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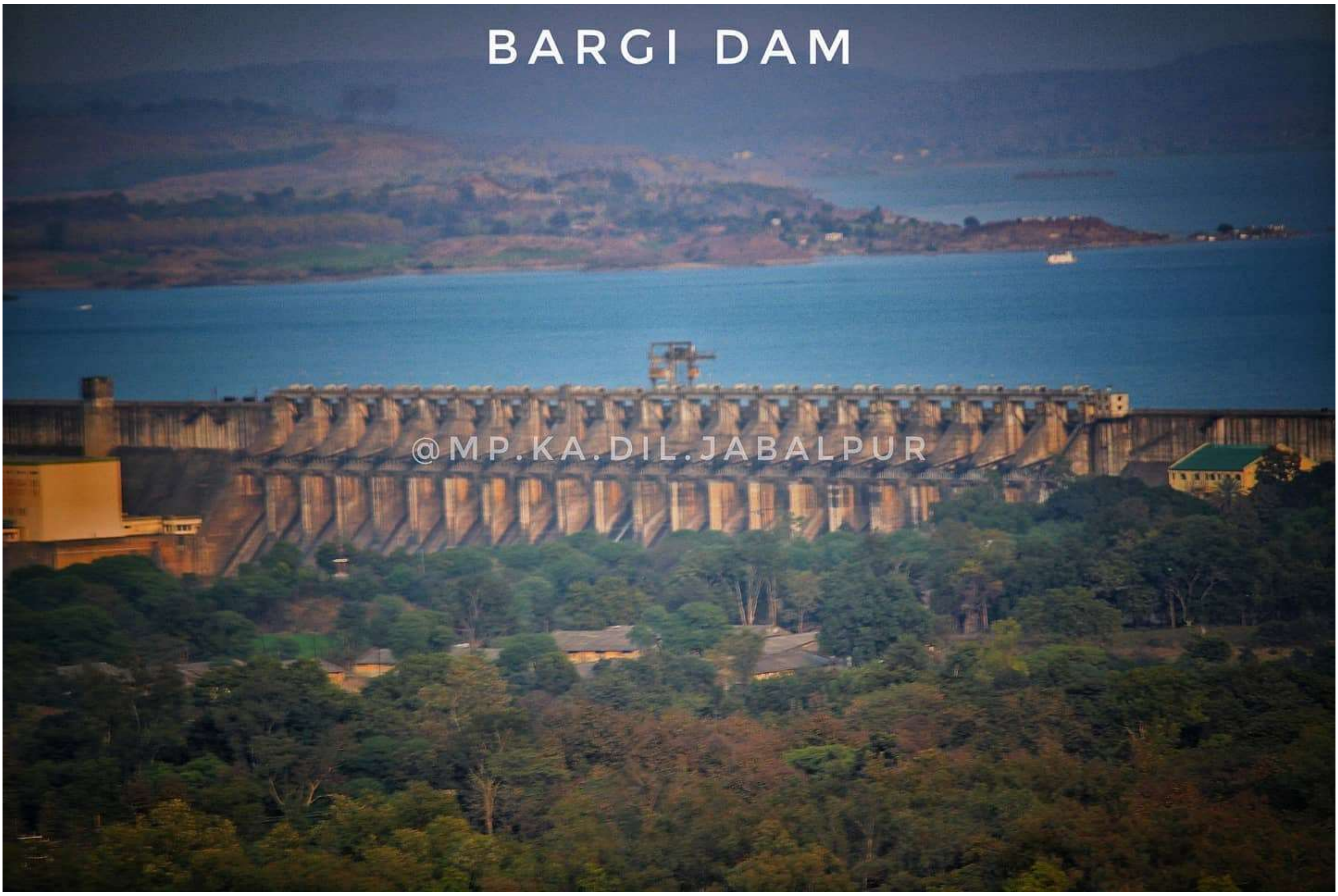
Guidelines for Usage and Upscaling of Water Resources Management Climate Change-Decision Support System in Madhya Pradesh



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Abbreviations

CBA	Cost Benefit Analysis
CHRIPS	Climate Hazards Group InfraRed Precipitation with Station data
CIMP6	Coupled Model Intercomparison Project-6
DEM	Digital elevation Model
EAC	Elevation Area Curve
GCM	Global Climate Model
GFS	Global Forecast System
HE	Hydroelectric
India-WRIS	Water Resources Information system
IRR	Internal rate of return
IT	Information Technology
MARR	Minimum acceptable rate of return
MCA	Multi Criteria Analysis
Modis	Moderate Resolution Imaging Spectroradiometer
NAM	Nedbor Afstromings Model
NDAMS	National Disaster & Management System
NPV	Net Present Value
NRSC	National Remote Sensing Centre
PET	Potential Evapotranspiration
PVB	Present Value of Benefit
PVC	Present Value of Cost
QA	Quality Assurance
QC	Quality Check
RCP	Representative Concentration Pathways
SAC	Space Applications Centre
SAS	Samarat Ashok Sagar
SSP	Shared Socioeconomic Pathways
TRMM	Tropical Rainfall Measuring Mission
UHM	Unit Hydrograph Method
WIMS	Water Information Management System
WIMS	Water Information Management System
WRS	Water Resource Software

EXECUTIVE SUMMARY

The Climate change has already been introduced to us for last two decades now. The management of water resources always requires diverse approaches in which multiple skills and capacities are nested together, especially when critical situations are considered, such as climate change scenarios. Decision Support Systems (DSSs), applied to the management of water resources, play an essential role since they must allow the different stakeholders and competencies involved to summarize results and produce decisions on a common and shared basis. Many studies and other examples from world highlight the benefit to involve various disciplines in the decisional phase, e.g., climatology, meteorology, hydrology, ecology, environmental science, agricultural science, water resources engineering, socioeconomics, law and public policy. Therefore, an optimal management of water resources should be addressed by a multidisciplinary approach in which multiple skills and capacities are nested together.

CC-DSS is one of the tools for water recourse management in the light of climate change developed in this view by Madhya Pradesh Water Resources department (MP-WRD) funded by Swiss Development Corporation (SDC). The current document presents the guidelines to make use of this decision support system in full capacity and to upscale it to be usable for all the water complexes available in states. The guidelines presented in this document incorporates the important information about the requirement of a DSS which can address the impacts of climate change on water resources through a smart and intuitive decision support system. The document briefly covers the results of studies done so far related to climate change in the state and changing water resources availability and dynamics. The CC-DSS benefits are explained in terms of identifying problem areas and identifying relevant adaptation options for meaningful policy formulation, planning and implementation. However, the entire CC-DSS is not just an IT structure, and its core part remains the modelling, which allows the user to simulate the real-world system including infrastructure, distribution, and policy in the state. This also enables the various scenario creations and to project various “what if” situations to have a modified or revised planning in terms of allocation and policy by the decision makers. For the existing project, MIKE HYDRO BASIN has been chosen as the modelling platform. The software has a long-established reputation for performing allocation modelling by representing the water complexes as in real world. The document also addresses the proven capability, input requirement and the basic modelling concept as adopted in MIKE HYDRO BASIN Framework. While this platform is desktop based, the CC-DSS has advanced its accessibility by providing it on Web-based platform. The planners and users can work on concerned area simultaneously, thus making integrated planning easier. Pre-modelling requirements, like data collection, consultation with stakeholders, QA/QC and analysis of data are addressed in chapter 2, for this being the pre-requisite and important input to all the steps ahead.

A system is developed with the vision not only to be capable, but to be usable to its maximum extent, Chapter 3rd focuses on usage of CC-DSS, which comply with objectives and mandates of the State Water Resources Department. The developed system will enhance the functioning of the department by allowing more informed water planning and sectoral allocation by parallelly looking at the availability of water in the basin, in different seasons, and under the impact of projected climate change. It is to be highlighted, that the system not only embed the information that resides with state department, but the system is also enriched by providing open source globally available satellite products, which improves the analysis resulting in better decision making. Chapter 3 incorporates detailed capabilities and usages of CC-DSS. The current CC-DSS is advanced in comparison to its previous version developed for SAS dam which could only be used with offline modelling and single purpose dams, since now it is capable to address different users in addition to irrigation like, domestic, industrial, Hydropower etc with online modelling. Different irrigation projects and reservoirs have different type of users/sectors to which water is being allocated, and this functionality of CC-DSS makes it usable to all those projects in state. The system also features Multicriteria analysis functionality, enabling the system to analyse different possible features with user defined model setup, and can help to assess with the most appropriate scenario of all. The cost benefit analysis tool will be able to assess the scenarios for its viability in terms of its economic evaluation. Towards end of the document, the inter-departmental usage of CC-DSS is also discussed which addresses fostering information exchange, integrated basin planning, capacity building of the planners and field officers with advanced technology etc.

INTRODUCTION

Wise management of water resources must consider hydrologic conditions as well as how the flow and storage of water affects the ecological, social, and economic systems. Due to the complexity of the hydrologic cycle its interaction with socioeconomic and ecological systems in a basin, using numerical model technologies to assist managers in understanding risks and developing water management alternatives greatly adds to the ability to develop and implement water management decisions. Water resources software (WRS) such as hydrologic, hydraulic, hydro-geologic, and water quality simulation and optimization model provide a means to quantitatively test and evaluate the concepts and management strategies addressing water resource issues. Specifically, WRS supports water resource management in the following manner:

- Illustrating the fundamental function and operation of systems.
- Identifying and displaying data availability and deficiencies.
- Identifying and quantifying the functional and operational limitations in systems (what is the problem).
- Determining the optimal design for systems.
- Providing water managers, a means of testing design, policy, and management strategies prior to implementation; and
- Communicating results for better understanding of water managers, interested stakeholders, and the public.

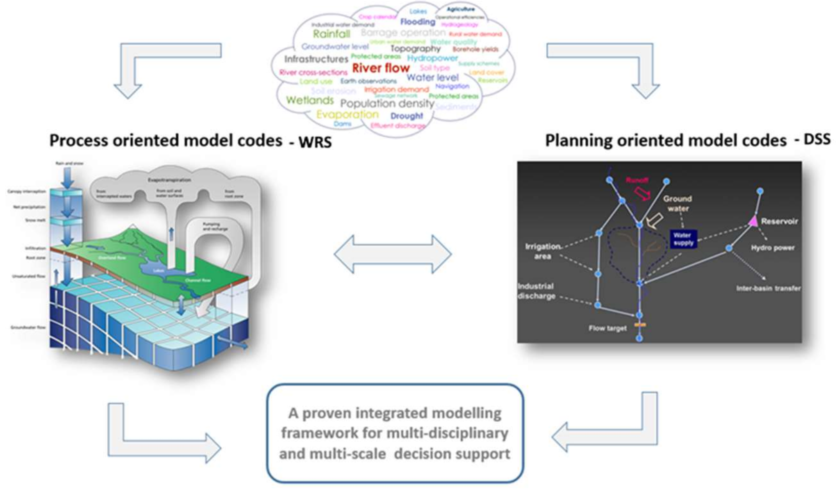


Figure 1: Water resource software connectivity with Decision support system

Thus, the use of WRS for developing decision support systems to understand the systems, organize data, predict future conditions, and communicate information become a powerful tool when managing water resources as shown in (Figure 1). Important elements of effective water resource management include the ability to address specific water resource issues, provide a relevant representation of the systems being evaluated, output simulation results related to key indicators in management decisions, and be capable of evaluating a range of decisions (from simple to complex). The desirable attributes for decision support system include the organization of data used in evaluating alternatives; a flexible structure to accommodate evolution of decisions, issues, data, scenarios, and model; and production of reliable and transparent output. Furthermore, the output should be linked to relevant indicators used in evaluating policies and decisions that, directly or indirectly, affect water resources in a basin. This document provides an overview of Climate Change Decision Support System (CC-DSS) developed with the same concept using MIKE HYDRO Basin, a water allocation model and can be applied to water management issues and help water managers in making more informed decisions for short term and long-term planning.

Water Resources in Madhya Pradesh

Madhya Pradesh state is rich in water resources. Centrality and topography of the state results in rivers originating from within the state but draining out into the neighbouring states. Ganga, Godavari, Tapti, Narmada and Mahi are the major river basins fed within the state. The State is further divided in to ten river sub basins. These are: 1) Chambal 2) Sindh 3) Betwa 4) Ken 5) Tons (Tamsa) 6) Son 7) Narmada 8) Wainganga 9) Tapti and 10) Mahi shown in (Figure 2).

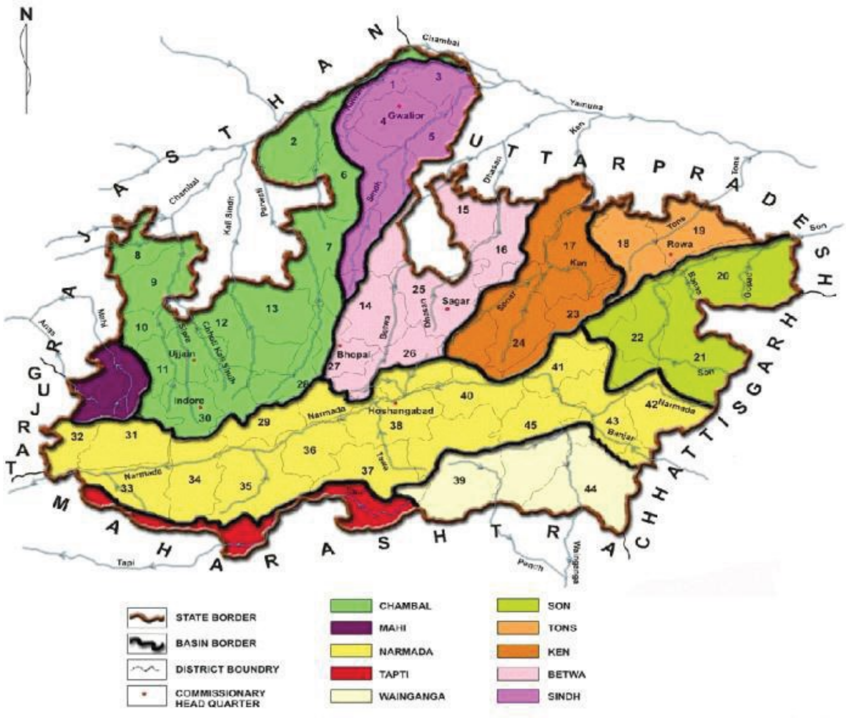


Figure 2: River Basins of Madhya Pradesh

The northern part of the state drains largely into the Ganga basin and the southern part into the Godavari and Tapti (Tapi) system. The Narmada, Tapi and Mahi rivers flow from east to west. The Vindhyas forms the southern boundary of the Ganga Basin, with the western part of the basin draining into the Yamuna and the eastern part directly into the Ganga itself. All the rivers, which drain into the Ganga basin flow from south to north, with the Chambal, Shipra, Kali Sindh, Parbati, Kuno, Sind, Betwa, Dhasan and Ken rivers being the main tributaries of the Yamuna, joining the Ganga. While Tons and Son which originate in the state directly join the Ganga. The Son is of great significance in that it is the largest tributary going into the Ganga from the south bank and arising out of the hills of Madhya Pradesh rather than from the Himalayas.

Importance of storage structures in water resources management

Sustainable management of a river as a resource requires that water is delivered at the time of need for human use and that the supply is reliable. At the same time, water should be available for the survival of the riverine ecosystems. Dams are constructed across valleys or rivers to store, regulate and divert water for various purposes such as agricultural production, hydropower generation, human and industrial use and flood peak attenuation. Most dams serve multiple purposes. Large areas along the river stream are submerged by the reservoir created behind the dam. Instream regulating devices, such as weirs and locks, result in areas of permanent inundation within the main channel, thereby negating the normal ecological functions associated with flood events.

Flood control dams store all or portions of the flood waters in the reservoir, particularly during peak floods, and then release the water slowly. Typically, the principal use of such dams is to store a portion of the flood volume, to delay and attenuate flood peaks downstream. Space within a reservoir is generally reserved to store impending floods. Based on hydrological forecasts, the reservoir is regulated in a way to minimize the chances of coincident peaks from floods in different tributaries synchronizing in the main stem of the river downstream. Small to medium floods generated from the catchment are fully captured by the reservoirs. However, extreme flood events are only attenuated partially and their transformation downstream is delayed. The extent of attenuation depends on the available storage capacity vis-à-vis the magnitude of the flood event. The main performance parameter in assessing the flood control benefits of a reservoir is, therefore, the extent of the flood peak reduction during extreme events.

Many dams have multiple purposes and flood management may be required only for a few days or weeks in any particular year. Potential conflicts between flood management objectives (where storage space in the reservoir is required) and hydropower and irrigation (where it is desirable to keep the storage capacity as filled as possible) make it difficult to operate a multiple purpose reservoir. While allocating water for various uses, the need to maintain environmental flows should also be addressed.

There are 758 dams on various rivers in Madhya Pradesh. The major Hydro Power Stations in Madhya Pradesh are listed below:

1. Bansagar Tons HE projects (River Sone)
2. Indirasagar HE project (NHDC) (River Narmada)
3. Omkareshwar HE project (NHDC) (River Narmada)
4. Madikheda HE project (River Sindh)
5. Bargi HE project (River Narmada)

6. Pench HE Project (Joint venture of MP & Maharashtra) (River Pench)
7. Rajghat, HE projects (Joint venture of MP & UP) (River Bewas, Ken system)
8. Maheshwar, HE projects (Under Construction)- Under Private sector (River Narmada)
9. Tawa HE Project (Under private sector) (River Narmada)
10. Birsinghpur HE project (River Johilla, Sone system)

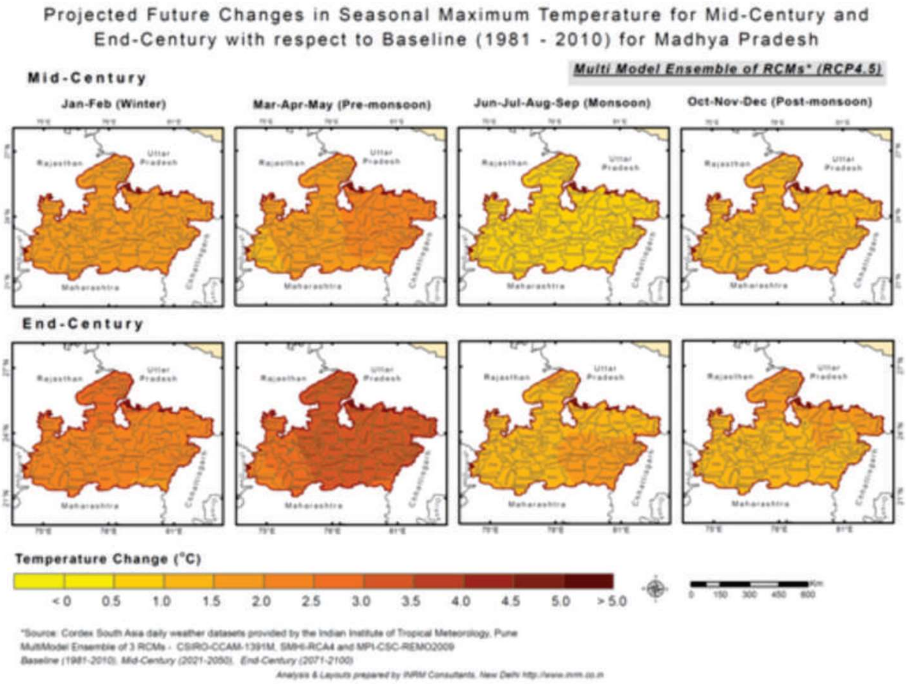
Climate change impact on water resources in Madhya Pradesh

“Climate change has the potential to affect fundamental drivers of hydrological cycle, and consequently may have a large impact on the water resources. This in turn might affect society in many ways and particularly the sectors fully dependent on water. Climate changes will affect not only the state of resources but also the ways and magnitude of consumption. Potential water resources management sector impacts are briefly summarized as follows ([4] Sharma and Gosain, 2010)

1. Available water resources for municipal, industrial, and agricultural use, navigation support, hydropower and environmental flows is a significant concern. Potential climate change impacts affecting water availability include changes in precipitation amount, intensity, and timing, changes in evapotranspiration.
2. Water demand for irrigation may increase as transpiration increases in response to higher temperatures.
3. Water quality is impacted by changing precipitation and temperature resulting from climate change. Changes in water resources may affect chemical composition of water in rivers and lakes.
4. Storm water and wastewater infrastructure may need to include climate change effects in their design and evaluation to improve performance under changing water availability, water demand and water quality conditions.
5. New flood risk reduction structures required to prevent inundation, because of more frequent and severe flooding. Reservoir water control plans may need to be adjusted to reflect new flood regimes.
6. Drought results when precipitation is significantly below normal, causing serious hydrological imbalances that adversely affect land resource production system.
7. Hydropower generation will be affected by changes in water resources where impacts have already been reported. Hydropower production at facilities that are operated to meet multiple objectives of flood risk reduction, irrigation, domestic and industrial water supply, flow augmentation and water quality may be especially vulnerable to climate change.

To work out the impact of climate change on the water resources of Madhya Pradesh, it is important to understand the change in temperature and rainfall. Change in precipitation and temperature in 2030s and end of the century 2080s have been derived with respect to 1970s (1961-1990) ([6]Patwardhan, S., Kulkarni, A. & Rao, K.K. (2018).

Temperature: The average surface daily maximum temperatures, in the period 2030s is projected to rise by 1.8-2.0°C throughout Madhya Pradesh and the daily minimum temperature is projected to rise between 2.0°C to 2.4°C during the same period; the eastern half of the state experiencing more warming than the western half. By 2080s, the maximum temperature is projected to rise between 3.44° C to 4.44° C with northern region experiencing warmer temperatures. The minimum temperatures are likely to rise by more than 4.4° C all over Madhya Pradesh. Project future changes in seasonal maximum temperature with respect to baseline shown in (Figure 3)


Projected Future Changes in Seasonal Maximum Temperature for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Madhya Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)
Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

Figure 3: Projected future change in seasonal maximum temperature

Rainfall: Projections of rainfall in Madhya Pradesh for the period 2021 to 2050 indicates that there is likely to be decrease in winter rainfall as one moves from eastern part of MP to western part of MP.

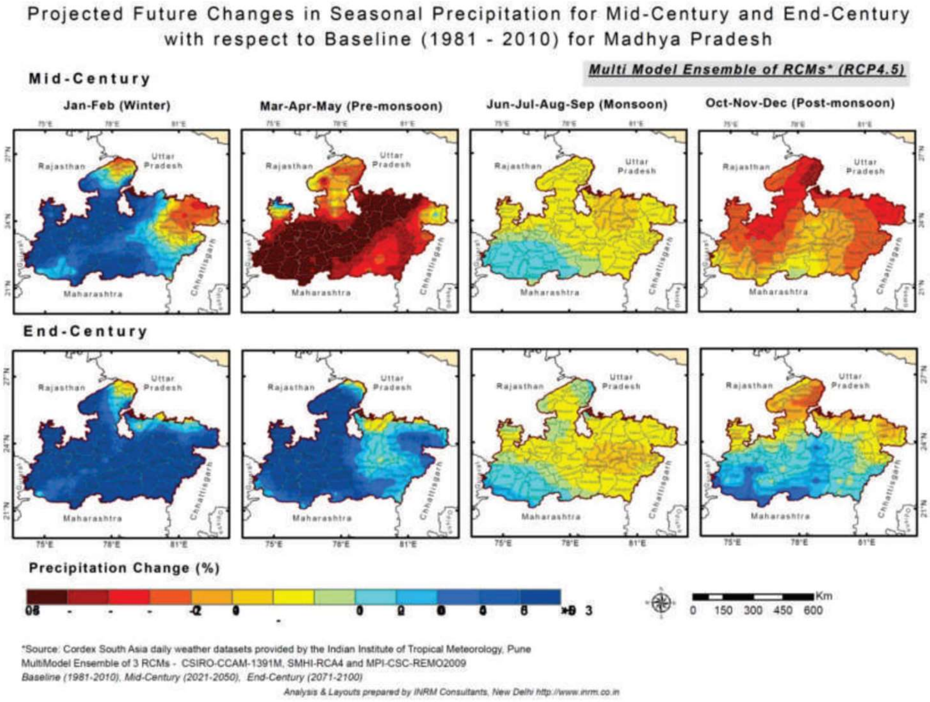


Figure 4: Projected future change in seasonal maximum precipitation

In pre-monsoon period, the rainfall is increasing only in the Southern part of MP, with decrease in rain fall in all other parts. In the Monsoon period, there is an increase in rainfall all over MP (the increase being 1.25 times the rainfall observed in the current climate), and with no change in the Morena, Shivpuri, Bhind, Gwalior area. During post monsoon period, the western end of MP is likely to face decrease in rain fall, with no change or little increase in rainfall in most other parts of the state. In 2100 there is an overall increase in rain fall with southern states likely to receive more rain fall than the northern states. The increase in rainfall during the post monsoon and pre monsoon periods are projected to be more than the increase in rain falls projected for the monsoon period. Project future changes in seasonal maximum precipitation with respect to baseline shown in (Figure 4)

Introduction to CC-DSS and its role in water resources management in Madhya Pradesh

Adaptation Planning and decision making must be based on a solid knowledge base of the impact and climate change, including the physical, socio-economic, and environmental impacts and on the appropriate measures to reduce or minimize these impacts. The combination of climate change and Hydrological modelling can address many of these issues. Thus, there is a need for decision support tools to mainstream Climate Change into Water Resource Management and perhaps more importantly to communicate amongst decision makers, stakeholders and the public, the implications of climate change and climate adaptation measures. In addition, the need for such decision support system has arisen as water resource policies, decisions and related research are a data-driven process. Most importantly at present the data-driven decision making doesn’t include and integrate climate change concerns into it. In addition, currently there is a lack of consistency, compatibility, and comprehensiveness in data structures, due to the complexity in compilation of water resources related data, climate data which is attributable to the variety of data types and multiplicity of data sources. The data which come from a variety of sources must be integrated in a way that satisfies the needs of water resource planning, modelling, evaluation, and policymaking from a climate change perspective. With evolving requirements and expectations, newer issues surface that need to be studied, researched, and integrated in decision making.

The CC-DSS is to enhance the decision-making capabilities of the Madhya Pradesh Water Resource Department and other related stakeholders through scientific analysis of the spatial and non-spatial data for improved water resource management from a climate change perspective. The CC-DSS can help in identifying problem areas and identifying relevant adaptation options for meaningful policy formulation, planning and implementation. The CC-DSS is based on the various model interactions between climatic and hydrological parameters and inform decision makers on sustainable management strategies for water resources in the state. CC-DSS has the following features shown in (Figure 5)

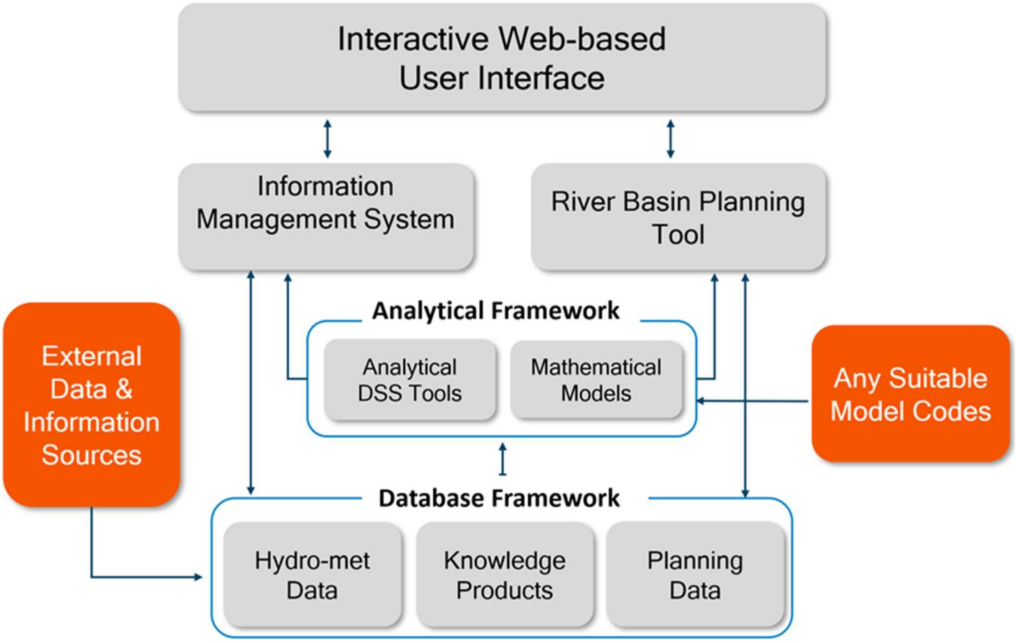


Figure 5: CC-DSS framework and various components

- An Information / Knowledge Database, populated with temporal and spatial data / information and knowledge products describing the basins.
- An embedded modular mathematical modelling framework with a range of accepted simulation models, which in combination can simulate complex water-related issues on required temporal and spatial scales.
- Analytical CC-DSS tools for supporting impact assessment against indicators; multi-criteria analyses; uncertainty analyses and comparison of scenarios.

- Interactive web-based dashboards for access and operation by professionals and stakeholders to be informed and receive relevant knowledge products according to designated access rights; and
- The CC-DSS supports interactive planning across multiple temporal and geo-spatial scales A sustainable, flexible, and expandable DSS framework to cater for innovative technologies and other basins as required.

Benefits to the agency from this CC-DSS

This climate change decision support system is beneficial to the Water Resources Department for the planning and management of water resources. It will help the Department to reduce the risk of climate change and provide the guidance for the planning of water resources.

- **Crop water planning:** It will determine allocations for the full irrigation and deficit irrigation modelled under each weather condition. This ensures optimum water availability for all weather conditions to maintain highest possible total farm income even under deficit irrigation.
- **Adaptation to Flood/Drought Situation:** Through simulation of climate and hydrology of the reservoir, CC-DSS will help the department to plan much in advance for maintaining the water balance of the reservoir in water deficit and water surplus periods in the future.
- **Adaptation for climate change in the Reservoir Basin:** Based on the inferences of the water balance components under climate change scenarios from the CC-DSS, departments can implement relevant climate change adaptation strategies (e.g., use of Drip/Sprinkler Irrigation to increase the water use efficiency, Artificial Groundwater recharge etc.) in the command area
- **Planning of Catchment:** CC-DSS will be benefited in command area and in catchment area. MPWRD can plan check dams, rainwater harvesting structures in catchment area and analyses their effect on reservoir.

Modelling needs and options in the CC-DSS

Purpose of the Modelling

The objective of the mathematical water resources Modelling Framework of the CC-DSS is to provide a scientific-based analytical toolset to represent the hydrological and water resources processes and relevant basin characteristics in the basin planning.

The modelling framework is fundamental for supporting the water resources assessments, creating the river basin profiles, and being able to carry out river basin planning scenario analyses.

Water resources models are necessary for providing a consistent scenario analysis based on large amounts of data and information to best represent the river basin characteristics and be able to:

- Match water demands of the existing water users and projected developments with the available resources in time and space and return the results in the form of time series of consumption, supply deficits and generated hydropower,
- Predict impacts of the projected developments on other parts of the system such as reduced river flows caused by increased groundwater extraction or new flow diversions, upstream

inundation by new reservoirs, higher low flows, changed flood frequencies or morphological changes due to reservoir regulation etc.,

- Pinpoint sub-areas of the basin which will be positively, and/or which will be negatively affected by a given scenario and through this improve the assessment for the population groups, environmental areas or cultural heritage likely to be affected,
- Provide design criteria for hydraulic structures (dams, barrages or flood and erosion protection structures), and assess siltation rates for assessment of reservoir lifetimes,
- Quantify impacts from future changes in climate and land use on the water availability and water related risks in the basin and

The Concept Design

The mathematical modelling framework consist of a set of models, which have been established to simulate historical and future conditions for basins and be able to address the relevant planning and management issues in the basins. The outputs generated by the modelling framework are further processed in the CC-DSS to produce useful assessment and planning information, e.g., defined indicators. As it is illustrated in (Figure 6)Figure 5, the modelling framework, together with other CC-DSS tools, constitute the analytical toolset of the CC-DSS.

A schematic representation of the modelling framework is presented inFigure 6. It shows that the modelling framework basically consists of two types of model codes:

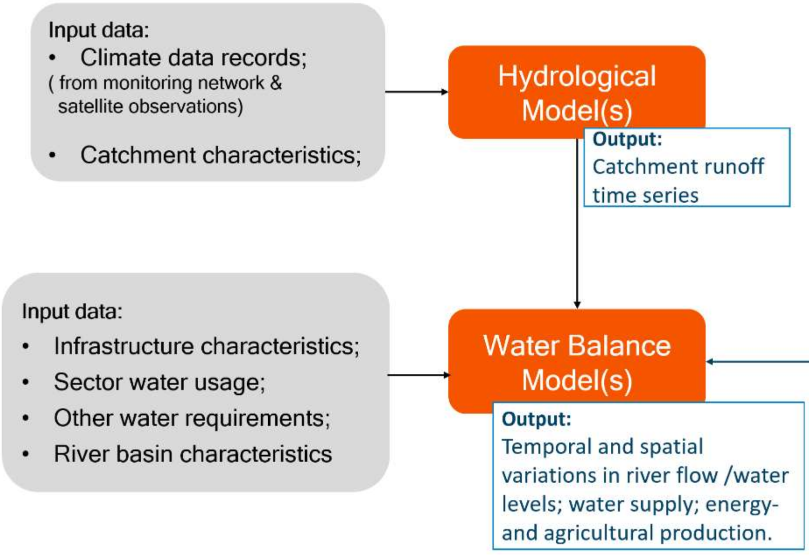


Figure 6: Modelling framework

Modelling Framework

In contrast to other parts of the CC-DSS, the modelling framework is not an IT development process, but rather a modelling exercise carried out by water resources modellers. The model development process consists of setting up the specific simulation models that represent the river basins. This consists of several tasks as illustrated inFigure 7.

Figure 7: Workflow of the developing the modelling framework development of the DSS

The above (shown in Figure 7) workflow is based on an understanding and definition of planning and management issues (needs) in the basins, which must be addressed by the CC-DSS. The model framework must be able to provide the required data and information to be post-processed into useful planning information, e.g., by defined indicators values.

Model formulation: Defining the conceptual model setup describing how the basin and the hydrological and water resources processes are presented in the model code. This will also define what data is required for representing the basin processes.

Data collection and processing: Assembling all required data and feed these into the model code to construct numerical model. The required data concerns a long array of input data (e.g., climate and river flows) and parametric data describing the characteristics of the basins (e.g., topography, river cross-sections, soil and vegetation pattern, land use, demography etc.), infrastructures (including the operational data), agricultural schemes (e.g., fields and crop management) and other important features.

Calibration and Validation: It is the process of tailoring the model parameters to ensure that the model appropriately represents the basin conditions. This is carried out by comparing time series of model simulation output against observed /gauged variables. This applied mainly to river flow but can also include other variables such as water levels in lakes, reservoirs and rivers. Other model output, which may be more difficult to test includes groundwater levels, soil water conditions, actual water usages etc. Discharge observed data from the gauging stations can be added to Source model to compare to modelled data for the calibration.

Simulations: It is the process of using the calibrated model to simulate identified scenarios of future conditions. The simulations results will be time series of conditions in the basins, e.g., river flow, reservoir water levels and releases etc. These time series will subsequently be post-processed to create appropriate indicator estimations.

In terms of modelling framework, CC-DSS provide advance functionalities for model development and scenario generation. It allows users to develop MIKE HYDRO Basin (MHB)model for the selected area using desktop-based modelling tool and upload in CC-DSS or develop complete model using web-based CC-DSS.

Advantages of choosing MIKE HYDRO Basin for the CC-DSS

MIKE HYDRO Basin is a multipurpose, map-based decision support tool for integrated water resources analysis, planning and management of river basins. MIKE HYDRO Basin is designed for analysing water sharing issues at international, national or local river basin scale. It’s a comprehensive yet simple product for investigating options and making reliable decisions.

- MIKE HYDRO Basin provides an easy-to-use, map-based modelling framework for water resources management and planning in river basins.
- It includes all model features required in most projects for efficient and accurate water resources modelling.
- Mature and reliable river basin simulations capability obtained from more than a decade long record of project applications.
- Comprehensive and effective model components for IWRM applications and decision support systems.
- Water resource planning without limits.

MIKE HYDRO Basin is a commercial software developed by DHI, Denmark. To run MIKE HYDRO Basin on desktop user will need a hardware or internet license from DHI.

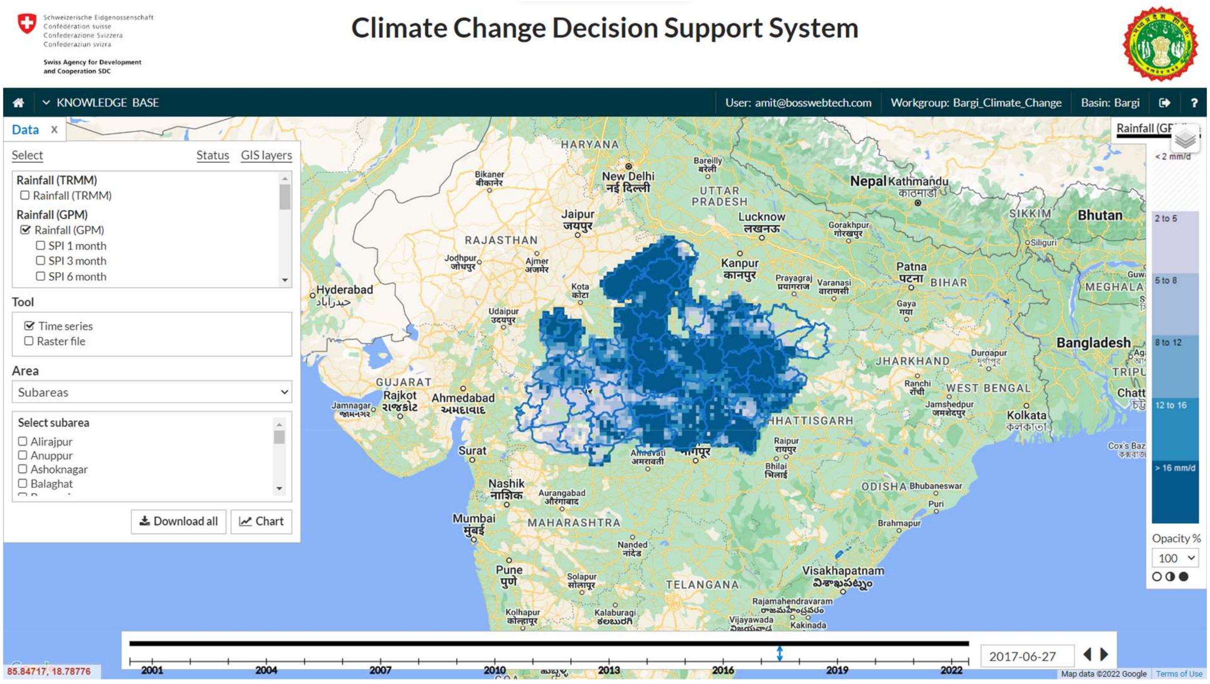
Web-based Modelling

Desktop software will likely continue to play a key role in the model development and visualization for expert users, and developers familiar with the MHB model. However, there are limitations to how useful these tools can be for stakeholders without technical training in the modelling, but for whom data and information from the models is a vital part of their decision process. Operating system compatibility, licensing costs, and software versioning issues can often inhibit users from having access to the newest or most robust technologies. In addition, the ‘local’ nature of these technologies causes issues when sharing data across disciplines or organizations is required. The technical expertise needed to create a custom model using these desktop applications requires computational and storage resources locally to run the model and store all the outputs. This severely limits the potential for data sharing and collaboration between users unless they are all looking at the same computer screen. On the other hand, the open nature of the web technologies facilitates a much higher level of stakeholder collaboration and data sharing, than the technically exclusive desktop applications.

Key functionalities of web-based modelling

Accessing MHB climate inputs

Surface water planning module has connectivity with knowledgebase. Climate data can be used directly from knowledgebase. It gives users access to the knowledgebase (Figure 8) data processing functions, the purpose of which is to create MHB model compatible climate input files, within an easy-to-use interface.



Climate Change Decision Support System

KNOWLEDGE BASE — User: amit@bosswebtech.com — Workgroup: Bargi_Climate_Change — Basin: Bargi

Data

Rainfall (TRMM)
☐ Rainfall (TRMM)
Rainfall (GPM)
☑ Rainfall (GPM)
☐ SPI 1 month
☐ SPI 3 month
☐ SPI 6 month

Tool
☑ Time series
☐ Raster file

Area: Subareas

Select subarea
☐ Alirajpur
☐ Anuppur
☐ Ashoknagar
☐ Balaghat

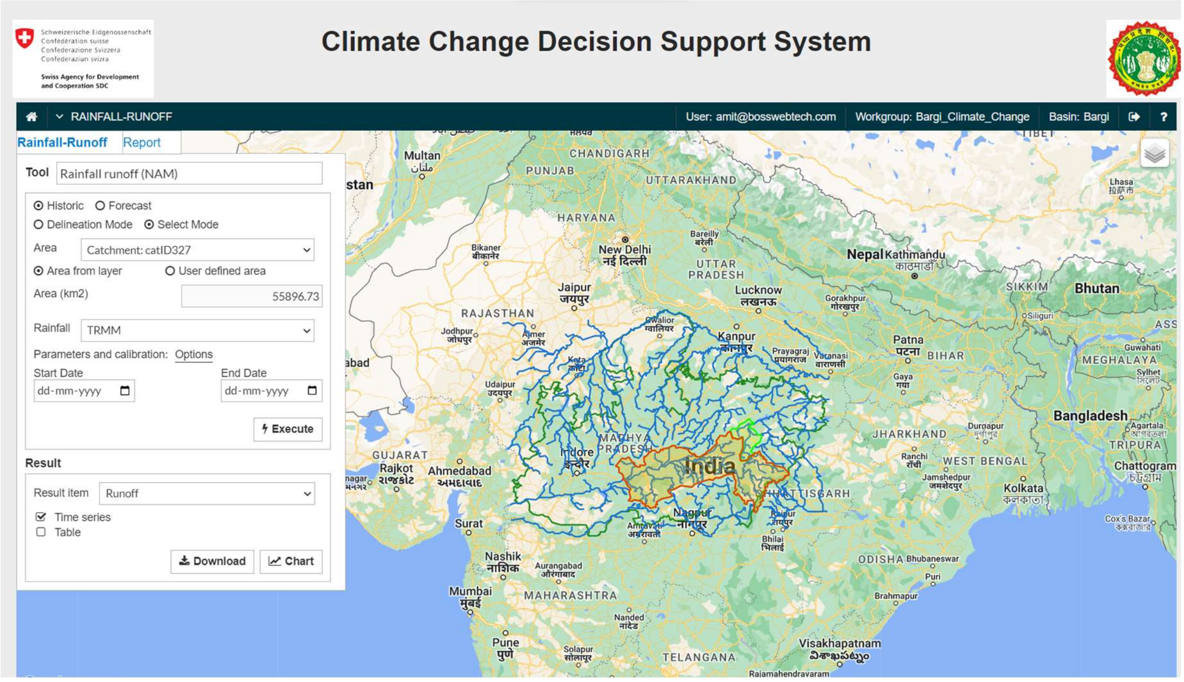
Date: 2017-06-27

Opacity %: 100

Figure 8: Knowledgebase for all climate data

Catchment Delineation on the selected point

CC-DSS has rainfall runoff module which gives the functionality to delineate catchment (Figure 9) on the selected point of interest at any flow drainage path. User can select any satellite rainfall from the given options define period and simulate runoff for the delineated catchment. CC-DSS also provide functionality of autocalibration for NAM parameters based on observed discharge.



Climate Change Decision Support System

RAINFALL-RUNOFF — User: amit@bosswebtech.com — Workgroup: Bargi_Climate_Change — Basin: Bargi

Rainfall-Runoff | Report

Tool: Rainfall runoff (NAM)

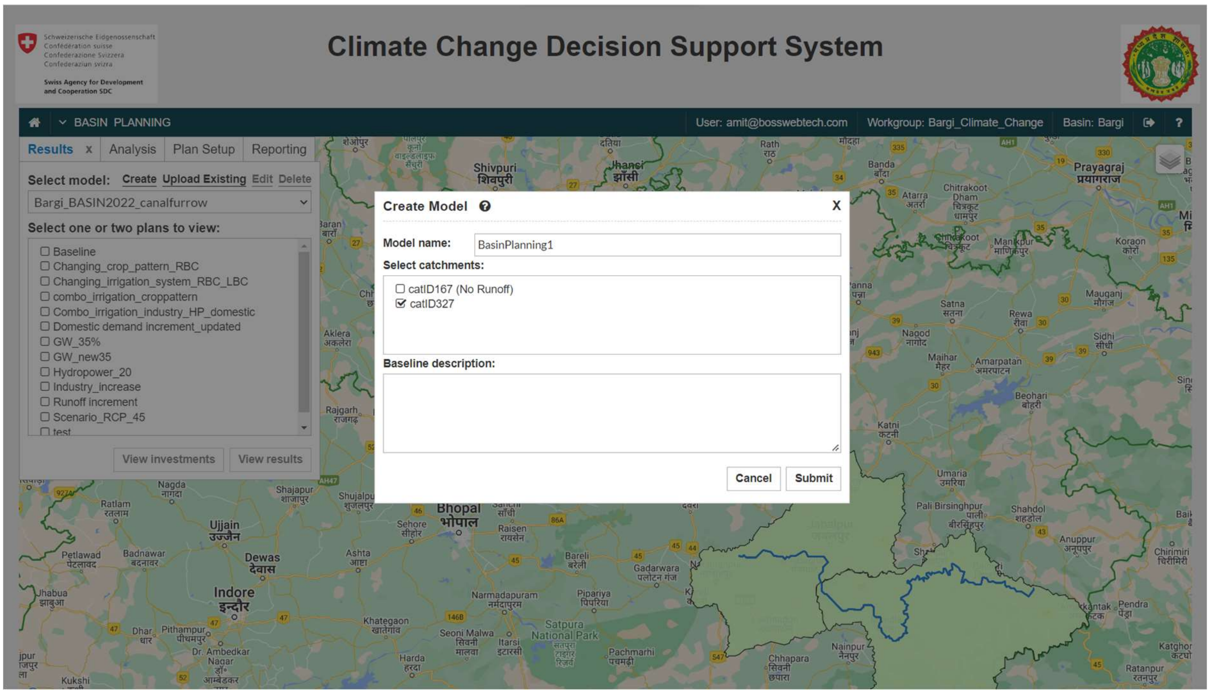
● Historic ○ Forecast
○ Delineation Mode ● Select Mode

Area: Catchment: catID327
● Area from layer ○ User defined area
Area (km2): 55896.73
Rainfall: TRMM
Parameters and calibration: Options
Start Date: dd-mm-yyyy
End Date: dd-mm-yyyy

Result
Result item: Runoff
☑ Time series
☐ Table

Figure 9: Catchment delineation on the flow drainage

The model development and time-series visualization



Model name: BasinPlanning1

Select catchments:

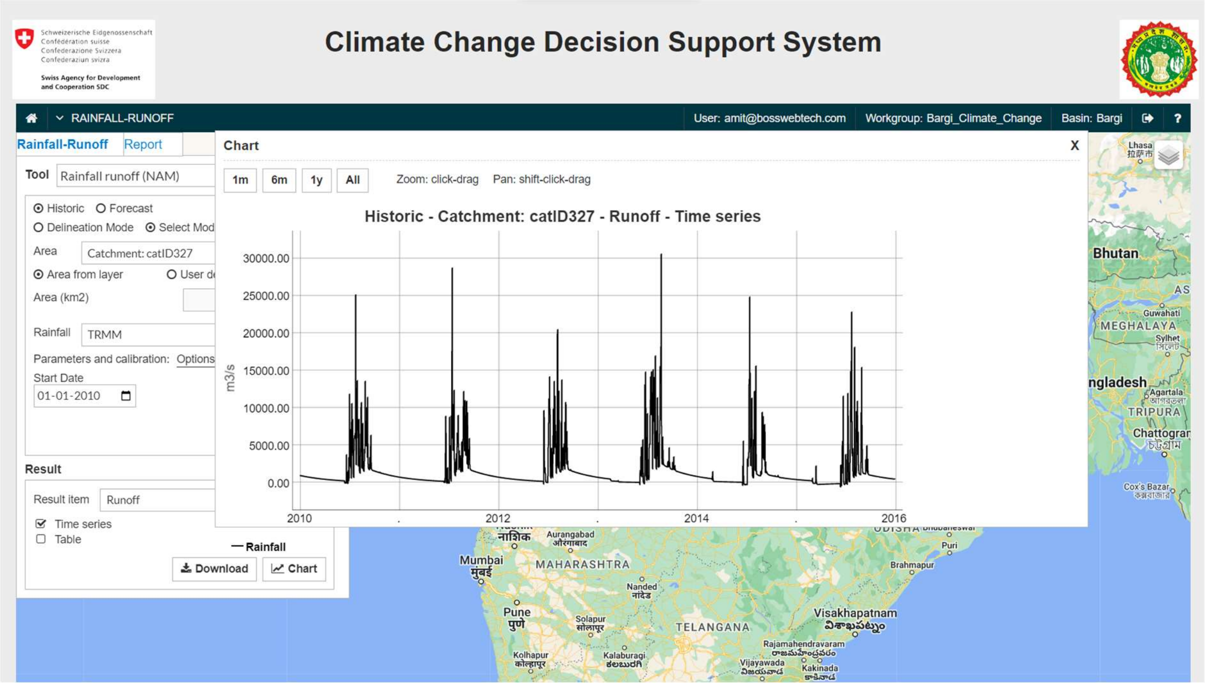
☐ catID167 (No Runoff)

☑ catID327

Baseline description:

Figure 10: Create new model for selected catchment

After catchment delineation and runoff calculation user can create model for selected catchment to start model development (Figure 10). User can define other model objects e.g., reservoir, water supply users, irrigation users, hydropower user and simulate these for the defined period. The CC-DSS supports time series visualization (Figure 11) of variables from the MHB output file.



Tool: Rainfall runoff (NAM)

● Historic ○ Forecast

○ Delineation Mode ● Select Mod

Area: Catchment: catID327

● Area from layer ○ User d

Area (km2)

Rainfall: TRMM

Parameters and calibration: Options

Start Date: 01-01-2010

Result

Result item: Runoff

☑ Time series

☐ Table

Figure 11: Output time series

Need and provision for up scaling of the CC-DSS

The CC-DSS enables the state government to assess the water availability situation in advance by running the simulations of the scenarios and adaptation measures. Scenario analyses using CC-DSS helped the MP-WRD to provide the guidance for the overall planning of water resources in Samrat Ashok Sagar (SAS) Reservoir. The CC-DSS developed in the first phase was capable to assist in taking decision on meeting future water demands based on optimal use of water storage. It also allows decision makers to assess the impact of potential adaptation options under various scenarios and enable WRD to compare and evaluate various climate change adaptation options. However, SAS is an irrigation and water storage reservoir and for the CC-DSS to be widely applicable it is important that it can simulate the operations of a multipurpose dam which combines storing and supplying water for irrigation, industry and drinking with other uses such as flood control, power generation, and navigation. In MP, there are a total of 1440 large dams as per record (http://www.mpwrd.gov.in) In addition to supplying water for irrigation, the Department provides water to various industries in addition to providing drinking water supply to the metropolitan cities, major towns and villages in the vicinity of the projects.

Under the current assignment, the CC-DSS is to be upgraded to enable its application for multi-purpose dam projects of MP with water usages for irrigation, drinking, and industrial purposes and showcase climate change mainstreaming into Integrated Water Resource Management (IWRM). The multiplicity of demand of water for various purposes, viz, agriculture (irrigation), hydroelectric power, industry, domestic use (municipal water), and industrial use needs optimal utilization of available water in multipurpose reservoirs. The CC-DSS should include optimizing routines and allow trade-offs between different sectors. The trade-off should be based on prevailing government policy, current water availability and future changes in the context of climate change, considering future land use pattern, population, industrial growth, reclamation and reuse of treated wastewater, and sectoral water demands.

CHAPTER 2: DATA COLLECTION &DEVELOPMENT OF MIKE HYDRO BASIN MODEL

The entire model development process can be divided into 2 major parts-

1. Data need assessment, data collection & processing: which also involves, purpose identification, stakeholder identification and consultation. This also includes identifying sources of data, field visits, departmental discussions, downloads, and analysis.
2. Model setup and simulations: This process involves providing input to MIKE HYDRO BASIN, validating model, and running simulations to get results.

