1.1	0.7	1.0
	Jul	1.1	0.9	0.9	0.8	1.2	1	0.6	0.9
	Aug	1.4	0.7	1.1	0.9	0.9	1	0.7	1.0
	Sep	1	0.9	0.9	0.9	1.2	1.1	0.8	1.0
	Oct	1.1	0.9	0.7	1	1.3	1	0.7	1.0
	Nov	1.1	1	0.7	0.9	1.2	0.8	0.6	0.9
	Dec	0.9	1	0.8	0.8	1.2	0.5	0.6	0.8
2049-2078	Jan	1.8	1.4	2.1	1.6	1.1	1	1.2	1.5
	Feb	1.9	1.3	2.2	1.6	1.8	0.9	1.2	1.6
	Mar	1.9	1.2	1.8	1.4	1.5	0.9	1.2	1.4
	Apr	2.2	1.3	1.7	1.4	1.4	1.3	1.3	1.5
	May	2.1	1.2	1.7	1.4	1.8	1.3	1.2	1.5
	Jun	2.2	1.3	1.8	1.5	1.9	1.3	1.2	1.6
	Jul	2	1.3	1.6	1.5	1.8	1.3	1.2	1.5
	Aug	2.2	1.2	1.7	1.5	1.5	1.3	1.1	1.5
	Sep	2.1	1.2	1.3	1.7	1.5	1.4	1.3	1.5
	Oct	1.9	1.3	1.2	1.7	1.9	1.3	1.3	1.5
	Nov	1.8	1.2	1.2	1.7	1.9	1.1	1.2	1.4

	Dec	1.6	1.4	1.7	1.7	1.2	1	1.2	1.4

Table 4.31 Increase (^{0}C) in monthly minimum temperature for RCP 6.0 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIOESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.1	0.9	1.3	0.8	1.1	1.0	0.8	1.0
	Feb	1.1	0.8	1.0	0.8	1.7	1.0	0.9	1.0
	Mar	1.1	0.8	0.8	0.8	1.2	1.0	1.1	1.0
	Apr	1.4	0.7	0.8	0.9	1.4	1.0	0.8	1.0
	May	0.8	0.8	0.9	0.8	1.4	0.9	0.8	0.9
	Jun	0.9	0.8	0.9	0.8	1.5	0.8	0.7	0.9
	Jul	1.2	0.8	0.9	0.9	0.6	0.6	0.5	0.8
	Aug	1.2	0.8	0.9	0.8	0.6	0.6	0.6	0.8
	Sep	1.0	0.8	0.8	0.9	0.7	0.7	0.9	0.8
	Oct	1.0	0.8	0.9	0.9	1.5	0.9	0.8	1.0
	Nov	1.0	0.8	0.6	0.9	1.3	0.9	0.8	0.9
	Dec	1.4	0.9	0.8	0.8	1.2	1.0	0.7	1.0
2049-2078	Jan	2.5	1.2	2.0	1.5	1.5	1.2	1.1	1.6
	Feb	2.2	1.2	1.7	1.5	1.9	1.3	1.2	1.6
	Mar	2.3	1.2	1.3	1.4	1.5	1.4	1.4	1.5
	Apr	2.5	1.2	1.6	1.5	1.1	1.4	1.2	1.5
	May	2.2	1.1	1.4	1.4	1.5	1.4	1.3	1.5
	Jun	1.8	1.2	1.6	1.4	2.0	1.1	1.3	1.5
	Jul	2.1	1.1	1.5	1.5	1.1	0.9	1.2	1.3
	Aug	2.1	1.1	1.5	1.5	0.9	0.7	1.1	1.3
	Sep	2.1	1.0	1.5	1.6	1.1	0.8	1.3	1.4
	Oct	1.9	1.0	1.4	1.7	1.8	1.2	1.5	1.5
	Nov	2.3	1.1	1.5	1.6	1.9	1.4	1.4	1.6

	Dec	2.7	1.3	1.6	1.5	1.7	1.4	1.3	1.6

RCP 8.5

Projection of Rainfall

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

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

Table 4.32 Number of floods and droughts as per RCP 8.5 for Vijayawada

	Global Climate Models						
	NCAR CESM1 (CAM5)	**FIOESM**	**NIMR KMO KadGEM2 A0**	**MIROC ESM CHEM**	**NCC NORESM1-M**	**BCC CSM 1.1 M**	**BCC CSM 1.1**
Extreme drought	0	4	0	0	1	25	4
Severe drought	6	22	10	6	16	9	17
Moderate drought	16	9	19	18	12	9	12
Normal	15	13	12	14	15	12	15
Moderate flood	8	5	6	8	7	2	5
Severe flood	9	4	8	4	5	1	3
Extreme flood	4	1	3	8	2	0	2

