Hydrological Modelling for Evaluation of Return Flow and Irrigation Planning for Optimal Utilization of Water Resources in the Command of Sanjay Sagar Project in Madhya Pradesh

(PDS NO: NIH-28_2017_69)

National Hydrology Project
Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, New Delhi

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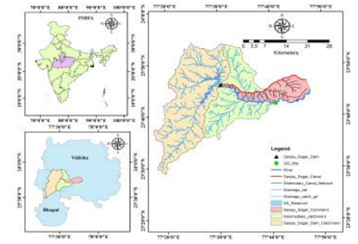
Water Resources Department, Govt. of Madhya Pradesh, Bhopal (M.P.)



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December 2023

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PREFACE

The reservoir and surface irrigation are important for the development of the agro-based economy of India. Madhya Pradesh is one of the leading states for the development of irrigation facilities and got the Krishi Karman award for the fifth time in a row. Although the state has achieved significant recognition and performance in enhancing irrigated areas, the performance of existing water projects is minimal due to lower conveyance and application efficiencies. One of the major reasons for lower efficiencies is poor maintenance of canals, flooding method of irrigation, and lack of knowledge and data for improved reservoir operation. Due to all these problems, a significant amount of water reaches downstream of the project as a regenerated flow and an increased groundwater table as a return flow. The Water Resource Department, Govt. of Madhya Pradesh considers a fixed 10% as regenerated flow from command for planning off downstream projects and entrusted the National Institute of Hydrology Regional Centre Bhopal to carry out a joint study to compute various hydrological components of irrigation water in the command of water resource projects in the state.

The Purpose-driven Study (PDS) titled "Hydrological Modeling for Evaluation of Return Flow and Irrigation Planning for Optimal Utilization of Water Resource in the Command of Sanjay Sagar Project in Madhya Pradesh (NIH-28_2017_69)" has been awarded to NIH, Regional Centre Bhopal, and WRD, Govt. of Madhya Pradesh, Bhopal under National Hydrology Project of World Bank with the objectives to evaluate return flow coefficients through modeling technique, assessment of various scenarios for irrigation planning and reservoir operation in command, development mobile application for farmers to optimize the uses of water resources and awareness program for farmers & public. The results of this PDS study will be a great help in reservoir operation and the availability of reservoir water for irrigation may be extended by the measures adopted based on technical knowledge and scientific research. This study may be used as guidelines for planning water conservation measures for sustainable development and reduction of losses in command areas (as irrigation return flow). The final report contains the various aspects of hydrological interaction in, catchment and command, a review of literature, GIS database, existing database and analysis, analysis for the computation of regenerated flows, field data collection and survey results, reservoir operation, Application of MIKE HYDRO Basin, development of excel based irrigation planning and web and Mobile application-based irrigation planning and management, etc. The report was prepared by Dr. R. K. Jaiswal, Scientist-F as P.I. and Dr. Ravi Galkate, Scientist-F, Dr. T. Thomas, Scientist-F and Mrs. Shashi Indwar, Scientist-

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Name and designation (Co-PI up to ____)

Title	Hydrological Modelling for Evaluation of Return Flow and Irrigation Planning for Optimal Utilization of Water Resource in the Command of the Sanjay Sagar Project in Madhya Pradesh
PDS number	NIH-28_2017_69
Date of approval	11/03/2019
Budget at the time of original approval (For Partner and Lead)	Total approved Budget: Rs. 64.36 Lakh NIH RC Bhopal: Rs. 43.26 Lakh WRD Bhopal: Rs. 21.20 Lakh
Revised Budget (For Partner and Lead)	-
Date of commencement	
Date of completion	Sept 30, 2023
Number of pages	227
Number of figures and tables	89/53

Abstract

India is an agrarian country that uses its major portion of surface and groundwater resources for irrigation. The losses through conveyance and application are the major losses in irrigation and a significant portion of released water from the reservoir may emerge downstream of the river called regenerated flow. Presently in Madhya Pradesh state, a fixed 10% of water release is used as regenerated flow from the command which needs to be verified using scientific assessment for optimal utilization. The WRD MP and NIH RC, Bhopal took up a collaborative research study to identify different hydrological components for computation of return flow and development of a management model for optimal utilization of irrigation water in the irrigation command. This purpose-driven study under the National Hydrology Project has been taken up on the command of the Sanjay Sagar Project situated on the Bah River in the Vidisha district of M.P. Under the Sanjay Sagar project, a dam is constructed in the year 2014 on river Bah with a gross storage capacity of 86.40 MCM to irrigate 9398 ha area in the command during the Rabi season.

In the present study, three different modeling and measurement techniques i.e. water balance, isotopic analyses, and hydrological modeling were used to compute surface and sub-surface components of irrigation return flow in an irrigation command. The water balance technique was applied through monitoring and measurement after careful analysis of the system. More than 400 water samples from diverse sources including rainfall, dams, canals, rivers, open/bore wells, and hand pumps were analyzed for isotopic analysis. The end member

mixing model was used to identify the contribution in open wells and rivers from rainfall and canal/dam water. The SWAT model was used as the third method, a well-proven model for analyzing large-scale hydrological processes in a basin. The model was initially calibrated and validated for virgin flow for the period of 1991-2013 and then two different runs were made with and without the dam and command for the period of 2014 to 2022 (After the construction of the dam in 2013). For running these scenarios, necessary changes were made in the model structure, and results were compared to compute return flow components. The water balance analysis confirmed that a major portion of released ware from the dam in the range of 12.3 to 35.9% with an average of 22.9% reaching the Bah river as regenerated flow, while 1.9 to 16% with an average of 10.2% reached groundwater as recharge. The isotopic analysis provided qualitative results of contribution in open and confined wells and rivers from irrigation water with nearly 81 % and 9% contribution of canal water to open wells and bore wells respectively. The SWAT model results showed nearly 27.8% emerged as regenerated flow and 8.9% as recharge due to the application of irrigation in Sanjay Sagar‘s command.

The field data for soil samples were collected and analyzed for textural analysis and soil water retention properties. Soil water retention is an important characteristic of irrigation planning. The soil is mainly silty loam having field capacity and wilting point of 35.8 and 19.6% respectively. The NAM model for the Bah River up to the G/D site was set up and the model was calibrated and validated for the period from 1991 to 2005 and validated from 2006 to 2013. The coefficient of determination (R^2) found during calibration and validation for daily modeling were 0.68 and 0.62 respectively showing a good match between observed and simulated runoff data. After successfully developing the NAM model, a MIKE HYDRO basin model for irrigation management of Sanjay Sagar command was developed in which calibrated parameters of the NAM model were used to determine inflows into the reservoir to feed water to four water user associations (WUAs) as irrigation users. The cropping pattern in the study area is mainly wheat and very small areas of gram. The developed management model in MIKE HYDRO basin was run from 2015 to 2021 and determined yearly demand and deficit for different WUAs. The model was run for four different management scenarios and the best result was found with no deficit was found at 75% conveyance efficiency with the sprinkler irrigation method.

During the study, the difficulties in the use of sophisticated models and software by field engineers were observed, and based on the request of WRD, Govt of MP, an excel based reservoir operation and planning module was developed for planning irrigation releases from the Sanjay Sagar Project. The developed excel based program is simple but intrusive and can compute the demand/deficit of all water user associations, water availability in the reservoir, losses, etc. using forecast data of meteorology for 15 days. The program automatically computes crop water requirements using crop coefficient and soil moisture accounting for crops in different WUAs. A daily water balance of the reservoir is made using inflows, reservoir level, losses (evaporation, seepage & leakage), crop water requirement with conveyance, and application losses. The different sheets of the Excel program were connected and simple information given by users in the Dashboard resulted in the deficit for different WUAS and reservoir levels at the start and end of the cropping period. The future forecast data of temperature and rainfall for 15 days can be downloaded in the program through VBA programming to operate the reservoir.

A comprehensive web and mobile application (KISAN-MAITRI) based Decision Support System (DSS) has been developed to address water management challenges in agriculture, specifically focusing on irrigation planning and reservoir operation in the Sanjay Sagar command area where an indigenously developed Excel module works in the back end. A mobile application complements the web platform, enabling farmers to access essential information like reservoir status, crop estimates, weather forecasts, market rates, etc.

The study examined the best GCM for future climate projection over the study area, the performance of 13 Global Climate Models (GCMs) of CMIP6 during 1991-2014 for rainfall and temperature to apply these data for preliminary use at the start of the model. Once the future models were selected, their climate data was compared with IMD rainfall data using various Shared Socioeconomic Pathway (SSP) datasets and visual crossing website data. The SSP2.6 scenario of MPI-ESM1-2-LR was found the best-fit model for projecting future rainfall and temperature data from 2015 to 2022 when compared with IMD rainfall data.

The results of the study concluded that the return flow amounts are site-specific and depend on several interrelated factors like geology, soil, topography, crops, methods of irrigation and no standard percent can be used uniformly. These results can be used as guidelines in similar regions having similar characteristics but with some more studies on more sites. It is recommended to apply modeling techniques in some other regions of Madhya Pradesh before finalizing the appropriate rate of irrigation return flow. The findings of the study have significant implications for various applications, including water resource planning, reservoir operation, and irrigation scheduling. The future projections based on the

selected GCMs and SSP data can be utilized for informed decision-making and improved utilization of available resources. The web/mobile-based application developed under the PDS suggested a way to design the generic version of the application where WR managers can develop their own web/mobile system for their command and interact with end users i.e. farmers for efficient operation of reservoir, timely supply of water and optimum production as emphasized in More Crop Per drop initiative.	
Originating unit	National Institute of Hydrology, Jal Vigyan Bhavan, Roorkee (U.K.)
Key words	Irrigation return flow, SWAT model, MIKE HYDRO Basin, Web & Mobile Application
Security classification	Restricted
Distribution	Restricted

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CHAPTER-1: INTRODUCTION

1.1 General

The management of irrigation water to meet the crop's water requirement is an essential component that necessitates knowledge of the soil, the crop, and the availability of water, as well as the techniques of water conveyance and application. Usually, in an agricultural command, more water is applied than is required for the crop. As a result, irrigation water that is not being utilized is discharged into the river through surface and subsurface flow, and it eventually becomes a part of the groundwater. Therefore, it is essential to investigate the movement of soil water in the root zone depth to measure the amount of water that is provided more than what is required for the crops and soil types to be consumed. The soil-plant-atmosphere continuum is an extremely intricate system. The water transport phenomena that occur within the continuum of soil, plant, and atmosphere play a significant role in the terrestrial sector of the hydrologic cycle. These phenomena are dependent on the infiltration, drainage, and retention of water in the soil, as well as evapotranspiration from the crop. With the assistance of the subsurface flow component and the evapotranspiration from the crops, it is possible to gain an understanding of these processes.

Surface irrigation is considered the most cost-effective method of irrigating agricultural land in many instances. This technique involves applying water at the uppermost part of the field, and then allowing it to flow downwards by gravity until it reaches the lowermost component. To keep plant growth going until the next irrigation is performed, the primary goal of surface irrigation is to supply sufficient water to the soil moisture storage system. To determine the appropriate frequency of irrigation, it is necessary to consider the moisture retention capacity of the soil, the rate of evapotranspiration, and the stage of crop evolution. In the event of surface irrigation in the hard rock region, a significant amount of water traverses horizontally through surface and subsurface drainages, and some part percolates below the root zone depth and eventually reaches the local water table. An excessive amount of water that has percolated through the ground is not only wasteful but also has the potential to cause drainage issues. The plant, on the other hand, would be subjected to moisture stress before the next irrigation due to less availability of water, which would result in a decrease in production. Hence, it is necessary to provide the root zone with an adequate amount of water to achieve the highest possible yield.

1.2 Irrigation Return Flow

In irrigation, a certain portion of the applied water, over and above the consumptive use, infiltrates into the ground to reach either an aquifer as deep percolation or a nearby stream as interflow. This contributory replenishment from irrigation is referred to as "Irrigation Return Flow". Seepage losses from canals conveying water to the command area for irrigation are also one of the components of irrigation return flow. Irrigation return flow is one of the most significant components of the hydrology of command and its solution requires detailing the water balance of the command. Quantification of irrigation return flow can be made both at the micro-scale integrating the process level models into a groundwater balance model for the whole command. The distributed mathematical model of groundwater flow, which simulates the groundwater level in a canal command area for given stresses on the groundwater regime can be used to compare the irrigation return flow determined at the micro-level using process-level modeling, or for estimating the irrigation return flow independently

The Groundwater Estimation Committee (GEC. 1997) norms suggested that irrigation return flow may amount to as much as 20% to 40% of the volume of water applied for irrigation. In the absence of any studies, it is usually taken as 35% of the water applied for irrigation in the case of canal irrigation and 30% in the case of irrigation from groundwater to small segments of irrigation commands. Estimation of irrigation return flow is a complex problem and its solution requires a detailed water balance study in a command area. When irrigation water is supplied from a canal system, the water is applied to convey it over long distances, and the transmission loss is large. When irrigation water is supplied from the groundwater reservoir, the water is applied without conveying it over long distances and the transmission loss is small. In applying groundwater, crop needs and extractions can be matched evenly. In such cases, the irrigation return flow depends on local soil characteristics, meteorological factors, the method of irrigation, and the type of crops grown.

The irrigation returns flow (IRF) and regenerated flow are important components of the hydrological cycle in irrigation command. The IRF can be defined as the part of irrigation water not absorbed by plants or evaporated into the atmosphere and reaching an aquifer and surface water bodies such as drainage/stream or lake downstream including leakage and seepage from canals. Irrigation return flow also depends upon the geological setup of the command, soil moisture characteristics, hydro-meteorological parameters, (such as intensity and duration of rainfall, relative humidity, temperature, potential evaporation, and inter-storm period), crop types, method of irrigation, and depth to the water table. Application of fertilizers and leaching requirement of soil salts may result in the application of more irrigation water leading to more return flow. Based on agro-climatic zones and variations in geological setup, the magnitude of the irrigation return flow may vary widely across the commands.

The Return flows are understood in the broader context of the interaction of surface and groundwater flow systems, although the definition of return flow varies slightly according to the context (Bekam *et al.* 2013). The IRF consists of two parts including horizontal or quick return flow and vertical or delayed return flow component. The horizontal component or quick return flow consists of surface runoff, seepage from fields, and canals that move in the soil profile and contribute to the river or drainage as surface and subsurface flow. The vertical component or delayed return flow infiltrates the soil profile and aquifer, which will then affect aquifer storage and further base flow (Zeng & Cai 2014).

1.3 Origin of the Study

In India, irrigation has gained substantial importance due to the erratic behavior of the monsoon and more crop production to feed an increasing population. The surface irrigation projects where extra rainfall water during monsoon season is stored in dams and supplied to fields during crop growing season through a network of main, distributaries, and outlets running on low efficiency in the range of 40 to 50% only. The loss of water through conveyance and application emerges as irrigation return flow that can be reused to increase the efficiency of the irrigation system. The quantification of return flow from an irrigation system is usually done through the thumb rule without considering important criteria including soil properties, topography, crop condition of the distribution system, application methods, etc. Very few efforts have been made to quantify irrigation return flow and are still considered a grey area in irrigation management. The quantum of irrigation return flow from a command depends on several interdependent factors including canal condition, application methods, crops, irrigation releases, climate, soil type, geology groundwater, etc. Similarly, an accurate estimate requires monitoring and measurement of field data, detailed soil testing, and hydrological modeling for surface and groundwater flow characteristics.

The state of Madhya Pradesh (M.P.) is trying hard to increase its irrigation intestines and maximize crop production to make agriculture profitable. Several irrigation projects have become operational or under progress to harness a large amount of surface water. Despite significant efforts, the losses in the command are very high and a considerable amount of water goes into the river without any consumptive use. During the design of a water resource project downstream of a water resource project in M.P. state, it is assumed that 10% water of stored capacity of the upstream project will appear as a return flow. But no scientific study on this very important has not been carried out in M.P. where quick or horizontal interflow contributes mainly towards regenerated flow with very minimal recharge due to basaltic geology and limited depth of soil. The Regional Centre, NIH Bhopal, and Water Resources Department have taken a scientific study as a PDS under the National Hydrology Project to study the hydrology of flow in the command for estimation of regenerated and return flow. So, the command of the Sanjay Sagar Project situated in the Vidisha districts of Madhya Pradesh has been selected for hydrological modeling with the objective of computation of irrigation return flow. The Sanjay Sager project is a medium project constructed on the Bah River, a tributary of river Betwa of the Ganga River system. The dam has gross and live storage capacities of 86.6 Mm^3 and 76.52 Mm^3 respectively.

1.4 Objective of the Study

The report is a part of the R & D Project entitled "Hydrological Modeling for evaluation of return flow and irrigation planning for optimal utilization of water resource in the command of Sanjay Sagar Projects in Madhya Pradesh", sponsored by the Ministry of Water Resources, Govt. of India under the World Bank funded "National Hydrology Project". The main objectives envisaged in the PDS study are:

- Assessment of different components of hydrological cycles for computation of irrigation return flow coefficient and rejuvenated flow from the command
- Investigation of various scenarios including conjunctive use, irrigation water management, cropping pattern changes, variable climate, etc. for irrigation planning and reservoir operation in the command
- Development of a mobile application for WR managers and farmers for optimal release and management of water resources
- Capacity building and development of public awareness through workshops, conferences, seminars, and preparation of manuals, leaflets, etc.

CHAPTER-2: REVIEW OF LITERATURE

The present study has been taken with the objective of the assessment of return flow using hydrological modeling, water balance, and isotopes, application of remote sensing data for irrigation planning, Irrigation water requirement, Web and Mobile Application based Decision Support System, development of the management model for optimal utilization of resources. A detailed literature review of different aspects has been presented below.

2.1 Estimation of irrigation returns flow using SWAT Model

The SWAT (Soil and Water Analysis Tool) model has been used to predict the impact of different management practices on rainfall-runoff response, return flow sediment, and contaminant transport, besides establishing water balances. Gosain et al. (2005) used Soil and Water Assessment Tool (SWAT) model to predict the net water usage in the irrigated area by simulating the domain with and without utilizing the water flowing through the irrigation canal and the difference between the actual quantity of water supply and the predicted utilization of water by the developed SWAT model was treated as the return flow amount. Dewandel et al. (2008) applied a cost-effective and useful methodology for assessing irrigation return flow coefficients (Cf D irrigation return flow/pumping flow) based on (i) basic crops field survey and meteorological data and (ii) the use of a simple hydraulic model that combines both water balance technique and unsaturated/saturated flow theory. The methodology has been used for estimating the irrigation return flow of rice (Paddy field), vegetables, and flower fields at the watershed and seasonal scale for the rural watershed. The proposed methodology allows relatively good estimates of the irrigation return flow coefficients at watershed and seasonal scales. The irrigation return flow coefficients are calculated as 51 ± 8% in the rainy season (Kharif) and 48 ± 4% in summer (Rabi) for rice; 26 ± 11% in the rainy season and 24 ± 4% in summer for vegetables; 13 ± 8% in the rainy season and 11 ± 3% in summer for flowers.

Mohan & Vijayalakshmi (2009) used a hierarchical modeling technique, namely, a regression tree developed for return flow estimation. The regression tree is built through binary recursive partitioning. The effective rainfall, inflow, consumptive water demand, and percolation loss are taken as predictor variables and return flow is treated as the target variable. The model performance shows a good match between the simulated and the field-measured return flow values. Results of statistical analysis indicated that the correlation coefficients are high for both single as well as double crop seasons.

Huang and Li (2010) used SWAT to assess the crop water productivity (CWP) index on a basin scale in fertile basins of China. The model was calibrated using monthly stream flows to estimate actual evapotranspiration for the main crops (rice, wheat, maize, and soybean). The simulated hydrologic and crop components were then coupled together to assess basin-scale CWP.

Garg et al. (2011) used SWAT to obtain spatial maps of economic water productivity (EWP) for sugarcane, millet, and sorghum in the Upper Bhima River basin in India. Xie & Cui (2011) used Soil and Water Assessment Tool (SWAT) popular tool for understanding the hydro agronomic processes. SWAT model is developed to incorporate new processes for irrigation and drainage. The model is tested in Zhanghe Irrigation District, China. The simulated runoff matches well to the measurements and the results indicate the developed model is preferable to the original edition of SWAT. The estimate of the paddy rice yield is acceptable and the dynamics of water balance components approximately characterize the state of water movements in paddy fields. Therefore, the developed framework for SWAT is practical and capable of representing the hydrological processes in this irrigation district.

Kang, M., & Park, S. (2014) applied the Synthetic Stream flow and Reservoir Regulation (SSARR) model to simulate the water flows, considering irrigation return flows and reservoir operations. The heuristic search method was used for calibration. The simulated stream flows and reservoir water levels were in good agreement with the observed. The irrigation return flow from paddy fields considerably affected the flow regimes of the streams. Specifically, the return flow rates of the irrigation water ranged from 28.0% to 35.0%. Ahmadzadeh et al. (2016) used the Soil and Water Assessment Tool (SWAT) in Zarrineh Rud River, the main feeding river of northwest Iran's Lake Urmia, as the case study to explore this methodology. SWAT cannot directly simulate changing the irrigation system from surface to pressurize. The innovative approach is applied to the model to simulate different irrigation systems considering real irrigation management variables such as the depth and date of each irrigation event. For the performance simulation of such systems, a comprehensive calibration procedure was used based on a wide range of data for hydrological and agricultural variables. The results showed that changing the current irrigation to a pressurized system can increase water productivity by 15% due to increases in crop yield, better water distribution, and greater actual evapotranspiration. However, pressurized irrigation results in no significant change in total inflow to the lake. Notably, these systems can intensify the drawdown of the basin's water table by 20%. So, any significant "real water saving" program in the basin must be associated with the reduction of evapotranspiration by adopting measures like reducing cultivated areas, changing cropping patterns to less water-consuming plants, or applying deficit irrigation. The applied methodology of the comprehensive calibration and setup of the SWAT model with the readily available hydrological and agricultural variables can be a good sample for similar works.

Dai et al. (2016) modified the SWAT model in the modules of the irrigation water movement and the water cycle in paddy fields based on the hydrological characteristics of the paddy fields in the hilly regions of southern China. Githui et al. (2016) applied SWAT to simulate water balances for an irrigated catchment in southeast Australia during the period 2008–2010. Two methods for estimating irrigation inputs were tested. One method was based on a fixed irrigation application rate, whereas the other one had variable irrigation rates depending on the season and the irrigated crop. These two approaches were also compared with the 'auto-irrigation' method within the Soil and Water Assessment Tool model. The method with variable irrigation rates resulted in the most reasonable interpretation of the readily available irrigation data, consistent estimates of irrigation runoff coefficients throughout the year and the best fit to observed data on both drain flows at the catchment outlet and spatial evapotranspiration patterns and found that the different irrigation inputs significantly affected simulated water balances, in particular deep percolation under relatively dry climatic conditions.

Chen et al. (2017) used the Soil and Water Assessment Tool (SWAT) to simulate irrigation and other associated water balance components are critical for meaningful evaluation of the effects of irrigation management strategies in the semi-arid Texas High Plains. Results indicated good agreement between simulated and observed daily ET during both model calibration (2001–2005) and validation (2006–2010) periods for the baseline scenario (Nash-Sutcliffe efficiency; 0.80). The auto-irrigation scenarios resulted in reasonable ET simulations under all the thresholds of soil water deficit (SWD) triggers as indicated by NSE values > 0.5. However, the auto-irrigation function did not adequately represent field practices, due to the continuation of irrigation after crop maturity and excessive irrigation when SWD triggers were less than the static irrigation amount.

Yalcin (2019) applied the Soil and Water Assessment Tool (SWAT) model to assess the return flow ratio of an irrigation abstraction using the flow records. The results show the necessity of irrigation project-based return flow analyses using regional fine-scale datasets, instead of rule-of-thumb assumptions, to determine the effects of irrigation activities on flow regimes more accurately. Wu et al. (2019) used the modified SWAT (Soil and Water Assessment Tool) model to better represent the characteristics of paddy rice irrigation systems, which includes a simulation module for automatic multi-source irrigation (AMSIM) to investigate the fate of return flows and the scale effects of reuses. The modified SWAT model was used to simulate the hydrological processes in the Yangshudang (YSD) watershed of the Zhanghe Irrigation System (ZIS) in China. The proposed methodology was used to calculate the amounts of return flows and the reused amount based on the output of the model. The sub-basins nesting method was used to divide the study area into six scales. It was observed the rainfall & irrigation water reuse rates (η_{I+P}) and the irrigation water reuse rates (η_I) at different scales and analyzed the changes of these two indicators over different scales. The results revealed that the modified SWAT model succeeded in simulating hydrological processes in a paddy rice irrigation system.

Veettil et al. (2021) used fully distributed AgES (Agricultural Ecosystems Services) and the semi-distributed SWAT (Soil and Water Assessment Tool) models in the Big Dry Creek Watershed to investigate spatial patterns of water balance components and nitrate transport. SWAT predicted extremely low interflow and routed excess irrigation water to surface runoff and groundwater discharge. The AgES produced a realistic estimation of stream flow, irrigation return flows, and nitrate; simulation of less surface runoff and greater interflow and base flow contributed to improved simulation of nitrate transport in the interior watersheds.

2.2 Application of Isotopes in IRF Studies

Isotopes of the water molecule (^{18}O and ^{2}H) are a well-used tool for investigating groundwater origin and history (i.e. tracing the recharge conditions over time, processes occurring during the infiltration of rainwater towards aquifers, and those involved in the water-rock interaction and mixing of different waters). Noble et al. (2019) found that an integrated approach of multidisciplinary techniques is effective in assessing the recharge processes and groundwater potentiality in the Vidarbha region, Maharashtra, India which is a drought-prone area. In this study, groundwater recharge processes, monsoon characteristics, and climate variables during evaporation in the region were evaluated using environmental isotope techniques. Additionally, electrical resistivity surveys were also conducted to understand the aquifer geometry and weak zones (fractures, lineament) for sustainable groundwater development. Environmental isotope data show that the groundwater is predominantly recharged from the southwest monsoon, and the contribution from the northeast monsoon is insignificant. Tritium data indicate that the groundwater is modern, and its residence time is of the order of a few years.

2.2.1 Stable Isotope Mass Balance

The supply of irrigation water often overcomes crop evapotranspiration, and the resulting return flow may infiltrate and significantly contribute to an aquifer water budget. Stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$) have been used since the pioneering work of Craig (1961) and Dansgaard (1964) to trace the water cycle. Unlike many physical measurements generally used for implementing hydrogeological models, stable isotopes of water can monitor the hydrologic behavior of an entire reservoir (Gat and Gonfiantini, 1981).

Christine et al. (2017) confirmed the ability of geochemical tracers to provide recharge rates fully independent of flux measurements. Here, a chloride mass balance was combined with an isotopic mixing model ($\delta^{18}O$ and δD) to quantify return flow coefficients, in the Crau alluvial-type aquifer (Southern France), characterized by a long-term traditional practice of flood irrigation. The values around 0.53 ± 0.16 were found for well-defined stream lines averaging the functioning of the upstream aquifer, which leads to a return flow rate of 1190± 140 mm per year. They can be further used to assess the irrigation efficiency in other similar systems or to monitor the variations of irrigation return flow, which will result from future modifications of land use, irrigation practices, and climate.

Gabriel et al. (2020) focused on using the isotopic tracer method in detailed cross-sections sampled at different times during the year as a tool to determine how the interflow changes with time. The stable H- and O-isotope composition of water for this alpine lake is a powerful tool to trace the Rhône River intrusion within the lake. They found that, during summer and early autumn, when the lake is thermally stratified, the Rhône River intruded into the metalimnion as an interflow, and it is directed by the currents in the top layer. The stronger the thermal stratification, the more concentrated and vertically constrained will also be the Rhône interflow. Thus, a stable isotope mixing model proposes a quantification of irrigation return flow coefficients, which is fully independent of groundwater flux estimates and able to evaluate recharge fluxes at a more detailed scale.

2.3 Crop water requirement assessment

The accurate estimation of irrigation water demand is also essential for developing a rational policy for sustainable water resources. Rainfall is a basic input for fulfilling the crop water requirement in any region. For the planning of irrigation and efficient operation of water resources projects, the water requirement of crops under different rainfall scenarios and probability analysis of rainfall are essential in semi-arid and drought-affected regions. Irrigation water requirements are usually defined to avoid crop stress implicitly assuming that maximum yield is desired. Improvements in irrigation management are urgently needed in regions where water resources for irrigation are being depleted.

Kuo et al. (2001) studied on Crop wat Model to Evaluate Crop Water Requirements in Taiwan and an irrigation management model, CROPWAT, was used to estimate crop evapotranspiration, irrigation schedules, and agricultural water requirements for different cropping patterns. Field experimental data from Taiwan were analyzed and input into the model. Results showed that in the Hsueh Chia area, annual potential evapotranspiration was 1,444 mm, effective rainfall was 897 mm, and crop water requirements for paddy fields varied depending on the rice crop. The model demonstrated the ability to estimate crop water requirements effectively, but further research is needed to adapt it to complex cropping patterns and enhance irrigation management capabilities in Taiwan.

Doll & Siebert (2002) studied on Global modeling of irrigation water requirements to evaluate future water and food scenarios. It is crucial to model irrigation water needs due to their significant global consumption. This study introduced a global model that utilizes a high-resolution map of irrigated areas. It accurately simulated cropping patterns, growing seasons, and irrigation requirements for rice and non-rice crops. The model's performance aligns well with independent estimates, making it suitable for global and continental research on water and food dynamics. Liu et al. (2009) studied on Spatial distribution characteristics of irrigation water requirement for main crops in China and this study assessed the temporal and spatial distribution of crop water requirement and irrigation requirement in China. Utilizing meteorological data from over 200 stations and crop growth stage data, crop water requirement (ET_c) and net irrigation requirement (IR) were estimated for 30 crops. The results were validated against observed data from irrigation stations. Isoline maps of average ET_c and IR were created using GIS and interpolation methods. Analysis of wheat, maize, cotton, and rice revealed their spatial distribution characteristics. The irrigation requirement index (IR/ETc) indicated that certain regions relied heavily on irrigation, while others had lower irrigation needs.

Chakraborty et al. (2013) studied long-term changes in irrigation water requirement in the Context of Climatic Variability and this study examines the impact of climatological variables on reference evapotranspiration and agricultural water use in the Seonath basin, Chhattisgarh State. The analysis reveals a significant rise in annual temperature over 51 years, with more pronounced increasing trends. The study emphasizes the importance of considering changing irrigation demand in future irrigation management systems for the Seonath river basin due to projected changes in meteorological variables. Lalic et al. (2013) studied on assessment of climate change impact on crop water requirements in Serbia in 2030 using CROPWAT mode and efficient and sustainable mitigation and adaptation options for crops and the environment are needed to address the impact of climate change on agriculture. A study used the CROPWAT 8.0 software package to calculate the impact of climate change on effective rain, crop water demand, and irrigation requirements in Serbia. Future climate projections were taken from ECHAM5 models with the SRES-A2 scenario for greenhouse gas emissions. Follow-up research is expected to focus on identifying crop varieties and soil management techniques to mitigate the negative effects of climate change. Saravanan & Saravanan (2014) studied on determination of water requirements of main crops in the tank irrigation command area using CROPWAT 8.0 and a study in the Perumal Tank irrigation area, Cuddalore district, determined water requirements for main crops (rice, groundnut, sugarcane) using climatic data and CROPWAT 8.0 software. Crop evapotranspiration ranged from 0.74 to 6.57 mm/day, with water requirements varying from 0.0 to 244 mm/dec. The peak water requirement was 9.6 mm/day (1.11 l/s/ha, 70% application efficiency). Bouraima et al. (2015) studied on Irrigation water requirements of rice using the CROPWAT model in Northern Benin and finds This study focused on estimating crop water requirements (CWR) for rice in the semi-arid Benin's sub-basin of the Niger River using the CROPWAT model. The results indicated an annual reference evapotranspiration of 1,967 mm, with the lowest monthly value in August (123 mm) and the highest in March (210 mm). Crop evapotranspiration and irrigation requirements were determined for both rainy and dry seasons, providing insights for efficient water use scheduling in irrigation projects.

Putthividhya & Sukgerd (2015) studied water requirements and irrigation scheduling of the Ban Khai Irrigation Project using GIS And CROP WAT Model in Rayong Province Thailand and found that water resource estimation plays a crucial role in planning and managing water resources, especially in the face of climate change and increasing water crises. The analysis highlighted the potential of supplemental irrigation schedules, developed using the CROPWAT model, to mitigate water stress and reduce yield losses in the future management of water resources. Surendran et al. (2015) analyses of the water resources and modeling of agricultural water needs using FAO-CROPWAT are used to manage water resources sustainably in the Kerala district of India's humid tropical climate. The CROPWAT 8.0 model of the FAO has been used to calculate the crop water requirements of the main crops in the various Agro-ecological zones of Palakkad, and the results have been compared with the district's water resources. It has been calculated how much water these crops will need overall in each Agro-ecological zone. Shah et al. (2015) studied wheat, rice, and sorghum crop water requirements and irrigation planning in the Waghodia region of Vadodara, Middle Gujarat, India. According to the study, sorghum requires a crop water demand of 187.5 mm. Net irrigation needs for sorghum are 173.3 mm per stage at a set interval, with four irrigations taking place on September 3, September 28, November 17, and December 17 at variable depths of 9.6 mm, 3.9 mm, 11.4 mm, and 48.4 mm, respectively.

Nithya and Shivapur (2016) studied on Study on Water Requirement of Selected Crops under the Tarikere Command Area using CROPWAT and found in Tarikere taluk, Karnataka, India, determined the crop water requirements for various crops using 30-year climatic data and CROPWAT. The reference evapotranspiration ranged from 2.5 to 3.36 mm/day. The gross water requirement for the entire crop area of 4466 ha was calculated as 342.42 mm/year, with a 70% application efficiency. Consequently, the dam's water supply of 16 MCM is sufficient to meet the irrigation needs. Khilesh et al. (2017) studied crop water need estimation and irrigation planning in the Bina River basin using CROPWAT. The Bina River basin's average daily reference evapotranspiration, which ranges from 3.05 to 7.63 mm/day, has been calculated to be 4.73 mm/day. In the Bina River basin, 682.5 mm of effective rainfall on average has been recorded. Using the CROP WAT 8.0 model, it was determined that the crop water requirements for wheat, gram, maize, black gram, mustard, soybean, groundnut, and rice in the Bina River basin were 372.6 mm, 312.6 mm, 432.2 mm, 273.1 mm, 330.3 mm, 486.5 mm, 314.8 mm, and 654.2 mm, respectively.

Hossain et al. (2017) worked on Irrigation Scheduling for T. Aman (wet season) and Boro (dry season irrigated) rice using the CROPWAT Model in the Western Region of Bangladesh. By employing historical climate data, soil information, and crop data, the model estimated annual reference evapotranspiration of 1408 mm, with the highest amount in April and the lowest in December. The model provided specific irrigation recommendations based on transplanting dates, with varying irrigation requirements for different rice varieties. The CROPWAT model demonstrated its potential for irrigation scheduling of various crops. Doriya et al. (2020) applied CROPWAT and the statistical downscaling model (SDSM) to project future crop water needs for 2020 and peaches in Southern Ontario. The baseline climate of 1971-2000 and two future periods from 2010- 2039 and 2040-2069 were compared in the analysis. The CROPWAT model (FAO, 1992) was used to simulate the daily and season total crop water needs (CWR) to forecast future crop water requirements (CWR).

Roja et al. (2020) used the FAO CROPWAT 8.0 Model to estimate the crop water requirements for the maize crop in the northern coastal districts of Andhra Pradesh. The Penman-Monteith technique was included in the model to calculate evapotranspiration. Irrigation was thought to be a viable option for 80% of critical soil moisture loss. The crop water requirements for the maize crop at various growth stages were estimated by the model on a daily, decadal, and monthly scale. The crop water and irrigation needed for the maize crop are 238.6 mm and 212.6 mm, respectively. The findings show that effective water management becomes essential and significant in typical situations. Sharma & Tare (2021) studied on Assessment of irrigation requirements and scheduling under the canal command area of the Upper Ganga Canal using the CROPWAT model & determine the timing and irrigation needs for the Upper Ganga Canal command region. In the Upper Ganga Canal command, this research identified the ideal irrigation area and its other irrigation needs. CROPWAT 8.0 simulation software was also suggested for irrigation planning. Due to inadequate planning and irrigation techniques, it is anticipated that the total agricultural water need in the command area is 1763 MCM, which is more than the actual water availability.

Agrawal et al. (2020) analyzed the Impact of Climate Change on rice crop water requirements in the Varanasi district, India. This study used the NEX-GDDP and CROPWAT 8.0 models to assess the impact of climate change on rice Crop Water Requirement (CWR) and Net Irrigation Requirement (NIR). Results showed an increasing trend in maximum and minimum temperatures, with an expected increase of 1.7°C by 2040. NIR could increase by 4% and 9% in 2030 and 2040, respectively, due to variations in effective rainfall. Linear scaling performed better than the modified difference approach. The study's findings can inform the development of adaptation measures to address the impact of climate change on rice production.

Jaiswal et al. (2021) assessed the impact of climate change on crop water requirements in the Tandula Command of Chhattisgarh (India). Statistical downscaling of climatic parameters using CMIP5 scenarios was employed to project future climatic conditions. The analysis revealed a rising trend in maximum temperature throughout the year, with a significant increase in minimum temperature during winter and the rainy season. The study estimated that the crop water requirement for Kharif paddy will increase during the near (2020-35) and mid-century (2046-64) periods but decrease during the far-century period (2018-99). The mid-century period is considered the most critical, requiring the development of adaptation measures to address climate change.

Jangre et al. (2022) studied on assessment of rice water requirements in the Inceptisol soil region of Raipur district in India using CROPWAT 8.0 and climate data from the past 21 years. The Penman-Monteith method was used to calculate reference evapotranspiration, and the crop coefficient was adjusted for different stages of rice growth. Effective rainfall was set at 80% of total rainfall, and field-specific water requirements for rice ranged from 1192.3 to 1317.9 mm, accounting for application losses and special requirements. Average irrigation needed for rice crops between June 23 and November 14 was 362.53 mm. Jaiswal et al. (2023) studied rainfall and agro-related climate extremes for water requirement in the paddy-grown Mahanadi basin of India and this study examined the impact of extreme climate events and seasonal rainfall on irrigation water requirements (IWR) for Kharif paddy crop in the Mahanadi basin of India. Analysis of rainfall and extreme indices revealed that higher demand, low seasonal rain, and intense extreme events in the upper part of the basin result in greater water requirements for paddy cultivation. A multi-linear regression model was developed with high accuracy to assess the influence of climate extremes on IWR, providing valuable insights for water resource planners and enabling optimal resource utilization. Similar regression models can be developed for other crops and regions based on relevant extreme indicators.

2.4 Application of MIKE-NAM Model

MIKE 11 NAM model is a conceptual, deterministic, and continuous time-scale rainfall-runoff model that is a part of the MIKE 11 RR module. Refsgaard and Knudsen (1996) validated the MIKE 11 NAM and MIKE SHE for three catchments in Zimbabwe to help with water resource management where at least one year’s data were available for calibration. Makungo et al. (2010) conducted a study and simulated the runoff hydrographs for the un-gauged Nzhelele River using the MIKE 11 NAM model and the AWBM. They found out that the simulated runoff hydrographs can be used in water resources planning and management, and water resources systems operation. The rainfall-runoff relationship in the Strymonas river catchment was studied by Doulgeris et al. (2012) using the MIKE 11 NAM model. MIKE 11 NAM was used for the simulation of the rainfall-runoff process in the Strymonas river and Lake Kerkini given by Doulgeris et al. (2008) for water resources management aspects.

Nannawo et al. (2022) applied a deterministic, lumped, and conceptual hydrological model (MIKE11-NAM) was used to explore the effects of hydro climatic factors on rainfall-runoff processes and river flow conditions in the Bilate basin and to maximize water resource management sustainably. The MK statistic (Kendall’s tau statistic) was used to assess a nonparametric trend in each of the stations on a seasonal and annual basis. The rainfall datasets revealed that there was no significant trend on an annual, downward trend in the spring and summer, while an increasing trend in temperature series. During calibration and validation, the R^2 values and water balance error were found as 0.83 and 4.9, and 0.76 and 8.6, respectively using the NAM model. The streams originating from the northern, northwest, and southwest highlands feed the river with a maximum inflow of 188.86 m3 /s, comprising 44% of the basin's mean annual stream flow. The basin's central part has the lowest mean annual stream flow of 112.62 m3 /s (26% of total flow). The average stream flow in the non-observable catchment is 130.37 m3 /s over the years.

Shamsudin & Hashim (2022) used the MIKE11 NAM model for the estimation of rainfall runoff in Layang River. The reliability of MIKE11 NAM was evaluated based on the efficiency index (EI) and root mean square error (RMSE). The EI and RMSE obtained during this study were 0.75 and 0.08 respectively. Kumar et al. (2022) used the MIKE 11 NAM model to examine the performance, efficiency, and applicability at the Ram Munshi Bagh gauging station of Srinagar in the Jhelum River basin. The model was evaluated for the years 2006-2013 in terms of reproducing the basin's hydrological response to the rainfall and accurately predicting daily runoff. The model was calibrated for the period 2006- 2009 and validated for the year 2010-2013. The Nash-Sutcliffe efficiency (NSE) was found as 0.907, the coefficient of determination (R^2) was 0.954 and the volume difference (Dv) was found as 17.8% for the calibration period and 0.963, 0.892, and 13% respectively during validation. It was concluded that the developed model for the Jhelum River may be applied to basin-scale integrated water resource management and production.

Ghosh et al. (2022) used the MIKE 11 NAM model to integrate rainfall-runoff analysis with the hydrodynamic condition through the flood region of the Bhagirathi–Hooghly River. The model was calibrated (2005–2014) and validated (2015–2018) based on the rainfall-runoff amount, including water level and runoff discharge. The calibrated result creates a good relationship with the simulated data using efficiency, coefficient of determination, RMSE, and percentage bias (PBIAS) values. This model also gives a good idea of the region's water balance, and parameters such as coefficient of runoff (CQOF), time coefficient (CK 1,2), and soil moisture in lower zone (Lmax) were found very sensitive to high runoff discharge in this region. Wickramaarachchi & Gunasekara (2023) applied MIKE 11 NAM to investigate the temporal transferability of a lumped conceptual hydrological model for rainfall-runoff simulations in two different periods in Gin catchment, Sri Lanka. MIKE 11 NAM model was calibrated from 1995 to 1998 with Nash Sutcliffe efficiency (NSE) = 0.73, percent bias (PBIAS) = 3.9%, and the ratio of the root mean square error to the standard deviation of measured data (RSR) = 0.52. After successful calibration, the model was validated from 1999 to 2002 (NSE=0.66, PBIAS = 8.7%, RSR = 0.59). The temporal transferability of the calibrated/validated model parameters was tested using two scenarios formulated based on the temporal lag between the calibration period and the transfer period: i. Scenario A has a 4-year time lag, and ii. Scenario B has an 8-year time lag. Scenario A which evaluated the model performance using 2003-2006 stream flow data indicated only a marginal loss in the model performance in comparison to the calibration. It showed an overall ‘good’ performance (NSE=0.64, PBIAS = 8.6%, RSR = 0.59) including the promising capability to reproduce the peak flows.

Slieman & Kozlov (2023) applied the MIKE 11 NAM model to surface runoff modeling in case of lack of data as a case study on the upper basin of the Orontes River in Syria. The results showed the lack of reliability of this model according to the used data in the event of a lack of data in the study area. Therefore, this study recommended continuing researching for the possibility of conducting hydrological analysis and modeling considering the lack of data, as is the case resulting from crises of wars, and trying to use remote sensing and satellite data in this field, to verify the possibility of applicability of other models. Singh et al. (1999) applied MIKE SHE, a physically-based distributed modeling system, to simulate the hydrological water balance of a small watershed in the western part of the Midnapore district of West Bengal, India, to develop the irrigation plan for paddy crops. The results of the study showed that it is possible to meet the irrigation demand of the crops with proper planning and applicability of a MIKE SHE as a comprehensive hydrological modeling system.

2.5 Reservoir Operation and Application of MIKE HYDRO Basin Model

The management of water resources is an utmost important issue because of considerable spatial and temporal variability of precipitation, fast-growing population, infrastructural problems, lower efficiencies of projects, distribution issues, declining groundwater, climatic change, etc. One of the major challenges for the present scientific community is equitable and sustainable management of water resources for different needs such as domestic, agriculture, industrial, etc. considering the non-uniform spatial and temporal distribution of precipitation further adversely affected by plausible climate change. The conflict of interests between different completive demands is one of the concerns in the present era of limited water availability and integrated water resources management may pave the way for success in sustainable development

(Savenije & Van der Zaag, 2000; Savenije & Van der Zaag, 2008). The water resources, in general, are planned considering stationary conditions will no longer be valid in the context of climate change (Brekke *et al.*, 2009; Milly *et al.*, 2008; Georgakakos *et al.*, 2014). MIKE HYDRO basin is a complete suite of basin management models for reservoir operation, irrigation planning, water transfer, power generation, and water balance in a complex system.

Bhadra et al. (2009) developed an integrated reservoir-based canal irrigation model (IRCIM) and successfully simulated the operation of a reservoir to determine a better delivery schedule than presently used. The modular structure of IRCIM has three modules including a catchment module for computation of runoff from the SCS-CN model coupled with the Muskingum routing technique or artificial neural network, a reservoir module that works on mass conservation technique to determine daily reservoir storage and crop water demand module computes water balance from paddy or other crops.

Canon et al. (2009) conducted a study on reservoir operation and water allocation to mitigate the effects of drought on crops using multilevel optimization and drought frequency index (DFI). The analysis used a trigger mechanism for the operation of a multi-reservoir system where DFI is computed as a drought indicator for the Conchos River basin-a tributary of river Rio Grande/Bravo between the United States and Mexico. A multilevel nonlinear optimization procedure has been developed to achieve the goals of reducing water deficits in the United States and maximizing net benefits for farmers in Mexican irrigation districts. The DFI characterized droughts according to their duration and intensity using the probabilistic criterion that considers the perseverance of extremely low precipitation values. The performances of the system with and without DFI were evaluated using reliability and resilience indices. The results indicated that the inclusion of the DFI improves the reliability of both reservoirs and water deliveries to users during periods of drought by overall improvement of net benefits associated with crop production in Mexican irrigation districts.

Noory et al. (2012) applied linear and a mixed-integer linear (MIL) model for optimizing irrigation water allocation for a multi-crop planning problem. The main objective was to maximize the net benefit for all cultivated crops within irrigated areas of a reservoir system in Iran. The linear programming (LP) and continuous particle swarm optimization (CPSO) algorithms were used and found comparable. However, the optimally allocated areas for both crops and orchards obtained by the LP method and CPSO algorithm were not directly applicable in real crop planning situations. Consequently, the MIL model was developed for which a discrete particle swarm optimization (DPSO) algorithm was used to obtain an applicable solution for the problem. Contrary to LP and CPSO, the DPSO algorithm was found competent to solve the problem in the MIL model. The results showed that the discrete nature of cropping area variables in the MIL model had a significant effect on assigned areas and reservoir operation policies. It was found that the inapplicable area assigned by the LP method and CPSO algorithm for some crops was eliminated by the DPSO algorithm.

Ahmed et al. (2013) proposed an optimization-simulation model for the system analysis of water resources for the Dokan reservoir in Iraq. In the study, two linear programming (LP) models were developed for the estimation of maximum safe (firm) yield from the reservoir system with the allowable deficit. One model was a full optimization (complete), while the other was a simplified optimization, also known as yield model. These two models were used as a preliminary screening tool. Based on the result obtained from LP models, it has been observed that the full optimization model provided a more accurate representation of the system behavior than the yield model. However, the limitation of the full optimization model lies in its size so when a multi-reservoir system is involved, it may require a long time to run the model. The choice of model for yield assessment should be decided based on several factors such as the nature and purpose of the study and the size of the given problem.

Jaiswal et al. (2013) used the MIKE BASIN model for optimum planning of reservoir releases from the Mahanadi reservoir project (MRP) in the Chhattisgarh state of India having Ravishankar Sagar, Maramsilli and Dudhawa reservoir in Mahanadi and Dudhawa reservoir in Pairi basin. A model representing the water transfer system along with users and canals was prepared in MIKE BASIN software. This software has extensive reservoir modeling capabilities and can accommodate multipurpose reservoir systems. In the study, three different cases for possible transfer from upstream reservoirs were simulated for a twenty-one-year period (1975 to 1995). In the first model, Murumsilli reservoir was assigned top priority and then Dudhawa fed water to Ravishankar Sagar reservoir. The second model considered the top priority to Dudhawa reservoir and then to Murumsilli reservoir, while the third model has equal priority to both these reservoirs. The Municipal and Industrial demands were given priority on irrigation demand. The analysis indicated that the first model performed better than other models and provided similar results to earlier optimization given by Verma et al., 2010. The study emphasized that the MIKE BASIN model can be utilized for reservoir operation of reservoirs in MRP and Mahanadi basin having an average annual spill of nearly 300 MCM that can be transferred to adjoining water deficit Tandula reservoir.

Jaiswal et al. (2014) developed MIKE BASIN-based decision support for the Rangawan reservoir which is an inter-state project of Madhya Pradesh and Uttar Pradesh states of India having a water-sharing agreement between these states. The reservoir operation in MIKE BASIN cannot be done for irrigation commands connected with the reservoir having a water allocation system. This problem was overcome by developing two coupled models where the first model computed crop water requirement of command and the results of the first model were applied as the input to the second model for water users connected with the reservoir in the water allocation system. In the analysis, twelve different scenarios were generated to operate the Rangawan reservoir under variable climatic, conjunctive use, field application, and conveyance efficiency conditions. The analysis suggested that the deficit in the average/wet year for design cropping patterns under 60% conveyance and 70% application efficiencies may be about 14.39 MCM. This deficit can be reduced to 1.51 MCM if conveyance and application efficiencies increase to 70 and 80% respectively and 20% of demand is met through groundwater.

Yu et al. (2015) established MIKE HYDRO Basin, a large-scale basin model for river Tarim in China with a catchment area of 1.02 × 106 sq km to address conflicts of upstream and downstream irrigation water and optimal resource utilization. The Tarim catchment has been divided into four sub-basins having cotton is the main crop in the region. The NAM model along with the Muskingum routing method was used for rainfall-runoff modeling. The network model comprising branches, catchments, reservoirs, water users, canals, and connections for the Tarim river system has been developed. The model consists of irrigation water users for irrigated areas with cotton, wheat, and tomatoes are the main crops and non-irrigation water users depicting other demands in the catchment. In the study, two irrigation and three land use scenarios were developed and analyzed using separate simulations in the model. The first irrigation scenario consists of seven sub-scenarios of different total available water (TAW) ranging from 0.7 to 0.1, while the second irrigation scenarios were designed based on the application of drip irrigation under mulching (DIUM). The three land use scenarios designed in the study consist of a decrease (LUD), increase (LUI), and crop type change (CTC) in the land use scenarios. The analysis of results indicated a six percent drop in cotton production when TAW was reduced from 0.4 to 0.7 with optimum production at TAW of 0.4. Tomatoes have been found the most sensitive crop in the region and should be grown in the areas that have ensured a source of supply. The implementation of DIUM has a noticeable reduction in spray loss and wetting friction that may save a considerable amount of water and reduce the demand deficit.

Gurav (2016) developed multi-objective fuzzy linear programming (MOFLP) based model for irrigation planning and reservoir operation for the Zayakbadhi Phase II project on river Sindhaphana in Maharashtra state of India to address uncertainties and conflicts of interest among various uses. The MOFLP model was developed in LINGO13 optimization software for the optimization of net benefit, crop production, employment generation, manure application, releases for irrigation, and power. The results of the analysis suggested that a compromised solution under MOFLP can be obtained with maximum benefits of 1088.46 million rupees, crop production of 0.24 million tonnes, employment generation of 23.13 million-man days, manure utilization of 0.11 million tonnes with irrigation intensity of 79.40%. It has been emphasized that the present solution can be used for irrigation release with prime consideration of social, economic, and environmental issues. Saxena & Yadav (2016) prepared water distribution for Surat city in the WEAP model by depicting all demands and supply nodes considering the year 2011 as the base period. The simulation runs of the WEAP model were made by increasing 1.5% as low and 3.5 % as high population growth scenarios and found its suitability in assessing future water demand and supply for integrated management. Visescu et al. (2017) described the capabilities of MIKE HYDRO Basin as a decision support tool with water sharing at regional, national, and international scales can link hydrological, meteorological, engineering, water quality, agriculture, environmental information for integrated water resources management. Several simulations run from 1977 to 1979 were made to determine inflows, outflows, mass balance, runoff, water deficit, and relative deficit for all nodes in the basin. It has been concluded that different scenarios generated in the study may be useful to identify optimal strategies for policymakers.