Data need assessment, collection, and processing

Stakeholder identification

Ideally, this action is also done in initial stage s of the project, but the identified stakeholders are generally decision makers and their one level sub-officers in department and doesn't represent the entire hierarchy up to filed officers / Water user associations / farmers which are unavoidable part of implementation stage. The key stakeholders are also the people who have crucial data with them, and thus, identification is the first step.

Data need assessment

The data needed to accomplish the objective of the task is to be listed and mapped. This can be done by listing requirements by the tools and methods adopted for the study. In this case, for CC-DSS, there are two key components - Model development and Knowledgebase.

The model used in this system is MIKE HYDRO BASIN. This propriety software package has specific data requirements to be able to complete model development activity correctly and successfully. The input quality and resolution of the data will change the output quality.

The other data platform that CC-DSS provides is knowledgebase which allows access to global satellite datasets. There are numerous satellite derived products available on global platforms which are created for different applications. The scripts are written at the backend to download the products in readable raster format and to present in spatial and non-spatial form on user interface map area.

The products chosen are to be selected on basis of model development requirement and allied information helpful in making inferences or arriving at decisions.

Data source identification

National centralized data resources

Many organizations provide national data sources for Water resources and allied themes. Most of these datasets are accessible on the Internet through web portals. India-WRIS (Water Resources Information system), WIMS (Water Information Management System), NDAMS (National Disaster & Management System), Bhuvan portal etc. National data sources are useful because they provide national and often state level information from credible sources. You have the flexibility of using pre-defined query systems or downloading data directly for analysis. There may be a fee for downloaded data, but the query systems are generally provided at no cost to the user. Data are de-identified already, so confidentiality issues are not a major concern.

State and Local Data Resources

Data available at the state and local level vary. Many states require mandated reporting of state-wide data (e.g., Water availability, Land use, Allocations, distribution, distribution network, storage operations etc.). Individual-level data may be available for analysis; however, there may be a fee to obtain the data. There may also be restrictions placed on how the data are used, and strict confidentiality rules must be followed to protect individual information. Many agencies/organizations may have Web-based data query or database systems available as well. This allows easy access to information; however, only aggregate-level data is generally available.

Use research data

There are many sources of valuable data on research platforms as well. Be sure to take inventory of what's already available before starting to design a survey or sampling scheme to get your own data. Even if you don't find exactly the data you need, you will probably find resources for guiding your work. Look for reputable websites and local, state, or federal organizations which may have data related to your project already available to you.

Collecting new data

If you find that you need to collect new data to meet your project objectives, there are several things to think about before you get started:

- What is your population of interest?
- What information will you gather or what questions will you ask from your population?
- What variables/data fields do you need?
- How will each variable/data field be defined?
- How will this information be stored?
- How will this information be analysed?
- What reports will you want to generate with this information?
- What tables, charts, and graphs will be useful in presenting the information?

Remember, the most important thing to do before collecting data is to think through exactly what you will need to meet your objectives

Data Collection

Before collecting any data, it is useful to stop and assess the situation, to make sure that money and time is not wasted. The basic principles of data collection include keeping things as simple as possible; planning the entire process of data selection, collection, analysis and use from the start; and ensuring that any data collected is valid, reliable, and credible. It is also important that ethical issues are considered. There are 4 prime principles to be followed for Data collection

Simple Approach

In any project, program or organization, basic monitoring needs to be carried out. At project level there is often little difference between monitoring and project management. For example, project monitoring may involve simple processes such as conducting regular meetings, reviewing documents or records, discussing issues informally with staff, etc. In these cases, there is no need to engage in complex methodologies of data collection and analysis. Sometimes, more complex methodologies need to be adopted. For example, if carrying out an evaluation of a large program it may be necessary to implement a formal methodology, such as a Randomized Control Trial or Qualitative Comparative Analysis, which requires specialist skills. But it is important not to undertake any data collection or analysis methodology that is more complex or expensive than is necessary.

Planning the whole process

It is always important to know why information is needed before collecting it. A common mistake is to collect information before working out how it will be analysed or used. Sometimes, this means that the information cannot be properly analysed and used because it has not been collected in the right way, at the right time or in the right place. Some basic questions to ask before collecting any information are as follows.

- What information do you intend to gather?
- Where will you get this information, and how will it be collected?
- Why is the information needed, and what questions is the information going to answer?
- Who will use the information once collected?
- How will the information be analysed?
- How will any analyses be used?

If the answers to any of these questions are unknown or uncertain then it is important to find out the answers before going any further. Huge amounts of time, money and energy are wasted every year because information is collected that is never analysed or used.

Ensuring reliability, credibility, and validity

As far as possible, all information collected and used in CC-DSS should be reliable, valid and credible.

- Data is considered reliable when there is confidence that similar results would be obtained if the data collection exercise was repeated within the same period, using the same methods. If data is reliable, it means it is not too heavily dependent on the skills and honesty of the person collecting it.
- Data is valid when it measures or describes what it set out to measure or describe. Data is not valid if it is misused. For example, information collected on attendance at a training session would be valid if used to show that the training session was held, and people turned up. But information on attendance would not be valid if used to claim that participants had increased their awareness or understanding of an issue. Another common mistake is to get information from just one or two stakeholders and then to use this information as if it represents the views of a much wider population.
- Data is considered credible when it is believable and is consistent with a 'common sense' view of the world. But just because data is not credible does not mean it is inaccurate. It simply means that it needs further checking.

  For example, if a small pilot project claimed to have data that showed it had greatly increased the living standards of farmers in a region the data may not be considered credible at first. But further data collection and analysis might confirm the findings and explain why such large changes had occurred. In that case the new data would be considered credible.

Addressing the ethics of data collection

Atypical project or program may be acquiring information from stakeholders on a regular and ongoing basis and would not be expected to describe the purpose of data collection every time. However, there are some fundamental ethical principles that should always be adhered to whenever carrying out any activity. Some of these are described below.

- Avoidance of harm is a key principle whenever data is collected. People should not be put in a position where they might suffer because of the information they provide. Any confidential data, which have secrecy agreements within organization or may pose any threat to security to the system, or authority or nation. Such as discharge through transboundary rivers (chin to India) or similar. Measures should always be taken to mitigate the possibility of harm. If this is not possible then the data should not be collected.
- The benefits and costs to different stakeholders need to be considered. For example, there may seem little harm in getting together a group of farmers to engage in a focus group discussion about farming methods. But in some cases, this might mean taking them away from their fields at harvest time. Where possible, it is important to balance the costs and benefits of data collection activities to the stakeholders themselves, as well as to the organization, program or project.
- Confidentiality needs to be respected. Some people may be willing to express opinions provided they are not quoted, or the information is not used widely. If this is the case, then this needs to be clearly recorded alongside any notes taken. The information should not then be disseminated or used without the consent of the person who supplied the information. However, it is normally acceptable to use the information to shape judgements or come to conclusions.

Data Standardization

Data standardization is the process of bringing data into a uniform format that allows analysts and others to research, analyse, and utilize the data. In statistics, standardization refers to the process of putting different variables on the same scale to compare scores between different types of variables. With more consistent data, it becomes easier, faster, and more cost-efficient to analyse customer behavior, find trends, target, nurture, and convert. It also helps deliver more personalized customer experiences. There are many methods to standardize data, and analysts can do it in many different programs, like Microsoft Excel. Each has different features that can help standardization or even hinder it. These are the basic steps to standardizing data:

Step 1: Conduct a data source audit

Step 2: Define standards for data formats

Step 3: Standardize the format of external data sources

Step 4: Standardize existing data in the database

Step 5: Data quality checking

Step 6: Gap Analysis and filling

Data input in CC-DSS

The data collected is collected from various sources which are listed below –

- National data portals
- State Portals,
- Water user associations
- State Departments – Digital and hardcopy records
- Other research sources

The data received is in various formats, hardcopy reports, digital formats – excel, words, images, maps, emails etc. The end-to-end procedures for input of data must follow below guidelines –

- Data collection
- Data – standardization / Quality Checking / Gap filling
- Data Preparation – In required format of the model used or in formats required at user end

Hydrological model setup

Prior to model setup, it is important to understand the concept forming backbone of the task at hand. The hydrological modelling has evolved in many ways through past decades, and ranges from simplest to complex mathematical formulations to address the objective of the study. The model embedded in CC-DSS is MIKE HYDRO BASIN.

Modelling concept

MIKE HYDRO BASIN works on two approaches here – Rainfall-runoff simulation and water balance approach. A detailed water balance study is carried out for a greater understanding of the basin. The key goal of the water balance study is the analysis of evaporation, precipitation, surface water runoff into the cascade of tanks, infiltration, and outflows to various users, environmental flow, and groundwater recharge. Water balance study is carried out at the basin and sub-basin-scale to estimate supply and demand of water in the basin, where supply can be derived from river, tanks, groundwater, and canals and demand accounts water as the irrigation water demand, the domestic water demand, industrial demand, environmental flow demand, and livestock water demand. Figure 12 shows the concept of a water balance and Figure 13 shows the overall approach of water balance modelling. For analysis, the components are divided into basically three units concerning the catchment, which are input, output, and storage components.

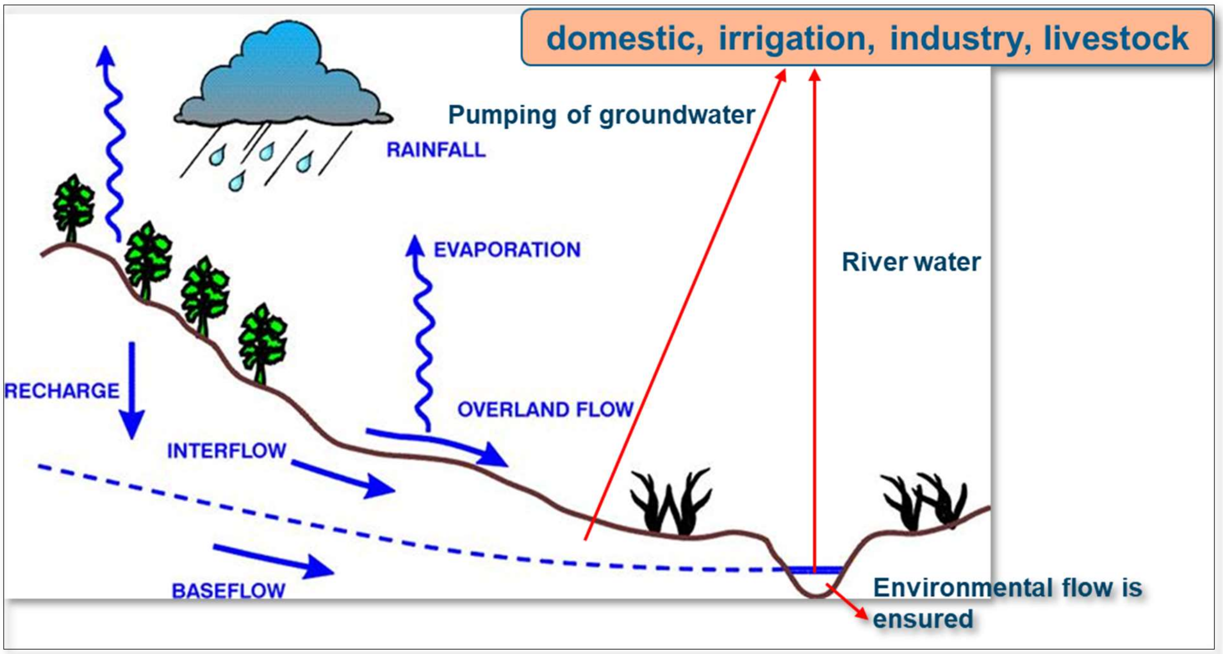


Figure 12: Schematics of Water Balance Concept

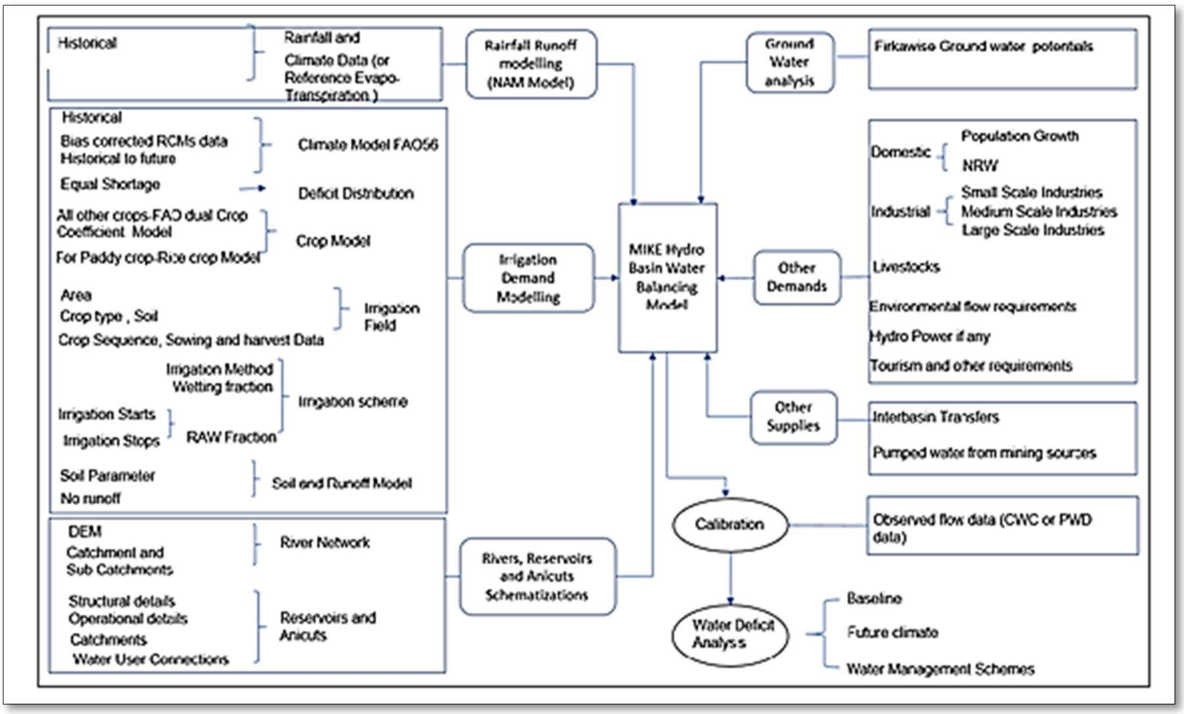


Figure 13: Methodology of Water Balance

MIKE HYDRO BASIN Framework

MIKE HYDRO BASIN operates based on a ‘digitized’ river network established directly on the computer screen. All information regarding the configuration of the flow simulation network, location of water users, reservoirs and intakes and outlets of return flow are also defined by on-screen editing.

Often, several users may want to receive water from the same resource. Within the MIKE HYDRO Basin network model concept, this situation is represented by several users connected to a single supply node. In situations of water shortage, a conflict arises of how to distribute the water available at a supply node among the user nodes that are connected to it. A rule for resolving the distribution problem is required. MIKE BASIN can solve the water distribution problem for two types of priority rules, local and global. Local priority rules imply that the allocation problem is always solved for neighbouring nodes that are connected directly. In a global scheme, in contrast, far-away nodes can matter as well. Global priority is typically used in river basins where users have prior rights, i.e., the right to water is determined by date of establishment. In those basins, upstream users often cannot exploit their geographical position.

In MIKE HYDRO Basin, the global priority algorithm is implemented by a set of rules. Different types of rules can be defined. Rules affect at least the node they are attached to, and possibly a second node, the extraction point of the former. Multiple rules can be associated with a single water user, not necessarily with consecutive priority ranks. For example, a user can have a high-priority rule for a necessary minimum supply, and a low-priority rule for additional supply. It would be perfectly legal to have some medium-priority rules attached to other nodes that also affect flow at that user’s extraction point. For a particular user, multiple rules can refer to either a single extraction point (node on the river) or to different ones. The global priority scheme does not account for delays in flow (routing, groundwater processes).

Coupled Model Setup

MIKE HDYRO BASIN is a coupled model which integrates Rainfall runoff and mass balance approaches through same UI. While it runs on Rainfall-runoff mode, the output of the same module goes as input to mass balance module and further simulations takes place. The model is capable to run independently on these sub modules. Various components and model representation is shown in (Figure 14)

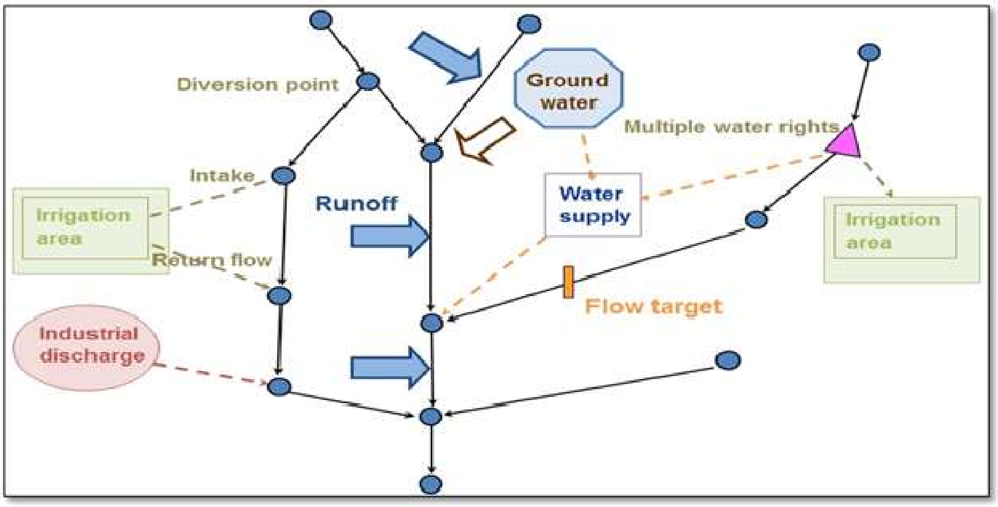


Figure 14: Model representation in MIKE HYDRO Basin

Rainfall Runoff module

Rainfall-runoff modelling can be included in the River model. Inclusion of Rainfall runoff in a simulation requires that one or more Catchments are defined in the River model. Runoff from catchments is calculated from user-defined Catchment characteristics and meteorological data. Following rainfall-runoff models are available:

NAM: A lumped, conceptual rainfall-runoff model, simulating the overland flow, interflow, and base flow components as a function of the moisture contents in four storages.

UHM: The Unit Hydrograph Model includes different loss models (constant, proportional) and the SCS method for estimating storm runoff.

Calibration: The rainfall runoff models are calibrated against collected data in the historical period. The simulation results are compared against measurements using the coefficient of determination (R2) value and graphically analysed for the degree of agreement between simulated and measured values.

Basin simulation module

Basin modules support the delicate balance between water availability and demand by creating large-scale, multi-year simulations. MIKE HYDRO Basin offers the same extensive selection of conceptual hydrological models as MIKE HYDRO River accounting for all main processes and phases of the hydrological cycle. Basin simulation includes the options for calculating a large variety of differ-ent processes and model components taking part in the water consumption and influencing the water balance with a river basin. Basin simulation utilise the calculation engine from DHI's predecessor to MIKE HYDRO for water resources management simulations; MIKE BASIN, and most of the calculation methods for specific modelling features are therefore mature and validated through intensive project applications over a large period of time.

Input data requirements:

Basic input to the model consists of time series data of catchment run-off for each branch. Additional input files define reservoir characteristics and operation rules of each reservoir, meteorological time series, and data pertinent to each water supply or irrigation scheme such as diversion requirements and other information describing return flows. The details of input and possible sources of data are given below-

DEM (Digital elevation Model): This dataset is required to delineate the branches and catchments. The data resolution can vary from sources to sources, but the better spatial resolution would yield in precise delineation. The DEM available from open sources is from program – Shuttle Radar Topographic Mission (SRTM) – is at two resolutions – 90 m and 30 m that is available for free download and is rectified. The other source of DEM is – ASTER, CARTOSAT etc.

Branches – The branches denote the streams or river network. This can be obtained in following ways

1. Delineating from DEM

2. Shapefiles obtained from national/state data portals (India-WRIS, MP WRD, SAC)

3. Digitizing on spatial imagery

Catchments – The catchments are hydrological units. This can be obtained in following ways –

1. Delineating from DEM using MIKE HYDRO BASIN auto tool

2. Shape files obtained from national/state data portals (India-WRIS, MP WRD, SAC)

3. Digitizing on spatial imagery using allied branch network and contour maps

Reservoirs – The data pertaining to Reservoir module is required to model storage and operation.

General data comprises of Elevation area curve (EAC), Flood control time series, Losses and gains from reservoir, characteristic levels. Other set of data input required is operation data of reservoir which includes information on all operation levels, like minimum maximum flows maintained, spill releases etc. Third set of data is users' data – which prominently includes the allocations to users from the reservoirs and their policy guidelines like priority and reduction levels. Various zones of reservoir shown in (Figure 15)

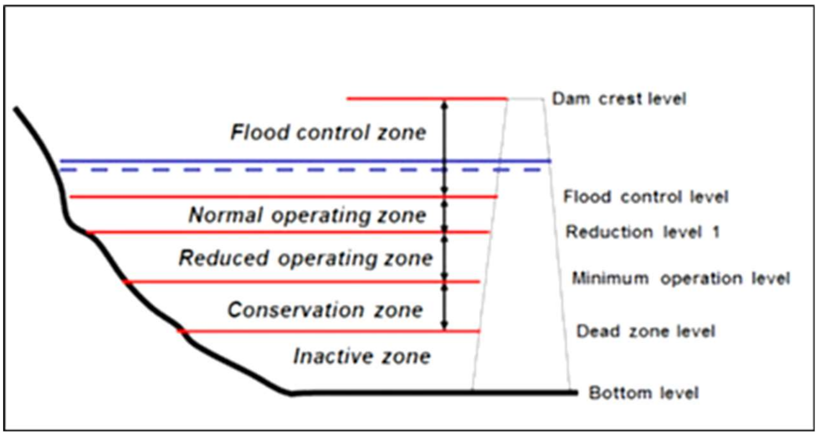


Figure 15: Various zones of reservoir

Hydropower – The Hydropower component input is important to model hydropower components. Since the operation of hydropower user is very different. The data required is about power demands, target powers, installed capacities, power efficiency, losses, head values. This information also is maintained by WRD department of the specific states. Salient features can be obtained from published reports or from data portals.

Irrigation users – This module require specific information on types of crops, crop area sown, type of irrigation, and crop and soil parameters to model crop water demand. The MIKE HYDRO BASIN provides ready to use model equations, which user can opt for. For standard parameters the sources which can referred area – CGIAR, ICAR, FAO, State Agriculture reports, bulletins, state Agriculture department, NRSC land use maps.

Water users – This set of users denotes users like industrial, domestic, livestock, recreational-flows etc. The data is generally maintained by WRD, and daily releases are also maintained by the department. If the data for irrigation user is not available, the same can be created as water user and a water demand can be given as input time series. Various water users shown in (Figure 16)

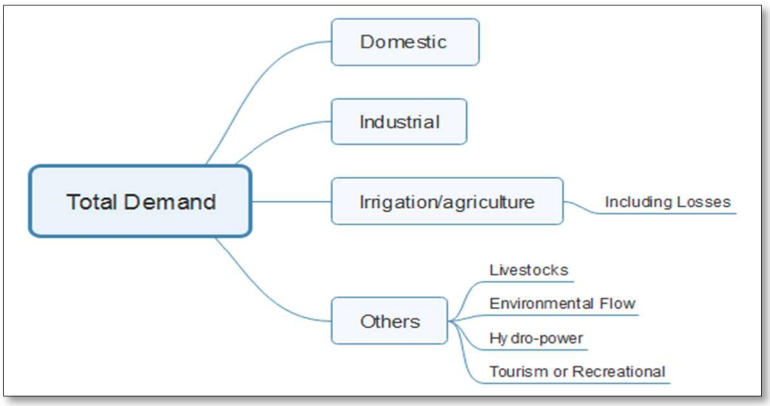


Figure 16: List of water demands

CHAPTER 3: USAGE & UPSCALE OF CC-DSS

Various usages and capabilities of the CC-DSS

The CC-DSS enables the Water Resources Department to assess the impacts of climate change on reservoir system, optimize reservoir water balance and manage water releases for competing demands (irrigation, drinking etc.). In addition, it will help the department to adapt to Drought/Flood situations well in advance through simulation of scenarios and adaptation measures. Therefore, Climate Change DSS will reduce the risks and provide guidance for effective planning of the water resources. Most importantly this intervention envisions to converge with Government initiatives in the present and in the future to mainstream climate change into Integrated Water Resource Management (IWRM), build the capacity of the officials for adaptation planning and to upscale to other sub basins/basins of the State.

Climate Change Decision Support System (CC-DSS) is a web based GIS aided tool for planning and management of multi-purpose dams. It supports online modeling and scenario generations based on climate change adaptions policies.

Figure 17: CC-DSS home page

Usages of CC-DSS

Basin water resources planning

The basin planning application is a modelling and analysis tool available in CC-DSS that can be used to evaluate water resource management plans, including plans that include new infrastructure.

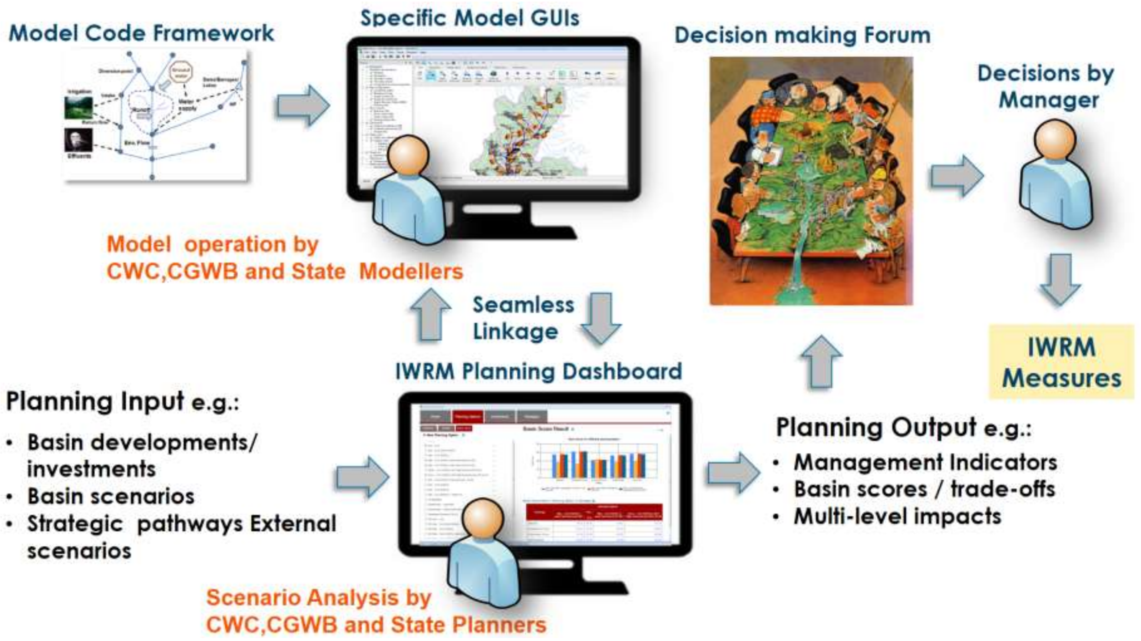


Figure 18: Various steps of basin planning using CC-DSS

Complete flow of basin planning is shown in (Figure 18). Underlying the basin planning application, model can be developed for selected basin/sub basin using the software package MIKE HYDRO Basin. The model simulates rainfall-runoff processes, lakes, reservoirs, water uses (including irrigation), and hydropower. The model can be used to investigate how changes to rainfall and evaporation resulting from climate change may affect water availability and the performance of water infrastructure.

The basin planning application also includes post-processing functionality that can be used to explore the sensitivity of model performance to economic conditions. The functionality includes a net present value (NPV) calculator that estimates NPV based on a discount rate and an expected annual return. The annual return can be linked to other indicators to become a function of hydrological conditions.

Climate change analysis

Climate change scenarios are used to estimate the impact of long-term changes in climate on meteorological variables including precipitation and potential evapotranspiration. Climate model scenarios are developed from global and regional climate models, which simulate the Earth’s climate into the future using different assumptions about greenhouse gas emissions.

CC-DSS provides bias-corrected data of precipitation and evapotranspiration calculated based on maximum temperature, and minimum temperature. Considering the climate change impacts in South Asia, a bias-corrected dataset of daily precipitation, maximum and minimum temperatures using output from 13 GCMs that participated in the Coupled Model Intercomparison Project-6 (CMIP6). The 13 GCMs were selected based on the availability of daily precipitation, maximum and minimum temperatures for the historical and four scenarios (SSP126, SSP245, SSP370, SSP585). These are the “Shared Socioeconomic Pathways” (SSPs). A number of these SSP scenarios have been selected to drive climate models for CMIP6. The CMIP6 model future projections under the four scenarios demonstrate that this increasing trend will continue, and the trend will get stronger from SSP126 to

SSP585. It represents low-end (SSP1-2.6: “ssp126”), medium-end (SSP2-4.5: “ssp245”), and high-end (SSP3-7.0: “ssp370”; SSP5-8.5: “ssp585”) forcing scenarios.

Empirical quantile mapping (EQM) was used to develop bias-corrected data at daily temporal and 0.25° spatial resolution for six countries in South Asia (India, Pakistan, Bangladesh, Nepal, Bhutan, and Sri Lanka).

Four climate change scenarios are available in the CC-DSS for each of the 13 RCM simulations. The four scenarios provide estimates for two points in the future, near-term and end-of-century.

The near-term and end-of-century climate change estimates are developed by comparing climate model outputs from the two future periods (2016-2035 and 2081-2100) to a 1986-2005 baseline. Average monthly changes are estimated by comparing average monthly values from the baseline period to the average for the same month in the future. The resulting set of 12 monthly “change factors” can be used to modify inputs to the basin planning application’s MIKE HYDRO Basin model by modifying each value in an input time series using the appropriate monthly change factor.

The two sets of assumptions about anthropogenic activities are from the Representative Concentration Pathways (RCP) scenarios developed by the Intergovernmental Panel on Climate Change as part of its fifth Assessment Report (Pachauri et al., 2014). The RCP 4.5 scenario assumes that greenhouse gas emissions will peak in 2040, and then decline slightly. The RCP 8.5 scenario assumes that greenhouse gas emissions will continue to rise throughout the 21st century.

The four scenarios are summarized below:

- rcp45 2016-2035: This scenario estimates near-term climate changes based on the RCP 4.5 greenhouse gas concentration scenario
- rcp85 2016-2035: This scenario estimates near-term climate changes based on the RCP 8.5 greenhouse gas concentration scenario.
- rcp45 2081-2100: This scenario estimates end-of-century climate changes based on the RCP 4.5 greenhouse gas concentration scenario.
- rcp85 2081-2100: This scenario estimates end-of-century climate changes based on the RCP 8.5 greenhouse gas concentration scenario.

Using CC-DSS various adaptation options can be analysed

Sectoral demand management

Irrigation

When irrigation infrastructure is built, irrigation water demands may be uncertain. Contributing factors include uncertainty about:

- Evapotranspiration and rainfall.
- Types of crops that will be grown.
- Irrigation methods.
- Future crops

To account for uncertainty in irrigation demands, CC-DSS allows users to estimate irrigation demand and crop water requirement as per their current crop area and irrigation methods. CC-DSS has functionality to add new crops in the system to estimate the demand of any future crop. Using CC-DSS user can change the irrigation methods available in the model to estimate gain and loss in crop yield during irrigation.

Hydropower

Hydropower water use can be defined as the use of water by a power plant where the turbines are driven by falling water. Power generation can be increased by using the spills in the case of more water and decreased in the case of dry year. CC-DSS can help in analysing these scenarios. CC-DSS allow users to estimate demands based on increasing or decreasing power generation for defined time periods. It provides to change the power demand for the specific time period which help users in reservoir operations. CC-DSS can help in analysing differential impacts of climate change on hydropower plants located in rivers fed by varying amounts of rainfall at different decades in this century. This type of integrated assessment of climate change impact will support the scientific understanding of hydrologic flow and its impacts on a hydropower economy under various climate scenarios, as well as generate information about water resource management in a changing climate.

Domestic and Industrial Demand

Domestic, municipal, and industrial (DMI) water demands are typically based on projections of population and socioeconomic activities. The domestic demand is the household demand. The municipal demand covers the water requirements of the commercial sector (shops, department stores, hotels and so on) and for the services sector (hospitals, offices, schools, and others). In most river basins, this demand is small compared to the demand for irrigation. However, given the importance of this demand for human health and economic developments, it is often given priority.

Predicting DMI demands can be difficult. A common approach is to use the demand predictions of the public water supply authorities in the basin. They base their predictions on estimates of population growth, growth in demand per capita and so on, often using statistical trends. Domestic use can be estimated on the basis of water consumption per capita and coverage rates, taking into account differences in social strata. Municipal demand is often assumed to be a percentage of the domestic water demand (usually in the range of 15–35%). Industrial water demand is the most difficult to estimate, as it depends on the type of industry and the production processes being used. In most cases estimates are made based on statistical projections or water demand depending on the type of industry.

CC-DSS provides options to define rate of population growth for estimation of domestic demand and allow user to increase/decrease demand of water supply user (DMI user) for the selected time period.

Capabilities of CC-DSS

Knowledge base

CC-DSS Knowledgebase provides an integrated solution allowing its users to access spatial data, time series data (historical as well as real-time), climate change data and metadata through a state-of-theart web user interface. It allows the user to search for information based on metadata, e.g., rainfall data for a given period within a specified catchment related to gauge site etc. CC-DSS Knowledgebase provides all this functionality from a user interface with which users immediately feel at ease. The user interface is GIS based and allows the user to navigate the data from spatial selections. CC-DSS keeps downloading satellite data from various resources and processes them for all the basins and sub basins. Downloading and processing will be done on the central server. Whenever the user logs in to CC-DSS web portal, user will be able to see the latest processed data for selected basin and sub basins.

Knowledge base user interface

Another layer of Knowledgebase is user interface which allows user to interact with Knowledgebase. Only authorized users can access the Knowledge base. Various parts of Knowledgebase are shown in Figure 19

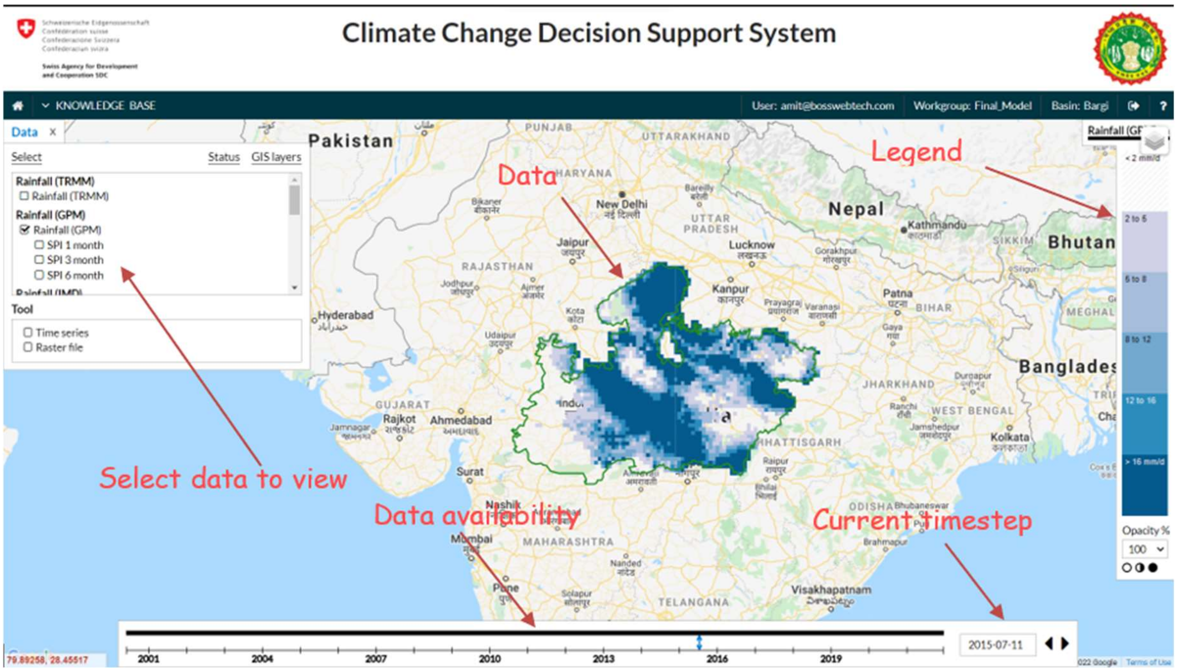
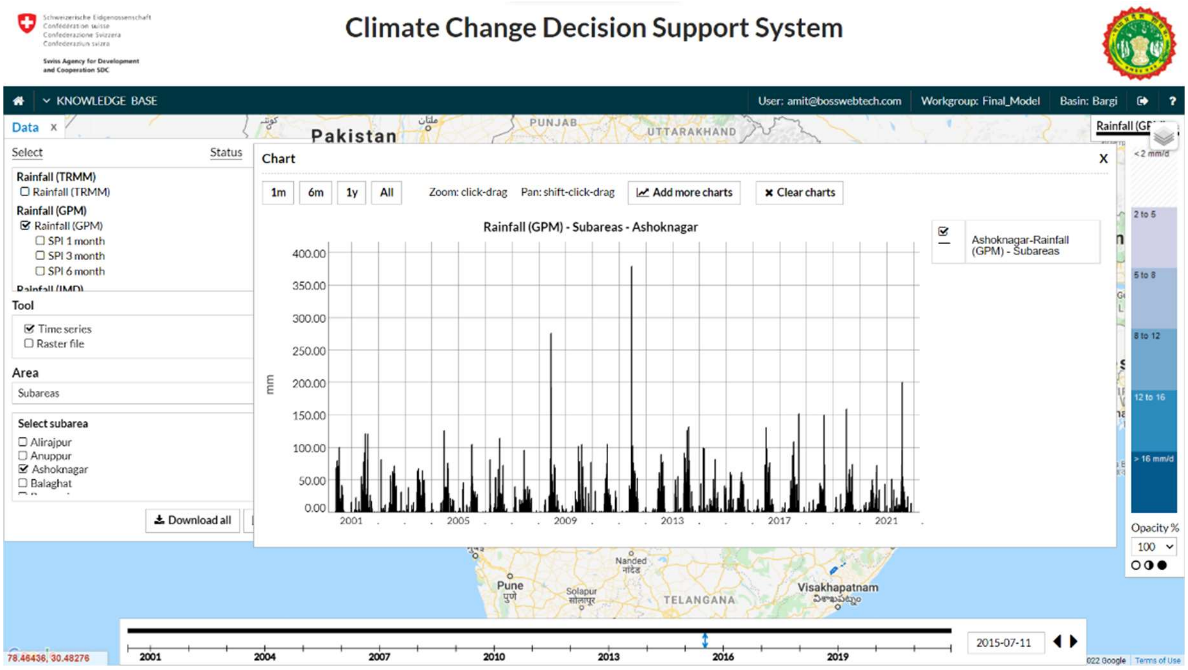


Figure 19: Knowledge base user interface and its components

The tools menu contains several options for processing and analyzing the selected data types. Data can be extracted at different spatial resolutions from the entire focus area in the form of net CDF file which can be visualized in any GIS software and can be presented as time series plots or chart plots as shown in Figure 20



User: amit@bosswebtech.com
Workgroup: Final_Model
Basin: Bargi

Rainfall (GPM)
☐ Rainfall (TRMM)
☑ Rainfall (GPM)
☐ SPI 1 month
☐ SPI 3 month
☐ SPI 6 month

Tool
☑ Time series
☐ Raster file

Area: Subareas

Select subarea
☐ Alirajpur
☐ Anuppur
☑ Ashoknagar
☐ Balaghat

Rainfall (GPM)

2015-07-11

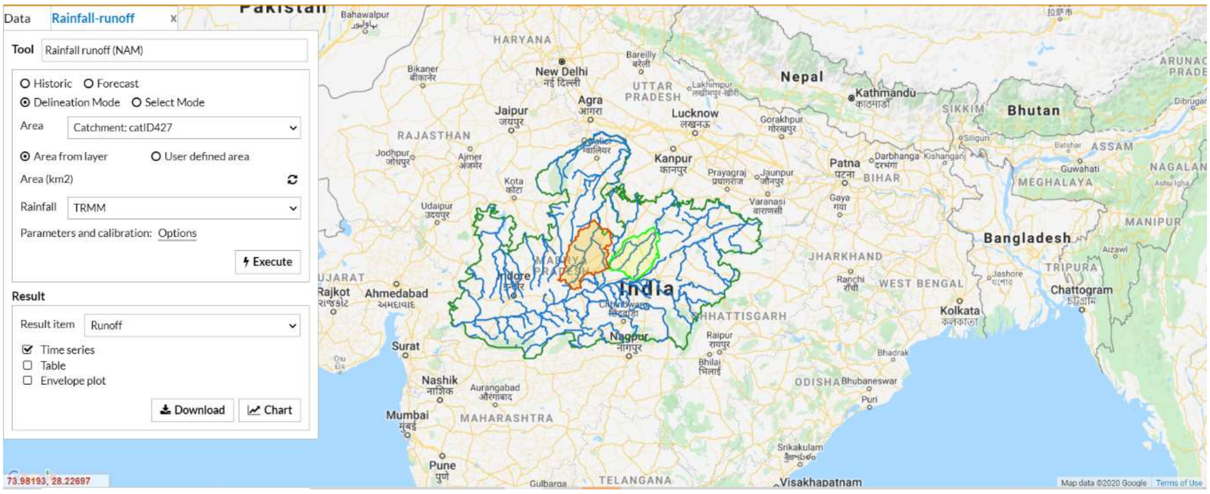
Figure 20: Visualisation of time series in Knowledgebase

Online model development for single reservoir

The unique feature online model will be used for developing small MIKE HYDRO Basin models online using CC-DSS. In this approach a template of MIKE HYDRO Basin file will be stored in the CC-DSS and user will be able to add required components online and simulate the model for scenario generation. CC-DSS will also provide interface to run Rainfall – Runoff model or user will be able to provide direct inflow generated from the catchment. Once the online model is ready it will be used in the same way as an uploaded MIKE HYDRO

Catchment Delineation and Runoff Estimation

CC-DSS will already contain a pre-processed DEM file for whole MP with traced river network. Users will be able to click on any point on traced river network to delineate a catchment as shown in Figure 21. Once the user defines catchment it will be stored in a database with a unique ID number.



Tool: Rainfall runoff (NAM)

○ Historic ○ Forecast
● Delineation Mode ○ Select Mode

Area: Catchment: catID427

● Area from layer ○ User defined area

Area (km2)

Rainfall: TRMM

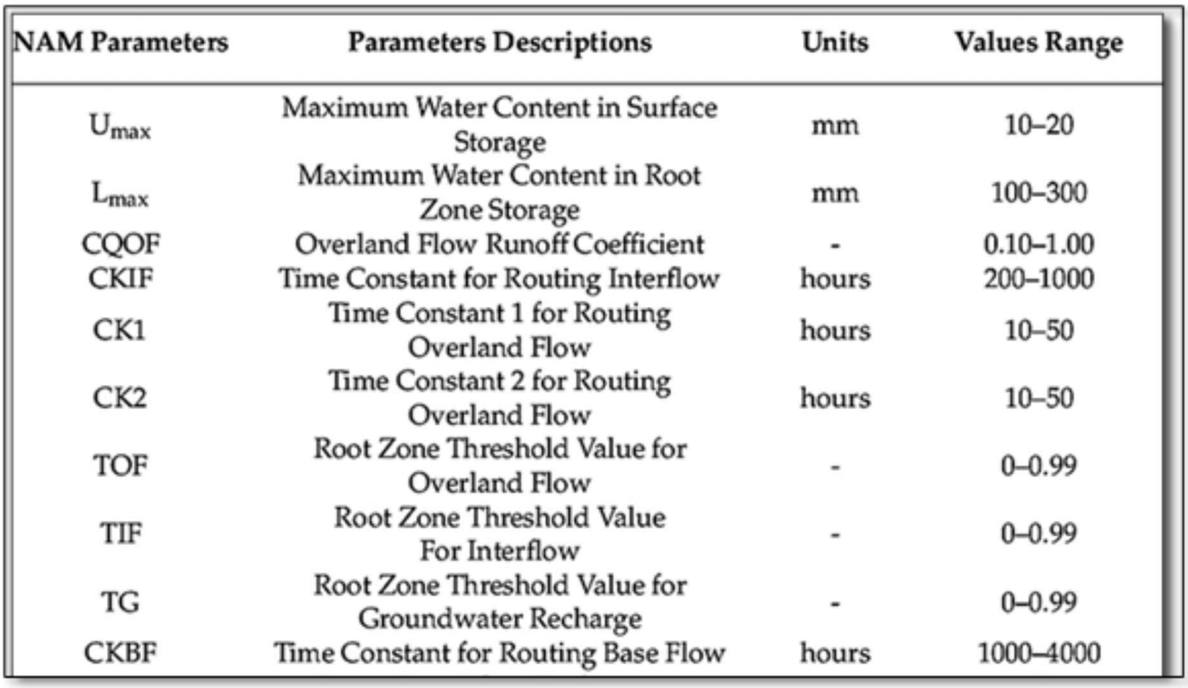
Result

Result item: Runoff

☑ Time series
☐ Table
☐ Envelope plot

Figure 21: Interface for catchment delineation and runoff estimation

After finishing catchment delineation for the desired outlet point's user will be able to select catchment from drop-down to run the calculation and area will be derived from calculation or can be user-defined. Users will be allowed to modify the 7 (between point 1-6 as shown in Figure 22) model parameters listed below and save them for later use.

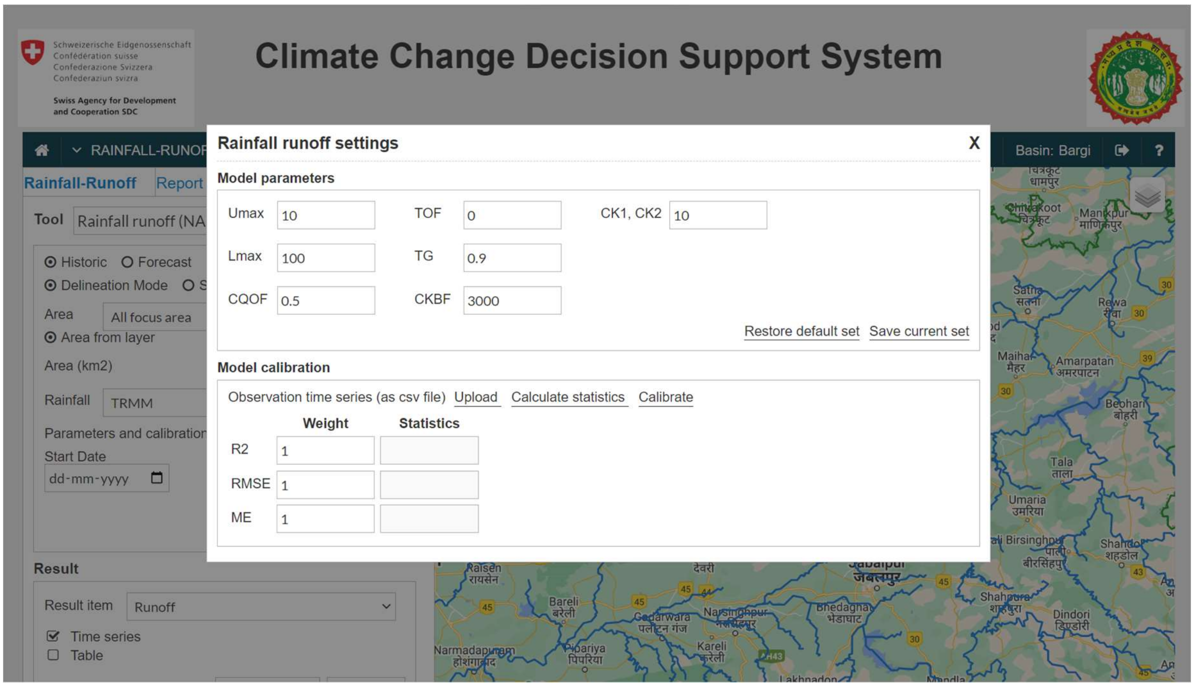


NAM Parameters	Parameters Descriptions	Units	Values Range
U_{max}	Maximum Water Content in Surface Storage	mm	10–20
L_{max}	Maximum Water Content in Root Zone Storage	mm	100–300
CQOF	Overland Flow Runoff Coefficient	-	0.10–1.00
CKIF	Time Constant for Routing Interflow	hours	200–1000
CK1	Time Constant 1 for Routing Overland Flow	hours	10–50
CK2	Time Constant 2 for Routing Overland Flow	hours	10–50
TOF	Root Zone Threshold Value for Overland Flow	-	0–0.99
TIF	Root Zone Threshold Value For Interflow	-	0–0.99
TG	Root Zone Threshold Value for Groundwater Recharge	-	0–0.99
CKBF	Time Constant for Routing Base Flow	hours	1000–4000

Figure 22: NAM model parameters with default values

The default values will keep the standard values as stated above. Users can upload the observed runoff in .csv format and can calculate the statistics and can calibrate the model using R2, Root mean Square and Mean Error. The calibrated parameters are then ingested to execute the NAM and results can be seen in the results tab for following - Runoff, Runoff Acceleration. Evapotranspiration, Recharge, Rainfall, and Duration Curve. CC-DSS will provide all the rainfall and evapotranspiration time series data using various satellite products. After catchment delineation, the user needs to perform the following steps:

Step 1: Model Run	**Step 2: Calibration**
• Selection of Area • Input Data selection • Rainfall - ○ TRMM (0.25) ○ Chirps (0.05) ○ GFS • PET- MODIS 16 (500 m) • Temperature – CRU (0.5)	• Observed data upload • Model efficiency using RMSE, ME & R^2 • Model parameter refinement **Step 3: Output generation**



Rainfall runoff settings

Model parameters

Umax 10
TOF 0
CK1, CK2 10
Lmax 100
TG 0.9
CQOF 0.5
CKBF 3000

Restore default set Save current set

Model calibration

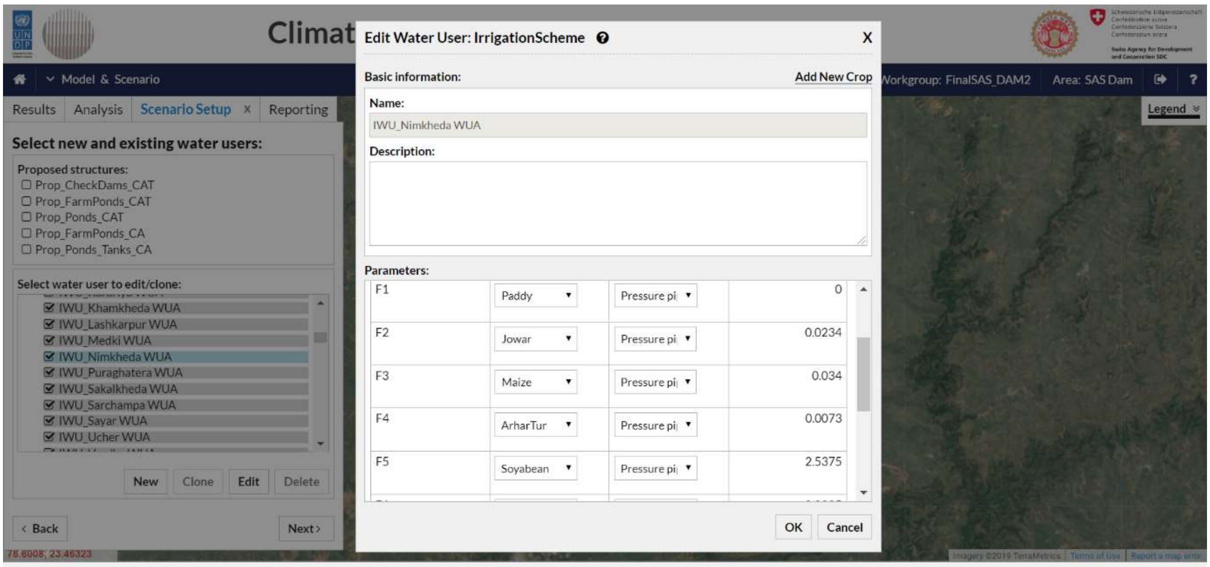
Observation time series (as csv file) Upload Calculate statistics Calibrate

	Weight	Statistics
R2	1	
RMSE	1	
ME	1	

Figure 23: The window showing option to calibrate model parameters using observed time-series

Adding of Reservoirs and Water Users

CC-DSS provides functionality to add water users, irrigation users, hydropower dam and reservoirs directly in MIKE HYDRO Basin model. CC-DSS provides interface to define all input data from web in MIKE HYDRO Basin as shown in (Figure 24) model except irrigation user. Irrigation users need lot of input so to keep it simple a template irrigation user will already be defined in file which will be cloned or changed during online modelling. Once defining of all reservoirs and water users is finished, CC-DSS will allow user to simulate this model on web server.