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

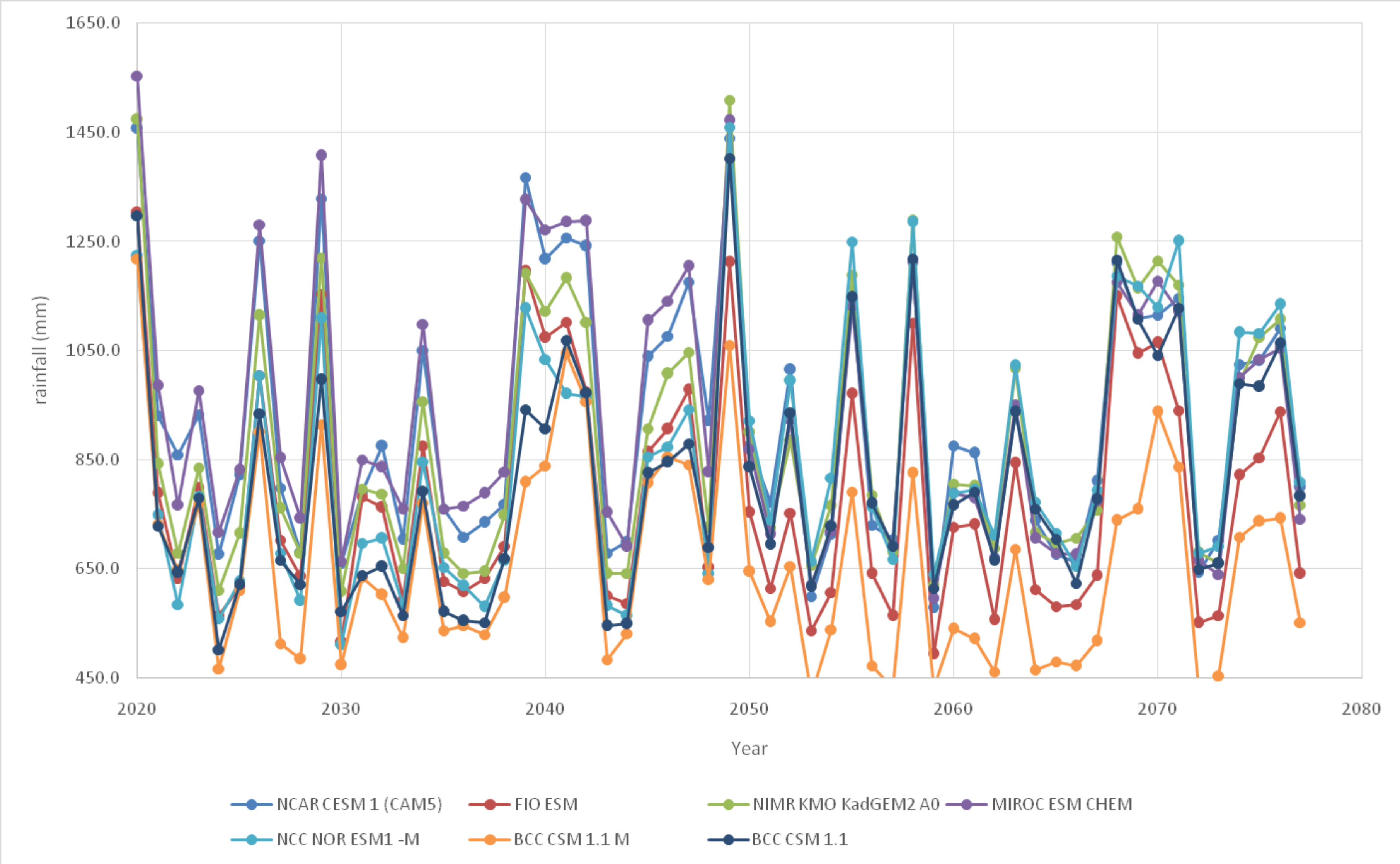


Fig 4.12 Annual rainfall projection for RCP 8.5 scenario for Vijayawada

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

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	12.2	-16.9	23.2	20.3	-28.9	3.0	-1.5	1.6
	Feb	0.4	14.9	-47.5	12.9	-1.7	-20.3	-4.2	-6.5
	Mar	-0.1	-2.8	-8.1	7.9	1.6	2.1	-3.2	-0.4
	Apr	131.1	6.4	-17.0	-4.9	-24.6	-3.4	20.1	15.4
	May	-10.9	1.2	16.6	2.2	-27.6	-0.5	-2.6	-3.1
	Jun	-5.6	3.5	-2.4	0.6	-16.5	-0.2	-18.8	-5.6
	Jul	-6.9	2.0	-2.3	-8.5	-6.2	-64.0	-40.8	-18.1
	Aug	-5.1	-17.3	-17.3	24.6	-20.3	-30.5	-31.5	-13.9
	Sep	31.6	-33.5	-2.3	11.1	-19.2	-11.1	-5.0	-4.1
	Oct	8.3	-26.9	-10.5	11.4	-17.6	-2.9	-14.6	-7.6
	Nov	-5.0	0.4	21.6	16.8	-2.0	-34.5	35.1	4.6
	Dec	0.8	-13.9	-19.5	20.8	22.1	-4.4	-3.7	0.3
2049-2078	Jan	63.5	-24.4	32.8	12.1	-16.3	-29.1	-13.8	3.6
	Feb	18.1	21.3	-18.7	13.6	11.5	-8.6	4.7	6.0
	Mar	-1.0	13.8	-25.4	6.6	7.5	-6.2	-6.9	-1.6
	Apr	48.5	4.0	-0.3	3.4	-28.3	-21.3	8.6	2.1
	May	-16.4	-7.3	11.9	0.1	-23.5	-11.4	-31.1	-11.1
	Jun	40.7	-3.4	-7.7	-2.2	1.2	-22.0	-2.6	0.6
	Jul	-11.4	-2.9	-3.6	-14.1	-19.7	-64.2	-7.5	-17.6
	Aug	-33.3	-26.9	0.4	-6.0	-9.7	-33.6	-23.7	-19.0
	Sep	-11.0	-23.2	5.1	-9.5	27.9	-19.0	6.8	-3.3
	Oct	12.7	-31.5	1.1	6.4	24.5	-22.2	5.9	-0.5
	Nov	23.2	-22.4	6.2	23.6	12.2	-38.9	35.1	5.6