Sanghy et al. (2017) used MIKE HYDRO, Cropwat, and Nile Basin Decision Support (NB-DSS) for the Mpioka basin, in the Democratic Republic of Congo for integrated water resources management by developing one baseline and three development scenarios derived with the consultation of different stakeholders in the region. In the study, the model for the study area was developed in the MIKE HYDRO basin for simulation and then registered in NB-DSS for analysis using data collected from diverse sources from 1991 to 1998. Based on consultations, initially, three different scenarios have been considered for evaluation. The first development scenario (SC1) consists of water supply by the construction of the Mpioka reservoir and power generation from the Mpioka reservoir. The second scenario (SC2) had two connections and one irrigation user node, while the third scenario (SC3) had two connections and one user node. All these scenarios were evaluated with the help of economic, social, and environmental criteria, and found that economic and social consultation sessions preferred the SC1 scenario, while SC3 was preferred by the environment group. The stakeholder group agreed unanimously that the Mpioka dam construction (SC1) seems to be the first development priority in the Mpioka basin, but the model run indicated that it may create a strong water deficit to the Nkamba-Ntimansi node.

Santos et al. (2018) used two separate software packages to fulfil the proposed goal, SWAT, and MIKE HYDRO Basin in the Sabor River in Portugal. The SWAT was used in the construction of the hydrological model and MIKE HYDRO Basin in the simulation of water allocation, namely irrigation and domestic consumption. Primary results indicated that the low population density 16 recorded in the basin area between 1960 and 2009 was negligible and had no significant impact on the flow. However, as the agricultural area occupies 59% of the basin, the water consumption for irrigation represented, on average, 27% of the stream flow. Jaiswal et al. (2021) developed a decision support system (DSS) framework for strategic water resources planning and management under projected climate scenarios for a Tandula reservoir complex system of Chhattisgarh state for three future assessment periods of 2020-35, 2046-64, and 2081-99. The developed DSS framework incorporated eighty-four diverse management plans to deal with climate uncertainties using possible improvements in efficiencies and consumptive use for three future assessment periods. Furthermore, the performance of the developed plans was evaluated using multi-criteria decision support in the three-layer hierarchal process. The decision support analysis suggested that the second assessment period (FP-2: 2046-64) will be more crucial from the management point of view where 54 out of 81 plans could not perform as par with the present performance of the system.

Jha et al. (2022) developed Irrigation decision support systems (IDSS) for the State of California to support diverse challenges, including drought, energy, nitrogen, and salinity management. Firstly, review the current existing IDSS available to California growers, their underlying science, incentive policies, and anticipated outcomes. Most of the irrigation decision support tools used in California were based on fewer components of the water budget, and none of the available IDSS provided an estimation of all parameters together. In addition to water management, these policies also aim to manage groundwater and require the record keeping of water use, nitrogen (N) leaching, salinity management, and energy consumption. Remote sensing IDSS was useful to determine the spatial scale information based on spectral data, but the interpretation of multispectral/thermal imagery was complicated for growers to base decisions for water, nutrient, and salinity hotspots.

Van Tra et al. (2023) used the MIKE HYDRO basin to assessment the impacts of deep uncertainties on the water resources system, climate stress test, and land use change for the Ba River Basin. A model was developed for 7 irrigation regions, 45 irrigation users, 8 regular users, 48 reservoirs, 10 hydropower plants, and 40 different combinations of climate conditions and land use change. The results revealed that climate and land use change was expected to reduce water supply reliability in the river basin by between 2.1% and 5.2%. The most significant reliability decreases were in Nam Bac An Khe (− 29.4%), while the most increase was in Upper Ayun (+10.9%) sub-basins. Thanh et al. (2023) used MIKE 11 NAM and MIKE HYDRO Basin models for rainfall-runoff (R-R), and water balance modeling respectively for the La Nga-Luy River basin, and the Keetch–Byram Drought Index (KBDI) was used to estimate the magnitude of the droughts. The results identified areas within the Nga-Luy River basin where abnormally dry and moderate drought conditions were common, and subbasins, i.e., in the southeast and northeast, where severe and extreme droughts often prevailed. The analysis showed that the water demand for irrigation was met 100% and 75–80% of the time during moderate, and extreme or severe droughts, respectively, through increased water use efficiency.

2.6 Web and Mobile Application-based Decision Support System

Recently, applications of recent technology like artificial intelligence, machine learning, open space data, and mobile-based information systems are being proposed and implemented by researchers and policymakers. Bartlett et al. (2015) presented a pioneering initiative in irrigation scheduling technology and devised an online evapotranspiration-based irrigation scheduling tool named Water Irrigation Scheduling for Efficient Application (WISE). This tool employs the soil water balance method and integrates data queries from the Colorado Agricultural Meteorological Network (CoAgMet) and Northern Colorado Water Conservation District (NCWCD) weather stations. This application enables users, including agricultural producers, irrigation managers, and research scientists, to swiftly access crucial information such as soil moisture deficit, and weather measurements, and input applied irrigation amounts directly into WISE. The innovation lies in the mobility offered by the smartphone app, granting users the flexibility to engage with the tool from any location within a cellular data network. the authors highlighted the critical role of irrigation in Colorado, a headwaters state, where the imperative for viable agricultural production places a substantial demand on water resources. Addressing the challenges posed by the foreseen population growth.

Migliaccio et al. (2016) developed an android application Smart Irrigation to provide real-time irrigation schedules for selected crops (i.e., avocado, citrus, cotton, peanut, strawberry, and vegetables). Irrigation schedules in smartphone apps are based on evapotranspiration (ET) or a water balance methodology using real-time weather data from the Florida Automated Weather Network and the Georgia Environmental Monitoring Network. The FAO Penman-Monteith method is used for calculating reference ET, and crop coefficients (Kc) are applied based on time after planting, calendar month, or a crop’s phenological stage. The functionality of each app was customized for each user group considering the most common irrigation systems used. Custom features include water conservation options, splitting irrigation events, spreadsheet output emails, and notifications. The inputs to the mobile application varied based on crop types (primarily due to the irrigation system used); however, all apps require root depth, irrigation rate, and soil type except the strawberry app. The application outputs also vary and include estimated reference ET, days between irrigation events, irrigation depth and duration, accumulated rain for the previous seven days, and growing degree days. The forecast data from the National Weather Service are also used in the apps for the computation of water requirements.

Vellidis et al. (2016) presented a valuable contribution to the field of irrigation scheduling through the development and evaluation of an APP for the Cotton crop (Cotton APP). The app utilized an interactive ET-based soil water balance model, integration of various data sources, and real-time notifications to make it a user-friendly and effective tool for cotton growers. The successful performance of the Cotton App in field trials and its ongoing development to expand its geographical coverage demonstrated its potential to improve water use efficiency and crop productivity in cotton 18 cultivation. Further research and evaluation in diverse cotton-growing regions and similar applications for other crops may provide additional insights into the app's applicability and benefits, promoting sustainable irrigation practices in agriculture.

Hemamalini et al. (2019) addressed the challenges faced by the agricultural sector in India, where 70% of the population is employed in farming, relying on conventional techniques. Existing technologies are often expensive or fail to meet the specific needs of farmers. In response, the authors developed a mobile application, the developed mobile application monitors key factors such as moisture level, temperature, soil nutrient composition, and pest detection. Additionally, it incorporates an automatic motor ON/OFF process to optimize water consumption. A distinctive feature of their work involves the utilization of image-processing algorithms to identify weeds in crops, contributing to increased crop yield. The authors highlight the affordability and cloud-based nature of the proposed system, positioning it as a cost-effective and technologically advanced solution for smart irrigation.

Agulto and Ella (2022) undertook the development of a mobile application for efficient irrigation water management, focusing on wireless sensor networks. This study utilized the Flutter SDK and Dart to create a comprehensive application capable of monitoring Smartmesh IP sensors (Neomote sensors) and ESP8266-based sensors. The mobile application not only provides real-time readings from the sensors but also displays graphical historical data, offering a holistic approach to irrigation management. The user interface of the mobile application incorporates both text widgets and sync fusion gauge meter widgets to display the latest sensor readings, adapting to the sensor type in use. Graphical historical data, on the other hand, are presented using fl_chart's line graph widgets. The integration of a REST API and HTTP get method facilitates the retrieval of data from the server, while control commands are transmitted using the HTTP post method. The study successfully demonstrated the application's ability to interact effectively with Neomote and ESP8266 sensors, with response times for 24 hours, one week, and one month of historical data falling below one and three seconds, respectively.

Ale et al. (2023) developed an innovative mobile application Irrigation named Decision-support for Conserving Resources and Optimizing Production (idCROP) for cotton irrigation management. The application addresses the challenges associated with existing irrigation decision support tools, such as high costs, technical requirements, and limited user adoption rates. The idCROP app is designed to be a user-friendly and cost-effective solution to assist cotton producers in the Texas Rolling Plains and High Plains regions. The application was built upon the Decision Support System for Agro technology Transfer (DSSAT) crop simulation model and incorporated a novel economic model into the idCROP app. This integration enables real-time irrigation schedules and economic projections based on water use and production goals. The app leverages a combination of real-time management information and weather data to generate efficient irrigation schedules, providing forecasts for cotton yield and economic returns. Ale et al highlight the flexibility of the app, accommodating various irrigation strategies and the optional integration of remote plant water stress detection sensors.

From the review of literature on various aspects of irrigation return flow, it has been found that the approach for the computation of IRF is site and purpose-specific and no universal method can be suggested. From the review of past studies, the following important issues have been identified in respect of irrigation return flow:

- Despite the significant importance of irrigation return flow in water resource management, its measurement is still difficult due to various reasons and no specific methodology can be recommended (Vallet-Coulomb et al 2017).
- The amount and distribution of IRF vary significantly in different regions based on factors such as soil, crop, geology, topography, canal condition, irrigation method, and season.
- The site-specific approach and system analysis are useful for quantifying different components of hydrological processes in the command.
- Most of the past studies were conducted on paddy irrigation in alluvial plains where water is standing for a long period and groundwater recharge is the major component in IRF.
- Past studies were focused on water balance and very few applied modeling and isotopic analysis.
- In the hard rock region, the regenerated flow may be the major component of return flow than then the groundwater recharge which was not addressed in most of the past studies.

Based on the findings from the review of literature, three different techniques including the water balance approach, isotopic analysis, and modeling approach were applied on the command of the Sanjay Sagar project in Vidisha district of M.P. for computation of rejuvenated flow and groundwater recharge. MIKE 11 NAM in conjunction with MIKE Hydro Basin and an Excel-based module was applied for irrigation planning. A web and mobile-based application was developed for the constant and timely transfer of information among farmers and WR managers for efficient irrigation planning.

CHAPTER-3: STUDY AREA

3.1 General

The present study has been carried out on the Sanjay Sagar project situated on the Bah River in the Vidisha district. There are 7 tehsils and 7 blocks in the district. The block headquarters are Vidisha, Gyaraspur, Basoda, Nateran, Kurwai, Sironj, and Lateri. The district is encircled by Guna district in the north, Sagar and Raisen in the east, Raisen in the south, and Bhopal in the west.

3.2 Madhya Pradesh State

Madhya Pradesh is in Central India and is surrounded by Uttar Pradesh in the north, Chhattisgarh in the east, Maharashtra in the south, and Gujarat and Rajasthan in the west. The most spoken language of the state is Hindi, English, and Marathi are the other languages used by the people of the state. Bhopal (The capital) Indore, Gwalior, Jabalpur, and Ujjain are some of the key cities of the state. There are 11 agro-climatic zones and 5 crop zones. There are a variety of soils available in the state to support the cultivation of a wide range of crops. Madhya Pradesh got the honour of the best agriculture state of India in the year 2013 for the highest agriculture growth of 18 percent per annum. Madhya Pradesh also stood in top highest position in India for producing pulses and oilseeds in the year 2013 and for record production and procurement of wheat at minimum support price (MSP) in the year 2011–12. The state also received the “Krishi Karmath Award” for continues 6 years (2012 to 2017) for the development and extension of new modern technology of agriculture and enhancement of production and productivity. The state is a leading producer of soybean, wheat, gram, garlic, and coriander. The state of Madhya Pradesh can be divided into the eleven agro-climatic zones and Vidisha along with Sehore, Bhopal, Raisen, Sagar, and Damoh districts is situated in Vindhyan Plateau as shown in **Figure.3.1.** The details of agro-climatic regions and crop zones shown in **Table 3.1**.

3.3 Vidisha District

Vidisha district with an area of 7371 km^2 lying between the North Latitudes 22° 20’ and 24° 22’ and East Longitudes 77° 16’ and 78° 18’ falls under the Survey of India toposheet No. 54H, 54L, 55E, and 55I. Agriculture is the main occupation of the people in this district. Wheat, jowar, gram, maize, and soybean are the major crops sown in the district. The salient features of the Vidisha district are given in **Table 3.2**.

Figure 3.1 Agro-climatic zone of Madhya Pradesh

Table 3.1 Agro-Climatic Regions and Crop Zones in M.P.

S. No.	Crop Zones	Agro Climatic Regions	Soil Type	Rainfall (Range in mm)	District Covered	Details of Partly Covered Districts
1	2	3	4	5	6	7
1	Rice zone	Chhattisgarh plains	Red & Yellow (Medium)	1200 to 1600	Balaghat	
2	-do-	Northern Hill Regions of Chhattisgarh	Red & Yellow Medium Black & Skeltal (Medium/light)	1200 to 1600	Shahdol, Mandla, Dindori, Anuppur, Sidhi (Partly), Umaria	Sidhi: Singroli Tehsil (Bedhan)
3	Wheat Rice Zone	Kymore Plateau & Satpura Hills	Mixed red and black soils (Medium)	1000 to 1400	Rewa, Satna, Panna, Jabalpur, Seoni, Katni, Sidhi (except Singroli tehsil)	

4	Wheat zone	Central Narmada Valley	Deep black (deep)	1200 to 1600	Narsinghpur, Hoshangabad Sehore (Partly), Raisen (Partly)	Sehore: Budni Tehsil. Raisen: Bareli Tehsil.
5	-do-	Vindhya Plateau	Medium black & deep black (Medium/Heavy)	1200 to 1400	Bhopal, Sagar, Damoh, Vidisha, Raisen (except Bareli Teh.), Sehore (except Budni Teh.), Guna (Partly).	Guna: Chanchoda, Raghogarh & Aron Tehsils.
6	Wheat-Jowar	Gird Region	Alluvial (Light)	800 to 1000	Gwalior, Bhind, Morena, Sheopur-Kala, Shivpuri, (except Pichore, Karera, Narwar, Khania - dana Teh.), Guna (except Aron, Raghogarh, Chanchoda Tehsil) Ashoknagar	
7	Wheat-Jowar:	Bundelkhand	Mixed red and black(Medium)	800 to 1400	Chhatarpur, Datia, Tikamgarh, & Shivpuri (Partly)	Shivpuri: Karera, Pichhore, Narwar & Khaniadhana Tehsils.
8	-do-	Satpura Plateau	Shallow black (Medium)	1000 to 1200	Betul & Chhindwara	
9	Cotton Jowar	Malwa Plateau	Medium black (Medium)	800 to 1200	Mandsaur, Neemuch, Ratlam, Ujjain, Dewas, Indore, Shajapur, Rajgarh & Dhar (Partly) Jhabua (Partly)	Dhar: Dhar, Badnawar & Sardarpur Tehsils. Jhabua: Petlawad Tehsil.
10	-do-	Nimar Plains	Medium black (Medium)	800 to 1000	Khandwa, Burhanpur, Khargone, Barwani, Harda, Dhar (Partly) District.	Dhar: Manawar, Dharampuri & Gandhawani Tehsil.
11	-do-	Jhabua Hills	Medium black skeletal (Light/Medium)	800 to1000	Jhabua District. (Except Petlawad Tehsil) & Dhar (Partly)	Dhar: Only Kukshi Tehsil.

Table 3.2 Salient features of Vidisha district (CGWB, 2013)

S. N.	ITEMS	STATISTICS
1.	**General Information**	
	i) Geographical area	7371 Km^2
	ii) Administrative Divisions (As of 2012) Number of Tehsil/Blocks No of Villages	10/7 (Vidisha, Gyaraspur, Basoda, Nateran, Kurwai, Sironj, Lateri) 1624
	iii) Population (Census 2011)	1458212
	iv) Average Annual Rainfall (mm)	1135.5
2.	**Geomorphology**	

	1. Major Physiographic Units: 2. Major Drainage: Land Use (km^2)	Malwa Plateau, Vindhyan Hill Range and Betwa Alluvium Betwa River, Bah Nadi, Nion River, Keother Nadi, Bina River, Kethan Nadi and Sindh River	
3.	**Land Use (Km^2)**		
	i) Forest area:	1096	
	ii) Net area is sown:	7444	
	iii) Cultivable area:	5847.32	
4.	Major Soil Types	Black Cotton	
5.	Area Under Principal Crops	2478.92 Km^2	
6.	Irrigation by Different Sources	Nos.	Irrigated area (km^2)
	Dug wells	11816	427
	Tube wells/Bore wells	16057	1063
	Tanks/Ponds	23	48
	Canals	11	399
	Other Sources		618
	Gross Irrigated Area		2555
	Predominant Geological Formations	Deccan Trap basalts underlined by Vindhyan sandstone and overlain by river alluvium	
8	Hydrogeology Major Water Bearing Formation Pre-monsoon depth to water level Post-monsoon depth to water lev	Weathered/vesicular basalt, flow contacts, fractured sandstone, and granular sand 2.8–16.2 mbgl m/annum fall 2.08–9.58 mbgl/annum rise Pre-monsoon: 0.1- 0.83 m fall/ Post-monsoon: 0.02- 0.83 m rise	

3.3.1 Rainfall and climate

The climate of Vidisha district is characterized by a hot summer and general dryness except during the southwest monsoon season. The year may be divided into four seasons. The cold season, December to February is followed by the hot season from March to the middle of June, the monsoon season from June to September, and the post-monsoon or transition period in October and November. The normal rainfall of Vidisha district is 1135.5 mm. It receives maximum rainfall during the southwest monsoon period. About 91.4% of the annual rainfall received during monsoon seasons. Only 8.6 % of the annual rainfalls take place during the October to May period. The surplus water for groundwater recharge is available only during the southwest monsoon period. The maximum rainfall received in the district at Kurwai i.e. 1191.0 mm and the minimum at Bareli i.e. 1150.3 mm.

The normal maximum temperature is 41.7°C in May, while the minimum is 8.9°C in December. The normal annual means maximum and minimum temperature of Vidisha district is

32.0° C and 17.9° C respectively. During the southwest monsoon season, the relative humidity generally exceeds 94% (August month) and the rest of the year remains dry. The driest part of the year is the summer season and April month when relative humidity is observed less than 39%. The wind velocity is higher during the pre-monsoon period as compared to the post-monsoon period. The maximum wind velocity is 11.2 km/hr observed during June and a minimum of 1.5 km/hr during December. The average normal annual wind velocity of Vidisha district is 5.3 km/hr.

3.3.2 Geomorphology

Based on physiography, the district can be divided into three major units i.e. Malwa Plateau, Vindhyan Hill range, and Alluvium plain (Table 3.2). The district is formed by the valleys of major rivers like the Betwa basin and the Sindh River. Most of the district, measuring more than 80% is in the Betwa river basin, which is drained by its tributaries like Bah, Nion, Keother, Bina, and Kethan. The presence of elevated ground on all the sub-basins marks the surface water divides. The interior area of the basin is marked by undulating topography with elevated plains with very few low-altitude isolated hills. The ground elevations in the area vary between about 383 m (Kurwai Block) in the northeast and about 550 m (Lateri Block) in the northwest part of the district.

3.3.3 Soils

The district is generally covered with black cotton soils covering almost three-fourths of the area. This part is occupied by Deccan Basalts. The rest part has red-yellow mixed soils derived from sandstone and shale. The alluvial soils are found along the river courses. The higher elevations i.e., the hilly regions have a cover of murmur, which is made up of small rounded pieces of weathered trap. The Vindhyans and Bijawars have a thin cover of sandy loams. The alluvium is derived from hill slopes by numerous streams and watercourses.

3.4 Sanjay Sagar Project

The Bah River Basin is situated in the Vidisha districts of Madhya Pradesh, India. It is a tributary of the Betwa River. The catchment of the basin lies between northern latitude 23° 28′ to 23º54' and eastern longitude 77° 17′ to 77°40' respectively. The total catchment area of the basin up to the GD site is 879.58 km^2. The Sanjay Sagar Dam is one of the important medium water resource projects situated on river Bah in Samshabad block of Vidisha district. The catchment area of river Bah up to the dam site is about 562 km^2 and it was constructed in 2014 to irrigate 9893 Ha rabi and 8049 Ha kharif crops, but due to less demand in kharif season, the project is presently supplying water to 9398 Ha rabi crops only. The location of the Dam catchment and GD catchment is shown in **Figure 3.2**. The gross and live storage capacities of the reservoir are 86.4 Mm^3 and 76.52 Mm^3 respectively (**Table 3.3**). Wheat and gram are the main crops grown in the study area during the rabi season when water is supplied from the dam. The salient features of the Sanjay Sagar (Bah) medium project are given in **Table 3.4.** The soil in the study area is mainly clayey soil with limited infiltration capacity and depth from a few inches to 2 m at different places. The geological succession, formation, and lithology in the study area are presented in **Table 3.5**. Due to the Deccan trap and Vindhyan formation with a limited depth of water, the recharge to groundwater is very less and most of the water applied through irrigation reaches to nalahas and rivers as quick interflow or surface flow.

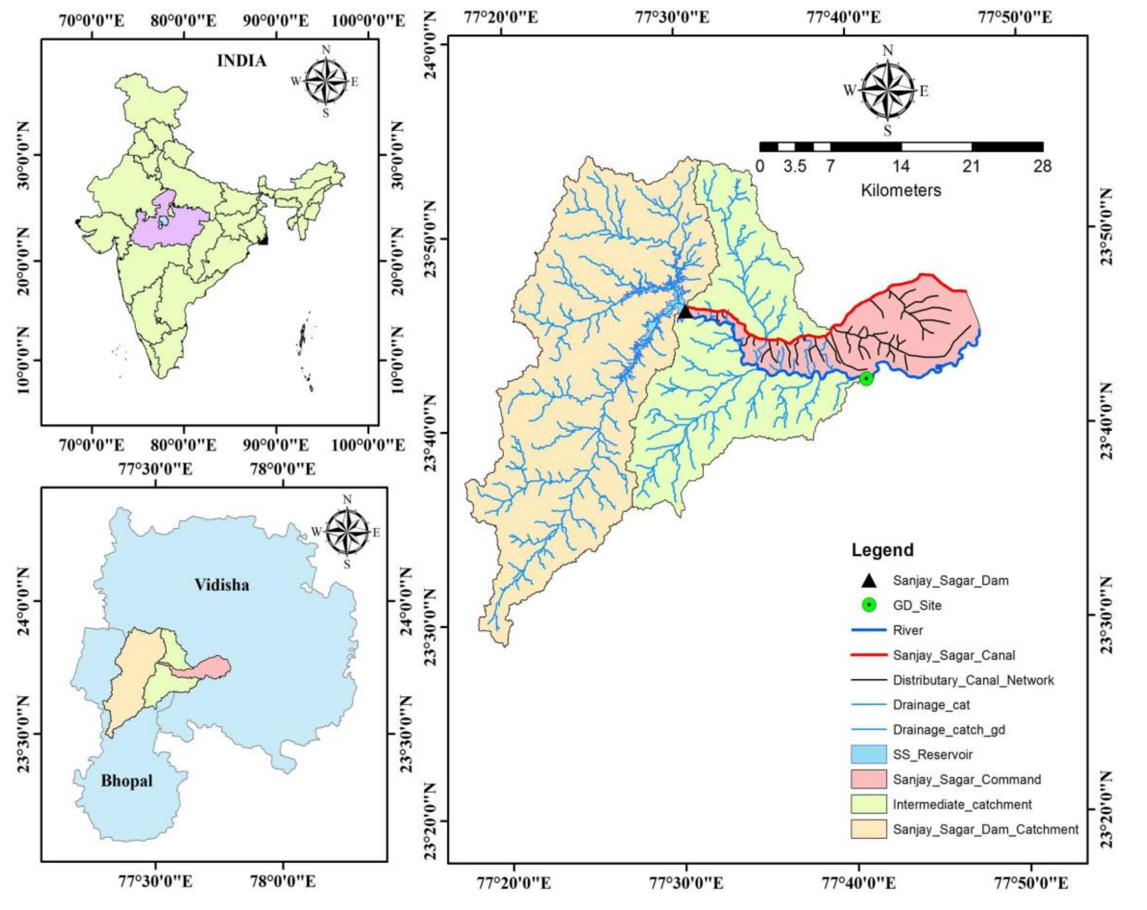


Figure 3.2 Location map of the study area

Table 3.3 Area-Elevation-Capacity of the Sanjay Sagar Reservoir

Elevation (m)	Area (km^2)	Volume (mcm)
438	0	0
440.5	6.58	9.88

441	6.91	11.54
441.5	7.30	13.50
442	7.77	15.83
442.5	8.30	18.50
443	8.91	21.57
443.5	9.61	25.07
444	10.41	29.03
444.5	11.30	33.48
445	12.30	38.49
445.5	13.46	44.27
446.5	16.06	57.29
447	17.44	64.21
447.5	18.90	71.52
448	21.05	82.25
448.2	21.88	86.4
450	22.5	91.2

Table 3.4 Salient features of Sanjay Sagar (Bah) Medium project

GENERAL		
1.0	State	Madhya Pradesh
1.2	District/Tehsil/Block	Vidisha/Basoda/Samshabad
1.3	Latitude	23° 46’ N
1.4	Longitude	77° 31’ E
1.5	River	Bah River
HYDROLOGY		
2.1	Catchment Area	562 km2
2.2	Maximum flood discharge	8935 m3/sec
2.3	Annual average Rainfall	974.36 mm
2.4	75% dependable yield.	191.38 Mm3
RESERVOIR		
3.0	River level (N.B.L.)	426.73 m
3.1	T.B.L.	453.20 m
3.2	M.W.L.	448.20 m
3.3	F.T.L.	448.20 m
3.4	L.S.L.	440.50 M
3.5	Gross storage capacity at F.T.L.	86.40 Mm3
3.6	Live storage capacity	76.52 Mm3
3.7	Dead storage capacity	9.88 Mm3
3.8	Submergence at F.R.L. in Ha.	2188.454 Ha
DAM		
4.1	Type of Dam	Earthen Dam

4.2	Top Width	Central spillway
4.3	Maximum height of Dam	7.50 m
4.4	The total length of Dam	26.47 m
4.5	Length of Earthen Dam	37.02 m Overflow
	SPILLWAY	
5.1	Length of the central spillway	294.25 m
5.2	Level of the spillway crest	440.50 m
5.3	Number of bays/Gates	12 Nos
5.4	Size of Bay/Gate	15.00 x 7.70 m
5.5	Top of gate S.L.	448.20 m
5.6	Discharges capacity	8935 Mm3
	CANAL SYSTEM	
6.1	C.C.A.	9893 Ha
6.2	Surface area	9893 Ha
6.3	Annual Irrigations	17807 Ha
	(a) Rabi	9398 Ha
	(b) Kharif	8409 Ha
6.4	Length of Main Canal	27.43 km
6.5	Length of Distributaries	20.932 km
6.6	Full Supply Discharges	3.10 m3/sec

Table 3.5 Geological formation in the study area

Age	Formation		Lithology
Recent to Pleistocene	Alluvium		Clay with Kankar Sand and river alluvium
	Laterite		Small capping of lateritic on hills and patches in the river valley
Upper Cretaceous to Lower Eocene	Deccan Trap		Lava flows of basalt with red bole and inter trappean beds
Upper Pre-Cambrian to lower Palaeozoic	Vindhyan System	Upper Bhander series	Lower Bhander sandstone but intercalated bands of shales known as Sanchi shale, Bhander limestone, and Ganurgarh shale
		Lower Bhander series	

3.4.1 Canal Network in Sanjay Sagar (Bah) Project

The command area of the Sanjay Sagar Project has one Main Canal which offtakes directly from the Dam. The main canal supplies irrigation water throughout the command with the help of some branch canals, minors, and two distributaries. After 16.74 km and 22.77 km from the dam the 1st Distributary (D1) and 2nd Distributary offtakes from the main canal respectively. The 12 km long D1 provides irrigation water to 2587 Ha of land with the help of 11 minors. Similarly, 6.6 km long D2 irrigates 2187 Ha fields with the help of 9 minors. The details of the distribution network of the canal command are given in **Table 3.6.** The canal network of command is shown in **Figure 3.3**.

Table 3.6 The details of the distribution network of the canal

S.No	Name of canal		Offtake R.D.		CCA in Ha.		
			Main Canal (m.)	Distr (m.)	From Main Canal	From Distr/ Minors	Total
1	Direct out-let – 1	D.O. - 1	630		21.3		21.3
2	Direct out-let – 2	D.O. - 2	810		25.6		25.6
3	Direct out-let – 3	D.O. - 3	1320		11.9		11.9
4	Direct out-let – 4	D.O. - 4	1410		12.8		12.8
5	Direct out-let – 5	D.O.-5	1980		28.2		28.2
6	Direct out-let – 6	D.O - 6	2400		16.2		16.2
7	Left Direct out-let.- 1	Left D.O.- 1	2750		9.4		9.4
8	Right Minor-1 (RM-1)	M-1	3075		47.1		47.1
9	Right Minor-2 (RM-2)	M-2	3750		38.9		38.9
10	Direct out-let - 7	D.O - 7	3990		32.4		32.4
11	Direct out-let - 8	D.O - 8	4380		34.2		34.2
12	Right Minor-3 (RM-3)	M-3	5775		87		87
13	Direct out-let - 9	D.O - 9	6930		26.5		26.5
14	Right Minor-4 (RM-4)	M-4	7320		243.5		243.5
15	Right Minor-5 (RM-5)	M-5	7800		107.4		107.4
16	Direct out-let -10	D.O. -10	8220		29		29
17	Right Minor-6 (RM-6)	M-6	9250		291.10	291.1	481.1
18	Sub Minor of Right Minor-6 (RM-6)		1075 of RM-6		190	190	
19	Right Minor-7 (RM-7)	M-7	10110		82.2		82.2
20	Right Minor-8 (RM-8)	M-8	10790		353.6		353.6
21	Right Minor-9 (RM-9)	M-9	12480		439.4		439.4
22	Left Direct out-let.- 2	Left D.O.- 2	13050		23.9		23.9
23	Right Minor-10 (RM-10)	M-10	14045		180.40	180.4	267.7
24	Sub Minor of Right Minor-10 (RM-10)		710 of RM-10		87.30	87.3	
25	Right Minor-11 (RM-11)	M-11	15360		749.7		749.7
26	Right Minor-12 (RM-12)	M-12	15700		381.2		381.2
	Distributory-1	DIST-1	16880				2587
27	Right Minor-1 of Distributory-1	RM-1	1312 of D-1			395.79	
28	Left Minor-1 of Distributory-1	LM-1	1512 of D-1			136.11	
29	Left Minor-2 of Distributory-1	LM-2	2550 of D-1			95.47	

30	Right Minor-2 of Distributory-1	RM-2	2810 of D-1			240.19	
31	Sub Minor-1 of Right Minor No 2 of Distributory-1		825 of RM-2 of D-1			80.1	
32	Left Minor-3 of Distributory-1	LM-3	3460 of D-1			104.64	
33	Left Minor-4 of Distributory-1	LM-4	4065 of D-1			223.41	
34	Right Minor-3 of Distributory-1	RM-3	4843 of D-1			222.01	
35	Left Minor No-5of Distributory-1	LM-5	5783 of D-1			128.83	
36	Right Minor-4 of Distributory-1	RM-4	5828 of D-1			169.58	
37	Sub Minor-1 of Right Minor No 4 of Distributory-1		575 of RM-4 of D-1			74.34	
38	Left Minor No 6 of Distributory-1	LM-6	6500 of D-1			90.28	
39	Sub Minor-1 of Left Minor No 6 of Distributory-1		390 of LM-6 of D-1			95.3	
40	Right Minor-5 of Distributory-1	RM-5	7327 of D-1			299.06	
41	Tail Minor of Distributory-1	TAIL	7397 of D-1			232.29	
42	Right Minor-13 (RM-13)	M-13	17954		592.5		592.5
43	Left Minor-1 (LM-1)	LM-1	18410		102.6		102.6
44	Right Minor-14 (RM-14)	M-14	20610		298.2		298.2
45	Left Direct out-let- 3	Left D.O.- 3	22299		30.7		30.7
	Distributory-2	DIST-2	22965				2251
46	Right Minor-1 of Distributory-2		716 of D-2			341.72	
47	Left Minor-1 of Distributory-2		1827 of D-2			354.11	
48	Left Minor-2 of Distributory-2		2865 of D-2			224.33	
49	Right Minor-2 of Distributory-2		3150 of D-2			278.04	
50	Left Minor-3 of Distributory-2		3580 of D-2			346.82	
51	Left Minor-4 of Distributory-2		4570 of D-2			222.23	
52	Right Minor-3 of Distributory-2		5300 of D-2			264.75	

53	Tail Minor of Distributory-2		5340 of D-2			219.1	
54	Left Direct out-let- 4	Left D.O.- 4	23200		28.2		28.2
55	TAIL -MINOR	TAIL - MINOR	24000		452.1		452.1
	TOTAL				5054.5	4838.5	**9893**

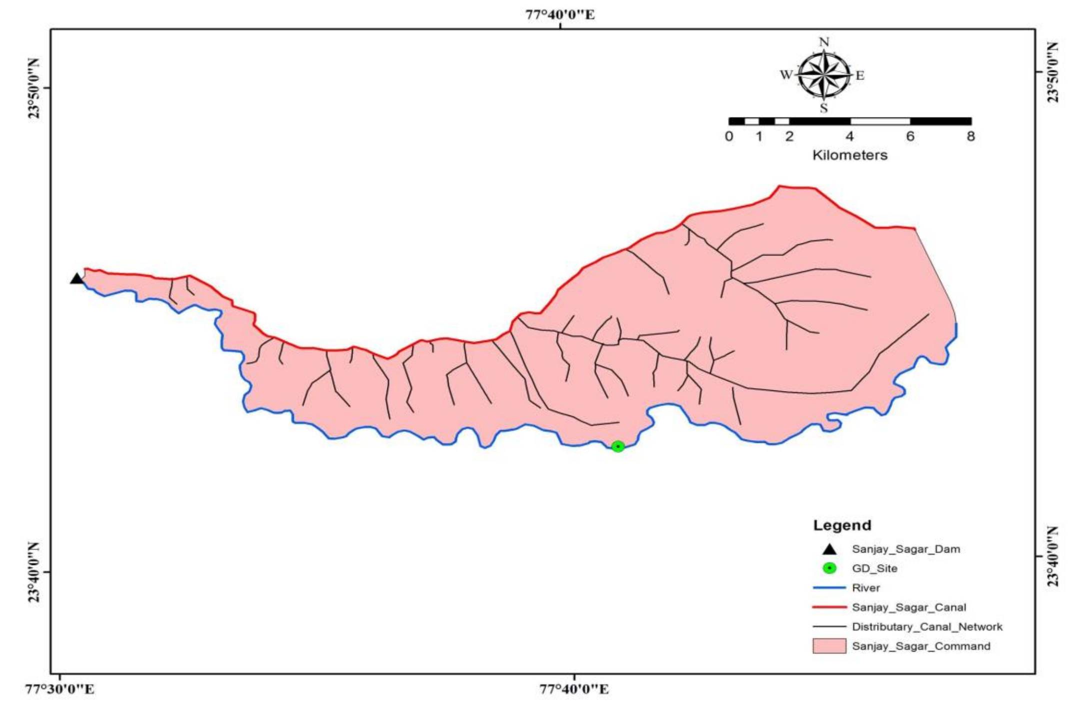


Figure 3.3 The canal network of Sanjay Sagar command

3.4.2 Water User Association (WUA)

The Command Area Development and Water Management (CAD&WM) program was started in Dec. 1974 to minimize the gap between irrigation potential created and actual irrigation achieved and optimize agriculture production and productivity through an integrated and coordinated approach by efficient water management. The Command Area Development and Water Management (CAD&WM) Programme is being implemented holistically with Irrigation Projects, especially under the Accelerated Irrigation Benefit Programme (AIBP). For the implementation of CAD&WM works in the Sanjay Sagar project, the command has been divided into four water user associations namely Khajuri Samshabad, Pipaldhar, Ravan, and Seu. The area under different water user associations in Sanjay Sagar command is presented in **Table 3.7.** and village map shown in **Figure 3.4.**

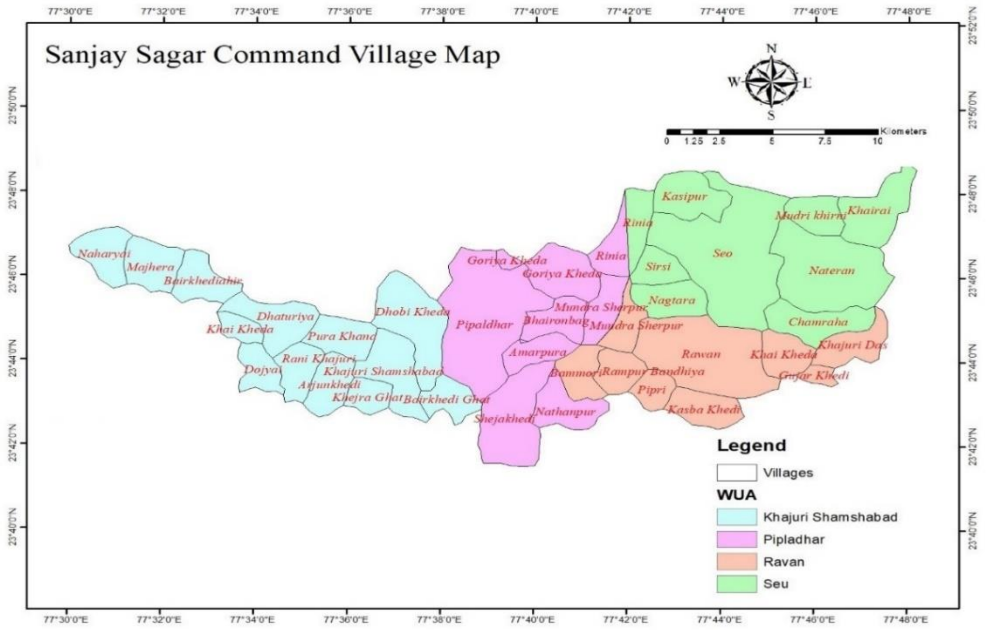


Figure 3.4 The Sanjay Sagar command village map

Table 3.7 Area under different water user associations in the Sanjay Sagar Project

S.N.	Water User Association	Command area (Ha)
1.	Khajuri Samshabad	1868
2.	Pipaldhar	2382
3.	Ravan	2766
4.	Seu	2877
5.	**Total**	**9893**

3.4.3 Barrages on Bah River

The Bah River has 6 barrages where excess water from the command is stored and used for irrigating crops by pump irrigation **(Figure 3.5)**. These barrages accumulate regenerated water obtained from the field due to irrigation. Detailed information including location, the area served, and benefitted villages are given in **Table 3.8 and Annexure-I.**

3.5 Data Collected/Used

The WRD, MP has a gauge-discharge site on river Bah downstream of Sanjay Sagar reservoir and has been operational since 1989. The daily discharge data of the Bah G/D site for the period 1989 to 2022 has been collected and used for the determination of the flow regime before (1989-2013) and after the construction of the dam (2014-2022). The releases from the reservoir and canals were used to compute the amount of water supplied for irrigation from the reservoir. The land use map of the catchment of the Bah River between the dam and gauging site was determined from Landsat data soil map from NBSSLUP, and Nagpur maps. The rainfall data of three rain gauge stations (Lateri, Nateran, and Berasia block from 1978 to 2022) were used for the application of the SCS-CN model in irrigation management. The meteorological data including the monthly average of minimum temperature, maximum temperature, average wind speed, average relative humidity, and sunshine hour of Vidisha district (M.P.) from 1991 to 2022 have been used for computation of reference crop evapotranspiration and crop water need. The crop water requirement includes evapotranspiration, application losses, and special needs. All type of data used, with the period is listed in **Table 3.9.**

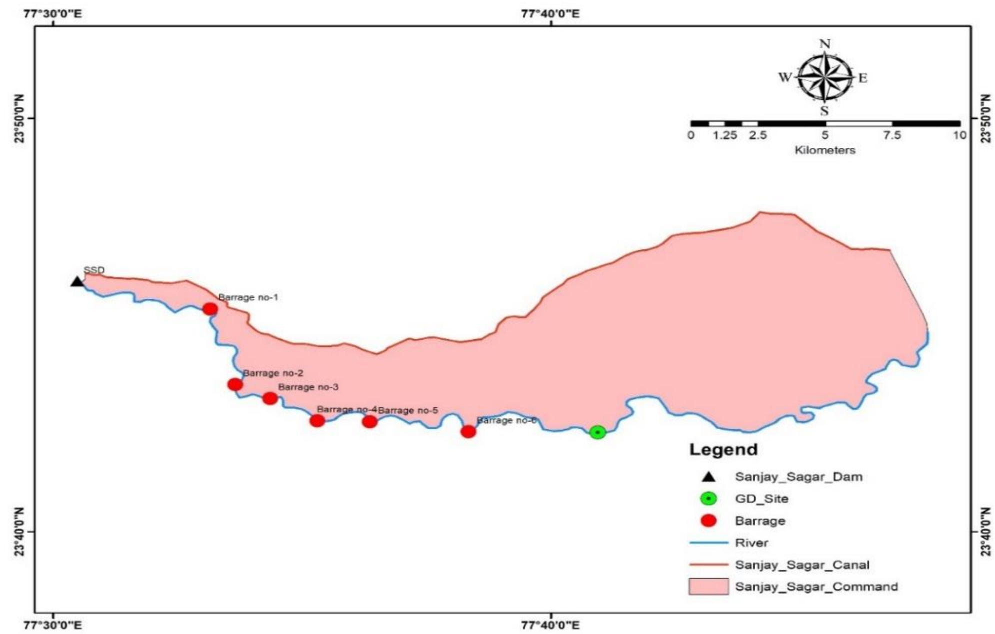


Figure 3.5 Locations of six barrages on the Bah River

Table 3.8 Information of barrages on Bah River after Sanjay Sagar dam

S. N.	Name of Barrages	Long. (E)	Lat. (N)	Length (m)	Area (ha)	Benefitted Village
Barrage no-1	Manpura	77° 32' 42"	23° 45' 22"	45.25	132	Manpura, Barkheri, Aheer

Barrage no-2	Barkhera Yakub	77° 35' 11"	23° 42' 35"	43.25	115	Barkhera Yakub, Arjun Kheri, Hingoni, Khajuri Rani
Barrage no-3	Dojayi	77° 33' 45"	23° 44' 00"	42.4	146	Dojayi, Khejara Parihar, Khaikhera
Barrage no-4	Khajurghat	77° 37' 45"	23° 42' 55"	51.45	153	Laharpur, Barkhedi Ghat
Barrage no-5	Jhanakpur	77° 34' 30"	23° 43' 00"	32.6	76	Ghanakpur, Haripur, Ghatkhedi
Barrage no-6	Babachiya	77° 36' 45"	23° 42' 15"	34.8	70	Babachiya, Khejraghat, Arjunkhedi

Table 3.9 List of collected and created GIS Data

S.N.	Description of data	Period	Source
1.	Runoff data at the Bah G/D site	1989-2022	Water Resource Deptt., Govt of M.P.
2.	Rainfall data from 3 rain gauge stations	1989-2022	Water Resource Deptt., Govt of M.P.
3.	Climate data (Max & min temperature of Vidisha)	1989-2022	Indian Meteorological Department, Govt. of India
4.	Reservoir levels, releases, elevation-capacity table, etc.	2014-2022	Water Resource Deptt., Govt of M.P.
5.	Flows in canals, crop types,	2019-2022	Measured
6.	Landsat data	2005, 2011 and 2015	USGS website
7.	Soil map	-	NBSS&LUP, India
8.	Geology map	-	CGWB, India
8.	Soil testing on 5 sites using double ring infiltrometer	-	-
9.	Water sampling for isotopic analysis	2019-2021	OB wells, hand pumps, canals, rivers, sites, rainfall
10.	Soil moisture samples	2020-2022	Soil sample collection and moisture measurement in the laboratory
11.	Soil moisture (SMAP) data	2016-2022	Online

CHAPTER 4: RESEARCH METHOD AND THEORY

The sustainable economic growth in any command cannot be fulfilled by a single factor which is the provision of an adequate and timely supply of water. It must be supplemented with new technologies of irrigation practices, quality seeds, fertilizers, training, and capacity building including exposure visits. The irrigation commands in Madhya Pradesh are suffering from huge conveyance and application losses due to poor maintenance, inequitable distribution, flood irrigation, lack of awareness, etc. In the present study, three different approaches i.e. water balance technique, isotopic analysis, and hydrological modeling were used to assess regenerated and groundwater recharge from the Sanjay Sagar command in Madhya Pradesh. For irrigation management and optimal releases from the dam in the Sanjay Sagar command, MIKE Hydro basin and Excel-based decision support were developed and integrated with web/mobile-based applications for the timely transfer of information to the farmers. For assessment of different components of return flow, detailed filed testing of soils, and isotopic composition of water in canals, rivers, wells, etc. were determined. A GIS data base was prepared and used in the analysis. Detailed field surveys, soil testing, isotopic analysis, measurement of gauge, and awareness in farmers were made under the PDS and described below:

4.1 Creation of GIS Database

Preparation of data base is an important aspect of a research study and in the present PDS, a GIS-based database consisting of drainage, digital elevation model, soil, geology, canal network, and land use/land cover maps was prepared for further analysis.

4.2 Soil Testing and Analysis

Water and soil are two important resources to produce crops. The movement of water on and beneath the earth largely depends upon the physical and chemical properties of soil. In the present study, the following in-situ and laboratory tests have been carried out for soil suitability, water balance modeling, fertilizers requirement, etc.

- Infiltration test
- Hydraulic conductivity test
- Soil water retention curve
- Particle size analysis
- Dry density

4.2.1 Infiltration test

In the present analysis, the double-ring infiltrometer has been used to determine the infiltration curve and rate of infiltration for soils on different sites. Kostiakov's and modified Kostiakov's model have been applied and parameters of these models have been computed to understand the infiltration process in the command areas.

4.2.1.1 Kostiakov's model

Kostiakov (1932) and independently Lewis (1938) proposed the following empirical infiltration equation based on curve fitting from field data.

$$f_p=K_k t^{-A} \tag{4.1}$$

Where K_k and *A* are the empirical parameters of Kostiakov's model.

4.2.1.2 Modified Kostiakov's model

The Modified Kostiakov's model can be expressed as:

$$i = Bt^{-n}+i_c \tag{4.2}$$

Where *i* is the infiltration rate at any time *t*, i_c is the asymptotic steady infiltration flux and *B* and *n* is the characterizing constants.

4.2.1.3 Horton's model

Horton described the infiltration process more implicitly and recognized that infiltration capacity (p) decreases with time until it approaches a minimum constant rate (f_c). The equation can be described by the following equation:

$$\frac{-df_p}{dt}=\beta(f_p-f_c) \tag{4.3}$$

Where β is a soil parameter that controls the rate of decrease of infiltration and depends on initial water content. Integrating the above equation, we can get

$$In(f_p-f_c)= -\beta t+C \tag{4.4}$$

To derive the value of *cons*, the limiting condition was applied. According to this condition, at $t = 0$, the $f_p = f_0$, and cons will be (f_o-f_c). Putting the value of C in the above equation, the final equation of Horton's model can be written as:

$$f_p=f_c+(f_o-f_c)e^{-\beta t} \tag{4.5}$$

Where f_p is the infiltration capacity or potential infiltration rate, f_c is the final constant infiltration rate, f_o is the infiltration capacity at t = 0; β is a soil parameter and t is the time after the start of infiltration.

4.2.1.4 Philip two-term model

The general form of the Philip infiltration model for computation of cumulative infiltration in the powers of the square-root of time (7) can be expressed as:

$$F = St^{1/2} + At + Bt^{3/2} \quad (4.6)$$

Where F is the cumulative infiltration at time t, S is the Sorptivity depends upon initial (θ_i) and final soil water content (θ_n), A and B are the constants depending on both soil properties and on θ_i, and θ_n. Philip (1957) proposed that by truncating this series solution for infiltration from a ponded surface after the first two terms, a concise infiltration rate equation could be obtained. The resulting equations for cumulative infiltration and infiltration rate (f) may be:

$$F = St^{1/2} + At \quad (4.7)$$

$$f = \frac{1}{2} St^{-1/2} + At \quad (4.8)$$

In the present analysis, integral square error (ISE), root mean square error (RMSE), and efficiency (η) have been used for the selection of the best-fit infiltration model for the site and the region. The *ISE* is a measure of system performance formed by integrating the square of the system error over a fixed interval of time; the smaller the *ISE* value closer the match. The *RMSE* is the square root of the mean-squared error. The *RMSE* ranges from 0 to infinity, with 0 corresponding to the ideal. The efficiency indicates the deviation of initial and remaining variance expressed in percentage. The formulae for the computation of ISE, RMSE, and efficiency are given below:

a) Integral Square Error (ISE):

$$ISE = \frac{[\sum_{i=1}^{n} \{I_o(t) - I_c(t)\}^2]^{0.5}}{\sum_{i=1}^{n} I_o(t)} \quad (4.9)$$

b) Root Mean Square Error (RMSE):

$$RMSE = \frac{[\sum_{i=1}^{n} \{I_o(t) - I_c(t)\}^2]^{0.5}}{n} \quad (4.10)$$

c) Efficiency

$$\eta = \frac{IV - RV}{RV} \quad (4.11)$$

$$IV = \sum_{t=1}^{n} [\, I_O(t) - \bar{I}_O]^2 \quad (4.12)$$

$$RV = \sum_{t=1}^{n} [\, I_O(t) - I_c(t)]^2 \quad (4.13)$$

Where, $I_O(t)$ and $I_c(t)$ are the observed and computed rate of infiltration or cumulative infiltration at any time *t*, *n* is the no. of observation, IV is the initial variance and RV is the remaining variance.

4.2.2 Hydraulic conductivity test

Hydraulic conductivity is the measure of the ability of the soil to transmit water and depends on the properties of both soil and water. It is defined as the volume rate of flow of water through a unit area of the soil under a unit gradient. The measurement of hydraulic conductivity is also of considerable importance for irrigation, drainage, and evaporation studies. In the project, the field-saturated hydraulic conductivity has been measured using the Guelph permeameter. The Guelph permeameter is essentially an “in- hole” Mariotte bottle constructed of concentric transparent plastic tubes. The apparatus consists of a tripod assembly, support tubes, lower air tube fittings, reservoir assembly; wellhead scale and upper air tube fittings, and auxiliary tools. The reservoir assembly provides a means of storing water and measuring the outflow rate. The Guelph permeameter method measures the steady-state liquid recharge necessary to maintain a constant depth of liquid in an uncased cylindrical well finished above the water table. The Richard analysis is the basis for the calculation of the field-saturated hydraulic conductivity.

After setting up the instrument at the desired depth of the whole, a 5 cm wellhead height is established. The rate of fall of water in the reservoir is noted. The rate of fall of water in the reservoir is noted at 2-minute intervals. The difference of readings at consecutive time intervals divided by the time interval is equal to the rate of fall of water in the reservoir. The monitoring is continued till the rate of fall does not change significantly in three successive time intervals. This steady-state rate of fall of water in the reservoir is denoted as ‘R1’ for a wellhead height of ‘H1’. Similarly, a wellhead height of 10 cm is established (‘H2’) by raising the air inlet tip to a height of 10 cm. The rate of fall of water is monitored and the steady-state rate of fall of water in the reservoir is denoted as ‘R2’ for the wellhead height of ‘H2’. The field-saturated hydraulic conductivity (K_{fs}) in cm/sec and metric flux potential (ϕ_m) in cm2/sec can be calculated using the following equation:

$$K_{fs} = X\ (0.0041R_2 - 0.0237R_1) \quad (4.14)$$

$$\phi_m = X\ (0.0572R_1 - 0.0237R_2) \quad (4.15)$$

Where X is the reservoir constant equal to 35.39 when reservoir combination and 2.14 when the only inner reservoir is used. $R1$ and $R2$ are the steady rates of fall of water in the reservoir in cm/sec for a wellhead of 5 cm and 10 cm respectively. The sorptivity (S), which is an important parameter in soil infiltration processes can also be computed if the ambient volumetric water content (θi) and field-saturated volumetric water content (θs) are known. The following equation can be used for the estimation of sorptivity in cm/sec$^{-½}$.

$$S = (2(\Delta\theta)\emptyset_m)^{1/2} \tag{4.16}$$

Where, $\Delta\theta = \theta s - \theta i$

The constant α in cm^{-1} can be computed using the following equation.

$$\alpha = \frac{K_{fs}}{\phi_m} \tag{4.17}$$

4.2.3 Soil moisture characteristic curve

The soil, plant, and atmosphere act as a continuum along which soil water moves in response to gradients in energy. The energy potential of the water relative to that of pure water helps determine the amount of water stored in the soil, moved through the soil, and moved into and through the plant to the transpiring surface of the leaf. The permanent wilting point (PWP) is defined as the largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid chamber. It is often estimated by the water content at -1500 kPa (-15 bars). The field capacity is reached when the downward drainage of water caused by gravity ceases and typically occurs 2-3 days after saturation. The soil water potential at this time is approximately -10 to -30 KPa. In the laboratory, this condition is recreated by applying a tension of -33 KPa (-1/3 bar) on the pressure plate apparatus (Henry, 1984).