Select new and existing water users:

Proposed structures:
☐ Prop_CheckDams_CAT
☐ Prop_FarmPonds_CAT
☐ Prop_Ponds_CAT
☐ Prop_FarmPonds_CA
☐ Prop_Ponds_Tanks_CA

Select water user to edit/clone:
☑ IWU_Khamkheda WUA
☑ IWU_Lashkarpur WUA
☑ IWU_Medki WUA
☑ IWU_Nimkheda WUA
☑ IWU_Puraghatera WUA
☑ IWU_Sakalkheda WUA
☑ IWU_Sarchampa WUA
☑ IWU_Sayar WUA
☑ IWU_Ucher WUA

Edit Water User: IrrigationScheme

Basic information: Add New Crop

Name: IWU_Nimkheda WUA

Description:

Parameters:

F1	Paddy	Pressure pi	0
F2	Jowar	Pressure pi	0.0234
F3	Maize	Pressure pi	0.034
F4	ArharTur	Pressure pi	0.0073
F5	Soyabean	Pressure pi	2.5375

Figure 24 Change in the model object properties

Cost-Benefit Analysis (CBA)

While the hydrological model uploaded to the CC-DSS can calculate flow in the river, power production, crop yield etc. the model does not provide any information about the economic costs and benefits of the investments. The user will add this information to the investment in the CC-DSS to enable calculation of key economic parameters. The CBA has two components: 1) Definition and calculations, and 2) Analysis and visualization. Both of these are briefly described below.

Definition and calculation:

Activities related to defining parameters for cost-benefit analyses are expected to be carried out by the water resources planner, who also sets up the scenarios. The following key parameters have to be defined for each investment where cost and benefits will be assessed:

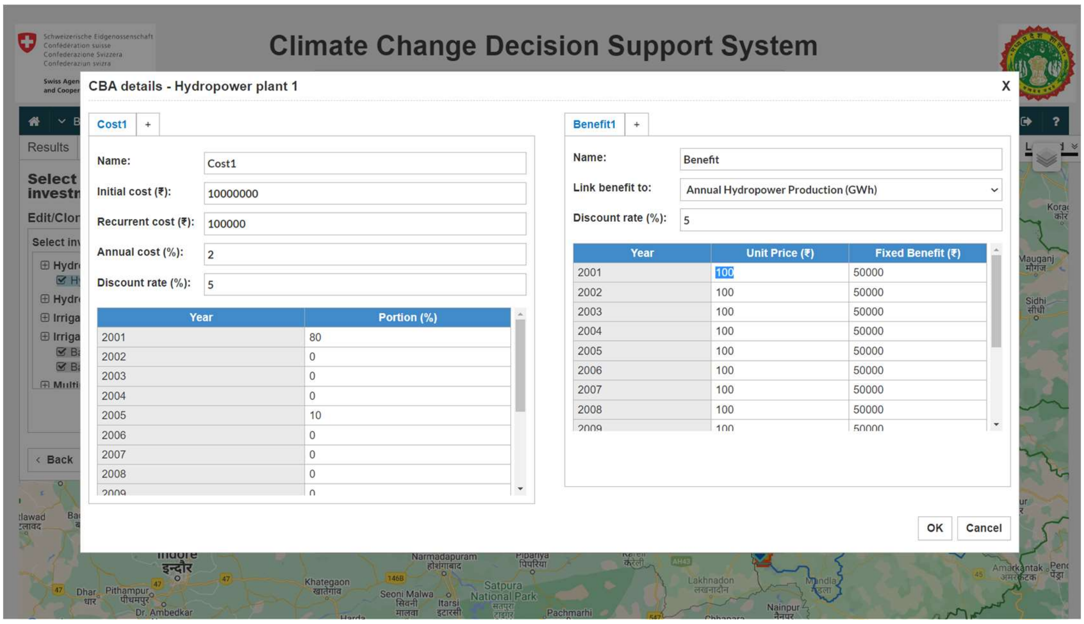
a. Time horizon
b. Discount rate
c. Cost streams which include both capital costs and operation and maintenance costs
d. Input for calculating benefit stream: yearly time series of unit prices for outputs/yield from the investments (e.g., for a hydropower plant: unit price per MWh to be multiplied with average annual energy)

When a scenario is executed, the following CBA-outputs will automatically be calculated by the CC-DSS:

- Present value of costs and benefits
- Internal rate of return
- Present value of net benefits
- Benefit-cost ratio
- Sensitivity of benefits and costs as a function of discount rate
- Analysis and Visualisation:

Once the CBA input parameters are saved and the CBA results are calculated for a scenario, the CC-DSS provides the user with the following analysis and visualization functionalities:

a. Visualise CBA input parameters of investments as shown in Figure 25



Name: Cost1
Initial cost (₹): 10000000
Recurrent cost (₹): 100000
Annual cost (%): 2
Discount rate (%): 5

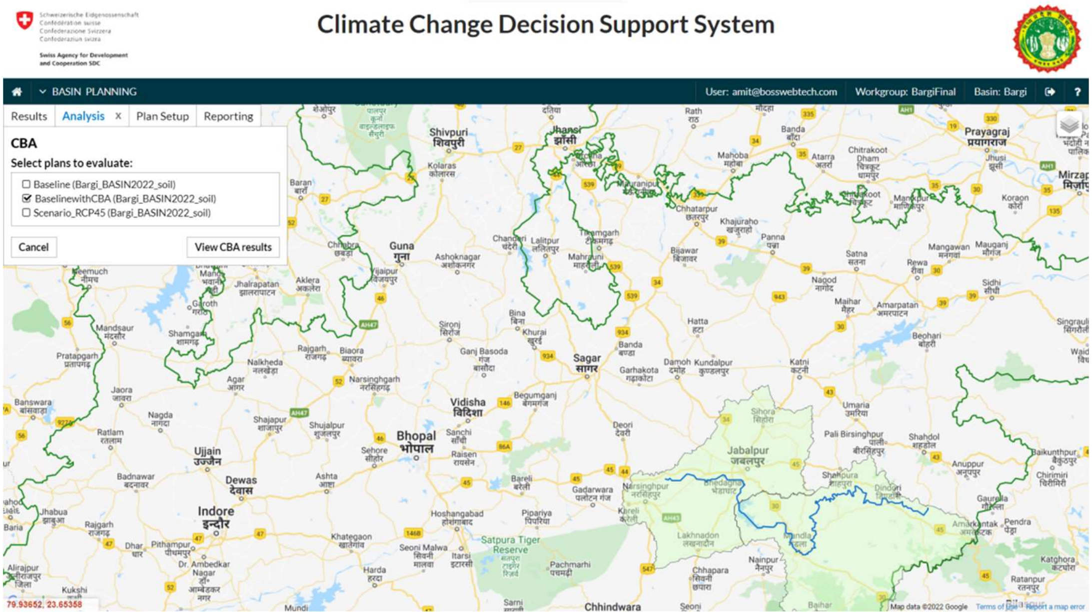
Year	Portion (%)
2001	80
2002	0
2003	0
2004	0
2005	10
2006	0
2007	0
2008	0
2009	0

Name: Benefit
Link benefit to: Annual Hydropower Production (GWh)
Discount rate (%): 5

Year	Unit Price (₹)	Fixed Benefit (₹)
2001	100	50000
2002	100	50000
2003	100	50000
2004	100	50000
2005	100	50000
2006	100	50000
2007	100	50000
2008	100	50000
2009	100	50000

Figure 25: Define cost and benefit for the selected investment

b. Visualise CBA input parameters of the scenario (Figure 26): When the user selects this option, CBA input parameters of all investments in the scenario are shown jointly.



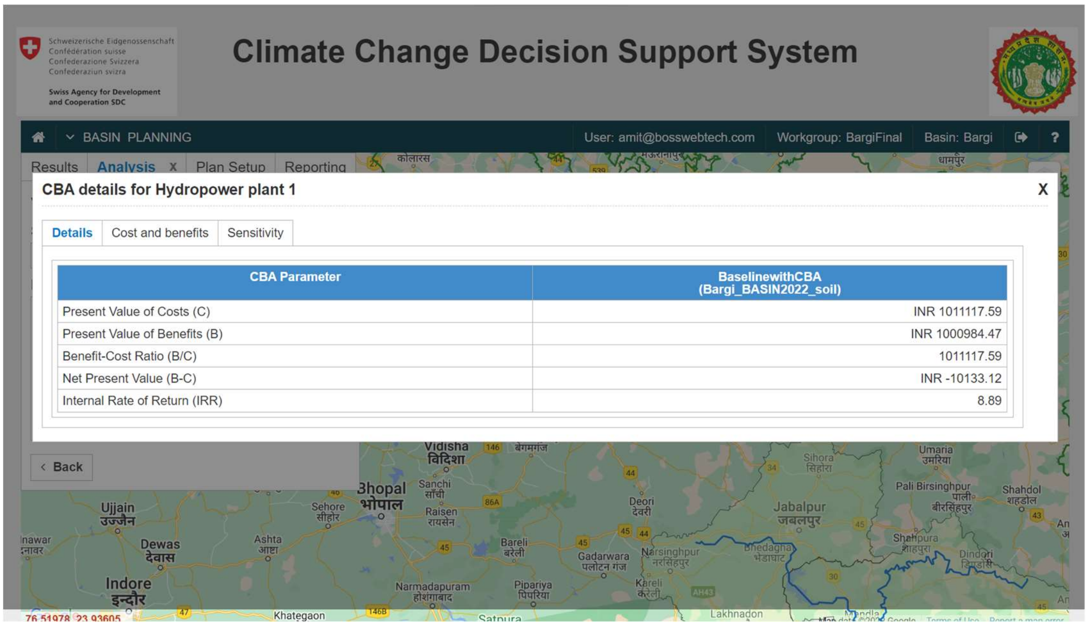
CBA

Select plans to evaluate:

☐ Baseline (Bargi_BASIN2022_soil)
☑ BaselinewithCBA (Bargi_BASIN2022_soil)
☐ Scenario_RCP45 (Bargi_BASIN2022_soil)

Figure 26: Selected scenario for cost benefit analysis

c. Visualise CBA-results of investments: The CBA results will be shown in Figure 27 a window as charts and/or in tabular form.



CBA Parameter	BaselinewithCBA (Bargi_BASIN2022_soil)
Present Value of Costs (C)	INR 1011117.59
Present Value of Benefits (B)	INR 1000984.47
Benefit-Cost Ratio (B/C)	1011117.59
Net Present Value (B-C)	INR -10133.12
Internal Rate of Return (IRR)	8.89

Figure 27: CBA results in tabular form

d. Visualise CBA results of a scenario: When the user selects this option, CBA results of all investments in the scenario will be shown jointly in tabular form including the aggregations (e.g., totals of present values, ratio of totals of present values).

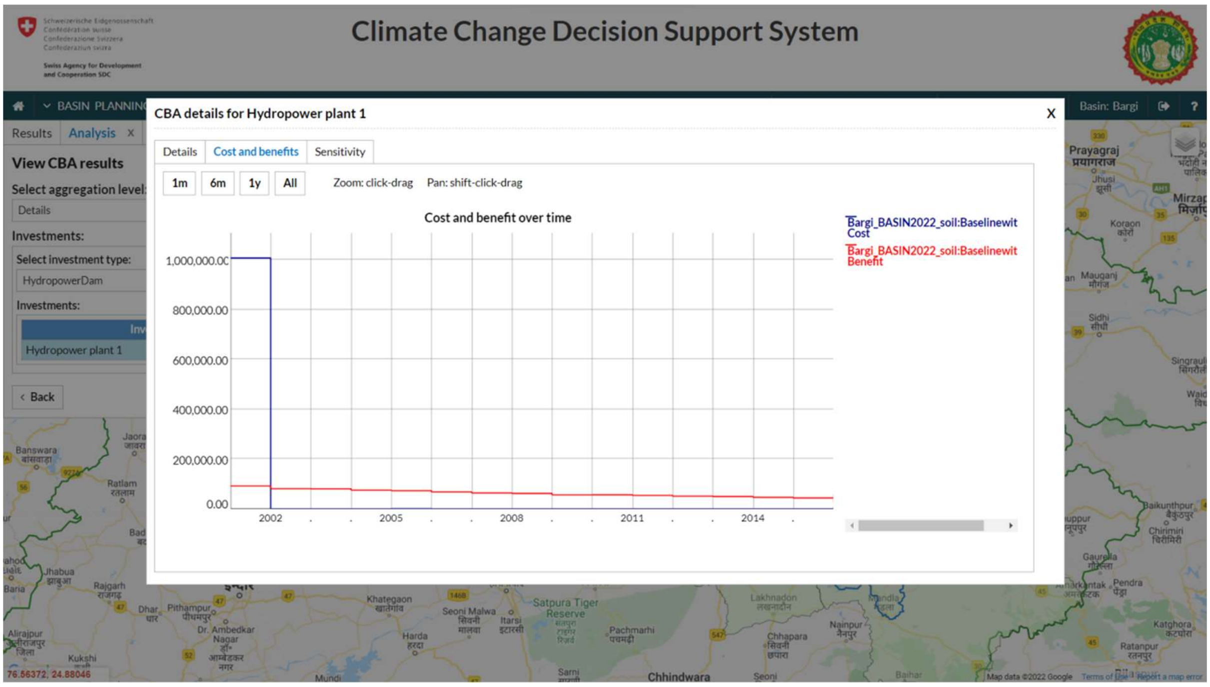


Figure 28: CBA results in chart

Cost benefit analysis - Calculations

We have introduced discounted cash flow analysis. We will examine investment criteria for selecting a project (i.e., formulae): Net Present Value (NPV), Benefit-Cost Ratio (B/C ratio), Internal Rate of Return

(IRR) and for projects of unequal length (i.e., Equivalent Annual Net Benefits and Common Multiples of Duration).

Net present value criterion

The Net Present Value (NPV) criterion is the principal government investment project evaluation criterion. The cash flows consist of a mixture of costs and benefits occurring over time. Net present value is merely the algebraic difference between discounted benefits and discounted costs as they occur over time. The formula for NPV is:

$$NPV = \frac{B_0 - C_0}{(i+1)^0} + \frac{B_1 - C_1}{(i+1)^1} + \cdots \ldots \ldots \ldots \ldots . + \frac{B_T - C_T}{(i+1)^T}$$

Where: NPV, T = year, B = benefits, C = cost, i = discount rate.

Two sample problems:

Example 1

Canal repair project; 5 yrs.; i = 4% (real discount rates) and benefit = 120000 start from 2nd year of the project

year =	1	2	3	4	5
Benefits (INR)	0	120000	120000	120000	120000
- Cost (INR)	300000	0	0	50000	0
B-C (INR)	-300000	120000	120000	70000	120000
Disc. Factor	1.04^1=1.04	1.04^2= 1.082	1.04^3=1.125	1.04^4=1.169	1.04^5=1.217
Disc. Annual Cash Flows (INR)	-288461.00	110906.00	106667.00	60189.00	98603.00

Sum NPV = INR 87904.00

A single project with a positive NPV is a go.@

Example 2

Lift irrigation project 5 yrs.; i = 7.8%. Begins in time = 0. Benefit = 250000 start from 1st year of the project and will increase with increase in command area by 20%

Year=	0	1	2	3	4	5
Benefit (INR)	0	250000	250000	250000	300000	300000
Cost (INR)	1000000	50000	50000	50000	50000	50000
Net (INR)	-10,00000	200000	200000	200000	250000	250000
Disc. Factor	1.078^0=1	1.078^1= 1.078	1.078^2= 1.162	1.078^3= 1.253	1.078^4= 1.35	1.078^5= 1.45

Year=	0	1	2	3	4	5
Disc Cash Flow (INR)	-1000000	185528.00	172117.00	159617.00	185185.00	172414.00

Sum NPV = (INR1125.39). Decision: Result is negative, hence no go.

Benefit/Cost ratio

Most of us have heard of B/C ratio. Although not the preferred evaluation criterion, the B/C ratio does serve a useful purpose which we will discuss later. B/C formula:

$$^{B}/_{C} = [\frac{B_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{B_T}{(i+1)^T}] \Big/ [\frac{C_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{C_T}{(i+1)^T}]$$

Internal rate of return (IRR)

The IRR is used more for private sector projects, but it is important to know.

IRR is different than our other project evaluation criteria. In our previous formula, i is known and we solved for the discounted cash flows. With IRR, i is the unknown. IRR is the annual earnings rate of the project.

To find IRR we will be interested to know: what is the discount rate that will equate a time series of benefits and costs? @ Or otherwise stated: PVB = PVC; or where PVB - PVC = 0

$$\left[\frac{B_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{B_T}{(i+1)^T}\right] = \left[\frac{C_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{C_T}{(i+1)^T}\right]$$

Or

$$\left[\frac{B_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{B_T}{(i+1)^T}\right] - \left[\frac{C_0}{(i+1)^0} + \cdots \ldots \ldots \ldots + \frac{C_T}{(i+1)^T}\right] = 0$$

Once the unknown i@ has been determined, we can compare i to the best available alternative rate of return. If the calculated i (IRR) is greater than the minimum acceptable rate of return (MARR) (i.e., we won't accept an earning rate less than the MARR) then you will go with your project. Note: Calculated i@ = internal rate of return; MARR = external rate of return.

A word on computational difficulties: One problem with IRR is that it cannot be solved for in a direct algebraic fashion because user needs one equation for each unknown to solve. With IRR user have more unknowns than equations. Thus, user cannot solve the i easily.

Hence, IRR must be solved for in iterative trial-and-error fashion.

Procedure for trial and error:

a) set-up your annual benefits and costs separately
b) put in an initial discount rate, discount all benefits and cost,
c) examine to see if B=C
d) if not, repeat calculations with a new discount rate,
e) repeat calculations with a new i until B=C (to first decimal place).

IRR Example 3

We take a series of annual cash flows, begin with 7% discount rate:

Year	1	2	3	4	5
Cost (INR)	85,000	5000	5000	5000	5000
Disc Fact.	1.07	1.14	1.22	1.31	1.4
PVC (INR)	79,439	4385	4098	3816	3571
Benefits (INR)	0	20000	25000	35000	50000
PVB (INR)	0	17534	20491	26717	35714

At 7% discount rate: sum PVB = INR 100456 - sum PVC = INR 95309 = INR 5147.

Decision: increase or decrease i? A; if B>C, the increase i and try again at 8% B-C = INR2710. at 9% B-C = INR586; at 9.3% benefits = costs, thus IRR = 9.3%

The external rate of return (MARR) is the discount rate so that the NPV of the costs is equivalent to the future value (FV) of the benefits.

IRR is the annual earning rate of the project. Rule: accept project if IRR>MARR.

Multi-Criteria Analysis (MCA)

Multi-Criteria analysis (MCA) is an instrument for comparing and, where necessary and possible, ranking scenarios using criteria/indicators of interest. The comparisons allow setting different weights to criteria to reflect preferred areas of focus, for example economic aspects, environmental aspects or social aspects depending on the interest of the stakeholder and decision makers. Thus, MCA is a good tool to facilitate stakeholder discussions and find out where they have common interests and where there may be conflicting interests, and how such conflicting interests can best be addressed.

The CC-DSS should have the following MCA functionalities:

a. The user can select the set of scenarios to be compared in the context of MCA.
b. The user selects the set of criteria from a list of indicators based on which the scenarios should be evaluated.
c. For each criterion, the user defines whether the criterion is performing better if it has a higher numerical value.
d. Based on the above an MCA matrix is constructed

The above will normally be done by the water resources planner. When the MCA matrix is made available to the users/stakeholders, they can do the following:

a. Define MCA sessions and assign weights to criteria. Each sector / interest group can make their own session. The weights of criteria reflect scenarios of preferences, for example- are economic aspects to be preferred to environmental aspects.

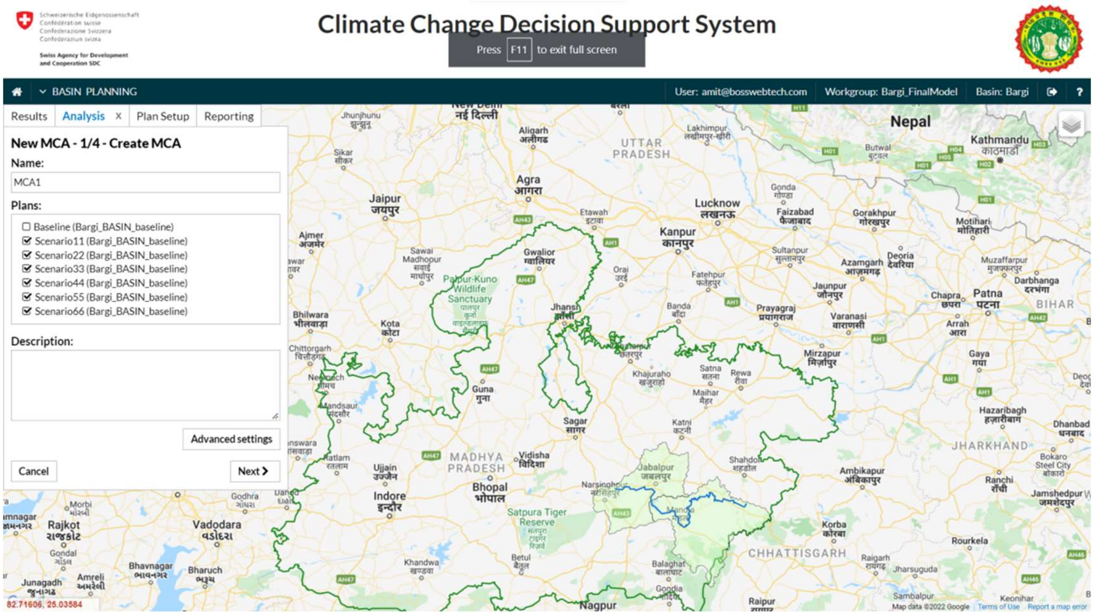
b. Investigate how the different sets of weights affect the ranking of the options/scenarios for each session.

c. Share and discuss the MCA sessions and the respective results in the Planning Tool with other users

Steps Performed in CC-DSS for Multi Criteria Analysis

a) Step 1: Identify criteria

Step 1 is identifying criteria which mean the user needs to identify various performance indicators on which selected options will be tested. In case of CC-DSS options are scenarios developed by user as shown in Figure 29



New MCA - 1/4 - Create MCA

Name: MCA1

Plans:

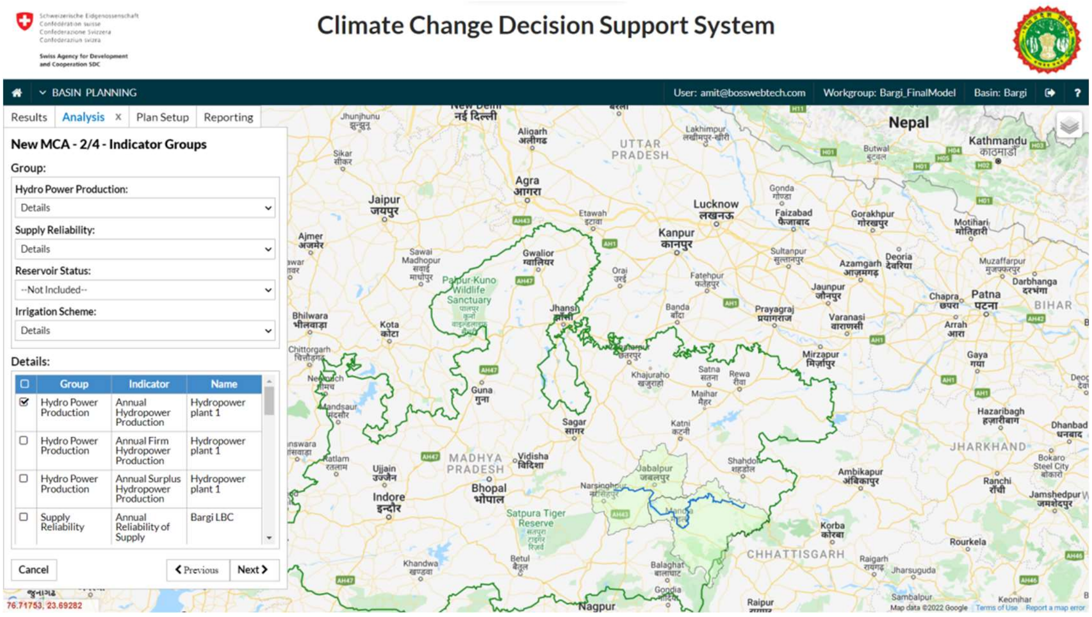
☐ Baseline (Bargi_BASIN_baseline)
☑ Scenario11 (Bargi_BASIN_baseline)
☑ Scenario22 (Bargi_BASIN_baseline)
☑ Scenario33 (Bargi_BASIN_baseline)
☑ Scenario44 (Bargi_BASIN_baseline)
☑ Scenario55 (Bargi_BASIN_baseline)
☑ Scenario66 (Bargi_BASIN_baseline)

Description:

Figure 29: Selected options (scenario) to perform Multi Criteria Analysis

For various demand types, criteria (indicators Figure 30) have been selected which will help to quantify all the demands. Following criteria have been selected for different type of demands

- Hydropower demand - Annual Hydropower Production,
- Water supply user - Supply reliability and
- Industrial user - Supply reliability



New MCA - 2/4 - Indicator Groups

Group:

Hydro Power Production: Details

Supply Reliability: Details

Reservoir Status: --Not Included--

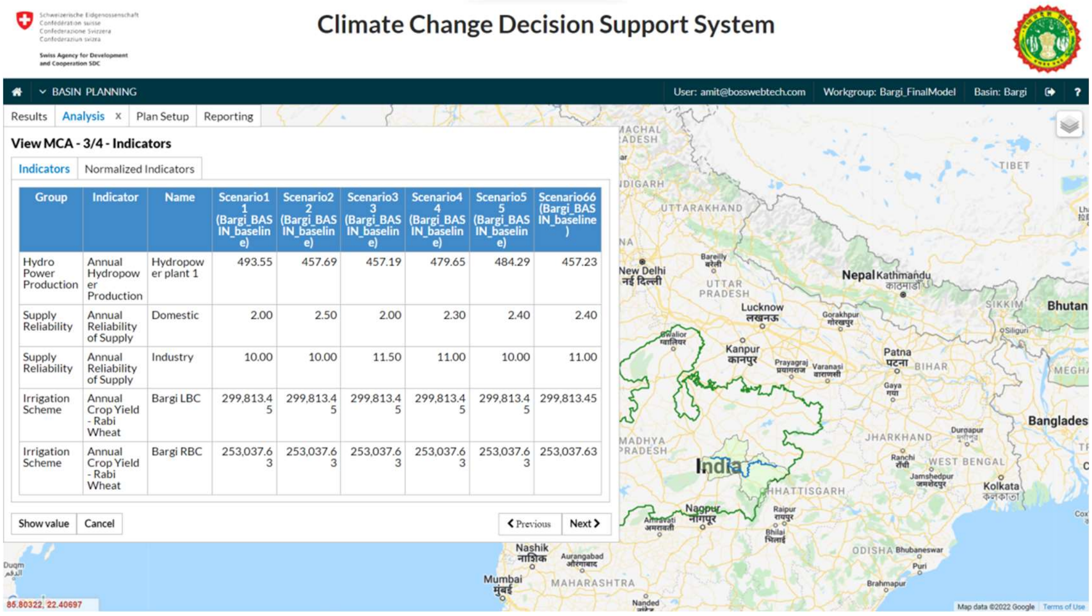
Irrigation Scheme: Details

Details:

☐	Group	Indicator	Name
☑	Hydro Power Production	Annual Hydropower Production	Hydropower plant 1
☐	Hydro Power Production	Annual Firm Hydropower Production	Hydropower plant 1
☐	Hydro Power Production	Annual Surplus Hydropower Production	Hydropower plant 1
☐	Supply Reliability	Annual Reliability of Supply	Bargi LBC

Figure 30: Selected criteria (indicators) for scenarios

b) Step 2: Identify the outcome and performance of options (Figure 31)

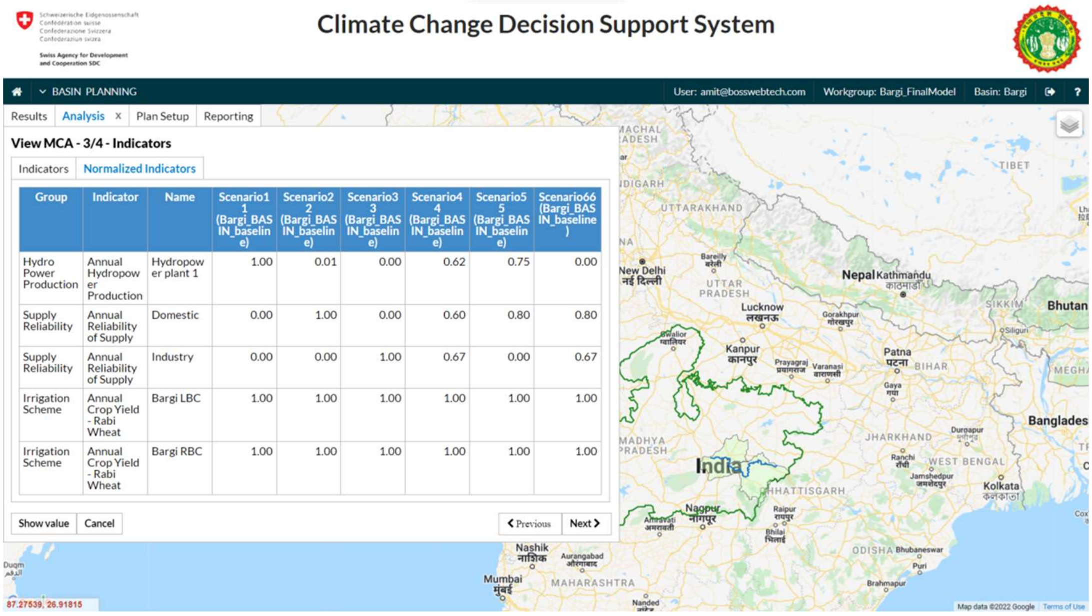


View MCA - 3/4 - Indicators

Indicators | Normalized Indicators

Group	Indicator	Name	Scenario1 1 (Bargi_BASIN_baseline)	Scenario2 2 (Bargi_BASIN_baseline)	Scenario3 3 (Bargi_BASIN_baseline)	Scenario4 4 (Bargi_BASIN_baseline)	Scenario5 5 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Hydro Power Production	Annual Hydropower Production	Hydropower plant 1	493.55	457.69	457.19	479.65	484.29	457.23
Supply Reliability	Annual Reliability of Supply	Domestic	2.00	2.50	2.00	2.30	2.40	2.40
Supply Reliability	Annual Reliability of Supply	Industry	10.00	10.00	11.50	11.00	10.00	11.00
Irrigation Scheme	Annual Crop Yield - Rabi Wheat	Bargi LBC	299,813.45	299,813.45	299,813.45	299,813.45	299,813.45	299,813.45
Irrigation Scheme	Annual Crop Yield - Rabi Wheat	Bargi RBC	253,037.63	253,037.63	253,037.63	253,037.63	253,037.63	253,037.63

Figure 31: Indicator values for each scenario



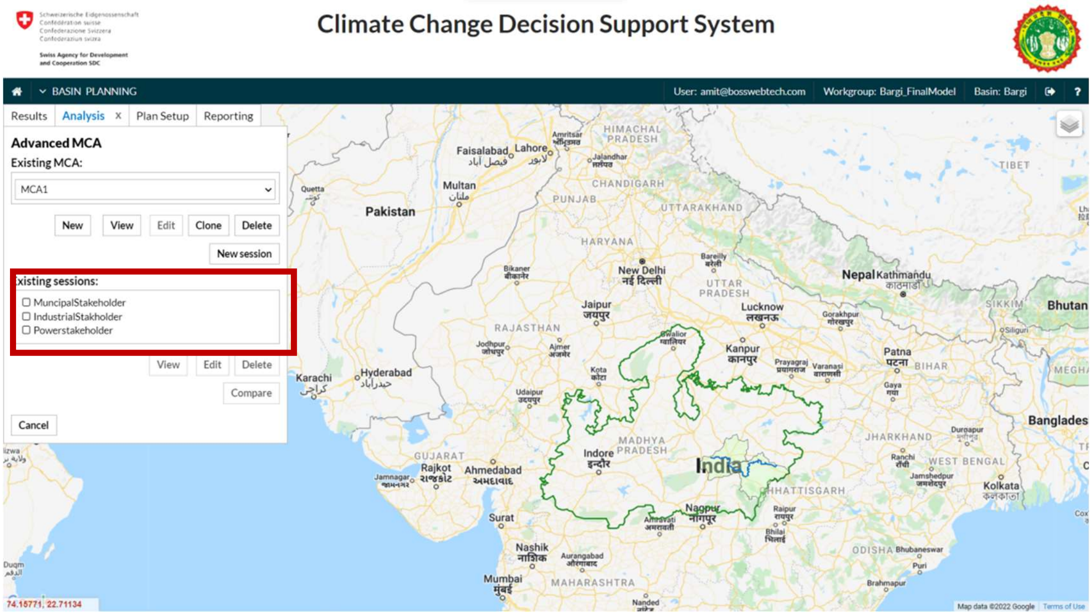
View MCA - 3/4 - Indicators

Group	Indicator	Name	Scenario1 1 (Bargi_BASIN_baseline)	Scenario2 2 (Bargi_BASIN_baseline)	Scenario3 3 (Bargi_BASIN_baseline)	Scenario4 4 (Bargi_BASIN_baseline)	Scenario5 5 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Hydro Power Production	Annual Hydropower Production	Hydropower plant 1	1.00	0.01	0.00	0.62	0.75	0.00
Supply Reliability	Annual Reliability of Supply	Domestic	0.00	1.00	0.00	0.60	0.80	0.80
Supply Reliability	Annual Reliability of Supply	Industry	0.00	0.00	1.00	0.67	0.00	0.67
Irrigation Scheme	Annual Crop Yield - Rabi Wheat	Bargi LBC	1.00	1.00	1.00	1.00	1.00	1.00
Irrigation Scheme	Annual Crop Yield - Rabi Wheat	Bargi RBC	1.00	1.00	1.00	1.00	1.00	1.00

Figure 32: Normalised indicator value for each scenario

c) Step 3: Assign weights to each criterion

After selecting options and criteria for all options CC-DSS asks for weights to be provided as per the stakeholders. All the stakeholders can provide weights as per their area of interest. User of CC-DSS can define various stakeholders in the system as shown in (Figure 33).



Advanced MCA

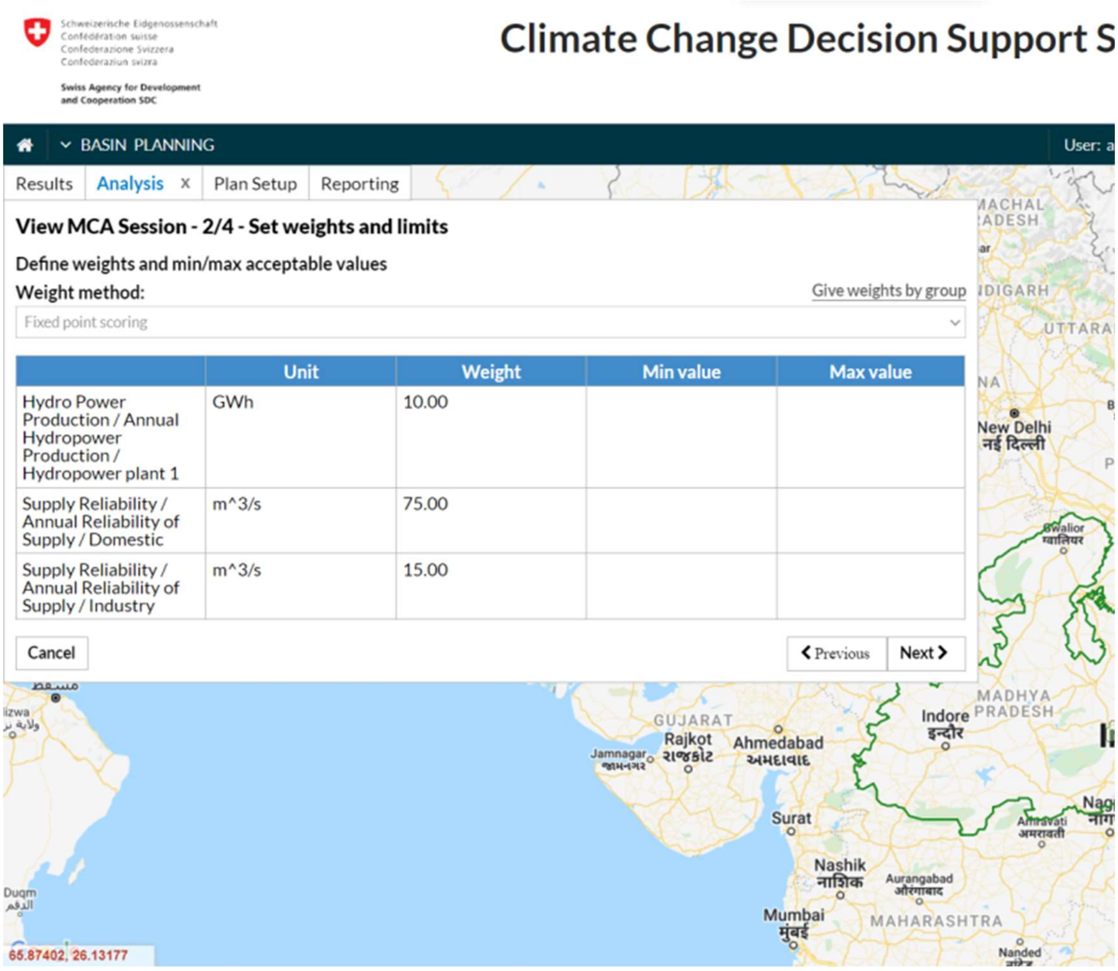
Existing MCA: MCA1

xisting sessions:

☐ MuncipalStakeholder
☐ IndustrialStakholder
☐ Powerstakeholder

Figure 33: Defining all stakeholders

Municipality stakeholders which are more concern about reliability in water supply will usually put more weightage to the reliability in water supply as shown in Figure 34



View MCA Session - 2/4 - Set weights and limits

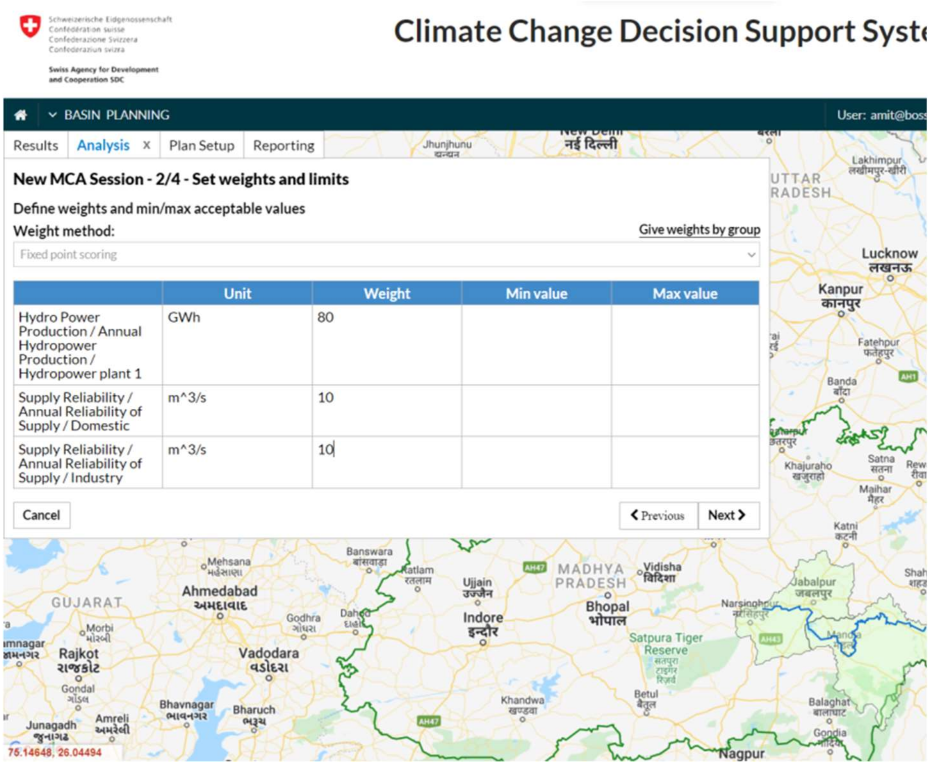
Define weights and min/max acceptable values

Weight method: Fixed point scoring

	Unit	Weight	Min value	Max value
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	GWh	10.00		
Supply Reliability / Annual Reliability of Supply / Domestic	m^3/s	75.00		
Supply Reliability / Annual Reliability of Supply / Industry	m^3/s	15.00		

Figure 34: Weights assigned to municipality stakeholder

Power Department stakeholders which are more concerned about the generation of more power to supply will usually put more weightage to annual average power generation as shown in Figure 35.



New MCA Session - 2/4 - Set weights and limits

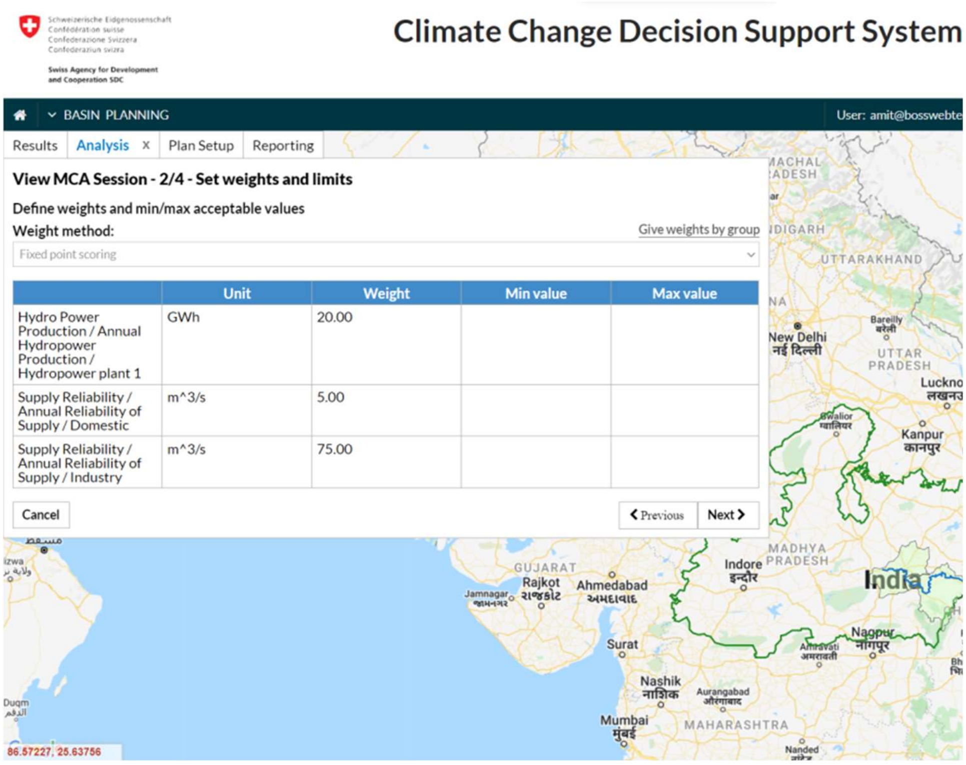
Define weights and min/max acceptable values

Weight method: Fixed point scoring

	Unit	Weight	Min value	Max value
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	GWh	80		
Supply Reliability / Annual Reliability of Supply / Domestic	m^3/s	10		
Supply Reliability / Annual Reliability of Supply / Industry	m^3/s	10		

Figure 35: Assign weights to power stakeholder

Industrial Department which are more concerned about the supply of water will usually put more weightage on water supply reliability as shown in Figure 36.



View MCA Session - 2/4 - Set weights and limits

Define weights and min/max acceptable values

Weight method: Fixed point scoring

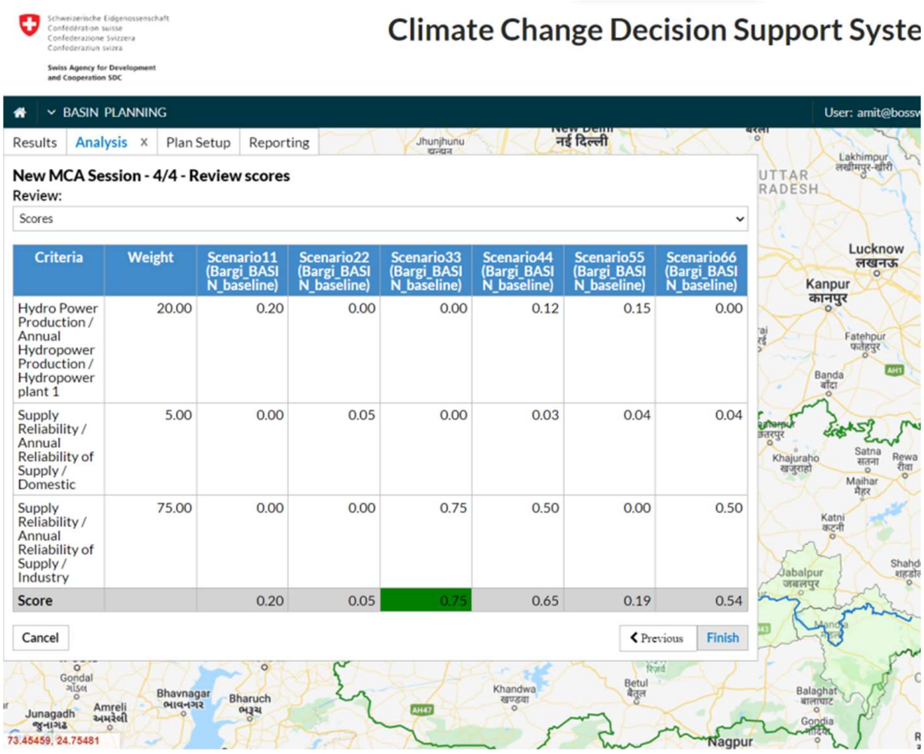
	Unit	Weight	Min value	Max value
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	GWh	20.00		
Supply Reliability / Annual Reliability of Supply / Domestic	m^3/s	5.00		
Supply Reliability / Annual Reliability of Supply / Industry	m^3/s	75.00		

Figure 36: Weights assigned to industry stakeholder

d) Step 4: Examine results

Using indicators and weightages CC-DSS will calculate the final score for all the stakeholders as shown below

- Industry Stakeholders



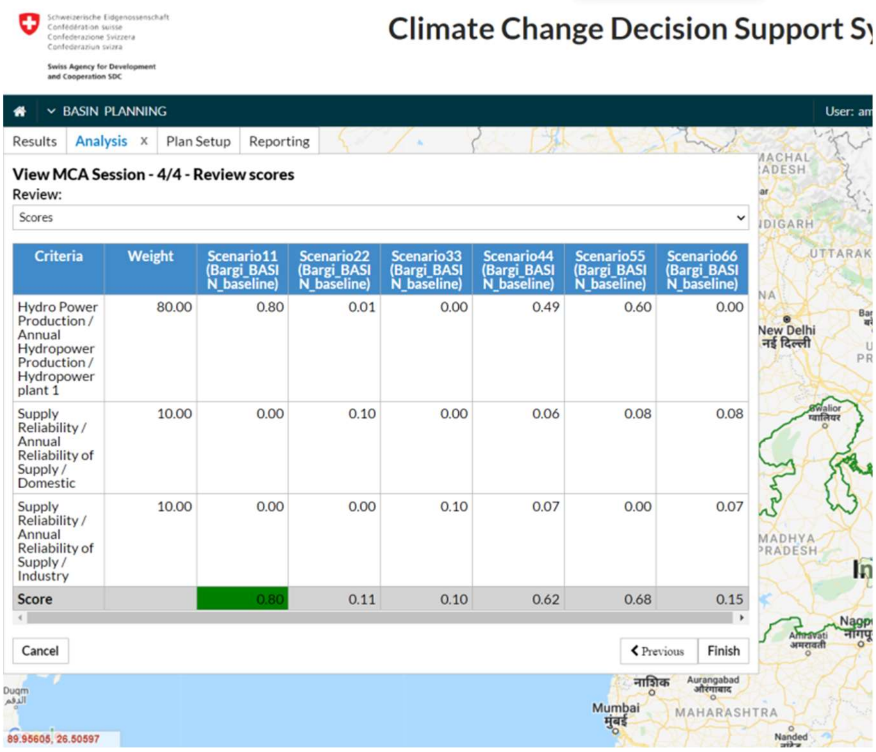
New MCA Session - 4/4 - Review scores

Review: Scores

Criteria	Weight	Scenario11 (Bargi_BASIN_baseline)	Scenario22 (Bargi_BASIN_baseline)	Scenario33 (Bargi_BASIN_baseline)	Scenario44 (Bargi_BASIN_baseline)	Scenario55 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	20.00	0.20	0.00	0.00	0.12	0.15	0.00
Supply Reliability / Annual Reliability of Supply / Domestic	5.00	0.00	0.05	0.00	0.03	0.04	0.04
Supply Reliability / Annual Reliability of Supply / Industry	75.00	0.00	0.00	0.75	0.50	0.00	0.50
Score		0.20	0.05	0.75	0.65	0.19	0.54

Figure 37: Calculated scores for industry stakeholder

- Power Stakeholder



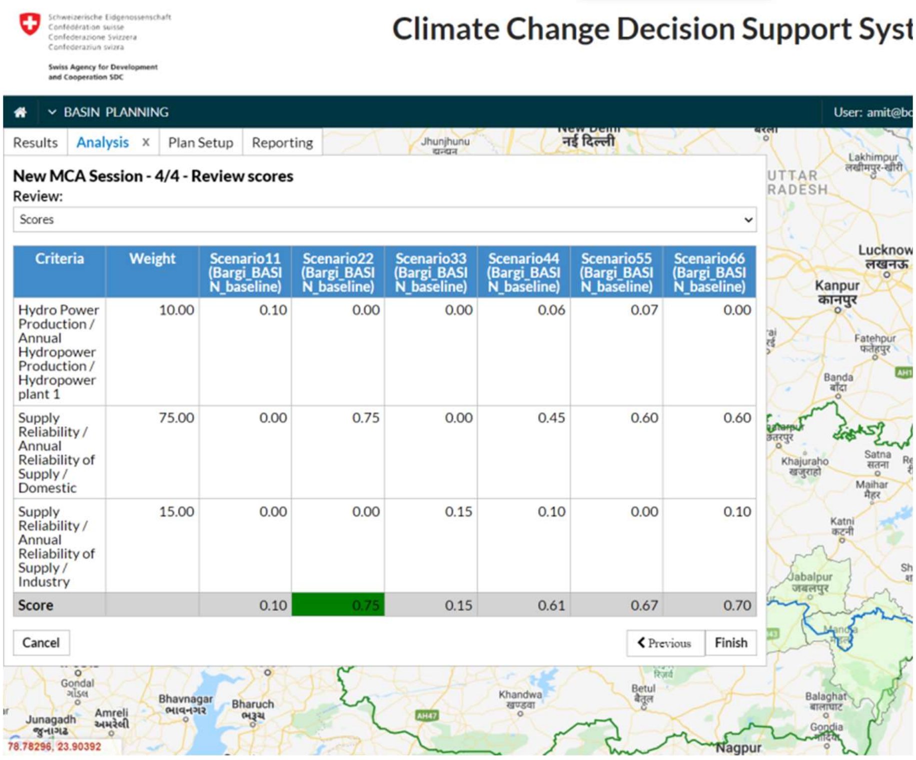
View MCA Session - 4/4 - Review scores

Review: Scores

Criteria	Weight	Scenario11 (Bargi_BASIN_baseline)	Scenario22 (Bargi_BASIN_baseline)	Scenario33 (Bargi_BASIN_baseline)	Scenario44 (Bargi_BASIN_baseline)	Scenario55 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	80.00	0.80	0.01	0.00	0.49	0.60	0.00
Supply Reliability / Annual Reliability of Supply / Domestic	10.00	0.00	0.10	0.00	0.06	0.08	0.08
Supply Reliability / Annual Reliability of Supply / Industry	10.00	0.00	0.00	0.10	0.07	0.00	0.07
Score		0.80	0.11	0.10	0.62	0.68	0.15

Figure 38: Calculated scores for power stakeholder

- Municipality Stakeholder



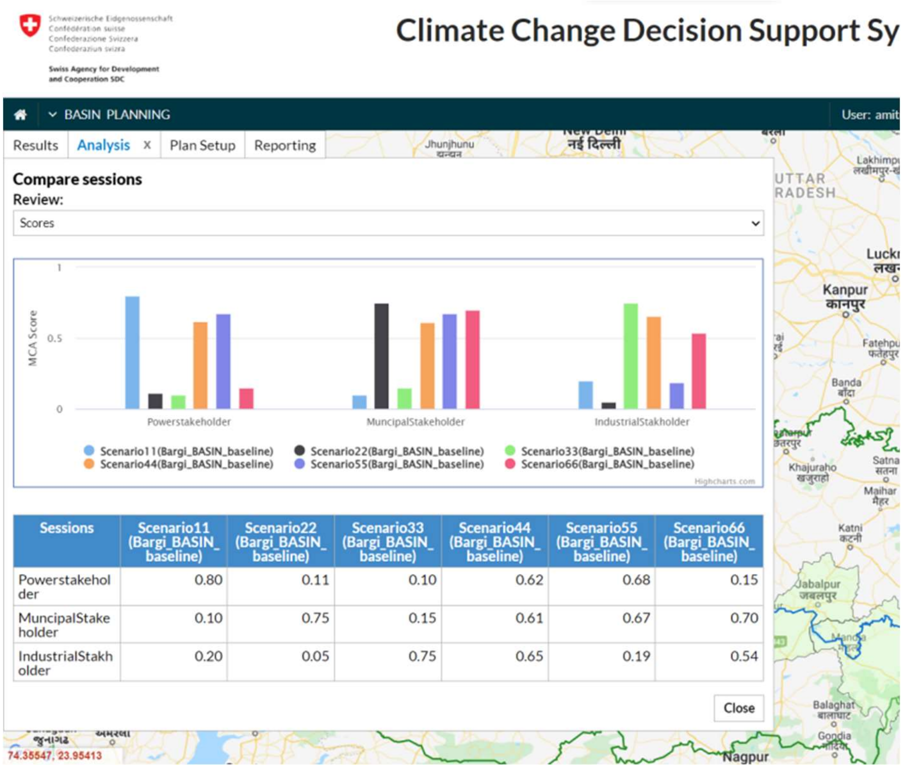
New MCA Session - 4/4 - Review scores

Review: Scores

Criteria	Weight	Scenario11 (Bargi_BASIN_baseline)	Scenario22 (Bargi_BASIN_baseline)	Scenario33 (Bargi_BASIN_baseline)	Scenario44 (Bargi_BASIN_baseline)	Scenario55 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Hydro Power Production / Annual Hydropower Production / Hydropower plant 1	10.00	0.10	0.00	0.00	0.06	0.07	0.00
Supply Reliability / Annual Reliability of Supply / Domestic	75.00	0.00	0.75	0.00	0.45	0.60	0.60
Supply Reliability / Annual Reliability of Supply / Industry	15.00	0.00	0.00	0.15	0.10	0.00	0.10
Score		0.10	0.75	0.15	0.61	0.67	0.70

Figure 39: Calculated scores for municipality stakeholder

Based on scenarios in the Bargi application, the indicator values are calculated, and the following ranks are assigned to different scenarios -



Compare sessions

Review: Scores

Sessions	Scenario11 (Bargi_BASIN_baseline)	Scenario22 (Bargi_BASIN_baseline)	Scenario33 (Bargi_BASIN_baseline)	Scenario44 (Bargi_BASIN_baseline)	Scenario55 (Bargi_BASIN_baseline)	Scenario66 (Bargi_BASIN_baseline)
Powerstakeholder	0.80	0.11	0.10	0.62	0.68	0.15
MuncipalStakeholder	0.10	0.75	0.15	0.61	0.67	0.70
IndustrialStakholder	0.20	0.05	0.75	0.65	0.19	0.54

Figure 40: Result comparison based on Multi Criteria Analysis

Conclusion

With all the scenarios created, scenario44, which proposed to cater development in all sectors. Scenario44 scored equally in all the sectors which shows development of all the sectors simultaneously whereas all other scenarios have gained poor ranks in terms of performance for all the three stakeholders. Thus, the decision-makers can choose to go with scenario44 considering its optimum performance under the situation assumed in the example.