	Dec	14.5	-14.3	0.0	14.3	20.4	-16.8	60.1	11.2

Projection for Maximum Temperature

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

Projection for Minimum Temperature

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

Table 4.34 Increase (^{0}C) in monthly maximum temperature for RCP 8.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	1.5	1.0	1.2	1.0	2.4	0.9	1.0	1.3
	Feb	1.6	0.9	1.1	1.0	1.8	1.1	1.0	1.2
	Mar	1.5	0.9	1.0	1.0	1.6	1.1	1.1	1.2
	Apr	1.7	1.0	1.0	1.1	1.7	1.1	1.1	1.2
	May	1.7	0.9	1.1	1.1	2.1	1.1	1.0	1.3
	Jun	2.2	0.9	0.9	1.1	2.0	0.9	0.9	1.3
	Jul	2.3	0.8	0.9	1.2	1.6	0.5	0.8	1.1
	Aug	2.2	0.8	0.9	1.1	1.2	0.5	0.7	1.1
	Sep	1.0	0.7	1.1	1.2	1.9	0.5	0.9	1.1
	Oct	0.8	0.9	1.0	1.2	2.0	1.0	1.2	1.1
	Nov	1.9	0.9	0.8	1.2	2.2	1.2	1.1	1.3
	Dec	1.2	1.0	0.7	1.1	1.3	1.1	1.0	1.1
2049-2078	Jan	2.4	1.9	2.5	2.3	2.9	1.9	1.8	2.2
	Feb	2.8	1.8	2.4	2.3	2.3	1.9	2.0	2.2
	Mar	3.0	1.8	2.0	2.2	2.1	2.0	2.0	2.1
	Apr	3.7	1.8	2.0	2.3	2.9	2.0	2.0	2.4
	May	3.4	1.8	2.1	2.2	2.9	2.0	1.9	2.3
	Jun	3.4	1.9	2.1	2.3	3.2	1.6	1.8	2.3
	Jul	3.2	1.8	2.1	2.2	2.7	1.1	1.7	2.1
	Aug	3.4	1.8	2.2	2.2	2.8	1.1	1.6	2.1
	Sep	3.1	1.7	2.2	2.2	1.8	1.6	2.0	2.1
	Oct	2.6	1.8	2.2	2.3	2.8	1.9	2.2	2.3
	Nov	3.7	1.8	1.8	2.3	2.4	1.9	2.0	2.3
	Dec	3.0	2.0	2.1	2.3	2.0	2.0	1.9	2.2

Table 4.35 Increase (^{0}C) in monthly minimumtemperaturefor RCP 8.5 for Vijayawada