4.2.4 Particle size analysis

Many of the soil properties depend on the sizes of different particles and their combination in the soil mass. The particle size analysis is carried out to determine the relative proportion of different grain sizes that make a given soil mass. There relative proportion of sand, silt, and clay determines the soil texture. Soil textures are classified by the fractions of each soil (sand, silt, and clay) separately present in a soil. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particle sizes, e.g. “sandy clay" or “silty clay." Loam is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications, e.g. “clay loam" or " silt loam". The particle size analysis is carried out by sieve analysis and sediment analysis. The soil can be classified into twelve major textural classes using the soil triangle suggested by the United States Department of Agriculture (USDA).

4.2.5 Dry density

The dry density is used in the water balance model for water resources management. The cylindrical core cutter is used for the determination of dry density (γ_d) in gm/cm^3 on the field. The soil sample collected is dried in the oven for more than 24 hours and weighed. The volume of the core cutter and the weight of dry soil are used to compute the dry density of different soils in the area.

4.2.6 Soil moisture analysis

The topsoil layer is important for crop production as well as other vegetation. Moisture in the soil has a range of indirect effects on us. The timely availability of knowledge of moisture availability in soils is an essential part of efficient planning of irrigation. The soil moisture sensors and volumetric analysis are commonly used to measure soil moisture in the field. In the present study, Soil Moisture Active Passive (SMAP) data are downloaded and compared with field-collected soil moisture. SMAP is an orbiting observatory that measures the amount of water in surface soil all over the world. SMAP measurements provide direct sensing of soil moisture in the top 5 cm of the soil column. However, L4 SMAP produce are derived from sensor input and modeling approach to determine soil moisture up to root zone depth at an interval of 7 days with a spatial resolution of 9 km. The SMAP data can be conveniently accessed through the USGS website or Google Earth Engine, etc. The soil samples at the depth of 0 cm, 30, and 60 cm were collected on the very date of passes of the SMAP satellite, analyzed for computation of gravimetric water content, and converted to volumetric moisture content using the specific gravity of soil. The soil moisture at different sites was compared with SMAP soil moisture.

4.3 Irrigation Return Flow and Influencing Factors

The irrigation return flow (IRF) can be characterized as the surplus water that is not consumed by crops through evapotranspiration, but instead drains away through direct surface drainage and eventually infiltrates the aquifer. This percentage varies widely, from around 50% for paddy cultivation employing standing water irrigation to almost 0% for the drip irrigation technique. Besides crop type, the quantity of return flow also depends on the soil, geology, slope, canal conditions, and lining in case of open flow, method of irrigation, and crop seasons (Yalcin 2019; Kim et al. 2005). The horizontal component or quick return flow of IRF consists of surface runoff, seepage from fields, and canals that move into the soil profile and contribute to river or drainage as surface and subsurface flow. On the other hand, the vertical component or delayed return flow infiltrates the soil profile and aquifer and enhances aquifer storage (Zeng and Cai 2014). For efficient management of water resources in the command, it is generally desired to reduce the return flow component for improvement of irrigation efficiencies for optimal use of water resources (Bresciani et al. 2014; Yakirevich et al. 2013; Batchelor et al. 2014; etc.). The amount of the IRF and their portioning in rejuvenated flow depends on several factors including geology, soil, method of conveyance and application, time of supply, crop type and stage, leakage from source and conveyance system, etc. The alluvial plains where soil is mainly sandy and loamy type have more groundwater recharge then rejuvenated flow. In the paddy crops where standing water remains for a long time in plain topography, most of the water reaches to groundwater table. On the other hand, in undulating topographic land, wheat, or other dry crops with clay types of soil, the rejuvenated water is more predominate than the recharge. Also, the open canal system has a higher amount of seepage loss than the piped and sprinkler system.

4.4 Assessment of Irrigation Return Flow from the command

The return flow consists of regenerated flow as a horizontal component and recharges as a vertical component of the hydrological cycle in the command. The computation of return flow is site-specific and no uniform method can be identified. Based on the literature review, three different approaches including water balance technique, isotopic analysis, and hydrological modeling method have been found suitable and applied in the Sanjay Sagar command and a detailed description of these methods has been presented in the next sections.

4.4.1 Water Balance Technique

The water balance is one of the most common approaches to understanding the contribution of different components and determining the non-measured components of the hydrological cycle. It is a major challenge in the region where measurement facilities are not available and direct measurement of all the components is not possible (Falalakis and Gemitzi, 2020). The water balance for any system that works on the principle of mass conservation can be expressed as:

$$I_t - O_t = \Delta S \qquad (4.23)$$

Where *it* and O_t are the inflows and outflows during time t and ΔS is the change in storage. The river generally has its drainage system in the command and the excess irrigation water flowing through the command can be regarded as the regenerated flow through surface and subsurface processes in the command.

Before applying water balance, a detailed system analysis of the canal as the producing body, command as the processing unit, and river as the receiving body in the continuum was made to identify different water balance components. The command of Sanjay Sagar dam lies in Vidisha district having Deccan Trap formation where lithology consists of lava flows of basalt with the red bole of intertrappean beds (CGWB, 2013) and there is an extremely limited connection of top unconfined layer with confined aquifer which is of Vindhyan formation that can be characterized as poor aquifer (**Table 4.1**).

Table 4.1 Geological formation and lithology in Vidisha district

Age	Formation		Lithology
Recent to Pleistocene	Alluvium		Clay with Kankar Sand and river alluvium
	Laterite		Small capping of lateritic on hills and patches in the river valley
Upper Cretaceous to Lower Eocene	Deccan Trap		Lava flows of basalt with red bole and intertrappean beds
Upper Pre-Cambrian to lower Paleozoic	Vindhyan System	Upper Bhander series	Lower Bhander sandstone but intercalated bands of shales known as Sanchi shale, Bhander limestone, and Ganurgarh shale

The clayey soil is found in most of the parts of the command where percolation in the deep water is minimal. The recognizance survey of command, canals, and river system in the command area and the following hydrological aspects were observed:

- A significant amount of water applied in the field reached as regenerated flow to the Bah River.
    - To capture regenerated flow, six different barrages were constructed on the Bah River and farmers on the other side of the command carry this water up to half a kilometer distance
- The geology of command comprises the Deccan trap that has limited capability to recharge through irrigation water.
    - Unconfined aquifer having a depth of 2 to 4 meters only
    - The infiltrated water contributes to the river in the form of effluent flow
    - Infiltration tests were conducted on different sites
- A point source adds water to the river just before the G/D site on the Bah River.
- The canals in Sanjay Sagar command are mostly unlined having significant seepage loss that needs to be assessed.

The comparison of cumulative loss of water in canals and gain in the river which is the receiving object was considered as the water lost by the process of evapotranspiration and base flow of groundwater through the boundary of command and hence, the water balance of the canal, command, and river was made and described here.

4.4.1.1 Water balance of the command

In the Sanjay Sagar command, the regenerated flow is the major portion of irrigation excess as the surface rejection, lateral, and excess flow from the canal and fields. All the components of the hydrological cycle in the command were studied in detail with field observation and ground truthing, then a water budget balance model for the command was developed. **Figure. 4.1** represented the physical and schematic representation of all the components in the Sanjay Sagar command system. The following water balance equations for the command have been devised.

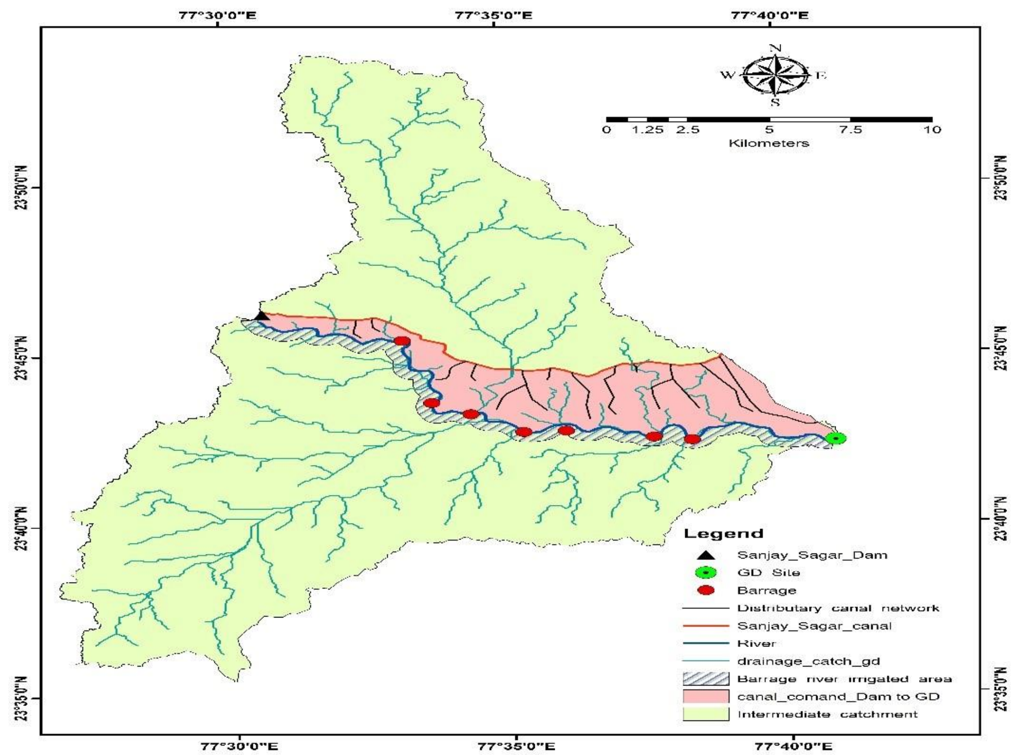
$$(Q_{sc} + Q_{seepc}) + P_{com} - Q_{etcom} - Q_{infil} = \varepsilon \quad (4.24)$$

$$(Q_{sc} + Q_{seepc}) + P_{com} - Q_{etcom} - Q_{rec} - (Q_{srcom} + Q_{efcom}) \pm \Delta S_m = \varepsilon \quad (4.25)$$

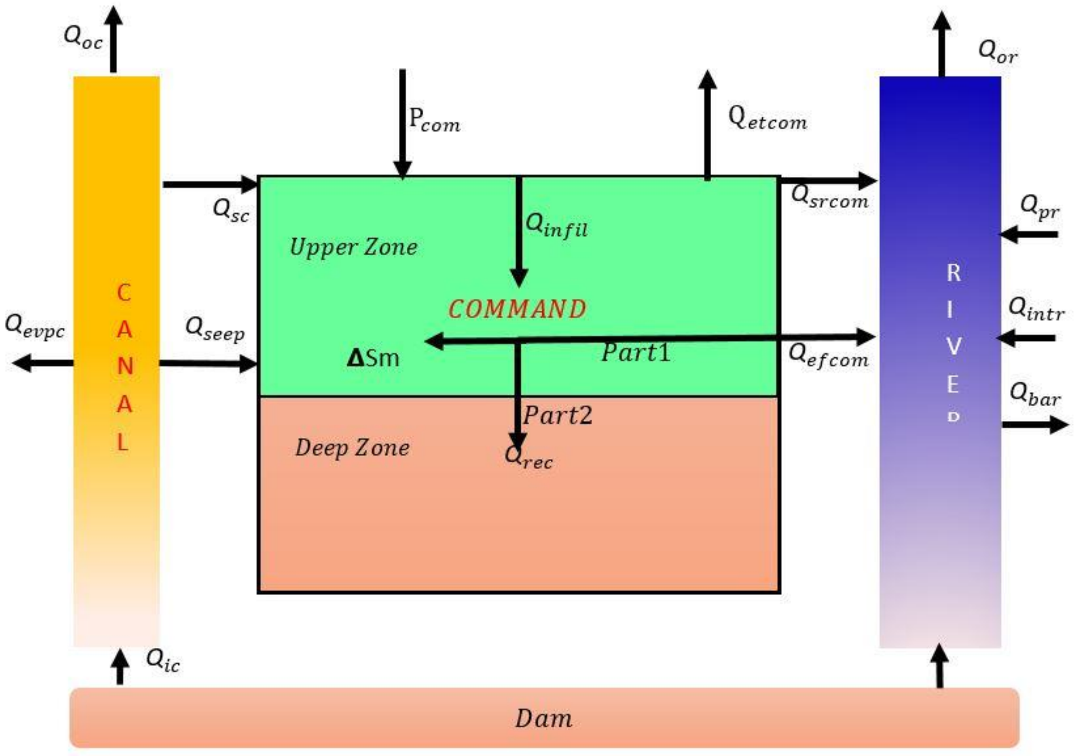
Where Q_{sc} and Q_{seepc} are the canal supply and seepage from the canal (inflow) into the command, P_{com} is the rainfall in the command, Q_{srcom} is the loss of water as surface runoff from command to river, Q_{etcom} is the loss of water through crop evapotranspiration, Q_{infil} is the infiltrated water. The infiltrated water due to irrigation and rainfall and seeped water through canals are understood to be divided into three parts namely effluent flow from command (Q_{efcom}) and recharge or return flow from command (Q_{rec}) and change of soil moisture $\pm\Delta S_m$). The ε is the error due to uncertainties and measurement errors. The water balance for determination of regenerated flows and groundwater recharge was conducted up to the Bah G/D site situated in the middle portion of the command. The measurement of different components was made through the measurement of flows, computation through models, and some empirical equations.

Crop evapotranspiration (Q_{etcom})

The evapotranspiration from the crop is the loss of water from the command and was computed using crop areas and climate data from CROPWAT 8.0 software. The water requirement for a crop may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in each period for its normal growth under field conditions at a place. The CROPWAT 8.0 uses the FAO Penman-Monteith formula (Allen et al., 1998; Bodner et al., 2007; Song et al., 2019; Xystrakis and Drainage, 2011) for the computation of evapotranspiration for the reference crop. The reference crop may be defined as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered. The following equation can be used to compute reference crop evapotranspiration.



a. Physical



b. Schematic

Figure 4.1. Physical and schematic representation of water balance in the Sanjay Sagar command

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34 u_2)}\ \pi r^2 \quad (4.26)$$

Where ET_o is the reference evapotranspiration (mm/day), Rn is the net radiation at the crop surface (MJ/sq. m/day), G is the soil heat flux density (MJ/sq. m/day), T is the mean daily air temperature at 2 m height (°C), $u2$ is the wind speed at 2 m height (m/sec), es is the saturation vapor pressure (kPa), ea is the actual vapor pressure (kPa), (es - ea) is saturation vapor pressure deficit (kPa), Δ is the slope vapor pressure curve (kPa/°C) and γ is the psychometric constant. The crop coefficients (K_c) at different periods were used to compute crop evapotranspiration for the major crop (wheat) along with very little crop (gram) in the region. The method overcomes the shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide.

Infiltration (Q_{infil}) and recharge (Q_{rec})

To determine the amount of water infiltrated due to irrigation, the infiltration tests were carried out on five sites in the command and the average constant rate of infiltration was determined. The crop area, average number of irrigation supply days, and rate of infiltration along with rainfall were used to compute the amount of water infiltrated into the ground. The recharge was computed as the friction of water supply (recharge coefficient) to command suggested as 10 to 15% for the basaltic region using the following equation:

$$Q_{rec} = RC * (Q_{infil} + Q_{seepc} + P_{com}) \quad (4.27)$$

The water that is infiltrated through irrigation, seepage from the canal, and rainfall reached to enhance groundwater in upper and lower zones and considered to be divided into three parts i.e. effluent flow from command to the river (Q_{effcom}), recharge to lower zone as recharge (Q_{rec}) and change in soil moisture (ΔS_m).

Change in soil moisture (ΔS_m)

The soil moisture change during the rabi crop period was computed as the difference in soil moisture at the time of showing and harvesting of the crop. The soil moisture active passive (SMAP) datasets were validated through soil sampling from the field and laboratory analysis.

4.4.1.2 Water balance of canal

The water released from the dam to the canal (Q_{ic}) is considered as input in the canal system, while outflow from a designated point (Q_{oc}) was measured in the field. The following water balance was made to determine the combined surface and seepage flow from contour canals to the command.

$$Q_{sc} + Q_{seepc} = Q_{ic} - Q_{oc} - Q_{evpc} \tag{4.28}$$

Where Q_{sc}, $Q_{seepc,}$ and Q_{evpc} are the supply of water from the canal to the command, seepage from the canal, and evaporation from the canal respectively.

Seepage from the canal (Q_{seepc})

The seepage from the canal was computed using the empirical equation suggested by (Swamee et al., 2001) for unconfined flow conditions where the potential difference is very large e.g. when the water table lies at a very large depth.

$$q_s = k * y_n * F_s \tag{4.29}$$

Where q_s is the seepage discharge per unit length of canal (m^2/s), k is the coefficient of permeability (m/s), y_n is the normal depth of flow in the canal (m) and F_s is the seepage function (dimensionless), which is a function of channel geometry. The seepage from canals depends on the shape of the canal and (Swamee et al., 2001) suggested the following equation to compute the seepage function (F_s) for the trapezoidal section:

$$F = \left(\left\{[\pi(4 - \pi)]^{\frac{1}{3}} + (2m)^{\frac{1}{3}}\right\}^{\frac{0.77+0.462m}{1.3+0.6m}} + \left(\frac{b}{y}\right)^{\frac{1+0.6m}{1.3+0.6m}}\right)^{\frac{(1.3+0.6m)}{(1+0.6m)}} \tag{4.30}$$

Where m is the side slope, b is the width of the channel and y is the depth of flow in the channel. The canal material, condition, and lining status can be depicted in the computation of seepage using the permeability coefficient and given for different materials in **Table 4.2.**

Table 4.2 Permeability (k) for different materials (Thanaveswar, 2009)

S. N.	Type of lining	Permeability k (m/s)
1.	Unlined canal	4.5×10^{-5}
2.	Brick lining	6.02×10^{-6}
3.	P.C.C. lining	0.331×10^{-6}
4.	P.C.C. with LDPE film	0.141×10^{-7}

Evaporation from the canal

The evaporation from the open water body of the canal was computed using the top width, length of the canal, and evaporation data as it controls water balance mainly in an arid region (Lhomme et al., 2015)

$$Q_{evpc} = \frac{K_p}{K_c} * L * W \tag{4.31}$$

Where, K_p and K_c are the pan and conversion coefficients respectively, and L and W are the lengths and top width of canals.

4.4.1.3 Water balance of the river

The river is the receiving body in the canal-command-river interaction system. A detailed survey of the river stretch was made to identify different input and output sources. Bah river in the stretch of command receives the water as surface flow (Q_{srcom}) and effluent flows (Q_{efcom}) from command due to excess irrigation, runoff from intermediate catchment (Q_{intr}), point runoff in the river (Q_{pr}) from nearby command, flow from reservoir due to leakage from spillway gates (Q_{ir}). Water is extracted by seven barrages situated on the river (Q_{bar}) for irrigation on the other side of the command, evaporation from the water surface of the river (Q_{evpr}), and outflow from the river (Q_{or}). The following equation was derived as the water balance of the river.

$$Q_{srcom} + Q_{efcom} = Q_{or} - Q_{ir} - Q_{evpr} - Q_{bar} + Q_{pr} + Q_{intr} \tag{4.32}$$

The leakage from the gates of the spillway of the dam was measured and a relationship was developed based on the reservoir level to compute the inflow (Q_{ir}) to the river system. A G/D site is available and the outflow (Q_{or}) was regularly measured. The evaporation rate and top area were used to compute evaporation from the river. The river has seven barrages in different locations between the dam and the G/D site. The farmers fetch water stored in these barrages to the fields up to half a km in length. A buffer of half km was prepared and the water requirement of crops was considered as the combined outflow (Q_{bar}) from these barrages.

Runoff from the intermediate catchment *(Q_{intr})*

Although there is very limited rainfall during the rabi season in the region, the estimation of surface runoff from the intermediate catchment was computed using the SCS-CN method. The SCS CN model (USDA, 1972) was developed by the United States Department of Agriculture - Natural Resources Conservation Service and is widely used for the computation of surface runoff (Bhadra et al., 2010; Shi and Wang, 2020). The SCS CN model is an empirical model developed with observed data based on the simple principle that the ratio of actual runoff to the maximum runoff (rainfall) is equivalent to the ratio of actual potential retention and the maximum potential retention (Satheeshkumar et al., 2017). The following formulae are used to compute surface runoff using the SCS-CN method.

$$Q = \frac{(P - I_a)^2}{P - I_a + s} \tag{4.33}$$

Where, I_a = 0.2S for antecedent moisture condition II (AMC II), Q is the surface runoff in mm, P is the rainfall in mm, I_a is the initial abstraction and, S is the surface retention can be computed by the following equation:

$$S = \frac{25400}{CN} - 254 \tag{4.34}$$

Where, *CN* is the curve number depends on soil type, land use, management practices, and antecedent moisture condition. The *CN* values as defined in the SCS technique for AMC II are used in the model and modified for antecedent moisture condition I (dry condition) or III (wet condition) in the model based on 5-day antecedent moisture.

4.4.1.4 Computation of regenerated flow and recharge

After determining all the components of water balance for command, the error was evaluated using equation (4.24) to ascertain the validity and uncertainties of the proposed model. The percent regenerated flow (R_F) at the river exit corresponding to the total loss of canal water was computed using the following equation:

$$R_F = \frac{V_g}{V_C} * 100 \tag{4.35}$$

Where Vg is the volume of flow gained between entry and exit points and V_C is the volume received in the command. The equation of R_F can be written as:

$$R_F = \frac{Q_{or} - Q_{ir} - Q_{evpr} - Q_{bar} + Q_{pr} + Q_{intr}}{Q_{ic} - Q_{oc} - Q_{evpc} + P_{com}} * 100 \tag{4.36}$$

For the computation of actual recharge from the irrigation and rainfall in the command, the water balance of groundwater in the command was made and computed using the following equation:

$$R_c = \frac{Q_{infil} + Q_{seepc} - Q_{efcom} \pm \Delta S_m}{Q_{ic} - Q_{oc} - Q_{evpc} + P_{com}} * 100 \tag{4.37}$$

The combination of regenerated and recharge can be considered as the return flow from the command due to irrigation.

4.4.2 Isotopic analysis for computation of Regenerated and Recharge

The water molecule consists of two natural isotopes of hydrogen (^{1}H and ^{2}H) and three isotopes of oxygen (^{16}O, ^{17}O, and ^{18}O). In water, ^{1}H is found in abundance at 99.985%, and ^{2}H or δD at only 0.015%. On the other hand, ^{16}O, ^{17}O, and ^{18}O are found in ratios of 99.76%, 0.04%, and 0.2%, respectively (Wenninger, 2020). Stable isotope compositions are normally reported in delta (δ) notation which can be considered as deviations relative to the standard of known composition. As the concentration of these isotopes is very less, the units of parts per thousand (denoted as ‰) are used. The equation used to describe the composition (δ) of the natural isotope of water is given below:

$$\delta = \left(\frac{R_x}{R_s} - 1\right) * 100 \tag{4.38}$$

Where R_x and R_s are the ratios of heavy and light isotopes ($^{18}O/^{16}O$ or $^{2}H/^{1}H$) in the sample and standard respectively. To determine the values of δ, Vienna SMOW (VSMOW) suggested by (Gonfiantini, 1978) was used as the standard ratio (R_s). The process of fractionization in both the elements (hydrogen and oxygen) of water remains almost similar causing a similar covariance between these isotopes during the meteoric and other phases of the water cycle. Initially, (Craig, 1961) related δD with $\delta^{18}O$ from precipitation on a global scale in a linear form and described it as the global water meteoric line (GWML). The linear relationship for global precipitation suggested by (Craig, 1961) is given below.

$$\delta D = 8\delta^{18}O + 10 \tag{4.39}$$

Rozanski et al. (1993) modified the equation given by (Craig, 1961) based on 206 global precipitation stations from the IAEA network. The equation given by (Rozanski et al., 1993) is given below:

$$\delta D = (8.17 \pm 0.06) * \delta^{18}O + (10.35 \pm 0.65) \tag{4.40}$$

These straight lines can be used as references to identify the origination and mixing of water in different sources. The deuterium excess (d) is the function of the isotopic composition of hydrogen and oxygen in water based on the equation suggested by the global precipitation model using the Raleigh approach. The following equation is used to compute deuterium excess (Bershaw, 2018) and used to identify the initial source of precipitation (Cui et al., 2009; Lide et al., 2005) and fractionation during evaporation (Froehlich et al., 2008; Pfahl and Niedermann, 2011), and recirculation in the system (Sreedevi et al., 2021).

$$d = \delta D - 8\delta^{18}O \tag{4.41}$$

Deuterium excess is responsible to represent primarily for evaporation and its decreasing value denotes an increasing vapor phase and can be used to characterize the evolution of water in the hydrological cycle (Bershaw, 2018). In the present study, water samples from different sources such as rainfall, dams, canals, rivers, public and private open wells, hand pumps, and bore wells during the irrigation and non-irrigation seasons of 2019 to 2021 were collected in 20 ml polypropylene bottles that were rinsed twice before the collection of the sample. The analysis of isotopes of water was conducted with the help of Continuous Isotopic Ratio Mass Spectrometers (CIRMS) at the Hydrological Investigation Lab of the National Institute of Hydrology, Roorkee India) using standard methodology suggested in the literature (Bajracharya, 2018; Brenninkmeijer and Morrison, 1987; Sengupta et al., 2014). The precision (based on 10 repeated measurements of each sample) of the measurement was better than ±0.1‰ for $\delta^{18}O$ and ±1‰ for δD relative to the international standard VSMOW.

4.4.2.1 End-members mixing model

The stable isotopes are added naturally to the water during precipitation which gets enriched, mixed, and fractionated during the natural movement of water due to evaporation and condensation (Gat et al., 2001; Jung et al., 2020; McGuire and McDonnell, 2007). The mixing percentage from sources in the recipient source can be computed through the two to six-end members mixing model using Ca, Na, Cl, water isotopes, and alkalinity being some of the main tracers (Barthold et al., 2011). The water in the unconfined aquifer of Sanjay Sagar's command during the rabi crop season may have a joint contribution from rainfall and canal water due to irrigation. For the identification of recharge components from the canals due to irrigation, it is assumed that the isotopic composition of waters in open wells within the command has the mixing of canal water and rainwater. If the water in the unconfined aquifer or open well has the contribution as f_{cw} and f_p from canal and rainfall respectively and $\delta^{18}O_{cw}$, $\delta^{18}O_p$ and $\delta^{18}O_{ow}$ are the concentration of oxygen isotopes in the canals, open wells, and rainfall respectively then the following mass balance of isotopes can be written.

$$f_{cw} + f_p = 1 \tag{4.42}$$

$$\delta^{18}O_{cw} * f_{cw} + \delta^{18}O_p * f_p = \delta^{18}O_{ow} \tag{4.43}$$

The following equation can be derived to compute the ratio of canal water to the rainfall in open wells as (Rc/p)ow by solving the above two equations.

$$(R_{c/p})_{ow} = \frac{\delta^{18}O_{ow} - \delta^{18}O_p}{\delta^{18}O_{cw} - \delta^{18}O_p} \tag{4.44}$$

This is indicative of the contribution of canal water into open wells or unconfined aquifers. The equation can be used for the contribution of canal water to the hand pump (confined aquifer).

$$(R_{c/p})_{hp} = \frac{\delta^{18}O_{hp} - \delta^{18}O_p}{\delta^{18}O_{cw} - \delta^{18}O_p} \tag{4.45}$$

Where, $(R_{c/p})_{hp}$ is the ratio of canal water to rainfall in the hand pump, $\delta^{18}O_{hp}$ is the concentration of oxygen isotopes in the hand pump water. Similarly, the ratio of the contribution of canal water to rainfall in river water $(R_{(c/p)})_{river}$ which indicative of regenerated flow was computed using the following equation:

$$(R_{c/p})_{river} = \frac{\delta^{18}O_{rw} - \delta^{18}O_p}{\delta^{18}O_{cw} - \delta^{18}O_p} \tag{4.46}$$

4.4.3 Assessment of return flow using SWAT model

4.4.3.1 Description of SWAT model

The United States Department of Agriculture's Agricultural Research Services (USDA - ARS) Soil and Water Research Laboratory in Grassland, Texas, developed the SWAT, or Soil and Water Assessment Tool. It is a long period, continuous-time simulation, and physically distributed parameter model. The major reason behind the development of SWAT is to speculate the response of human involvement as well as natural disasters and other practices like livestock grazing, use of fertilizers, and other harvesting methods on water, sediment, and release of chemicals because of agriculture in gauged and ungauged catchments. The model can simulate runoff processes and land management processes using the spatial distribution of soil, land use, and topography. This is done by separating basins into sub-basins and HRUs, which allows the model to operate on sub-daily/daily time steps. There may be a group of HRUs, ponds or wetlands, groundwater, climate, and a primary channel or reach that drains the basin for each sub-basin in the SWAT model. The main data inputs for the model include soil data, meteorological data, digital elevation model, and land use, and as a result, it can forecast groundwater contribution, soil erosion, sub-basin-wise runoff, base flow, nutrient status, sediment output, etc. (Santhi et al., 2006).

To evaluate the runoff volume the Soil Conservation Services (SCS) curve number technique is used in the SWAT model. The runoff of each HRU and also for sub-watersheds are routed by the river network by making use of the method of Muskingum routing or variable storage. (Neitsch et al., 2001; Neitsch & Arnold, 2005) explains the SWAT model and its application. The SWAT model has a lot of parameters for describing the spatial variability of the hydrological characteristics of the river basin, of which some parameters differ by land use, sub-basin, or soil type, whereas others can be calculated using literature, data, or field measurement. The working principle of the SWAT model is based on water balance, and the two key elements of the hydrological cycle are calculated considering the physical process in the river basin. In the first stage, the runoff, nutrients, sediment, and pesticide heaping to the major channel of each of the basins is computed, whereas the second stage focuses on routing for movement of the produced runoff, nutrient, sediment, and pesticide by the network of a channel to the basin outlet. In the

SWAT model, the various components of the hydrological cycle can be shown through the following water balance equation:

$$SW_i = SW_0 + \sum_{i=1}^{t}(P_i - SQ_i - ET_i - Wseep_i - Qgw_i) \quad (4.47)$$

Where SW_0 is soil water content (mm) on the initial day and SW_i on the t^{th} day. P_i is precipitation, SQ_i is surface runoff, ET_i is evapotranspiration, $Wseep_i$ is water entering into the vadose zone and Qgw_i is the return flow of H_2O, each in *mm* of the i^{th} day. The computed runoff at each HRU is routed to obtain the total runoff at the basin outlet. For the computation of surface runoff, the SWAT model uses the Green and Ampt method or SCS curve number method. The precipitation which is input in the model at first goes through interception and is computed through the canopy of the method of SCS curve or the user-defined leaf area index for the Green and Ampt method. There are two methods for the calculation of infiltration in the SWAT model, one is by using the Green and Ampt method, and the other is by using the remaining water after the daily runoff generation in the SCS method.

The model proposed by (Ritchie, 1972) is applied for evaporation from water and soil computation separately. There are three methods used to calculate evapotranspiration: Priestley-Taylor (Priestley & Taylor, 1972), Hargreaves (Hargreaves et al., 1985), and Penman-Monteith (Monteith, 1965). The drained water to the bottom area is divided into interflow and base flow. The kinematic storage model is used for the computation of interflow or subsurface flows in each soil layer, whereas groundwater or base flow is jumbled in the SWAT model using two aquifer systems. Within the watershed, the upper aquifer provides return flow, and the deep aquifer outside of the watershed is indicated by the underlining (Arnold et al., 1993). Only after the water level in the shallow aquifer has reached a level specified by the user is the baseflow allowed, and at that point, the baseflow is estimated by the advice of (Hooghoudt, 1940) using the study-state response of groundwater flow. The setting up of the SWAT model can be made through six different menus present in Arc SWAT GUI including SWAT project setup, Watershed Delineator, HRU Analysis, Write Input Tables, Edit SWAT Input, and SWAT Simulation. The SWAT model methodological framework for a river basin is depicted in **Figure 4.2**.

For setting up a basin model in SWAT, the digital elevation model (DEM) or user-defined sub-watersheds with drainage, soil, and land use maps are required. Based on land use, soil, and slope classes, the model divides the whole area into watersheds, sub-watersheds, and hydrological response units (HRUs). The watershed and HRU reports provide information regarding area, soil, slope, and land use classes in each sub-watershed and HRU. The write input tables menu generates the database and enables the user to write default values of different parameters in different tables and climatic parameter values in the weather generator. The Edit SWAT input menu is an important option used for changing different values, which after rewriting can be used for sensitivity, calibration, and simulation run through the SWAT Simulation menu. In the present study, SWAT models for different catchments were set up in Arcswat 10.2, and sensitivity, calibration & validation have been carried out using SWAT-CUP.

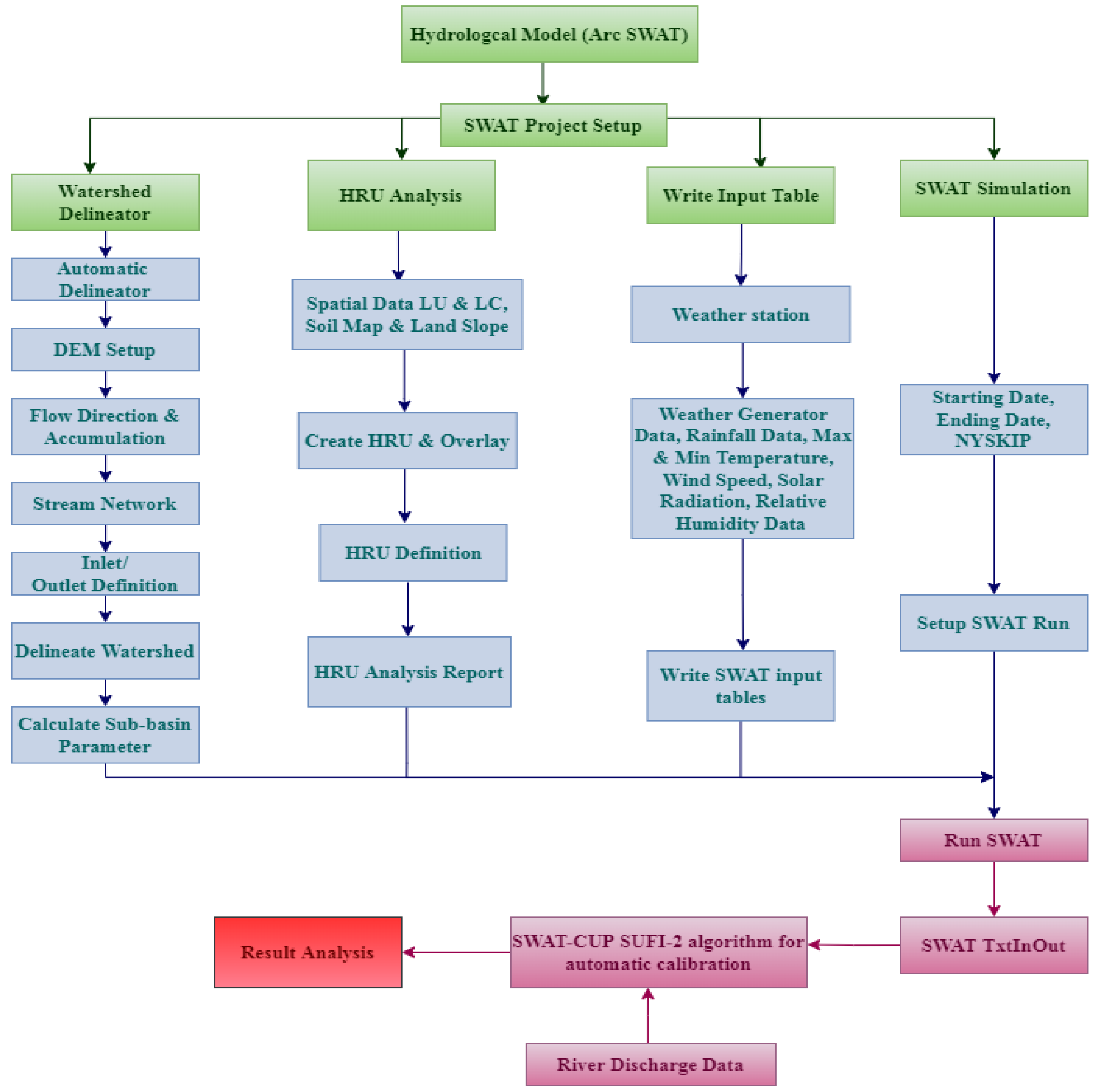


Figure 4.2. Methodological framework adopted for SWAT Model

4.4.3.2 SWAT-CUP application

The SWAT-CUP is a generic interface program for calibration, validation, uncertainty, and sensitivity analysis for the SWAT model. The SWAT-CUP interface has been developed to address the issue of uncertainties in hydrological modeling mainly due to model, input, output, and parameters. The model uncertainties may occur due to the simplification of complex hydrological processes in the model through a conceptualized mathematical equation, some processes occurring in the watershed but not incorporated in the model, while others included in the model but their occurrence are unknown to the modeler and their combinations. The input uncertainties may occur in the model due to errors of measurement and the use of point values in a distributed manner (Xue *et al.*, 2014). The SWAT model has several parameters that vary in time and space but are considered constant for a sub-basin also adds uncertainties. The uncertainties analysis helps to select a set of parameters that can produce the best possible results or contain the maximum portion of observed data using inverse modeling (Abbaspour *et al*., 1997, 2007; Duan *et al*., 2003, etc.). The graphical user interface (GUI) of the SWAT-CUP application has been presented in **Figure 4.3**.

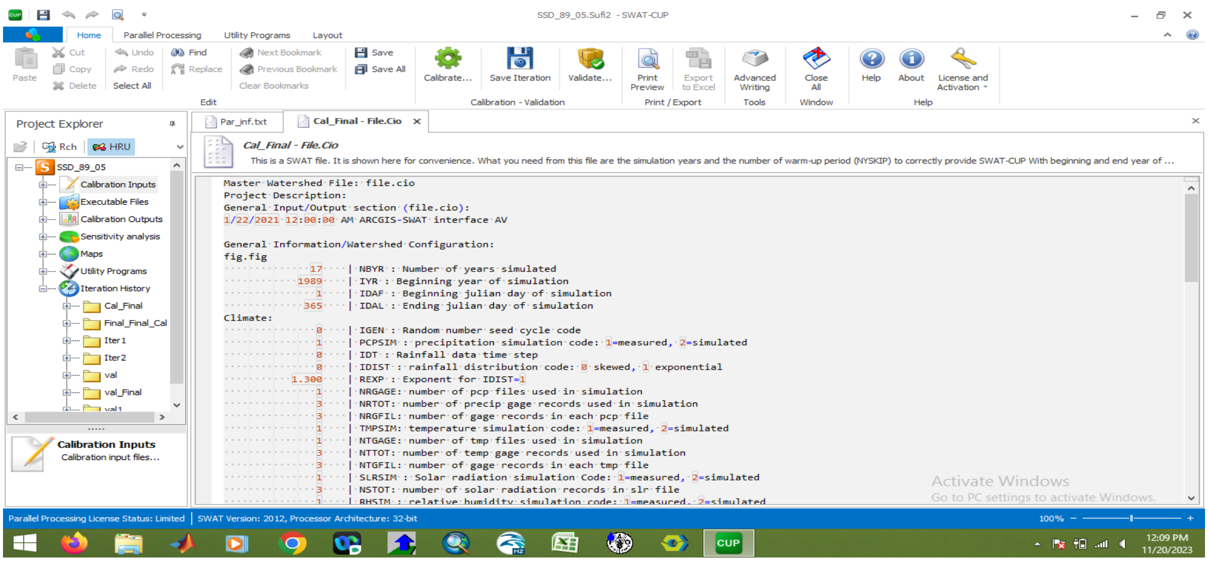


Figure 4.3 SWAT-CUP GUI for calibration, validation, and sensitivity analysis

For setting up a new SWAT-CUP project, the SWAT model of the study area should be prepared and a simulation run should be conducted in the SWAT model so that the "textInOut" directory may be created and ready for application in the SWAT-CUP application. During setting up a model in SWAT-CUP, the name of the model, the "TextInOut" directory, and the optimization method need to be mentioned. The SWAT-CUP has five optimization techniques including sequential uncertainty fitting (SUFI2), generalized likelihood uncertainty estimation (GLUE) (Beven & Binley, 1992), parameter solution (ParaSol) (van Griensven & Meixner, 2006), Markov chain Monte Carlo (MCMC) and particle swarm optimization (PSO) for calibration and any one of these need to be specified during setting up of the model. For calibration of the model, different files (Par_inf.txt, *_swEdit.def, File.io, Observation, Extraction, Objective Function, and

No Observation) available in the calibration input folder need to be modified through form or table view. A schematic of the linkage between SWAT and the five optimization programs is illustrated in **Figure 4.4.**

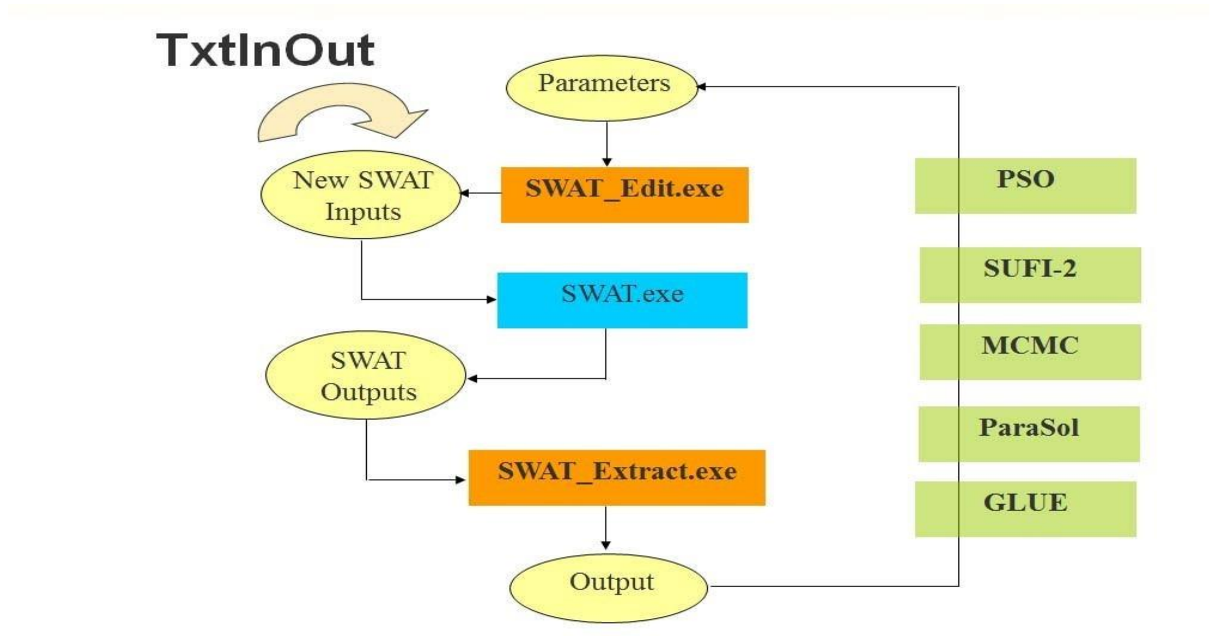


Figure 4.4 A schematic of the linkage between SWAT and five optimization programs

The Par_inf.txt file contains parameters and their range specified by the user for optimization. The *_swEdit.def file is created automatically and contains the name of the optimization technique in place of *. This file also contains the initial and final numbers of simulations. The File.Cio is the master file created automatically containing information regarding the number of years of simulation (NBYR), beginning year (IYR) and the number of years to be skipped (NYSKIP). The Absolute_SWAT_Values.txt file contains the absolute range of various parameters of the SWAT model. The Observation folder has three flies namely Observed_rch.txt, Observed_hru.txt, and Observed_sub.txt. These files can be edited to provide requisite information or data series. A folder with the name Extraction created automatically contains three text files namely Var_file_rch.txt, Var_file_hru.txt, and Var_file_sub.txt for editing and their corresponding definition file *_extract_rch.def, *_extract_rch.def and *_extract_rch.def used in calibration. In the setup of SWAT-CUP, the Objective Function folder created automatically contains editable Observed.txt and Var_file_name.txt files. The Observed.txt file contains information regarding the objective function and observed data, baseflow separation percentage of measured error, etc., whereas Var_file_name.txt contains the name of all variables used in optimization and the objective function for calibration.

Sensitivity analysis

The different processes in the SWAT model are expressed using a large number of parameters and all the parameters are not necessarily important or sensitive for a watershed/catchment. Therefore, a sensitivity analysis in SWAT-CUP can be carried out using the Latin Hypercube generated One-factor-at-a-Time (LH-OAT) technique which regressed through multiple regression systems to get *t-stat* and *p-value* for a parameter. The *t-stat* value of a parameter can be compared with student-t distribution and used to test how the mean of a sample of certain numbers is expected to behave. The *p-value* of each parameter is used to test the null hypothesis which indicates the low value (generally less than 0.05) can reject the hypothesis which finally gives the impression that the parameter is not very sensitive.

Calibration/Validation of the model

The calibration is one of the important tasks in any hydrological modeling to optimize its parameters. In the SWAT-CUP, calibration can be done with the help of a ninety-five percentage uncertainty plot (95ppu plot) and anyone among nine goodness of fit parameters including the multiplicative form of squared error (*mult*), the sum of squared error (*sum*), coefficient of determination (R^2), Chi-squared (χ^2), Nash-Sutcliffe efficiency (*NSE*), Coefficient of determination multiplied by the coefficient of the regression line (∅), the sum of squared residuals (*SSQR*), percent bias (*PBIAS*) and the ratio of the RMSE to the standard deviation of measured data (*RSR*) as per their suitability for different optimization techniques. The value of the multiplicative form of squared error (mult) can be computed by the following equation:

$$mult = \frac{\sum_{i=1}^{n_Q}(Q_{mi}-Q_{si})^2}{n_Q} * \frac{\sum_{i=1}^{n_S}(S_{mi}-S_{si})^2}{n_S} * \frac{\sum_{i=1}^{n_N}(N_{mi}-N_{si})^2}{n_N} \quad (4.48)$$

Where, Q_{mi}, Q_{si}, S_{mi}, S_{si}, N_{mi}, and N_{si} are the measured and simulated variables such as discharge, sediment, nitrate, and n_Q, n_S, and n_N are the number of observations for discharge, sediment, and nitrate respectively. This function should be minimized during optimization. The summation of the squared error (*sum*) that needs to be minimized is written by the following equation:

$$sum = W_1 \sum_{i=1}^{n_Q}(Q_{mi} - Q_{si})^2 + W_2 \sum_{i=1}^{n_S}(S_{mi} - S_{si})^2 + W_3 \sum_{i=1}^{n_N}(N_{mi} - N_{si})^2 \ldots \quad (4.49)$$

Where, W_1, W_2……. are the weight of variables. The coefficient of determination (R^2) is minimized during calibration can be computed using the following equation:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{mi}-\overline{Q_m})(Q_{Si}-\overline{Q_S})\right]^2}{\sum_{i=1}^{n}(Q_{mi}-\overline{Q_m})^2 \sum_{i=1}^{n}(Q_{si}-\overline{Q_s})^2} \quad (4.50)$$

Where, $\overline{Q_m}$ and $\overline{Q_S}$ are the average of measured and simulated variables respectively. The chi-square (χ^2) value needs to be minimized in calibration is computed using the following equation:

$$\chi^2 = \frac{\sum_{i=1}^{n}(Q_{mi}-Q_{si})^2}{\sigma_m{}^2} \tag{4.51}$$

Where, $\sigma_m{}^2$ is the variance of measured data. The Nash-Sutcliffe efficiency (*NS*) is one of the important parameters used in the calibration of hydrological modeling ranges between -∞ to 1 and can be computed using the following equation:

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_{mi}-Q_{si})^2}{\sum_{i=1}^{n}(Q_{mi}-\overline{Q_m})^2} \tag{4.52}$$

The multiplication of the coefficient of determination and coefficient of the regression line ($\emptyset$) is also an important goodness of fit criteria used in the hydrological analysis and can be expressed using the following equation:

$$\emptyset = \begin{cases} |b|R^2 \ldots\ldots..if\ |b| \le 1 \\ |b|^{-1}R^2 \ldots..if\ |b| > 1 \end{cases} \tag{4.53}$$

Where *b* is the slope of the best-fit line drawn between observed and measured variables. The sum of squared residual (*SSQR*) needs to be minimized in optimization. The *SSQR* can be represented by the following equation:

$$SSQR = \sum_{i=1}^{n}(Q_{mi} - Q_{si})^2 \tag{4.54}$$

The percentage bias (*PBIAS*) can be computed by the following equation and needs to be minimized for optimization.

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_{mi}-Q_{si})}{\sum_{i=1}^{n}Q_{mi}} * 100 \tag{4.55}$$

In the SUFI2 optimization technique, any of the above objective functions can be selected, while *SSQR* is available in the case of ParaSol optimization (Mamo & Jain, 2013). The calibration tab of the SWAT-CUP can be used for calibration of the model and the results can be seen through 95PPU plot, dotty plots, best_Par.txt, best_Sim.txt, goal.txt, summary_Stat.txt files. The full details regarding the application of SWAT-CUP can be seen in Abbaspour *et al.* (2007). The steps involved in the calibration process are given in **Figure 4.5**.

Uncertainty analysis

In SWAT modeling, the uncertainty analysis is carried out to determine the degree to which all uncertainties are accounted for and represented by *P-factor* and *R-factor* in the SWAT-CUP application. The *P-factor* is a measure to represent how well-measured data lie within the bracket of 95% prediction uncertainty (95 PPU) and varies between 0 to 100% and prediction error (100-*P-factor*) indicates the percentage of data not bracketed by 95PPU (Arnold *et al*., 2012). The *R-factor* may be defined as the ratio of the average width of the 95PPU band and the standard deviation of observed data. The *R-factor* varies from 0 to infinity and is indicative of the quality of the calibration. The *P-factor* as 100% and *R-factor* as 0 can be considered as the perfect match where simulated data exactly replicates the observed data during calibration. Generally, when the value of the *P-factor* is increased, the corresponding *R-factor* is also increased, so during calibration, a balance between these two is maintained and it is tried to get the maximum value of the *P-factor* with the minimum value of the *R-factor* and in combination indicate model calibration and uncertainty analysis.

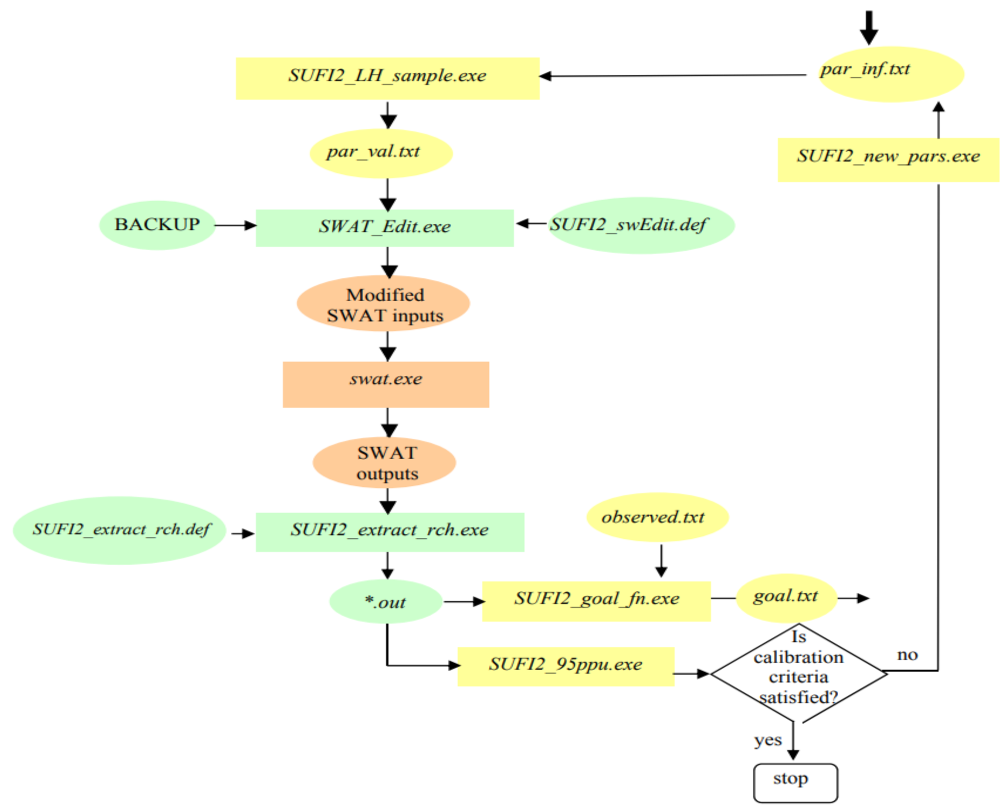


Figure 4.5 The steps involved in the calibration process in SWAT-CUP

4.4.3.3 Application of SWAT model for assessment of return flow

The SWAT model is a complete suite of a modeling approach for the computation of runoff, sediment, hydrological components, chemical transport, reservoir operation, irrigation application, return flow, water quality modeling, point & non-point pollution, and impact assessment analysis (Arnold et al., 1999, 1998; Bingner, 1996; Emam et al., 2017; Farhan and

Thamiry, 2022; Gassman et al., 2007; Ghaffari et al., 2010; Himanshu et al., 2017; Labrière et al., 2015; Pandey et al., 2017; Peterson and Hamlett, 1998; Qiao et al., 2013; Saleh et al., 2000; Santhi et al., 2006; Schuol et al., 2008; Singh and Saravanan, 2022, 2020; Srinivasan et al., 2010; Swain et al., 2022; Tran et al., 2014; Veith et al., 2010). The following steps were used for the computation of recharge and regenerated flow from Sanjay Sagar's command.