Problem and purpose Identification

Problem Identification: Following are the relevant and important concerns pertaining to integrated water resource management in the basin, which need to be addressed through new and emerging science-based techniques and tools -

1. *Lack of a centralised water database:* Need to handle information from diverse physical and social datasets, and to develop holistic and integrative database for planners. Information on the state of water resources is a must for planning and developing resources management strategy. New technologies like GIS and Remote sensing together with domain skills have proven their application in successful mapping, evaluation, and developing strategies for water resources. This includes all varied sources data collection, standardization, and storage of the entire gamut of information on a nationalized scale. Hence, providing an operational system for all kind of users with increased visibility and global standard platform on public domain is necessary for the following:
    - To address complex interaction at basin scale and evaluate various future scenarios
    - Equitable sharing of water
    - Efficient sectoral demand management
    - Long term and seasonal planning
2. Availability *and accessibility to water:* Access to water for drinking and other domestic needs continues to be a problem in many areas. Skewed availability of water between different regions and different people in the same region and the intermittent and unreliable water supply system have the potential of causing social unrest.
3. *Fragmented planning:* Water resources projects, though multi-disciplinary with multiple stakeholders, are being planned and implemented in a fragmented manner without giving due consideration to optimum utilization, environment sustainability and holistic benefit to the people.
4. *Water sharing disputes and understanding among stakeholders:* Inter-regional, inter-State, intra-State, as also inter-sectoral disputes in sharing of water, strain relationships and hamper the optimal utilization of water through scientific planning on basin/sub-basin basis.
5. Lack *of digitalisation for infrastructure monitoring:* inadequate maintenance of existing irrigation infrastructure has resulted in wastage and under-utilization of available resources. There is a widening gap between irrigation potential created and utilized. Natural water bodies and drainage channels are being encroached upon and diverted for other purposes.

6. *Low consciousness* about the overall scarcity and economic value of water results in its wastage and inefficient use. The lack of adequately trained personnel for scientific planning, utilizing modern techniques and analytical capabilities incorporating information technology constrains good water management. A holistic and inter-disciplinary approach at water related problems is missing.
7. *Sharing amongst stakeholders:* The public agencies in charge of taking water related decisions tend to take these on their own without consultation with stakeholders, often resulting in poor and unreliable services characterized by inequities of various kinds.

CC-DSS can help in building climate resilience of the various water users through scientific decision making for adaptation planning in the sub-basin area. The purpose of the system is too upscale the last developed Climate change decision support system in terms of functionalities and applicability towards the dams with multipurpose. It was important to upscale the CC-DSS to increase its applicability for all type of dams. The following section emphasises on need and purpose of the upscaling of CC-DSS by bringing all dams having allocations

1. The CC-DSS is purposefully designed in such a way that it involves planning, development, and management of water resources to be governed by common integrated perspective considering local, regional, State, and national context, keeping in view the human, social and economic needs.
2. The developed system can be a robust part of good governance. The multiuser management is required to transparent informed decision making which is crucial to the objectives of equity, social justice, and sustainability.
3. The CC-DSS will bring meaningful intensive participation, transparency and accountability should guide decision making and regulation of water resources. Water needs to be managed as a common pool community resource held, by the state, under public trust doctrine to achieve food security, support livelihood, and ensure equitable and sustainable development for all.
4. Water is essential for sustenance of eco-system, and therefore, minimum ecological needs should be given due consideration. Safe Water for drinking and sanitation should be considered as pre-emptive needs, followed by high priority allocation for other basic domestic needs (including needs of animals), achieving food security, supporting sustenance agriculture and minimum eco-system needs. The CC-DSS with modelling capabilities allows to assign priorities to different users.
5. Available water, after meeting the above needs, should be allocated in a manner to promote its conservation and efficient use. All the elements of the water cycle, i.e., evapotranspiration, precipitation, runoff, river, lakes, soil moisture, and ground water, sea, etc., are interdependent and the basic hydrological unit is the river basin, which should be considered as the basic hydrological unit for planning. The knowledgebase section of CC-DSS encompasses all major global datasets on different components and provides a complete dynamic of hydrological cycle.

Given the limits on enhancing the availability of utilizable water resources and increased variability in supplies due to climate change, meeting the future needs will depend more on demand management, and hence, this needs to be given priority, especially through (a) Optimised allocation which economizes on water use and maximizes value from water, and (b) bringing in maximum efficiency in use of water and avoiding wastages. The impact of climate change on water resources availability must be factored into water management related decisions. Water using activities need to be regulated keeping in mind the local geo climatic and hydrological situation.

Need based scenario development

The CC-DSS application can be used as a planning and management tool capable of assisting users to plan and manage water resources after careful assessment of the water availability, distribution and allocation policies and operational behaviour of the entire project system in a catchment or river basin level. The tool allows users to work on hydrological models simultaneously across different user groups thus making sure the completeness of data and common understanding about the operation of the system. The stakeholders can now test the response of the system based on different management policies or scenarios. Scenario generation is a key functionality whereas the stakeholder does not need to be an expert of hydrological modelling. The user may be a Govt. or, a dam authority official who by, knowing the various components of the system can create different operation situations by editing the components which are actually water users. The modeler can add all possible water users, which are identified by the decision-makers to be included in one or more of the scenarios.

When creating a scenario, the user will get an overview of all the available water users which are embedded in the model and select/deselect the same to be included in any scenario. In addition to adding or removing water users, the user can also modify existing water users, e.g., increase the area of an irrigation scheme, change in the initial water level of the existing reservoir etc. The examples of scenario creation are provided with example further in this chapter.

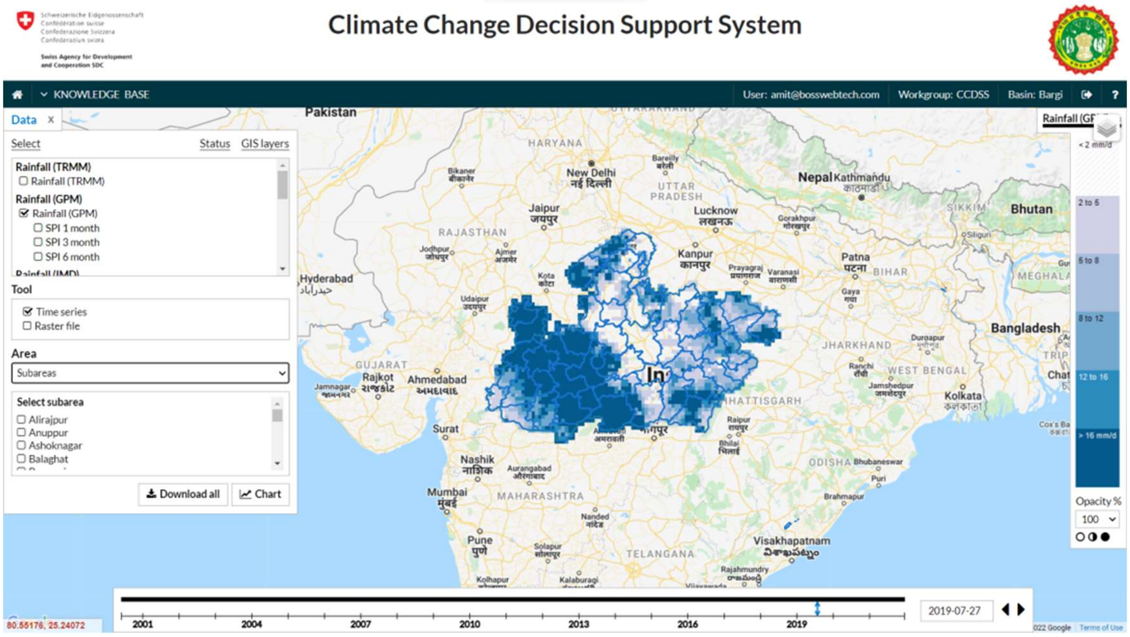
Under basin planning and management modules of the CC-DSS, following are the key functionalities, which can be used by user for decision making –

- Assessing water availability, demands, deficits, varying water level in storages, across different simulation time, using uploaded model and results in form of reporting and graphical representation.
- Creating different scenarios, by adding, deleting, entire component or by modifying their values.
- Providing management policy and operation restrictions in form of reduction levels of the reservoirs, changing hydropower efficiencies, crop areas, type of crops, adding/ removing crops, changing demands by computing population growth and per capita requirements for future
- Changing rainfall input by increasing or decreasing by percent values, this creating dry or wet water year period and to rerun model to see its performance allowing users to cater to water need in more informed and efficient manner.
- Performance is usually quantified by indicators, which are derived numbers from model properties, model inputs, and most importantly model results. CC-DSS calculates indicators based on the model inputs and qualifies and rank the performance.

Upscaling a CC-DSS for multiple dams

CC-DSS can be upscaled easily and used on other dams of Madhya Pradesh. CC-DSS has the following functionalities which make upscaling of CC-DSS for multiple dams

- It is a web-based application, and it doesn't need any installation for the user computer. Any user from any dam location can access it via internet. Every user can access it directly from MPWRD server.
- It has satellite data available for whole Madhya Pradesh



Climate Change Decision Support System

User: amit@bosswebtech.com
Workgroup: CCDSS
Basin: Bargi

Rainfall (TRMM)
☐ Rainfall (TRMM)
Rainfall (GPM)
☑ Rainfall (GPM)
☐ SPI 1 month
☐ SPI 3 month
☐ SPI 6 month

Tool
☑ Time series
☐ Raster file

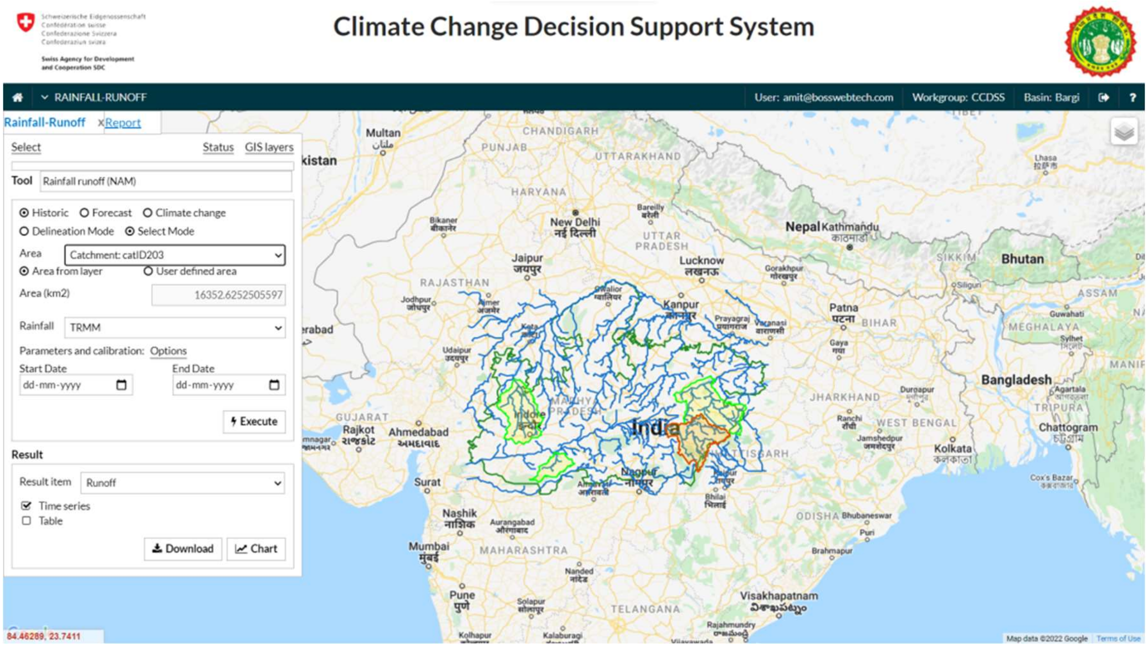
Area: Subareas

Select subarea
☐ Alirajpur
☐ Anuppur
☐ Ashoknagar
☐ Balaghat

2019-07-27

Figure 41: Data downloading and processing for MP

- For preliminary study the user can use rainfall runoff module to calculate runoff at any point of interest in any sub catchment within the catchment.



User: amit@bosswebtech.com
Workgroup: CCDSS
Basin: Bargi

Tool: Rainfall runoff (NAM)

Area: Catchment: catID203

Area (km2): 16352.6252505597

Rainfall: TRMM

Start Date: dd-mm-yyyy

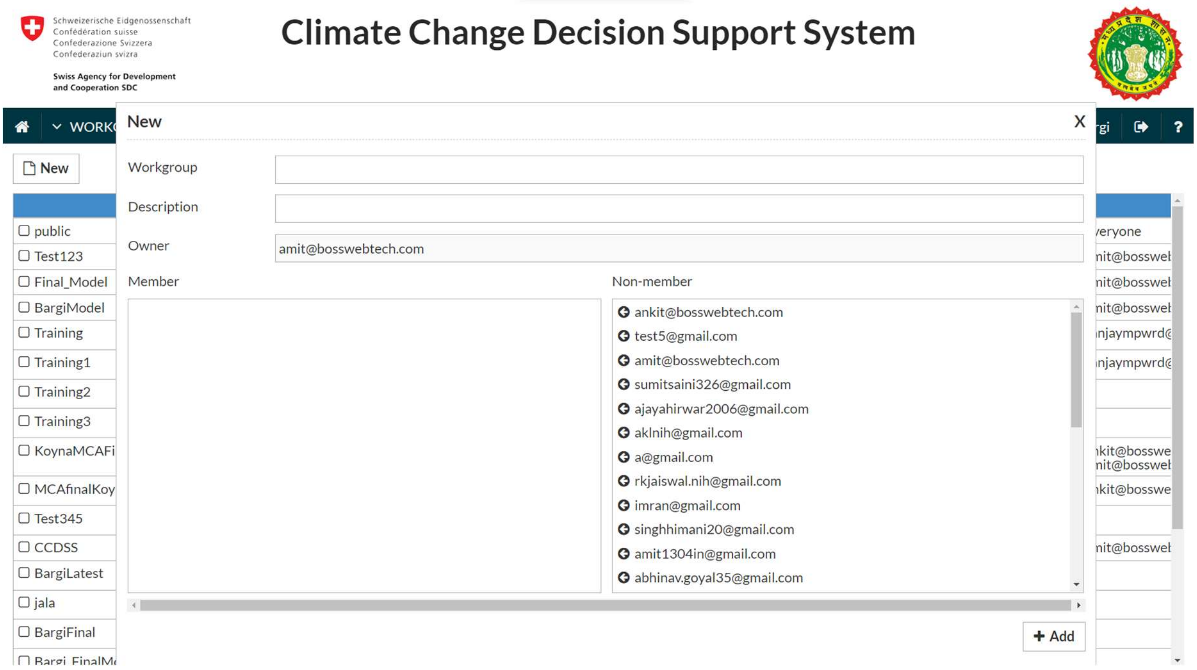
End Date: dd-mm-yyyy

Result item: Runoff

84.46289, 23.7411

Figure 42: Flow drainage available for MP

- It supports basin- wide user login which allows different users from various basins can work on CC-DSS simultaneously.
- Multiple users can also work together in the same basin and develop various scenarios for uploaded model by creating various workgroups. Members of the workgroup can review and clone the works of other team members available in the workgroup.



public
Test123
Final_Model
BargiModel
Training
Training1
Training2
Training3
KoynaMCAFi
MCAfinalKoy
Test345
CCDSS
BargiLatest
jala
BargiFinal

Workgroup:

Description:

Owner: amit@bosswebtech.com

Non-member:

ankit@bosswebtech.com
test5@gmail.com
amit@bosswebtech.com
sumitsaini326@gmail.com
ajayahirwar2006@gmail.com
aklnih@gmail.com
a@gmail.com
rkjaiswal.nih@gmail.com
imran@gmail.com
singhhimani20@gmail.com
amit1304in@gmail.com
abhinav.goyal35@gmail.com

Figure 43: Adding workgroup for teamwork at basin level

- The CC-DSS also supports online modelling using for single reservoir system. The user can easily delineate the catchment at point of interest and then convert it into a complete water balance model by adding reservoir and users for that reservoir. User can also create scenarios after creating model to check various demand side situations

Usage of CC-DSS in the Govt's planning process

Strengthening water resources management is crucial in adopting adaptation measures to combat the projected climate change and related changes in terms of rainfall, water use patterns, and water quality. The adoption measures have to be implemented in a more timely and integrated manner as part of climate change management. In addition, the storage capacity of water resources needs to be increased by various means. These adaptation measures are at the core for climate change adaptation. The development and deployment of new technologies should be encouraged from the medium- to long-term perspective. Regarding the managing the industrial water use, readjusting the industrial structure according to the availability of water resources. However, because of its considerable socioeconomic implications, this option needs careful consideration.

Planning and empowerment regarding IWRM

Conventional water resources management has some drawbacks, including top-down and fragmented decision-making processes with little coordination between different sectors, and a disproportionate emphasis on the supply side and technical aspects. CC-DSS can help in water resources management process for achieving two objectives:

a. integrating all forms and phases of the water cycle (surface and groundwater, water quantity and quality, land use, ecosystems, etc.), all water-related sectors (flood control, water supply, irrigation water, industrial water, water for power generation, water for environmental enhancement, etc.), and a wide range of stakeholders; and
b. Water use and control practices required to secure the quantity and quality of water resources to support the achievement of a sustainable and flourishing society, notably optimal water allocation to different water users through cooperation and coordination among them. The impacts of a changing climate suggest that it is increasingly necessary to reconcile conflicting interests over the use and allocation of water resources. Developing systems for water use allocation and coordination is possible with the help of CC-DSS.

Monitoring and data collection regarding water resources

Water use coordination essentially requires collecting, accumulating, disclosing, and sharing data on the amount of water resources (rainfall, reservoir storage, river discharges, groundwater potential, groundwater levels, water quality, etc.), and on water allocations (water intakes, water demand, and related seasonal changes, etc.). CC-DSS knowledgebase and user management can help all the stakeholders to manage data which can be used in planning processes.

Making water use more efficient with demand-side management

It is necessary to utilize the finite source of water efficiently to minimize vulnerability to climate change impacts. Measures to reduce water demand provide an effective solution to this end. Such measures include:

- Promoting water-saving irrigation technologies (drip irrigation, etc.).
- cultivating to crops with low water requirements.
- Increasing utilization efficiency by improving irrigation canals (lining, better maintenance, etc.).
- Promoting the rational use of industrial water (reuse, cascade use, water-saving processes, and use of water efficient equipment).
- Reducing water use (fair water pricing, metered charging, progressive charging, water-saving equipment).

CC-DSS has the capability to develop online MIKE HYDRO Basin model and scenarios for assessing all the above situations for water resource planning and analyse the impact of climate change.

Readjusting the industrial structure

The idea of readjusting the industrial structure according to the availability of water resources, may entails social and economic implications. However, some examples may be:

- Reviewing of water-intensive industries in water scarce areas,
- Developing water use facilities and establishing industries in underdeveloped regions. This option; however, may, needs careful consideration due to other implications.

Cost-benefit analysis:

The rationale behind cost-benefit analysis is that a certain course of action should only be pursued if its net present value is positive. To this end, cost-benefit analysis estimates in monetary terms both the costs and benefits of that course of action. Often, this requires that assumptions are made about elements in the cost or benefit decision for which there are no markets: for those elements, monetary values must be derived through purpose-developed valuation techniques. In all cases, cost and benefits that accrue in the future are valued less than those that accrue in the present, a practice that is referred to as ‘discounting’.

Cost-benefit analyses can be especially useful for decisions involving non-market goods and services, such as those related to emissions of greenhouse gases: lacking market signals about those goods and services, cost-benefit analysis can be used to estimate the costs and benefits associated with a project that impacts on the said goods and services. In general, cost-benefit analysis has become commonplace for most public policy decisions with potentially large economic impacts.

Cost-benefit analysis can be used to assess the feasibility of a project, to justify investment programmes or identify appropriate cost reduction strategies, and to quantify hidden costs and intangible benefits. In all these instances costs-benefit analysis acts as an accountability mechanism that helps justify the course of action taken. In the area of climate change, cost-benefit analysis has been used in most sectors, from infrastructure projects, where purely financial criteria, like returns on investment, play a key role in the decision-making process, to projects aimed at accounting for non-market goods and services, such as those involved in afforestation projects, where financial issues play a much less important role. When it comes to the latter, cost-benefit analysis arguably should be complemented with other types of analysis, such as multi-criteria decision analysis

Multi-criteria decision:

This analysis multi-criteria decision analysis refers to a range of formalised methods that are used as input to the decision-making process in situations where uncertainty is high, objectives are different or even conflicting, metrics are heterogeneous, and complex systems are the subject of the analysis. Multi-criteria decision analysis (i) takes account of multiple objectives through the criteria it uses, and the weight each criterion is given; (ii) involves a transparent process that produces easy to-communicate results; and (iii) provides results in a manner that supports stakeholder engagement, without incurring prohibitive financial costs or requiring unreasonably long-time frames.

Still today cost-benefit analysis is the decision support tool that enjoys most popularity as aid to decision making within climate change (and more broadly environmental management). This is partly because cost-benefit analysis has been widely used in most public policy decision processes, owing to its strong economic focus. Familiarity with the tool has helped extend its use to decision-making for climate change. Multi-criteria decision analysis is emerging as the tool of choice in decision processes faced with multiple metrics, or diverse and sometimes conflicting priorities.

Multi-criteria decision analysis has been suggested as particularly well-suited to planning for climate change. Reasons cited include: (i) it allows for an integrated treatment of socio-economic, ecological, institutional and ethical perspectives; (ii) it can take into account issues such as morbidity and mortality, equity, environmental damage, catastrophic risks and uncertainty; and (iii) its application is not limited to areas that can be described fully through monetary values. In its simplest form, multi-criteria decision analysis provides several options (for managing the problem of interest) against a range of indicators. Each indicator reflects the extent to which a criterion considered of importance for the decision is met. The option whose aggregate score is highest will in principle be the most appropriate option for responding to the problem being analysed.

Interdepartmental usage of the CC-DSS

The water resources management practices in India are governed by different departments. Since, water being the state subject, it’s often the state agencies controlling the water on ground. Even within the states, there are different departments, looking at different water sectors, like agriculture, environment, hydropower etc, but all encompasses and harness the water. The CC-DSS however, will bring all these sectors together to present a holistic plan for water resource management. The Decision support systems for planning/management can harness vast data sources, facilitating collection, storage, access, analysis, visualization, and collaboration by scientists, analysts, and decision-makers. Such technologies allow for rapid scenario building and testing using many different variables, enhancing capacity to measure the physical impacts of climate change. These technologies are managing an increasing volume of data from satellite instruments, in situ (direct) measurement networks, and increasingly detailed and high-resolution models. Thus, the ground information and assessments which are performed by different departments can be validated and any gaps can be filled.

The CC-DSS will play a key vital role once adopted by different departments managing/harnessing water

1. Participation and Coordination Mechanisms: The CC-DSS can cater to different sectoral needs and departmental concerns, hence bringing more coordinated approach towards climate change and water management.

2. Flexibility of involving several stakeholders/departments as a user group in decision-making: The user management capabilities of CC-DSS will create flexibility of involving different stakeholders.

3. Fostering Information Sharing and Exchange of technologies: The different departments can exchange the best practices and data and the in-house developed tools to cultivate information and collaboration.

4. Every organization needs to have well trained and experienced people to perform various activities. If current or potential employees can meet these requirements, training is not important. On the other hand, if this is not the case, it is necessary to raise the skill levels and increase the versatility and adoptability of the employees.

Trainings

Training Need Assessment

Training is a planned process to improve of upgrade the attitude, knowledge, or skills through learning capacities of the individuals to satisfy the current and future needs of the organization.

The personnel who are already available or chosen to carry out the modelling, scenario generation or scenario analysis may have to be trained through special courses or by “on the job training” to ensure that these personnel are thoroughly trained to carry out the required work properly.

A systematic plan of action of any training programme includes:

- Identification and assessment of the need for planned training
- Defined training objectives
- Appropriate strategy for training
- Provision for assessing effectiveness of training

Training of Professionals

Hands-on training on MIKE HYDRO Basin modelling, scenario generation using CC-DSS and climate change analysis will be required. It should start with an overview of the core principles of numerical modelling and cover the data preparation, model development and climate change analysis.

Training should be oriented to the practical application of insights from theory and analysis. The lectures should cover key theoretical principles and illustrate how the theories are applied in modelling. The modelling approach for water resource evaluations as implemented in MIKE HYDRO Basin allows user to conduct a diversity of management and planning related applications. MIKE HYDRO Basin is the ideal software for

- Multisector solution to water allocation and water shortage problems
- Climate change impact assessments on water resources availability and quality
- Evaluation and improvement of irrigation scheme performance
- Integrated water resources management (IWRM) studies

After modelling, training should cover the usage of CC-DSS for scenario generation and analysis of the results and performance indicators. Here is a general structure of the training curriculum for introduction and use MIKE HYDRO Basin and the CC-DSS.

Training	Course Description	Duration
Water Balance Model (MIKE HYDRO Basin)	MIKE HYDRO Basin is a multi-purpose, map-centric decision support tool for integrated river basin analysis, planning and management. MIKE HYDRO Basin is designed for analysing water use at the river basin level. A mathematical representation of the river basin is defined including the configuration of river and reservoir systems, catchment hydrology and water user schemes. Other modules are available for more detailed representation of irrigation, rainfall-runoff processes, river routing, surface water-groundwater interaction, and water quality processes. This course should cover following topics: • Introduction to the MIKE HYDRO Basin modelling framework • Introduction to model design • Operational framework and water user allocation rules • Result presentation and analysis • Groundwater and river routing modelling • Detailed irrigation demand and management analysis • Hydrological modelling	3 Days
CC-DSS Overview	Describe decision support systems and their benefits and analyse their role in management support. This course should give the conceptual idea of CC-DSS components and data flow. This training should cover the overall flow of CC-DSS • How are models connected to CC-DSS? • How new scenarios can be generated? • How to clone of existing scenarios? • How models can be simulated for climate change scenarios? • Post processing of results	1 Day

	Courses will focus on applying the IT technologies, tools and mathematical models in operational mode, where the participants walk through all the important workflow processes.	
Scenario Generation and Indicators	Objective of this course should be to carry out baseline assessments using readily available data, impact assessments through the analysis of the data, planning options and a means for disseminating information to relevant groups or individuals. Understanding how to use these tools is an important aspect of the future operational use. Detail training of scenario generation, processing of climate change data and using case studies.	2 Days
Data and Tools	CC-DSS provides suitable and user-friendly interface for automatic downloading and updating various type of satellite data into the system to keep CC-DSS up and running in future. This part of the trainings will cover timeseries tools. This course will also include adding/editing of time series, time series association with GIS feature class, plotting of time series on chart, running quality check functions.	2 Days
Online model development	Online catchment delineation Online Rainfall-runoff estimation using NAM Online Single reservoir model development Analysis of results	2 Days

Training of Decision makers

As the policy and decision makers take decision for reservoir operations and basin planning, it is necessary that they are aware of the capabilities of the CC-DSS, its usage and how CC-DSS can be used for informed decision making. For that, trainings and workshops for policy and decision makers should also be conducted periodically. This will enhance the efficiency and regularity in the system which will be useful for sustainability of CC-DSS

Training	Course Description	Duration
CC-DSS Overview	Describe decision support systems and their benefits and analyse their role in management support. This course should give the conceptual idea of CC-DSS components and data flow. This training should cover the overall flow of CC-DSS • How are models connected to CC-DSS? • How new scenarios can be generated? • How to clone of existing scenarios? • How models can be simulated for climate change scenarios?	1 Day

	- Post processing of results Courses will focus on applying the IT technologies, tools and mathematical models in operational mode, where the participants walk through all the important workflow processes and prove that they master the system confidently.	
Scenario Generation and Indicators	Objective of this course should be to carry out baseline assessments using readily available data, impact assessments through the analysis of the data, planning options and a means for disseminating information to relevant groups or individuals. Understanding how to use these tools is an important aspect of the future operational use. Detail training of scenario generation, processing of climate change data and indicator calculations.	2 Days
Data and Tools	CC-DSS provide suitable and user-friendly interface for automatic downloading and updating various type of satellite data into the system to keep CC-DSS up and running in future. This part of the trainings will cover timeseries tools. This course will also include adding/editing of time series, time series association with GIS feature class, plotting of time series on chart, running quality check functions.	2 Days

Deployment of CC-DSS in MP-WRD

CC-DSS is a web-based application and has been developed on top of MIKE OPERATIONS. Following are the system requirements:

Table 1: Minimum hardware requirement

S.No	Component	Configuration
1	**Operating System**	Windows 10/ Windows Server 2016 or later
2	**Processor**	Any configuration will work (Recommended i7 or higher**)**
3	**RAM**	Minimum 32 GB, expandable up to 128 GB
4	**Storage**	Minimum 1 TB of SATA/SSD, expandable up to 4 TB

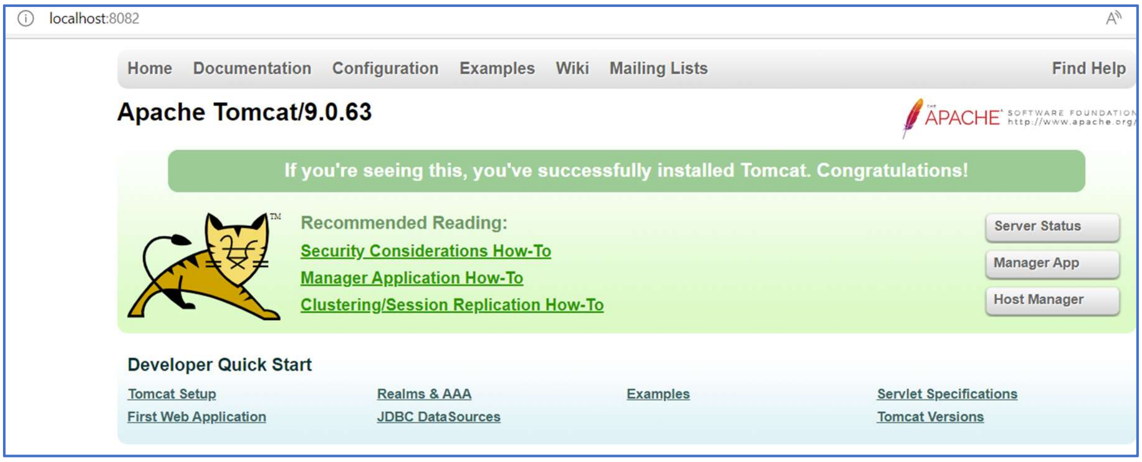
CC-DSS uses several components which are required to be installed on the server hosting CC-DSS. The details of the components are listed below:

Table 2: List of required software

S.No	Software Name	License Type
1	MIKE OPERATION 2020	License Required
2	MIKE HYDRO BASIN 2020	License Required
3	Geo Server 2.21	Open Source
4	NcWMS	Open Source
5	Anaconda	Open Source
6	PostgreSQL	Open Source

Here are the steps to configure the system on a server:

1. Install MIKE OPERATIONS 2020 Update 2
2. Install MIKE ZERO 2020 Update 1
3. Install Tomcat Apache 9.0.63 (https://tomcat.apache.org/download-90.cgi#9.0.63)
    a. Use port 8082 while installing Apache Server
    b. After installation, confirm that //<serverip>:8082/ is accessible and opening up Apache Tomcat home page (Figure 44).



Apache Tomcat/9.0.63

If you're seeing this, you've successfully installed Tomcat. Congratulations!

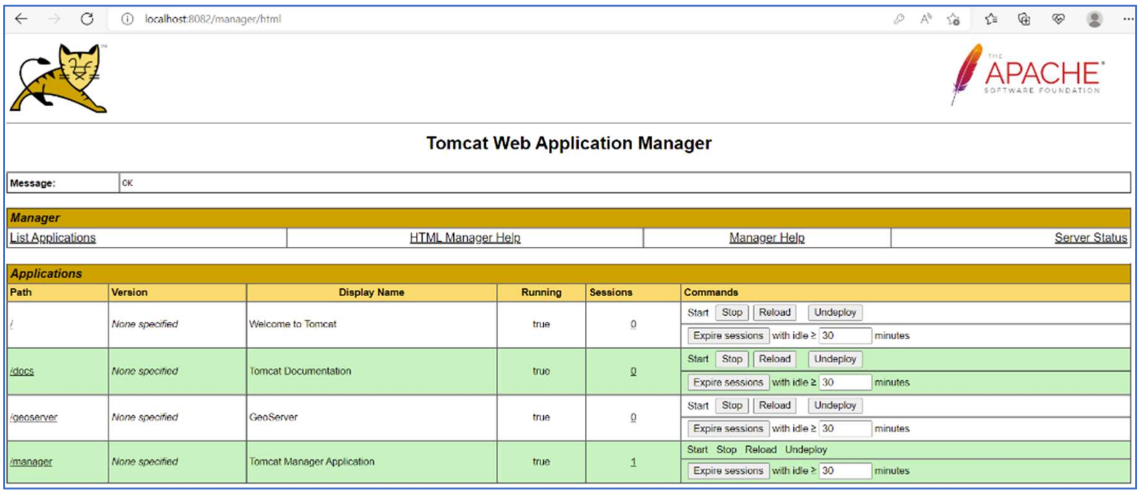
Recommended Reading:
Security Considerations How-To
Manager Application How-To
Clustering/Session Replication How-To

Developer Quick Start

Tomcat Setup	Realms & AAA	Examples	Servlet Specifications
First Web Application	JDBC DataSources		Tomcat Versions

Figure 44: Apache Tomcat home page

4. Install latest Geo Server (https://geoserver.org/download/)
   a. Install GeoServer using the instructions given here: https://docs.geoserver.org/latest/en/user/installation/win_installer.html
   b. Confirm that GeoServer is listed in Tomcat apps as shown in Figure 45.



Tomcat Web Application Manager

Message:	OK

Manager			
List Applications	HTML Manager Help	Manager Help	Server Status

Applications

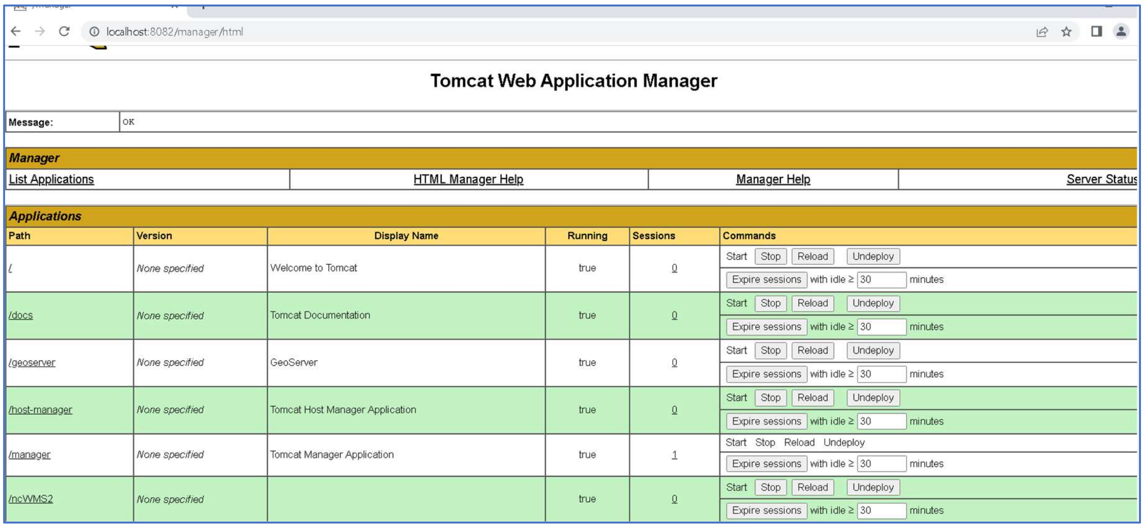
Path	Version	Display Name	Running	Sessions	Commands
/	*None specified*	Welcome to Tomcat	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/docs	*None specified*	Tomcat Documentation	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/geoserver	*None specified*	GeoServer	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/manager	*None specified*	Tomcat Manager Application	true	1	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes

Figure 45: GeoServer is listed in Tomcat apps

5. Install ncWMS (reading-escience-centre.github.io)

a. Install ncWMS using the instructions given in following link: https://reading-escience-centre.gitbooks.io/ncwms-user-guide/content/02-installation.html

   b. Confirm that ncWMS2 is listed in Tomcat apps as shown in Figure 46.



localhost:8082/manager/html

Tomcat Web Application Manager

Message: OK

Manager

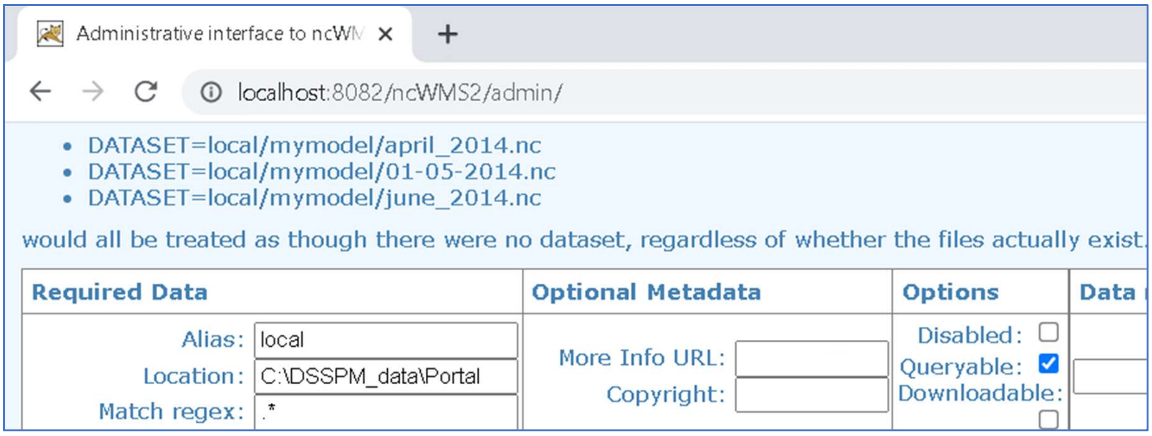
List Applications | HTML Manager Help | Manager Help | Server Status

Applications

Path	Version	Display Name	Running	Sessions	Commands
/	*None specified*	Welcome to Tomcat	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/docs	*None specified*	Tomcat Documentation	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/geoserver	*None specified*	GeoServer	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/host-manager	*None specified*	Tomcat Host Manager Application	true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/manager	*None specified*	Tomcat Manager Application	true	1	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes
/ncWMS2	*None specified*		true	0	Start Stop Reload Undeploy Expire sessions with idle ≥ 30 minutes

Figure 46: ncWMS2 is listed in Tomcat apps

c. Setup the path of knowledgebase data files so that it can be rendered using WMS. Go to admin interface of NCWMS2 in Tomcat server and configure the required data path as shown in the Figure 47:



localhost:8082/ncWMS2/admin/

- DATASET=local/mymodel/april_2014.nc
- DATASET=local/mymodel/01-05-2014.nc
- DATASET=local/mymodel/june_2014.nc

would all be treated as though there were no dataset, regardless of whether the files actually exist.

Required Data

Alias: local

Location: C:\DSSPM_data\Portal

Match regex: .*

Optional Metadata

More Info URL:

Copyright:

Options

Disabled: ☐

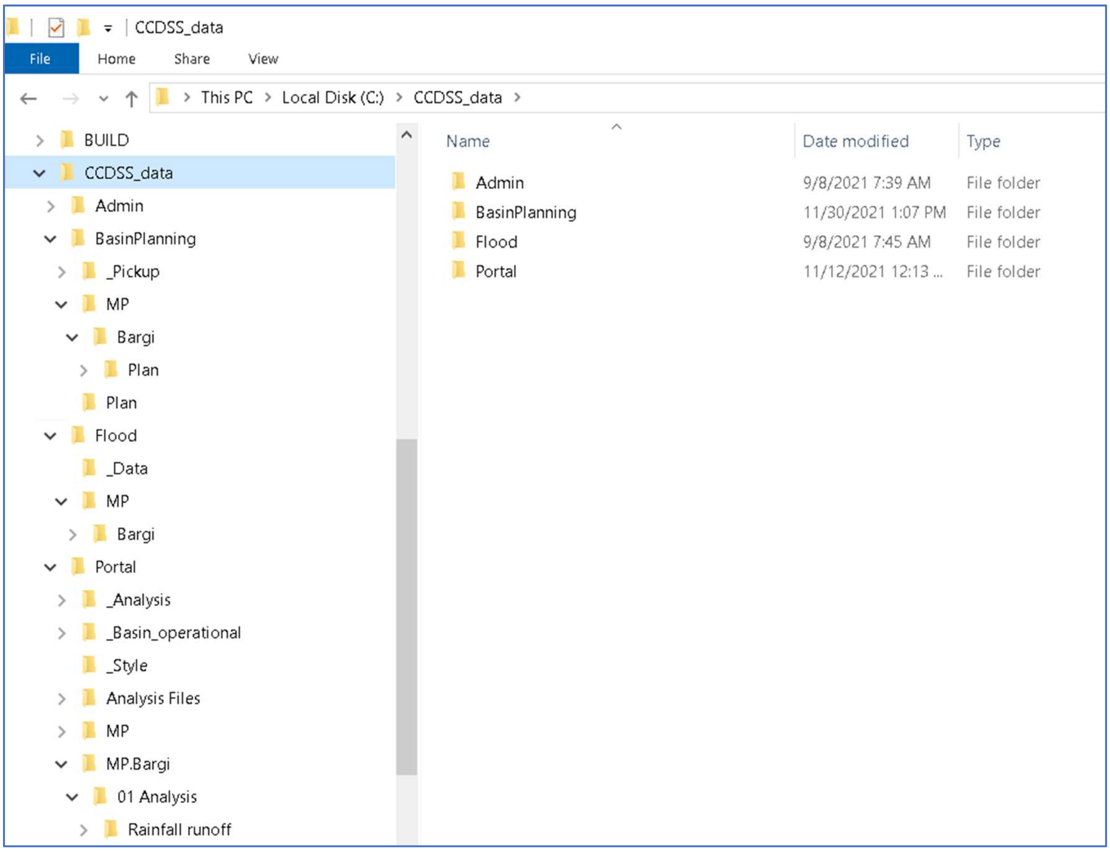
Queryable: ☑

Downloadable: ☐

Data

Figure 47: Configure the required data path in Tomcat Server

6. Configuration of data folder
   a. Create a folder named “CC-DSS_data” and move the provided content in his folder as shown in Figure 48.
   b. This folder consists of all uploaded models, satellite data, time series etc.



Name	Date modified	Type
Admin	9/8/2021 7:39 AM	File folder
BasinPlanning	11/30/2021 1:07 PM	File folder
Flood	9/8/2021 7:45 AM	File folder
Portal	11/12/2021 12:13 ...	File folder

Figure 48: Data folder structure

7. Host the website
   a. Create an application in IIS with the name “CC-DSS (Figure 49)”.
   b. Publish the provided binaries within this application.

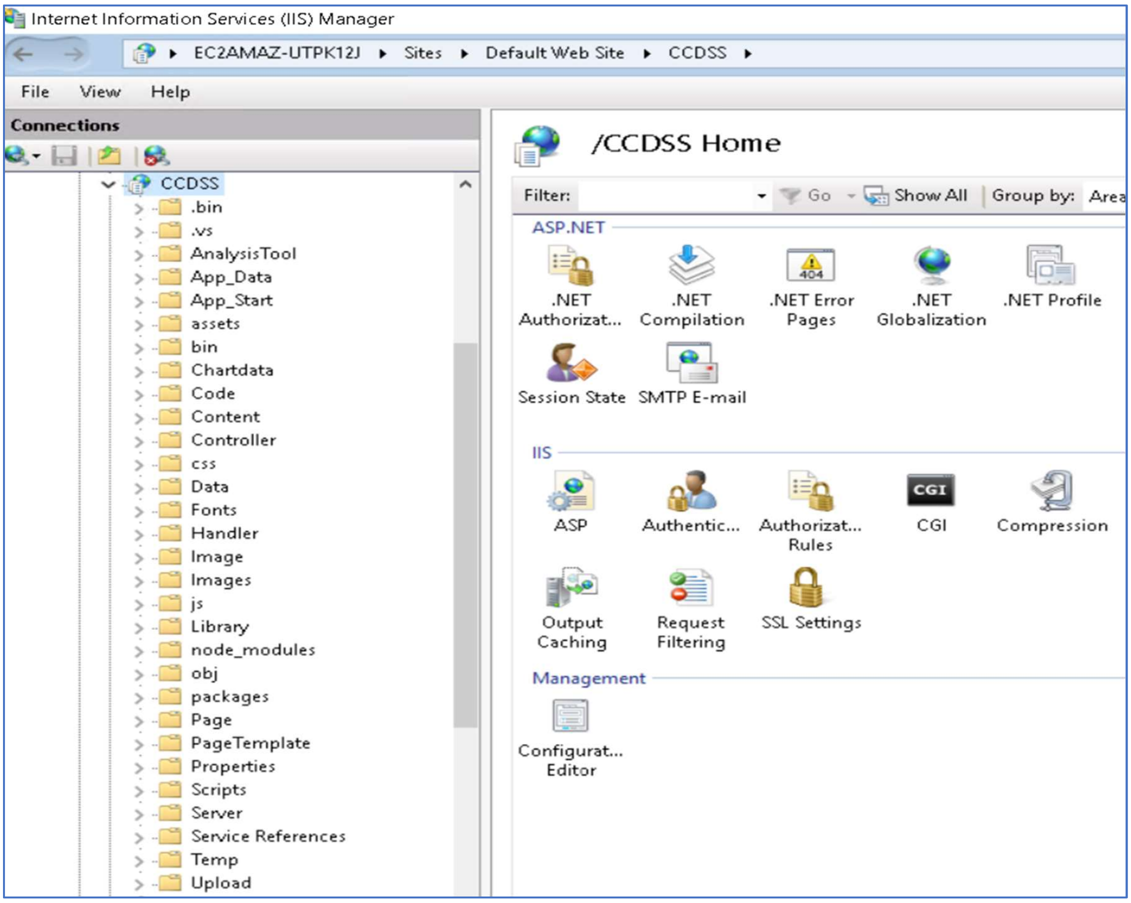


Figure 49: Create application in IIS

  c. Update the config.json file to include URL of Tomcat server.
  d. Update path of CC-DSS_data folder in config.json file.
  e. Confirm that website is accessible from browser.

8. Website should be ready to use.

Climate Change Decision Support System (CC-DSS) is a web based GIS aided tool for planning and management of multi-purpose dams. It supports online modeling and scenario generations based on climate change adaptions policies.

Figure 50: Home page CC-DSS

MPWRD is still in process of procuring the server for deploying CC-DSS. For now, website is hosted at 13.232.198.136/CC-DSS and is fully functional. Once the server is procured by MPWRD then it can be easily setup by following the above instructions.

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4. Sharma, K.D., Gosain A.K., (2010). Application of Climate Information and Predictions in Water Sector: Capabilities, Procedia Environmental Sciences, Volume 1, Pages 120-129, ISSN 1878-0296

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6. Patwardhan, S., Kulkarni, A. & Rao, K.K. Projected changes in rainfall and temperature over homogeneous regions of India. Theor Appl Climatol **131,** 581–592 (2018). https://doi.org/10.1007/s00704-016-1999-z

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Web resources

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2. http://www.mowr.gov.in/sites/default/files/WaterConservation-MP.pdf

3. https://doi.org/10.1007/978-3-030-57488-8_9

4. http://climatechange.mp.gov.in/sites/default/files/resources/MP_SectoralBrief_Water_Final_LR.pdf

5. http://www.climatechange.mp.gov.in/sites/default/files/resources/Madhya%20Pradesh%20Climate%20Change%20Vulnerabilities%20&%20Response%20Strategies.pdf

6. https://dolr.gov.in/sites/default/files/Madhya%20Pradesh_SPSP.pdf)

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10. http://climatechange.mp.gov.in/sites/default/files/resources/MP%20Climate%20Change%20Impacts.pdf

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development
and Cooperation SDC

A.1 Report on Model Development and Scenario Analysis

Finalisation of the Decision Support System for Water Resource Management for Reservoirs in Madhya Pradesh (MP)

Report on Model Development and Scenario Analysis

Phase 2

Prepared for: Swiss Agency for Development and Cooperation

Prepared by: BOSS Webtech Pvt Ltd. New Delhi

Team Leader	Amit Garg
Quality supervisor	Ankit Jain
Authors	Amit Garg, Jala Alora, Ankit Jain, Dr. O.P. Dubey

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Abbreviations

CC	Climate Change
CCA	Cultivable Command Area
DSS	Decision Support System
GCA	Gross Command Area
LBC	Left Branch Canal
MP	Madhya Pradesh
RABSP	Rani Avanti Bai Sagar irrigation project
RBC	Right Branch Canal
WRD	Water Resources Department
Ha	Hectare

Introduction

The Swiss Agency for Development and Cooperation's (SDC) Global Programme Climate Change and Environment (GPCCE) India is supporting the operationalization of climate change adaptation actions in the mountain states of Uttarakhand, Sikkim and Himachal Pradesh through the "Strengthening Climate Change Adaptation in Himalayas (SCA-Himalayas)" project that was launched in 2020.