Period	Month	Global Climate Models							Mean
		NCAR CESM 1 (CAM5)	FIO ESM	NIMR KMO KadGEM2 A0	MIROC ESM CHEM	NCC NORESM 1 -M	BCC CSM 1.1 M	BCC CSM 1.1	
2020-2048	Jan	2.0	1.0	1.4	1.0	1.3	0.9	1.0	1.2
	Feb	1.6	0.9	1.1	1.0	1.8	1.1	1.0	1.2
	Mar	1.4	0.9	0.9	1.0	1.7	1.1	1.1	1.2
	Apr	2.0	0.9	1.0	1.2	1.5	1.1	1.1	1.3
	May	1.8	0.9	1.1	1.1	1.4	1.1	1.0	1.2
	Jun	1.4	0.9	0.9	1.1	1.3	0.9	0.9	1.1
	Jul	1.3	0.8	0.9	1.2	0.5	0.5	0.8	0.9
	Aug	1.3	0.8	0.9	1.1	0.2	0.5	0.7	0.8
	Sep	1.3	0.7	1.1	1.2	0.9	0.5	0.9	1.0
	Oct	1.2	0.8	0.8	1.2	1.4	0.9	1.2	1.1
	Nov	1.6	0.9	0.7	1.2	1.9	1.2	1.1	1.2
	Dec	1.4	1.0	0.7	1.1	1.6	1.1	1.0	1.1
2049-2078	Jan	2.9	1.9	2.7	2.3	2.3	1.9	1.8	2.3
	Feb	3.2	1.8	2.5	2.3	2.7	1.9	2.0	2.3
	Mar	2.9	1.8	2.0	2.2	2.5	2.0	2.0	2.2
	Apr	3.9	1.8	2.1	2.3	2.8	2.0	2.0	2.4
	May	2.7	1.8	2.1	2.3	2.4	2.0	1.9	2.2
	Jun	2.8	1.9	2.1	2.3	2.6	1.6	1.8	2.2
	Jul	2.8	1.8	2.0	2.3	1.5	1.1	1.7	1.9
	Aug	2.9	1.8	2.1	2.3	2.0	1.1	1.6	2.0
	Sep	2.7	1.7	2.0	2.3	2.1	1.6	2.0	2.0
	Oct	2.6	1.8	2.0	2.4	2.9	1.9	2.2	2.2
	Nov	3.4	1.8	1.6	2.3	3.0	1.9	2.0	2.3
	Dec	3.3	2.0	2.2	2.3	2.5	2.0	1.9	2.3

4.4.3 Sum

mary

Rainfall

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

Maximum Temperature

Table 4.37 shows the increase in monthly maximum temperature for all the RCP scenarios. It is evident that in any case the maximum temperature is bound to rise at least by 1^0C. From 2020 to 2048, the change in temperature for RCP 2.6 is 0.9^0C, change in temperature for RCP 4.5 and RCP 6.0 is around 1^0C-1.2^0C 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. 2^0C also.

Minimum Temperature

Table 4.38 shows the increase in monthly minimum temperature for all the RCP scenarios. It is evident that even if RCP 2.6 follows, the minimum temperature will rise by about 0.8^0C to 0.9^0C. From 2020 to 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 increase in maximum temperature and minimum temperature is almost the same. Fig. 4.42 shows a projection of monthly minimum temperature for all RCPs.

Table 4.36 Percentage change in monthly rainfall for all RCPs for Vijayawada

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

Table 4.37 Increase (^{0}C) in maximum temperature for all RCPs for Vijayawada

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

Table 4.38 Increase (^{0}C) in monthly minimum temperature for all RCPs for Vijayawada

Period	Month	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2020-2048	Jan	0.9	1.1	1.0	1.2
	Feb	1.0	1.2	1.0	1.2
	Mar	0.9	1.2	1.0	1.2
	Apr	1.0	1.2	1.0	1.3
	May	0.8	1.1	0.9	1.2
	Jun	0.7	1.0	0.9	1.1
	Jul	0.8	0.8	0.8	0.9
	Aug	0.7	0.9	0.8	0.8
	Sep	0.9	1.0	0.8	1.0
	Oct	0.9	1.1	1.0	1.1
	Nov	0.9	1.0	0.9	1.2
	Dec	1.0	1.0	1.0	1.1
2049-2078	Jan	1.0	1.6	1.6	2.3
	Feb	1.1	1.7	1.6	2.3
	Mar	1.1	1.4	1.5	2.2
	Apr	1.1	1.5	1.5	2.4
	May	1.1	1.5	1.5	2.2
	Jun	1.1	1.5	1.5	2.2
	Jul	0.9	1.2	1.3	1.9
	Aug	0.9	1.2	1.3	2.0
	Sep	1.0	1.5	1.4	2.0
	Oct	1.1	1.6	1.5	2.2
	Nov	1.0	1.6	1.6	2.3
	Dec	1.0	1.5	1.6	2.3

Vijayawada

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

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

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

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

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

7.2 Hydrological Modelling

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

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

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

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

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

7.3 Urban Heat Island Map

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

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