Step 1: Setting up of SWAT model for virgin Flow

The SWAT model was first developed for virgin flow before the operation of the Sanjay Sagar dam in the year 2014. The land use map of 2005, DEM, and soil map from NBSSLUP, Nagpur were used to derive basins, sub-basins, and HRUs. Look-up tables of soil map and land use were prepared and uploaded for reclassification as it was needed for SWAT according to its coding convention. The recommendation of (Cherie, 2013) was followed for land cover, soil, and topography. Accordingly, for each land use, soil and slope minimum threshold levels were set as 10%, for improved estimation of stream flow of Bah River sub-basin. The developed SWAT model was calibrated for the period from 1991 to 2005 and validated from 2006 to 2013 using the SUFI2 optimization technique in SWAT CUP for virgin flow.

Step 2: Virgin flow simulation for the period of 2014 to 2022

After calibration and validation of the SWAT model, the model was run from 2014 to 2022 to compute the virgin flow from the catchment without adding a reservoir.

Step 3: Simulation with dam and command for the period of 2014 to 2022

In the last step, a reservoir is added to the model, and characteristics of the reservoir and water were withdrawn from the reservoir to the command with the application for wheat as the major crop in the command was assigned to the selected sub-basins. In the assessment of return flow after adding the reservoir, reservoir characteristics, and irrigation schedule from the SWAT model setup, the first step was to define the watershed boundaries. The flow chart for the computation of regenerated and recharge flow using the SWAT modeling approach is presented in **Figure 4.6.** To minimize the uncertainty of the model related to input data watershed is delineated and further subdivided into 23 sub-basins based on the default threshold area for defining the accumulation and flow direction as it is enough for visualization of the significant streams. A reservoir was added at the location of Sanjay Sagar dam and all necessary reservoir data were given to the model as shown in **Tables 4.3 & 4.4**. Once the reservoir data was added the next step was to upload the ground water parameters (after final calibration) from the sub-basin data.

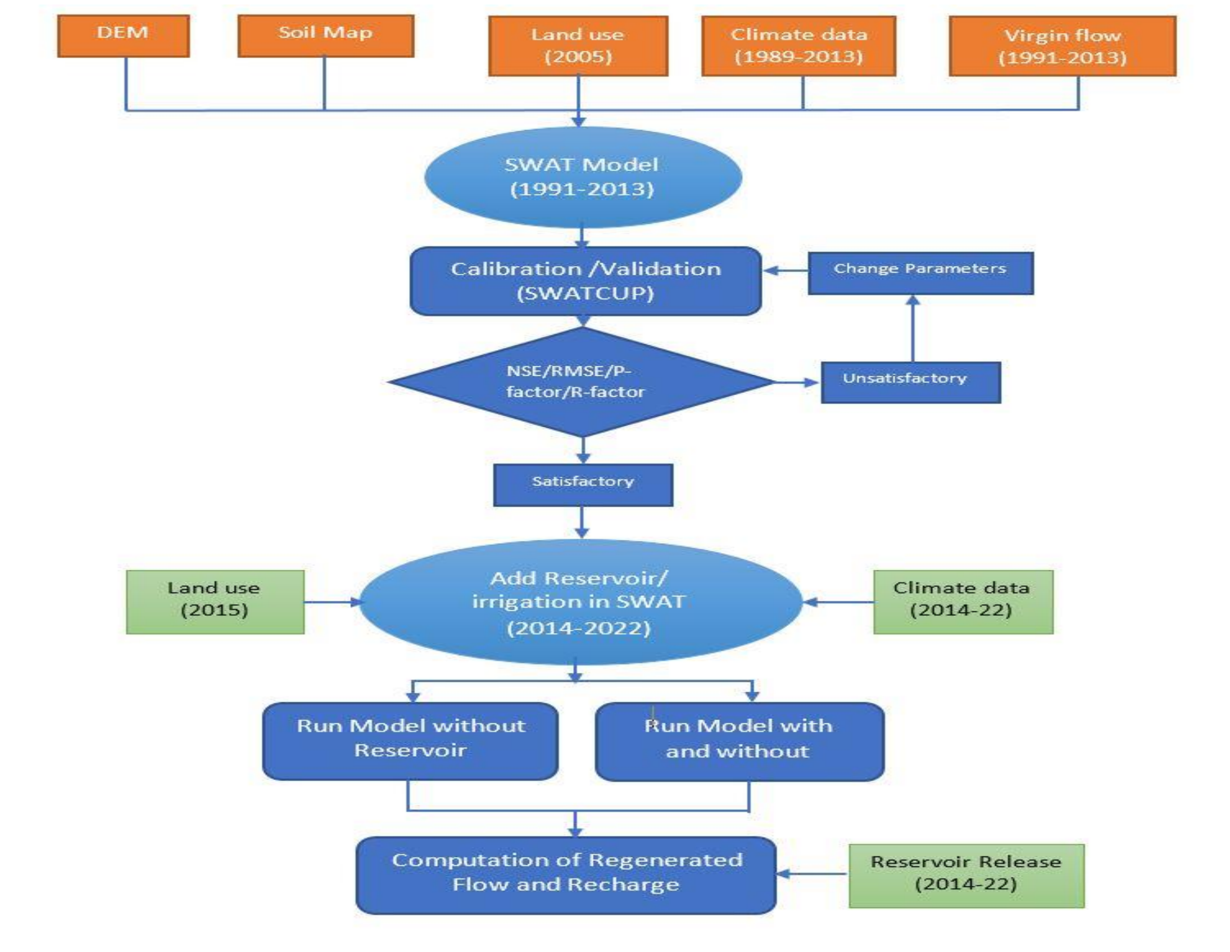


Figure 4.6 Workflow for computation of regenerated flow and recharge using the SWAT model

Table 4.3 Reservoir data of Sanjay Sagar Dam

Variable	Definition	Value
IYRES	Year of the simulation the reservoir became operational.	15 June 2015
RES_ESA	Reservoir surface area when the reservoir is filled to the emergency spillway (ha)	2188.454
RES_EVOL	The volume of water needed to fill the reservoir to the emergency spillway (10^4 m^3)	8640
RES_PSA	Reservoir surface area when the reservoir is filled to the principal spillway(ha)	2188.454
RES_PVOL	Volume of water needed to fill the reservoir to the principal spillway (10^4 m^3).	8640
RES_VOL	Initial reservoir volume (10^4 m^3)	988
IRESCO	Simulated controlled outflow target release	IRESCO=2
IFLODR1R	Beginning month of non-flood season.	November
IFLOD2R	Ending month of non-flood season.	June
NDTARGR	Number of days to reach target storage from current reservoir storage.	50

Table 4.4 Monthly target reservoir storage

Month	Storage (10^4 m^3)
January	3500
February	1500
March	1000
April	900
May	800
June	1500
July	4000
August	7000
September	8000
October	8640
November	8640
December	6000

Overlaying the soil map, land use and slope percentage have been divided into 147 HRU. After that weather parameters were uploaded, and then from the 'Edit SWAT Input' section, reservoir data and sub-basin data were added. Then in the management file, the sub-basin data that comes under the irrigation are added. The SWAT model setup is shown in **Figure 4.7.** In this section two dataset are required: (i) General Parameters and (ii) Operation. General parameters include initial land cover, curve number, reservoir location, etc. the input parameter shown in **Table 4.5**. In the operation method, the irrigation operation method was adopted the input parameters are shown in **Table 4.6**. For irrigation operation, define the management operation number MGT_OP=2 from the operation file. This operation method is extended to all sub-basins HRU which comes under irrigation. All the given information is rewritten in the SWAT input file. Finally, the SWAT model was simulated from 2014 to 2022 with reservoir, command, and supply of water from the reservoir to the specific sub-basins. The flow at the Bah G/D site with and without reservoir and groundwater recharge in the irrigated sub-basin was used to compute regenerated flow and recharge. The following equations were used to compute regenerated flow and recharge using simulated flow from the SWAT model.

$$R_F = \frac{Q_{sim_{wi}} - Q_{sim_{woi}}}{Q_{supp_{net}}} * 100 \quad (4.56)$$

$$R_c = \frac{R_{sim_{wi}} - R_{sim_{woi}}}{Q_{supp_{net}}} * 100 \quad (4.57)$$

$$Q_{supp_{net}} = Q_{ic} - Q_{oc} - Q_{evpc} + P_{com} \quad (4.58)$$

Where, $Q_{sim_{wi}}$ and $Q_{sim_{woi}}$ are runoff with and without irrigation and dam from 2014 to 2022, $R_{sim_{wi}}$ and $R_{sim_{woi}}$ are recharge from irrigation sub-basins, and $Q_{supp_{net}}$ are the net supply from the canal to the command.

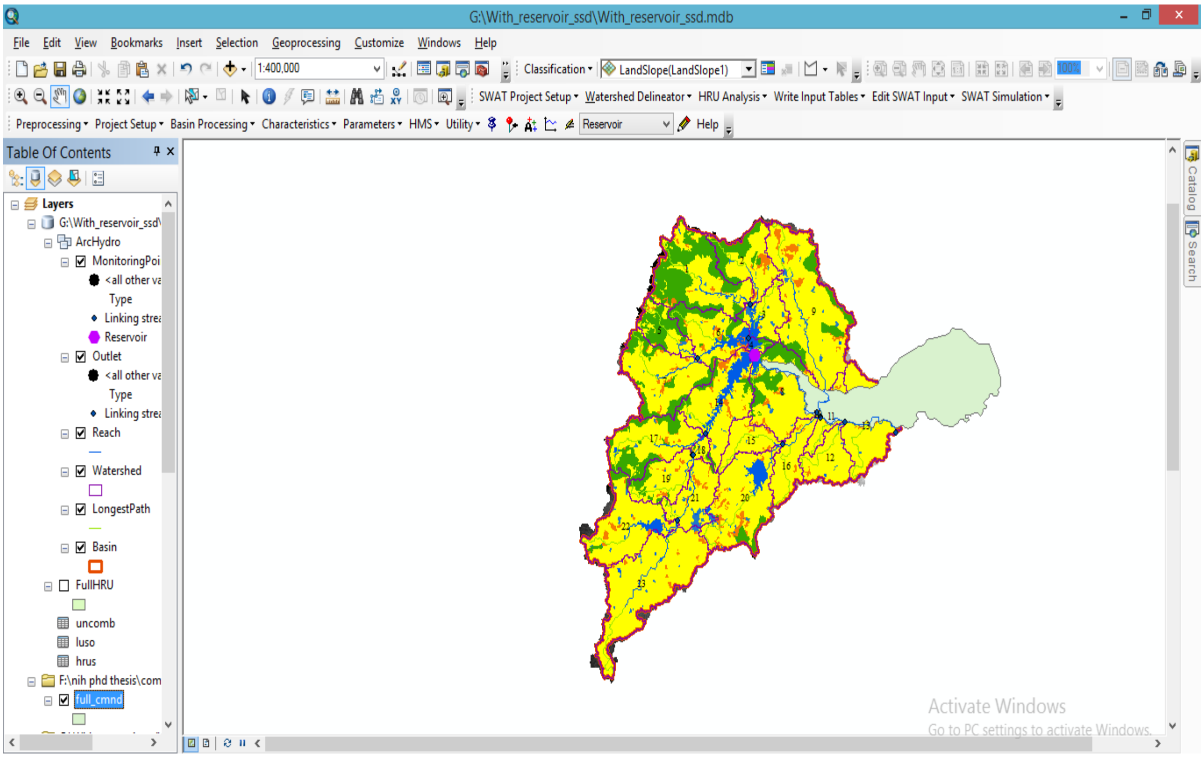


Figure 4.7 SWAT model setup with reservoir

Table 4.5 General Parameter of sub-basin

Variable Name	Definition	Value
Initial Land Cover	Initial Land Cover	Wheat
LAI_INT	Leaf Area Index	4
PHU_PLT	Potential Heat Unit	0.5
BIOMIX	Biological Mixing Efficiency	0.2
CN2	SCS runoff curve number for AMCII	85
USLE-P	Soil loss according to slope	0.60
IRRIGATION SOURCE	Irrigation source	Reservoir (1)

Table 4.6 Irrigation operation detail

Variable name	Definition	Value
MONTH	Month operation takes place.	November
DAY	Day operation takes place	15
IRR_AMT	Depth of irrigation water applied on HRU (mm)	100

IRR_EFM	Irrigation efficiency	.50
IRR_SQ	Surface runoff ratio	0.30
IRR_SC	Irrigation code	2=reservoir
IRR_NO	Irrigation source location	2

4.5 Decision Support Systems for Irrigation Planning

A decision support system is "a computer information system that supports decision-making activities." It is designed to access databases and use analytical decision models to provide information that supports effective decision-making. A river management DSS is designed to evaluate the hydrological, economic, environmental, and policy impacts of different development andmanagement options. More advanced river DSSs can provide planning frameworks with real-time system operations and controls (Labadie, 2006).

Developing water allocation plans for different classes of basins/catchments follow different approaches (Dinar et al.1997 & Speed et al. 2013). Hydrological and operational modeling and system yield and optimization models for the water resource systems are key assessments and analyses for developing an allocation plan.These analyses are functions of river management DSS of which several modeling tools can be used to guide decisions made on water allocation. The common approach to water allocation problems has been nodal network approaches where a river catchment is represented ina model as a series of nodes. Each node represents a point where extractions and other activities impacting stream flow are combined (Letcher et al. 2004). These water allocation models are useful in considering the impacts and possible mitigation actions of differentallocation scenarios within the modeled catchment.

Different models have been developed over time to enable the development and simulation of water allocation and are classified as either simulation or optimization models based on the techniques of modeling that are used. Simulation models depict the behavior of water resources according torules dictating the water allocations and operations. Simulation models are useful where support is required on decisions related to water quantity, water quality, and the economic and social implications of alternative allocation scenarios. Optimization models evaluate the best available solutions to allocation targets based on outlined objectives and constraints. These models calculate flows and perform mass balance using a simulation component (Loucks et al.2005) and some of them are being described here.

RiverWare

RiverWare modeling tool was designed for rivers and reservoirs developed by CADSWES at the University of Colorado Boulder. It models hydrologic aspects of rivers, reservoirs, groundwater (interactions with surface water and conjunctive use), water quality, and water rights. As a result, it can be used to inform aspects such as planning, forecasting, and scheduling operations as well as policy evaluation. RiverWare provides three types of solvers within the program: rule-based simulation, pure simulation, and optimization (RiverWare, 2015).

Aquarius

Aquarius is a software application developed by the U.S. Forest Service and Colorado State University. It models the allocation of water fluxes both temporally and spatially among competing water uses in a river catchment (Diaz et al. 2000). The program uses a nonlinear optimization to determine economically efficient water allocation i.e., stream flow is reallocated until there is equilibrium in net marginal return for all water uses (Diaz et al. 2000). The software considers various water uses i.e.: municipal and industrial, agricultural, habitat protection, storage, flood control area and recreational.

MODSIM

MODSIM was developed at Colorado State University in 1978. This DSS allocates limited waterresources by analyzing water resource elements and then performing optimization using a minimum cost optimization solver that uses the network costs as constraints. To achieve credible results, users need to understand the DSS's structure (Johnson, 2014). MODSIM can be linked to MODFLOW and QUAL2E for the analysis of conjunctive use of groundwater and surface water and analyzing the effectiveness of pollution control measures respectively (Sechi & Sulis, 2010).

RIBASIM

This model is a generic package developed by Deltares. The model is designed to analyze the behavior of river catchments under different conditions by linking hydrological inputs with specific water uses at different locations in the catchment system (Deltares, 2019). RIBASIM features include the ability for users to define operating and planning scenarios characterized by either operating rules or water supply projections with a GIS-based graphical interface enabling the creation of user-defined objectives to allow for comparison of scenarios. A drawback of the model is the data requirements as it requires extensive and significant data to perform analysis (Sechi & Sulis, 2010).

WEAP

Water Evaluation and Planning System (WEAP) is a generic computer software used for catchment surface water planning developed by the SEI. The software operations are guided by water demand and the environmental flow requirements in a catchment. The model uses the constraints of supply preferences and demand priorities. These constraints are used to determine water allocation and provide analysis through a scenario-based approach (Yates et al. 2005a, b). Detailed documentation is available online at the SEI website (http://www.weap21.org).

MIKE HYDRO Basin

MIKE HYDRO Basin is a GIS-based DSS tool for the analysis, management, and planning of river basins developed by DHI (2019). The model provides temporal and spatial simulation and visualization making it suitable for analysis of water sharing issues at different scales.

In this present study, the MIKE HYDRO basin has been used for irrigation planning and management scenarios considering its integration with the MIKE 11 NAM model for rainfall-runoff modeling. The DSS(PM) is being developed under the National Hydrology Project and is based on the MIKE HYDRO Basin, so the developed management model can be incorporated into this DSS. Before applying the MIKE HYDRO Basin, the MIKE model calibration and validation were necessary. The description of the MIKE 11 NAM model is given below.

4.5.1 MIKE-11 NAM model

The MIKE11 NAM is a professional hydrological tool that was developed for water resource planning and management applications. The MIKE11 NAM was developed by the Danish Hydraulic Institute, Denmark. Mike 11 modeling system includes a module that simulates rainfall-runoff processes at the catchment scale called NAM. The inputs of one or more contributing catchments can be used to simulate the dynamics of a river network either independently or as part of a larger simulation of the whole system. This approach enables it to predict the extent and flow of rivers and waterways in a single catchment as well as a large drainage basin of rivers and streams containing a mix of catchments within a complex network of rivers and channels.

NAM is an abbreviation of “Nedbor-Afstromnings-model” and is a lumped, conceptual, and deterministic model to understand hydrological processes in the catchment. The catchment is considered a single unit since it is a lumped model. However, even though the model parameters and variables are averaged across the entire catchment, the module can estimate parameter values by calibrating them against hydrological observations over time. During runoff estimation, this module addresses four different types of interrelated storage that represent different physical characteristics of a catchment. NAM replicates the land phase of the hydrological cycle including manmade interventions such as irrigation and groundwater pumping, in addition to the four basic storage namely Surface storage, Lower or root zone storage, Groundwater storage, and Snow storage. NAM continuously accounts for water content in mutually interrelated storage representing the overland flow, interflow, and base flow. In the present study, snowmelt storage is not considered because the temperature in the study area has never fallen below freezing point**.** The structure of the NAM model for rainfall-runoff simulation is shown in **Figure 4.8.**

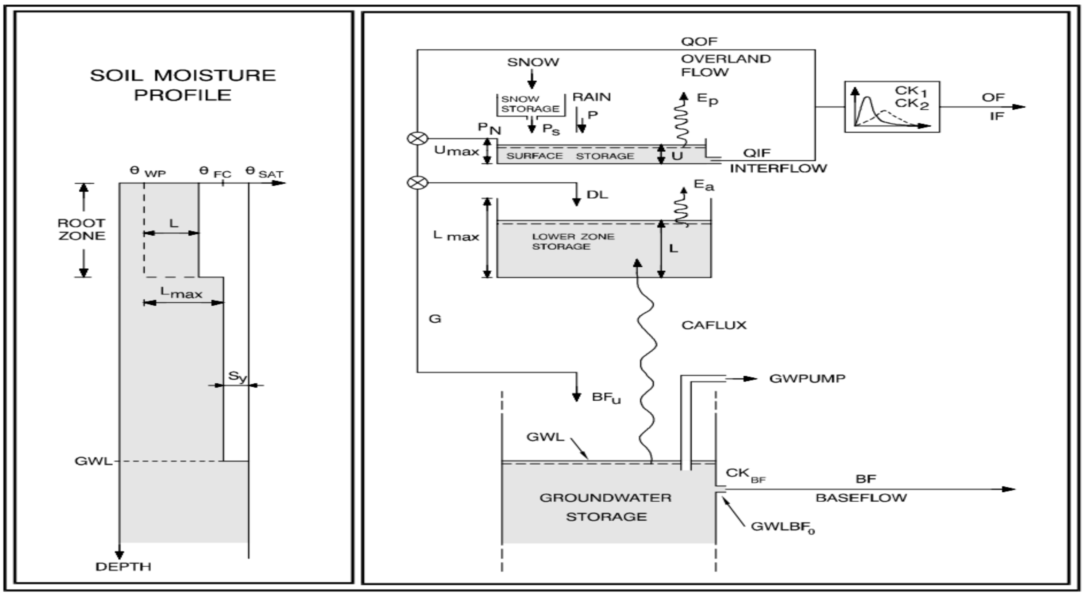


Figure 4.8 The structure of the NAM model for rainfall-runoff simulation (Reproduced from MIKE Manual)

4.5.1.1 Data requirement

The following input data are required for the MIKE11 NAM model

a. Meteorological and hydrological data
b. Model parameter
c. Initial conditions

Based on the above inserted data model generates the time series of catchment runoff, subsurface flow contribution, and information related to other components of the hydrological cycle such as groundwater recharge, soil moisture content, etc. The results depend on the quality and consistency of the input data, and proper modeling procedures. Thus, it is required to input well-arranged and processed data for more accurate results.

4.5.1.2 Model parameter

The hydrological processes in the basin are defined in MIKE 11 NAM model through nine different parameters i.e. maximum water content in surface storage (U_{max}), the maximum water content in the lower zone/root storage (L_{max}), overland flow coefficient (*CQOF*), interflow drainage constant (*CKIF*), time constant for overland flow and interflow (CK_{12}), Threshold for overland flow (*TOF*), Threshold for interflow (*TIF*), threshold for groundwater recharge (*TG*), and Time constant for base flow (*CKBF*) which are divided into four groups: Surface storage, rootzone storage, Groundwater, and snow storage. However, in this study snow storage was not considered because in the study area, the temperature has not fallen below the freezing temperature. The description of model parameters and their effects are represented in **Table 4.7**.

Table 4.7 Description of model parameters and their effects

Parameter	Unit	Description	Effects	Common Range
U_{max}	mm	Maximum water content in surface storage	overland flow, infiltration, evapotranspiration, interflow	5-35
L_{max}	mm	maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, base flow	50-400
CQOF	-	Overland flow coefficient	Volume of overland flow and infiltration	0.0-0.1
CKIF	mm	Interflow drainage coefficient	Drainage of surface storage interflow	200-2000
TOF	-	Threshold for overland flow	Soil moisture demand that must be satisfied for overland flow to occur	0-0.9
TIF	-	Threshold for Interflow	Soil moisture demand that must be satisfied for interflow to occur	0-0.9
TG	-	Threshold for groundwater recharge	Soil moisture demand that must be satisfied for groundwater recharge to occur	0-0.9
CK_{12}	hrs	Time constant for overland flow and interflow	Routing overland flow along catchment slopes and channels	3-72
CKBF	hrs	Time constant for base flow	Routing recharge through linear groundwater recharge	500-5000

Water content in surface storage (*U* and U_{max})

Surface storage includes the total quantity of water stored in intercepting storage (i.e., on plants and depressions) and in the top soil layers. The maximum water content in surface storage (U_{max}) denotes the total water content of the interception storage (on vegetation), surface depression storage, and storage per area in the uppermost (a few cm) layers of the soil. Evaporative losses and interflow are continuously causing depletion in the quantity of surface water storage (*U*). When the surface storage reaches its maximum capacity, part of the surplus water (P_N), flows as overland flow into streams, and the remaining water enters the rootzone and groundwater storage. Typical values range from 10 to 20 mm.

Water content in root or lower zone storage (*L* and *L_{max}*)

Root zone storage is the moisture available below the land surface. The L_{max} represents the upper limit of moisture in this storage ranges from 50 to 300 mm. Plants can extract this water through roots to fulfill transpiration losses. The groundwater recharge and interflow will depend on the availability of water in rootzone storage. In the NAM model, the evapotranspiration demands of the basin are first met by surface storage, and when the requirement exceeds a water content in surface storage ($U< E_p$), the remaining fraction of the requirement is assumed to be accomplished from the rootzone storage. The actual evapotranspiration (E_a) is proportional to the potential evapotranspiration and varies linearly with the relative soil moisture content (L/L_{max}) of the lower zone storage.

$$E_a = \left(E_p - U\right)\frac{L}{L_{max}} \quad (4.59)$$

The lower zone storage is the water present in the root zone. After dividing the net rainfall between groundwater infiltration and overland flow, the remaining part of the rainfall increases the moisture content L in the lower zone storage by the amount ΔL can be represented by the following equation:

$$\Delta L = P_N - Q_{OF} - G \quad (4.60)$$

Overland flow coefficient (*CQOF*)

This parameter specifies how surplus rainfall is distributed between overland-flow by infiltration. When the upper soil surface gets saturated i.e. $U>U_{max}$, the excess water P_N leads to overland flow and infiltration. The C*QOF* denotes the fraction of P_N that contributes to overland flow ranges from 0 to 1. The P_N is assumed to vary linearly with the relative soil moisture content, L/L_{max}, of the root zone storage.

$$QOF = \begin{cases} CQOF\,\frac{L/L_{max} - T_{OF}}{1 - T_{OF}} P_N & for\ L/L_{max} > TOF \\ 0 & for\ L/L_{max} \le TOF \end{cases} \quad (4.61)$$

Where; $CQOF$ is the overland flow runoff coefficient and TOF is the threshold value for overland flow.

Interflow coefficient (*CQIF*)

The interflow contribution can be represented by a coefficient (*CQIF*) that is assumed to be directly proportional to U and to vary linearly with the relative moisture content of the root zone storage.

$$CQIF = \begin{cases} (CKIF)^{-1} \frac{L/L_{max} - TIF}{1-TIF} \, U & for \; L/L_{max} > TIF \\ 0 & for \; L/L_{max} \leq TIF \end{cases} \quad (4.62)$$

Where; $CKIF$ is the time constant for interflow and TIF is the root zone threshold value for interflow and ranges from 0 to 1.

Root zone threshold value for interflow (*TIF*)

The root zone threshold value for interflow (*TIF*) controls the relative moisture content in the root zone (L/Lmax) above which interflow occurs in the model.

The time constant for overland flow and interflow (*CK₁₂*)

A linear reservoir concept is used to route the interflow through two linear reservoirs in series with the constant CK_{12}. The overland flow is structurally similar but with a variable time constant.

$$CK = \begin{cases} CK12 & for \; OF < OF_{min} \\ CK12 \left(\frac{OF}{OF_{min}}\right)^{-b} & for \; OF \geq OF_{min} \end{cases} \quad (4.63)$$

Where, OF is the overland flow (mm/hour), and OF_{min} is the upper limit for linear routing. In practice, $OF_{min}$is taken as 0.4 mm/hour. For overland flow, *b*=0.4 corresponds to using the manning formula to model the flow. The above equation ensures that the surface flow will be routed kinematically. While subsurface flow is treated as overland flow and routed as a linear reservoir. The value ranges from 3 to 48 hours.

Threshold for overland flow (*TOF*)

The root zone threshold value for overland flow (*TOF*) determines the relative moisture content in the root zone (L/Lmax) above which overland flow occurs. The predominant impact of T_{OF} is obvious during the onset of a wet season when increasing the parameter value delays the commencement of runoff as overland flow. The threshold values fluctuate from 0 to 0.7 % of Lmax and range between 0 and 0.99.

The time constant for base flow (*CKBF*)

The base flow (*BF*) from the groundwater storage is calculated as the outflow from a linear reservoir with a time constant (*CKBF*) which determines baseflow and groundwater recharge. Groundwater recharge of any area depends on the relative value of the root zone's moisture content.

$$G = \begin{cases} (P_N - Q_{OF})\frac{L/L_{max} - TG}{1-TG} & for\ L/L_{max} > TG \\ 0 & for\ L/L_{max} \leq TG \end{cases} \quad (4.64)$$

Where TG is the root zone threshold value for groundwater recharge.

Root zone threshold value for groundwater recharge (*TG*)

The root zone threshold value for groundwater recharge (*TG*) establishes the relative moisture content in the root zone (L/L_{max}) over which groundwater recharge occurs. The major effect of increased TG is that groundwater storage receives less recharging. Its value ranges from 0 to 0.7 percent of L_{max}, with a maximum value of 0.99 permitted.

Initial conditions

Initial conditions refer to the state of the basin at the start of a storm event. The MIKE11-NAM model requires an initial set of conditions including surface, root zone, and interflow data, as well as base flow and overland flow initial conditions. At the end of a dry period, it is often sufficient to set all initial values to zero, except the moisture content in the root zone and the base flow. Ideally, the root zone should contain moisture between 10% and 30% of the capacity, with a base flow value close to the observed discharge.

4.5.1.3 Data requirement

Rainfall

Three rain gauge stations situated in the catchment of Bah River Basin namely Lateri, Berasia, and Nateran were used in the development of rainfall-runoff modeling. The daily rainfall data at these stations was collected for the period of thirty-four years i.e. from 1989 to 2022 from the Water Resource Department, Madhya Pradesh. The Thiessen polygon method was used to calculate a weighted average of precipitation in the catchment with the help of Arc Map 10.2 software.

Potential Evapotranspiration

Potential evapotranspiration (ET_0) is one of the most essential inputs to setup the MIKE 11 NAM model because of its large impact on runoff in the form of losses from the surface. Daily potential evapotranspiration data for the period of 1989-2022 was used to setup the model. Numerous scientists around the world have developed a large number of more empirical methods for estimating evapotranspiration from various climatic variables. The Penman Montieth equation was used to compute evapotranspiration because of its suitability and recommended by the FAO.

The ET_0 calculator developed by the FAO was used to calculate the daily evapotranspiration using daily maximum temperature and minimum temperature as inputs.

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (4.65)$$

Where ET_0 is the reference evapotranspiration (mm/day), R_n is the net radiation at the crop surface (MJ/ m^2-day), G is the soil heat flux density (MJ/ m^2-day), T is the air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m/sec), e_s and e_a are the saturation and actual vapor pressures (kPa) respectively, Δ is the slope of vapor pressure curve (kPa/°C), and γ is the Psychrometric constant (kPa/°C).

Discharge

For model calibration and validation, observed discharge data at the catchment outlet is to be compared with simulated runoff. In the present study, daily discharge data in cumecs for a period ranging from 1989 to 2022 was used as input. The NAM Model used different input data in the specific formats and **Table 4.8** described the required input data and their required formats.

Table 4.8 Input data requirement for the model

Variable	Type	Unit	TS Type
Daily Rainfall	Rainfall	mm	Step accumulated
Daily potential evapotranspiration	Evaporation	mm	Step accumulated
Daily discharge	Discharge	m^3/s	Instantaneous

4.5.1.4 Calibration, validation of the NAM model

The NAM model of the Bah River basin was developed using a digital elevation model through an automatic delineation technique. The rainfall, evapotranspiration, and observed runoff were assigned to the model as inputs. The NAM model was calibrated from 1991 to 2005 and validated from 2006 to 2013 for virgin flow. Initially, an auto-calibration technique available in the model was chosen to fit the parameters automatically considering the rainfall and evapotranspiration as inputs and observed runoff as output. The comparison of daily and accumulated observed and computed runoffs, coefficient of determination, etc. were checked. The sensitivity of the parameters was assessed through the Latin Hypercube-One Parameter at a Time (LH-OAT) method, where systematically, the value of a parameter was changed in its reasonable range and the change in the coefficient of determination was determined. After getting a few sensitive parameters, fine-tuning through the trial-and-error method of these sensitive parameters was made to attain a higher degree of accuracy. After getting satisfactory results, the calibrated model was validated with an independent data set from 2006 to 2013 and analyzed for best-fit criteria. As the results were found satisfactory in calibration as well as in validation, the model can be used to understand the hydrological processes within the basin and the impact of land use/climate change on runoff. The developed model was used in the MIKE HYDRO Basin model for the planning of irrigation releases in the command and operation of the Sanjay Sagar reservoir.

4.6 MIKE-HYDRO Basin

The MIKE HYDRO Basin is a versatile, GIS-based decision support tool for integrated water resources management and planning that can be used for water allocation, conjunctive use, reservoir operation, or water transfer issues. The MIKE-HYDRO Basin combines the latest generation of graphical user interfaces with its own map-based GIS platform to digitize rivers, reservoirs, users, links, etc., or processing of DEM to automatically delineate rivers and catchments. This model allows the integrated management of water resources by estimating water availability, allocating water among different users, operating irrigation reservoirs, and analyzing water quality (DHI 2014). The catchment and command area water resources can be simulated in detail. The MIKE-HYDRO Basin has been used to simulate multiple scenarios under changing climatic and consecutive usage conditions.

Water resources projects can be simulated by using different tabs within the MIKE-HYDRO Basin, including specifications, digitization, connections, time series data, rules, etc. Different tabs used to set up the MIKE-HYDRO Basin model are presented in **Figure 4.9 (a), (b),** and workflow in **Figure 4.10.**

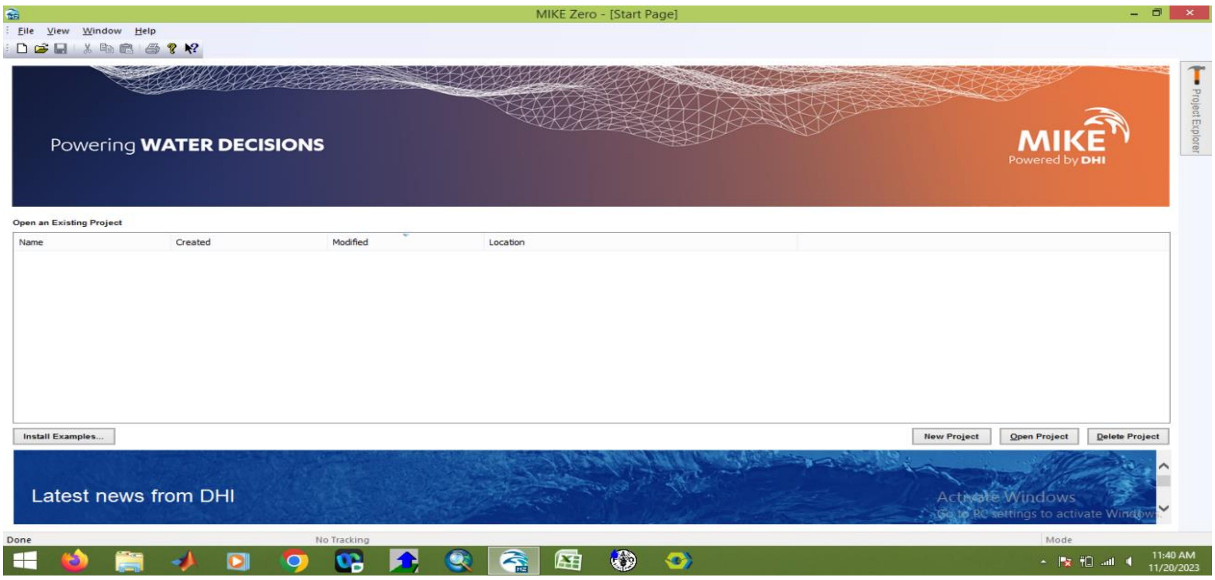


Figure 4.9 (a) Welcome screen of MIKE HYDRO Basin

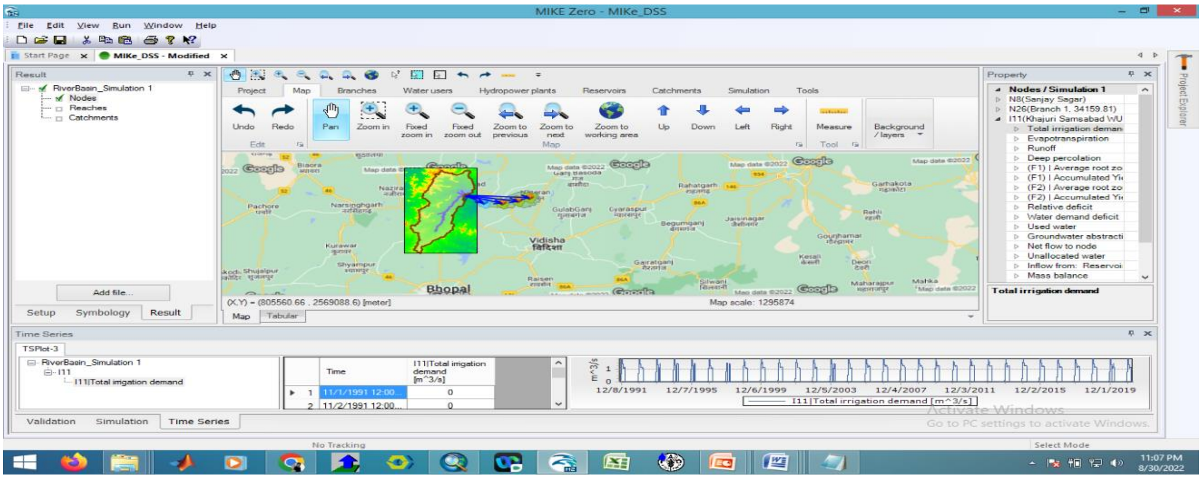


Figure 4.9 (b) User interface of the MIKE HYDRO basin

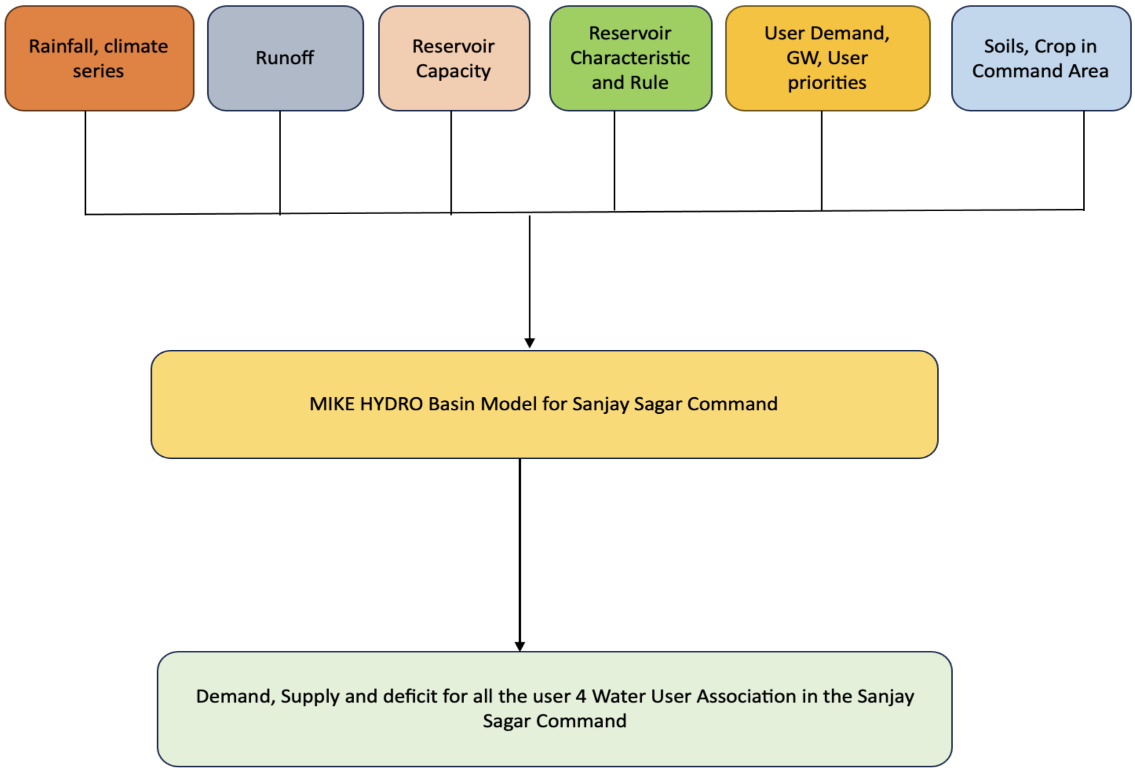


Figure 4.10 Work Flow for irrigation planning in MIKE HYDRO Basin

4.6.1 Simulation Specification

The simulation specification tab in MIKE HYDRO Basin allows users to specify the title and description of the project, the type of modeling (river or basin), groundwater application, the period of simulation, the time step, the number of iterations, and convergence criteria.

4.6.2 Map configuration

The map configuration tab allows to overlay the background map with a shape file and/or digital elevation model, etc. Various projection systems are offered in the software, and shape files can be imported directly into Google Maps.

4.6.3 River Network

The River Network tab allows the digitization of the branches, river nodes, priority nodes, and routing methods, and assigns properties

4.6.4 Catchment

It allows the user to define catchment areas, time series, etc. In this tab, the NAM parameters, rainfall, and evapotranspiration series can be assigned to carry out rainfall-runoff processes.

4.6.5 Water users

The model can accommodate two types of user nodes: simple water users and irrigation commands. Several supply sources can be connected to the water user nodes, with priorities, curtailments, etc. The water user node has a user-defined demand series, while the irrigation command node calculates irrigation demand based on climatic data, crop types, and areas under different crops.

4.6.6 Reservoir

A reservoir is one of the most critical features of the MIKE-HYDRO Basin, where single or multiple multi-purpose reservoirs can be accommodated and simulated based on operating policies or sharing rights. These policies and curves define the desired storage volume, water level, and releases at any given time based on the current water level, the time of year, and the demand for water, loss, and gain. MIKE HYDRO basin enables reservoirs to be positioned anywhere on the river branches except on major bifurcation nodes or upstream points. The input requirements for each of the following three types of storage reservoirs will differ depending on the reservoir type selected and the model can operate any one of these types mentioned in the simulation.

4.6.6.1 Rule curve reservoir

In the rule curve reservoir, users can draw water from the same reservoir, since it contains the same physical storage. Each user in this type of reservoir has its own operating rules, and water is supplied for each user from a common storage pool. The users are competing with one another to fulfil their right to extract water from the reservoir**.**

4.6.6.2 Allocation pool reservoir

Physical storage is provided in the allocation pool reservoir, but individual users have allocated specific storage rights within a zone of water levels to the allocation pool reservoir. For downstream minimum flow releases, an accounting procedure keeps track of the actual water stored in a pool and users can extract water from the pool based on their rights.

4.6.6.3 Lakes

Lakes are specific reservoirs with no operating rules. Lakes can have spillways that restrict their outflow.

4.6.6.4 Reservoir property tab

The reservoir properties dialog outlines essential details encompassing the reservoir's distinctive features, operational guidelines, and connections with upstream and downstream users and control points. Within this framework, the level-area-volume table serves as a pivotal tool for computing the reservoir's volume at varying levels. During the simulation, a sophisticated technique of linear interpolation is employed, entailing the use of a piece-wise linear EVA function to compute the area and volume of water in the reservoir at any time.

For the reservoir's dynamic behavior, a time series dataset capturing characteristic levels assumes significance. This dataset encompasses several crucial parameters, including the bottom level, upper limit of dead storage, dam crest level, and optionally, time series data concerning losses and gains. By assimilating these intricate reservoir properties and operational intricacies, a comprehensive understanding of its functioning and response emerges, facilitating effective simulation and analysis. **Figure 4.11** shows the data input options of the reservoir under the "reservoir definition" tab.

4.6.6.5 Reservoir operation properties

The "Operation" tab provides users with access to define specific rules for the management of the reservoir. These operational rules encompass a range of parameters, extending beyond mere storage target levels. For instance, they encompass the designation of various storage allocation zones, as well as criteria governing releases and spillage requirements, each subject to their respective constraints. This set of rules is subject to variation over time, delineated by rule curve time series. Through the utilization of the "Priority" tab, reservoirs can establish direct connections to multiple downstream nodes, including those related to water users, hydropower generation, or additional reservoirs. When such downstream nodes are linked to the reservoir, the rule field is automatically populated, streamlining the process.

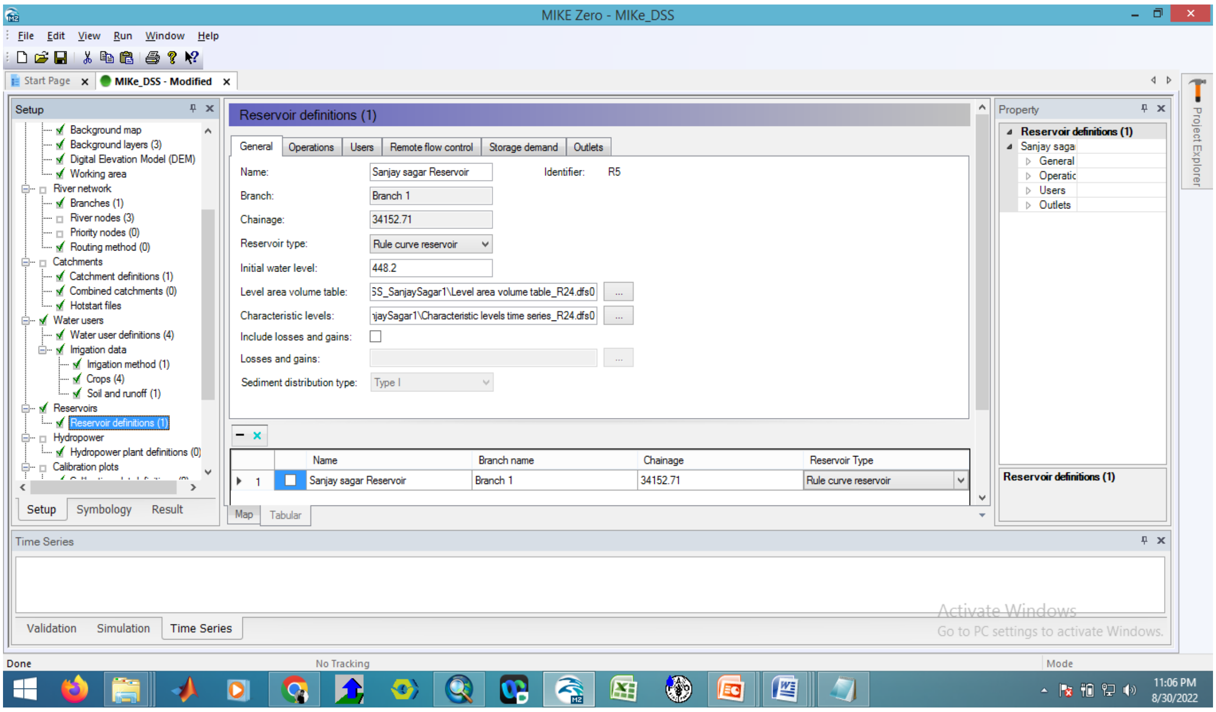


Figure 4.11 Reservoir data input option

The "Remote Flow" rules in the MIKE HYDRO Basin stand out as particularly significant. Differing from standard regulations, these rules involve logical connections between distant nodes that are not directly adjacent. This distinctive feature distinguishes them as exceptional, enabling the management of interactions between nodes that are not in proximity. The "Storage Demand" rule introduced an approach for managing two reservoirs, allowing for their operation either sequentially or concurrently. When these reservoirs are situated in sequence along the same river branch, it becomes beneficial to maintain higher water levels in the upstream reservoir. By incorporating the "Storage Demand" option, the discharge of water exclusively from the upstream reservoir is regulated to support a crucial water level in the downstream reservoir for effective management strategy in the case of interconnected reservoirs.

4.6.6.6 Spillway

In the MIKE HYDRO Basin, the management of water releases during flood control scenarios is facilitated through the utilization of two distinct spillway mechanisms. The first of these is the upper spillway, characterized by its spill capacity table and the critical threshold at which it comes into play. The second is the lower spillway, which operates based on a designated bottom outlet capacity time series. This lower spillway is commonly assumed to be positioned at the base of the dam structure. To orchestrate the controlled release of water, three key elements play a pivotal role: the spill capacity table, the specified spillway bottom level, and the time series delineating the bottom outlet capacity. These components collectively determine the precise functioning of the spillway system. It is noteworthy that while all three of these time series hold significance in shaping the spillway's operation, they are not obligatory components. In instances where these time series are not explicitly provided, any surplus water volume exceeding the Highest Flood Level will naturally flow downstream.

4.6.7 Irrigation module

Within the framework of the MIKE HYDRO Basin, the management of water releases in flood control situations is facilitated using two distinct spillway mechanisms. The first is the upper spillway, characterized by its spill capacity table and the critical threshold triggering its activation. The second mechanism is the lower spillway, typically located at the base of the dam, which operates based on a designated time series for the bottom outlet capacity. To regulate the controlled water release, three crucial elements come into play: the spill capacity table, the designated spillway bottom level, and the time series governing the bottom outlet capacity. These elements collectively dictate the precise functioning of the spillway system. It is important to note that while these time series significantly influence the spillway's operation, they are not mandatory components. In cases where these time series are not explicitly provided, any excess water volume beyond the Highest Flood Level will naturally flow downstream.

4.6.7.1 Climate sub-model

This sub-model encapsulates data related to prevailing climatic conditions in the target area. It encompasses parameters such as temperature, humidity, precipitation patterns, and wind speed. Accurate representation of climate data is crucial for simulating realistic irrigation scenarios.

4.6.7.2 Reference evapotranspiration (ET) sub-model

The reference ET sub-model provides insights into the water loss from a well-watered reference crop under standard conditions. It forms the basis for estimating crop water requirements and assists in determining the appropriate irrigation schedules.

4.6.7.3 Soil water sub-model

The main purpose of the soil water model is to oversee the measurement of accessible soil water for both soil evaporation and crop evapotranspiration during simulations. Moreover, the Irrigation sub-model utilizes the soil water content to determine irrigation needs. Within the MIKE HYDRO Basin model, the FAO56 Soil Water Model is integrated, effectively monitoring soil moisture across two storage layers: a surface storage for soil evaporation and a root zone storage for transpiration requirements. The depth of the evaporable layer is termed the "Depth of evaporable layer," while the root zone's depth corresponds to the root depth at each simulation point. The model assumes that the evaporable layer contributes to the root zone once it reaches field capacity. Introducing the concept of a wetting fraction, set to 1.0 for rain and user-defined for irrigation, allows for a nuanced computation of water exchange between the evaporable layer and the root zone. When wetting fractions are below one, water exchange considers average water content within the evaporable layer to maintain moisture levels below field capacity.

4.6.7.4 Runoff sub-model

The Runoff sub-model serves as an elective component, meaning that if no specific model is chosen within the designated field, the system assumes a runoff value of zero. The principal function of the runoff model involves determining the proportion of precipitation that will exit the designated field as surface runoff, consequently bypassing entry into the root zone of the soil. The inclusion of a runoff model is not obligatory, and its presence depends on the specific scenario's requirements. Within this sub-model framework, the calculation of surface runoff hinges on the assumption of a linear correlation between the intensity of rainfall and the volume of surface runoff produced. This approach facilitates a projection of how much water will flow off the field's surface based on the intensity of the precipitation experienced.

4.6.7.5 Irrigation method sub-model

The irrigation sub-module serves to define the manner and timing of irrigation for a given field. At present, the MIKE HYDRO Basin system incorporates the FAO 56 irrigation method. In this method, a wetting fraction is crucial in determining the proportion of the field surface that undergoes wetting during irrigation. For instance, in cases of sprinkler irrigation, this fraction tends to approach 1, while it could be as low as 0.1 for drip irrigation. This wetting fraction also plays a pivotal role in determining the amount of irrigation needed before the surface soil storage reaches capacity and consequently initiates the filling of the root zone. It is also essential to specify a spray loss factor, signifying the fraction of irrigation water that evaporates before reaching the soil surface. While sprinkler irrigation might incur a relatively high spray loss, it is comparably lower for flood and drip irrigation.

In the MIKE HYDRO Basin, three triggering options are available to ascertain the initiation of irrigation.

I. Fraction of Total Available Water (TAW): Irrigation commences as the soil moisture content reaches a designated fraction of TAW. TAW refers to the volume of water held in the root zone under field capacity conditions.