First phase of project on Climate Change Decision Support System (CC-DSS) aimed at enhancing the decision-making capabilities of the Madhya Pradesh Water Resource Department (MPWRD) and other related stakeholders through scientific analysis of spatial and non-spatial data for improved water resource management from a climate change perspective. The Climate Change DSS is deployed and tested at the Samrat Ashoka Sagar (SAS) reservoir (Halali). The irrigation and water storage reservoir are located on Betwa River, which is a tributary of the Ganga River.

This CC-DSS can help in assessing the impacts of climate change on the SAS Reservoir System to support optimization of reservoir water balance and managing water releases for competing demands. In order to ensure wider applicability of the CC-DSS in the water resource planning and management process for the various surface water reservoirs across MP, there is a need to finalize the CC-DSS as a generic system that can be easily customized to a particular reservoir by the team of the MP Water Resources Department (MP-WRD). The Madhya Pradesh Water Resources Department aims to enhance the climate change decision support system for water resources in the state. This project conducts an analysis of the current and future water balance of Bargi Reservoir in the Upper Narmada Basin.

The unique capabilities of CC-DSS are assessing water availability, demands, deficits, varying water level in storages, all across different simulation time, using uploaded model and results in form of reporting and graphical representation; Creating different scenarios, by adding, deleting, entire component or by modifying their values ; Providing management policy and operation restrictions in form of reduction levels of the reservoirs, changing hydropower efficiencies, crop areas, type of crops, adding/ removing crops, changing demands by computing population growth and per capita requirements for future ; Prediction of future mitigation investments on predicted climate change on basins ; Performance is usually quantified by indicators, which are derived numbers from model properties, model inputs, and most importantly model results. CC-DSS calculates indicators based on the model inputs and qualifies and rank the performance.

Objectives of this project

The specific objectives of this project are:

1. To mainstream climate change concerns in water resources planning through informed decision-making processes.
2. To provide the water management authorities with a structured, user friendly, practical water resources management - climate change based DSS.
3. To enable users to
    - analyses climate - hydrological data,
    - run hydrological simulation models in conjunction with climate change models,

- run water allocation models and
- study the effect of potential decisions.

4. Testing of any new/additional schemes proposed to the basin, by estimating water availability and distribution from the source for future scenarios with climate change effects with and without application
5. Selection of pilot basin as Upper Narmada Basin at Bargi reservoir as sources of water and carry out Water balance modelling for Bargi Reservoir
6. Develop and update the existing CC-DSS platform for Bargi reservoir and prepare water balance model
7. Provide capacity development training for the Generic CC-DSS to the stakeholders on both the dashboard and model development in MIKE HYDRO BASIN, which facilitates the following general objectives of Generic-CC-DSS
    - To meet future demand based on optimal use of water storage and allow decision makers to assess the impact of potential adaptation options under various scenarios.
    - To enable WRD to compare and evaluate various climate change adaptation options against business-as-usual activities.
    - To support the WRD in scaling up this pilot to other sub basin/basins and showcase climate change mainstreaming into Integrated Water Resource Management (IWRM).

Overview of Upper Narmada Basin

The Narmada Basin running generally from east to west in Madhya Pradesh occupies a central position in the State. The river Narmada has its source at Amarkantak in Shahdol District at an elevation of about 1,068.8m for about 1,079 km. the river runs through M.P. in the districts of Mandla, Jabalpur Narsinghpur, thereafter for about 40 km. it forms the common boundary between Maharashtra and Gujarat. It then runs through Gujarat for about 160 km. before falling in the Gulf of Khambhat near Broach. The current project focuses on the upper Narmada basin from the origin until an existing river GD station at Barmanghat as seen in Figure 51 It is in Jabalpur.

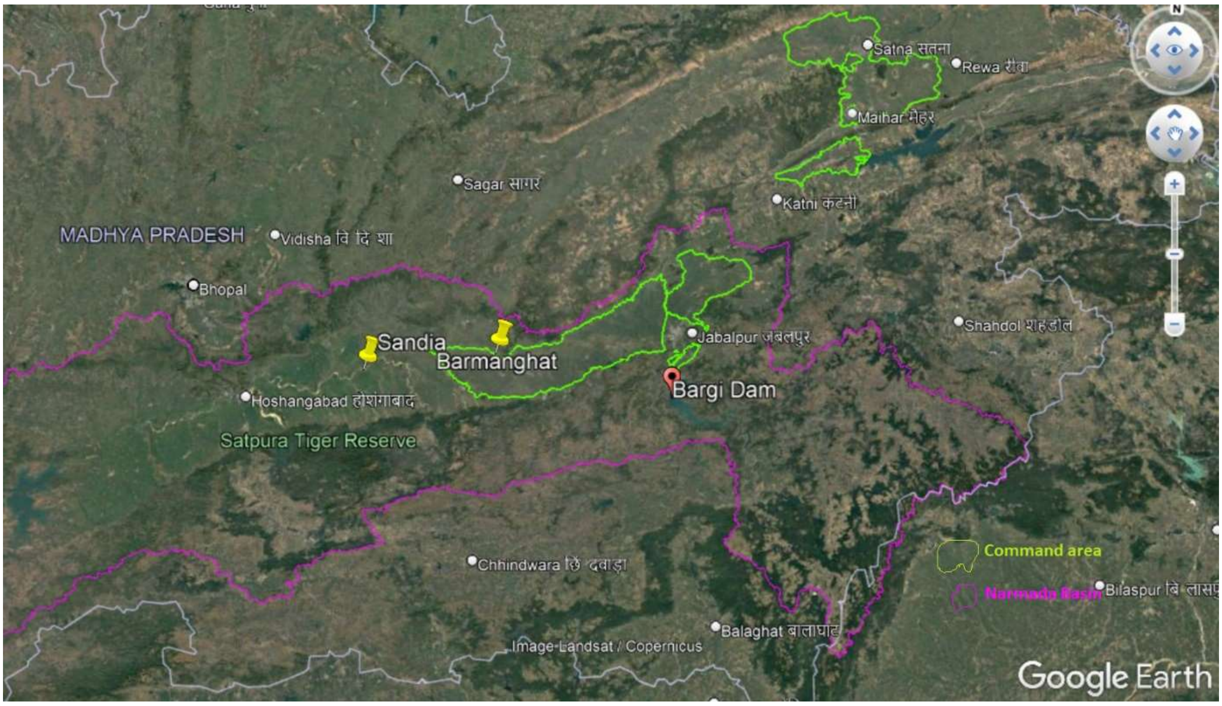


Figure 51: Catchment of Narmada River

The Rani Avanti Bai Sagar irrigation project is situated within this catchment area, and the storage reservoir of this project is called Bargi dam. Rani Avanti Bai Sagar irrigation project is utilized for irrigation, domestic/commercial water supply as well as hydropower generation, with irrigation being the main user.

This study models the water resources of the upper part of the Narmada basin, from the most eastern/upstream extent of the basin to the downstream gauging station at Barmanghat, draining about 30804 km2 which is 30 percentage of the total Narmada Basin (97560sq km). Major dams, abstractions, irrigation practices and corresponding canal networks are included to gain an improved representation of the impact of future climate change on water resources in the region. The study command area lies in five districts of Madhya Pradesh which are Jabalpur, Narsignpur, Katni and Satna. But the dam is located in Jabalpur district and the reservoir water spread area is situated in both Jabalpur and Mandla districts.

Topography

The topography of the upstream catchment is hilly. The topography of the upstream catchment is hilly. The elevation varies from 136m to 1236 m with respect to Mean Sea Level (MSL) as shown in Figure 52.

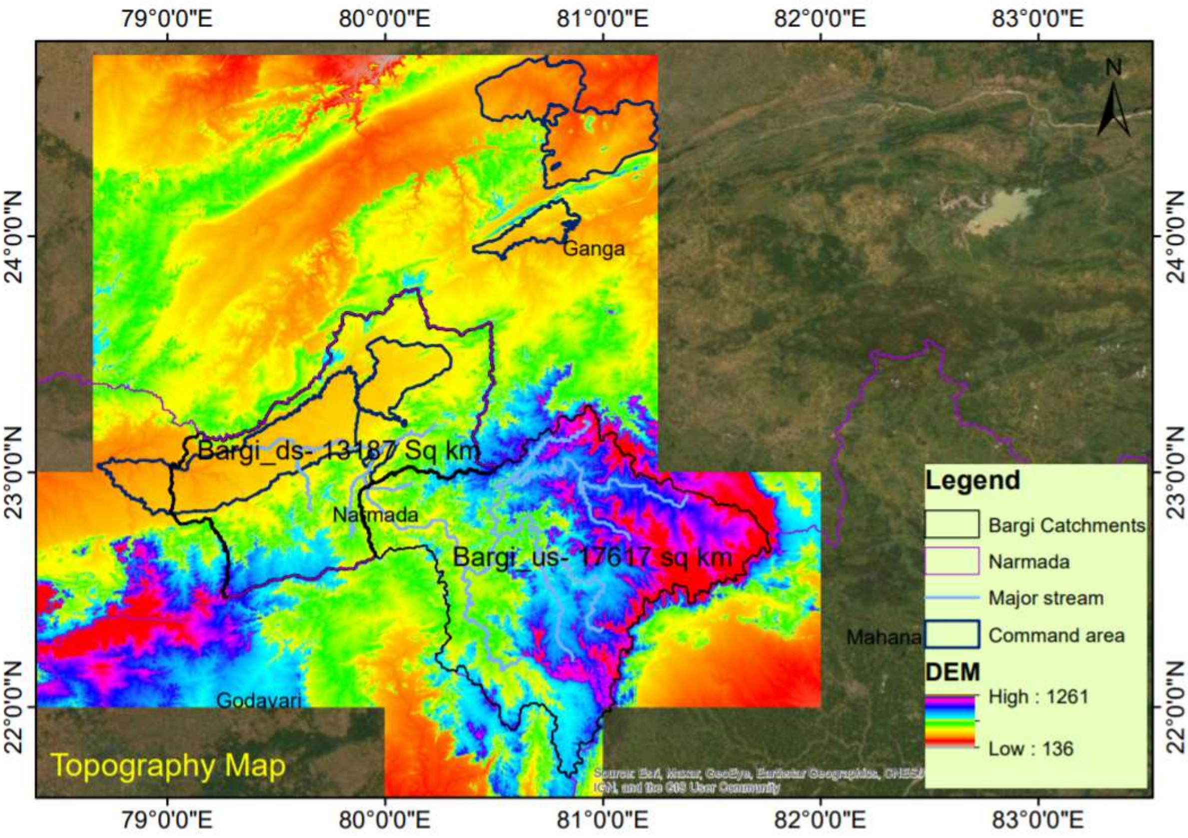


Figure 52: Topography Map of study area

The river Narmada flows from Amarkantak, the origin of the river, to the dam site near Village Bojora through upper hilly areas lying in the districts of (i) Shahdol, (ii) Mandla,(iii) Durg, (iv) Palaghat and (v) Seoni. The dam site is situated almost at the end of the upper hilly areas and commencement of the upper plains in the 378th km. of the river.

Land use

Land use is a description of how people utilize the land and socio-economic activity. Urban and agricultural land uses are two of the most known land use classes. Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. This basin holds a variety of land cover and land use classes. The level of utilization of land depends on the socio-cultural and economic achievement of people living under different nature environment. Accordingly, people have developed different land use techniques and the land use pattern. Thus, land utilization is a dynamic process, varied spatially and temporally. Land use pattern has a long-drawn effect on the economy as well as on the ecology of any area. The land use classification scheme developed by the National Remote Sensing Agency (Dept. of Space, Govt. of India) has been adopted for the various States of India. The Major classes of land use as identified by the State Remote Sensing Application Centre are built-up land, agricultural land, forest land, wasteland, water bodies and others.

As seen in Figure 53, this basin primarily consists of forest or grassland/cropland. Also seen are shrubs and bare soil.

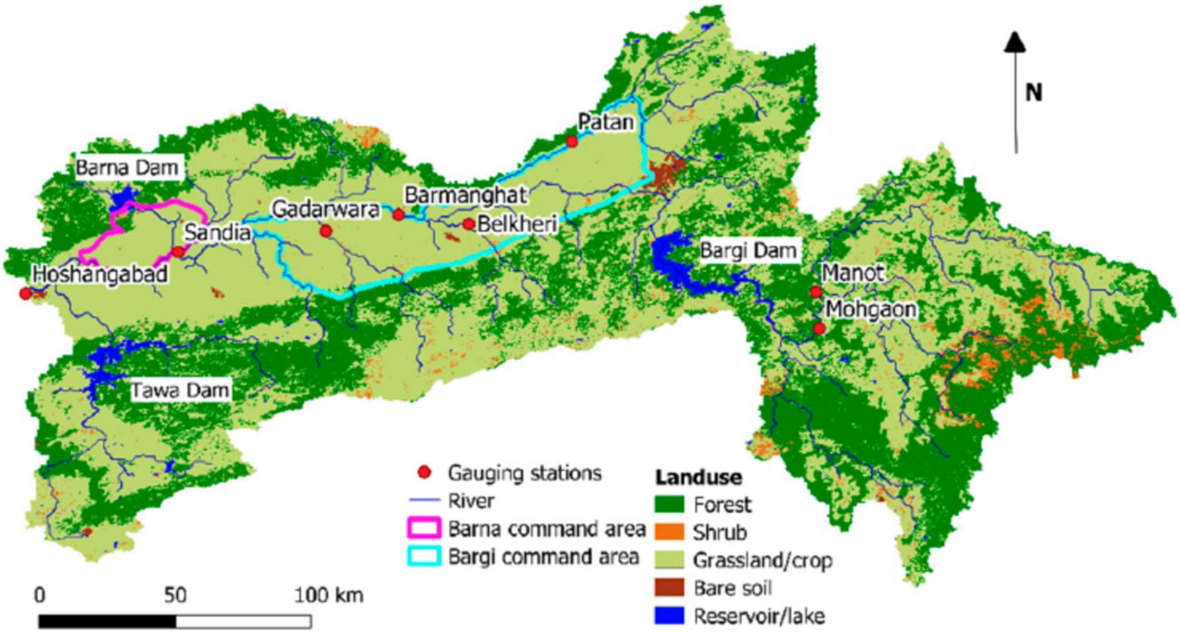


Figure 53: Land use map of the Upper Narmada Basin

Climate

The climate of the area is classified as sub-tropical, semi-arid. Average annual rainfall is 1350 mm about 80% of which is received during the monsoon period (July to September). The average annual evaporation recorded during the month of May is about 350.46 mm whereas minimum evaporation of 70 mm is observed during the month of December and average annual temperature is 25.7°C.

Soil

The general soil category as districts wise is mapped in Figure 54. Majority area consists of deep medium black soil. The advanced soil classification is clay-loam and has low phosphorous, medium Nitrogen and medium potassium.

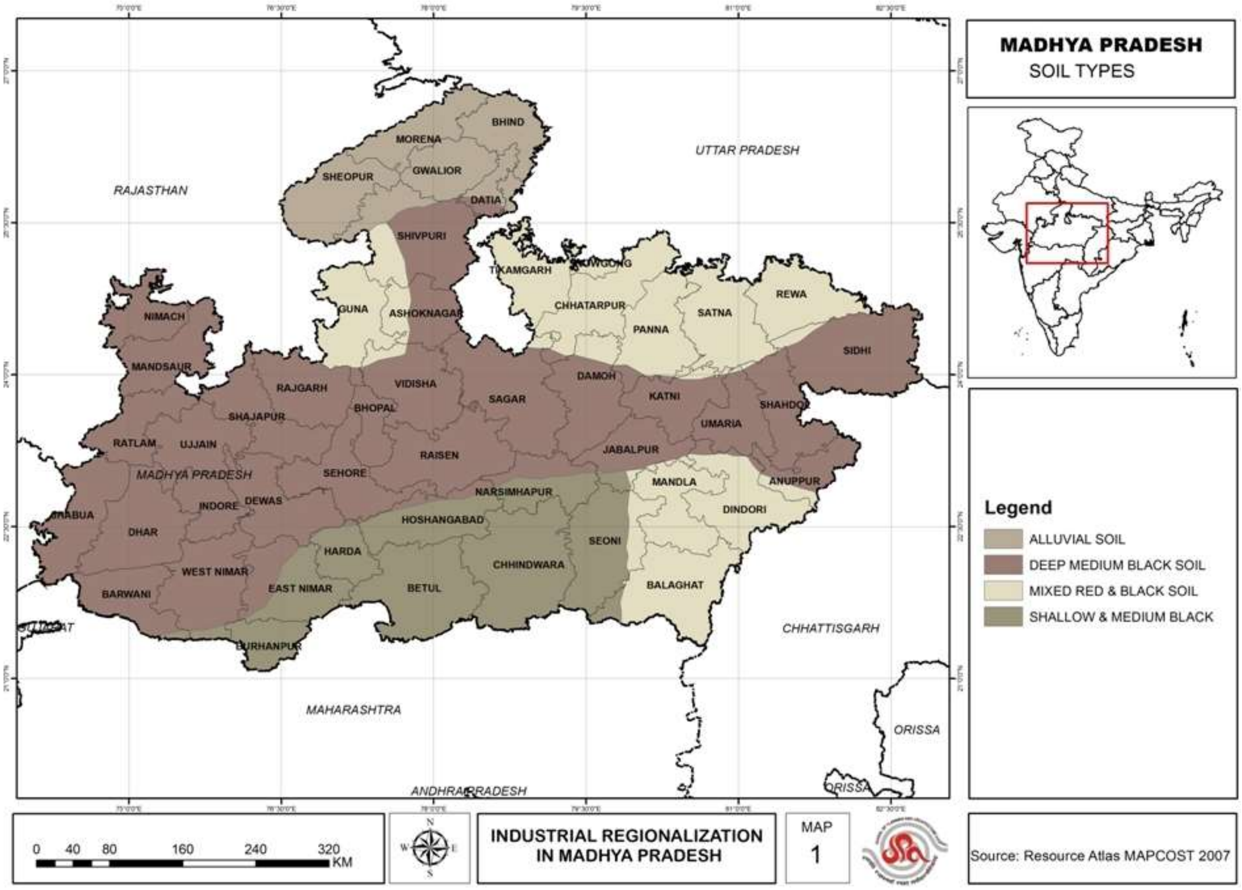


Figure 54: Soil map of study area

Catchment hydrology

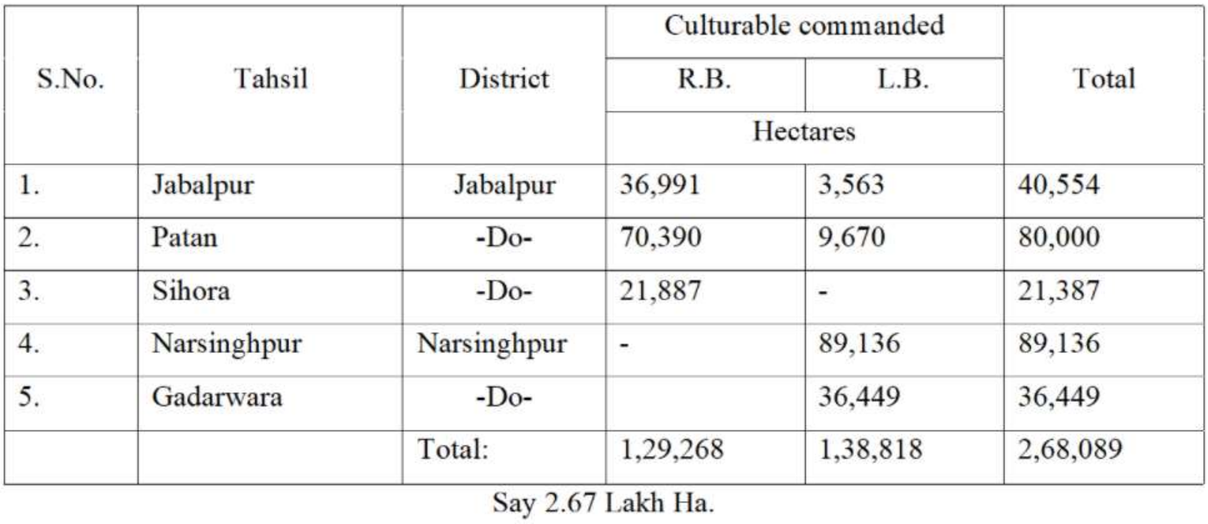
The study is primarily on the command development area of Bargi reservoir. The area of Interest is taken as upstream contributing catchment to Bargi and downstream benefitted catchment which includes command area of Bargi dam. The Bargi reservoir supplies water to the industrial and agricultural land outside Narmada Basin which is categorized as Inter-basin transfer. In other words, water demand from different users of Bargi is dependent on the catchment outside Narmada, 'Son-Ton' which is sub-basin of Ganga catchment. The total catchment area considered for the study is 30,804 square km out of which 17617 sq km is the upstream of Bargi dam and 13187 sq. km is the downstream catchment area till Barmanghat (CWC GD station) which is 104 km ds of Bargi Dam.

Command area of Bargi dam

The command areas details of both left and right bank canal systems are tabulated in Table 3.

The culturable area in the basin is about 3.02 percent of total culturable area of India. The total cropped area in the Basin form 2.02 percent of the total cropped area in the country. The area under irrigated crops is about 4.47 percent of the cropped area in the basin. The detailed description on command area is given in the following section.

Table 3: Command area distribution in administrative boundary wise



S.No.	Tahsil	District	Culturable commanded		Total
			R.B.	L.B.	
			Hectares		
1.	Jabalpur	Jabalpur	36,991	3,563	40,554
2.	Patan	-Do-	70,390	9,670	80,000
3.	Sihora	-Do-	21,887	-	21,387
4.	Narsinghpur	Narsinghpur	-	89,136	89,136
5.	Gadarwara	-Do-		36,449	36,449
		Total:	1,29,268	1,38,818	2,68,089

Say 2.67 Lakh Ha.

Ground water potential

About 87 percent of the basin area is occupied by the hard and semi-consolidated rocks belonging to age ranging from the Archaens to upper cretaceous and represented by the granites, graint-geneiss, sadists, Phyllite, quartzites, states, sandstones basaltic rocks and conglomeratic beds. The remaining 13 percent of the area is occupied by the recent alluvial deposits in the districts of Jabalpur, Narsinghpur, Hoshangabad and Raisen. The maximum thickness of the aluminium is recorded as 190 m. with 2 to 3 major granular zones, which are associated with high ground water yields.

The gross recharge to ground water body is estimated in the DPR as 16294MCM/year of which 11397 MCM is exploitable after deducting 4896.916 MCM as losses like evapotranspiration, Sub-surface outflow. The ground water balance available for exploitation is of the order of 9991.19 MCM, after deducting rate of utilization in the basin, which is 1406.167 MCM/year.

Details of Rani Avanti Bai Sagar irrigation project

The Bargi dam, which is a major dam in M.P., is built across the river Narmada and situated near the village Bijora that is about 43 km from the Jabalpur city. Rani Avanti Bai Sagar Project (RABSP) is associated with 20 lakh farmers of Mahakaushal and Vindhayachal region.

The reservoir is used for the following applications:

- Irrigation command areas- Left canal system (CCA= 1.57 lakhs Ha) and Right canal system (CCA=2.45 lakhs Ha)
- Domestic water use of Jabalpur city: 54Mm^3 per annum.
- Industrial water use at Katni city: 116 Mm^3 per annum.
- Hydropower- 2 units of 45 MW each on RBC and 2 units x 5 MW each on LBC.

Figure 55: Operation of Rani Avanti Bai Sagar irrigation project

The two irrigation canals that stem from the dam – the Left Bank Canal (LBC) and Right Bank Canal (RBC) are described further in the following sections.

The command area is depicted in Figure 56.

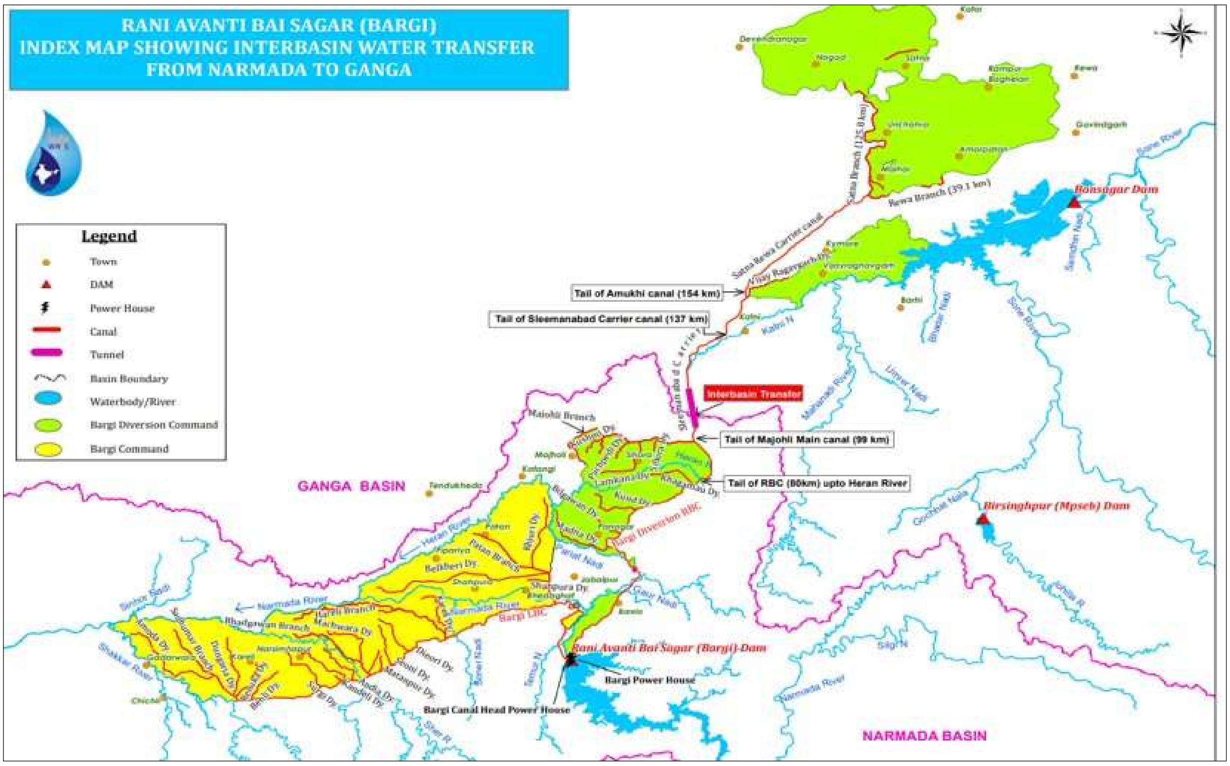


Figure 56: The command area components (Source: WRIS)

The salient features of Rani Avanti Sagar Dam as per Detailed project Report (1988)

Rani Avanti Bai Sager

Table 4: Salient features of Bargi dam

1.	GENERAL			
	Location		Near, Village Bijora	
			43 Km. from Jabalpur	
			10 Km. from Bargi on NH-7	
	Latitude		22°56'59.71"N	Top sheet
	Longitude			No.55, N 13
			79°55'54.08"E	
2.	HYDROLOGY			
	Catchment Area			14,556 Sq. Km.
	Rainfall	Maximum		2311 mm
		Minimum		664 mm
		Average		1414 mm
	Period of record			(1891-1980
	Annual yield			(Period 1949-1970)
	Maximum			16.02 BM^3
	Minimum			3.67 ”
	Average			7.19 ”
	50% dependable			8.07 BM^3
	75% ”			5.29 ”
	90% ”			4.10 ”
	100 year frequency flood			14744 Cusecs
	At Jamtara			(5.21 lac cusecs
	1000 year frequency flood			19782 Cusecs
				(6.99 lac Cusecs)
	Designed frequency flood			51,510 Cusecs
				(18.183 lac Cusecs)
	Moderated flood			43,000 Cusecs
				(15.18 lac Cusecs)
3.	RESERVOIR DATA			RL 367.0 M
	River Bed level			RL 401.0 M
	Sill level	(L.B.C)		RL 410.0 M
	Minimum draw down level	(R.B.C)		RL 403.55 M
	Crest level	(MDDL)		RL 407.50 M
	Full Reservoir level	(FRL)		RL 422.76 M
	Maximum Reservoir level	(MWL)		RL 422.70 M
	Top of Dam level	(TBL)		RL 426.90 M
	Tail water level	Minimum		RL 369.05 M
		Maximum		RL 370.88 M
	SUBMERGENCE			
	Area of Submergence	At MWL		30860 Ha.
		At FRL		26797 Ha.
	RESERVOIR CAPACITIES			
				M.Cum.
	Dead Storage Capacity at	MDDL		740
	Gross Storage Capacity at	Crest level		1140
	Gross Storage Capacity at	FRL		3920
	Gross Storage Capacity at	MWL		4806
	Live Storage Capacity at	FRL		3180
4.	DAM DATA			
	Type pf Dam		Composite Earth and Masonry	
		Length	Maximum height	Top width

		(M)	(M)	(M)
	Left NOF	209.6		7.2
	Right NOF	231.7	69.0	7.2
	Spillway	385.7	69.8	7.2
		827.0		
	EARTH			
		M		
	Right	1770	26	7.62
	Left	2770	29	7.62
	Total length of			
	Earth & Masonry Dam	5367		
	Free Board Above	FRL	4.14 M	
	Above	MWL	1.20 M	
5.	SPILLWAY GATES			
	No. of Spans		21 Nos.	
	No. and size of gates		21 Nos.	M
				13.71×15.35
				Lx H
	Type of Gates		Radial Gates	
	Sill level of Gates		407.31 M	
	Top level of Gates		422.76 M	
6.	OUTLETS		LBC	RBL
	Sill level		401.0 M	410.0 M
	Size		3×4 M	2.62×2.62 M
	Numbers		2	13
7.	POWER HOUSE			
	Location		Right Bank toe of Dam	
	Instated Capacity		2×45 MW	
			2×7.5 MW Proposed	
	Firm power & Load factor		58 MW at 60%	
			Load factor	
	Head	Maximum	56.40 M	
		Minimum	35.67 M	
		Designed	47.85 M	
	Penstocks	Number	2 Nos.	
		Diameter	5.50 M	
	Turbines	Number	2 Nos.	
		Discharge	98.40 cusecs	

Left Branch Canal - Rani Avanti Bhai Lodhi Sagar Project

The Left Bank Canal (L.B.C.) of Bargi dam covers Jabalpur and Narsinghpur district. Total length of L.B.C. is 137.2 km, out of which 65 km passes through Jabalpur district. The LBC is fully functional.

The cultivable command area (CCA) of the LBC is 1,57,000 Ha. Major crops are wheat, paddy, sugarcane and green peas.

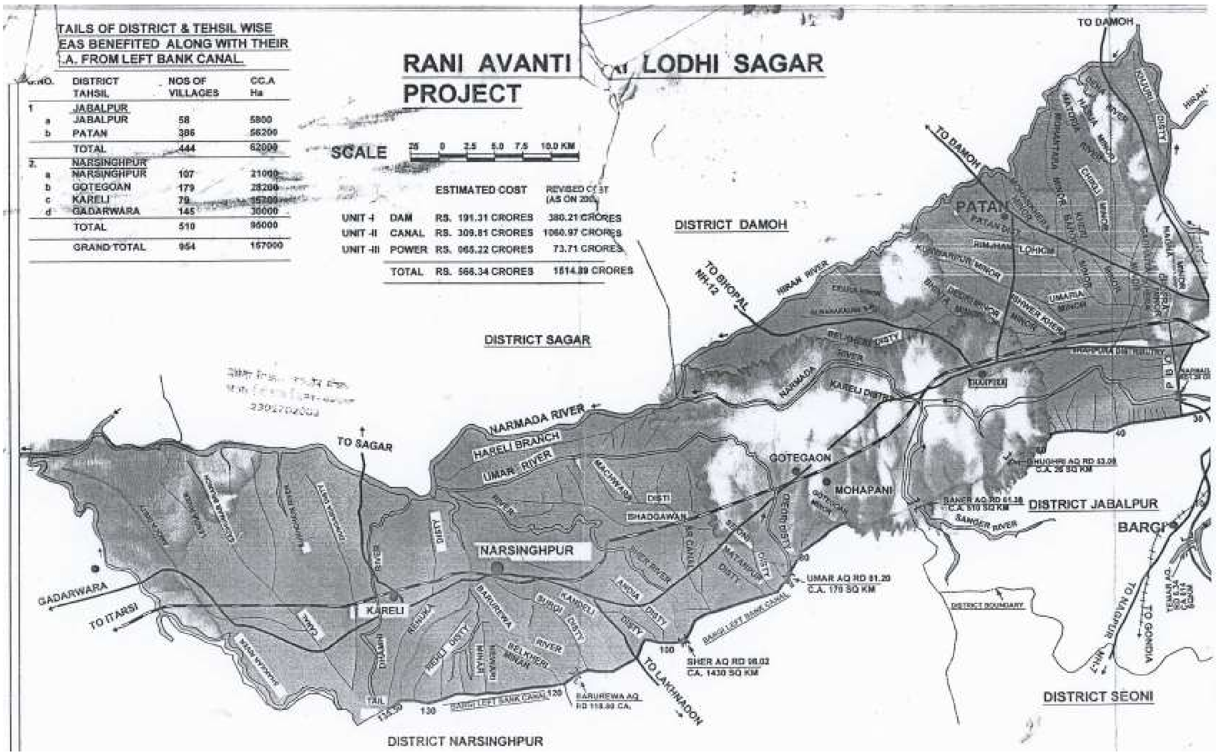


Figure 57: The Left Branch Canal command area

Table 5shows the year-wise development and utilization of canal command area for irrigation from 2015 -2021. As seen from the table, 156335 Ha of land has been developed for irrigation since 2019 however as of 2021, only 126202 Ha of that capacity is being utilized for irrigation.

Table 5: Year-wise development and utilization of Left Branch canal command area for irrigation from 2015 -2021

Year	District Area (Ha) for irrigation - Created			District Area (Ha) for Irrigation - Utilized			
	Jabalpur	Narsinghpur	Total	Crop	Jabalpur	Narsinghpur	Total
2015 - 2016	58430	97102	155532	Kharif	17000	5000	22000
				Rabi	25000	85000	110000
				Total	42000	90000	132000
2016 - 2017	58430	97305	155735	Kharif	22500	5000	27500
				Rabi	30000	77500	107500
				Total	52500	82500	135000
2017 - 2018	58430	97905	156335	Kharif	22500	5000	27500
				Rabi	30000	77500	107500
				Total	52500	82500	135000
2018 - 2019	58430	97905	156335	Kharif	25000	5000	30000
				Rabi	35000	80000	115000
				Total	60000	85000	145000
2019 - 2020	58430	97905	156335	Kharif	25175	3426	28601
				Rabi	27230	40960	68190
				Total	52405	44386	96791
2020 - 2021	58430	97905	156335	Kharif	30675	10587	41262
				Rabi	32240	52700	84940

Year	District Area (Ha) for irrigation - Created			District Area (Ha) for Irrigation - Utilized			
	Jabalpur	Narsinghpur	Total	Crop	Jabalpur	Narsinghpur	Total
				Total	62915	63287	126202

The Right Branch Canal - Bargi Diversion Project

The Right Branch Canal (RBC) command area lies within Jabalpur & Katni, Satna and Rewa districts as seen in Figure 58. This canal is not fully functional as only 20% has been completed. 100% completion is supposed to occur within 5 years.

Total CCA of this branch is meant to be 2,45,010 Ha upon full development. Currently 50,000 Ha of irrigable land has been built up and 47,050 Ha of this capacity is being utilized.

Table 6: Year-wise development and utilization of Right Branch canal command area for irrigation from 2015 -2021

Year	Area (Ha) developed for irrigation			Actual Area (Ha) utilized for irrigation		
	Kharif	Rabi	Total	Kharif	Rabi	Total
2015 - 2016	10000	40000	50000	4700	3676	8376
2016 - 2017	10000	40790	50790	10200	3705	13905
2017 - 2018	15000	35000	50000	8150	3501	11651
2018 - 2019	10000	35000	45000	7900	3210	11110
2019 - 2020	10000	35000	45000	9720	3197	12917
2020 - 2021	15000	35000	50000	13900	3515	17415

The major crops grown are paddy and wheat.

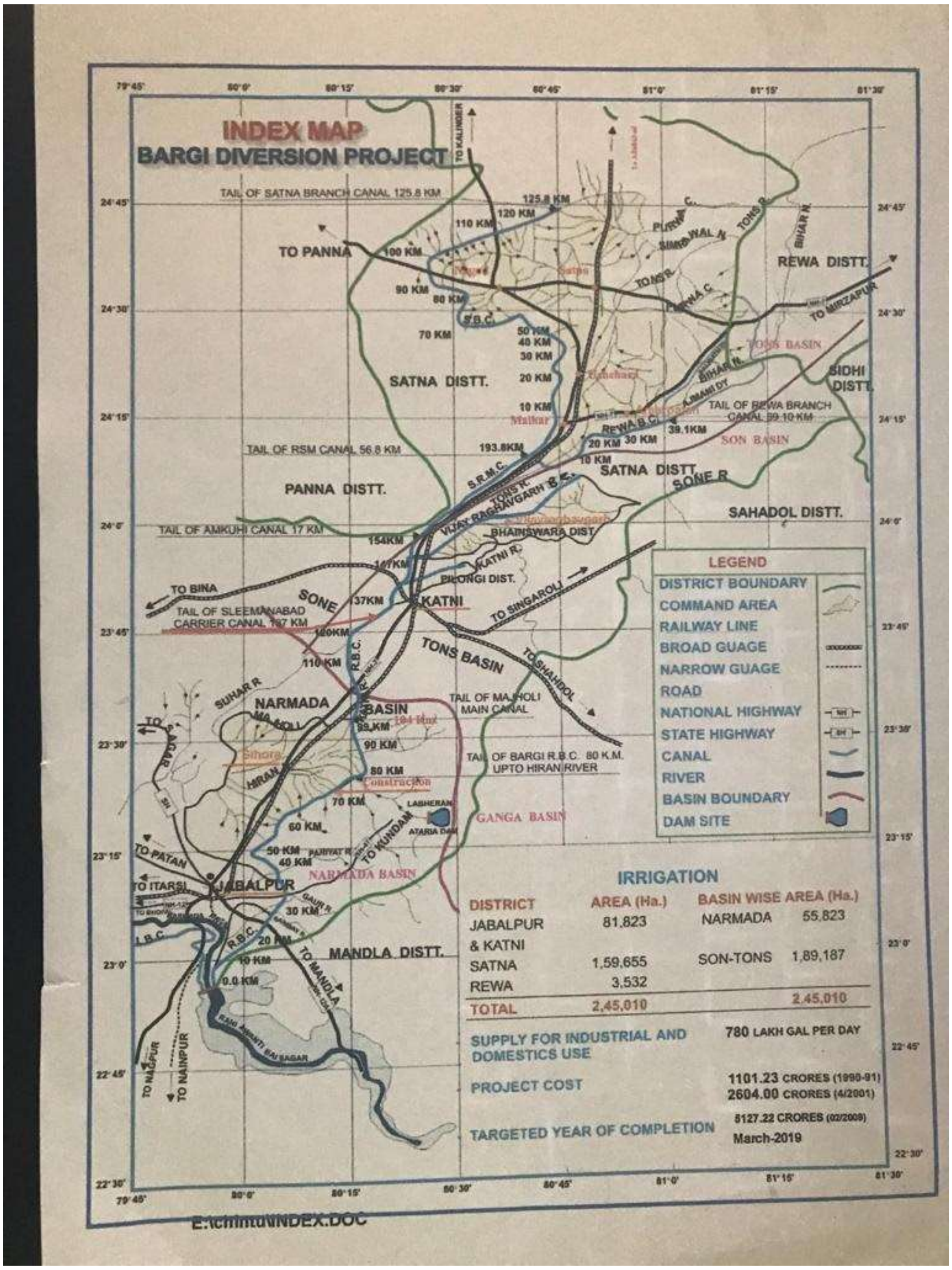


Figure 58: The Right Branch Canal command area

Powerhouse

This comprises of construction of powerhouse at the masonry dam toe in non-overflow of powerhouse at the masonry dam toe in non-overflow portion in Block numbers 31 & 32 and canal powerhouse in block No. 3. The dam toe powerhouse will have 2 units of 45 MW each and the canal powerhouse will have 2 units of 7.5 MW. each.

Land Irritability classification

It is an advance grouping of sail, irrigable, classes which considers the quality and quantity of irrigation water drainage requirements and Economic aspect such as production cost and yield potentials. Land Development cost and benefit Ratio.

Table 7: Land Classification

Class	Area(ha)	Percent
I	7770	2.8
II	255264	72.9
III	65837	18.8
IV	19215	5.5
Total	848066	100

Soil Irrigability classification

Soil irrigability classes are grouping of the soils according to their quality for sustained use under irrigation. The classification is not based on availability or irrigation water, its quality, land preparation cast, and drainage etc. and is purely based on the behavior of the soils to water application.

Table 8: Soil Classification

Class	Area(ha)	Percent
A	66286	18.9
B	28180	80.4
C	2072	0.7
Total	96538	100.0

Water Account:

The Narmada tribunal has allotted 22511.0 MCM. water to M.P. It is proposed to utilize this quantum of water as under. Irrigation Water use is given below.

Table 9: Water Distribution

Project	(Lakh ha.)	(MCM.)
Major	14.16	14002.465

Medium	4.678	3559
Minor	8.72	3099.7352
Domestic/Industrial use	-	1850.22
	27.55	22511.0

Approach and Methodology

The general approach and methodology are detailed in the inception report, Appendix B and Appendix C

Methodology Flow chart

Process modelling tool is the main component of CC-DSS which will be required for (a) to simulate hydrological processes for calculation of runoffs, (b) to route flows in the catchment-reservoir-command system (c) to allocate water to fulfil demands considering water availability in the system (surface water including reservoirs), (d) to determine crop water requirements for irrigated agriculture.

All components of the proposed CC-DSS described in detail in the following sections. A brief overview of the components and functionalities are provided below to give a better understanding of the interrelations between many functionalities.

The different components and key functionalities of the CC-DSS are illustrated in Figure 59 . The figure also indicates the parts of the system that will be used by the different user types. The system consists of three key components: Modelling, CC-DSS - Analysis, presentation, Planning

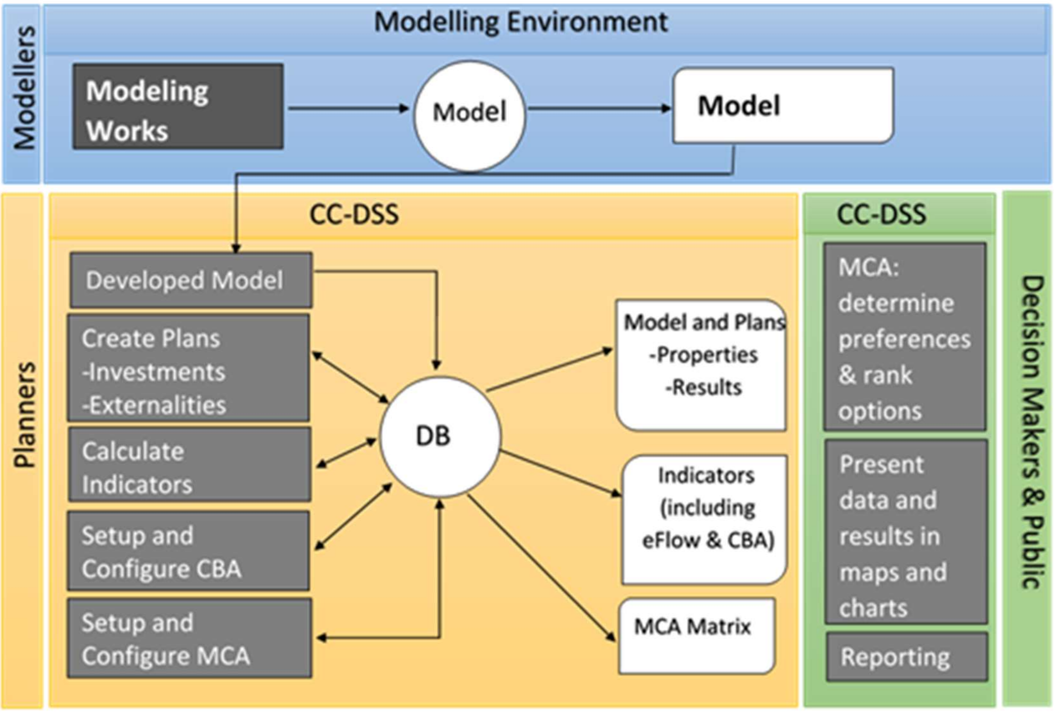


Figure 59: The methodology to develop CC-DSS

Model Framework

Water balance modelling has been carried out at the basin and sub basin scale to estimate supply and demand of water in the basin, where supply is derived from the reservoir and canals, and demand is for irrigation, domestic water use, hydropower generation and commercial use. Also, the modelling has been carried out to demonstrate the impact of storage measures including the surface and ground water management for various scenarios.

MIKE HYDRO Basin has been used to perform the water balance modelling. MIKE HYDRO Basin is a versatile and highly flexible model framework for a large variety of applications concerning management and planning aspects of water resources within a river basin.

Based on the field visit and collected data, a desktop study has been carried out to understand the catchment characteristics and hydrology. A detailed water balance study has been carried out for a greater understanding of the basin. The key goal of the water balance study is the analysis of evaporation, precipitation, surface water runoff into the cascade of tanks, infiltration, and outflows to various users, environmental flow, and groundwater recharge. Water balance study was carried out at the basin and sub-basin-scale to estimate supply and demand of water in the basin, where supply can be derived from river, tanks, groundwater, and canals and demand accounts water as the irrigation water demand, the domestic water demand, industrial demand, environmental flow demand, and livestock water demand. In this study, for simulating water balance model, MIKE HYDRO BASIN model is used MIKE HYDRO Basin is a versatile and highly flexible model framework for a large variety of applications concerning Management and Planning aspects of water resources within a river basin. Figure 60shows the concept of a water balance and Figure 61 shows the detailed components of MIKE HYDRO BASIN model. For analysis, the components are divided into basically three units concerning the catchment, which are input, output, and storage components.

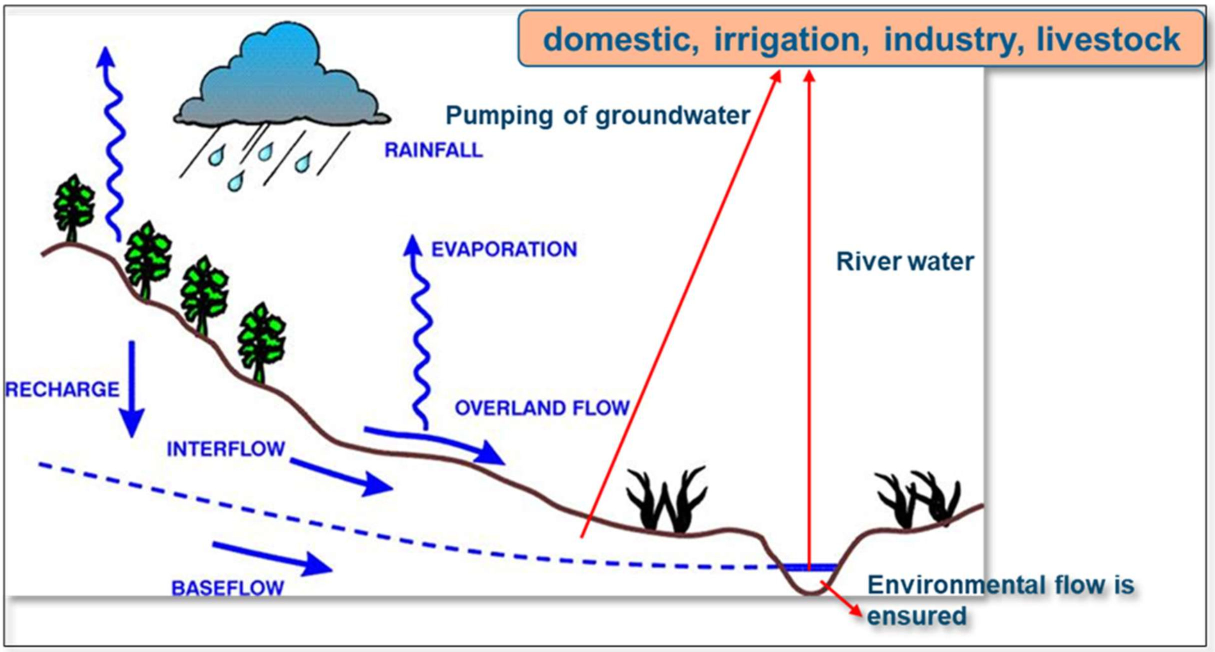


Figure 60: Schematics of Water Balance Concept

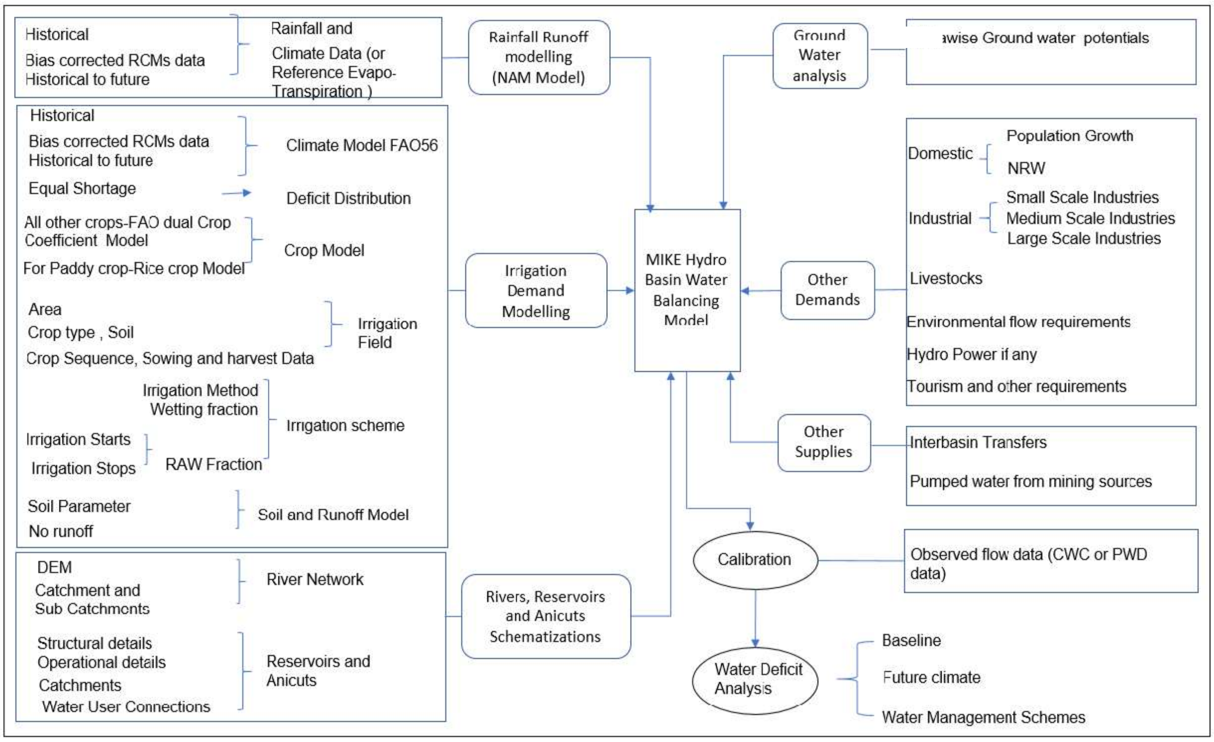


Figure 61: Water balance framework of MIKE HYDRO BASIN model

Features

Input components – Rainfall Runoff module

Rainfall is the primary input to the basin. The results of the rainfall runoff model and the river discharges will form part of the key inputs to the water balance study. The collected data is analysed and discussed in chapter 3.