II. Fraction of Readily Available Water (RAW): Irrigation starts upon the soil moisture content reaching a specified portion of RAW. RAW signifies the volume of water that the crop can transpire without experiencing soil water stress. RAW can be calculated using the following equation:

$$RAW = (1 - p) * TAW \tag{4.66}$$

where, 'p' denotes the factor based on the crop's sensitivity to soil moisture stress, specifically indicating the fraction of TAW at which soil moisture stress begins to affect crop transpiration.

III. Specified Depletion Depth: Irrigation initiation starts when the soil moisture content reaches the defined depletion depth.

Once irrigation is triggered according to the chosen option, the application depth is computed based on the following three application alternatives:

a. Fraction of Total Available Water (*TAW*): Irrigation stops as the soil moisture content attains the specified *TAW* fraction.
b. Fraction of Readily Available Water (*RAW*): Irrigation stops once the soil moisture content achieves the designated fraction of *RAW*.
c. Fixed Depth: A predetermined water depth is applied to the field.

4.6.7.6 Crop sub-model

The crop sub-model holds a pivotal role in computing both crop evapotranspiration and soil evaporation. This is accomplished by leveraging data on soil moisture content and reference evapotranspiration. Within the context of the MIKE HYDRO Basin, the current rendition of this sub-model uses the Dual Crop Coefficient model based on FAO56. The FAO56 model divides the crop growth cycle into distinct phases: initial, developmental, middle, and late stages. Each stage is assigned specific attributes, including duration and the Basal crop coefficient (K_{cb}). This Basal crop coefficient serves as a critical measure, expressing the ratio of crop evapotranspiration to reference evapotranspiration (ET_c/ET_0) during a particular stage.

In the initial and middle stages, the K_{cb} remains consistent, while a linear progression characterizes its shift between these stages. The extent to which the crop's root system can access water is governed by the root depth. Precisely defining the minimum and maximum root depths is imperative. Interestingly, the maximum root depth is assumed to manifest at the commencement of the middle stage. The progression from the initial depth to the maximum depth is quantified by the relationship depicted as follows:

$$R = \frac{(K_{cb} - K_{cb,ini})}{(K_{cb,mid} - K_{cb,ini})}(R_{max} - R_{min}) + R_{min} \quad (4.67)$$

Where, $K_{cb,ini}$ is the initial Basal coefficient, $K_{cb, mid}$ is the Basal crop coefficient in the middle stage, and R_{max} and R_{min} are the maximum and minimum root depths respectively. The influence of the surface roughness on the evapotranspiration can be considered through a climatic factor applied to the basal crop coefficient. If H_{max} is the maximum height of the crop, the vegetation height (H) is assumed to scale with the Basal crop coefficients and is calculated as:

$$H = \frac{(K_{cb} - K_{cb,ini})}{(K_{cb,mid} - K_{cb,ini})} H_{max} \quad (4.68)$$

4.6.7.7 Yield sub-model

The incorporation of the FAO 33 yield model within the MIKE-HYDRO BASIN software provides a robust tool for estimating crop yield. This model is rooted in the notion of potential yield (y_p), representing the achievable crop yield under ideal conditions without any soil moisture stress. It takes into account the dynamic responsiveness of crops to soil moisture stress, a factor influenced by the crop's growth stage. Generally, crops demonstrate heightened sensitivity to soil moisture stress during early growth stages in comparison to later stages. To accommodate this variability, the yield Response Factor (Ky) is introduced, requiring specific values for each of the four growth stages. Although the durations of these stages may differ from those in the crop model, they significantly contribute to determining the crop yield. The crop yield is calculated using the equation:

$$\frac{Y_a}{y_P} = \prod_{i=1}^{i=G} \left[1 - K_{yi}\left(1 - \frac{Et_a}{Et_p}\right)\right] \quad (4.69)$$

In this equation, Y_a signifies the actual yield, y_p symbolizes the potential yield, Et_a and Et_P represent actual and potential transpiration respectively, and index *i* pertains to the ith growth stage within a given growing season comprising G growth periods. This approach offers a valuable framework for precise crop yield projections that consider the intricate interplay between growth stages and soil moisture stress.

4.6.7.8 Crop sequence sub-model

The concept of a crop sequence serves as a practical framework for delineating the management approach employed in a specific field. Although not considered a distinct sub-model, the crop sequence provides a pragmatic method for outlining field management strategies. Given that identical crop sequences can be implemented across various fields, incorporating crop sequence details within sub-models is a logical decision. Essentially, a crop sequence consists of a series of crop rotations, each defined by its initiation date (sowing date), the cultivated crop, and potentially referencing the associated irrigation sub-model for watering. The duration of a crop rotation extends until the completion of the final growth stage of the cultivated crop in the field. If a crop is harvested before the subsequent crop is planted, the model assumes a period without any crops, indicating zero irrigation requirements.

4.6.8 Hydropower

A power plant can be added to a river node or channel connected to a reservoir by using the hydropower tab. This tab allows you to assign the power demand, time series, installed capacity, minimum head, head loss, and power efficiency.

4.6.9 River and catchment

The MIKE-HYDRO Basin works on a digitized network of branches and nodes. The rivers in the model can either be digitized directly using the map view or extracted from the digital elevation model. River network and water transfer are defined in the basin based on the connected river segments, as well as computational nodes and module-specific features. The catchment on any river node can be assigned to provide a river inflow series from the catchment up to that node in the system.

4.6.10 Channels

The channels in the MIKE HYDRO Basin refer to the distinct sections that serve as conduits connecting water users and hydropower nodes from either a river or reservoir. These channels play a pivotal role in facilitating the movement of water and energy. To comprehensively characterize these channels, two crucial sets of time series data come into play: flow losses and flow capacity. The flow losses time series encapsulates optional temporal data that is indispensable for accurately assessing the fluctuation of water quantities resulting from seepage and evaporation phenomena. Specifically, it enables the quantification of water loss attributed to seepage as well as the loss incurred due to evaporation. Both intricate processes can be precisely defined either as a dimensionless fraction of the actual flow rate or as a volumetric flux per unit time. To facilitate the robust representation of channel dynamics, the flow capacity time series emerges as a vital component. This temporal dataset portrays the upper threshold that the channel's capacity should never surpass under any circumstances. It serves as a critical parameter for maintaining the integrity of the entire system.

In parallel, the river hydraulics tab assumes significance, offering a comprehensive framework for specifying four distinct routing alternatives applicable to channels. These routing options encompass:

1. No Routing: This option implies a direct, uninhibited flow along the channel without any form of manipulation.
2. Linear Routing: Linear routing introduces a controlled progression of water through the channel, designed to mimic natural flow behavior.
3. Muskingum Routing: A more complex approach involving the Muskingum method, aimed at simulating intricate flow patterns within the channel.
4. Wave Translation Routing: This option involves wave translation techniques to model the movement of waves within the channel accurately.

4.6.11 Results

On this tab, you can define the name and location of the file that will store the results. Our study aims to develop an irrigation management model for the Sanjay Sagar Reservoir. This is done using a river network with catchments and reservoirs that provide water to command and user nodes through channels. This analysis uses a variety of components, which are described below.

4.6.12 Simulation

After setting up all sub-models, reservoirs, channel details, and priority settings, the model can be run for the simulation. The most general output items of the irrigation node, reservoir, and catchment are written to the MIKE HYDRO Basin. The output files contain evapotranspiration, total irrigation demand, net flow, demand deficit in irrigation nodes, stored volume and water levels in reservoirs, channel flows, etc at a given period assigned during the simulation.

4.6.13 MIKE HYDRO Basin-based irrigation management model for Sanjay Sagar command

To develop an irrigation management and reservoir operation model for the Sanjay Sagar Reservoir and its associated command area within the MIKE HYDRO Basin, a comprehensive approach has been undertaken. This approach involves the utilization of drainage and catchment boundary maps as primary inputs, which serve as foundational data. Additionally, the creation of Pseudo-Digital Elevation Models (DEMs), flow direction, and accumulation maps has been executed to facilitate the accurate delineation of river segments and catchment regions within the MIKE HYDRO Basin software. Sanjay Sagar's command through its 4 Water User Associations was digitized to control the distribution of water. Furthermore, a user node was created to oversee the supply of water to the command area. These elements have been interconnected through a network of canals originating from the reservoir. The visual representation of the integrated MIKE HYDRO BASIN model, encompassing the Sanjay Sagar reservoir, the user node for water supply, and the command area, is depicted in **Figure 4.12**. To enhance the model's fidelity, comprehensive details regarding the reservoir have been included. This information encompassed the elevation-area-capacity table, Full Reservoir Level (F.R.L.), Dead Storage Level (D.S.L.), water supply priorities, and provisions for supply reduction. These reservoir properties are systematically presented in **Figure 4.13**.

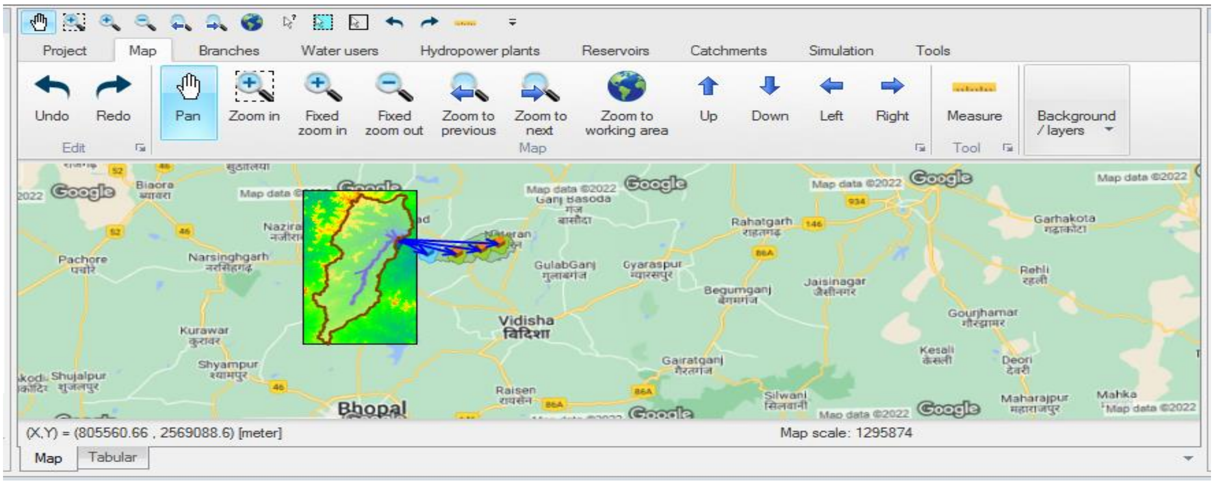


Figure 4.12 User nodes for water supply in the command area

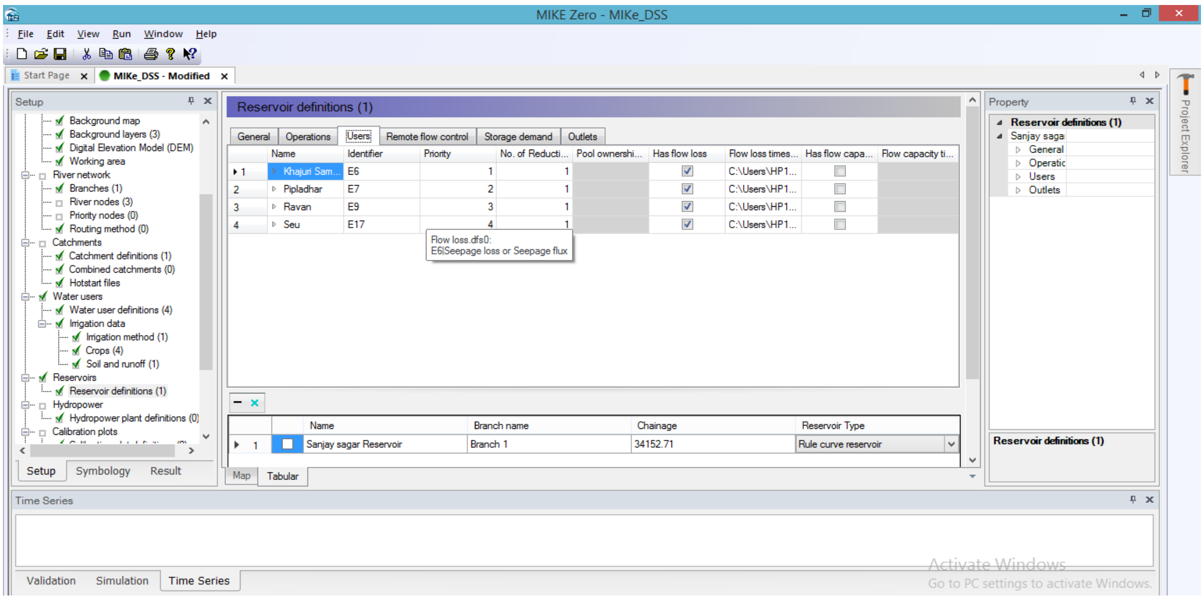


Figure 4.13 Priority nodes of water user

The model incorporated the climatological data from the Vidisha region to compute reference evapotranspiration. For precise agricultural assessments, the crop sub-model integrates crop coefficients specific to various crops. Wheat and gram are the primary crops in the command and are incorporated in crop sub-models. Additionally, the crop sequence and corresponding cultivation areas were allocated within the sequence sub-model. A thorough analysis of soil test data has enabled the categorization of soils within the command areas into two primary groups. These groups are distinguished by unique characteristics such as field capacity, wilting point, porosity, and other pertinent soil properties.

4.6.14 Simulation scenarios

The reservoir operation for efficient utilization of water resources and irrigation management was carried out through optimization or scenario-based simulation. Under the uncertainties of model, climate, and operational management strategies, the simulation-based approach can provide satisfactory results. Scenarios have served as a crucial instrument for systematically investigating future uncertainties in a logical, unified, and credible manner. Consequently, they have found extensive application in strategic planning and the formulation of policies. In the present study, four different scenarios with the participatory approach of farmers, water resource managers, and technocrats were devised and analyzed in the MIKE HYDRO Basin management model. The scenarios were designed based on the overall efficiency of the system, method of irrigation, and conjunctive use of surface and groundwater. The details of these scenarios are presented in **Table 4.9.**

Table 4.9 Scenario planning for the Sanjay Sagar reservoir project

S.N.	Overall efficiency	Method of irrigation	Groundwater use	Scenario No
1.	60%	Flood	No	SCN-1
2.	60%	Flood	5%	SCN-2
3.	75%	Sprinkler	No	SCN-3
4.	75%	Sprinkler	5%	SCN-4

4.7 Excel-Based Decision Support System for Irrigation Management

The management model developed using priced software is sometimes not useful due to recurrent costs, the requirement for efficient computing facilities, and software knowledge. These issues were discussed with the water resource managers of Madhya Pradesh and decided to develop a simple but intrusive water management model for the Sanjay Sagar project in Excel. The developed decision-making tool in Excel has facilitated the water balance calculation (a calculation of surplus or deficit in the water supply) for the Sanjay Sagar dam command area to assist decision-makers in making informed decisions. This Excel spreadsheet is constructed using data from many sources, including rainfall and temperature data (maximum and minimum temperature) derived from the IMD/Visual Crossing websites, crop information from the field, and reservoir data from operators. Based on the temperature and latitude of the specific location, the water balance model calculates potential evapotranspiration using Hargrieve's equation. The crop water requirement for wheat and gram crops in the different water user associations was computed using the crop coefficient of respective crops daily.

Additionally, the management model used land parameter information such as soil type, field capacity, and soil wilting point to determine the actual water requirement for the crops. The water demand can be modified with the help of user-assigned applications and conveyance losses. Knowing the current availability of water in the reservoir, future climatic conditions, and constraints of cropped areas, the model can suggest optimum areas of different crops with no or minimum deficit of water in the command using the optimization routine of Excel. The demand and supply for the wet year, drought year, and average year were calculated to derive various scenarios of irrigation management in the Sanjay Sagar dam. The User-Interface of Excel-based decision support system is depicted in **Figure 4.14.**

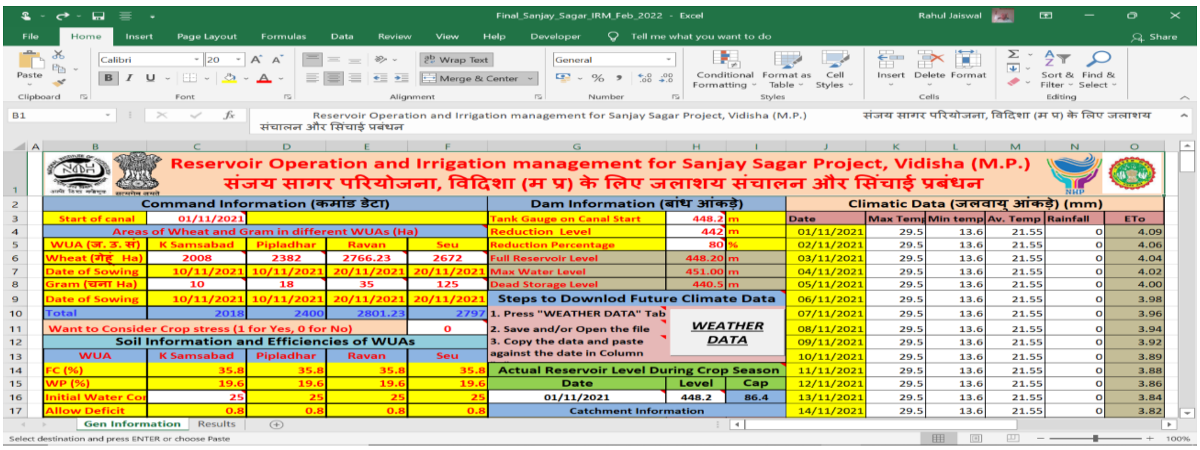


Figure 4.14 User Interface of Excel-based Decision Support System

The main concept put forward in this decision support to keep the dashboard simple but intrusive. The Excel programming consists of the computation of the irrigation water requirement of each crop for each WUA based on regularly updated climate data. For this, all 4 WUAs in the Sanjay Sagar command were distributed in four groups namely Khajuri Shamsabad, Pipaldhar, Ravan, and Seu. The simple but efficient and scientifically sound water balance model with the help of several interconnected sheets with the macro-based tool to fetch forecast climate data for fifteen days. The different components of excel Excel-based management model are described in the next sections.

4.7.1 Input data to the dashboard

The main input information to the dashboard of the management model is crop areas of two major crops i.e. wheat and gram in different WUA based on information collected from farmers. The percentage areas of different crops can be given by water resource managers so that the remaining areas can be filled up based on the suggested percentage. In some of the commands, a fixed amount of water is provided to the farmers for land preparation. So, in this management model, the water resource managers can provide a fixed amount of water in mm/day for the number of days for land preparation. Soil properties are very important for optimum growth of crops. The field capacity, permanent wilting point, and soil texture analysis on 12 different places in the command were carried out and used as input to four different groups of WUAs. An allowable deficit friction needs to be given to start supplying water in the WUA. The total depth of soil was given to determine the amount of water needed in a single irrigation. The conveyance and application efficiencies in different groups can be given to determine the amount of water needed at the head of canal and dam respectively.

The water resource manager needs to assign the start date of the canal, the initial reservoir level on the start date, the reduction level, and the percentage reduction. The reservoir level can be modified on any date of crop season in the middle of the cropping season, which will automatically be updated on the given date in the program and modify demand and deficit based on updated information. At the start of the irrigation season, the future climate (min & max temperature and rainfall) is not known to the planners and hence, a climate data set of the most suitable CMIP 6 GCM for this region was selected and provided to initiate the run the model initially and optimize the crop areas.

At the start of the irrigation season, the future climate is not known, and hence, to initiate the water balance model, a best-suited GCM model from thirteen different GCMs of CMIP6 was analyzed (**Table 4.10**) and compared with IMD data for root mean square error (RMSE), Nash Sutcliffe efficiency, and bias. The climate data (min & max temperature and rainfall) of the best-fit model was used for the initial run of the model. It gives an initial idea about the total irrigation demand, supplies, and balance of water in the reservoir. After that for each 10-daily or 15-daily period, the future climate data can be fetched through visual crossing/IMD website to replace initially used climate data to modify the results.

Table 4.10 CMIP 6 data analyzed for the management model

S. No.	Models	Country	Resolution	Key reference
1	ACCESS-CM2	Australia	1.9°×1.3°	Bi et al. (2020)
2	ACCESS-ESM1-5	Australia	1.9°×1.2°	Ziehn et al. (2020)
3	BCC-CSM2-MR	China	1.1°×1.1°	Wu et al. (2019)
4	CanESM6	Canada	2.8°×2.8°	Swart et al. (2019)
5	EC-Earth3	Europe	0.7°×0.7°	Massonnet et al. (2020)
6	EC-Earth3-Veg	Europe	0.7°×0.7°	Massonnet et al. (2020)
7	INM-CM4-8	Russia	2°×1.5°	Volodin et al. (2018)
8	INM-CM5-0	Russia	2°×1.5°	Volodin et al. (2018)
9	MPI-ESM1-2-HR	Germany	0.9°×0.9°	Gutjahr et al. (2019)
10	MPI-ESM1-2-LR	Germany	1.9°×1.9°	Mauritsen et al. (2019)
11	MRI-ESM2-0	Japan	1.1°×1.1°	Yukimoto et al. (2019)
12	NorESM2-LM	Norway	2.5°×1.9°	Seland et al. (2020)
13	NorESM2-MM	Norway	0.9×1.25	Seland et al. (2020)

4.7.2 Computation of Irrigation Water Requirement

4.7.2.1 Reference crop evapotranspiration

For the computation of crop water requirement, separate sheets for different crops in different WUAs groups using input temperature data from the dashboard were designed. The Hargreaves's method through the following equation was used to compute reference crop evapotranspiration (ET_o):

$$ET_o = 0.0023(T_{mean} + 17.4) * R_a * \sqrt{T_{max} - T_{min}} \tag{4.70}$$

Where T_{min}, T_{max}, and T_{mean} are the minimum, maximum, and mean temperature (^oC) respectively and R_a is the extra-terrestrial radiation (MJ/sqm-day). The Hargreaves method was used because of its simplicity (Kra 2014) and better performance in arid and semi-arid regions (Subburayan et al 2011; Gao et al. 2017, Shirmohammadi-Aliakbarkhani et al. 2020). The extra-terrestrial radiation was computed using latitude, month, and day through the website https://www.engr.scu.edu/~emaurer/tools/calc_solar_cgi.pl.

4.7.2.2 Irrigation water requirement

The evapotranspiration (ET_o), crop coefficients (K_c), crop stress factor (K_s) special needs (W_{SP}), water for land preparation (W_L), effective rainfall based on the constant percentage (P_{eff}), etc. were used to compute daily irrigation water demand (IWD).

$$IWD = K_c * K_s * ET_o - P_{eff} + W_L + W_{SP} \quad (4.71)$$

The program also assessed the crop stress based on soil moisture available in the soil. If soil moisture goes below the readily available soil moisture, crop stress comes into the picture which reduces the crop coefficient using a stress factor (K_s) that depends on moisture level in the soil. The stress factor depends on the availability of water in the soil. When the soil moisture is between field capacity and readily available moisture, the crop stress factor will be 1 and below readily available moisture to the permanent wilting point, the crop stress factor may vary in a linear direction from one to zero and lastly, below the permanent wilting point, the crop stress factor will be zero.

$$\begin{aligned} K_s &= 1 && when\ \theta_t \geq RAW \\ K_s &= \frac{TAW - RAW - \theta_t}{TAW - RAW} && when\ \theta_t < RAW \\ K_s &= 0 && when\ \theta_t \leq PWP \end{aligned} \quad (4.72)$$

This daily irrigation water demand was further intensified by conveyance (E_c) and application (E_A) efficiencies to determine total water demand at the head of reservoir (RWD) or head of the command using the following equation:

$$RWD = \frac{IWD}{E_c * E_A} \quad (4.73)$$

For the computation of crop water requirements for different WUAs, separate sheets for wheat and gram crops were created.

4.7.3 Catchment runoff

Although there are little possibilities of rainfall in the rabi crop season, a sheet was developed to compute surface runoff from the catchment to the reservoir using the SCS CN model (USDA, 1972) developed by the United States Department of Agriculture - Natural Resources Conservation Service (Bhadra et al., 2010; Satheeshkumar et al., 2017; Shi and Wang, 2020). The accumulated runoff increases the availability of water in the reservoir. The following formulae are used to compute surface runoff using the SCS-CN method.

4.7.4 Water balance of reservoir

A daily water balance of the reservoir was made based on reservoir level on start date, cropped areas, meteorological data, efficiencies, operation rules, etc. Initially, based on the reservoir level, the available reservoir storage was determined. The storage available for use was computed after deducting seepage loss, evaporation losses, and other losses like leakage if any. The demand computed for each crop is brought here and considered as probable demand ($WD_i^{\,j}$).

firstly, the probable supply (PWS_i^j) was determined based on a comparison of reservoir level with used defined reduction level according reduction was made using the following criteria for a crop water demand:

$$\begin{aligned} &If\ (RES_i \geq RL && PWS_i^{\ j} = WD_i^{\ j} \\ &If\ (RES_i < RL && PWS_i^{\ j} = \frac{RP}{100} * WD_i^{\ j} \\ &If\ (RES_i < DSL && PWS_i^{\ j} = 0 \end{aligned} \qquad (4.74)$$

Where RES_i is the reservoir level on an i^{th} day, PWS_i^j is the probable water supply, and *RL and RP* are the reduction level and reduction percentage respectively. Once, the probable supply for all the crops was determined for a WUA, the actual supplies ($AWS_i^{\ j}$) on an i^{th} day for j^{th} crops in a WUA were determined based on the canal capacity of the main canal.

$$\begin{aligned} &If\ (\textstyle\sum_{j=1}^{n} PWS_i^{\ j} \leq C_C && AWS_i^{\ j} = PWS_i^{\ j} \\ &If\ (\textstyle\sum_{j=1}^{n} PWS_i^{\ j} > C_C && AWS_i^{\ j} = \frac{PWS_i^{\ j} * C_C}{\sum_{j=1}^{n} PWS_i^{\ j}} \end{aligned} \qquad (4.75)$$

After determining the actual water supply for all WUAs for a day was determined and deducted from the reservoir available water on that day, the balance water became the initial water for the next day. The processes were carried out for the complete rabi crop period to compute the total demand, water supply, and deficit of all crops in all WUAs and the remaining water in the reservoir if any at the end of the crop period.

4.7.5 Results sheet

The result sheet of this dashboard provided the total demand, supply, and deficit for all WUAs in the form of graphs and numerical values. Total water available in the reservoir, water lost in evaporation, seepage, leakage, used by commands, and balance at the end of crop season can be seen in this sheet.

4.7.6 Crop area optimization module

The dashboard has the option to optimize the crops using the Solver tab of Excel based on water availability in the reservoir, efficiency condition, and future climate. This optimization will be useful to water resource managers to suggest farmers for their cropping pattern to minimize the losses and maximize the return.

4.8 Web and Mobile-Based Application DSS for Interactive Decision

In precision farming, the key areas examined for the design of Decision Support Systems (DSS) pertain to data collection, data transmission, and data processing. Commercially available software packages, such as database management systems (DBMS), spreadsheets, and Geographic Information Systems (GIS), can be utilized to enhance the storage, retrieval, analysis, and presentation of large amounts of data. The technologies and tools available can be adapted and transformed into operational DSS to assist managers in agriculture management (Ge et al., 2013).

A DSS can be defined as a computer-based interactive human-computer decision-making system that supports decision-makers rather than replacing them, utilizing data and models with varying degrees of structure. It solves problems through models, focusing on speculation rather than judgment skills. Abawi et al. (2001) emphasized the importance of conceptual models or frameworks for understanding complex systems. They define DSS as a widely accepted computer-based system that helps in using data and models to solve hypothetical problems.

4.8.1 Components of decision support systems (DSS)

The development of Decision Support Systems (DSS) necessitates an interdisciplinary approach, involving various disciplines such as computer science, decision theory, statistics, psychology, information and knowledge engineering, and organizational science (Mysiak et al., 2005). A DSS comprises two major subsystems: The Human Decision Maker & Computer System and the Computer System itself. It is important to note that a DSS does not make decisions; rather, it supports human decision-making processes. Structured or semi-structured decision-making, by definition, cannot be entirely programmed due to its elusive and complex nature. In such cases, the roles of human decision-makers become crucial. The role of the human decision-maker within a DSS is not merely to input data for database creation; instead, it involves exercising judgment and intuition throughout the decision-making process. On the other hand, the computer system components of a DSS encompass the data management subsystem, model management subsystem, interface and dialogue management subsystem, and knowledge-based subsystem. Each of these components plays a specific role in facilitating effective decision support within the system.

4.8.1.1 Data management subsystem

The Database Management Subsystem encompasses several crucial components, including the DSS database, Database Management System (DBMS), data dictionary and directory system, database query facility, model base, and program routines, functions, utilities, applets, and add-ons. DSS databases comprise decision-makers' databases, databases specifically created for the DSS, and data collected from other organizations or external databases. DBMS serves as computer programs primarily designed for creating, updating, and executing queries on large datasets. The DBMS can exist as a stand-alone program or be integrated inside a DSS generator. It empowers users to generate a database file, serving as input for the DSS.

4.8.1.2 Model Management Subsystem

The initial step in the decision-making process involves creating a decision support model using an integrated DSS support program, commonly referred to as a DSS Generator, which can take the form of a utility program, among others. This program enables users to develop user models, associated spreadsheets, and database files tailored to specific decision-making needs. These models and databases are then stored in model bases and databases residing on direct access storage devices, such as hard disks. Data management plays a critical role in the intelligent phase of the decision-making process (Intelligent Factor), but it alone is insufficient to fully support the formulation and selection stages of decision-making. DSS utilizes a diverse range of management science and operations research models, including linear, integer, and goal programming models, network models, statistical and simulation models, as well as spreadsheet modeling. All these models find a home in the model base. A Model-Based Management System (MBMS) refers to a set of computer programs embedded within a DSS generator. This system empowers users to create, reorganize, update, and delete models. Components of model management systems encompass model directories and modeling languages. Furthermore, in addition to model management, multiple criteria can be embedded within the decision-making model.

4.8.1.3 Knowledge-based subsystem

The Knowledge-Based Decision Support System (KBDSS), a subset of DSS, incorporates Expert Systems (ES) categorized into two parts: Expert Support System (ESS) and Intelligent Support System (ISS). ESS is designed to substitute human expertise with machine expertise, whereas ISS is crafted to augment the memory and intelligence of individuals and groups. The integration of ESS and ISS forms a new system capable of supporting decision-makers by leveraging the expertise of key members within the organization. The knowledge-based sub-system is an artificial intelligence application integrated into the DSS architecture. Its purpose is to aid users in selecting the appropriate model to address a problem, manage the model library, and incorporate uncertainties into mathematical models. This application proves valuable for decision-makers, enhancing their ability to navigate complex decision scenarios.

4.8.1.4 User Interface (UI)

The User Interface (UI) plays a pivotal role in Decision Support Systems (DSS) by facilitating interaction between decision-makers and the system. It serves as the gateway for users to access the data subsystem, which includes the database and database management software, as well as the model subsystem, comprising the model base and model base management software. The primary function of the UI subsystem in a DSS is to provide a user-friendly interface, enabling decision-makers to create, update, and delete database files and decision models. It allows users to manipulate and analyze data, and design, and execute various decision models. A well-designed UI offers the significant advantage of providing a variety of input and output formats. Decision-makers often require information in diverse formats, such as color graphics, tables, and multiple windows on a screen. The UI subsystem ensures the availability of these formats, making it easier for decision-makers to comprehend and interpret data and results. Moreover, it provides a range of interactive features that enhance user engagement and facilitate effective decision-making. Users can input preferences, criteria, and constraints, receiving real-time feedback and recommendations based on data and decision models. Decision-makers interact with the system through graphical user interfaces, forms, menus, buttons, and other intuitive elements, simplifying the process of searching and analyzing complex information.

Another critical aspect of the UI subsystem is its role in data visualization. Presenting data attractively and understandably through charts, graphs, and maps, helps decision-makers identify patterns, trends, and relationships not immediately apparent in raw data. Visualization enables quick insights, informed decisions, and effective communication of findings to stakeholders. Furthermore, the UI subsystem ensures the security and confidentiality of data within the DSS. It incorporates authentication and authorization mechanisms to control user access, preventing unauthorized manipulation or disclosure of sensitive information. Decision-makers can trust that their data and models are secure, allowing them to focus on making important decisions without worrying about data breaches or unauthorized access.

4.8.2 System architecture for irrigation management

The system architecture of an irrigation management decision support system (DSS) for web applications is typically composed of several components that work together to provide appropriate tools and information for successful irrigation management. The system architecture methodology is shown in **Figure 4.15.**

4.8.2.1 User Interface (UI)

This component is designed to provide both web and mobile interfaces for users to interact with the Decision Support System (DSS). It includes web pages, forms, menus, and visualizations to facilitate data entry (such as name, water user institution, crop names, crop production area, etc.) and access information regarding water availability in the dam, future weather, etc. Users can view result reports and obtain other crucial information related to irrigation management.

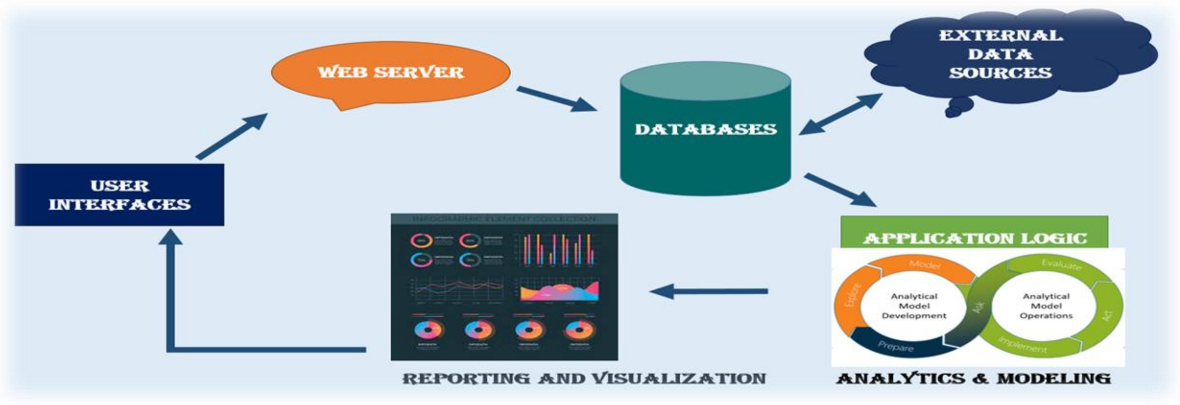


Figure 4.15 System architecture methodology

4.8.2.2 Web server

The web server handles user requests and processes web pages and resources concurrently. It receives user input from the UI, manipulates it with resources to produce useful results, and communicates with other system components to obtain and update necessary resources.

4.8.2.3 Database Management System (DBMS)

The DBMS component stores and manages the data required by the DSS. It utilizes an SQLite database to store information such as historical weather data, soil characteristics, crop types, irrigation schedules, and user preferences. The DBMS supports the decision-making process by handling data retrieval, storage, and updating tasks.

4.8.2.4 External data source

The DSS requires data from external sources to enhance its functionality, including weather data, soil moisture data, crop information, and other relevant information. The external data source component invokes APIs or services to obtain real-time or historical data for the DSS.

4.8.2.5 Analytics and Modeling

The Analytics and Modeling components utilize statistical analysis, machine learning algorithms, and mathematical models with data to generate various analyses and predictions. This component uses data stored in the DBMS and integrates it with external data sources to perform various

4.8.2.6 Reporting & visualization

The reporting and visualization component is designed to present the results of the DSS to users in a visually appealing and informative manner. This can include charts, graphs, maps, and other visualizations to effectively communicate the results and recommendations of the analysis. The user interacts with the UI by inputting data and submitting it; then, the UI sends the input data to the web server. The web server forwards the inputs to the application logic, which accesses the DBMS to retrieve or update the data and processes them. The application logic also interacts with external data sources to obtain additional information if necessary. The analytics and modeling component uses the retrieved data to perform analysis and generate insights, and the results are presented to the user through a reporting and visualization component.

4.8.3 System development environment

ASP.NET is a web framework developed by Microsoft for constructing modern web applications and services. It operates on the server side and aids developers in crafting dynamic web pages and web services. As a component of the .NET Framework, which is a free and open-source framework by Microsoft, there are open-source alternatives and extensions available within the .NET ecosystem. ASP.NET employs Web Controls or AJAX controls to create interactive web applications. AJAX, short for Asynchronous JavaScript and XML, is a technology that facilitates the creation of smooth and responsive web applications. It achieves this by exchanging data with the server asynchronously, eliminating the need for a full page reload. In terms of programming languages, ASP.NET supports several, including C# and Visual Basic.NET (VB.NET). C# is commonly used for server-side programming in conjunction with ASP.NET. Microsoft Visual Studio 2019, a popular Integrated Development Environment (IDE) provided by Microsoft, facilitates the development of applications using various technologies, including ASP.NET. SQLite, on the other hand, is an open-source, self-contained, serverless database engine widely integrated into ASP.NET applications. Notably, SQLite finds broad support on Android platforms and is commonly used in mobile applications. For mobile application development with the Android Framework, developers use Android Studio, the official Integrated Development Environment (IDE) for Android app development. Android Studio offers a range of tools and features designed to streamline the development process.

4.8.4 Web & mobile application

In the development of both the web and mobile applications, the objective was to collect crop area information from farmers. The determination of water demand and availability in the dam, along with future weather and soil moisture data, were used to assess the water needs and disparities among various water user associations. A water management model, grounded in water balance with reservoir operation, has been integrated into the Decision Support System (DSS) to optimize water resource allocation across different areas within a city (Zeng et al., 2012).

In the specific case study conducted on the river Bah in Samshabad block of the Vidisha district in Madhya Pradesh state, the developed DSS comprises four subsystems: database, model base, knowledge base, and a common user interface (GUI). This system is linked to the National Water Management Information System. Through the user interface, farmers can submit information about the area of crops sown, crop names, and sowing dates. The provided information is stored in an SQL database. The administrator utilizes this data to run the model, analyzing water demand, supply, and shortages in the designated area. The results, presented in the form of graphs, allow farmers to visualize water availability and shortages, along with information about water supply from the dam.

The DSS, developed using the ArcGIS engine, SQL Server, and web environment, can provide real-time information such as weather forecasts, market prices, spatial queries, and details about any damage or incidents related to the Kisan Canal. This system enables the Water Resources Department to receive information and offers farmers solutions to agriculture-related problems from subject experts. The successful pilot implementation of the DSS in the Samshabad block demonstrates its significance as a crucial step toward a fully integrated water-environment DSS for the Vidisha district. The work flow for developed web/mobile-based application for Sanjay Sagar project was presented in **Figure 4.16.**

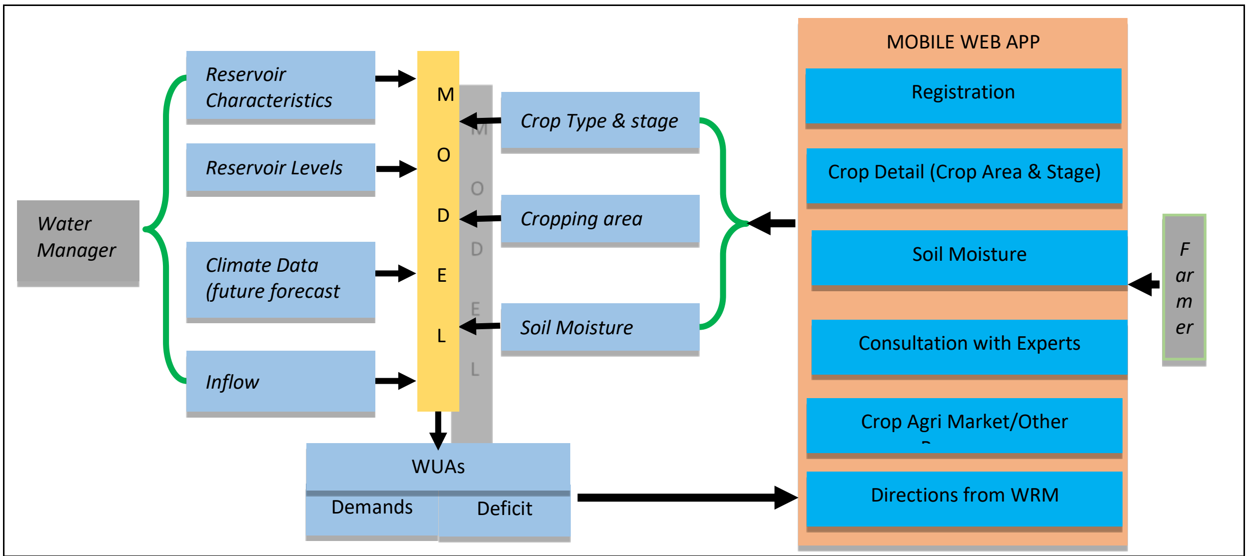


Figure 4.16 Workflow of information/modeling in web/mobile based application

4.8.5 Needs and Perspectives

In today's contemporary world, the imperative need to enhance agricultural practices and facilities underscores the importance of adopting smart farming strategies. Researchers are diligently working to develop sophisticated yet affordable and user-friendly equipment to assist in managing agricultural services operations. A cross-disciplinary approach is deemed necessary to effectively address these challenges. This discussion sheds light on the trends in the development of tools for irrigation water management, emphasizing their merits, limitations, and outstanding issues.

Effective irrigation water management and scheduling require the measurement of crop water needs, estimation of rainfall amounts for optimal use of rainwater, and identification of areas in the field where water is needed most. Numerous Decision Support Systems (DSS) for irrigation water management have been successfully developed and implemented across various fields. Geographic Information Systems (GIS) have been integrated into DSS to address spatial problems related to irrigation water management. This integration enables users to conduct analyses and provides real-time information about water conditions in the field (2012; Zeng et al., 2012).

A notable recent trend in this field is the establishment of real-time web service applications. This innovative approach not only serves as a database for DSS or Web GIS but also displays results in real time. This advancement simplifies challenges not only for stakeholders in irrigation services but also for policymakers and agribusiness entrepreneurs (Jia et al., 2009; Bonaiti & Fipps, 2012; Schmidt & Weiser, 2012; Wenkel et al., 2013). Many existing systems address specific aspects of irrigation water management, and comprehensive solutions must consider upstream/downstream water dynamics, on-farm water balance, groundwater considerations, and distribution parameters influenced by environmental conditions, rainfall variability, and cultural practices that vary by location (Lanter & Barbara, 1991; Khadra & Lamdda, 2010). Developed systems differ in concept and processes, some being site-specific, while others can be adapted for broader applications but may lack precision. System evaluation remains a challenge, primarily relying on user satisfaction and system usage as measures of effectiveness. To address this, there is a need to develop authentic tools for the assessment and evaluation of DSS standards.

4.9 Climate Change Scenarios

The future is always uncertain and it is highly difficult and challenging to exactly state the future conditions and happenings. To study the earth’s climate change and impact on various sectors, different scenarios are developed. These scenarios are alternate images of the future, with certain assumptions, answering how the future might be. In short, these are essential scientific tools or methods for exploring possible future in the context of climate change and its impact. The development of scenarios started in the 1990s with the IS92 scenarios (the first developed set of long-term scenarios) (Leggett, et al., 1992) and was most widely used by the IPCC Special Report on Emission Scenarios (SRES) in 2000 (Nakicenovic & Alcamo, 2000). The Four storylines A1, A2, B1, and B2 were developed and for each storyline separate scenarios were developed leading to a total of 40 scenarios, of which six were selected as demonstrative scenarios that can be widely used (one for each of the storylines in addition with high and low emissions variants of A1 storyline) (Ebi et al., 2014; IPCC, 2007). **Figure 4.17** shows all six SRES scenarios with GHG emissions along with global surface warming from 2000-2100 to better understand SRES scenarios.

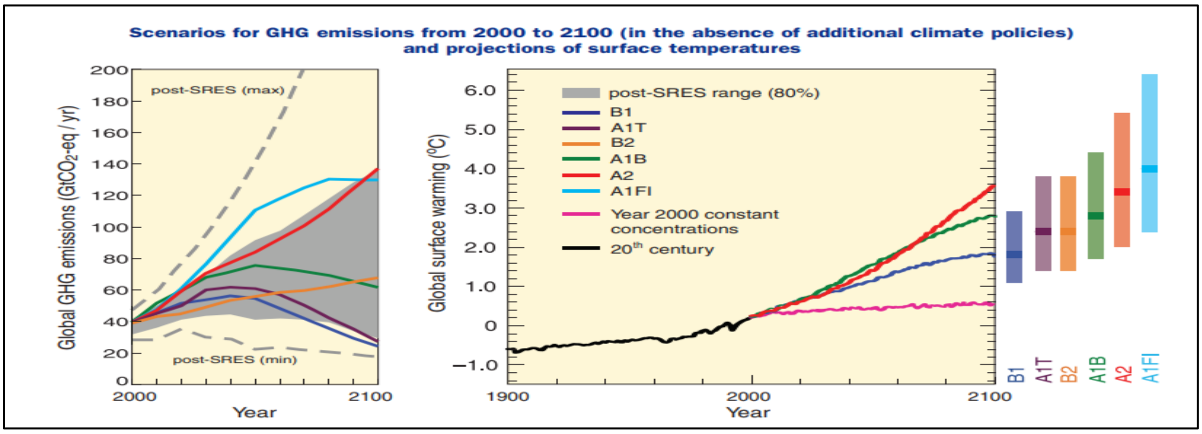


Figure 4.17 Global GHG emission and surface warming with SRES scenario (IPCC, 2007)

The four Representative Concentration Pathways (RCP2.6, 4.5, 6.0, and 8.5), as its name explains, have been suggested in the AR5 report where trajectories of GHG concentrations with radiative forcing (in W/m^2) along with mitigation actions in their formulation to stabilize the radiative forcing at the end of 21^{st} century. RCP2.6 is considered as the best-case scenario whereas RCP8.5 is considered as the worst-case scenario. The RCPs and their development are further elaborated by (Van Vuuren, et al., 2011). **Figure 4.18** shows the graphical picture of GHG emission with RCP scenario from 2000-2100 to better understand RCP scenarios.

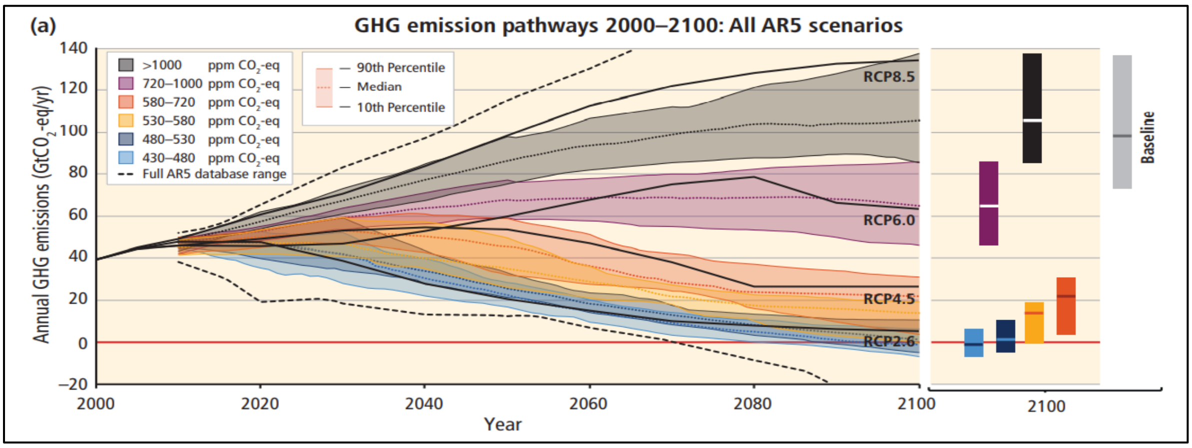


Figure 4.18 GHG emission with RCP scenarios (IPCC, 2014)

In the AR6 report of IPCC, five Shared Socioeconomic Pathways (SSP1, SSP2, SSP3, SSP4, SSP5) are development scenarios, each with different qualitative and quantitative characteristics that describe how the societal future might appear in terms of population growth, administrative effectiveness, inequality, socio-economic developments, institutional elements, technological evolution, and environmental conditions (Arnell & Lloyd-Hughes, 2014). The characteristics of SSPs explained by (O'Neill, et al., 2014) and extracted in short table format by (Arnell & Lloyd-Hughes, 2014) are shown in **Table 4.11.** The graphical representation of the SSP Pathway from 2014 to 2100 is presented in **Figure 4.19**. In the present study, to initiate a management model for the fourth coming rabi season and assess the impact of climate change on reservoir operation, climate data from downscaled GCMs of CMIP 6 were analyzed to select the most suitable model for the Sanjay Sagar project region.

Table 4.11 Shared Socioeconomic Pathways in context to mitigation and adaptation challenges level (O'Neill, et al., 2014; Arnell & Lloyd-Hughes, 2014)

Scenario	Condition	Challenges
SSP1	Sustainability	Low challenges to mitigation or adaptation
SSP2	Middle of the road	Intermediate challenges
SSP3	Fragmentation	High challenges to both mitigation and adaptation
SSP4	Inequality	Low challenges to mitigation, but high adaptation challenges
SSP5	Conventional development	Low challenges to adaptation, but high challenges to mitigation

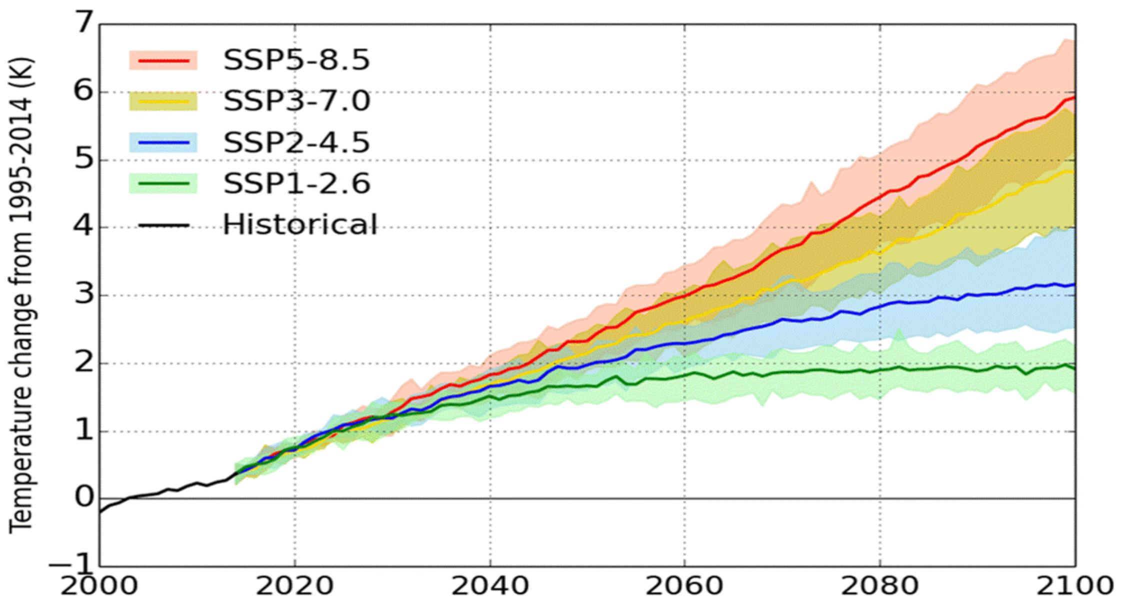


Figure 4.19 SSP Path (Source: Sung et al. (2021)

4.9.1 Climatic model used in the study

The bias-corrected and downscaled GCM dataset for different river basins across South Asia from 13 models taking part in the CMIP6 for future rainfall, maximum, and minimum temperature during 2015-2099 under SSP1-2.6, SSP2-4.5, and SSP5-8.5 from Mishra et al. (2020) (https://zenodo.org/record/3873998#.XthJB-TuGEd) were used in the analysis of climate change impact.

4.9.2 Selection of best suited GCM model

Climate models are intricate systems of equations and parameterizations that produce varying predictions for different regions and variables. It is crucial to assess the reliability and accuracy of these models by comparing their results with observed data, using statistical equations classified as frequency-based and time series-based metrics. The process of evaluating climate models is necessary to determine their dependability and trustworthiness and multiple criteria are available to judge the fitness of a GCM with concurrent observed data. In the present study, Nash-Sutcliffe efficiency (NSE), percentage bias (PBIAS), and coefficient of determination (R) were used and described here.

4.9.2.1 Nash-Sutcliffe efficiency (NSE)

The Nash-Sutcliffe efficiency can be computed using the following equation:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{i,obs} - Q_{i,sim})^2}{\sum_{t=1}^{T}(Q_{i,obs} - \overline{Q}_O)^2} \quad (4.75)$$

Where, $Q_{i,obs}$ and $Q_{i,sim}$ are the observed and simulated data at time i, and $\overline{Q_O}$ is the mean value of observed data. The NSE ranges from -∞ to 1, with 1 indicating a perfect match between the observed and modeled values, and values less than zero indicating that the model is worse than simply using the mean of the observed values. A value of zero indicates that the model predictions are as accurate as using the mean value of the observed data. In general, a higher NSE value indicates a better fit between the observed and modeled values, although the interpretation of what constitutes a good NSE value depends on the context and the specific application.

4.9.2.2 PBIAS (Percentage bias)

The PBIAS or percentage bias represents the cumulative difference in observed and simulated values about observed data. The PBIAS can be represented by the following equation:

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_{i,obs} - Q_{i,sim})}{\sum_{i=1}^{n} Q_{i,obs}} \times 100 \tag{4.76}$$

The optimum value of PBIAS is 0 whereas, the permissible range for a good performance model is between +15 to -15% (Shrestha et al, 2017; Sanchez, et al, 2017; Padhiary, et al, 2019). The model's positive value explains underestimation, and vice versa. The PBIAS represents the average tendency of the modeled values to be larger or smaller than the observed values. A PBIAS value of 0% indicates that the model has no systematic bias, i.e., the modeled values are on average as likely to be larger as smaller than the observed values. A positive PBIAS value indicates that the model tends to overestimate the observed values, while a negative value indicates that the model tends to underestimate the observed values. In general, a PBIAS value within +/-10% is considered acceptable for hydrological or environmental modeling applications.

4.9.2.3 R^2 (Coefficient of determination)

$$R^2 = \left(\frac{\sum_{i}^{n}(Q_{i,obs} - \overline{Q_{\mathrm{o}}})(Q_{i,sim} - \overline{Q_{,\mathrm{sim}}})}{\sqrt{\sum_{i=n}^{n}(Q_{i,obs} - \overline{Q_{\mathrm{o}}})^2 (Q_{i,sim} - \overline{Q_{\mathrm{sim}}})^2}} \right) \tag{4.77}$$

Where, $\overline{Q_{,\mathrm{sim}}}$ is the mean of simulated data. The value of R^2 value ranges from 0 to 1. Where a value nearer to 0 means very low correlation whereas a value close to 1 represents the highest correlation (Padhiary, et al., 2019; Vishwakarma, et al., 2020). The range of performance of model-based NSE, PBIAS (Sanchez, et al., 2017), and coefficient of determination (R^2) (Vishwakarma, et al., 2020) are presented in **Table 4.12**.

Table 4.12 Performance criterions for selection of model

Performance	NSE	PBIAS	R^2
Very good	0.75 to 1.00	$\leq \pm 10$	0.80 to 1.00
Good	0.65 to 0.75	$\leq \pm 15$	0.65 to 0.80
Satisfactory	0.50 to 0.65	$\leq \pm 25$	0.50 to 0.65
Unsatisfactory	Less than 0.5	$\geq \pm 25$	Less than 0.5

The best-selected model based on performance criteria can be selected for preliminary assessment of reservoir performance in DSS and future planning of irrigation and reservoir operation.

CHAPTER 5: RESULTS AND DISCUSSIONS

The irrigation return flow is a complex phenomenon of the hydrological cycle in the command affected by several interdependent factors like topography, soil, geology, method of conveyance & application, crop type and period, etc. The assessment of return flow is not easy and detailed system analysis is necessary to conclude to apply method for assessment of components of return flow. The present study was carried out to compute different components of irrigation return flow (rejuvenated and recharge) using three different techniques i.e. water balance, isotopic analysis, and hydrological modeling techniques. The study was planned for efficient irrigation management and hence MIKE Hydro Basin management model in conjunction with the MIKE 11 NAM model was developed for irrigation management in the Sanjay Sagar project. An Excel-based management model was developed which is simple but intrusive to take care of all aspects of water balance to optimize crop area for minimization of irrigation deficit. The web/mobile-based application developed under the study is an innovative effort to devise efficient communication among water resource managers, farmers, and other users for efficient operation of the reservoir using information and communication technology. The results of different analyses and development have been presented in the next sections.

5.1 Creation of GIS database

For scientific analysis and detailed study, the collection and analysis of available data are important to understand the cause and the magnitude of problems. The GIS database of the canal command area and Sanjay Sagar medium Project has been prepared using QGIS software and consists of various themes including the canal network map, Digital Elevation Model, soil map, command area map, etc. The QGIS has been used for the preparation of various thematic maps.

5.1.1 Drainage map

The drainage map of the catchment, of the Sanjay Sagar medium Project and its command up to the G/D site, has been prepared using Cartosat-1 Satellite data which are available on the Bhuvan portal of ISRO, as shown in **Figure 5.1**. The dam is constructed across the Bah River, which is a tributary of the Betwa River. It is an earth-cum masonry dam with a catchment area of 512 km^2 and provides irrigation facilities in the area of 9893 ha of CCA with G.C.A. of about 12783 Ha. in Vidisha Distt. It is located at 23^o 46' N & 77^o 31' E in District Vidisha.

5.1.1 Digital elevation model (DEM)

The DEM of the study area has been prepared from ASTER DEM and presented in **Figure**

5.2. The elevation in the catchment of Sanjay Sagar dam varied from 400 m to 584 m above msl. The topography of the catchment is of rolling nature with slight flat to moderated slope, while command has flat land.

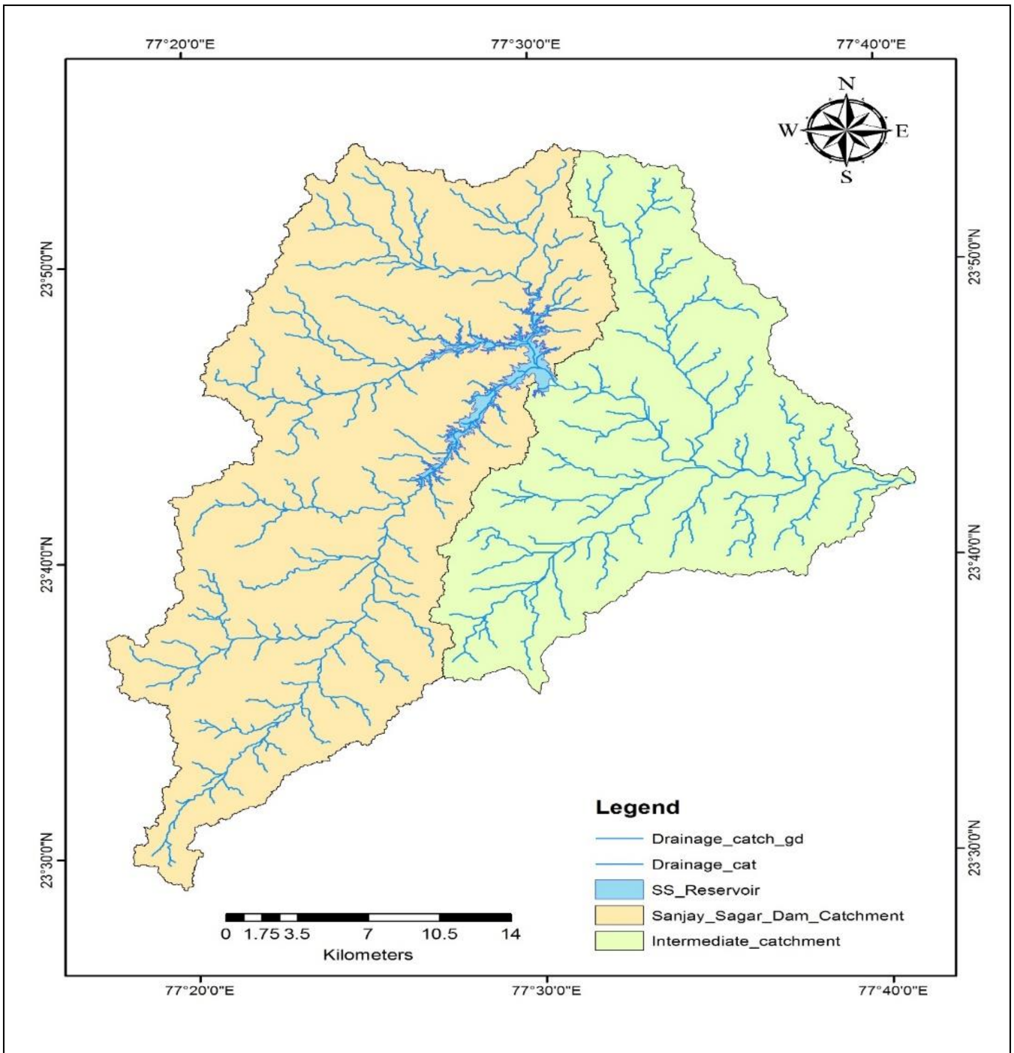


Figure 5.1 Drainage network map of catchment area

5.1.3 Soil Map

The soil map of the study area has been prepared from the soil map of the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP). According to the soil map, there are two major soils in which the maximum spread is clay soil consisting of 57% and loamy soil is 43%. The soil map has been presented in **Figure 5.3.**

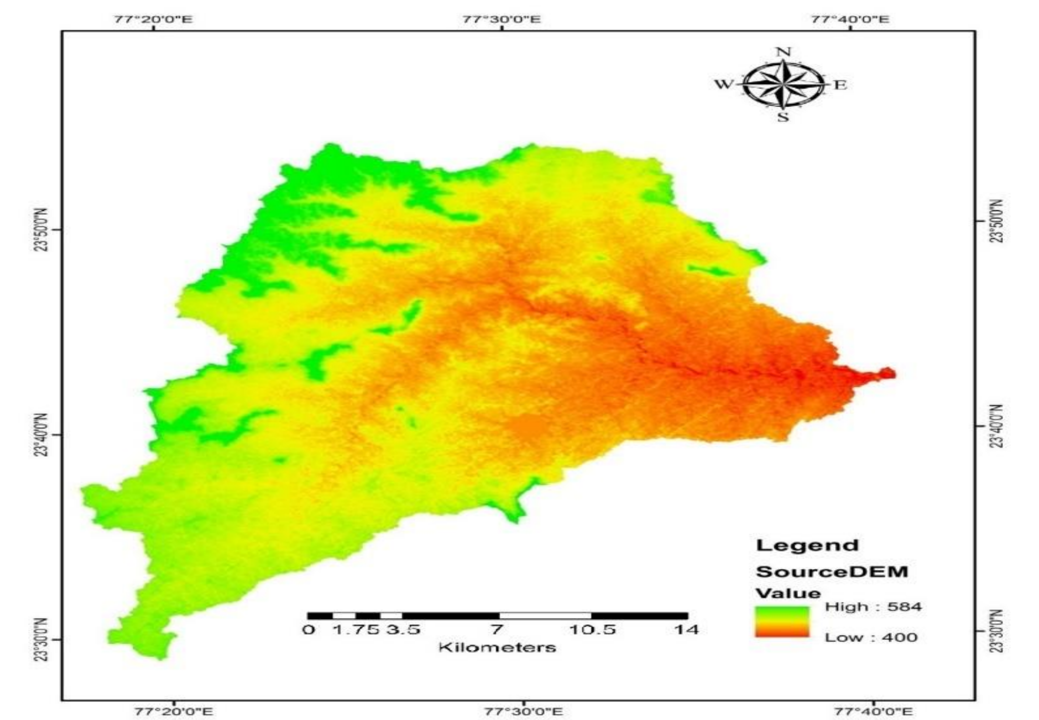


Figure 5.2 DEM of the catchment of the Sanjay Sagar Project

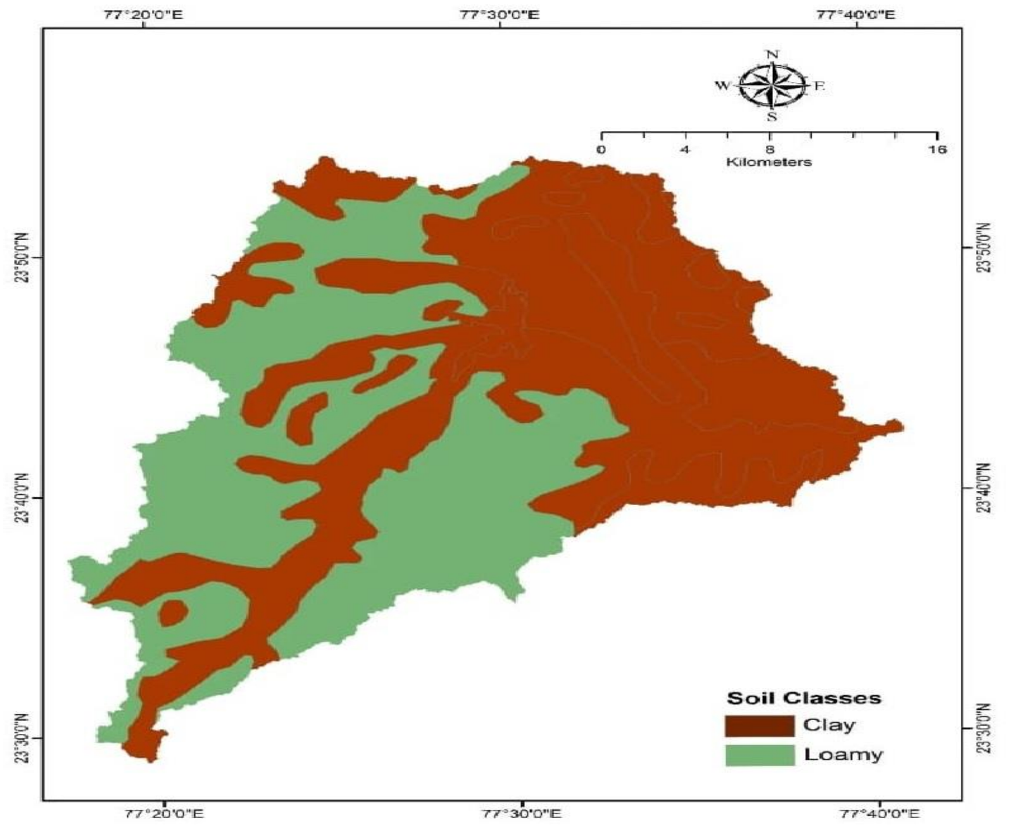


Figure 5.3 Soil map of the Study area

5.1.4 Land use and land cover (LULC)

In the present study, Landsat 8 images have been downloaded from the USGS website and the supervised classification technique of image processing has been used for the preparation of land use land cover maps prior (2005-06), (2011-12) and after the Sanjay Sagar dam (2015-16) for the catchment of the dam and intercepted area from dam to G/D site on Bah River in the command. The LULC maps of 2005-06, 2011-12, and 2015-16 have been shown in **Figures 5.4(a) to 5.4(c)** respectively.

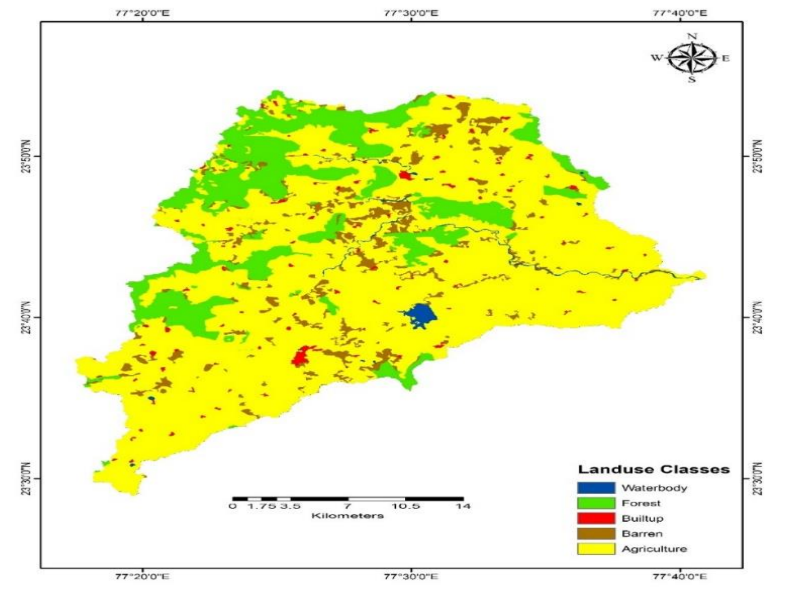


Figure 5.4(a) LULC of the year 2005-06

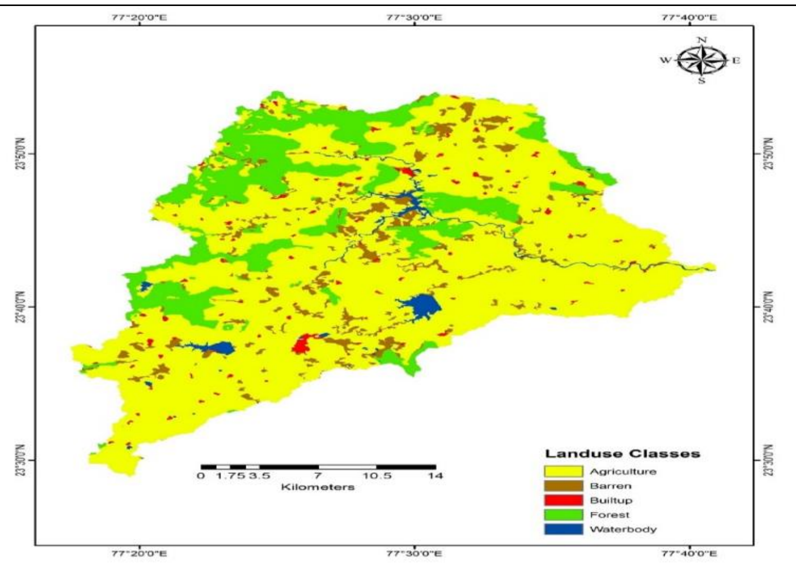


Figure 5.4(b) LULC of the year 2011-12

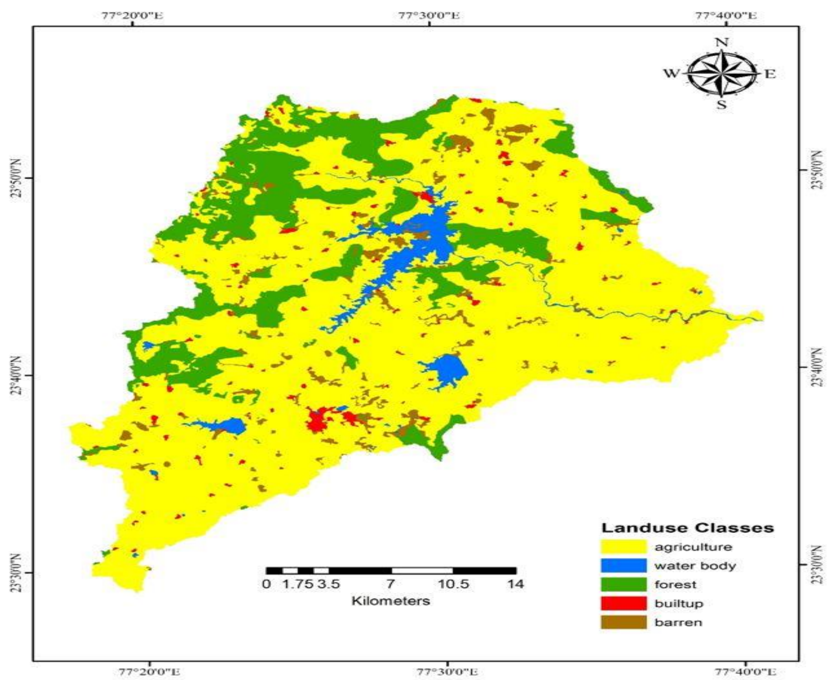


Figure 5.4(c) LULC of the year 2015-16

The tabular distribution of different classes and their changes has been presented in **Table 5.1.** From the analysis, it has been observed that the major land use in catchments is agriculture which contributed nearly 70 to 80% part in the catchment up to the Bah River G/D site. Due to the commissioning of the Sanjay Sagar dam, the agriculture and water bodies have increased while barren land has been reduced and converted into built-up land.

Table 5.1 Distribution of land uses in Bah River catchments up to G/D site (km^2)

Classifications	LULC (2005-06)	LULC (2011-12)	LULC (2015-16)
Agriculture	655.52	648.34	656.62
Water	7.50	15.40	30.23
Forest	153.32	151.26	144.41
Urban	9.70	10.10	12.82
Barren	53.46	54.44	35.49
Total	879.5	879.5	879.5

5.2 Results of Soil Testing

In the present study, detailed soil testing for soil water retention characteristics and textural analysis were carried out on twelve different sites in the Sanjay Sagar Command (**Figure 5.5**). The details of the soil sample location of Sanjay Sagar command have been presented in **Table 5.2.** The soil samples were collected using standard procedure and sent to NIH Roorkee lab for further analysis. In-situ testing for infiltration and saturated hydraulic conductivity was carried out using a double-ring infiltrometer and Guelph permeameter on twelve sites in the command.

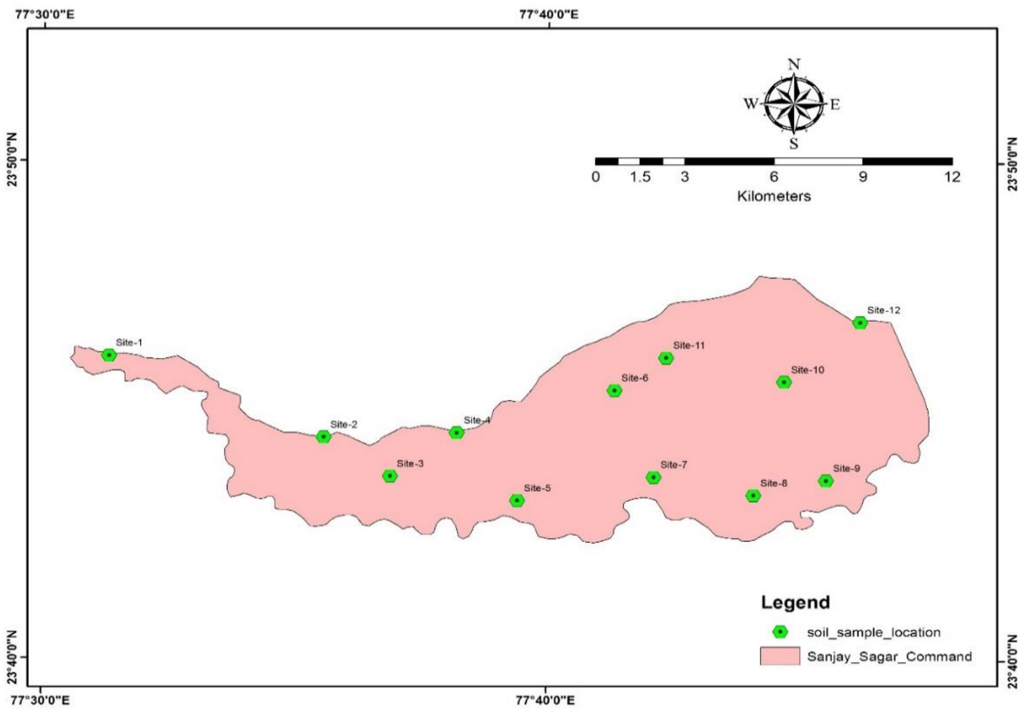


Figure 5.5 Location of soil sample sites in Sanjay Sagar Command

Table 5.2 Soil Sample Location of Sanjay Sagar Command

Site name	Lat	Long	Village Name	District
Site-1	23.768	77.522	Majhera	Vidisha
Site-2	23.741	77.593	Purakhana	Vidisha
Site-3	23.728	77.615	Khajuri Samshabad	Vidisha
Site-4	23.7426	77.637	Bhairbong	Vidisha
Site-5	23.72	77.657	Amarpura	Vidisha
Site-6	23.757	77.689	Rinia	Vidisha
Site-7	23.728	77.702	Pipri	Vidisha
Site-8	23.722	77.735	Kasba khedi	Vidisha
Site-9	23.727	77.759	Gujarkhedi	Vidisha
Site-10	23.76	77.745	Chamraha	Vidisha
Site-11	23.768	77.706	Sirsi	Vidisha
Site-12	23.78	77.77	Nateran	Vidisha

5.2.1 Textural analysis

The textural analysis was carried out using Particle Size Analyser and presented in **Table 5.3** and **Annexure-II.** From the analysis, it was concluded that the soil in the Sanjay Sagar command was mainly silty loam where silt (0.05 to 0.002 mm) was the major constituent. The silty loam soil is considered good for nutrient supplies and water retention.

Table 5.3 Results of textural analysis of soils in Sanjay Sagar command

S N	Site Code	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Soil Type
1	S-1	2.77	9.91	69.02	18.31	Silty Loam
2	S-2	0.03	11.55	72.03	16.39	Silty Loam
3	S-3	0.84	91.53	6.03	1.59	Sand
4	S-4	1.41	8.00	72.32	18.27	Silty Loam
5	S-5	1.44	6.33	68.20	24.04	Silty Loam
6	S-6	2.14	6.54	70.54	20.78	Silty Loam
7	S-7	4.55	9.51	63.31	22.63	Silty Loam
8	S-8	2.19	12.87	71.44	13.49	Silty Loam
9	S-9	2.63	9.13	63.51	24.74	Silty Loam
10	S-10	3.50	10.81	63.25	22.44	Silty Loam
11	S-11	0.97	10.16	73.14	15.73	Silty Loam
12	S-12	4.46	10.18	62.66	22.70	Silty Loam

5.2.2 Soil water retention analysis

The soil water rete Soil water-driven properties are basic requirements for water balance in irrigation and drainage, leaching requirements of salts, water supply to plants, and other agronomical and natural applications (Fredlund et al.1997; Rousseva et al 2017). The soil water retention at 0.33 and 15 bars is indicative of field capacity and permanent wilting point and determines the soil availability moisture readily available to plants. The soil samples collected from twelve different sites were analyzed at NIH Roorkee using Pressure Plate Apparatus for 0.1, 0.33, 0.50, 0.70, 1, 3, 5, 7, 10, and 15 bars, and soil moisture was determined. The soil moisture at different suction pressures is given in **Table 5.4** and the graphical representation in **Figure 5.6.** The soil in the command has average soil water retention at field capacity and permanent wilting points are 35.77 and 19.66% respectively. The results of the analysis have been used in developing the MIKE HYDRO basin model and irrigation planning through Excel programming.

Table 5.4 Results of soil water retention in soils of Sanjay Sagar command

S. N.	Site Code	Soil moisture (%) at different pressures in the bar									
		0.10	0.33	0.50	0.70	1.00	3.00	5.00	7.00	10.00	15.00
			Field Cap.								Wilt. Point
1	S-1	37.06	34.98	29.08	28.41	24.45	20.80	22.91	21.38	20.80	18.34
2	S-2	38.95	33.51	27.37	26.92	25.10	19.23	20.02	19.98	19.77	19.24
3	S-3	51.52	41.72	35.37	34.60	32.62	27.23	27.21	26.52	26.24	24.65
4	S-4	42.78	38.34	33.05	29.72	28.30	21.38	23.10	21.93	21.83	20.14
5	S-5	48.25	40.26	34.97	33.95	29.49	24.79	26.34	24.98	24.26	22.51
6	S-6	39.96	35.67	30.81	32.40	26.58	20.73	22.46	22.20	22.16	18.80
7	S-7	50.72	42.19	37.65	37.33	34.16	25.77	27.96	26.15	25.97	23.87
8	S-8	43.11	33.80	30.36	30.34	26.04	19.00	21.48	19.05	20.14	18.00
9	S-9	36.08	30.27	26.99	25.94	23.32	19.19	18.04	17.30	17.22	16.54
10	S-10	35.27	30.39	27.72	26.29	23.69	19.88	19.61	17.94	18.73	17.23
11	S-11	43.26	34.86	31.12	29.37	26.17	21.99	21.78	19.32	20.30	19.62
12	S-12	39.48	33.26	29.98	28.79	25.30	21.04	21.00	19.08	19.60	16.99
Average		**42.20**	**35.77**	**31.21**	**30.34**	**27.10**	**21.75**	**22.66**	**21.32**	**21.42**	**19.66**
Minimum		**35.27**	**30.27**	**26.99**	**25.94**	**23.32**	**19.00**	**18.04**	**17.30**	**17.22**	**16.54**
Maximum		**51.52**	**42.19**	**37.65**	**37.33**	**34.16**	**27.23**	**27.96**	**26.52**	**26.24**	**24.65**

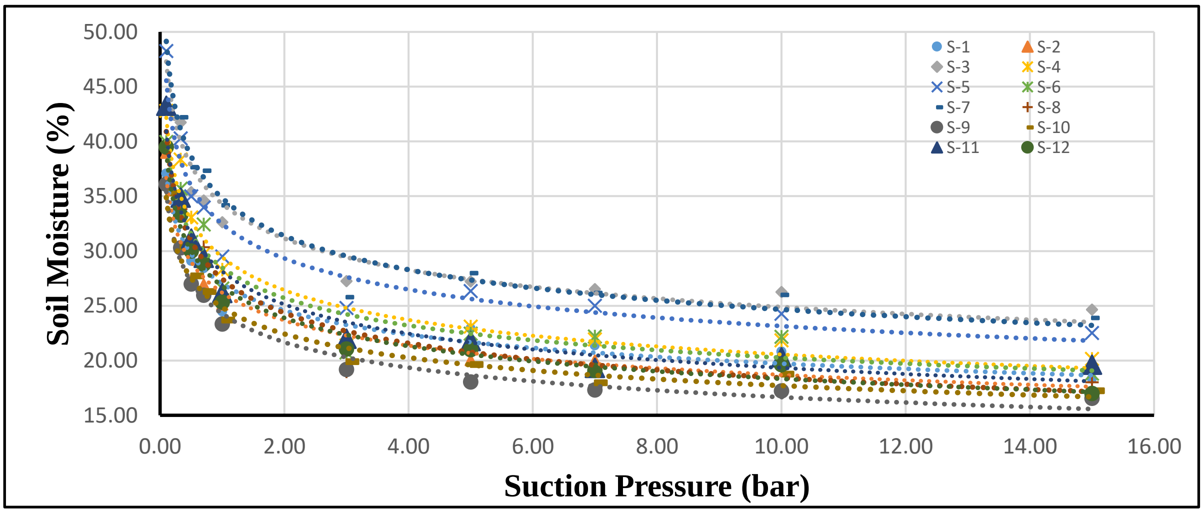


Figure 5.6 Soil water retention curves for soils in the Sanjay Sagar command

5.2.3 Results of Infiltration Tests

The rate of infiltration from the vadose zone of soil is one of the important factors for deciding the amount of water and its frequency for irrigation and water balance in command areas. The infiltration tests on twelve sites have been conducted using a double-ring infiltrometer.

Kostiakov's, modified Kostiakov's, Horton's, Green & Ampt's, and Philip's models have been fitted with test data for computation of model parameters which was used to understand the infiltration process in command areas. The parameters of various applied infiltration models have been presented in **Table 5.5**. For the determination of the best-fitted model at any site, root mean square (RMSE), Integral square error (ISE), and efficiency have been computed and results have been presented in **Table 5.6.** It has been observed that in most of the sites, Kostiakov's model has given lower RMSE, ISE, and higher efficiency except sites no. 2, 7, 8, and 9 where Modified Kostiakov's model was found the best-suited model and can be used as for computation of infiltration rate. The infiltration curves for these sites have been presented in **Figure 5.7(a)** and **Figure 5.7(b).** The spatial distribution of the constant rate of infiltration has been presented in **Figure 5.8.**

Table 5.5 Parameters of various infiltration models

Sites	Kostiakov's Model		Modified Kostiakov's Model			Horton's model			Philip's two-term model	
	K_K	*A*	*B*	*N*	*ic*	*fc*	*fo*	*k*	*S*	*A*
Site-1	0.698	0.8857	0.059	0.9311	0.0107	1.1	4.406	0.0135	0.0445	0.0383
Site-2	5.5493	0.3925	8.2495	0.3252	-3.3996	6.0	59.016	0.0359	4.6237	-0.0854
Site-3	0.2829	0.5945	0.2568	0.6131	0.0474	1.1	4.214	0.0196	0.2975	0.0144
Site-4	0.1958	0.5945	0.2547	0.5447	-0.1032	1.1	3.347	0.0186	0.1958	0.0126
Site-5	0.1193	0.7073	0.152	0.688	-0.0824	1.05	3.506	0.0152	0.0909	0.0295
Site-6	0.2176	0.4843	0.313	0.4204	-0.1339	0.6	4.418	0.0503	0.1835	0.006
Site-7	1.5497	0.4549	5.1555	0.2569	-4.3886	1.5	29.963	0.0434	0.9422	0.1279
Site-8	0.7353	0.3370	0.5742	0.3761	0.2082	0.8	11.010	0.0556	0.6587	00.0319
Site-9	0.9171	0.5266	1.7018	0.4163	-1.1755	0.6	15.483	0.0184	0.8242	0.0329
Site-10	0.2641	0.4178	0.2924	0.4010	-0.0392	0.4	2.784	0.0164	0.2336	-0.0035
Site-11	0.220	0.5775	0.1949	0.5999	0.0463	1.0	4.504	0.0243	0.2388	0.0068
Site-12	0.7555	0.4747	0.8519	0.4537	-0.1489	1.5	7.461	0.0205	0.7061	0.0006

5.2.4 Results of the hydraulic conductivity test

The Guelph permeameter has been used to determine the field saturated hydraulic conductivity in cm/hr, metric flux potential (ϕm) in cm^2/sec, sorptivity (S) in cm/sec$^{-½}$ and constant (α) in cm$^{-1,}$ and results have been presented in **Table 5.7.** From the analysis, it has been observed that the field-saturated hydraulic conductivity in the study area varies between 0.14 cm/hr to 8.64 cm/hr.

Table 5.6 Performance evaluation of various infiltration models

Sites	Kostikov's model			Modified Kostikov's model			Philip's two-term model			Horton's model		
	RMSE	*ISE*	η	*RMSE*	*ISE*	η	*RMSE*	*ISE*	η	*RMSE*	*ISE*	η
Site-1	0.055	0.037	97.98	0.067	0.045	96.99	0.067	0.045	97.03	0.338	0.122	-
Site-2	0.367	0.014	98.66	0.344	0.014	98.82	0.830	0.036	90.39	8.597	0.210	42.04
Site-3	0.018	0.006	99.90	0.019	0.006	99.88	0.043	0.015	99.24	0.659	0.183	26.53
Site-4	0.030	0.030	97.93	0.079	0.041	96.68	0.053	0.031	97.55	0.628	0.385	-
Site-5	0.029	0.028	98.39	0.056	0.089	94.32	0.138	0.092	83.45	0.333	0.155	27.69
Site-6	0.031	0.031	97.37	0.053	0.038	96.34	0.136	0.101	67.91	0.404	0.237	46.18
Site-7	0.475	0.055	84.38	0.247	0.029	95.78	2.709	0.326	-	1.879	0.131	72.03
Site-8	0.086	0.032	96.27	0.078	0.029	96.88	0.388	0.144	24.16	1.615	0.304	49.64
Site-9	0.352	0.048	91.01	0.245	0.033	95.66	0.529	0.074	77.22	1.433	0.156	55.95
Site-10	0.034	0.022	97.94	0.036	0.023	97.71	0.052	0.036	93.54	0.495	0.243	39.64
Site-11	0.025	0.016	99.53	0.056	0.022	98.90	0.037	0.021	98.62	0.447	0.167	51.07
Site-12	0.071	0.013	99.24	0.083	0.016	98.97	0.113	0.024	97.27	1.344	0.227	29.05

RMSE: Root mean square error, *ISE*: Integral square error, η: Nash-Sutcliffe efficiency

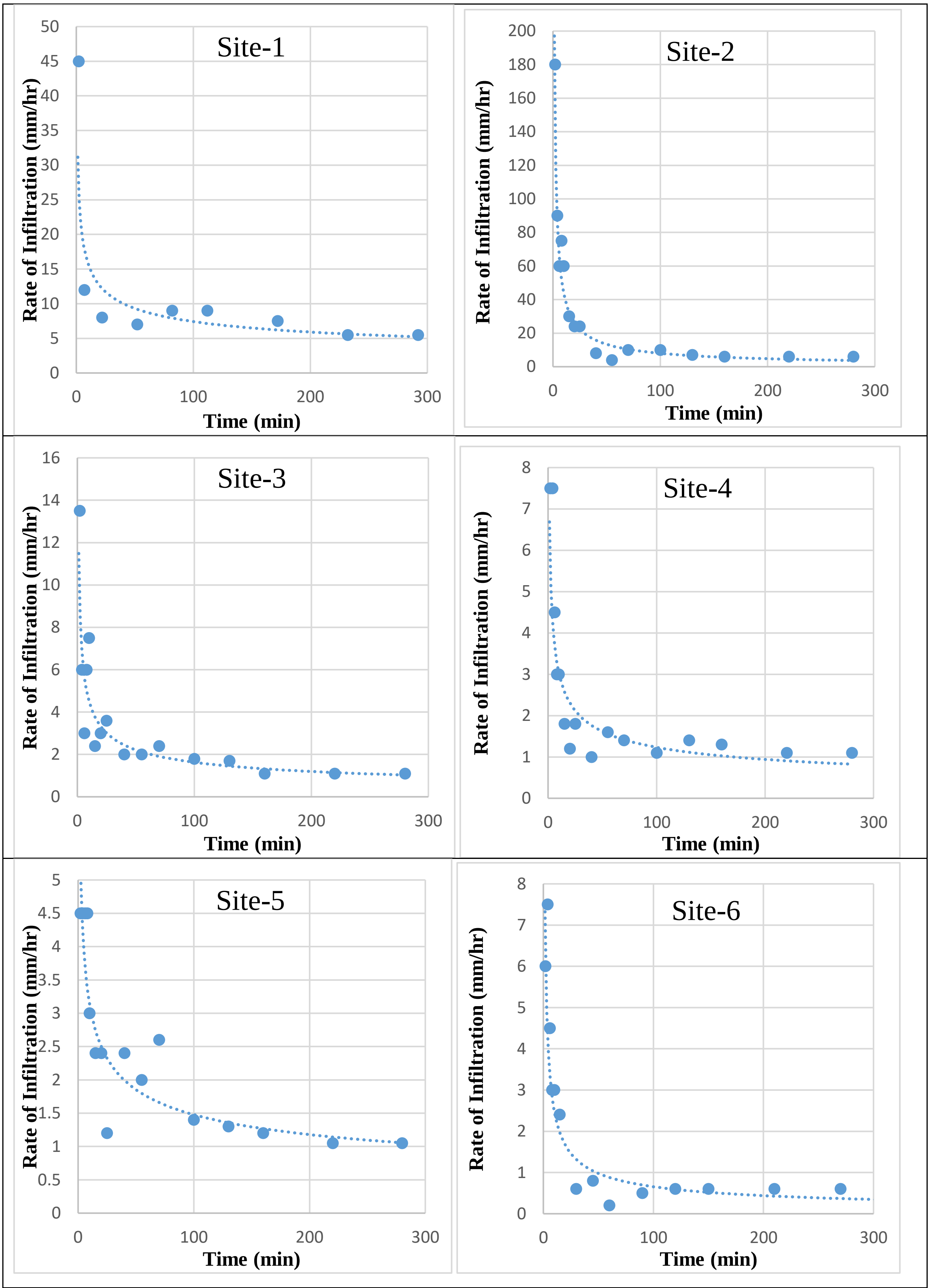


Figure 5.7(a) Infiltration curves for site-1 to site-6 in commands of Sanjay Sagar Dam

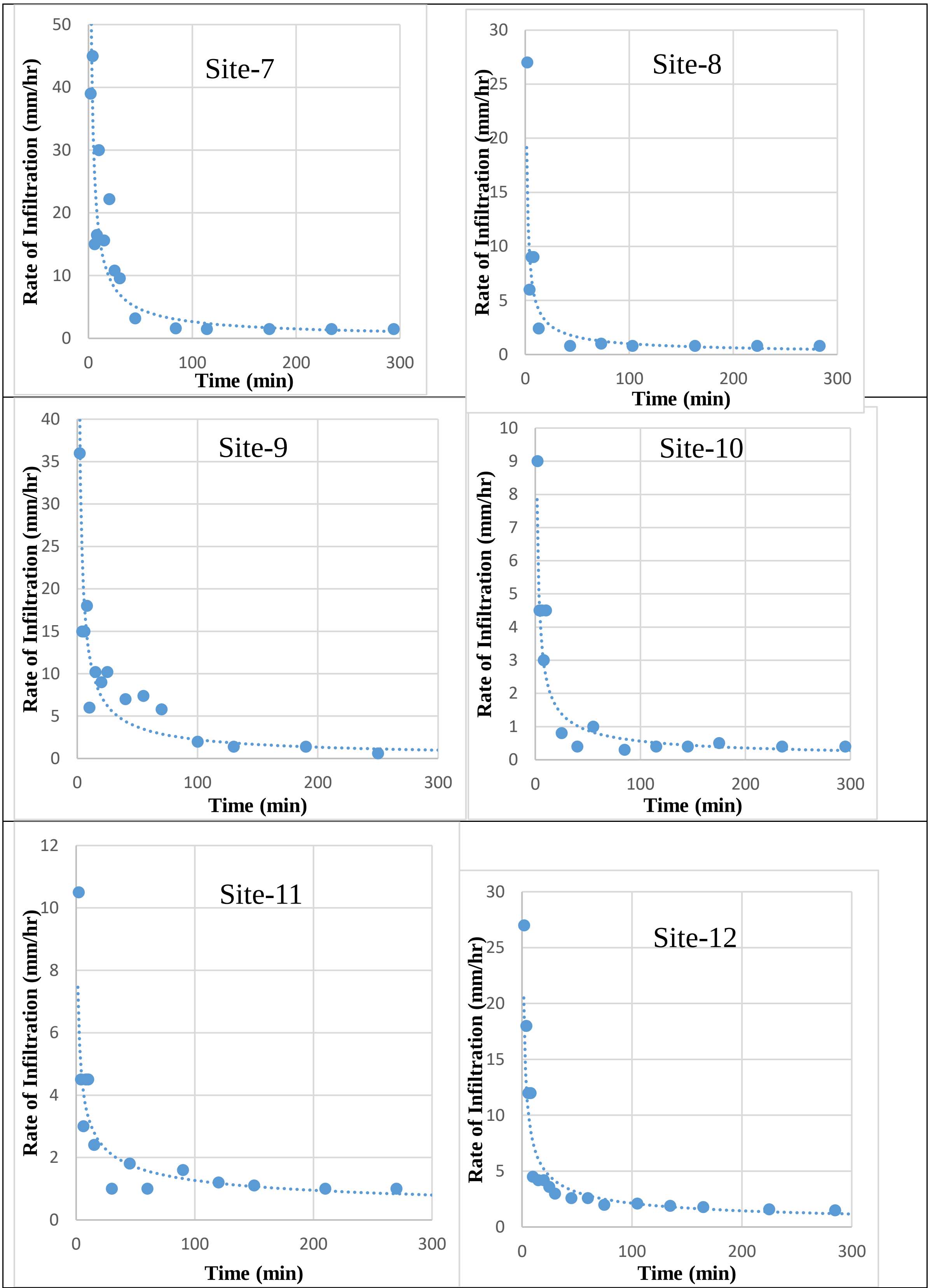


Figure 5.7(b) Infiltration curves for site-7 to site-12 in commands of Sanjay Sagar Dam

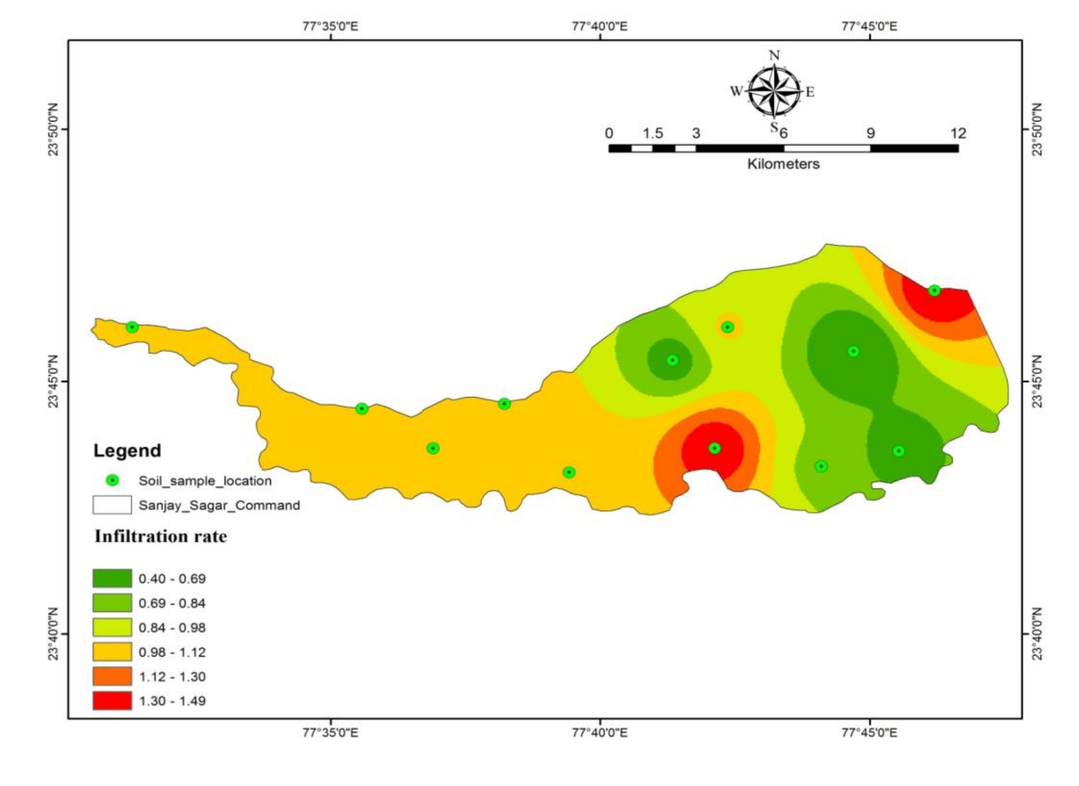


Figure 5.8 Spatial variation in infiltration rate of Sanjay Sagar Command

Table 5.7 Saturated hydraulic conductivity and other parameters for different sites in command of Sanjay Sagar Dam (Bah)

S.N.	Hydraulic conductivity (Ks) (cm/hr)	Metric flux potential (ϕm) (cm^2/sec)	Sorptivity (S) cm/sec$^{1/2}$	α (1/cm)
1.	0.383	0.0001	0.007	1.520
2.	0.157	0.0001	0.004	0.564
3.	0.157	0.0001	0.007	0.564
4.	0.191	0.0000	0.005	1.520
5.	8.642	0.0072	0.039	0.333
6.	0.148	0.0002	0.009	0.186
7.	0.191	0.0000	0.005	1.520
8.	0.157	0.0001	0.564	0.000
9.	0.991	0.0001	0.008	2.078
10.	0.191	0.0000	0.004	1.520
11.	4.608	0.0033	0.040	0.393
12	3.164	0.0006	0.006	1.520

5.2.5 Soil moisture assessment

The Soil moisture samples on four different sites the Sanjay Sagar command on the depth of 0, 30, 60, and 90 cm depths. The location map of the sites for the collection of soil moisture samples is presented in **Figure 5.9**. During the rabi period of 2021-22, samples were collected 5 times on each site and analyzed for volumetric contents. The depth average volumetric soil moisture on different sites is given in **Table 5.8**. From the analysis, the soil moisture in different periods varied from 4.96 to 9.49% during the 2021-22 rabi season.

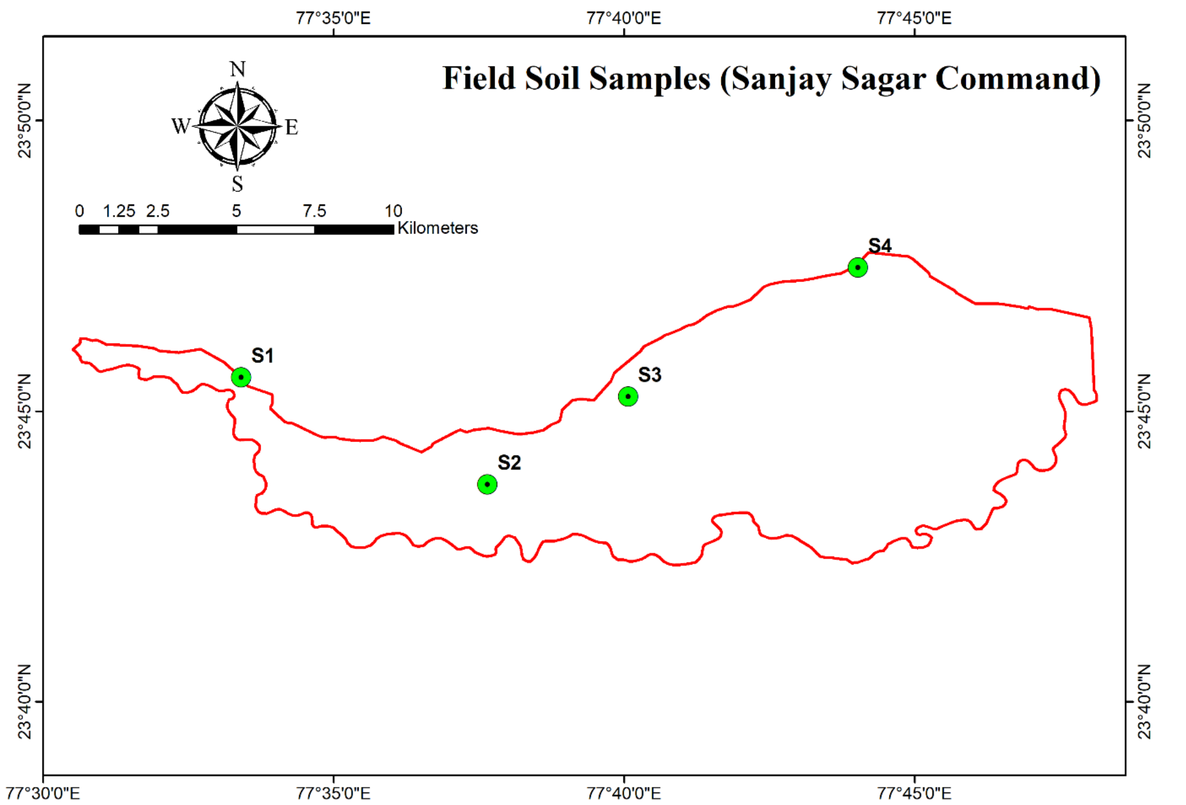


Figure 5.9 Sites for collection of soil moisture samples

Table 5.8 Soil moisture from field samples on different dates in the year 2021-22

Sr. No.	Sample ID	Date	Location	Water Content	%MC (Volumetric)
1	PDS_IRF_SS_13	8-Dec-21	S3	17.05	6.43
2	PDS_IRF_SS_18	8-Dec-21	S2	16.64	6.28
3	PDS_IRF_SS_20	8-Dec-21	S4	22.47	8.48
4	PDS_IRF_SS_21	8-Dec-21	S1	22.88	8.63
5	PDS_IRF_SS_3	15-Dec-21	S1	24.68	9.31
6	PDS_IRF_SS_6	15-Dec-21	S2	20.58	7.77

7	PDS_IRF_SS_9	15-Dec-21	S3	16.21	6.12
8	PDS_IRF_SS_33	15-Dec-21	S4	15.80	5.96
9	PDS_IRF_SS_55	4-Jan-22	S3	17.74	6.69
10	PDS_IRF_SS_58	4-Jan-22	S1	25.15	9.49
11	PDS_IRF_SS_59	4-Jan-22	S2	20.21	7.63
12	PDS_IRF_SS_29	14-Jan-22	S1	23.39	8.82
13	PDS_IRF_SS_32	14-Jan-22	S2	23.98	9.05
14	PDS_IRF_SS_65	24-Jan-22	S2	21.33	8.05
15	PDS_IRF_SS_67	24-Jan-22	S4	14.62	5.52
16	PDS_IRF_SS_69	24-Jan-22	S1	22.68	8.56
17	PDS_IRF_SS_44	3-Feb-22	S4	13.15	4.96
18	PDS_IRF_SS_45	3-Feb-22	S1	17.44	6.58
19	PDS_IRF_SS_50	3-Feb-22	S2	13.37	5.04

The SMAP (Soil Moisture Active Passive) data has been used to analyze the relationship of satellite data with the field survey points. The "NASA-USDA Enhanced SMAP Global Soil Moisture Data" subsurface soil moisture dataset was used to develop a relationship between the field and satellite results with the help of Google Earth Engine (**Figure 5.10**).