Calibration

The rainfall runoff models are calibrated against collected data in the historical period. The simulation results are compared against measurements using the coefficient of determination (R2) value and graphically analysed for the degree of agreement between simulated and measured values

Output components – Basin simulation modules

Water demands in the basins are the output components:

1) Irrigation demand.
2) Domestic demand.
3) Industrial demand.
4) Environmental flow requirements; and
5) Other uses such as livestock, power production, tourism, or recreational needs.

(i) Domestic water demand

The domestic water demand in the basin depends on the increase in populations and increase of per capita demand. The state WRD has provided the water released to the users for municipal sector, which is considered as domestic demand.

(ii) Livestock demand

No livestock demand is considered in current model setup.

(iii) Irrigation demand

Agriculture is either rain fed agriculture or irrigated through offtake from reservoirs, anicuts, tanks, canals, wells and tube wells. Simulation of irrigation demand is based on the meteorological data (air temperature, relative humidity and wind speed); and agricultural data (area of irrigated field, crop type and sowing data), soil properties, irrigation method and ability to generate runoff, where crops and irrigation method can change over time.

(iv) Industrial Demand

Industrial water demand has been increasing with the pace of industrial development. The growth in some of the water intensive industries has been significant, putting further pressure on the industrial demand for water. The industrial water demands are taken from state WRD which are actual allocated amounts to different small, medium or large-scale industries.

(v) Hydropower Demand

There two hydropower units present in the study area, left bank hydropower and right bank hydropower

The above demands are considered for water balance analysis.

(vi) Storage component and EV flow

The reservoir/tanks are described through an elevation-area-capacity table, characteristic levels of reservoirs, losses, rule curves, flood control zones, minimum operating zones, reduction level and reduction percentages, remote flow rule, and priorities to operate reservoirs as per management policies. The level in rule curve reservoir method is shown in Figure 2 5. Water is extracted directly from rivers or reservoirs. Any hydrological interventions in terms of base flow regulation or retention time increase which impact total runoff / ground water available will be modelled using above parameters. The impact could be estimated at the catchment level or at each user level. Future scenarios will be carried out in which the water availability changes and the capacity of the tanks change which affects the environmental flow.

Architecture of CC-DSS

The basic concept behind the CC-DSS is given in the Inception Report in detail. The overview shall be discussed here.

It is important to emphasize that CC-DSS requires a complete underlying system infrastructure with a back-end database system, a middle layer consisting of tools and functionalities to support data management, processing, and analysis to support the web-based interactive dashboards (front-end).

CC-DSS can be divided into three major parts:

- **Database -** A database is a collection of information that is organized to be easily accessed, managed, and updated. It is the collection of schemas, tables, queries, reports, views, and other objects. The data is typically organized to model aspects of reality in a way that supports processes requiring information. In a database, data is updated, expanded, and deleted as new information is added to the database
- **Workbench (Windows Interface) -** The MIKE Workbench Platform is a highly configurable and comprehensive development framework which has been developed to support water resource-oriented information management, planning and real-time control systems.
- **Web User Interface -** Web User interface is the main interface for model simulation, strategy analysis and reporting. This interface provides the functionality for visualization of spatial and non-spatial data. Based on user rights user access them.

Climate Change Decision Support System (CC-DSS) is a web based GIS aided tool for planning and management of multi-purpose dams. It supports online modeling and scenario generations based on climate change adaptions policies.

Figure 62: Architecture of CC-DSS

Data collection and analysis

The data required are as follows:

Table 10: List of Data collected

Type pf data	Usage	Source
Topography	Catchment delineation	Bhuvan, NRSC
Dam characteristics	To operate and guide the reservoir outflow	MPWRD
Details of Irrigation water use	To assess the irrigation demand	MPWRD
Crop cycles	To assess the irrigation demand	MPWRD, ICAR
Precipitation	To calculate the runoff from catchment and also to assess the irrigation demand and ground water recharge	IMD gridded data
Potential Evapotranspiration	To assess the losses from the system	IMD

Land Use	Assess the percentage rainfall contribution to runoff, to validate the total command area	WRIS, FAO global database
Soil	For irrigation demand and recharge calculation	WRIS
Canal command areas	Estimate irrigation demand	MPWRD

Rainfall

The collected rainfall data for the catchment is the IMD gridded data for 30 years (1990-2019). The daily data is plotted in Figure 63.

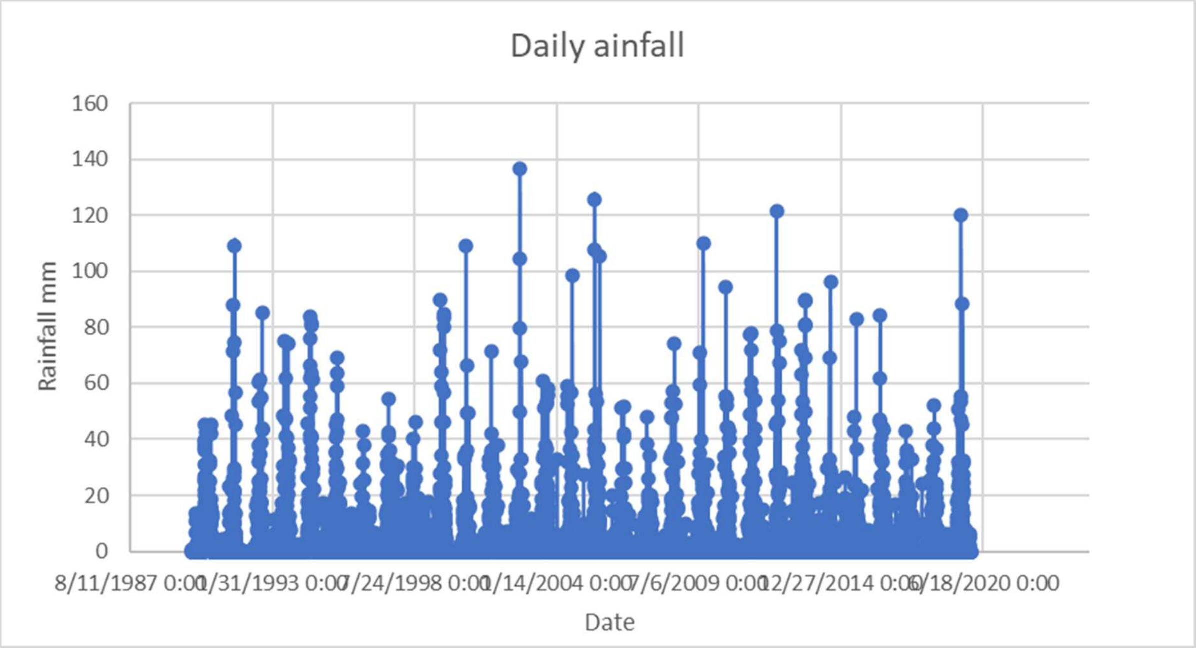


Figure 63: Historical Daily rainfall for 30 years for 1990-2019

The statistical analysis has been performed to see the general trend of data

The annual rainfall is calculated and plotted. The annual average rainfall for the study is estimated as 1220 mm. The minimum and maximum annual rainfall for the last 30 years is 693 and 1881 mm respectively.

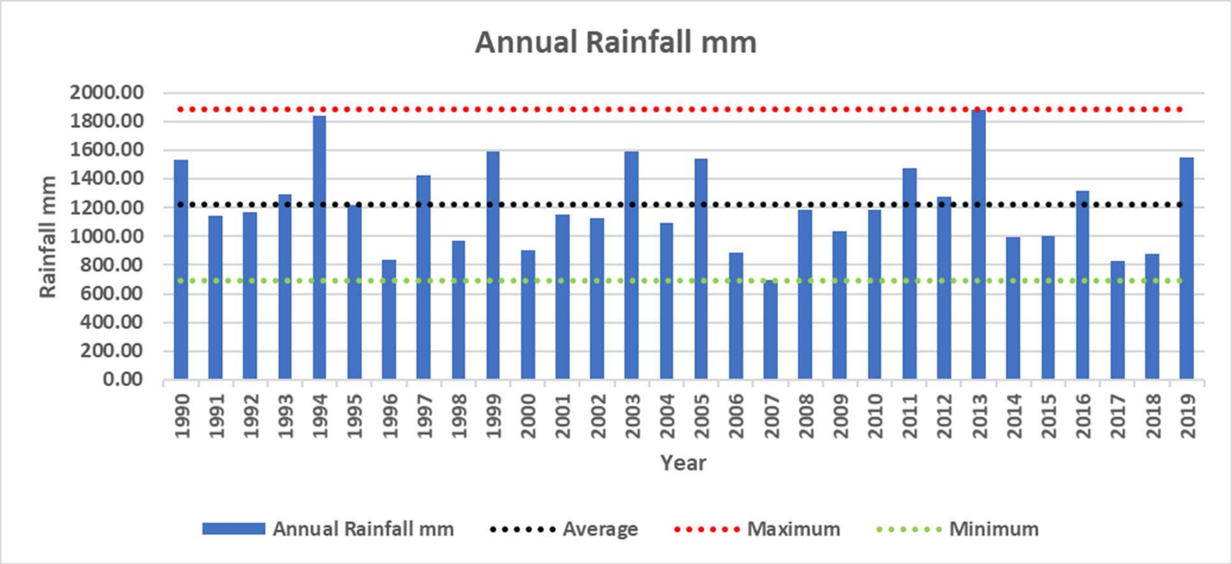


Figure 64: Annual rainfall for the study area

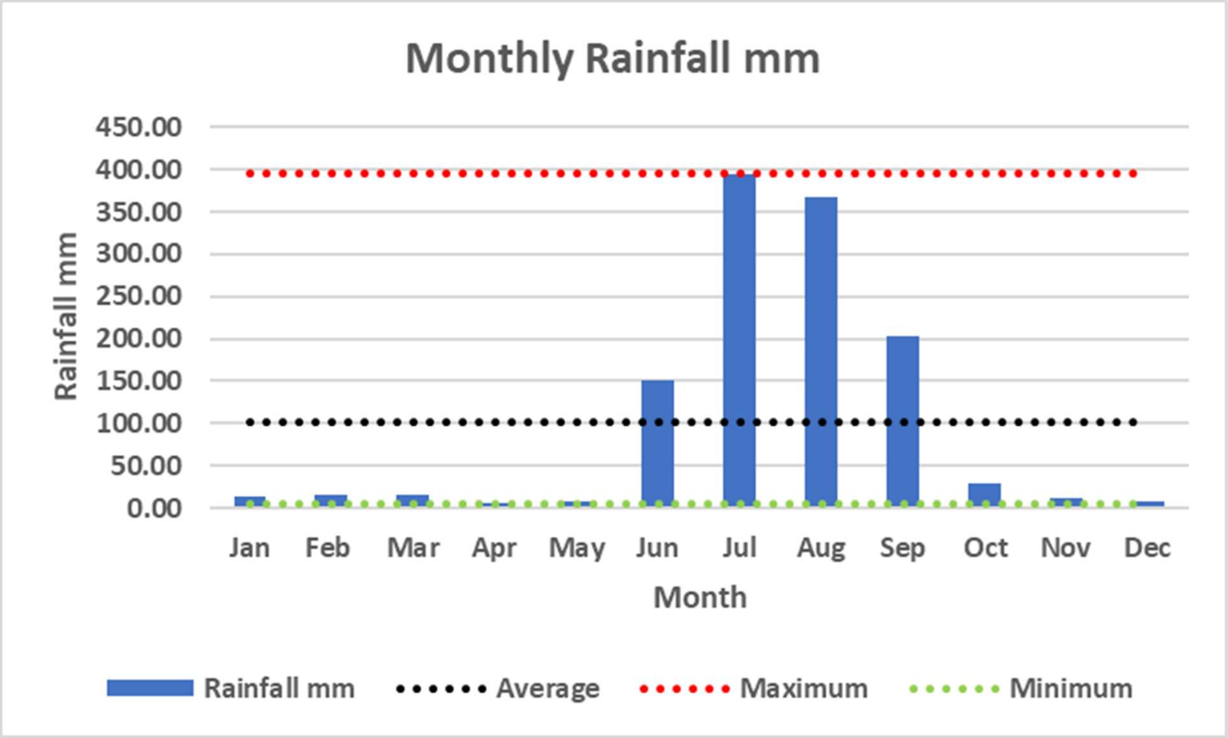


Figure 65: Monthly rainfall for the study area

The results were comparable with the rainfall data published in MPWRD website for Jabalpur site (refer:http://www.mpwrd.gov.in/documents/18/df6de417-8cd0-46ea-b67b-750b9a71b8bd). This also states the annual 75% dependable rainfall is 1083.15mm which also justifies the rainfall collected data's accuracy.

Evapotranspiration

The evapotranspiration is also collected from IMD gridded data for 30 years

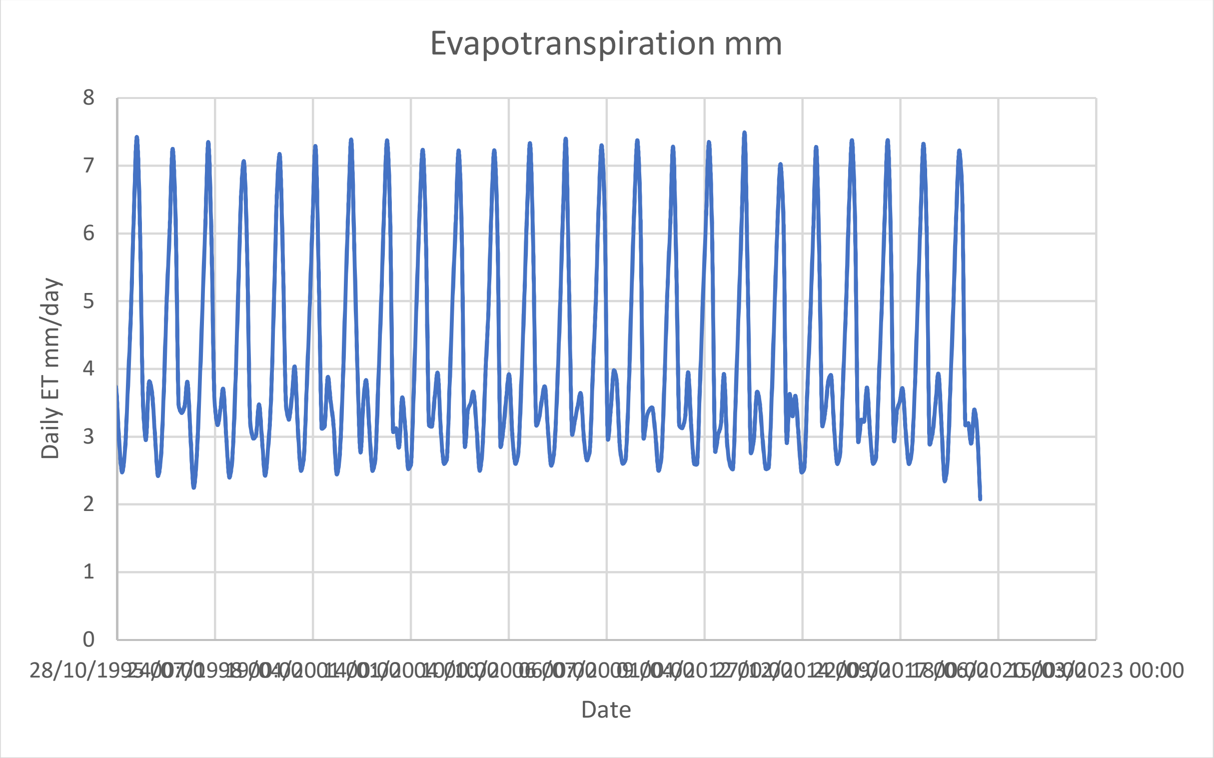


Figure 66: Daily average Evapotranspiration series in mm per day for each month

The monthly ET is estimated and shown Figure 67.

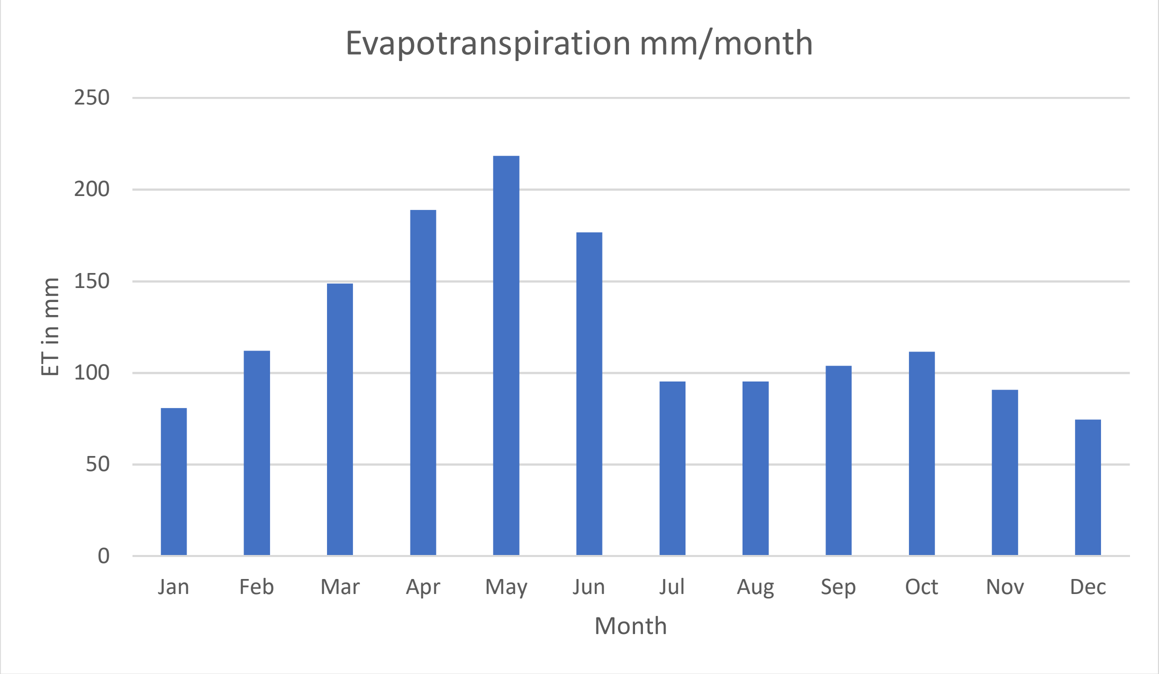


Figure 67: Monthly ET in mm

The annual statistics are plotted in Figure 68

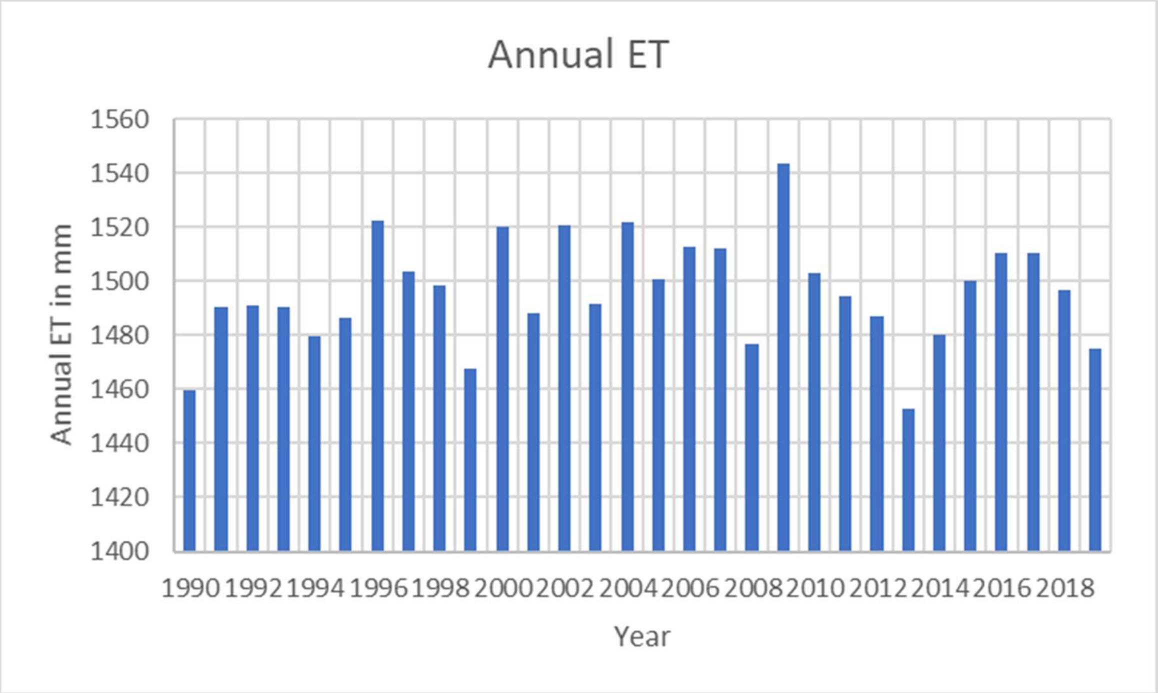


Figure 68: Annual variability of ET over 30 years

LAV-Level Area Volume and characteristics level

The LAV is collected from Bargi Dam office is tabulated Table 11.

Table 11: LAV table of Bargi reservoir

Level (m)	Surface Area (km^2)	Volume (MCM)
377	0	0
400	52.82	620.001
401	56.05	674.436
402	59.28	732.1
403	66.8	795.142
404	72.26	829.907
405	79.08	906.634
406	85.12	988.749
406	89.66	1054.31
407	91.17	1076.91

408	97.21	1171.12
409	103.26	1271.37
410	116.15	1391.92
411	128.09	1514.05
412	140.03	1648.11
413	151.97	1794.11
414	163.9	1952.04
415	175.84	2121.91
416	189.44	2322.81
417	201.82	2518.45
418	214.2	2726.46
419	226.57	2946.84
420	238.95	3179.6
421	251.33	3424.74
422	260.79	3655.22
423	271.24	3921.23
424	306.89	4398.19
426	319.34	4849.08

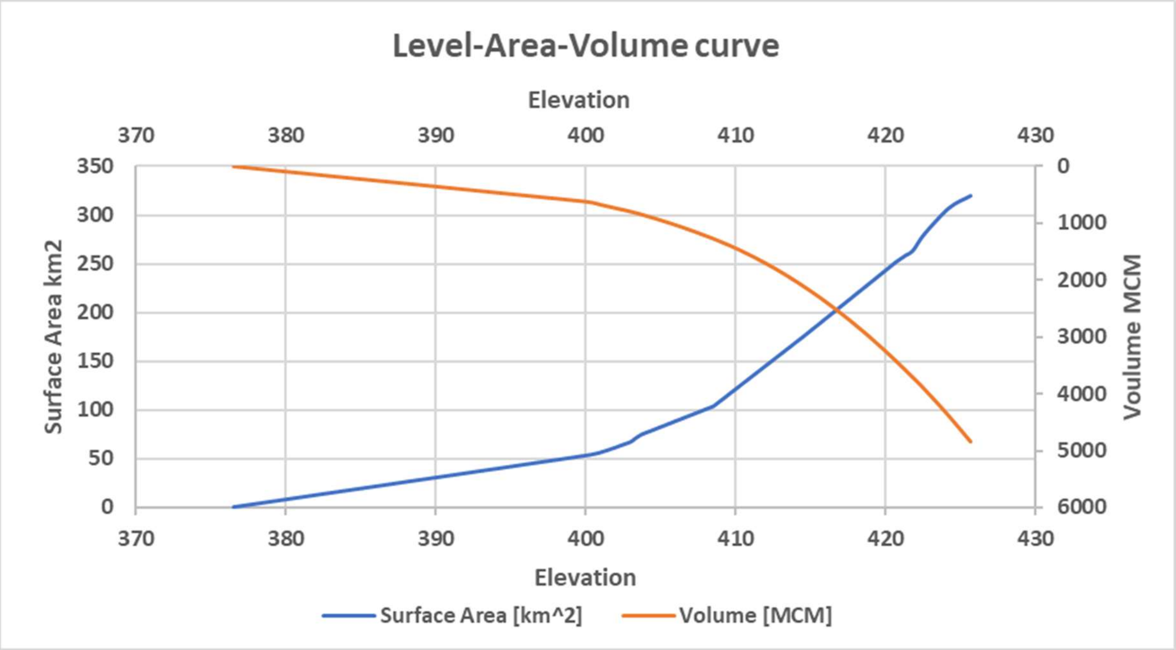


Figure 69: LAV curve of Bargi reservoir

The main characteristics levels of reservoir are listed in Salient features. The maximum reservoir level, full reservoir level (FRL), MDDL (minimum drawdown level/dead storage level) are 425.7m,422.7 and 403.5. The lowest bed level is 376.5m. The basic knowledge about these levels in the model will be considered as condition to maintain and release water from reservoir component. The water level in the reservoir is varied from dead storage level to full reservoir level based on the upstream catchment contribution.

Model development

Two climatic conditions were simulated and analysed, Baseline which represents the existing situation of water allocation and Climate change which represents future forecast based on the projected climate conditions.

Baseline

The baseline model utilizes the current climate parameters and land use. The coupled rainfall-runoff and basin water balance model is set up for the year 2001-2016.

The baseline model utilizes the current climate parameters and land use. The coupled rainfall-runoff and basin water balance model is set up for the year 2001-2016.

- Collected rainfall data and climate data are assumed to be correct. Analysis was done based on the data.
- Demand calculation is based on the base year data available during data collection.
- A storage volume elevation curve was constructed from the collected data on storage area elevation. It is assumed that the data provided is in terms of the surveyed data available with the state WRD.
- The irrigation method is taken as canal furrow method for all crop basin model. However, on ground, this may vary to an extent.
- In few of the projects, where demands are not provided separately for different users, users are divided as irrigation and non-irrigation.

A runoff model is a mathematical model describing the rainfall–runoff relations of a rainfall catchment area, drainage basin or watershed. It produces a surface runoff hydrograph in response to a rainfall event, represented by and input as a hyetograph. In other words, the model calculates the conversion of rainfall into runoff. The rainfall-runoff model used to simulate rainfall-runoff is NAM model. The NAM model has been used intensively for many catchments around the world, representing different hydrological regimes and climatic conditions. The NAM model is described in detail in MIKE 1D reference manual (DHI-b, 2017; Jaiswal et al., 2014). The NAM model is a lumped, conceptual rainfall-runoff model, simulating the overland, interflow, and base flow components as a function of the moisture contents in three storages (Figure 70 and Figure 71)

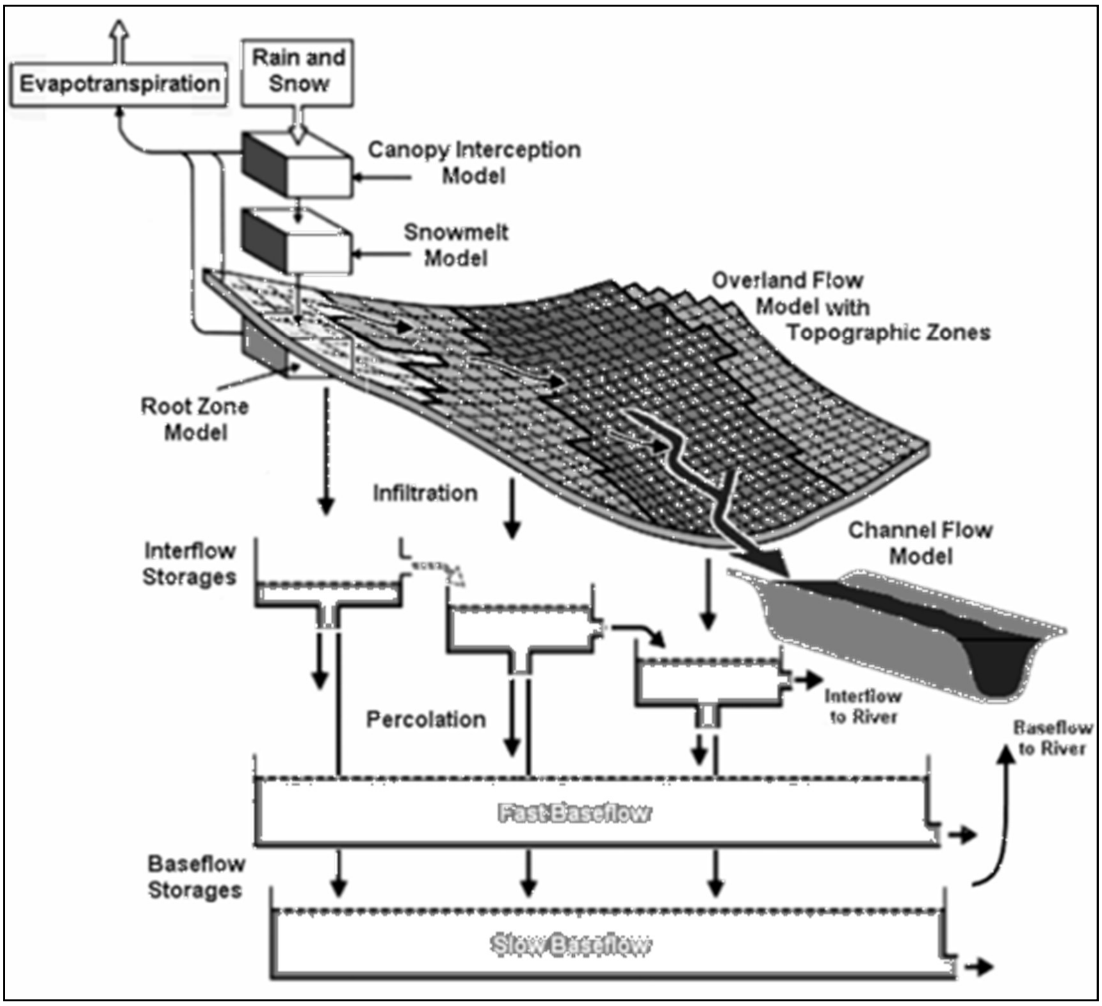


Figure 70: Overview of process in NAM

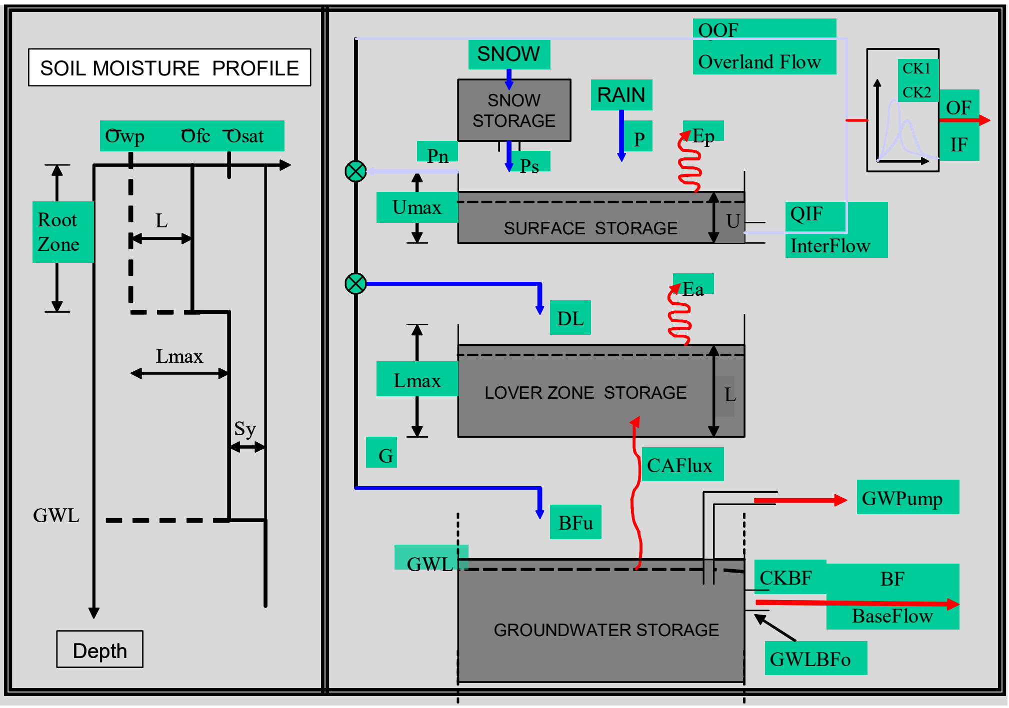


Figure 71: Overview of parameters in NAM

NAM includes three storages representing the surface zone, root zone and the groundwater storages. Description of the parameters and their effects is presented in Table 12. The overland flow routing is based on the linear reservoir concept but with a variable time constant. The amount of infiltrating water, G recharging the groundwater storage depends on the soil moisture content in the root zone. The base flow, BF from the groundwater storage is calculated as the outflow from a linear reservoir with a time constant CKBF. In this project, NAM.

Table 12: NAM parameters and their effects

Parameter	Unit	Description	Effect
Umax	mm	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration, interflow
Lmax	mm	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, base flow
CQOF	Fraction	Overland flow coefficient	Volume of overland flow and infiltration
CKIF	Hours	Interflow drainage constant	Drainage of surface storage as interflow
TOF	Fraction	Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
TIF	Fraction	Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG	Fraction	Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
CK1	Hours	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
CK2	Hours	Timing constant for interflow	Routing interflow along catchment slopes
CKBF	Hours	Timing constant for base flow	Routing recharge through linear groundwater recharge

The baseline water balance model is setup and rainfall runoff for both upstream and downstream catchment were connected to the different chainages of Narmada River. The model view and components are given in Figure 72. The upstream catchment runoff is connected to Bargi reservoir and from the reservoir, water is allocated to four water users: LBC irrigation, RBC irrigation, domestic and Industrial users. The return flow is connected to both RBC and LBC users. The dam d/s flow and return flow from users is added to the downstream catchment node. The combined flow is the net outflow which is available for the downstream users/reservoirs or the netflow from the system which is equivalent to Barmanghat GD site.

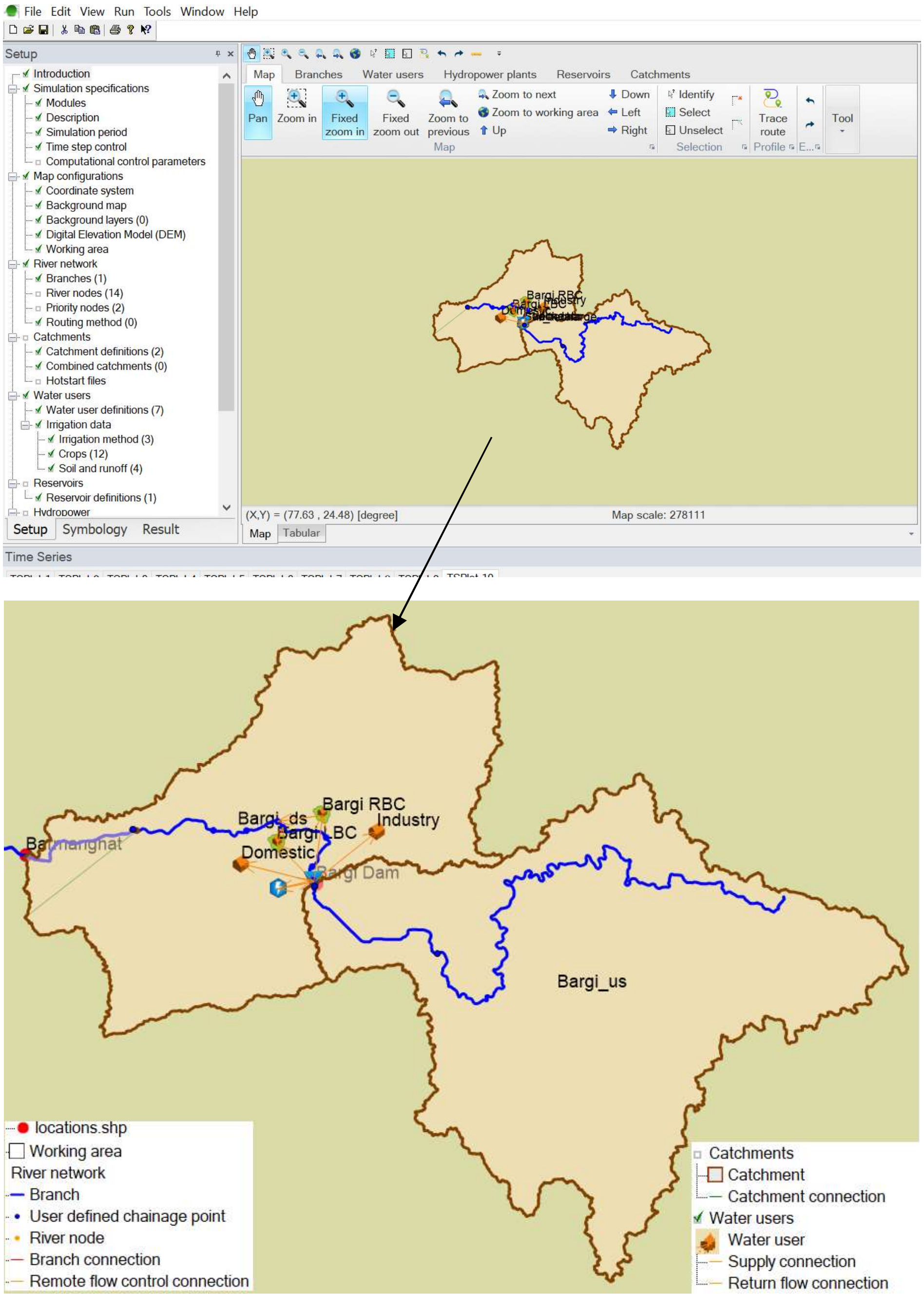
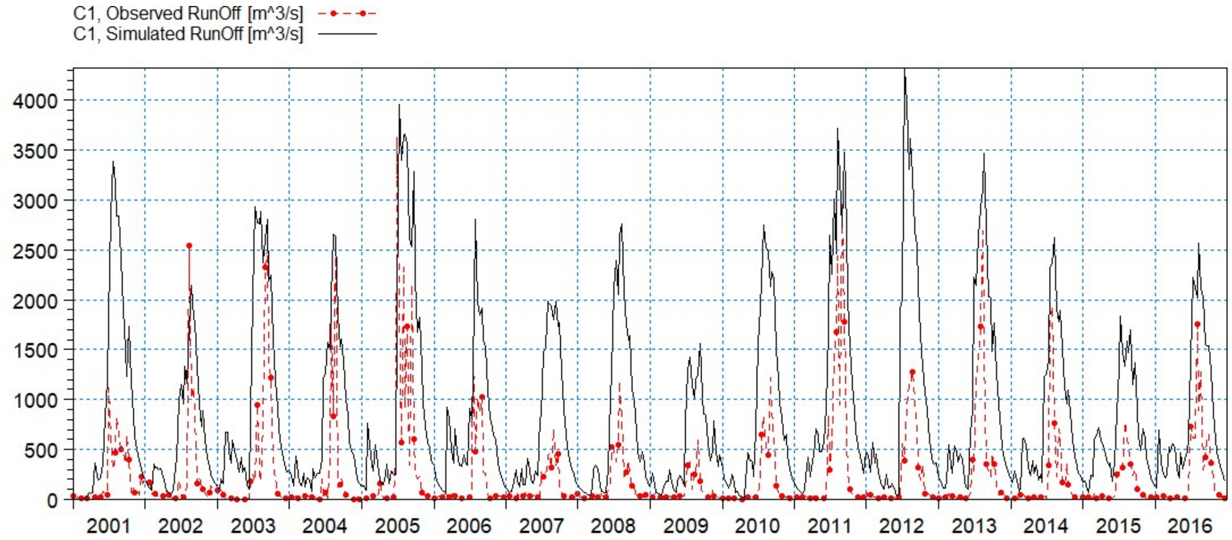


Figure 72: Baseline model-set up

The upstream catchment runoff is calibrated with reservoir inflow series collected. The calibration is carried out only for 10 years from 2001 to 2010 and validation is done for 2011 to 2016.



R^2= 0.68

Figure 73: The simulated (black firm line) and observed (red dotted line) upstream catchment runoff. R2=0.68

The reservoir inflow received as 10 daily accumulated flow, not spot measured flow. There is a high chance of missing the daily peak in the observed data. Secondly the flow series are generated from volume estimated with respect to the reservoir level. This is also another reason for getting the average daily flow in the observed series. The chances are high for variation in the simulated daily peak and observed flow series.

The direct calibration for the downstream catchment cannot be done using automatic calibration. The independent downstream catchment runoff plus the upstream river flow after the allocation to irrigation left and right bank users, domestic water user and industry water user is equivalent to observed flow at Barmanghat gauge station.

The comparison between the net flow to the downstream catchment node is compared with the observed flow series and plotted below. Considering the data gap in Barmanghat GD station in the year of 2013 and 2014. The calibration carried out from 2001 to 2006 and validation is done from 2006 to 2012.

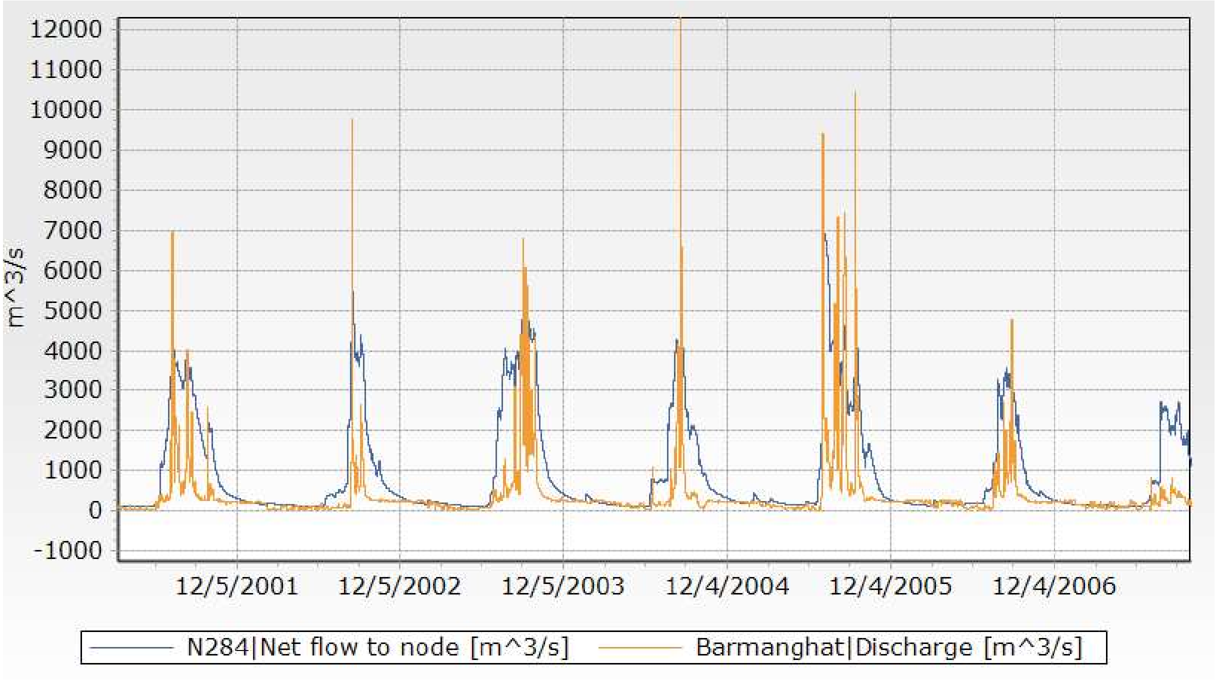


Figure 74: The simulated (blue firm line) and observed (orange firm line) at Barmanghat GD station. (R2= 0.61)

The baseline reservoir water level change is noted and analysed based on the catchment runoff generated.

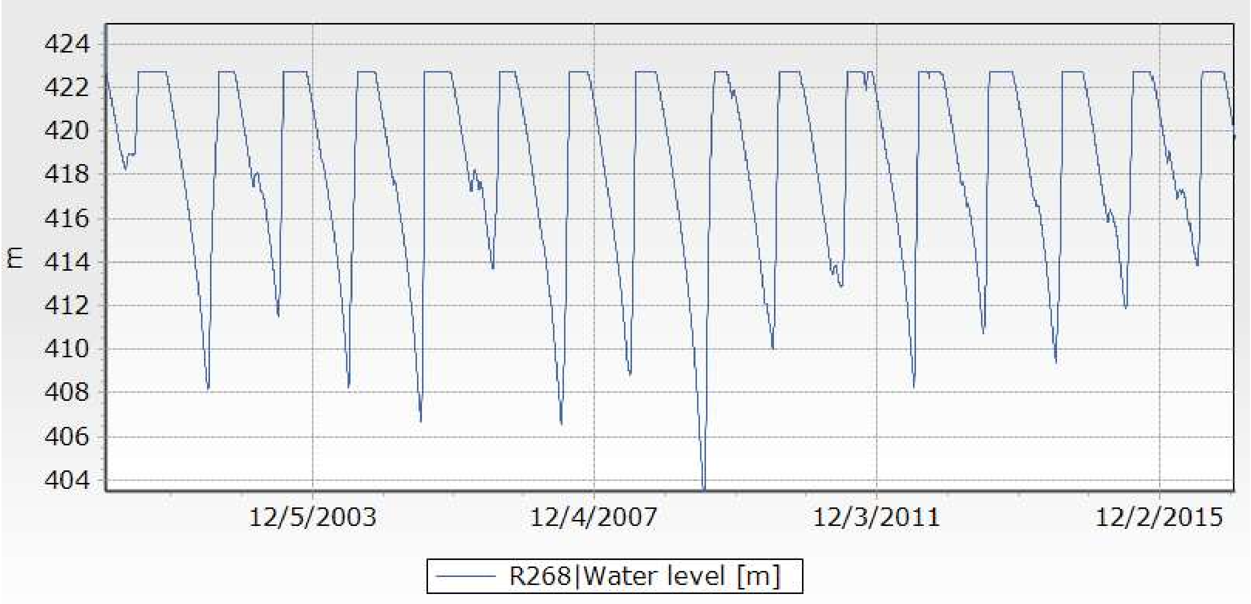


Figure 75: Reservoir water level change over the period 2001-2016 for baseline scenario

The water balance at reservoir is estimated for the year 2010 and plotted in Figure 76.

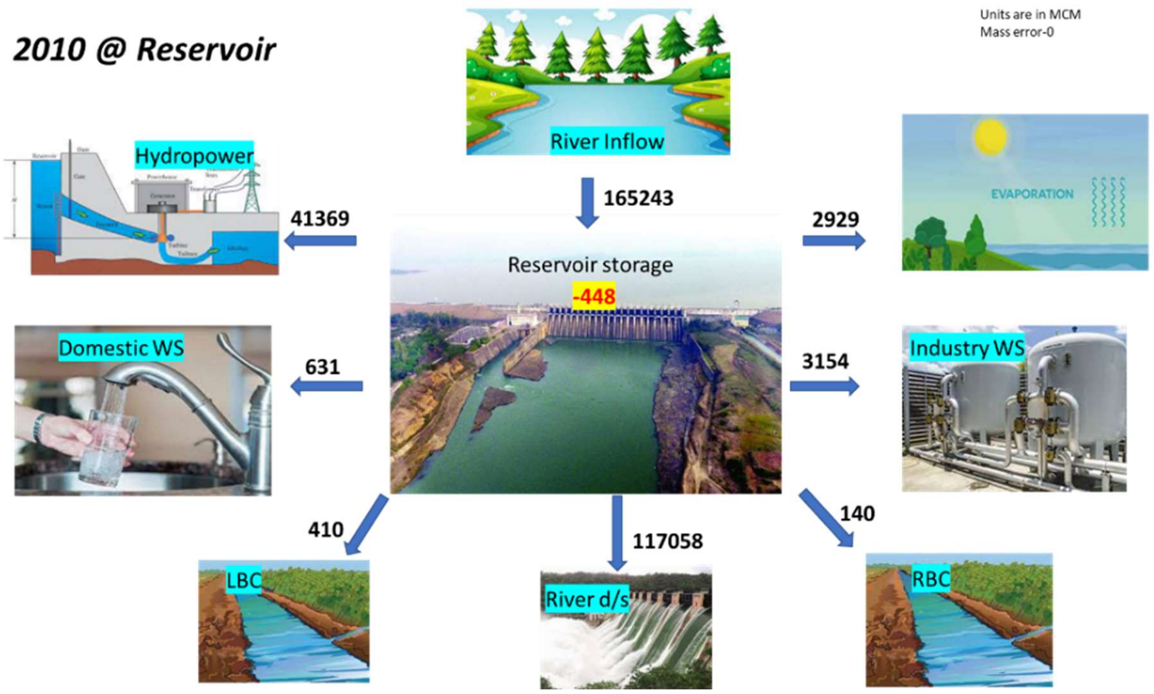


Figure 76: Water balance for the year 2010 at reservoir

The reservoir storage is -448 MCM which means, for the year 2010 the released water from reservoir is more than the annual flow received to reservoir through precipitation.

The other results generated for the baseline scenario are presented. The irrigation demand from RBC and LBC are presented on month and annual time scale in

Figure 77.

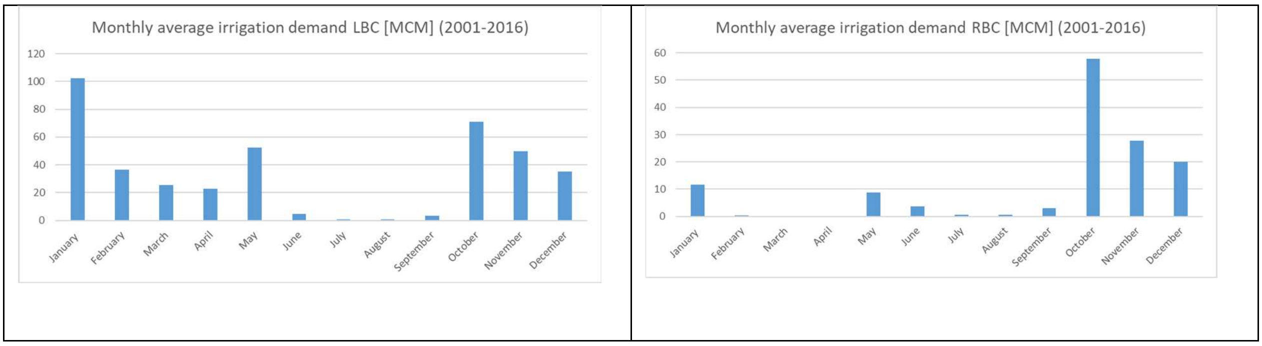


Figure 77: Monthly average irrigation demand of LBC (left) and RBC (right)

The annual irrigation is also estimated by summing up monthly and plotted in Figure 78.