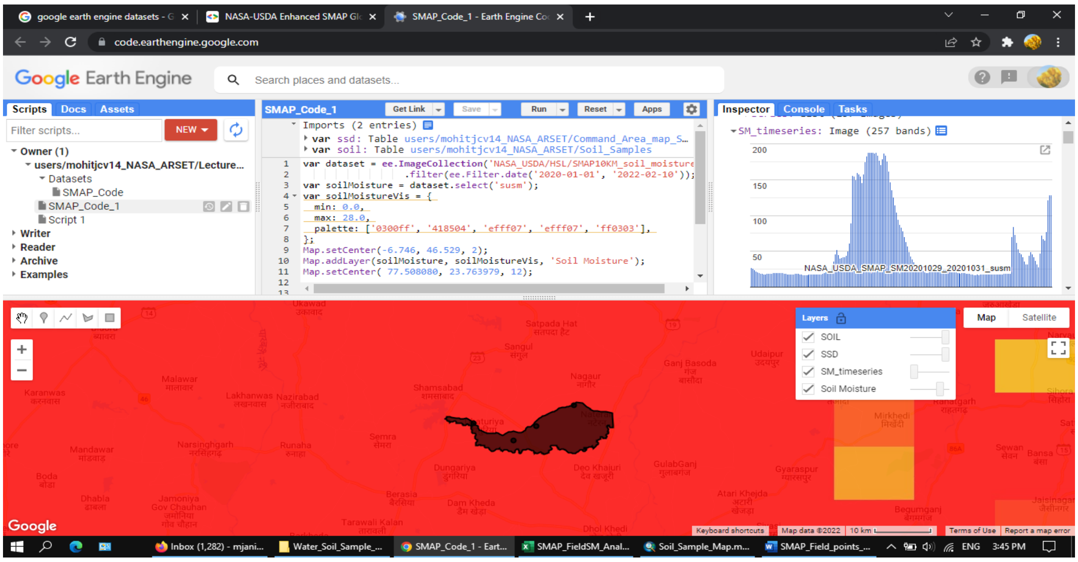


Figure 5.10 SMAP data in GEE

From the analysis, it has been found that three pixels of SMAP data covered the command of Sanjay Sagar command, and hence, three sites were used to compare SMAP soil moisture with field-driven soil moisture. The soil moisture on different sites and SMAP for the rabi crop seasons of 2020-21 and 2021-22 were presented in **Figure 5.11(a) to 5.11(c)** and **Table 5.9** with close resemblance so SMAP data can be used for moisture mapping**.**

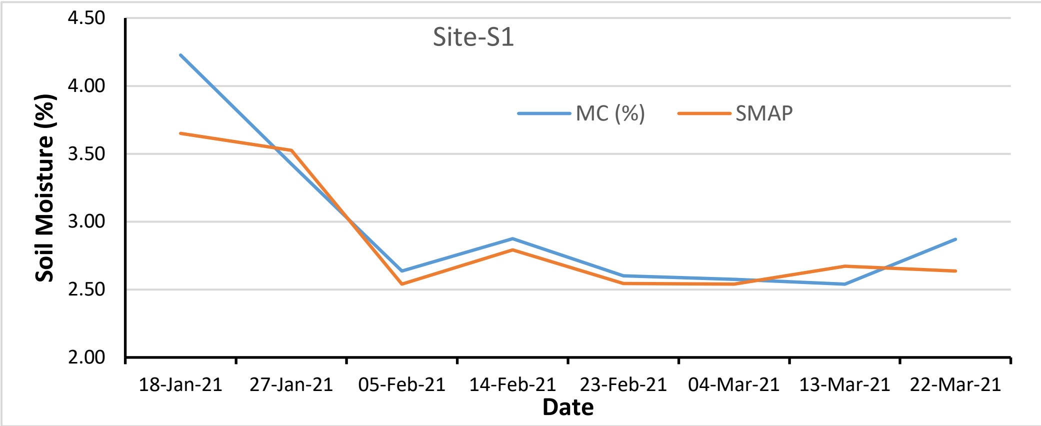


Figure 5.11(a) SMAP and observed soil moisture at Site S-1

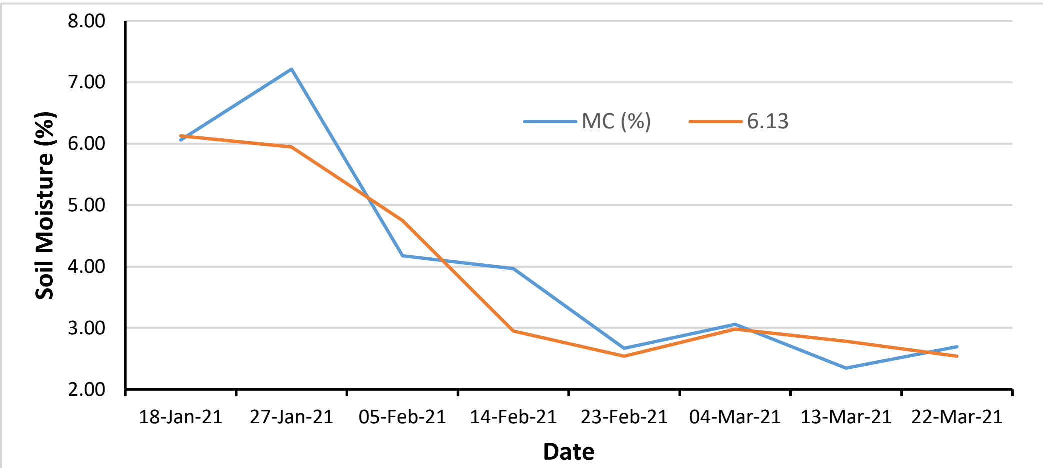


Figure 5.11(b) SMAP and observed soil moisture at Site S-2

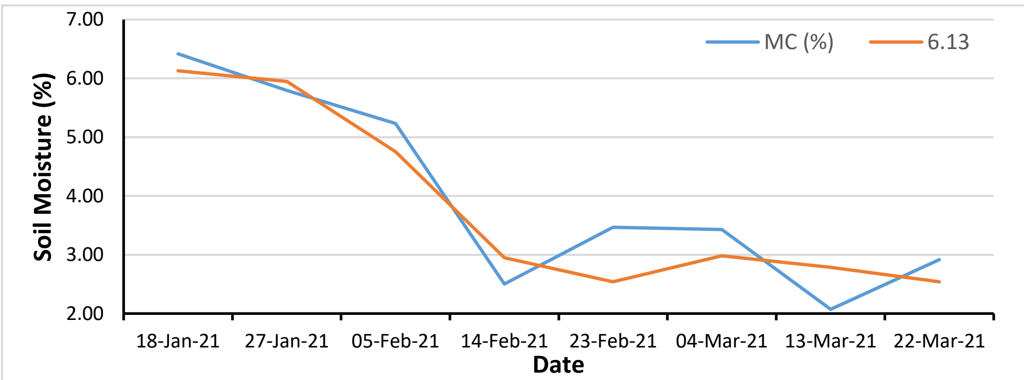


Figure 5.11(c) SMAP and observed soil moisture at Site S-3

Table 5.9 Soil moisture from field analysis and SMAP

Crop	Date	SMAP	S1	S2	S3
Crop Year 2020-21	18-Jan-21	6.13	6.42	4.23	6.07
	27-Jan-21	5.95	5.80	3.42	7.22
	5-Feb-21	4.75	5.23	2.64	4.18
	14-Feb-21	2.95	2.50	2.87	3.97
	23-Feb-21	2.54	3.47	2.60	2.67
	4-Mar-21	2.98	3.43	2.57	3.06
	13-Mar-21	2.79	2.07	2.54	2.35
	22-Mar-21	2.54	2.92	2.87	2.69
Crop Year 2021-22	8-Dec-21	6.74	8.63	6.28	6.43
	15-Dec-21	7.15	9.31	7.77	6.12
	4-Jan-22	8.89	9.49	7.63	6.69
	14-Jan-22	10.68	8.82	9.05	
	24-Jan-22	10.11	8.56	8.05	

The correlation between the SMAP dataset and field points is shown in **Figure 5.12(a) to 5.12(c).** The coefficient of correlations between observed and SMAP soil moistures in the sites S1 to S3 computed as 0.80, 0.81, and 0.83 respectively indicated an appropriate match. As SMAP data were matched appropriately with the field-collected samples from the command, it may be concluded that SMAP data can be used for the water balance analysis technique for the computation of IRF.

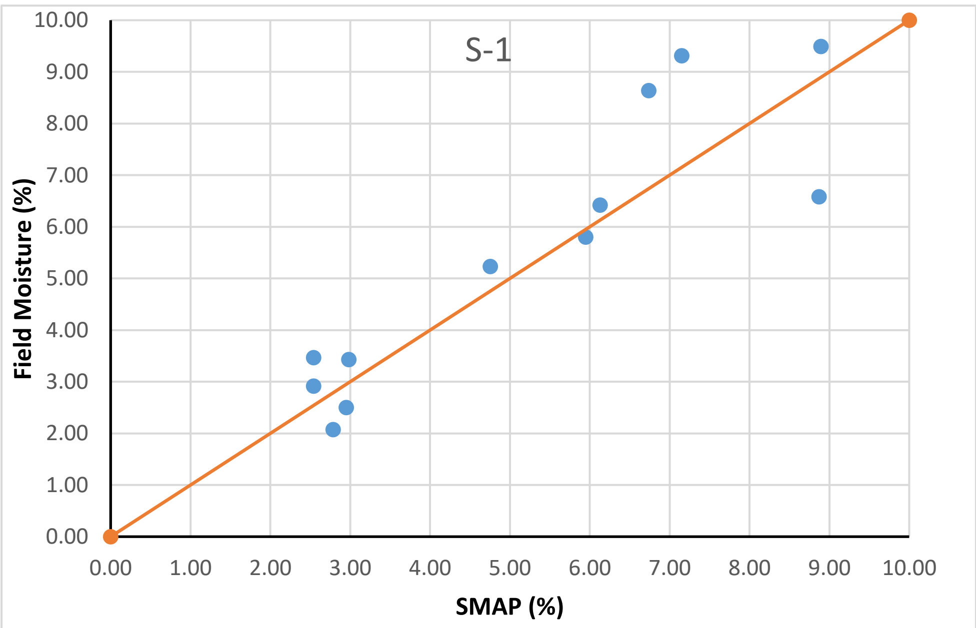


Figure 5.12(a) Field observed and SMAP soil moisture for Site S1

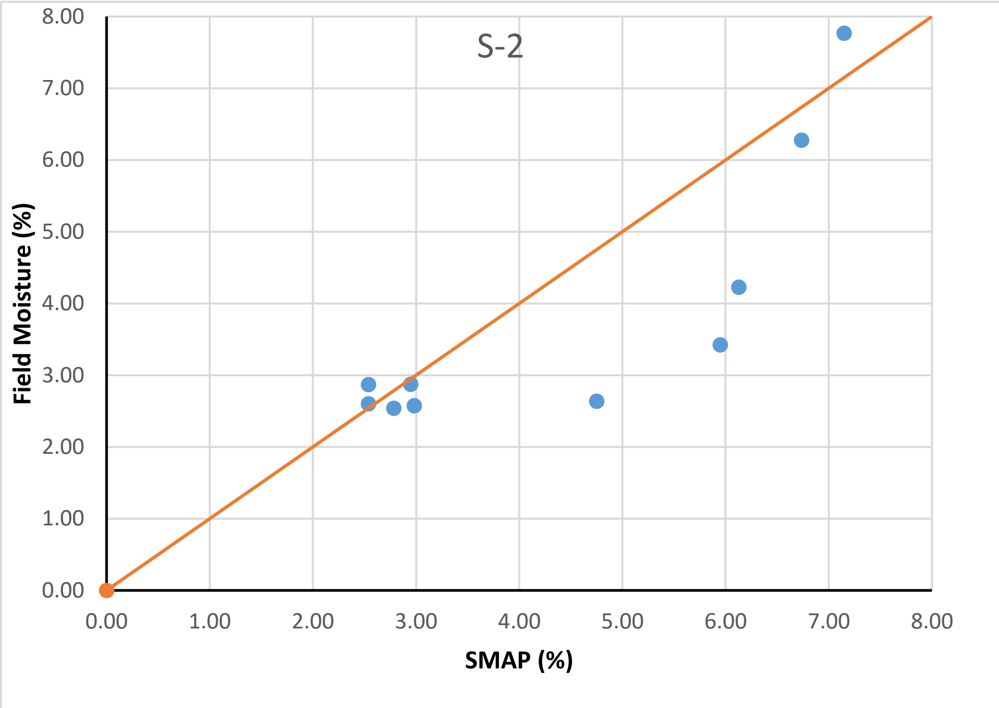


Figure 5.12(b) Field observed and SMAP soil moisture for Site S2

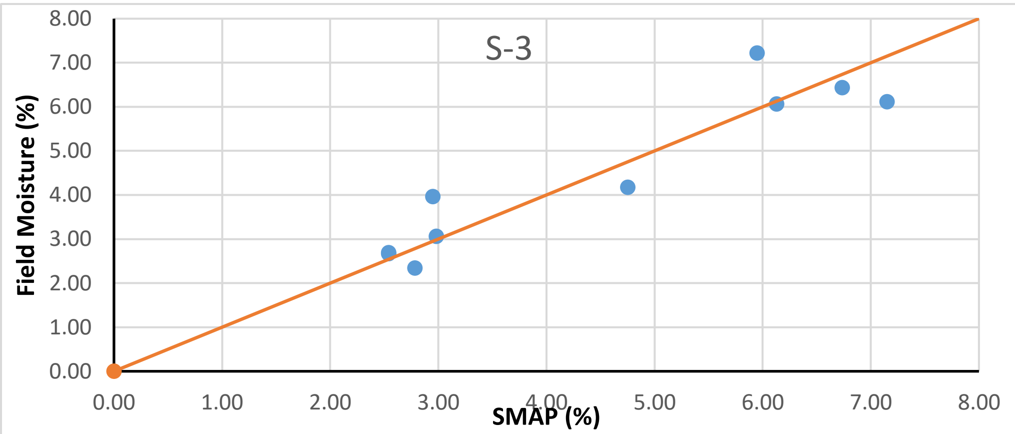


Figure 5.12(c) Field observed and SMAP soil moisture for Site S3

5.3 Hydrometeorological Data Analysis

5.3.1 Rainfall data

Nateran, Berasia, and Lateri are three rain gauge stations that have their effect in the catchment and command areas of the Sanjay Sagar Project. The rainfall data of all three stations have been collected from 1981 to 2022. The analysis of rainfall data helps to estimate flow in the Bah River after and before the construction of the dam during the Rabi session. The annual rainfall of all rain gauge stations has been presented in **Figure 5.13** and statistical analysis for Nateran, Berasia, and Lateri in **Table 5.10(a) to 5.10(c)** respectively. Nateran R.G. station has the highest mean annual rainfall of more than 1156 mm, while Berasia showed a minimum of 898 mm.

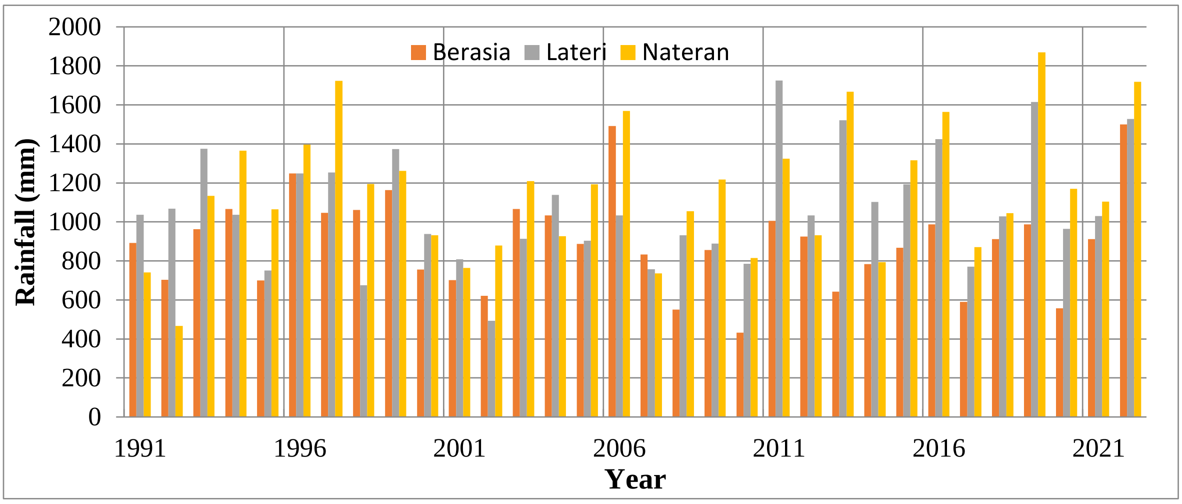


Figure 5.13 Rainfall distribution in three stations of the Bah River basin

Table 5.10(a) Statistical analysis of rainfall for Nateran RG station (mm)

Statistical Parameters	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Mean	1156.86	23.59	1061.62	43.81	27.84
Median	1151.58	14.22	1067.72	20.33	17.46
SD	335.71	30.88	313.76	71.61	35.36
CV	0.29	1.31	0.30	1.63	1.27
Max	1870.06	141.18	1764.92	350.00	169.50
Min	466.00	0.00	434.00	0.00	0.00

Table 5.10(b) Statistical analysis of rainfall data for Lateri RG station (mm)

Statistical Parameters	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Mean	1073.26	14.90	1004.63	31.25	22.49
Median	1032.85	0.00	986.57	2.71	8.07
SD	289.79	23.30	276.02	48.08	32.92
CV	0.27	1.56	0.27	1.54	1.46
Max	1724.80	86.76	1723.80	172.10	150.00
Min	493.00	0.00	489.00	0.00	0.00

Table 5.10(c) Statistical analysis of rainfall data for Berasia RG station (mm)

Statistical Parameters	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Mean	898.13	203.92	659.09	30.10	5.02
Median	901.45	35.93	670.20	6.25	0.00
SD	248.33	305.84	346.38	46.98	12.55
CV	0.28	1.50	0.53	1.56	2.50
Max	1499.24	1100.40	1360.37	182.90	57.74
Min	432.12	0.00	87.30	0.00	0.00

SD: Standard deviation, CV: Coefficient of variation

5.3.2 Meteorological data

The Meteorological data of Vidisha district is collected from IMD, Pune from 1989 to 2022, except the sunshine hour. Sunshine hour data of Bhopal is used because it was nearest to the study area. The mean monthly temperature, humidity & wind velocity of the study area (Vidisha observatory) have been presented in **Table 5.11**. The annual maximum and minimum temperatures for Vidisha are 32.31 & 18.97° C respectively.

Table 5.11 Details of Meteorological data of the study area

Year	Temperature (° C)		Wind speed (m/s)	Relative Humidity (%)
	Annual maximum	Annual minimum		
1991	32.96	18.55	2.45	46.00
1992	32.84	18.67	2.37	45.54
1993	32.64	18.75	2.46	47.99
1994	32.05	18.39	2.35	50.18
1995	32.33	18.65	2.35	49.89
1996	32.15	18.56	2.30	50.76
1997	31.01	18.32	2.36	55.69
1998	32.03	18.87	2.21	54.19
1999	32.64	18.49	2.39	48.96
2000	33.65	18.43	2.49	39.79
2001	32.53	18.45	2.22	47.30
2002	33.86	18.96	2.45	44.19
2003	32.03	18.73	2.35	53.48
2004	32.85	19.00	2.27	49.88
2005	32.32	18.67	2.26	49.65
2006	32.51	19.21	2.21	52.15
2007	32.31	18.80	2.18	51.03
2008	31.88	18.61	2.16	51.89

2009	33.05	19.39	2.30	51.03
2010	32.55	19.60	2.17	53.89
2011	31.74	18.75	2.16	54.73
2012	32.18	18.33	2.38	50.15
2013	31.23	18.49	2.30	57.48
2014	32.16	18.95	2.45	53.91
2015	31.92	18.68	2.35	54.43
2016	32.40	19.23	2.24	51.21
2017	33.15	19.21	2.29	47.27
2018	32.68	19.11	2.30	48.37
2019	31.48	19.15	2.21	55.64
2020	31.25	18.43	2.12	58.82
2021	31.76	19.03	2.26	55.93
2022	31.61	18.90	2.19	57.93
Average	32.31	18.79	2.30	51.23

5.4 Estimation of Irrigation Return Flow

The regenerated and recharge from the command are an important part of the development of downstream water resource projects. The preliminary analysis of rabi season flow at the Bah G/D site prior (1989-2013) and after dam construction (2014-18) (**Figure 5.14**) revealed a significant increase in river flow in rabi season after the construction of the dam and built a solid foundation for a systematic study on rejuvenated flow and groundwater recharge due to irrigation. The total command area is 139.78 sq. km. out of which 43.66 sq. km was selected within the G/D site.

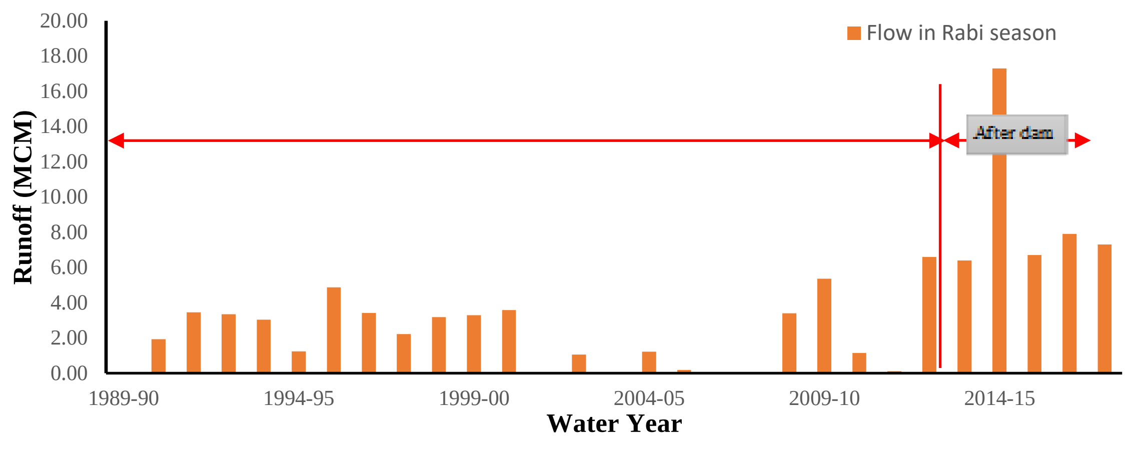


Figure 5.14 Average flow at Bah G/D site on river Bah in the rabi season

In the study, three different techniques i.e. water balance, isotopic analysis, and hydrological modeling were used to compute the regenerated and recharge part of IRF, and the results of these methods are described in the next sections.

5.4.1 Water Balance Technique

The water balance of the canal, command, and river was carried out for the computation of rejuvenated flow and recharge. The Sanjay Sagar dam started its irrigation in 2014 and hence the analysis has been carried out for rabi seasons from 2014-15 to 2021-22. The difference in canal water release (Q_{ic}-Q_{oc}) from the head of the reservoir has been divided into the same part as it is occupied by the command area up to the G/D site and varied in the range from 23.6 (2016-17) to 32.1 MCM (2019-20). The seepage from canals (Q_{seepc}) was computed using canal sections and levels using the equation suggested by Swamee et al (2004) with an average rate of 2.75 MCM (2.1 to 3.4 MCM) in a year. The irrigation water requirement (Q_{evp}) for rabi crops of the command was computed using climate data of Vidisha and found in the range of 9.1 and 11.5 MCM. The direct rainfall (P) in the command has been computed for the command using the Thiessen polygon.

The SCS CN model was applied for the computation of surface flow from the intermediate catchment during the rabi crop season. The intermediate catchment drained between the dam and the G/D site is 353.93 sq. km. The land use map of this catchment has been determined using the supervised classification of Landsat data. The soil in the intermediate catchment has been prepared using a map of the National Bureau of Soil Survey and Land Use Planning (NBSSLUP, Nagpur) and divided into two soil hydrological groups namely C and D. The composite curve number for the intercepted catchment was computed as 81.6 which may infer that most of the runoff occurs in the region as surface runoff. The land use, soil, and surface runoff computed from intercepted catchment during the period 2014 to 2022 are presented in **Figure 5.15** where it can be seen that there was a very minimal contribution of direct runoff from rain during the rabi season.

The infiltration rate in the command up to the G/D site varies from 0.60 to 1.0 mm/hr with an average infiltration rate of 0.90 mm/hr which is less than 1.45 cm/hr (SCS, 1983) in the command up to the G/D site (**Table 5.12**). The loss of water (MCM) with this infiltration rate during canal opening days is shown in **Table 5.13.** Considering the number of supply days, area of command, and rate of infiltration, the amount of infiltrated computed varied from 5.3 to 7.1 MCM. There are seven barrages in the river stretch from where water is exported to fields up to 0.5 km in length and crop water need is considered as withdrawal from the river and varied from 3.5 to 6.8 MCM.

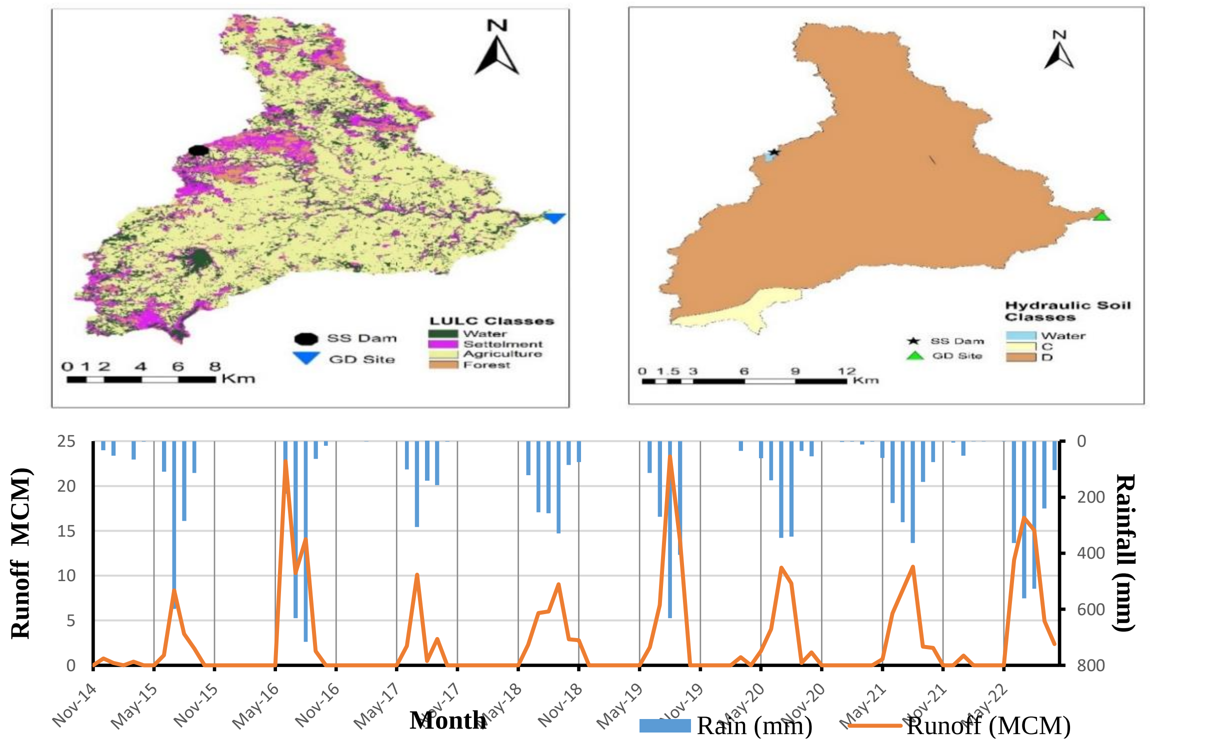


Figure 5.15 Land use, Soil and rainfall, and runoff using SCS CN model from intermediate catchment

Table 5.12 Estimated average infiltration rate

Area, km^2	Avg. Infiltration rate (mm/hr)
7.65	0.6
24.04	1
Wt. avg.	0.9

Table 5.13 Loss of water through infiltration (MCM) in canal opening days

Water Year	Canal opening Days	Infiltration	Periods	Area (km^2)	Infiltratio n (MCM)
2014-15	103	0.9	20.6	26.3	11.70
2015-16	134	0.9	26.8	26.3	15.22
2016-17	120	0.9	24	26.3	13.63
2017-18	111	0.9	22.2	26.3	12.61
2018-19	62	0.9	12.4	26.3	7.04
2019-20	112	0.9	22.4	26.3	12.72

The soil moisture has been computed in different periods of the command. The Soil Moisture Active Passive (SMAP) data acquired from the California Institute of Technology available from April 2015 on Google Earth Engine has been used. Variations in soil moisture during the rabi season from April 2015 to April 2020 as shown in **Figure 5.16**. The computed change in soil moisture during the rabi season from the year 2014-22 (**Table 5.14**).

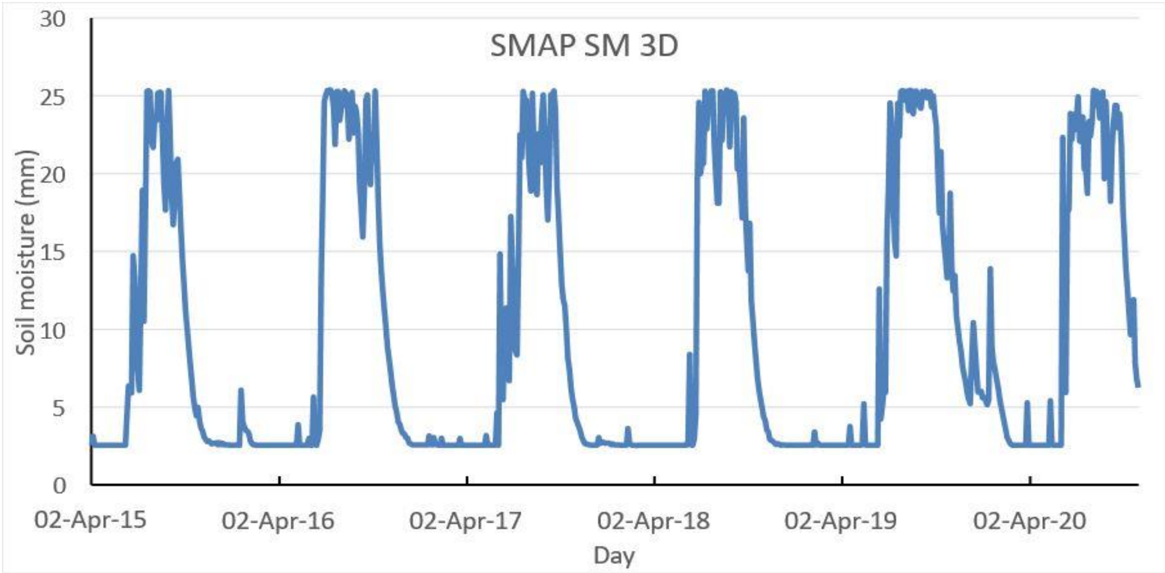


Figure 5.16 Variations in soil moisture during the rabi season

Table 5.14 Change in soil moisture during rabi season

Year	Rabi seasons	Soil moisture	Change in soil moisture, mm	Change in soil moisture, MCM
2015-16	Nov-15	3.12	-0.58	-0.03
	Apr-16	2.54		
2016-17	Nov-16	6.20	-3.66	-0.16
	Apr-17	2.54		
2017-18	Nov-17	3.30	-0.76	-0.03
	Apr-18	2.54		
2018-19	Nov-18	3.53	-0.81	-0.04
	Apr-19	2.72		
2019-20	Nov-19	13.11	-10.57	-0.46
	Apr-20	2.54		
2020-21	Nov-20	8.41	-7.17	-0.32
	Apr-21	1.23		
2021-22	Nov-21	13.40	-9.30	-0.41
	Apr-22	4.10		

The water balance computing different components of hydrological processes and computation of regenerated and recharge in the command up to the G/D site was presented in **Tables 5.15(a) & 5.15(b).** From the analysis, it has been observed that the error in the computation varies between -0.7 and 3.5 MCM which is less than 10 % of supplied water. The regenerated water ratio varied from 12.3 to 35.9% with an average of 22.9% which is reasonably high and indicated the need for efficient management in the command. The recharge from irrigation in Sanjay Sagar's command varied from 0.5 to 4.9 MCM with an average percent of 10.2% of supplied water.

5.4.2 Isotopic Analysis for Regenerated and Recharge

To analyze the contribution of dam water to the surface and sub-surface water, more than 500 samples of water from rains, canals, open wells, bore wells, and rivers were collected using standard collection protocol. The samples were analyzed for isotopes of hydrogen and oxygen in the nuclear lab of the National Institute of Hydrology, Roorkee.

5.5.2.1 Measuring points for isotopic analysis

In the present study, water samples from different sources such as rainfall, dams, canals, rivers, public and private open wells, hand pumps, and bore wells during the irrigation (rabi season) and non-irrigation seasons of 2019 to 2021 were collected in 20 ml polypropylene bottles that were rinsed twice before the collection of the sample. The samples collected were stored in a cool and dry place and sent to the nuclear lab of the Hydrological Investigation division of NIH Roorkee. The location of all measuring points is given in **Figure 5.17.** The collected water samples from all selected sites have been given in **Table 5.16.**

5.4.2.2 Local Meteoric Water Line

The isotopic analysis of water samples of rainfall, dam, canal, open wells, bore wells, hand pumps within and outside command, and river water samples from 2019 to 2022 were collected and analyzed for isotopes of hydrogen (δD) and oxygen ($\delta^{18}O$). A total of 33 rainfall samples were analyzed to capture the isotopic characteristics of precipitation through the local meteoric water line (LMWL) and compared with the global meteoric water line (GWML) suggested by (Rozanski et al., 1993) & (Craig, 1961) and found a close match in them **(Figure 5.18).** The following equation was found suitable for local precipitation in the Central India region.

$$\delta D = 7.26\delta^{18}O + 2.69 \quad (5.1)$$

Table 5.15(a) Water balance in the command and rejuvenated flow from the Sanjay Sagar project

Crop Year	P_{com}	Q_{ic}-Q_{oc}	Q_{seepc}	Q_{evc}	Q_{int}	Q_{evpc}	Q_{or}	Q_{ir}	Q_{bar}	Q_{pr}	Q_{evpr}	Q_{infil}	Q_{rec}	Ch in Soil Moisture	Error (ε)	R_F
	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(%)
2014-15	3.55	25.93	2.63	0.29	1.43	10.11	13.7	0.12	3.52	4.04	0.35	5.85	1.68	-0.04	2.18	26.70
2015-16	0.00	24.08	2.14	0.33	0.00	10.42	11.7	0.10	4.93	4.17	0.41	5.34	1.05	-0.03	1.83	12.27
2016-17	0.04	23.59	2.28	0.34	0.00	10.81	11.9	0.16	4.82	4.32	0.40	6.82	1.27	-0.16	0.21	12.87
2017-18	0.00	28.37	2.78	0.37	0.00	10.47	19.1	0.16	6.75	5.23	0.46	6.31	1.27	-0.03	-0.73	26.49
2018-19	3.24	28.84	2.65	0.31	2.81	9.15	18.6	0.19	5.58	4.58	0.33	6.53	1.29	-0.04	1.41	35.87
2019-20	1.53	32.05	3.16	0.39	0.89	10.33	19.3	0.35	5.98	5.17	0.46	6.36	1.33	-0.46	2.49	27.59
2020-21	0.76	31.65	3.37	0.32	0.00	11.51	17.62	0.37	4.63	4.34	0.41	5.87	1.29	-0.32	2.42	27.08
2021-22	2.52	28.51	2.96	0.34	1.09	11.34	13.43	0.30	5.01	5.21	0.40	7.12	1.41	-0.41	3.51	14.33
Average	**1.45**	**27.88**	**2.75**	**0.34**	**0.78**	**10.52**	**15.67**	**0.22**	**5.15**	**4.63**	**0.40**	**6.27**	**1.33**	**-0.19**	**1.66**	**22.90**

Table 5.15(b) Computation of recharge from the Sanjay Sagar command

Crop Year	P_{com}	Q_{sc}	Q_{infil}	Q_{evpc}	Q_{srcom}	Q_{seepc}	Q_{efcom}	Ch in Soil Moisture	Q_{rec}	R_c
	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(MCM)	(%)
2014-15	3.55	23.01	5.85	10.11	10.60	2.63	4.58	-0.04	3.86	13.23
2015-16	0.00	21.61	5.34	10.42	5.85	2.14	4.57	-0.03	2.88	12.13
2016-17	0.04	20.97	6.82	10.81	3.39	2.28	7.45	-0.16	1.48	6.36
2017-18	0.00	25.22	6.31	10.47	8.45	2.78	8.51	-0.03	0.54	1.92
2018-19	3.24	25.88	6.53	9.15	13.44	2.65	6.45	-0.04	2.70	8.49
2019-20	1.53	28.50	6.36	10.33	13.33	3.16	5.23	-0.46	3.82	11.52
2020-21	0.76	27.96	5.87	11.51	11.34	3.37	5.21	-0.32	3.71	11.56
2021-22	2.52	25.21	7.12	11.34	9.27	2.96	4.75	-0.41	4.92	16.03
Average	1.45	24.80	6.27	10.52	9.46	2.75	5.85	-0.19	2.99	10.15

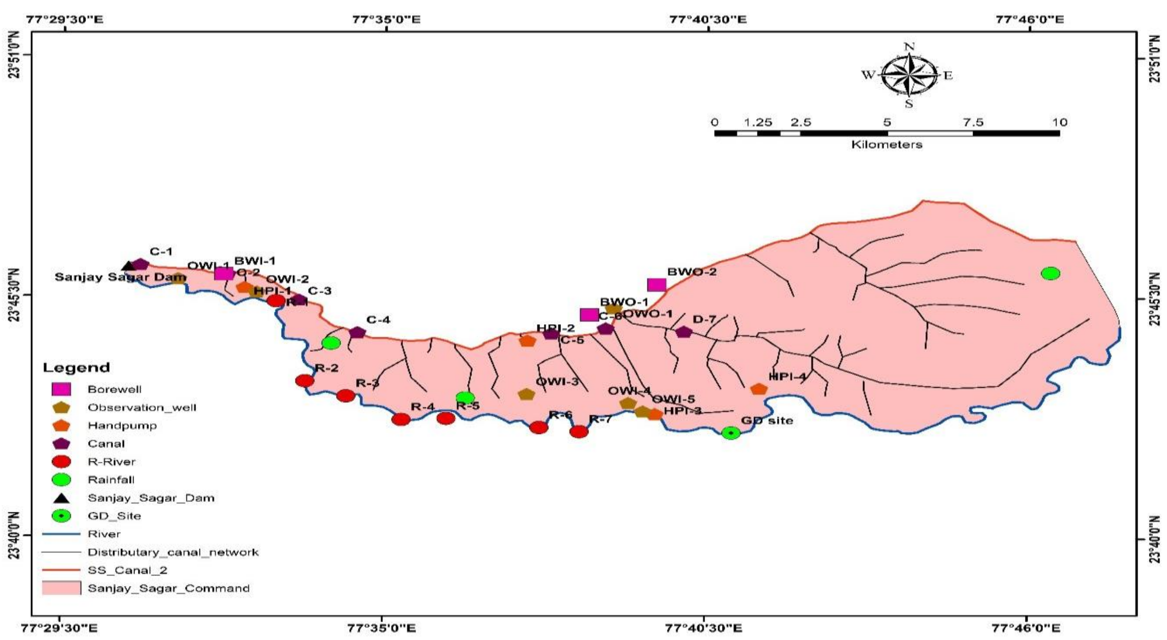


Figure 5.17 Location of different sampling stations for isotopic analysis

Table 5.16 Location of water samples

Site	Latitude	Longitude	Place
River			
R-1	23.756	77.552	Bairkhediahir
R-2	23.726	77.560	Dojyai
R-3	23.720	77.572	Haripur
R-4	23.711	77.588	Arjunkhedi
R-5	23.711	77.601	Khejraghat
R-6	23.708	77.627	Kherakherdi
R-7	23.707	77.639	Laharpur
Canal			
C-1	23.770	77.513	Sironj (Bhopal Road)
C-2	23.766	77.538	Bairakhedi (Majhera road)
C-3	23.757	77.559	
C-4	23.744	77.575	Dhaturia (Dojayai road)
C-5	23.744	77.630	Dhobi Kheda (Pipladhar road)
C-6	23.746	77.646	Vidisha-Shamshabad road
D-7	23.745	77.668	Amarpura (Bhaironbang road)
Hand Pump Inside the Command (HPI)			
HPI-1	23.761	77.543	Dhaturiya
HPI-2	23.741	77.624	Dhobikheda
HPI-3	23.713	77.660	Shejakheda
HPI-4	23.723	77.690	Bandhiya
Observation Well Inside the Command (OWI)			
OWI-1	23.765	77.526	Majhera (Field of Sri Gopi Lal)
OWI-2	23.76	77.547	Baikhediahir (Field of Sri Pop Singh)
OWI-3	23.721	77.624	Dhobikheda (Field of Sri Ram Charan)
OWI-4	23.718	77.653	Shejakhedi
OWI-5	23.714	77.657	Shejakhedi
Observation Well Outside the Command (OWO)			
OWO-1	23.754	77.648	Mahaneem square
Bore Well Inside the Command (BWI)			
BWI-1	23.766	77.537	Majhera command (Field of Sri Maujilal)
Bore Well Outside the Command (BWO)			
BWO-1	23.751	77.641	Pipladhar (House of Sri Ranveer Yadav)
BWO-2	23.763	77.661	Amarpura (House of Sri Ram Narayan Dhakad)

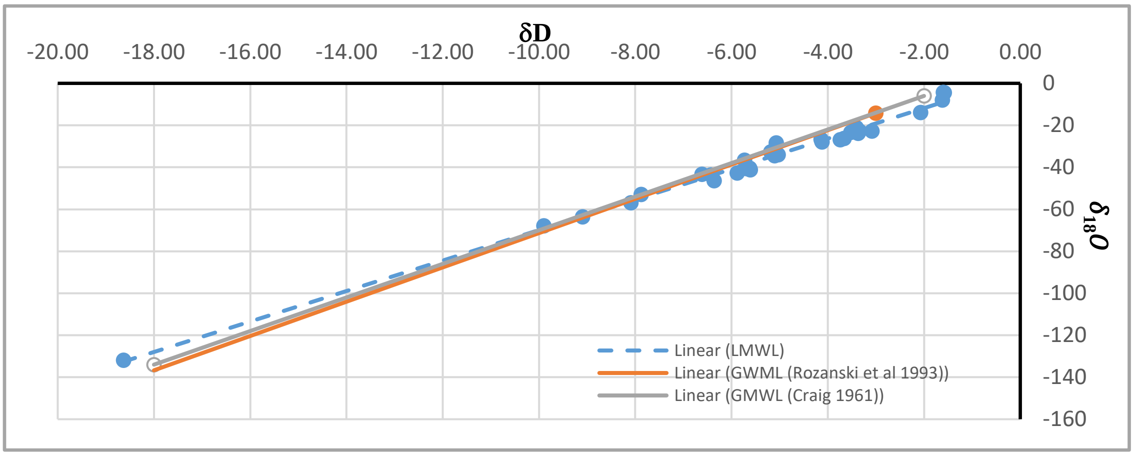


Figure 5.18 Comparison of LWML with GWML (Rozanski et al 1993 & Craig 1961)

The lower slope and intercept of LWML from GWML ($\delta D = 8\delta^{18}O + 10$) is indicative of the enrichment of heavier isotopes. The graphical representation of isotopes of oxygen and hydrogen of different water is presented in **Figure 5.19** and found that the open well and hand pump outside the command have signatures close to rainfall while wells inside the command showed closeness with canal water and enrichment from precipitation. The information and average values of isotopes of different sources along with the amount of weighted rainfall were presented in **Table 5.17.** The slope of the river and canal water, and groundwater (open well & hand pump) inside the command was found much lower than GMWL and LMWL however, the slope of the canal is slightly higher (5.14) in comparison to the slope of the river (4.63). This isotopic line for groundwater for confined aquifer outside and bore well in the command have slopes comparable to the slope of LMWL (s=7.26). Similarly, the intercept for LMWL and groundwater sourced from the borewell are positive. The intercepts of the canal, hand pump, and open well inside the command show the evaporation effects.

5.4.2.3 End-member mixing model

The end-member mixing model was used to compute the ratio of the concentration of canal water to the rainfall in the unconfined aquifer and found that nearly 88% of water in unconfined aquifers or open wells comes from the canal and the rest 12% from rainfall. The isotopic signatures of hand pump samples in the command were found similar to the rainfall samples which may be indicative of minimal recharge from canal water due to irrigation in the confined aquifer. The ratio of canal water to rainfall in the confined aquifer is about 8.99% only. Similarly, the river water has nearly 74.8% water from the canal and the rest from rainfall and the dam.

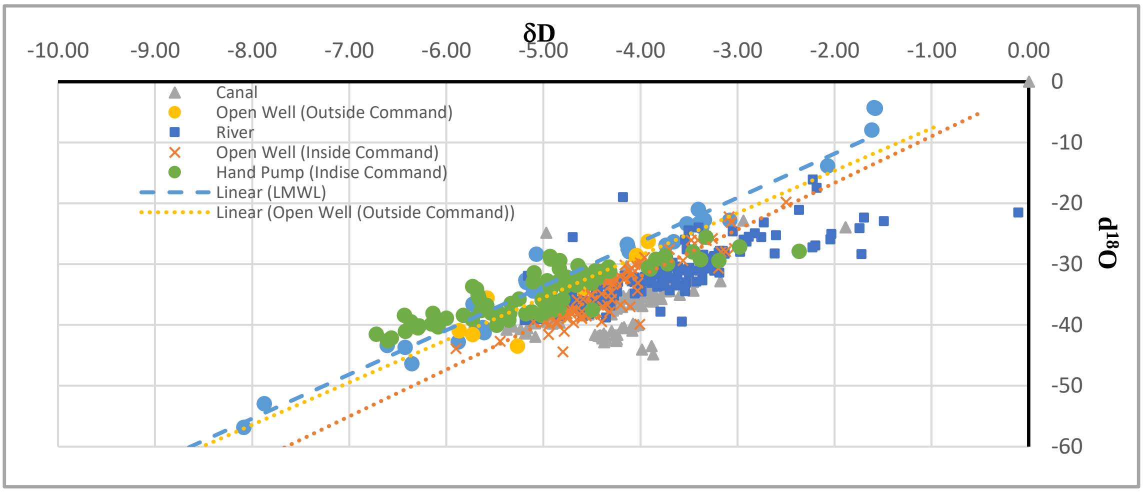


Figure 5.19 δD and $\delta^{18}O$ of different sources of water in the Sanjay Sagar command

Table 5.17 Isotopic analysis of water samples

Description	No of samples	$\delta^{18}O$		δD		d-index	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
			Rainfall				
Rainfall	33	-5.08	0.91	-33.04	5.88	7.64	1.37
			Observation Well Inside the Command (OWI)				
OWI-1	28	-4.44	0.42	-35.57	3.94	0.05	2.15
OWI-2	25	-4.32	0.49	-34.67	4.32	-0.06	1.91
OWI-3	26	-4.22	0.57	-33.24	4.98	-0.19	3.95
OWI-4	12	-3.95	0.86	-31.92	7.28	-0.45	2.82
OWI-5	12	-4.38	0.58	-34.56	4.97	-0.49	4.17
Overall average (OWI)	103	-4.30	0.58	-34.31	4.96	-0.15	2.92
			Observation Well Outside the Command (OWO)				
OWO-1	8	-5.10	0.79	-36.18	6.26	4.58	3.07
			Hand Pump Inside the Command (HPI)				
HPI-1	25	-5.79	0.62	-38.25	2.6	8.06	2.79
HPI-2	21	-4.19	0.73	-31.43	2.97	2.11	4.08
HPI-3	15	-4.92	0.52	-33.01	3.33	6.39	3.04
HPI-4	12	-4.90	0.86	-34.49	3.82	4.67	4.80
Overall average (HPI)	73	-5.01	0.92	-34.60	4.32	5.45	4.29
			Bore Well Inside the Command (BWI)				
BWI-1	6	-5.06	1.04	-38.04	9.58	2.44	2.49
			Bore Well Outside the Command (BWO)				
BWO-1	6	-5.14	0.08	-30.07	0.74	11.04	1.14
BWO-2	3	-5.49	0.06	-28.49	0.60	15.40	0,76

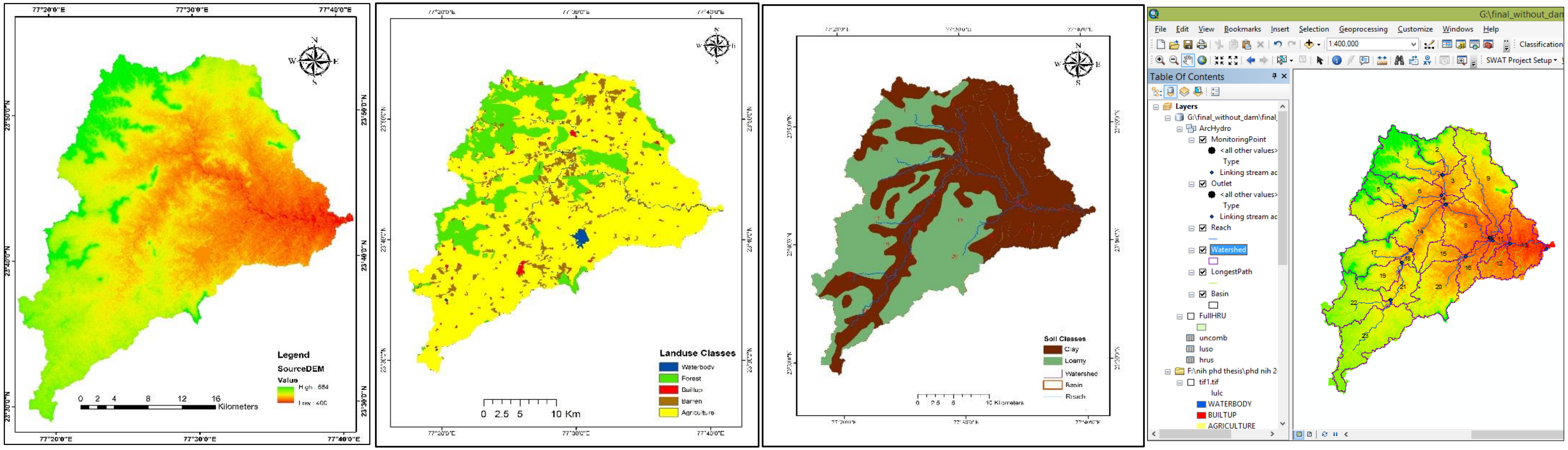
Overall average (BWO)	9	-5.25	0.19	-29.54	1.03	12.49	2.39
Canal							
C-1	24	-4.01	0.57	-36.47	4.96	-3.28	4.35
C-2	16	-4.13	0.55	-36.00	5.39	-2.99	3.38
C-3	17	-4.15	0.56	-35.65	5.85	-1.94	3.88
C-4	14	-4.10	0.44	-36.70	5.31	-3.92	4.97
C-5	15	-4.15	0.55	-36.70	5.02	-3.27	4.12
C-6	12	-4.36	0.47	-36.59	5.29	-3.10	4.35
D-7	4	-4.08	0.18	-37.09	7.71	-4.46	9.05
Overall average (Canal)	102	-4.13	0.57	-36.47	4.96	-3.28	4.35
River							
R-1	27	-4.19	0.81	-34.23	4.90	-0.75	5.31
R-2	26	-3.79	0.84	-31.95	55.58	-1.65	2.82
R-3	22	-3.76	0.84	-32.04	4.58	-1.96	2.57
R-4	25	-3.46	1.01	-30.34	4.25	-2.68	4.88
R-5	23	-3.68	0.79	-31.34	4.48	-1.93	2.81
R-6	14	-3.87	0.79	-31.92	4.90	-0.93	5.53
R-7	13	-3.91	0.78	-32.99	4.55	-1.68	2.87
Overall average (River)	156	-3.81	0.84	-32.09	4.74	-1.65	3.91

5.4.3 SWAT model-based assessment of irrigation return flow

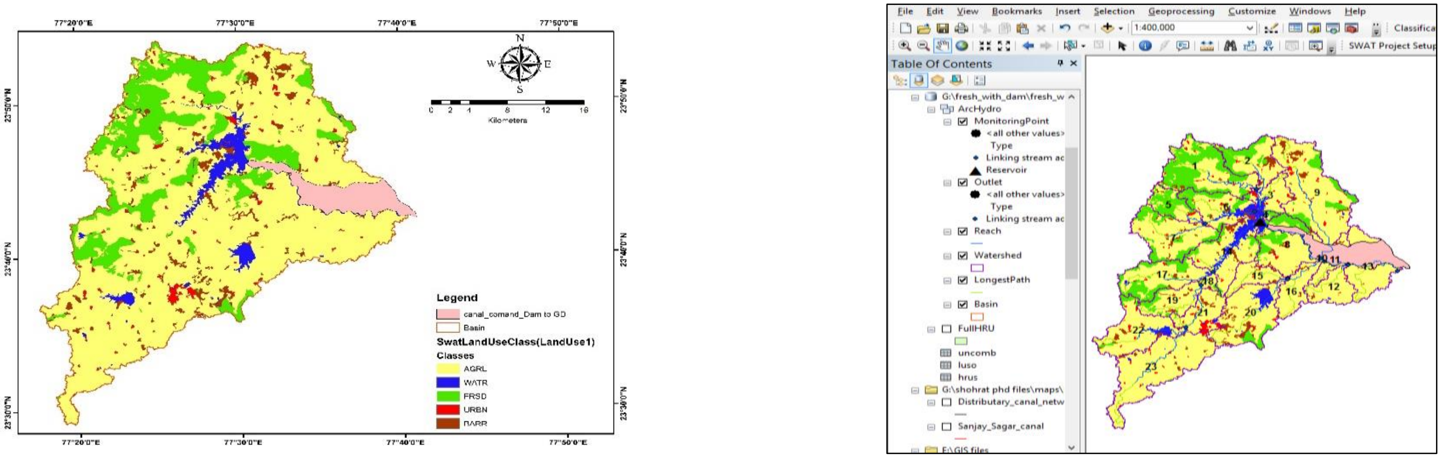
To determine the impact of irrigation water on runoff and groundwater recharge, initially, a SWAT model for Bah River up to the G/D site was set up using the digital elevation model, land use, and soil maps. The catchment area up to the Bag G/D site is 879.5 sq. km and was divided into 23 sub-watersheds and 144 HRUs. Initially, the SWAT model was run with virgin data for the period of 1991 to 2013. The required input maps and setup of the SWAT model for virgin flow (1991-2013) and with dam and irrigation supply (2014-2022) were presented in **Figure 5.20.**

5.4.3.1 SWAT-CUP for sensitivity, calibration, and validation

The sensitivity analysis is important to limit parameters to which the focus will be given during the calibration and validation of the model. In the study, the most used SUFI-2 technique was used for sensitivity, calibration, and validation. The *p-value* and *t-stat* are used to select the most sensitive parameters and found that the curve number (*CN2*), hydraulic conductivity in the main channel (*CH-K2*), baseflow Alpha factor (*ALPHA_BF*), groundwater delays (*GW_DELAY*), and the initial depth of water in the shallow aquifer (*SHALLST*) are the most important parameters for optimization. The calibration of the model was carried out for the period of 15 years from 1991 to 2005 with two years (1989 &1990) warmup periods.



a. SWAT model setup for virgin flow (1991-2013)



Lanusse (2015) SWAT model with reservoir and irrigation supply

b. SWAT model setup for regulated flow with reservoir and irrigation command

Figure 5.20 SWAT model setup for virgin flow and regulated flow with reservoir and irrigation command

The coefficient of determination (R^2) and Nash-Sutcliff efficiency were found as 0.74 and 0.73 respectively during the calibration. The validation was carried out with an independent dataset from 2006 to 2013 with a two-year warm-up period (2004 & 2005). The coefficient of determination (R^2) and Nash-Sutcliff efficiency were found as 0.72 and 0.66 during validation and it can be considered a satisfactory match. The 95 PPU graph is an important aspect of the SUFI-2 method which indicates the overall fitting of the model and is presented in **Figure 5.21.**

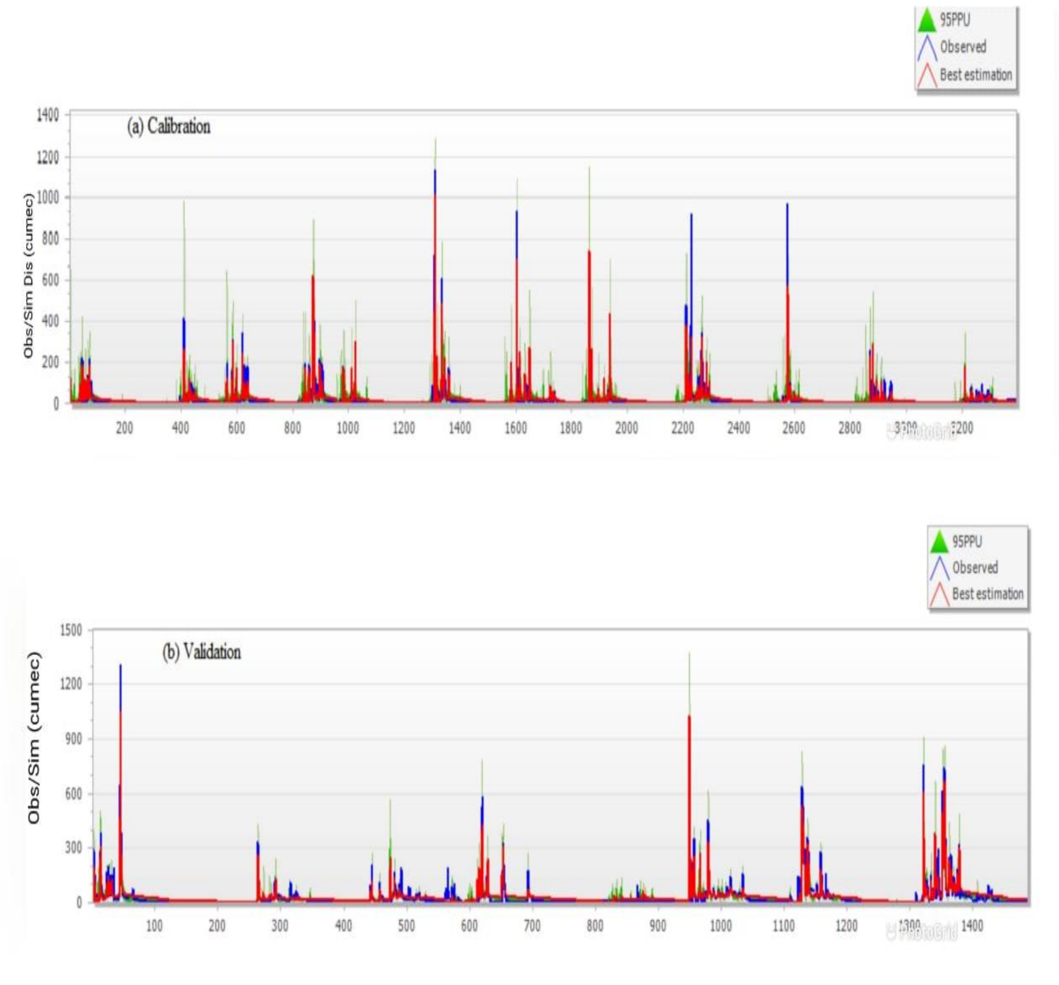


Figure 5.21 95 PPU diagram during calibration and validation of SWAT model

5.4.3.2 Impact of irrigation from the dam on the return flow

The calibrated and validated SWAT model for the period 1989-2013 was further run from 2104 to 2022 to obtain virgin flows and then modified by adding reservoir and supply irrigation in requisite sub-watersheds (WS-8, 10, 11, and 13) in the next step. The simulated runoff from the SWAT model from the virgin run and run with irrigation to command from the reservoir for the period 2014-22 were analyzed to assess the impact of irrigation (**Figure 5.22**).