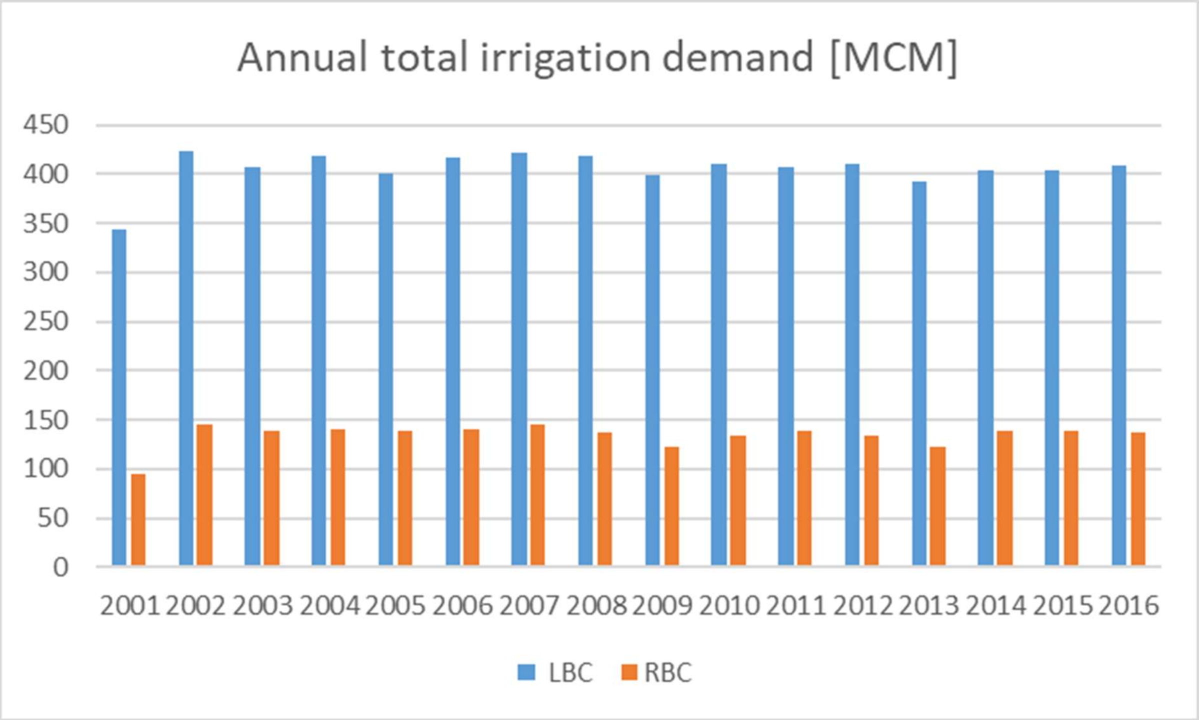
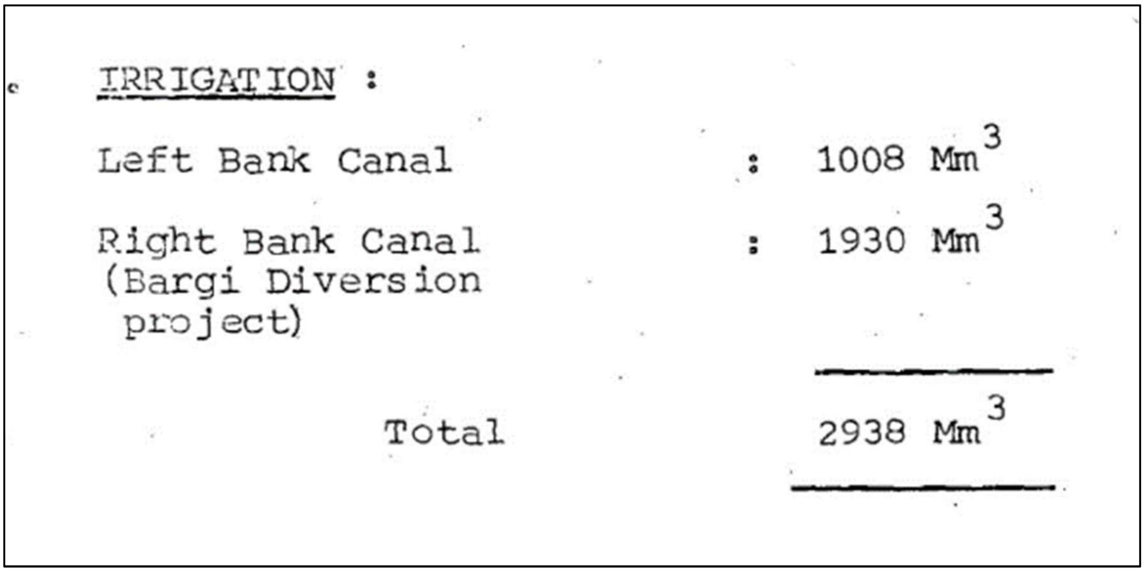


Figure 78: Annual irrigation demand of Bargi left and right bank irrigation users

The proposed irrigation demand in DPR is shown below. Only 20% of RBC is fully developed. The remaining 80% of command area must be developed which is under Bargi diversion project. As per current (baseline) scenario, LBC is having higher water demand compared to RBC. Once the RBC is completely developed, the irrigation demand will be more than the baseline RBC irrigation demand. Please refer Table 14 on the actual water demand on current scenario. The proposed water demand for each user is given below.

Table 13: Irrigation Demand

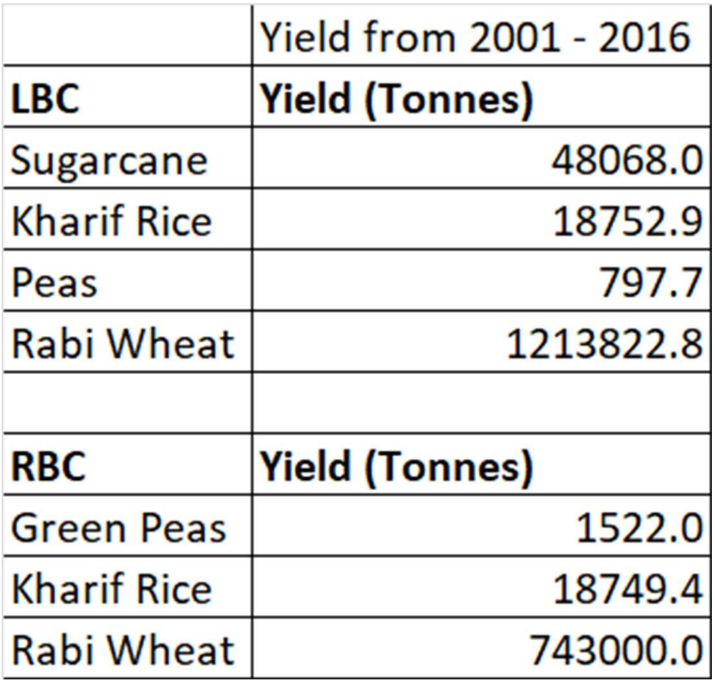


IRRIGATION :

Left Bank Canal	:	1008 Mm^3
Right Bank Canal (Bargi Diversion project)	:	1930 Mm^3
Total		2938 Mm^3

The total yield for baseline scenario for different crops is estimated and given in Table 14.

Table 14: Total crop yield for the year 2001 -2006



	Yield from 2001 - 2016
LBC	**Yield (Tonnes)**
Sugarcane	48068.0
Kharif Rice	18752.9
Peas	797.7
Rabi Wheat	1213822.8
RBC	**Yield (Tonnes)**
Green Peas	1522.0
Kharif Rice	18749.4
Rabi Wheat	743000.0

The command area yields more rabi crops than any other seasonal or perennial crop. It is necessary to manage the water available and gets stored in the reservoir during monsoon. As per DPR, the proposed cultivation for rabi is 60-70 percentage of the command area, and the rest is Kharif and mixed perennial crops and grams. In future there could be chances of changing the crop pattern and crops which are discussed in the application chapter (Chapter 5) how the irrigation demand and yield is going to change and cope up with the climate change.

Inference: The study conducted by C.D.Mishra and et. Al (March 2016, Journal of Soil & Water Conservation 15(1): 58-63, January-March 2016ISSN: 0022-457X) “Water resource characterization in canal command area for Jhansi minor (left bank canal of Bargi dam) of Rani Avanti Bai Sagar irrigation project” that canal irrigation is not only source of irrigation in Jhansi command area, but ground water is also being used at tail ends of command in ratio of 0.17 to 9.89 (Surface Water: Ground Water) in different reaches of Jhansi minor during 2001-10. Use of ground water is more in middle reach (36.09%) and tail reach (36.01%) than head reach (27%) due to surplus availability of canal water in minor at head reach.

Climate Change Analysis

For climate change analysis DSS(PM) is using Bias Corrected Climate Projections from CMIP6 Models for South Asia available at https://zenodo.org/record/3873998#.YVa21ZpBxPY

Above mentioned website has bias-corrected data of precipitation, maximum temperature, and minimum temperature are developed for six countries in South Asia. Each zipped country file contains 13 models, and each model includes five scenarios (historical, ssp126, ssp245, ssp370, and ssp585). Considering the climate change impacts in South Asia, a bias-corrected dataset of daily precipitation, maximum and minimum temperatures using output from 13 GCMs that participated in the Coupled Model Intercomparison Project-6 (CMIP6). The 13 GCMs were selected based on the availability of daily precipitation, maximum and minimum temperatures for the historical and four scenarios (SSP126, SSP245, SSP370, SSP585). Empirical quantile mapping (EQM) was used to develop bias-corrected data at daily temporal and 0.25° spatial resolution for six countries in South Asia (India, Pakistan, Bangladesh, Nepal, Bhutan, and Sri Lanka).

Methods

Bias-corrected projections were developed for South Asia (India, Pakistan, Bangladesh, Nepal, Bhutan, and Sri Lanka) and the 18 Indian sub-continental river basins. The study used basin boundaries in the Indian sub-continent. Used observed daily gridded precipitation, minimum and maximum temperatures for South Asia for the 1951–2018 period. Daily precipitation at 0.25° was obtained from the India Meteorological Department (IMD) for the Indian region. Pai et al. (2014, https://imdpune.gov.in/Clim_Pred_LRF_New/ref_paper_MAUSAM.pdf) developed gridded daily precipitation for India using station observations from more than 6000 stations located across India. The precipitation captures critical features of the Indian summer monsoon, including higher rainfall in the Western Ghats and northeastern India and lower rainfall in the semi-arid and arid regions of western India. Besides, gridded precipitation captures the orographic rain in the Western Ghats and foothills of Himalaya. The gridded precipitation data from IMD has been used for various hydroclimatic applications. Gridded daily maximum and minimum temperatures from IMD were developed using station-based observations from more than 350 stations located across India. There is bias in temperature observations from IMD in the Himalayan region, which can be attributed to sparse station density. Gridded precipitation and maximum and minimum temperatures were obtained from Sheffield et al. (Jul 2006, https://journals.ametsoc.org/view/journals/clim/19/13/jcli3790.1.xml) for the regions outside India. Datasets are available at 0.25° spatial and daily temporal resolutions. Nonetheless, we used IMD gridded dataset for the Indian region for bias correction of projections from CMIP6 as the IMD data is widely used for hydroclimatic studies in India. We used gridded observations for bias correction as station data are not available.

Table 15 Resolution for all the available climate change models in CIMP6

S. No.	Model name	Description	Latitude resolution (degree)	Longitude resolution (degree)
1	ACCESS-CM2	Australian Community Climate and Earth System Simulator (ACCESS), the model comprises of • the UKMO UM atmospheric model (v10.6), in the GA7.1 configuration, at N96 (1.875×1.25 degree), 85 level resolution. • The CABLE land surface model (CABLE2.5) • The GFDL MOM5 ocean model at 1 degree resolution (code base similar but not identical to ACCESS-OM2) • The LANL CICE5.1 sea ice model (UKMO configuration) • The OASIS-MCT coupler	1.25	1.875
2	ACCESS-ESM1-5	Australian Community Climate and Earth System Simulator (ACCESS), ACCESS-ESM1.5 comprises • The UKMO UM atmospheric model (v7.3), in the same configuration as ACCESS1.4, at N96 (1.875×1.25 degree), 38 level resolution • The CABLE land surface model with biogeochemistry (CASA-CNP) (CABLE2.4) • The GFDL MOM5 ocean model at 1 degree resolution (code base as ACCESS-CM2) • The WOMBAT Ocean carbon model • The LANL CICE4.1 sea ice model (version as ACCESS1.4) • The OASIS-MCT coupler	1.25	1.875

3	BCC-CSM2-MR	BCC-CSM2-HR is a high-resolution version of the Beijing Climate Center (BCC) Climate System Model (T266 in the atmosphere and 1/4◦ latitude × 1/4◦ longitude in the ocean). Its development is on the basis of the medium-resolution version BCC-CSM2-MR (T106 in the atmosphere and 1◦ latitude × 1◦ longitude in the ocean) which is the baseline for BCC participation in the Coupled Model Intercomparison Project Phase 6 (CMIP6) BCC-CSM2-HR is evaluated for historical climate simulations from 1950 to 2014, performed under CMIP6-prescribed historical forcing, in comparison with its previous medium-resolution version BCC-CSM2-MR. Observed global warming trends of surface air temperature from 1950 to 2014 are well captured by both BCC-CSM2-MR and BCC-CSM2-HR	1.1215	1.125
4	CanESM5	The Canadian Earth System Model version 5 (CanESM5) is a global model developed to simulate historical climate change and variability, to make centennial-scale projections of future climate, and to produce initialized seasonal and decadal predictions. This paper describes the model components and their coupling, as well as various aspects of model development, including tuning, optimization, and a reproducibility strategy. CanESM5 is comprised of three-dimensional atmosphere (T63 spectral resolution equivalent roughly to 2.8◦) and ocean (nominally 1◦) general circulation models, a sea-ice model, a land surface scheme, and explicit land and ocean carbon cycle models. The model features relatively coarse resolution and high throughput, which facilitates the production of large ensembles. CanESM5 has a notably higher equilibrium climate sensitivity (5.6 K) than its predecessor	2.7906	2.8125
5	EC-Earth3	EC-Earth is a modular Earth system model (ESM) that is collaboratively developed by the European consortium with the same name. EC-Earth3 comprises model components for various physical domains and system components describing atmosphere, ocean, sea ice, land surface, dynamic vegetation, atmospheric composition, ocean biogeochemistry, and the Greenland Ice Sheet	0.7018	0.703125
6	EC-Earth3-Veg	EC-Earth3-Veg is a configuration extending EC-Earth3 by the interactively coupled 2nd generation dynamic global vegetation model LPJ-GUESS (LPJ-GUESS stands	0.7018	0.703125

		for Lund-Potsdam-Jena General Ecosystem Simulator 2nd generation dynamic global vegetation model).		
7	INM-CM4-8	INM-CM4-8, released in 2016, includes the components: aerosol: INM-AER1, atmos: INM-AM4-8 (2x1.5; 180 x 120 longitude/latitude; 21 levels; top level sigma = 0.01), land: INM-LND1, ocean: INM-OM5 (North Pole shifted to 60N, 90E; 360 x 318 longitude/latitude; 40 levels; sigma vertical coordinate), seaIce: INM-ICE1. The model was run by the Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia (INM) in native nominal resolutions: aerosol: 100 km, atmos: 100 km, land: 100 km, ocean: 100 km, seaIce: 100 km.	1.5	2
8	INM-CM5-0	INM-CM5-0, released in 2016, includes the components: aerosol: INM-AER1, atmos: INM-AM5-0 (2x1.5; 180 x 120 longitude/latitude; 73 levels; top level sigma = 0.0002), land: INM-LND1, ocean: INM-OM5 (North Pole shifted to 60N, 90E. 0.5x0.25; 720 x 720 longitude/latitude; 40 levels; vertical sigma coordinate), sea Ice: INM-ICE1. The model was run by the Institute for Numerical Mathematics, Russian Academy of Science, Moscow 119991, Russia (INM) in native nominal resolutions: aerosol: 100 km, atmos: 100 km, land: 100 km, ocean: 50 km, seaIce: 50 km.	1.5	2
9	MPI-ESM1-2-HR	Max Planck Institute for Meteorology Earth System Model (MPI-ESM1.2) following the HighResMIP protocol. The simulations allow to analyses the separate effects of increasing the horizontal resolution of the ocean (0.4 to 0.1◦) and atmosphere (T127 to T255) sub-models, and the effects of substituting the Pacanowski and Philander (PP) vertical ocean mixing scheme with the K-profile parameterization (KPP). A key aspect of the project is improving the simulation of the European climate. It is High resolution model of MPI-ESM1-2	0.9351	0.9375
10	MPI-ESM1-2-LR	The MPI-ESM1.2 model consists of four model components and a coupler, which are connected as it was done in the predecessor MPI-ESM. The ocean dynamical model, MPIOM1.6, directly adverts tracers of the ocean biogeochemistry model, HAMOCC6. The atmosphere model, ECHAM6.3, is directly coupled to the land model, JSBACH3.2, through surface exchange of mass,	1.8653	1.875

		momentum, and heat. These two major model blocks are then coupled via the OASIS3-MCT coupler. It is low resolution model of MPI-ESM1-2		
11	MRI-ESM2-0	The new Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0) has been developed based on previous models, MRI-CGCM3 and MRI-ESM1, which participated in the fifth phase of the Coupled Model Intercomparison Project (CMIP5). The new model has nominal horizontal resolutions of 100 km for atmosphere and ocean components, similar to the previous models. The atmospheric vertical resolution is 80 layers which is enhanced from 48 layers of its predecessor. Accumulation of various improvements concerning clouds, such as a new stratocumulus cloud scheme, led to remarkable reduction in errors in shortwave, longwave, and net radiation at the top of the atmosphere	1.1215	1.125
12	NorESM2-LM	Norwegian Earth System Model (NorESM2) is based on the second version of the Community Earth System Model (CESM2), but has entirely different ocean and ocean biogeochemistry models; a new module for aerosols in the atmosphere model along with aerosol-radiation-cloud interactions and changes related to the moist energy formulation, deep convection scheme and angular momentum conservation; modified albedo and air-sea turbulent flux calculations; and minor changes to land and sea ice models. results from low (~2 ◦) and medium (~1 ◦) atmosphere-land resolution versions of NorESM2 that have both used to carry out simulations for the sixth phase of the Coupled Model Intercomparison Project (CMIP6). The stability of the pre-industrial climate and the sensitivity of the model to abrupt and gradual quadrupling of CO2 is assessed, along with the ability of the model to simulate the historical climate under the CMIP6 forcings	1.8947	2.5
13	NorESM2-MM	Same as NorESM2-LM, but differ in the horizontal resolution of the atmosphere and land component (approximately 2◦ for LM and 1◦ in MM). share the same horizontal resolution of 1◦ for the ocean and sea ice components. These versions are otherwise identical, except for a very limited number of parameter settings in the atmosphere component, and the parameterization used to diagnose the fraction of ice-clouds	0.9424	1.25

Scenarios

In the lead up to the IPCC AR6, the energy modelling community has developed a new set of emissions scenarios driven by different socioeconomic assumptions, these are the "**Shared Socioeconomic Pathways" (SSPs)**. A number of these SSP scenarios have been selected to drive climate models for CMIP6.

Specifically, a set of scenarios were chosen to provide a range of distinct end-of-century climate change outcomes. The IPCC AR5 featured four Representative Concentration Pathways (RCPs) that examined different possible future greenhouse gas emissions. These scenarios – RCP2.6, RCP4.5, RCP6.0, and RCP8.5 – have new versions in CMIP6. These updated scenarios are called SSP1-2.6, SSP2-4.5, SSP4-6.0, and SSP5-8.5, each of which result in similar 2100 radiative forcing levels as their predecessor in AR5.

Several new scenarios are also being used for CMIP6 in order to give a wider selection of futures for scientists to simulate. These scenarios are included in the chart below, which shows the annual CO2 emissions assumed under each scenario out to 2100. The new scenarios include SSP1-1.9 (purple line), SSP4-3.4 (blue solid), SSP5-3.4OS (blue dashed) and SSP3-7.0 (orange).

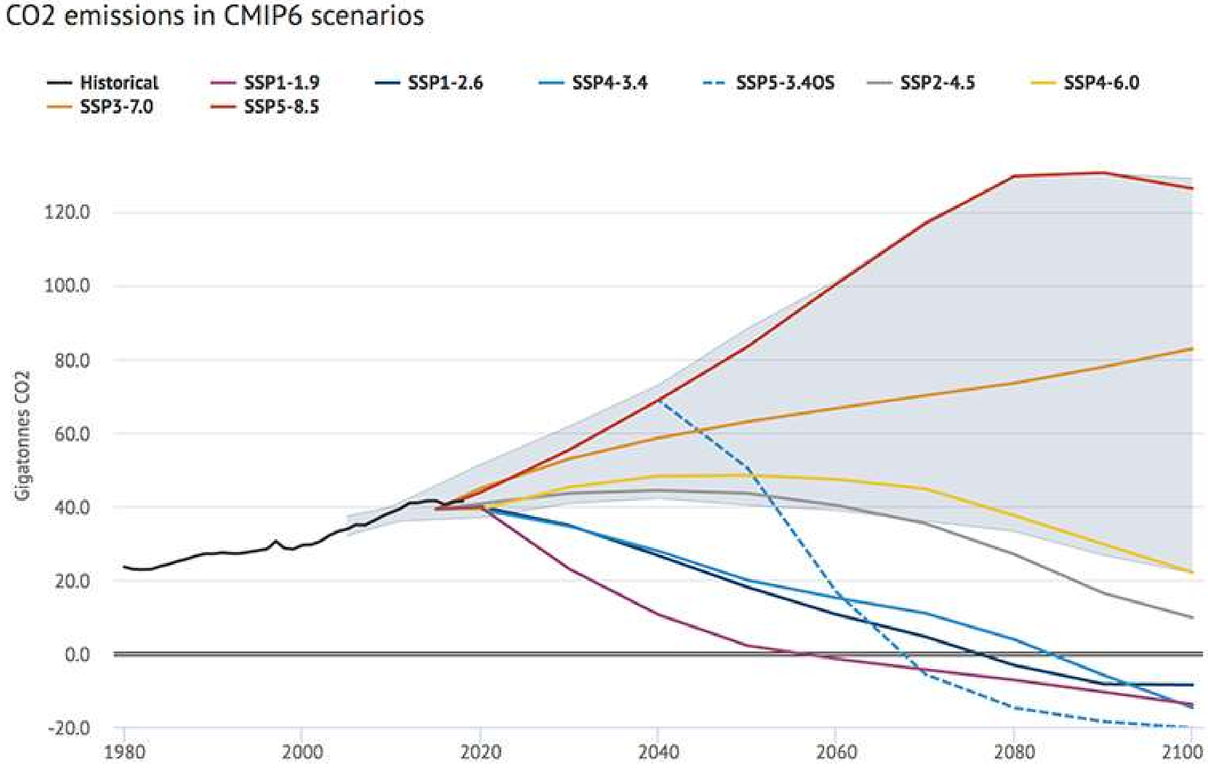


Figure 79: Future CO2 emissions scenarios featured in CMIP6, as well as historical CO2 emissions (in black). The shaded area represents the range of no-policy baseline scenarios.

Generating Rainfall Time Series from Downscaled Data for Bargi catchment

All the downscaled files have time series data at point level. To create a weighted average time series for Bargi sub catchments all the points has been plotted in QGIS and a grid file has been generated with center coinciding with point of downscaled files. Catchment file overlayed on the point shapefile and grid of resolution 0.25o X 0.25o for calculating weights for the catchment as shown in the Figure 80 for Bargi upstream and downstream catchment as example.

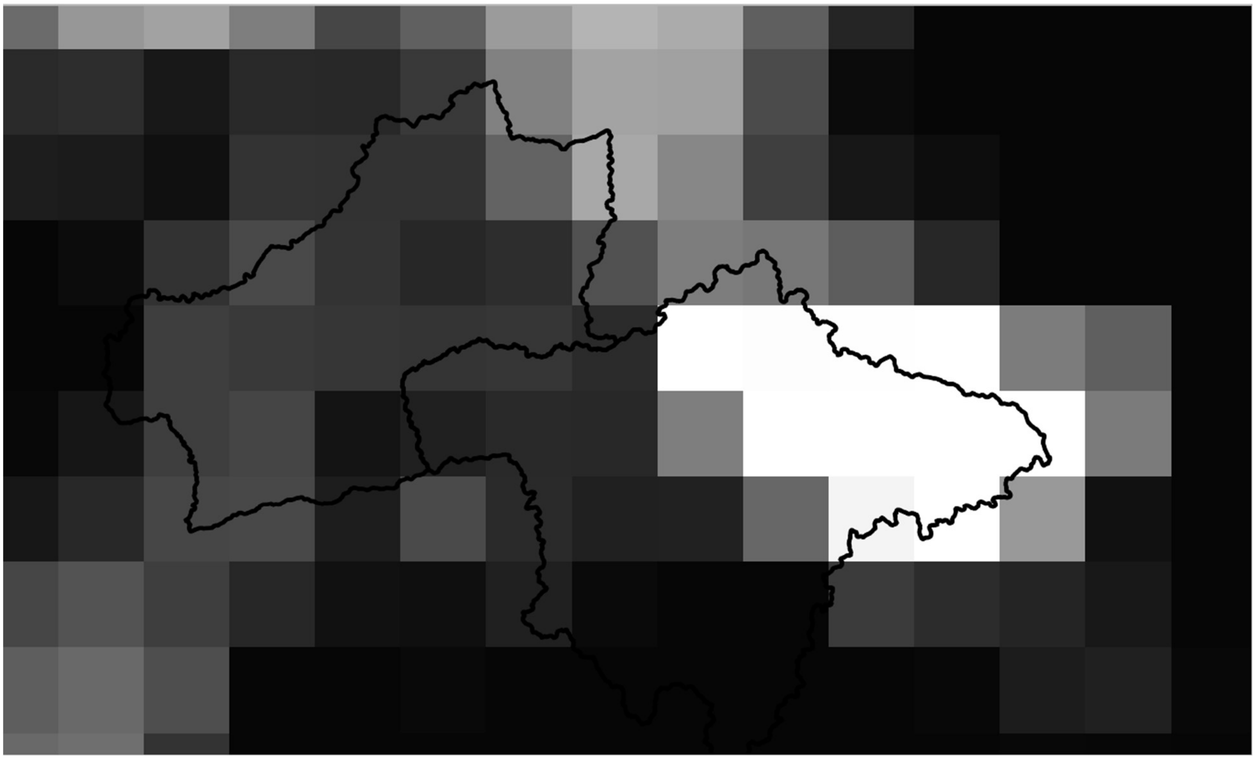


Figure 80: Grids for the catchment

After calculating rainfall time series, it was analysed for all the catchments for all the models. Figure 81 and Figure 82 show the annual rainfall plot for all the models for Bargi catchment. Graphical and statistical analysis is done for future predicted annual rainfall data FP (2015-2100) under future scenarios for all catchment of Bargi.

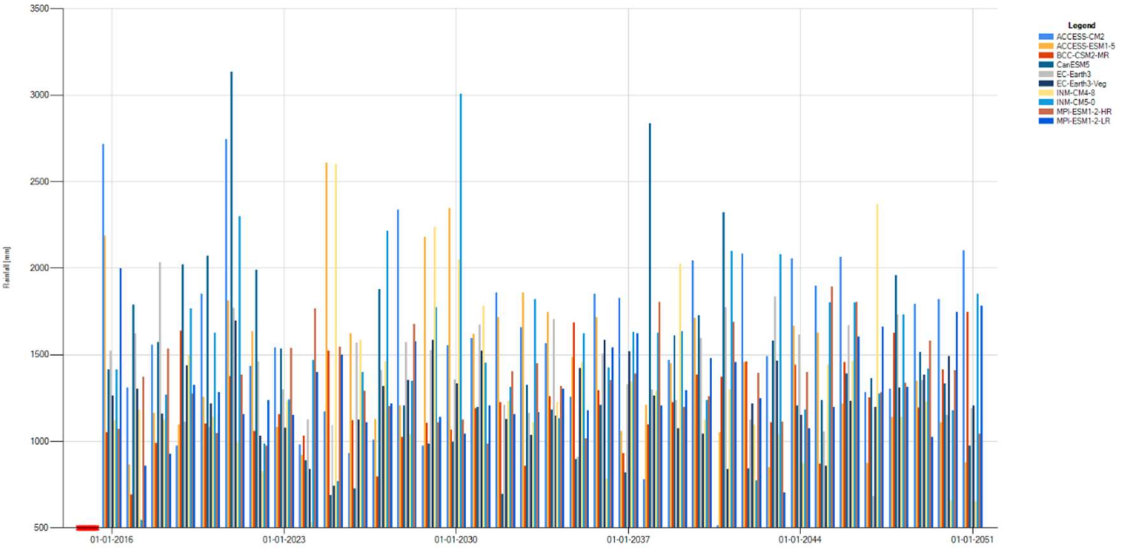


Figure 81: Bargi Upstream Catchment Rainfall for **1**. ACCESS-CM2 **2**. ACCESS-ESM1-5 **3**.BCC-CSM2-MR **4**. CanESM5 **5**.EC-Earth3 **6**.EC-Earth3-Veg **7**.INM-CM4-8 **8**.INM-CM5-0 **9**.MPI-ESM1-2-HR **10**.MPI-ESM1-2-LR

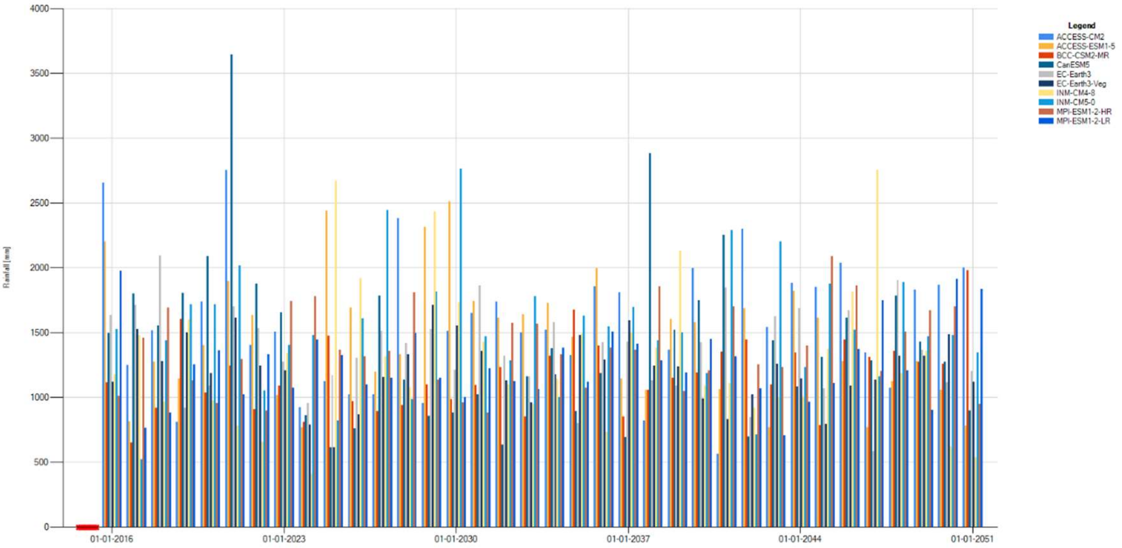


Figure 82: Bargi Downstream Catchment Rainfall for 1. ACCESS-CM2 2. ACCESS-ESM1-5 3.BCC-CSM2-MR 4. CanESM5 5.EC-Earth3 6.EC-Earth3-Veg 7.INM-CM4-8 8.INM-CM5-0 9.MPI-ESM1-2-HR 10.MPI-ESM1-2-LR

Statistical analysis and MK test results are mentioned in Table 16. In most of the cases Bargi upstream catchment has rising trend.

Table 16 Statistical Analysis for all the models for Bargi downstream catchment rainfall

Name	Maximum (mm)	Minimum (mm)	Standard Deviation (mm)	Average (mm)	Mann-Kendall Statistic	Significance Level
ACCESS-CM2	2743.71	511.86	509.55	1594.11	1.16	0.24
ACCESS-ESM1-5	2609.39	851.25	441.35	1441.60	-1.46	0.14
BCC-CSM2-MR	1745.98	690.10	255.35	1216.50	2.85	0.00

CanESM5	3132.99	688.65	569.22	1447.52	-0.48	0.63
EC-Earth3	2031.50	683.40	293.49	1398.63	-0.46	0.65
EC-Earth3-Veg	1696.19	742.33	226.64	1237.66	0.18	0.85
INM-CM4-8	2600.94	533.28	472.40	1312.61	-0.48	0.63
INM-CM5-0	3007.64	542.95	468.53	1533.30	0.86	0.39
MPI-ESM1-2-HR	1894.36	975.13	248.86	1361.81	1.14	0.26
MPI-ESM1-2-LR	2743.71	511.86	509.55	1594.11	1.16	0.24

Table 17: Statistical Analysis for all the model for Bargi upstream catchment rainfall

Name	Maximum (mm)	Minimum (mm)	Standard Deviation (mm)	Average (mm)	Mann-Kendall Statistic	Significance Level
ACCESS-CM2	2743.71	511.86	509.55	1594.11	1.16	0.24
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BCC-CSM2-MR	1745.98	690.10	255.35	1216.50	2.85	0.00
CanESM5	3132.99	688.65	569.22	1447.52	-0.48	0.63
EC-Earth3	2031.50	683.40	293.49	1398.63	-0.46	0.65
EC-Earth3-Veg	1696.19	742.33	226.64	1237.66	0.18	0.85
INM-CM4-8	2600.94	533.28	472.40	1312.61	-0.48	0.63
INM-CM5-0	3007.64	542.95	468.53	1533.30	0.86	0.39
MPI-ESM1-2-HR	1894.36	975.13	248.86	1361.81	1.14	0.26
MPI-ESM1-2-LR	2743.71	511.86	509.55	1594.11	1.16	0.24

Generating Evapotranspiration Time Series from Downscaled data for Study Basin

As mentioned above downscaled data has maximum and minimum temperature for the six countries. MIKE HYDRO Basin needs evapotranspiration for rainfall runoff estimation. In order to calculates evapotranspiration, Hargreaves equation is used. The Hargreaves equation is a second temperature-based method and although it gives an expression for the reference crop evapotranspiration. It is used as a representative expression for potential evapotranspiration (Hargreaves, 1981; Hargreaves et al., 1985). To use Hargreaves method, the python library ETo package is used. The ETo package contains a class and associated functions to calculate reference evapotranspiration (ETo) using the UN-FAO 56 paper [1]. Additional functions have been added to calculate historic ETo or potential evapotranspiration (PET) for comparison purposes. Graphical and statistical analysis has been done for future predicted annual evapotranspiration data FP (2015-2100) under future scenarios for all catchment of Bargi Basin.

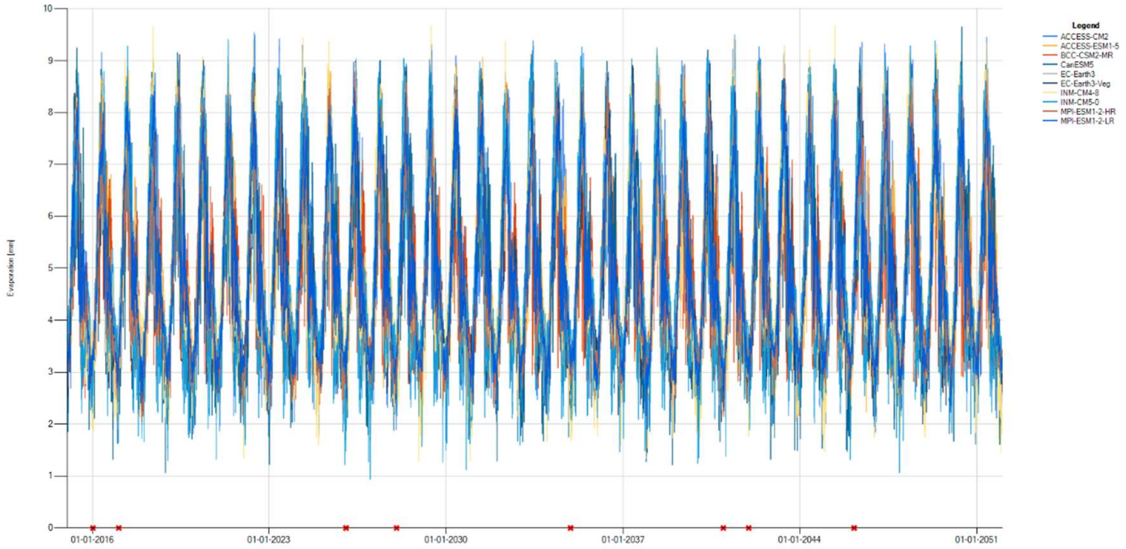


Figure 83: Bargi downstream catchment evapotranspiration for 1. ACCESS-CM2 2. ACCESS-ESM1-5 3.BCC-CSM2-MR 4. CanESM5 5.EC-Earth3 6.EC-Earth3-Veg 7.INM-CM4-8 8.INM-CM5-0 9.MPI-ESM1-2-HR 10.MPI-ESM1-2-LR

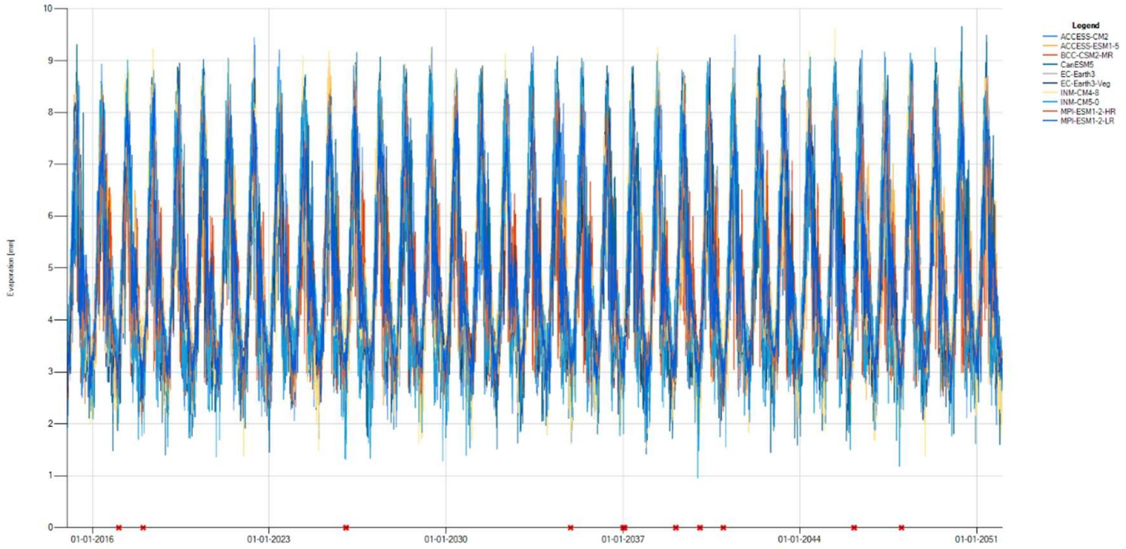


Figure 84: Bargi upstream catchment evapotranspiration for 1. ACCESS-CM2 2. ACCESS-ESM1-5 3.BCC-CSM2-MR 4. CanESM5 5.EC-Earth3 6.EC-Earth3-Veg 7.INM-CM4-8 8.INM-CM5-0 9.MPI-ESM1-2-HR 10.MPI-ESM1-2-LR

Statistical analysis and MK test results are mentioned in Table 18 In most of the cases study catchment has falling trend.

Table 18: Statistical Analysis for all the models for Bargi downstream catchment evapotranspiration

Name	**Maximum (mm)**	**Minimum (mm)**	**Standard Deviation (mm)**	**Average (mm)**	**Mann-Kendall test Statistic**	**Significance Level**
ACCESS-CM2	9.54	1.81	1.77	5.05	2.50	0.01
ACCESS-ESM1-5	9.09	2.14	1.69	4.89	0.16	0.87
BCC-CSM2-MR	9.12	2.02	1.46	4.89	0.24	0.81

CanESM5	9.75	1.06	1.82	4.91	0.55	0.58
EC-Earth3	8.86	1.94	1.60	4.82	-0.59	0.55
EC-Earth3-Veg	9.12	2.00	1.58	4.86	0.26	0.80
INM-CM4-8	9.69	1.28	1.69	4.83	-0.81	0.42
INM-CM5-0	9.41	0.94	1.73	4.79	1.33	0.18
MPI-ESM1-2-HR	8.79	2.04	1.46	4.85	1.81	0.07
MPI-ESM1-2-LR	8.66	1.90	1.45	4.92	-0.41	0.69

Name	Maximum (mm)	Minimum (mm)	Standard Deviation (mm)	Average (mm)	Mann-Kendall test Statistic	Significance Level
ACCESS-CM2	9.50	1.64	1.76	4.95	1.61	0.11
ACCESS-ESM1-5	8.99	2.10	1.64	4.83	0.25	0.80
BCC-CSM2-MR	8.95	2.20	1.43	4.81	-0.62	0.53
CanESM5	9.66	1.40	1.74	4.85	2.96	0.00
EC-Earth3	8.78	1.91	1.56	4.76	-1.07	0.28
EC-Earth3-Veg	9.06	1.93	1.54	4.79	0.25	0.80
INM-CM4-8	9.61	1.37	1.62	4.75	-1.64	0.10
INM-CM5-0	9.25	0.96	1.68	4.72	0.25	0.80
MPI-ESM1-2-HR	8.69	2.01	1.41	4.80	2.51	0.01
MPI-ESM1-2-LR	8.52	1.91	1.40	4.85	-0.07	0.94

Domestic Water Demand

With increasing household income and increasing contributions from the service and industrial sectors, the water demand in the domestic and industrial sectors could increase substantially. We assume that the average domestic water demand would increase from 85 liters per capita per day (lpcd) in 2000, to 125 and 170 lpcd by 2025 and 2050, respectively. The BAU scenario approach differs from the approach adopted by the National Commission of Integrated Water Resources Development-NCIWRD (GOI 1999) commission (India's Water Supply and Demand from 2025-2050: Business- as- Usual Scenario and Issues, International Water Management Institute, New Delhi, India https://publications.iwmi.org/pdf/H041798.pdf). They assumed norms where the rural domestic water demand in 2025 and 2050 are assessed at 70 and 150 lpcd, respectively, and the urban water demand at 200 and 220 lpcd, for 2025 and 2050 respectively. They also assumed 100 % coverage of domestic water supply for both the rural and the urban sectors. At this rate, the average per capita water demand in 2025 and 2050 is estimated to be 126 and 191 lpcd, respectively. The domestic water demand includes the livestock water demand as well, which we assume to be 25 liters per head for the cattle and buffalo population. The livestock population is projected at the rate of animal products calorie supply. Estimated livestock water demand to increase from 2.3 BCM in 2000 to 2.8 and 3.2 BCM by 2025 and 2050, respectively.

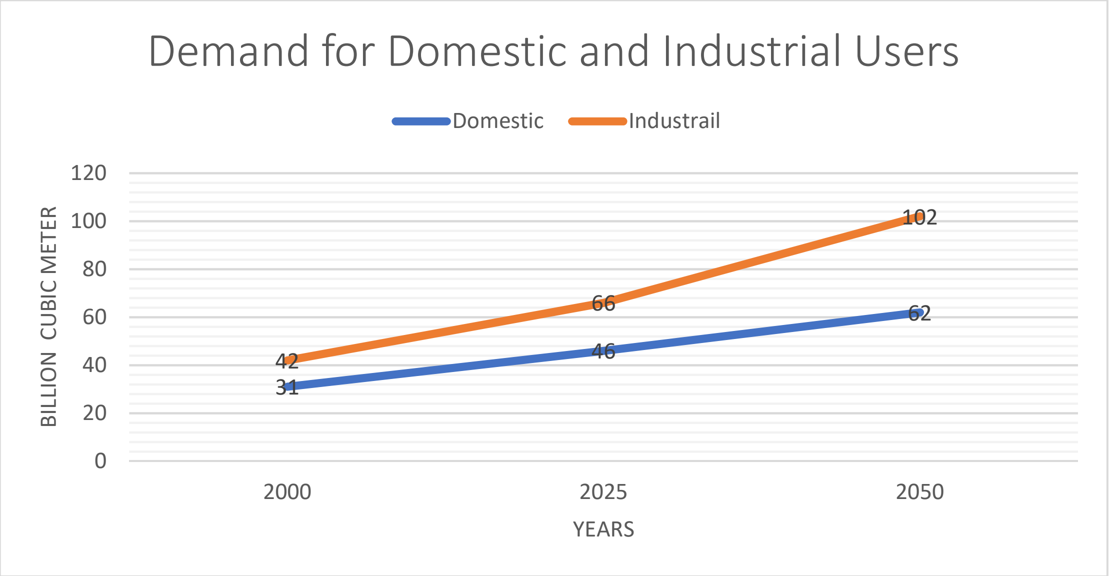


Figure 85: Projected domestic and industrial demand

Industrial Water Demand

In a rapidly booming economy, we expect the contribution of the industrial sector to increase very much, and the industrial water demand to also increase accordingly. However, the dearth of information—the types of industries, their growth, water use and the extent of recycling is a constraint for future projections in the context of increasing economic growth. The NCIWRD commission, based on a small sample of industries and their water use, projected that industrial water demand would increase from 30 BCM in 2000, to about 101 and 151 BCM by 2025 and 2050, respectively (https://publications.iwmi.org/pdf/H041798.pdf).

However, an analysis using the global trends show that, with the present economic growth rates, the per capita industrial water demand could increase from 42 m3/person in 2000, to about 66 and 102 m3/person by 2025 and 2050, respectively or the total industrial water demand to increase to 92 and 161 BCM by 2025 and 2050, respectively (Reference: Strategic Analyses of the National River Linking (NRLP) of India series 2, Published by IWMI). The BAU scenario too assumes these growth rates

Applications of the CC-DSS for climate change adaptation options

The CC-DSS application, as name suggests, the impact of climate change on basin scale is captured for planning and can be used as a management tool capable of assisting users to plan and manage water resources after careful assessment of the water availability, distribution and allocation policies and operational behavior of the entire project system in a catchment or river basin level. The tool allows users to work on hydrological models simultaneously across different user group thus making sure the completeness of data and common understanding about the operation of the system. The stakeholders can now test the response of the system based on different management policies or scenarios. Scenario generation is a key functionality whereas the stakeholder does not need to be an expert of hydrological modelling. The user, who can be a state official, a dam authority person, knowing the various components of the system can create different operation situations by editing the components which are water users. The modeler can add all possible water users, which are identified by the decision-makers to be included in one or more of the scenarios.

When creating a scenario, the user will get an overview of all the available water users which are embedded in the model and select/deselect the same to be included in any scenario. In addition to adding or removing water users, the user can also modify existing water users, e.g., increase the area of an irrigation scheme, change in the initial water level of the existing reservoir etc. The scenario creation is provided with example further in this chapter.

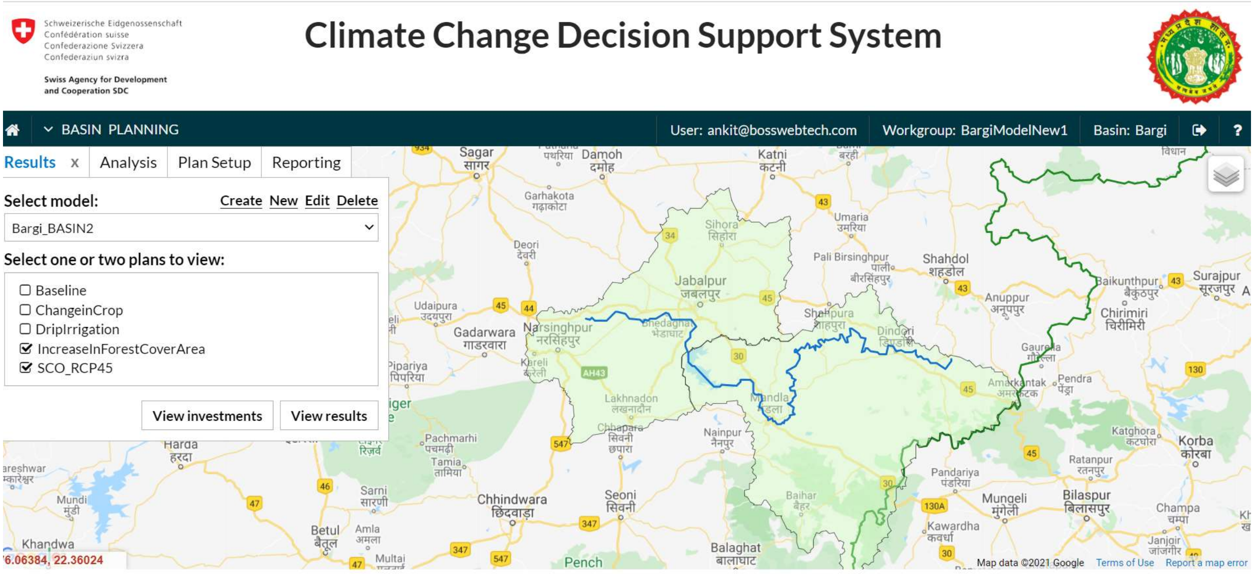
Under basin planning and management modules, following are the key functionalities, with which user can do decision making –

- Assessing water availability, demands, deficits, varying water level in storages, all across different simulation time, using uploaded model and results in form of reporting and graphical representation.
- Creating different scenarios, by adding, deleting, entire component or by modifying their values.
- Providing management policy and operation restrictions in form of reduction levels of the reservoirs, changing hydropower efficiencies, crop areas, type of crops, adding/ removing crops, changing demands by computing population growth and per capita requirements for future
- Prediction of future mitigation investments on predicted climate change on basins
- Performance is usually quantified by indicators, which are derived numbers from model properties, model inputs, and most importantly model results. CC-DSS calculates indicators based on the model inputs and qualifies and rank the performance.
- Reporting

CC-DSS unzip the uploaded and create a predefined folder structure for the uploaded model. It uploads all mandatory basin models, runs, time series and GIS files in database for scenario generation and comparison. Once all the processing will be finished user will receive an email on registered email ID about the status of model upload. After successful upload user will be able to see model name in the drop down of model list. The user now can clone the model under plan setup and make changes whatever required through the process. All the simulation runs, optimization runs, and forecast runs are imported in CC-DSS and their results can be visualized in the form of time series and statistical values.

Most of the conventional DSS platforms works for planning based on the interpolation of existing scenarios. But in this the base of comparison is future climatic conditions and further mitigations adaptation measures are analysed with predicted climate parameters. The analyses in the application are detailed below.

The main three modules of CC-DSS are basin planning, knowledge basin and rainfall-runoff. In any application to the system is called investment. The investments are added to the module and tested using different tools such as create/new/edit from an existing model or by adding a new model. The changes due to a particular investment is viewed under “view results” tab. The basin planning sub-section view is given below with invested plans in Figure 86.



Climate Change Decision Support System

User: ankit@bosswebtech.com

Workgroup: BargiModelNew1

Basin: Bargi

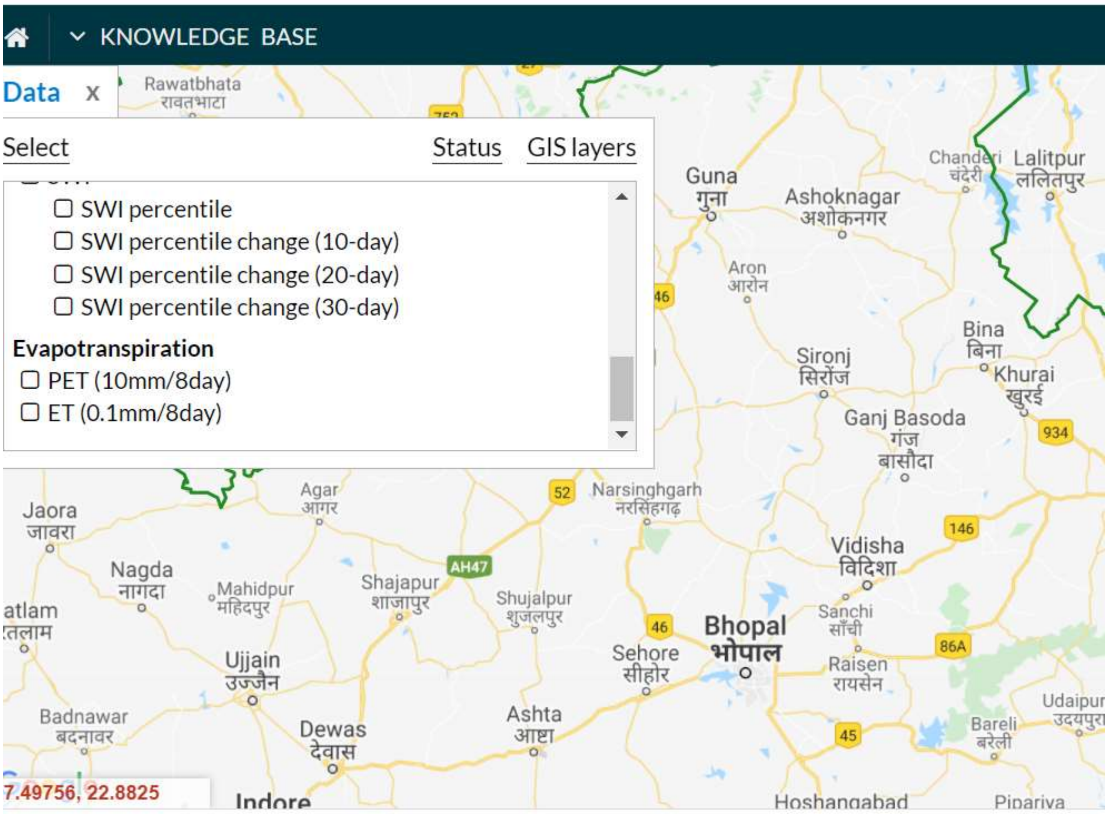
Select model: Bargi_BASIN2

Select one or two plans to view:

- ☐ Baseline
- ☐ ChangeinCrop
- ☐ DripIrrigation
- ☑ IncreaseInForestCoverArea
- ☑ SCO_RCP45

Figure 86: Basin planning module with investment and their result tab

The knowledge base is available with a lot of global data set such as NDVI, SWI (Soil Water Index), Rainfall (TRMM, GPM, IMD gridded) and Potential Evapotranspiration.



KNOWLEDGE BASE

Data x

Select Status GIS layers

☐ SWI percentile

☐ SWI percentile change (10-day)

☐ SWI percentile change (20-day)

☐ SWI percentile change (30-day)

Evapotranspiration

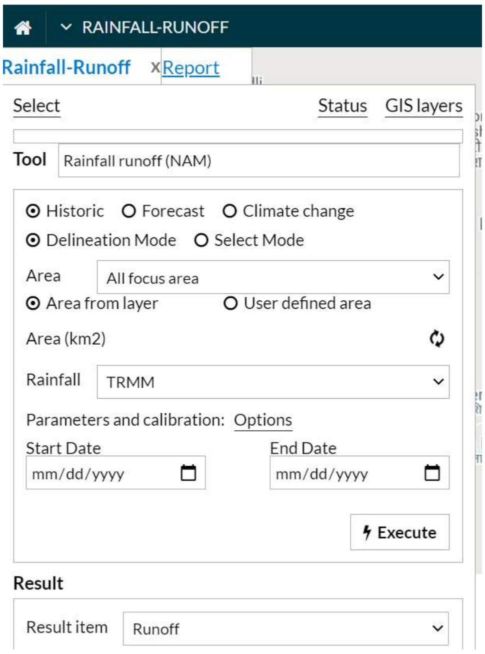
☐ PET (10mm/8day)

☐ ET (0.1mm/8day)

7.49756, 22.8825

Figure 87: Knowledge base module with dataset

The third module automatically delineate catchment and simulated rainfall-runoff model with the selected dataset and selected time period at any location within India. The rainfall-runoff model simulation report will be available in the report sub-section of the same module.



RAINFALL-RUNOFF

Rainfall-Runoff x Report

Select Status GIS layers

Tool: Rainfall runoff (NAM)

● Historic ○ Forecast ○ Climate change

● Delineation Mode ○ Select Mode

Area: All focus area

● Area from layer ○ User defined area

Area (km2)

Rainfall: TRMM

Parameters and calibration: Options

Start Date: mm/dd/yyyy

End Date: mm/dd/yyyy

Result

Result item: Runoff

Figure 88: Rainfall-Runoff Module

All baseline model results can be seen component wise under results tab. Following components and results can be seen.

Table 19: Baseline model results available in CC-DSS

Model Component	Property/ies
Catchment	• Runoff
Hydropower	• Generated power • Deficit as flow • Power Deficit
Irrigation	• Total irrigation demand • Net flow to node • Unallocated water • Water demand deficit
Water User	• Net flow to node • Unallocated water • Used Water • Demand Deficit
Reservoir	• Precipitation • Evaporation • Water Level

Each scenario is considered as an investment. The baseline model and climate change are the pre-investment scenario. The investments are called the main applications of CC-DSS. The investment or applications are listed below.

1. Future crop yield compared with current and future climate events
2. Change in the cropping pattern -Agronomic Changes
3. Changing the irrigation system
4. Change in irrigation demand due to the combined effect of changing the irrigation system and cropping pattern
5. Land use changes- converting urban areas into forest land on the upstream catchment

Additional applications are tested considering the future changes into account

1. Future domestic demand increment by 48% by 2025 and 100% by 2050 due to increment in the population
2. Future Industrial demand increment by 18% by 2025 and 50% by 2050
3. Improved recharge of ground water and change in agricultural demand
4. Increase in hydropower production by 20% by 2050 due to population growth
5. Multi-criteria analysis

Future crop yield for irrigation user

The baseline and climate change scenario were compared for LBC. The crop kharif yield plotted annually shown in Figure 89**Error! Reference source not found.**.

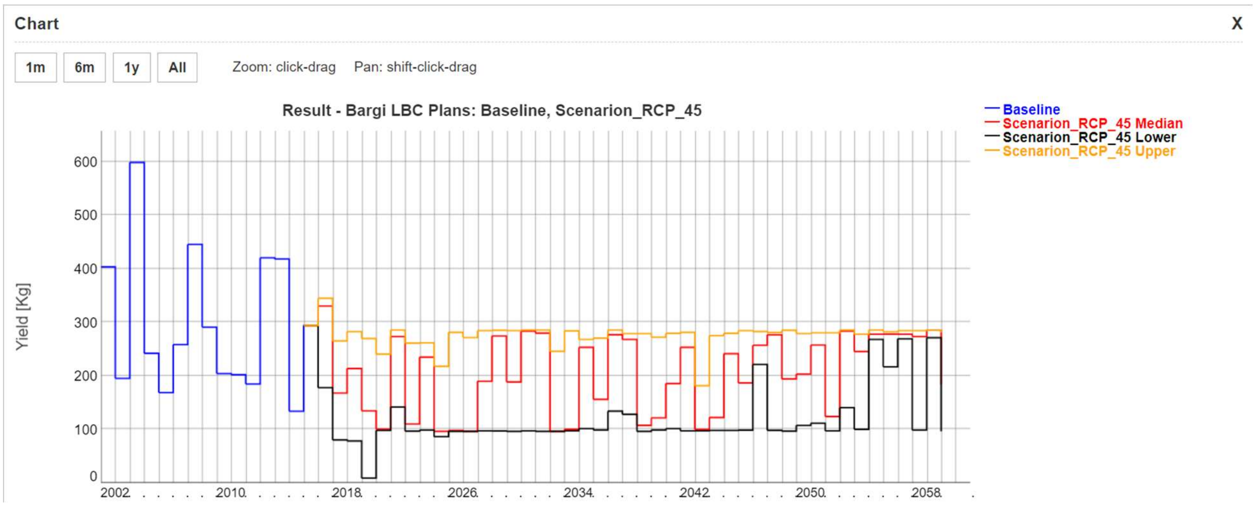
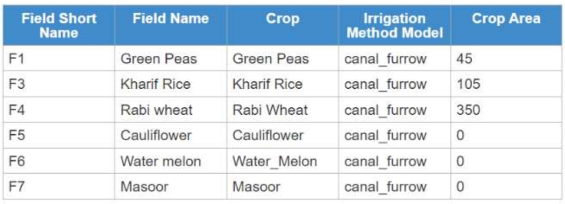


Figure 89: The annual crop yield for Kharif Rice for baseline and climate change

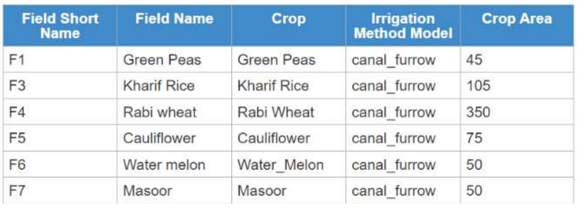
It is clearly visible that the crop yield is getting reduced in future if the no mitigation measures is planned. Inferring this, the future investments are tested by changing crop and area

Change in the cropping pattern

The crops in RBC are changed for the projected years, the additional crops such as Cauliflower, Watermelon and Masoor are added



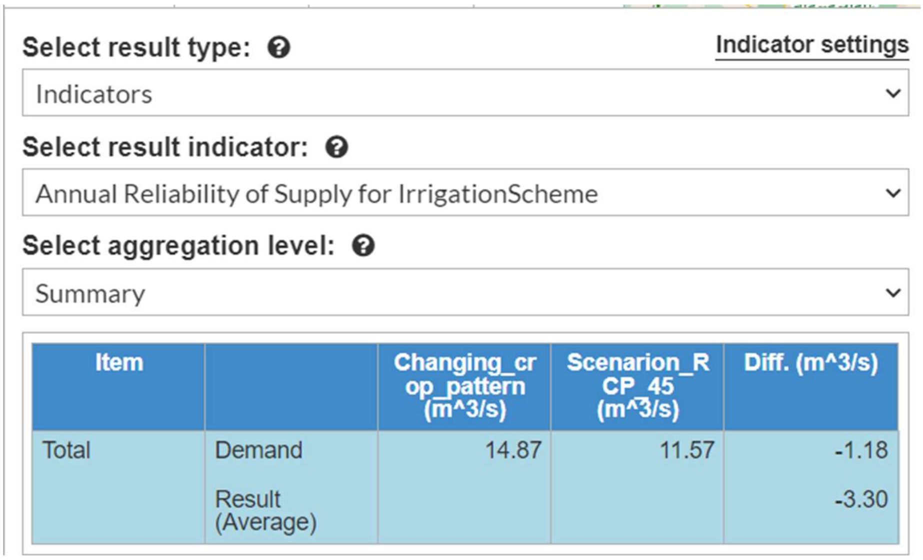
Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F1	Green Peas	Green Peas	canal_furrow	45
F3	Kharif Rice	Kharif Rice	canal_furrow	105
F4	Rabi wheat	Rabi Wheat	canal_furrow	350
F5	Cauliflower	Cauliflower	canal_furrow	0
F6	Water melon	Water_Melon	canal_furrow	0
F7	Masoor	Masoor	canal_furrow	0



Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F1	Green Peas	Green Peas	canal_furrow	45
F3	Kharif Rice	Kharif Rice	canal_furrow	105
F4	Rabi wheat	Rabi Wheat	canal_furrow	350
F5	Cauliflower	Cauliflower	canal_furrow	75
F6	Water melon	Water_Melon	canal_furrow	50
F7	Masoor	Masoor	canal_furrow	50

Pre-scenario

Post-scenario



Select result type: ❓ Indicator settings

Indicators

Select result indicator: ❓

Annual Reliability of Supply for IrrigationScheme

Select aggregation level: ❓

Summary

Item		Changing_crop_pattern (m^3/s)	Scenarion_RCP_45 (m^3/s)	Diff. (m^3/s)
Total	Demand	14.87	11.57	-1.18
	Result (Average)			-3.30

Figure 90: Irrigation water requirement changed from 11.57 cubic m/sec to 14.87 cubic m/sec

The annual demand has been increased (80 MCM to 115 MCM) and plotted in Figure 91.

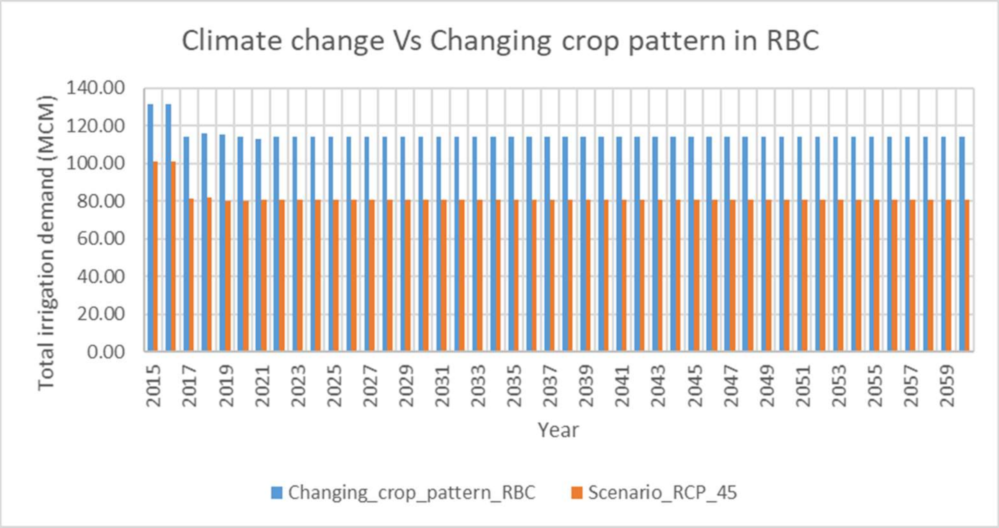
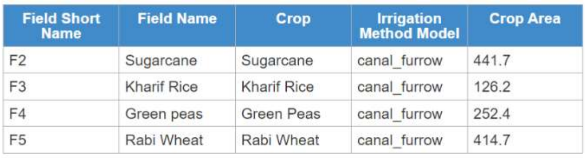


Figure 91: Total irrigation demand for RBC before and after change in the crop pattern

Due to the addition of crops such as Cauliflower, Watermelon and Masoor dal on RBC, the demand total irrigation demand is increased (orange line represents the climate change scenario for the projected years, blue represents after addition of crops)

Changing the irrigation system

Second application applied is the changing the irrigation method of LBC



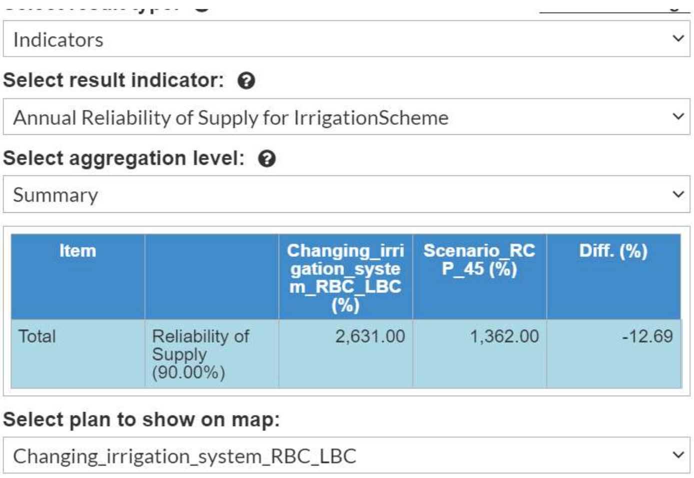
Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F2	Sugarcane	Sugarcane	canal_furrow	441.7
F3	Kharif Rice	Kharif Rice	canal_furrow	126.2
F4	Green peas	Green Peas	canal_furrow	252.4
F5	Rabi Wheat	Rabi Wheat	canal_furrow	414.7

Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F2	Sugarcane	Sugarcane	Drip	441.7
F3	Kharif Rice	Kharif Rice	Drip	126.2
F4	Green peas	Green Peas	Drip	252.4
F5	Rabi Wheat	Rabi Wheat	Drip	414.7

Pre-scenario

Post scenario

The current irrigation system is canal furrow method for both LBC and RBC. As an application scenario, the canal furrow irrigation is changed to drip irrigation system.



Indicators

Select result indicator:

Annual Reliability of Supply for IrrigationScheme

Select aggregation level:

Summary

Item		Changing_irrigation_system_RBC_LBC (%)	Scenario_RCP_45 (%)	Diff. (%)
Total	Reliability of Supply (90.00%)	2,631.00	1,362.00	-12.69

Select plan to show on map:

Changing_irrigation_system_RBC_LBC

Figure 92 The annual reliability of irrigation scheme from 1362 to 2631 due to change in the existing irrigation system

The total irrigation demand is estimated and plotted in for both LBC (Figure 93) and RBC (Figure 94)

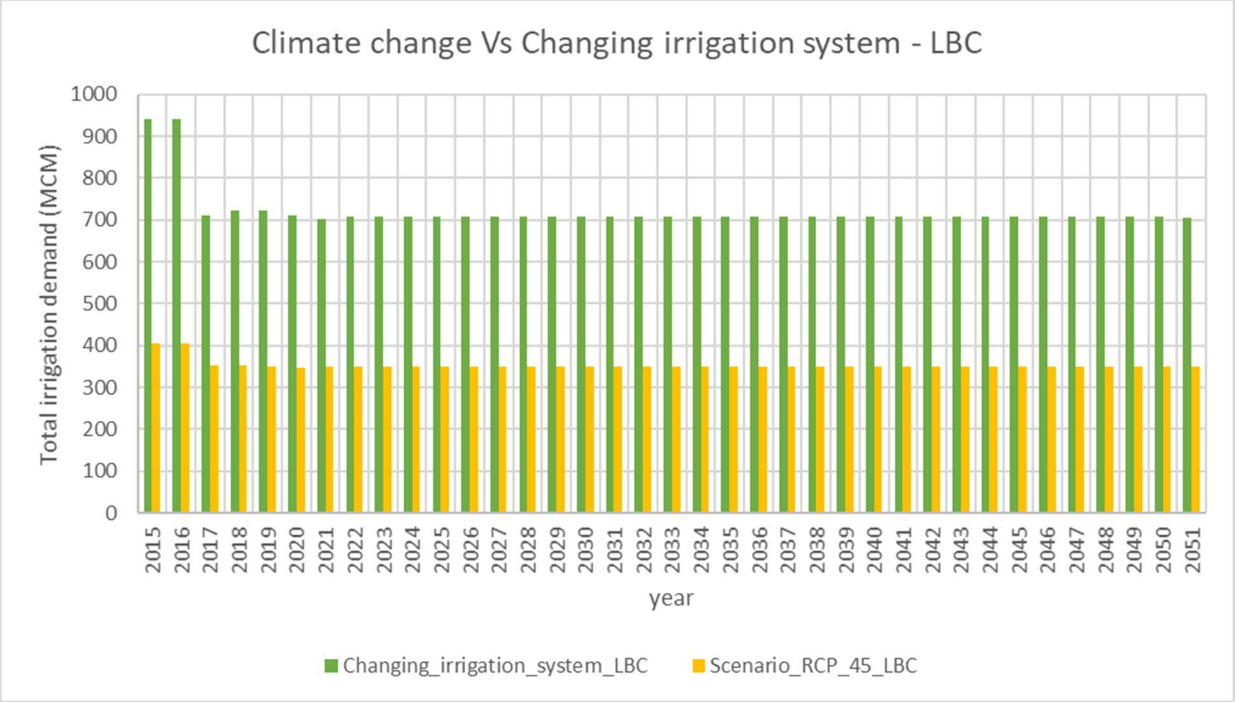


Figure 93: Total demand due to change in irrigation system (LBC)

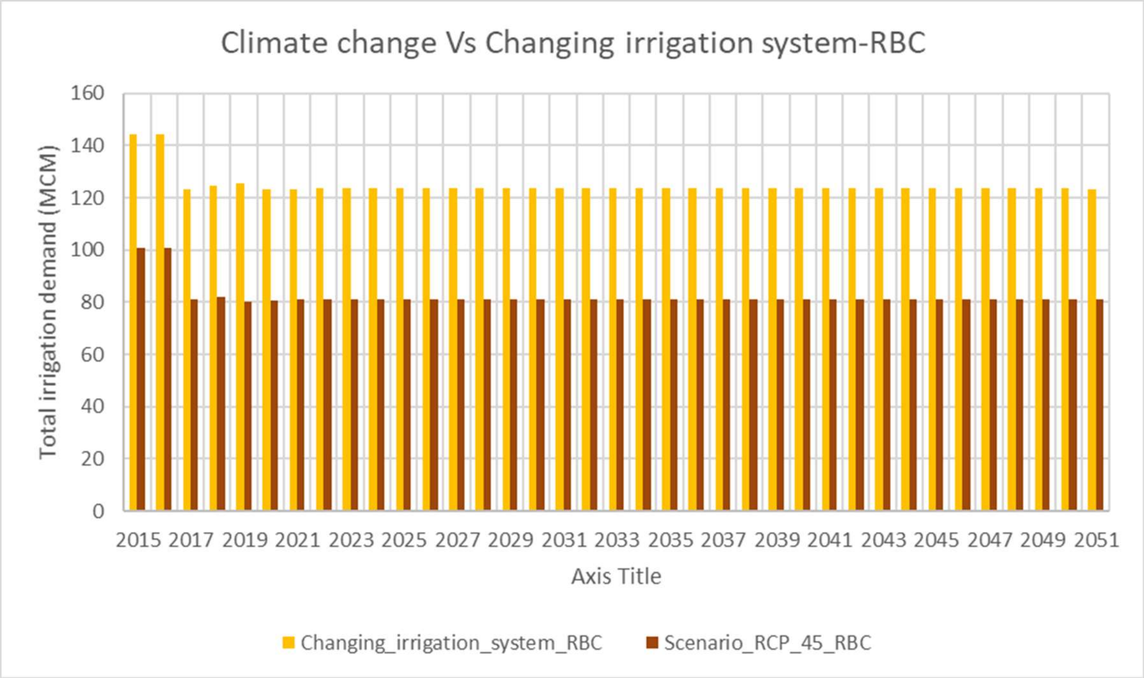
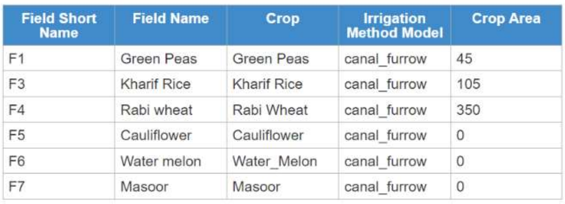


Figure 94: Total demand due to change in irrigation system (RBC)

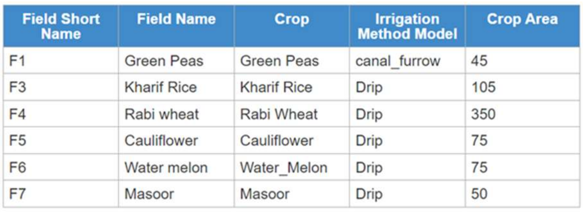
In both of the canal system, the irrigation method is changed from canal furrow method to drip irrigation system. The left plot is showing irrigation demand for LBC for drip irrigation (green color) is increased from the current system (yellow). It is the same case with RBC. The brown line shows the irrigation demand after application and yellow shows before application.

Combined change in irrigation system and cropping pattern

In this application, a combination of change in crop pattern and change in irrigation system is applied to RBC.



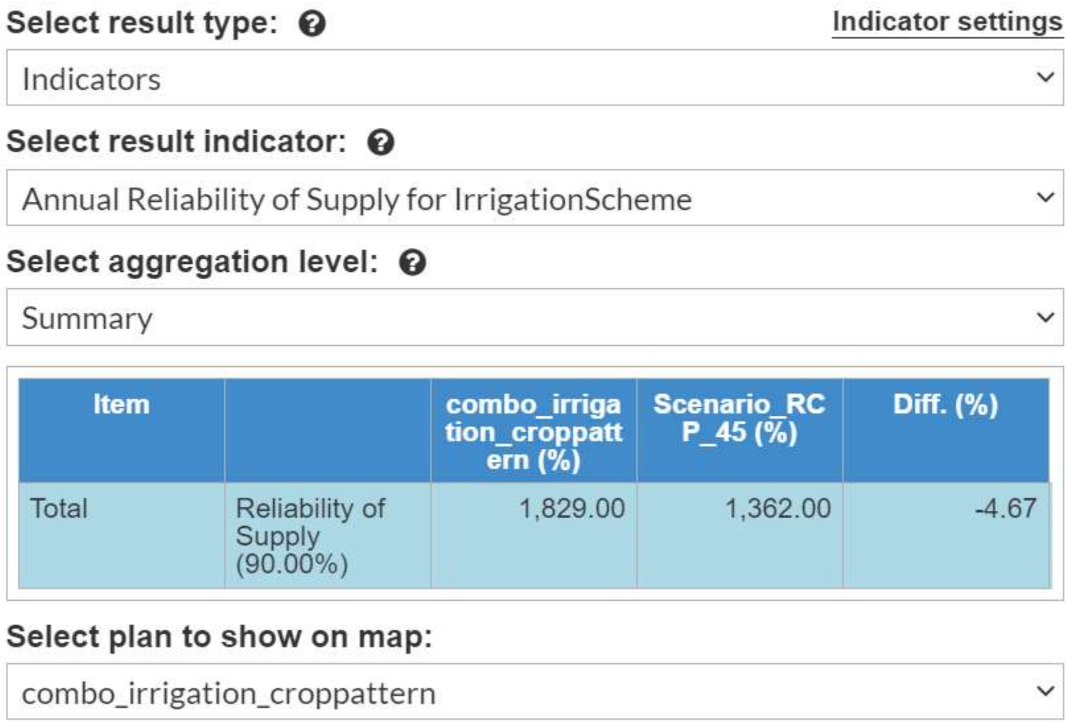
Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F1	Green Peas	Green Peas	canal_furrow	45
F3	Kharif Rice	Kharif Rice	canal_furrow	105
F4	Rabi wheat	Rabi Wheat	canal_furrow	350
F5	Cauliflower	Cauliflower	canal_furrow	0
F6	Water melon	Water_Melon	canal_furrow	0
F7	Masoor	Masoor	canal_furrow	0



Field Short Name	Field Name	Crop	Irrigation Method Model	Crop Area
F1	Green Peas	Green Peas	canal_furrow	45
F3	Kharif Rice	Kharif Rice	Drip	105
F4	Rabi wheat	Rabi Wheat	Drip	350
F5	Cauliflower	Cauliflower	Drip	75
F6	Water melon	Water_Melon	Drip	75
F7	Masoor	Masoor	Drip	50

Pre-scenario Post-scenario

Three new crops were added, and the existing irrigation system is changed from canal furrow method to drip irrigation. The indicator is changed from 1362 to 1829 and the same is shown in Figure 95.



Select result type: Indicators

Select result indicator: Annual Reliability of Supply for IrrigationScheme

Select aggregation level: Summary

Item		combo_irrigation_croppattern (%)	Scenario_RCP_45 (%)	Diff. (%)
Total	Reliability of Supply (90.00%)	1,829.00	1,362.00	-4.67

Select plan to show on map: combo_irrigation_croppattern

Figure 95: The change in the annual reliability of irrigation scheme is changed due to change in irrigation system and cropping pattern

The annual irrigation demand for RBC is plotted in Figure 96 before and after the application

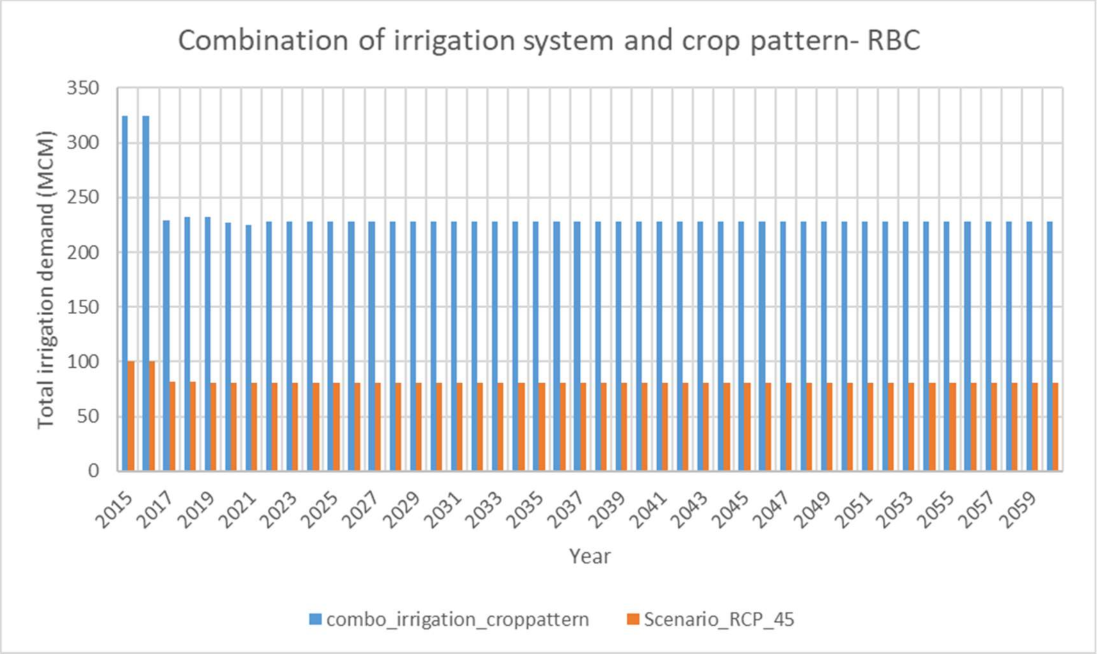


Figure 96: Change in annual irrigation demand due to the combined change in the crop pattern and irrigation system

The average demand is increased due to the proposed change from 80 MCM to 225 MCM

Land use changes- converting urban areas into forest land on the upstream catchment

The upstream catchment of Bargi reservoir is almost hilly and forest cover. But due to increment in rainfall and subsequently it results increment in the inflow to Reservoir. As mitigation to this, whether improving more forest cover will help the inflow to reservoir or not is tested and analysed.

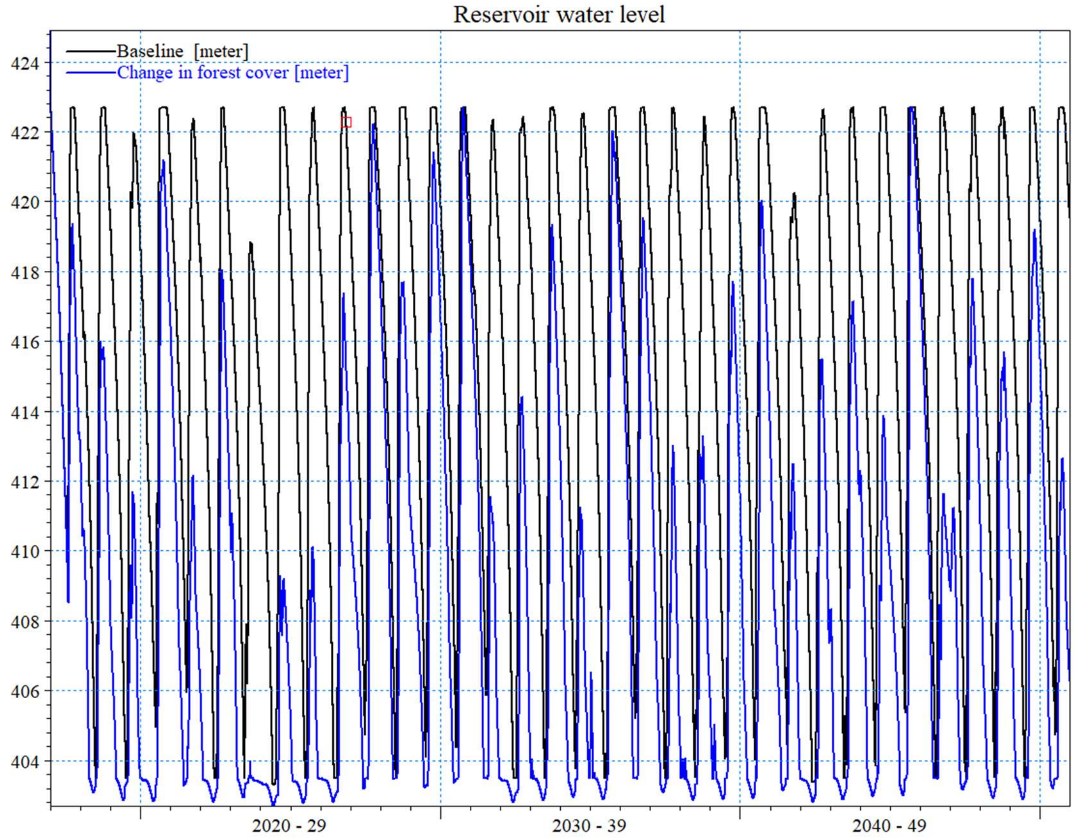


Figure 97: Water level in the reservoir before and after Investing more forest cover in the upstream catchment

It is evident that the water level is reduced after the investment as seen in Figure 97.

The irrigation deficit is also observed with the investment of forest cover

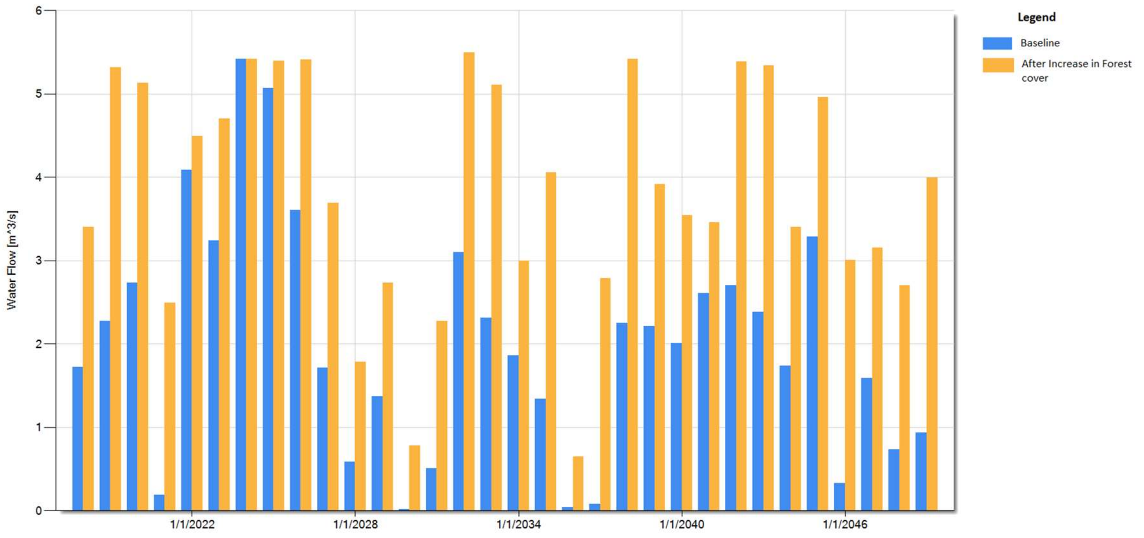
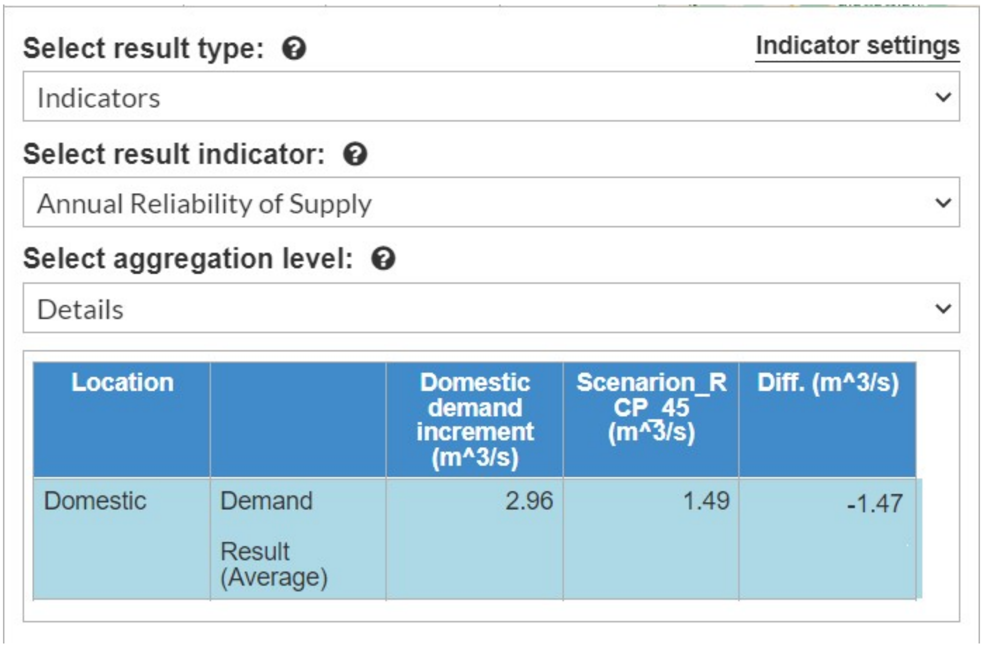


Figure 98: Irrigation deficit before and after the investment of forest cover

It can be understood that the irrigation deficit has increase due to the new investment. Most of the future years the deficit has almost doubled after 2030. It can be read as any mitigation plan to drought as storage structures or artificial check dams in the upstream areas could be negatively impact on the downstream users due to unavailability of water at the reservoir storage due to the low runoff to the dam. In effect, the operation water level is not available to distribute to the irrigation use. Therefore, the testing of mitigation plan/investment is always suggested to see the footprints and its consequences.

Changes in water availability and demand for drinking water due to population change

Future domestic demand increment by 48% by 2025 and 100% by 2050 due to increment in the population. The application is tested and mapped both the pre and post scenarios. The reliability indicator before and after scenarios are given and compared.



Select result type: Indicators

Select result indicator: Annual Reliability of Supply

Select aggregation level: Details

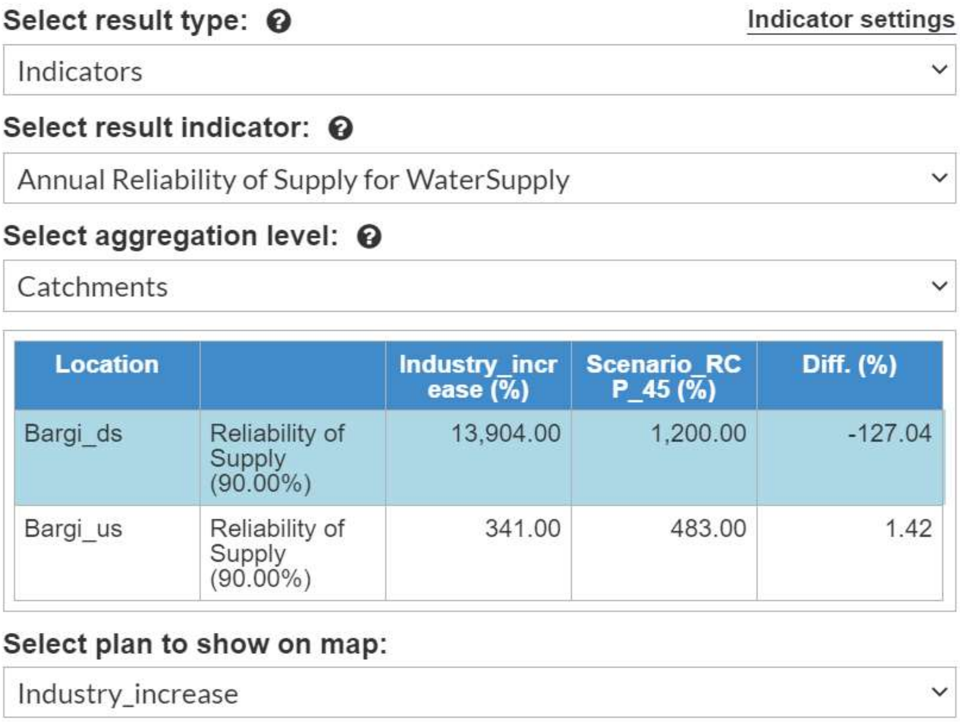
Location		Domestic demand increment (m^3/s)	Scenarion_RCP_45 (m^3/s)	Diff. (m^3/s)
Domestic	Demand Result (Average)	2.96	1.49	-1.47

Figure 99: Increased domestic demand by 1.47 m3/s (domestci demand in climate change scenarios 1.49 m3/s is increased to 2.96 m3/s)

Due to the increase in domestic water demand by 48% till the year 2025 and 100% till the end of year 2050, the average demand is changed from 1.49 m3/s to 2.96 m3/s.

Future Industrial demand increment

The future Industrial demand increment by 18% by 2025 and 50% by 2050, the indicator for the climate change scenarios is improved due to the increment of industrial demand as shown in the Figure 100 below.



Select result type: Indicators

Select result indicator: Annual Reliability of Supply for WaterSupply

Select aggregation level: Catchments

Location		Industry_increase (%)	Scenario_RCP_45 (%)	Diff. (%)
Bargi_ds	Reliability of Supply (90.00%)	13,904.00	1,200.00	-127.04
Bargi_us	Reliability of Supply (90.00%)	341.00	483.00	1.42

Select plan to show on map: Industry_increase

Figure 100: Industrial demand increment application led to downstream catchment reliability from 1200 to 13904

Improved recharge of ground water and subsequent change in agricultural demand

For the existing case, the use of ground water is 20% of the actual utilized water. For future scenario, assuming in case of more recharge structures, abundance of ground water is available to downstream catchment, the ground water usage is increased to 35% of total used water. The total irrigation demand is compared with before and after application and plotted Figure 101 .

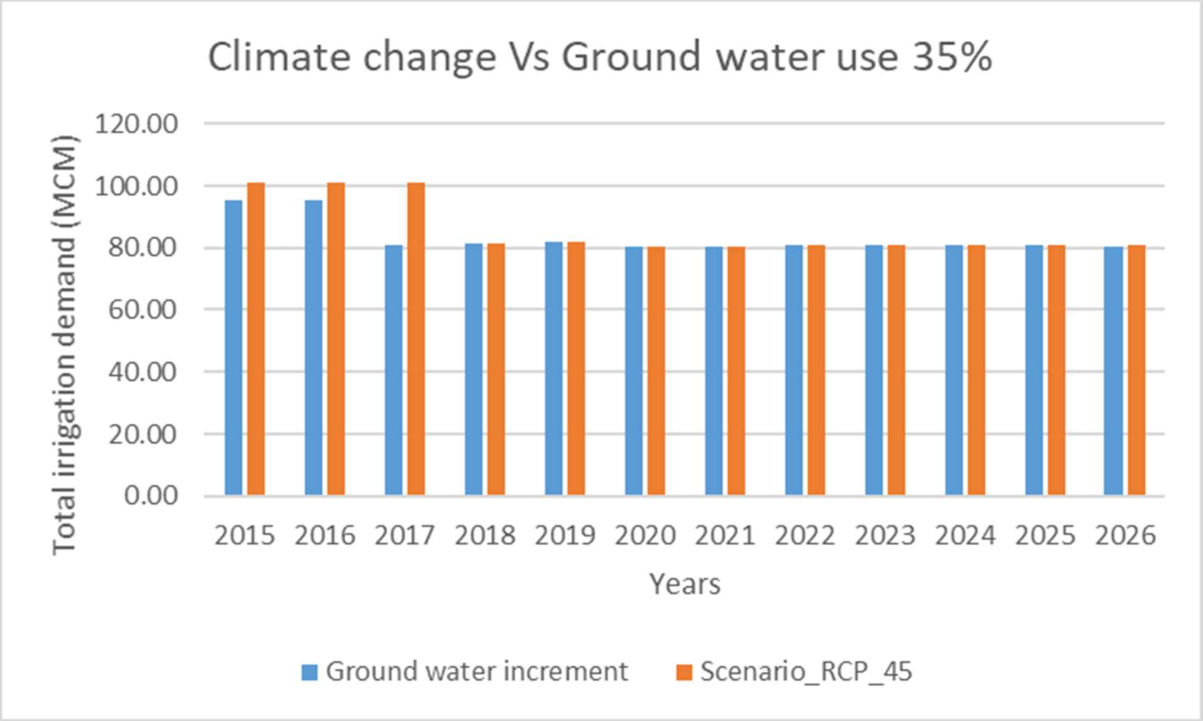
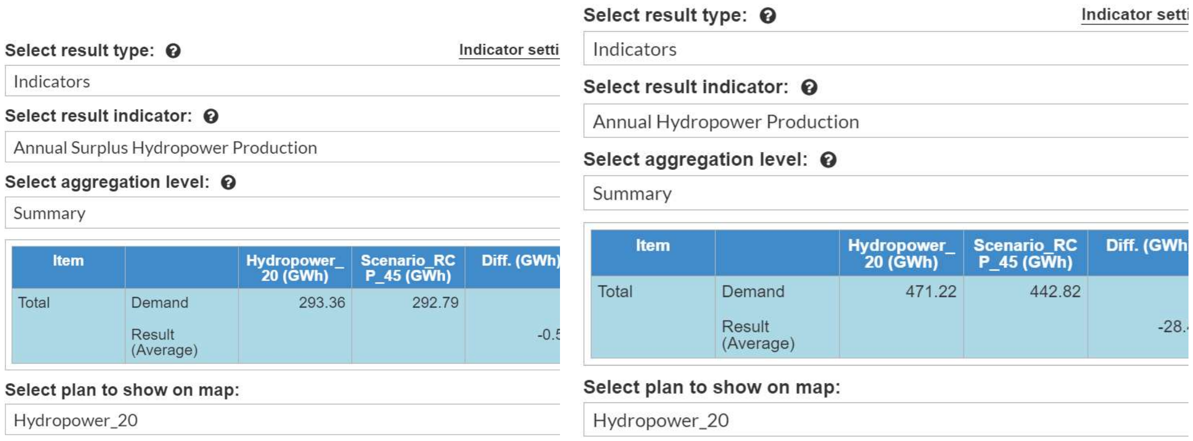


Figure 101: Ground water use fraction from 20% to 35% for irrigation users

It indicates that there is not much differences in the total demand if it is increased by 35% except the years 2015,2016 and 2017 due to the large difference in rainfall. IF the available water in the reservoir is less due to low rainfall received, the 75% of irrigation demand cannot be fulfilled even if GW is available in abundance. In that case, in order to make sure the water availability 100% ground water can be used for irrigation for as solution.

Increase in hydropower demand

The increase in hydropower production by 20% by 2050 due to population growth. The annual firm surplus power production changed from 292.79 to 293.79 GWh.



Select result type: Indicator setti

Indicators

Select result indicator:

Annual Surplus Hydropower Production

Select aggregation level:

Summary

Item		Hydropower_20 (GWh)	Scenario_RCP_45 (GWh)	Diff. (GWh)
Total	Demand	293.36	292.79	
	Result (Average)			-0.5

Select plan to show on map:

Hydropower_20

Select result type: Indicator setti

Indicators

Select result indicator:

Annual Hydropower Production

Select aggregation level:

Summary

Item		Hydropower_20 (GWh)	Scenario_RCP_45 (GWh)	Diff. (GWh
Total	Demand	471.22	442.82	
	Result (Average)			-28.

Select plan to show on map:

Hydropower_20

Figure 102 Indicator for annual surplus hydropower production pre-and post-application due to 20% increment of power demand (left), Indicator for annual firm hydropower production pre-and post-application due to 20% increment of power demand (right)

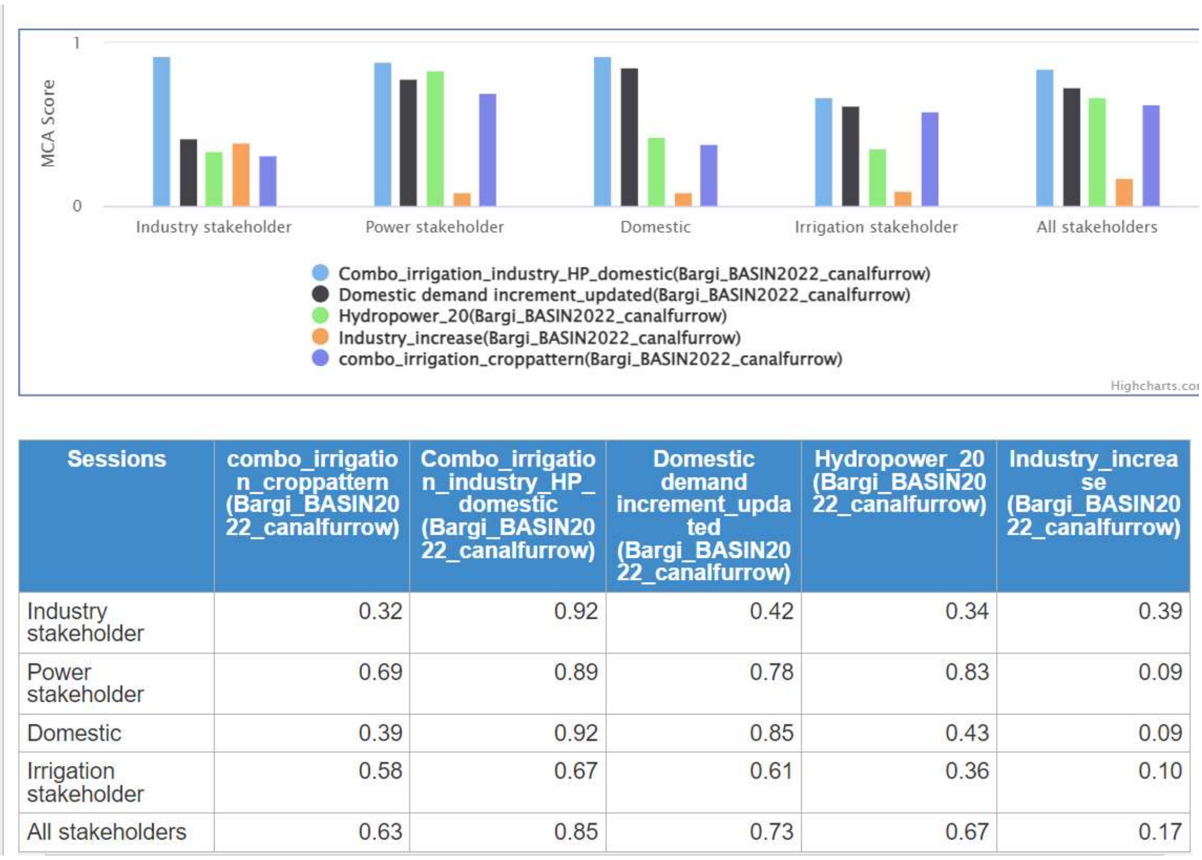
The power production has increased due to increased demand for the climate change conditions, it is depicted as an increment in the indicator power production is increased but annual surplus not much due to the marginal production of power as per the demand.

Multicriteria analysis (MCA)

This analysis multi-criteria decision analysis refers to a range of formalized methods that are used as input to the decision-making process in situations where uncertainty is high, objectives are different or even conflicting, metrics are heterogeneous, and complex systems are the subject of the analysis. In this project, five scenarios were tested for MCA. In its simplest form, multi-criteria decision analysis scores several options (for managing the problem of interest) against a range of indicators. Each indicator reflects the extent to which a criterion considered of importance for the decision is met. The option whose aggregate score is highest will in principle be the most appropriate option for responding to the problem being analysed.

For giving weightage to each stakeholder, five combinations are tried to do MCA.

1. **Industry stakeholder- MCA scenario “Industry_increase”:** The future Industrial demand increment by 18% by 2025 and 50% by 2050 (Refer section 5.7)
2. **Power stakeholder- MCA scenario “Hydropower_20”:** Water balance result from the increase in hydropower production by 20% by 2050 due to population growth is considered (Refer section 5.9)
3. Domestic stakeholder- **MCA scenario “Domestic_demand_increment_updtaed”:** Future domestic demand increment by 48% by 2025 and 100% by 2050 due to increment in the population (refer section 5.6)
4. **Irrigation stakeholder- MCA scenario “Combo_irrigation_croppattern”:** A combination of change in crop pattern and change in irrigation system is applied to RBC (Refer section 5.4)
5. **All stakeholders- MCA scenario “Combo_irrigation_industry_HP_doemstic”**: All the above combinations are applied as a single scenario.



Sessions	combo_irrigation_croppattern (Bargi_BASIN2022_canalfurrow)	Combo_irrigation_industry_HP_domestic (Bargi_BASIN2022_canalfurrow)	Domestic demand increment_updated (Bargi_BASIN2022_canalfurrow)	Hydropower_20 (Bargi_BASIN2022_canalfurrow)	Industry_increase (Bargi_BASIN2022_canalfurrow)
Industry stakeholder	0.32	0.92	0.42	0.34	0.39
Power stakeholder	0.69	0.89	0.78	0.83	0.09
Domestic	0.39	0.92	0.85	0.43	0.09
Irrigation stakeholder	0.58	0.67	0.61	0.36	0.10
All stakeholders	0.63	0.85	0.73	0.67	0.17

Figure 103: Multi-criteria analysis for different scenarios

Each session represents each stakeholder, where the weightage is given to that stakeholder. Each application is explained in above sections what is the change that has been made in terms of demand series. Four actual application scenarios and combination of all these four applications are also applied in a single application. Referring to Figure 103, MCA scores are comparatively high for all stakeholders when combination of all the applications are applied for which Industry and domestic stakeholder score is high which is 0.92 and the irrigation score is 0.67. It is suggested to go for combination of all the applications.

Results

The enhanced CC-DSS system is developed for Madhya Pradesh Water Resources Department. The project was conducted to fulfill climate change concerns in water resources planning and management for the future. To assess the future investment for Bargi dam command area, it is necessary to analyze the status of water balance and behavior. The following points were achieved through this study.

- CC-DSS system is developed and upon running for planning and management for the climate change projected year 2017-2050
- CC-DSS is set up with three main modules to handle basin planning, knowledge base and rainfall-runoff model for any catchments in India.
- The baseline or current scenario is developed for the historical year 2001-2016

- The CC-DSS users have the right to add or disable any features on the system in terms of water users
- The investment on upstream and downstream catchments in terms of structural or non-structural measures are tested and analyzed. The tested investments are changing the crop pattern or irrigation method, investing on improving the forest cover on the upstream catchment and combination of both the investment on a single command area.

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2. C.D. Mishra and et al. "Water resource characterization in canal command area for Jhansi minor (left bank canal of Bargi dam) of Rani Avanti Bai Sagar irrigation project- A case study;" Journal of Soil & Water Conservation 15(1): 58-63, January-March 2016 ISSN: 0022-457X
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4. Detailed Project Report of Bargi Dam published in 1988
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