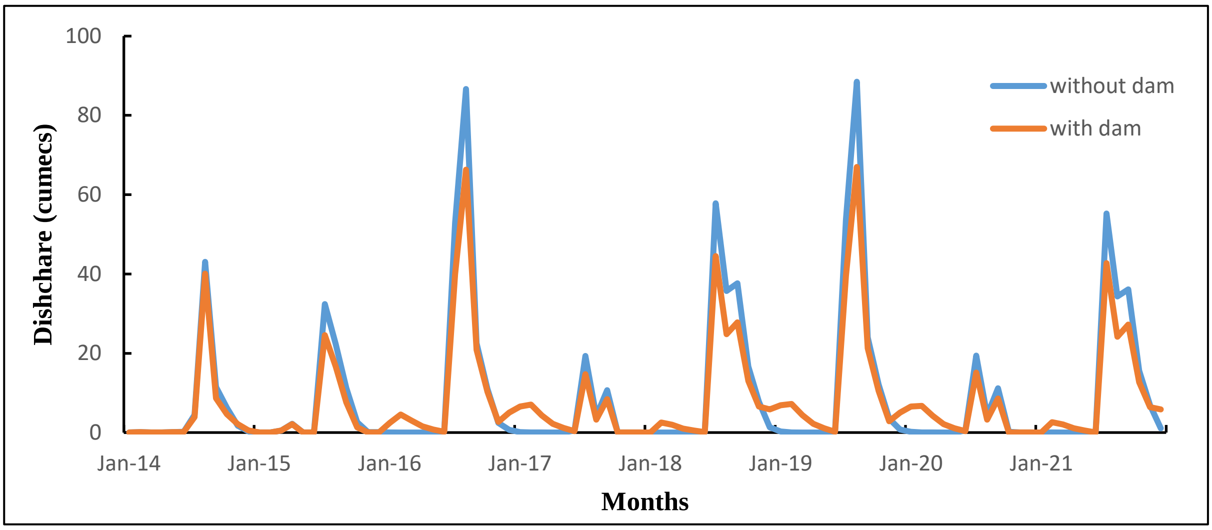


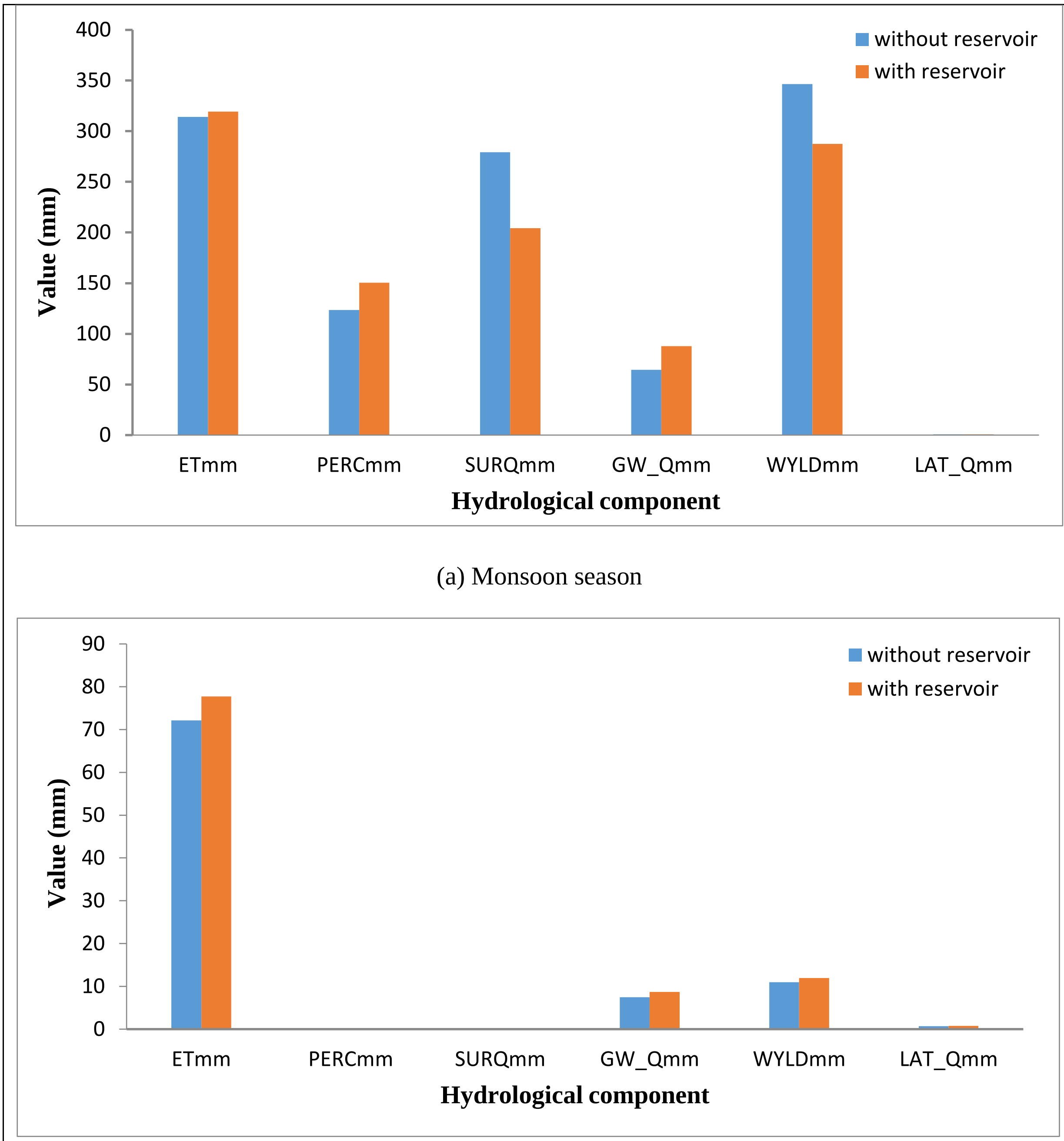
Figure 5.22 SWAT simulation results with and without reservoir and irrigation

From the analysis of results, the flows at the Bah G/D site were reduced during the rainy season because of storage in the dam, while the same was increased during the rabi season due to the application of water as irrigation in selected sub-basins of the study area. The results of the SWAT model simulation along with regenerated and return flow during rabi season from the above two runs are given in **Table 5.18** where the simulated virgin flow varied from 0.15 to 8.41 MCM while the same reached from 7.69 to 16.10 MCM after adding reservoir and supplies to command. The difference in simulated discharge between with and without irrigation at the Bah GD site can be characterized as excess water which is emerging as a regenerated flow that varied from 7.17 MCM to 9.43 MCM after the irrigation activities. The regenerated flow was found as 27.4 to 30.7% of water reached the command from the dam. The baseflow increased from 3.98 to 6.54 MCM due to the application of irrigation during the rabi season which was around 8.90% of supplied water.

A comparison of the different hydrological components from SWAT simulation during rabi and monsoon season has been presented in **Figure 5.23** and an increase of evapotranspiration (7.7%), groundwater recharge (16.8%), water yield (8.6%), and lateral flow (9.9%) was observed due to irrigation in rabi crop season, while a decrease of 26.8% in surface runoff and 17% in water yield during monsoon season due to storage effect of the reservoir. The analysis of results confirmed that the SWAT hydrological modeling has promising potential for the assessment of irrigation return flow. The regenerated flow is more than the assumed 10% by WRD MP and hence it is recommended to reconsider the fixed percentage after conducting a few more studies in the region.

Table 5.18 Results of SWAT model simulation (rabi season) and computation of regenerated flow and recharge

Year	**Q-supply (MCM)**	**Evaporation from canal**	**Rainfall in command**	**Rejuvenated flow (R_F)**				**Recharge (R_c)**			
				Q-sim. without irrigation (MCM)	Q-sim. with irrigation (MCM)	Q-reg. flow (excess water) (MCM)	Rej. flow (%)	Q-base flow without irrigation (MCM)	Q-base flow with irrigation (MCM)	Change in GW (MCM)	Recharge (%)
2014-15	25.93	0.29	3.55	6.03	13.69	7.66	27.43	0.22	0.64	0.42	1.44
2015-16	24.08	0.33	0.00	0.51	7.69	7.17	30.13	0.15	2.48	2.33	9.81
2016-17	23.59	0.34	0.04	8.36	15.61	7.25	30.73	4.45	7.78	3.33	14.30
2017-18	28.37	0.37	0.00	0.07	8.58	8.51	30.00	0.02	1.45	1.43	5.11
2018-19	28.84	0.31	3.24	8.41	16.10	7.69	27.41	18.58	22.01	3.43	10.80
2019-20	32.05	0.39	1.53	7.29	14.9	7.60	28.11	7.45	11.7	4.25	12.81
2020-21	31.65	0.32	0.76	0.15	9.57	9.43	29.78	0.15	2.65	2.50	7.79
2021-22	28.51	0.34	2.52	3.21	8.98	5.77	18.80	0.82	3.64	2.82	9.19
Average	**27.88**	**0.34**	**1.46**	**4.25**	**11.89**	**7.64**	**27.80**	**3.98**	**6.54**	**2.56**	**8.90**



(a) Monsoon season

(b) Rabi season

Figure 5.23 Comparison of different hydrological components in monsoon and rabi seasons

* ET: Evapotranspiration, PERC: Percolation, SURQ: Surface runoff, GW_Q: Groundwater, WYLD: Water yield, LAT: Lateral flow

5.5 Management Model for Reservoir Operation

The management of irrigation water is of utmost importance in surface water projects. In the study, MIKE HYDRO Basin was applied for the Sanjay Sagar project for irrigation planning and reservoir operation. MIKE 11 NAM model was applied for modeling rainfall-runoff processes which was further used in planning of reservoir operation in MIKE HYDRO Basin.

5.5.1 Application of NAM model

The NAM model for the Bah River basin has been developed to model the rainfall-runoff process for virgin flow to use compute inflow for developing a decision support system. The MIKE-11 NAM is a rainfall-runoff (RR) model created by the Danish Hydraulic Institute (DHI) as part of the MIKE-11 module. MIKE11 NAM can also be used to model lateral flows to a river basin from several contributing catchments (DHI 2017). The Nedbor Afstromnings Model (NAM) is a deterministic, lumped, and conceptual rainfall-runoff model that works by continually compensating moisture content in three separate and directly interconnected storages that depict overland flow, interflow, and base flow (DHI, 2008). The physical processes involved in runoff simulation in the model. It treats each sub-catchment as one unit, therefore the parameters and variables are considered for representing average values for the entire sub-catchments. The result is a continuous time series of the catchment runoff across the simulation period.

5.5.1.1 Model setup

To work effectively in the MIKE11 NAM tool, input data must be arranged in the form of a “Time Series”. To calibrate and validate the model, meteorological data, discharge data, catchment parameters, and initial conditions are required as input. Before importing data into the model, it is necessary to create the time series of all three parameters i.e. rainfall, potential evapotranspiration, and discharge data in dfso format, which can be created using MIKE ZERO software.

MIKE11 NAM model simulates runoff in a lumped manner therefore it is decided to take the weightage of precipitation from three rain gauge stations. Thiessen polygon map of Bah catchment is shown in **Figure 5.24** The areal precipitation was estimated by multiplying the rainfall at each station and their calculated percentage weight. **Table 5.19** shows the percentage weights that were inserted into the MIKE11 NAM model based on their contributions.

Table 5.19 Thiessen weight of different rain gauge stations in the Bah River basin

S. No.	Rain gauge station	Weights (Wi)
1.	Berasia	0.78
2.	Lateri	0.08
3.	Nateran	0.14

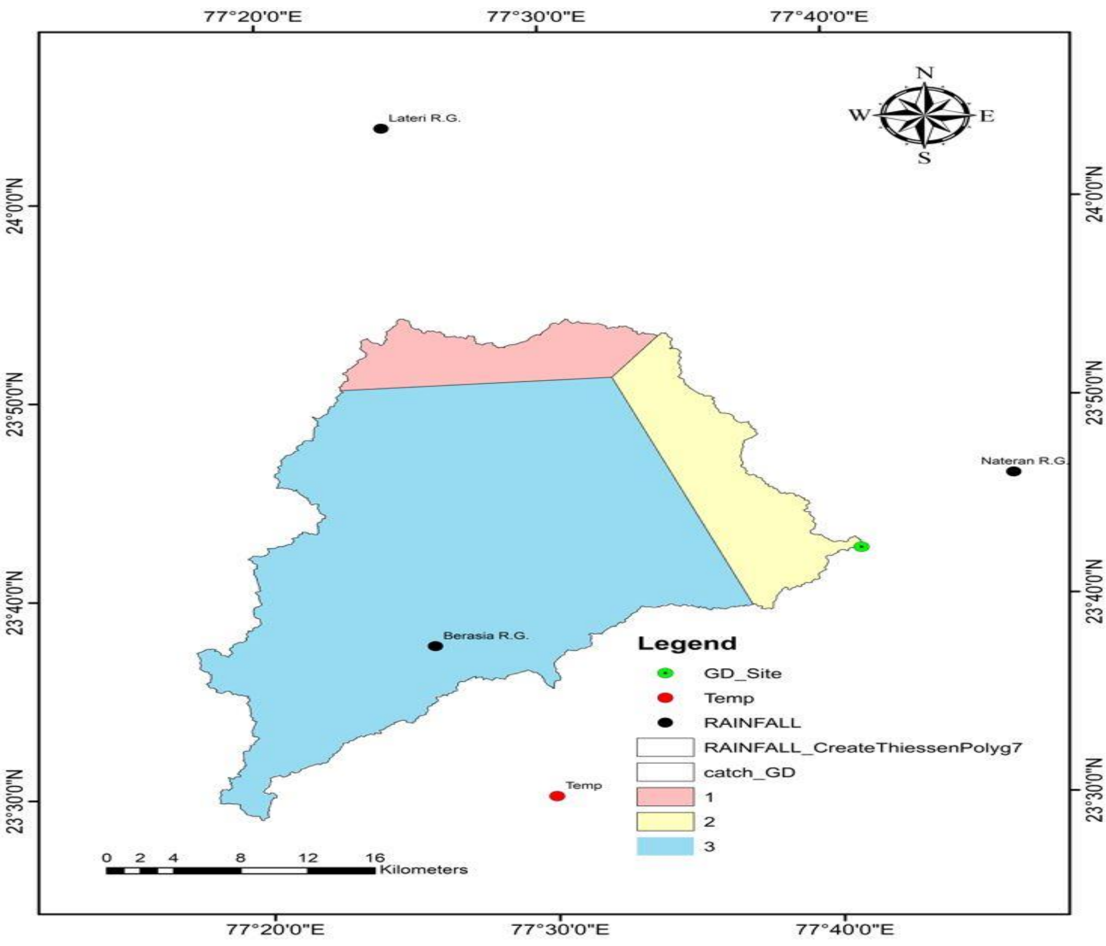


Figure 5.24 Thiessen polygon map of Bah catchment

5.5.1.2 Model calibration

The main goal of the model calibration is to obtain a set of parameters for a catchment that provides the best possible fit between the simulated and observed runoff for the calibration period. Calibration is the process of finding correction factors that can be used to standardize predicted values. Such empirical corrections are widely used in modeling and it is acknowledged that every hydrological model should be tested against observed data to ensure the model's reliability. In the MIKE-11 NAM model, initial calibration can be done through auto-calibration mode and later fine-tuned by manual calibration.

The calibration of the MIKE-11 NAM Model was done by inserting daily rainfall, potential evaporation, and observed discharge time series for the periods of 15 years from 1991 to 2005. Catchment definitions such as catchment name and area were specified. After importing the time-series the model was run under auto-calibration mode by taking the surface, rootzone, and groundwater storage parameters as default. The model output simulation results during calibration were checked for the coefficient of determination value and graphically analyzed for the degree of agreement between simulated and observed runoff. Then the model was run several times by adjusting these parameters by the trial-and-error method until the gap between observed and simulated discharge was reduced to an acceptable limit. The trial giving the best result is selected as the best-fit model and parameters are considered as the final parameters of model calibration. The model parameters thus obtained after refinement of the model were then used in the validation of the model. The steps in setting up of MIKE11 NAM Model during model calibration are shown in **Figure 5.25(a) to Figure 5.25(f).**

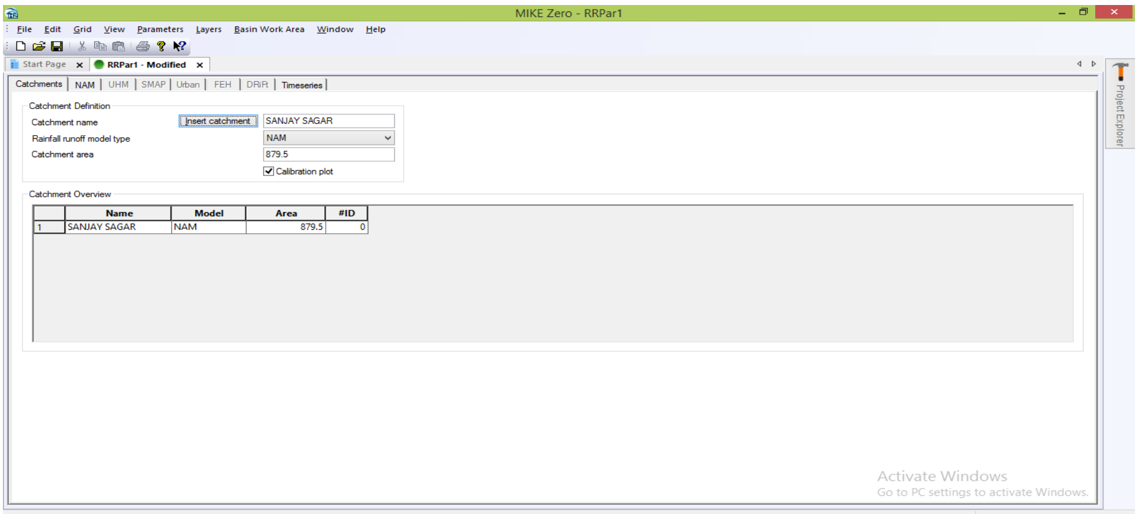


Figure 5.25(a) MIKE11 NAM model interface

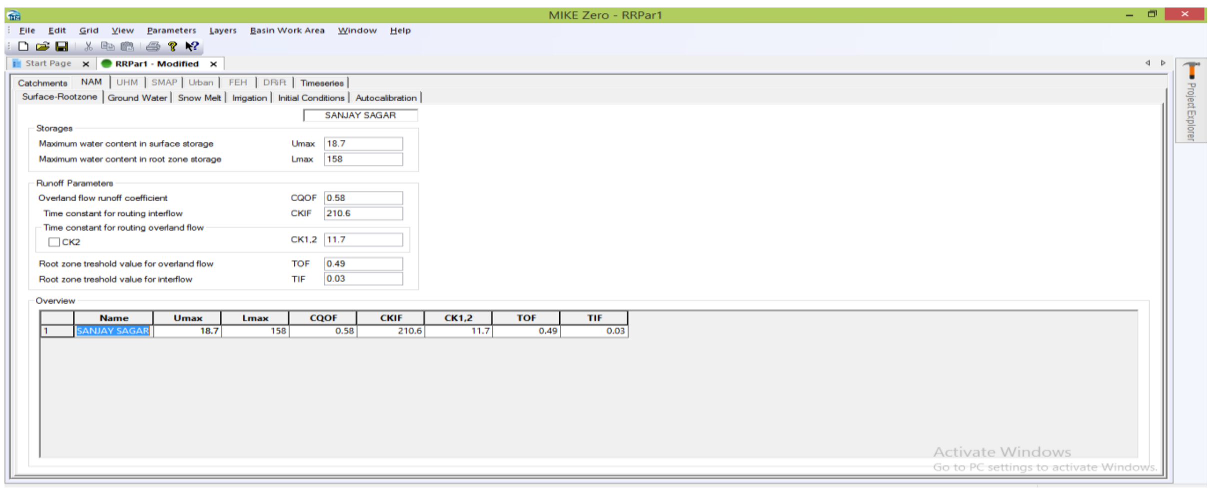


Figure 5.25(b) MIKE11 NAM model input default model parameters

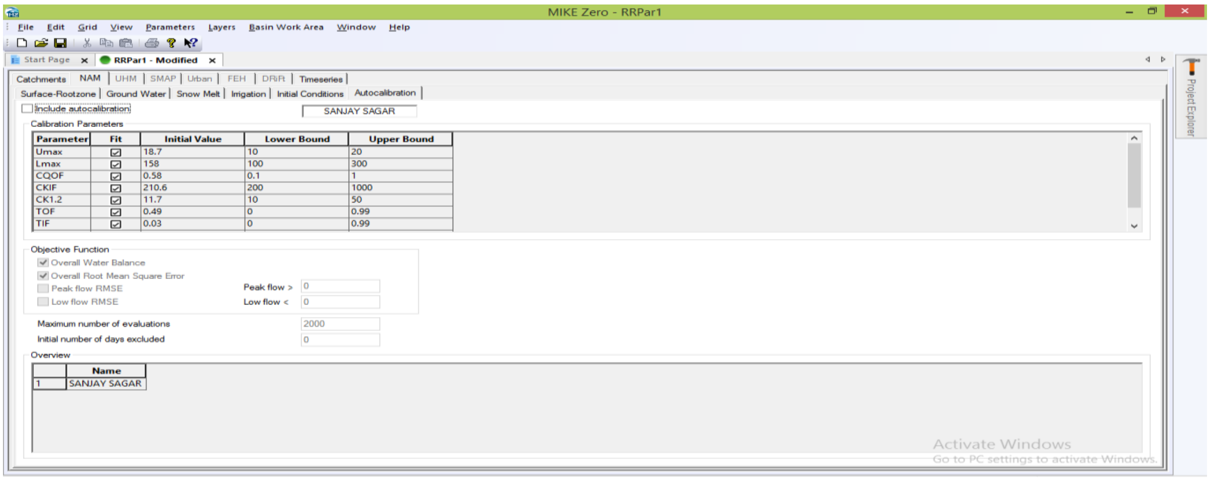


Figure 5.25(c) MIKE11 NAM model input default model parameters in Auto-calibration

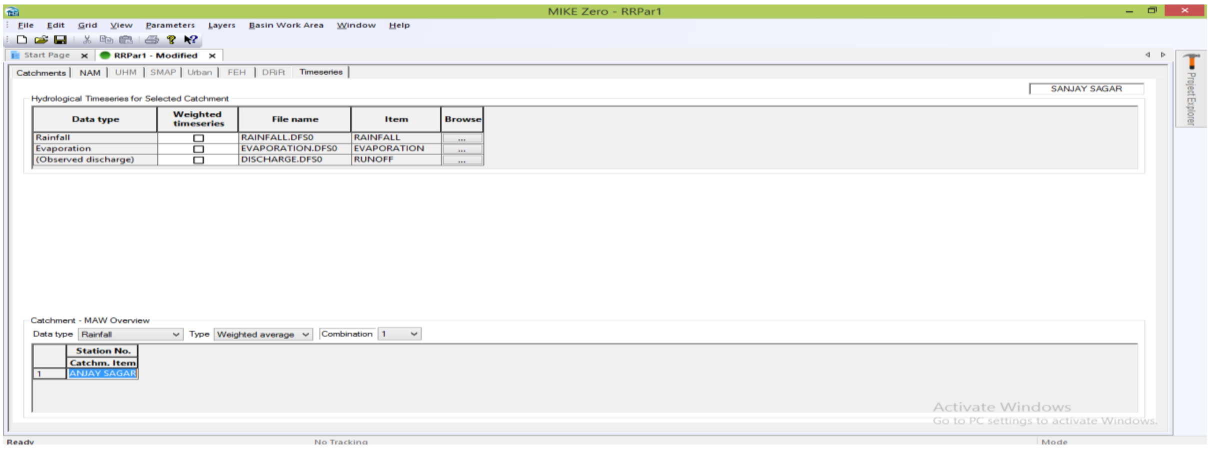


Figure 5.25(d) MIKE11 NAM model input data time series

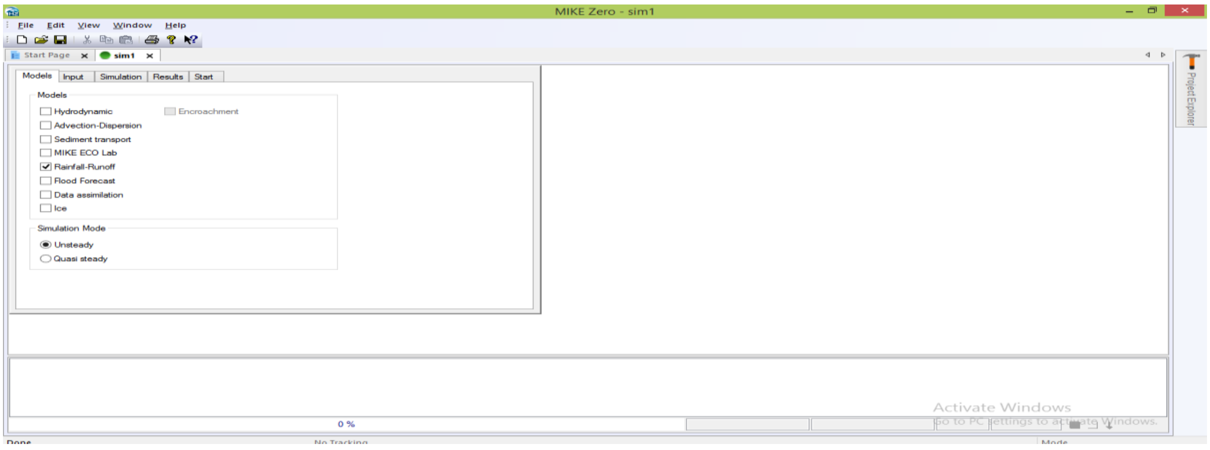


Figure 5.25(e) MIKE11 NAM model input for model simulation

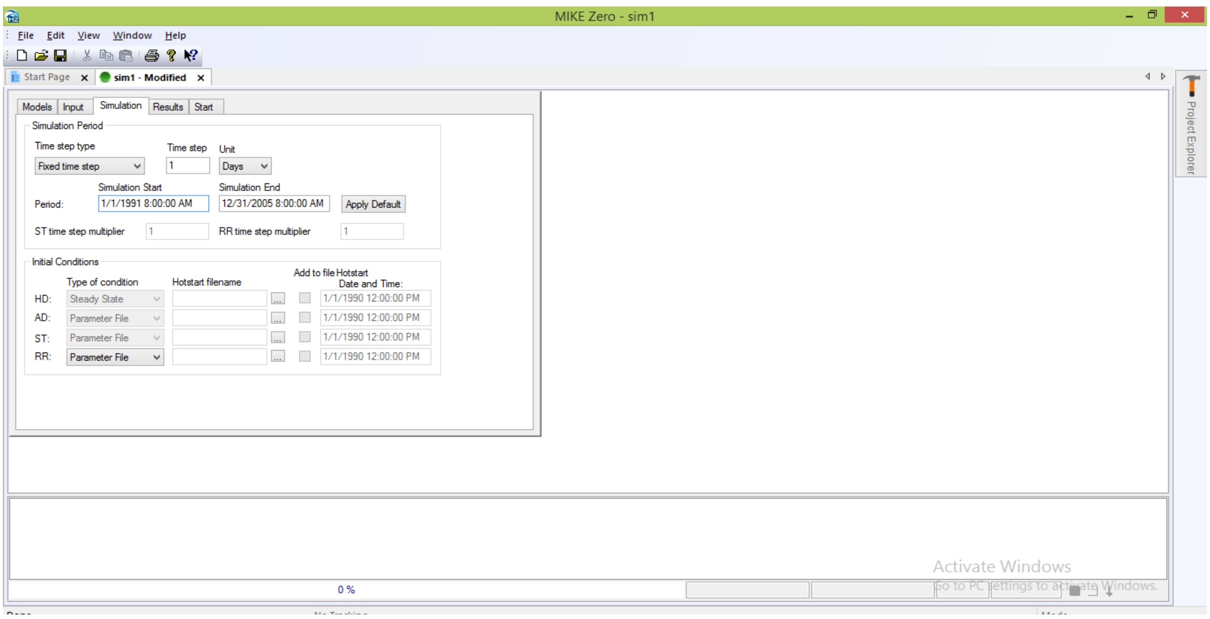


Figure 5.25(f) MIKE11 NAM model simulation period for calibration

The MIKE -11 NAM model was created for the Rainfall-Runoff modeling which utilized the daily rainfall time series data of three rainfall stations, potential evapotranspiration, and observed discharge data of the Bah G/D site for the period from 1989 to 2013. The area of the catchment upstream G/D site is 879.5 sq. km. First, MIKE 11 NAM was used to simulate the runoff by using the auto-calibration mode, and a set of model parameters for the period of 1991 to 2005. After that, the model was calibrated by modifying the model parameters to reduce the error between observed and simulated stream flow data. To obtain the best match between observed and simulated runoff, the model was refined. Throughout the model calibration, nine parameters were determined and the range of these parameters and best-fit values were given in **Table 5.20**.

Table 5.20 Final calibrated model parameter value and their range

Parameter	Parameter range	Best-fit value
U_{max}	10 - 20	18.7
L_{max}	100 - 300	157.821
CQOF	0.1 – 1.0	0.58
CKIF	200 - 1000	210.642
CK_{12}	10 - 50	11.737
TOF	0 – 0.99	0.49
TIF	0 – 0.99	0.03
TG	0 – 0.99	0.961
CKBF	1000 - 4000	3287

The daily observed and simulated runoff and their accumulated values have been presented in **Figure 5.26(a)** and **Figure 5.26(b)** respectively during calibration**.** The coefficient of determination (R^2) was found as 0.68 during calibration. **Table 5.21** presented various components of the hydrological cycle simulated during model calibration including runoff, actual evapotranspiration, groundwater recharge, overland flow, interflow, and base flow. The highest difference percentage of runoff was found in the years 2002 and 2004 at 100% and minimum in the year 1991. From the analysis, the recharge varies from 2.6 to 23.33% in different years. The average recharge percentage is 10.1%. The overland flow varied from 3.5 to 28.55%.

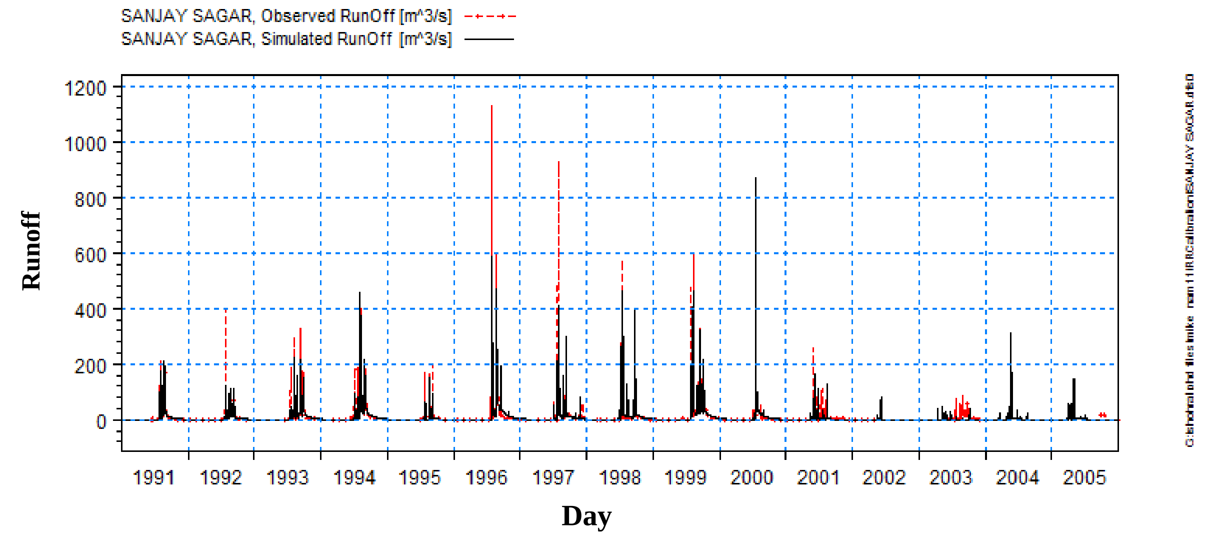


Figure 5.26(a) Comparison of observed and simulated runoff during calibration

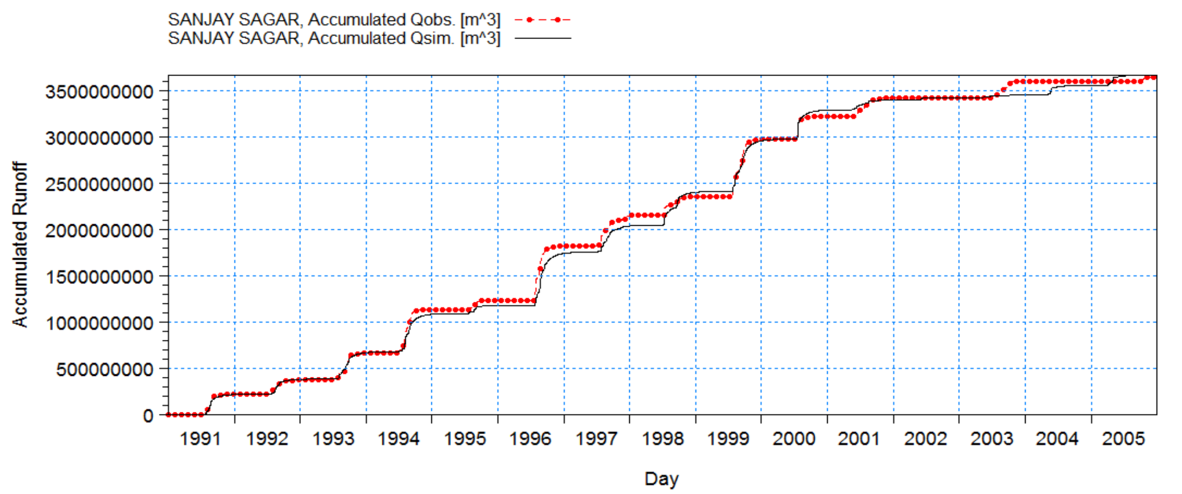


Figure 5.26(b) Observed and simulated cumulative runoff for the calibration

Table 5.21 Statistics of model calibration result from 1991-2005 (All values in mm)

Year	Q-obs	Q-sim	%diff	Rainfall	PotEvap	ActEvap	GWR	OF	IF	BF
1991	250.2	248.3	0.8	750.2	1749.4	472.6	88.9	145.9	18.5	83.9
1992	173.8	185.4	-6.3	666.6	1757.8	472.8	56.6	111.3	16.1	58
1993	331	327.5	1.1	950.6	1698.6	603.9	123.9	190.9	20.2	116.4
1994	528.6	471.6	12.1	1005.4	1651.9	550.7	193.4	252.6	24.4	194.7
1995	120.9	107.6	12.4	597.6	1692.3	501.7	20.8	71.5	7	29.2
1996	662.3	639.4	3.6	1209.4	1687.6	533.8	282.8	345.3	26.3	267.9
1997	376.9	338	11.5	1047.9	1584.2	654	114.8	191.6	21.9	124.5
1998	234.1	413	-43.3	1049.7	1633.8	690.8	156.8	239.2	20.6	153.1
1999	703.3	631.5	11.4	1285.3	1706.9	641.4	268.7	336.6	36.7	258.3
2000	284.3	377.7	-24.7	925.2	1779.6	606.8	145.9	205	10.1	162.5
2001	222.5	121.7	82.9	828.3	1686.4	711.3	21.7	84.6	11.7	25.4
2002	0	-25.3	100	646.6	1811.2	632.2	0	24.5	0.2	0.7
2003	209.3	132.2	58.4	1057.6	1646.7	994.1	0	37.2	0.3	0
2004	0	-121.2	100	1027.3	1731.9	924.1	26.9	91.6	2.9	26.7
2005	43.2	121.7	-64.5	931.3	1674.3	812.9	26.1	90.5	5	26.2
R^2 = 0.68										

(Q: Runoff, RF: Rainfall, PotEvap: Potential Evapotranspiration, ActEvap: Actual Evapotranspiration, GWR: Ground Water Recharge, OF: Overland Flow, IF: Inter Flow, and BF: Base Flow)

5.5.1.3 Model validation

After successful calibration, the same model was run without changing the parameters for validation with an independent dataset from 2006 to 2013 and found that the model worked satisfactorily with R^2 of 0.64. The comparison of computed and simulated daily and accumulated runoff during validation was presented in **Figure 5.27(a)** and **Figure 5.27(b).**

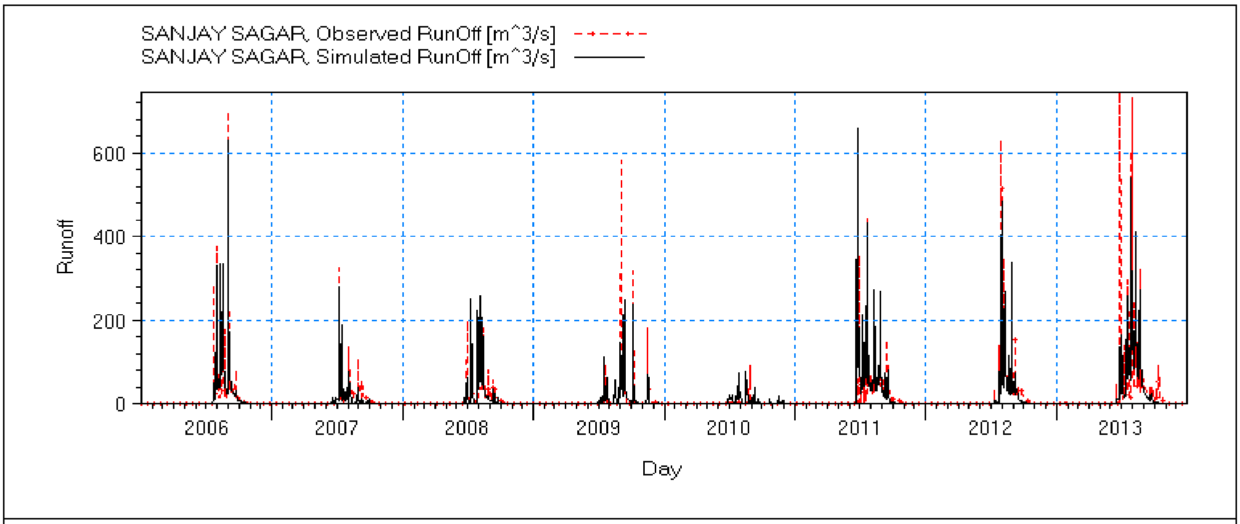


Figure 5.27(a) Comparison of observed and simulated runoff during Validation

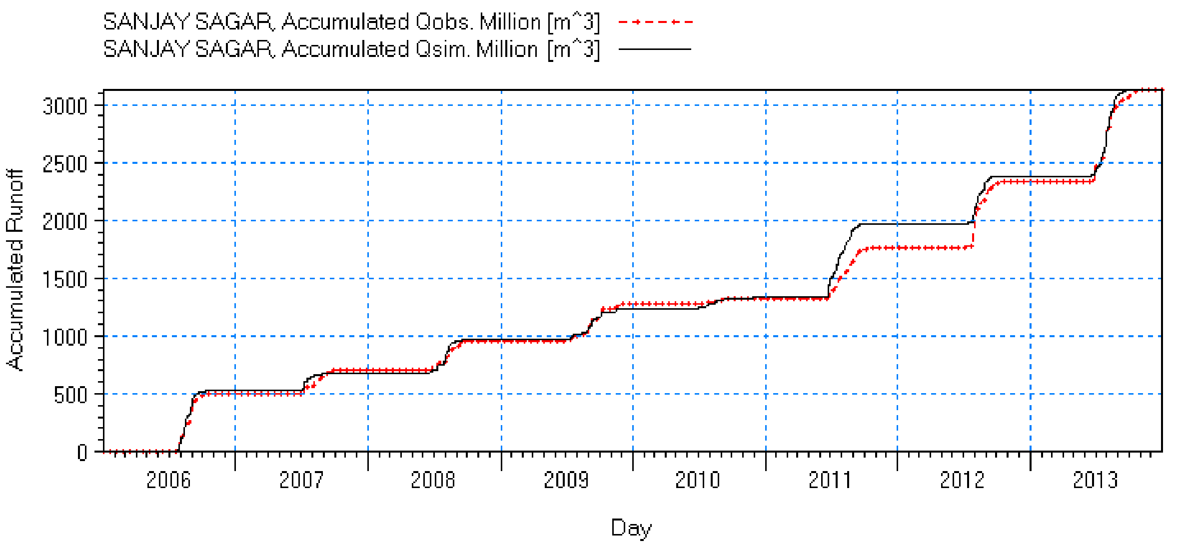


Figure 5.27(b) Comparison of accumulated observed and simulated runoff during validation

The yearly observed and simulated runoff, evaporation, recharge, overland flow, etc. during the validation period (2006 to 2013) is presented in **Table 5.22.** From the analysis, it may be seen that the percent difference in observed and simulated runoff varies from -44.6 to 27.7%. The average recharge and overland flow ratio during validation were computed as 9.4 and 18.9% respectively. As the calibration and validation model was found successful, the model parameters obtained through the NAM model were used in the MIKE HYDRO Basin model for reservoir operation.

Table 5.22 Statistics of model validation results from 2006-2013 (All values in mm)

Year	Q-obs	Q-sim	%diff	Rainfall	PotEvap	ActEvap	GWR	OF	IF	BF
2006	544.9	573.3	-5.2	1230.8	1673.5	645.9	181.9	308.9	82.5	181.9
2007	228.8	171.2	25.2	755.4	1711.1	588.6	23.7	84.4	63.1	23.7
2008	275.4	311.7	-13.2	961.2	1722.5	648.7	68.4	165.6	77.7	68.4
2009	343	288.1	16	1070.2	1694.9	734.5	32.9	154.2	101.1	32.9
2010	89.3	106.9	-19.71	797.9	1710	709.9	0	51.3	25.6	10
2011	484	699.9	-44.6	1346	1648.6	671.3	214.8	352.9	132.2	214.8
2012	619.7	448.1	27.7	1017.9	1703.3	571.6	136.9	238.3	72.9	136.9
2013	863.3	812.2	5.9	1523.8	1603.7	704.9	269.7	410.2	132.3	269.7
R^2= 0.64										

5.5.2 MIKE HYDRO Basin model for Sanjay Sagar project

MIKE HYDRO Release 2021 is a simulation model for rainfall-runoff modeling and water allocation representing the hydrology of basins in space and time and has been developed by the Danish Hydrological Institute (DHI), Denmark. The MIKE HYDRO Basin is a critical water resource management tool for managing the water resources in the command area, supplying water for various agricultural, industrial, and domestic purposes. Simulating a river basin includes calculating many different processes and components that influence water consumption and water balance. Simulations of water resources management use the calculation engine from DHI's predecessor to MIKE HYDRO; MIKE BASIN for simulations of water resources. Thus, most calculation methods for specific modeling features have been validated over a long period through intensive project applications.

In the present study, a reservoir operation and planning model was developed for the Sanjay Sagar project which consists of a catchment of Sanjay Sagar dam, a dam, and four irrigation water users representing 4 WUAs namely Khajuri Samshabad, Pipladhar, Seu, and Ravan **(Figure 5.28).** These users are connected through a canal where conveyance and application losses are assigned. The NAM model parameters obtained from the NAM modeling of the Bah G/D site were assigned to compute inflow from this catchment. The reservoir characteristics like dead storage level, full reservoir level, and elevation-area-capacity table were given for the Sanjay Sagar dam. Wheat is the main crop covered by all WUAs in Sanjay Sagar command followed by Gram in very limited areas. The climate, crops, and soil sub-models were developed using field information and data collected from different sites. The results of soil analysis carried out in the command were used to develop a soil model for the command. The cropping areas in different water user associations were assigned in the "Irrigation field" Tab of the Water user. The model was run on different irrigation efficiencies and irrigation methods. The simulation run daily was made from Nov 2015 to March 2021 and results were exported in Excel to compute total demand and deficit for WUAs.

In the study, four different scenarios based on different efficiencies, application methods, and conjunctive use were analyzed. The scenarios consisted of an overall efficiency of 60% in flood irrigation as SCN-1, an overall efficiency of 60% in flood irrigation and 5% groundwater use as SCN-2, an overall efficiency of 75% in sprinkler irrigation as SCN-3, and an overall efficiency of 75% in sprinkler irrigation and 5% groundwater use as SCN-4. The results of these scenarios are described in the next sections.

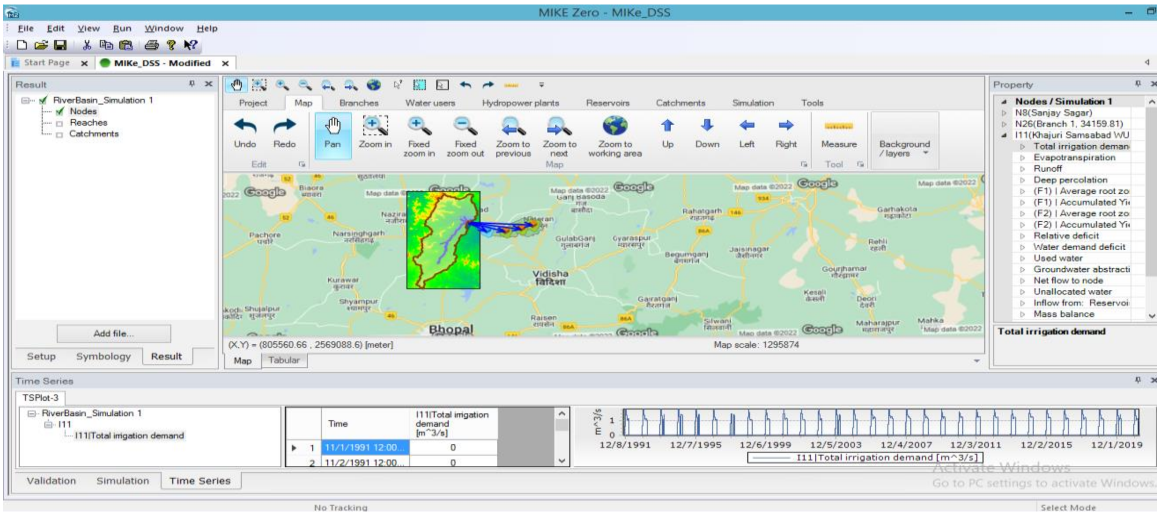


Figure 5.28 MIKE Basin setup for the Sanjay Sagar project

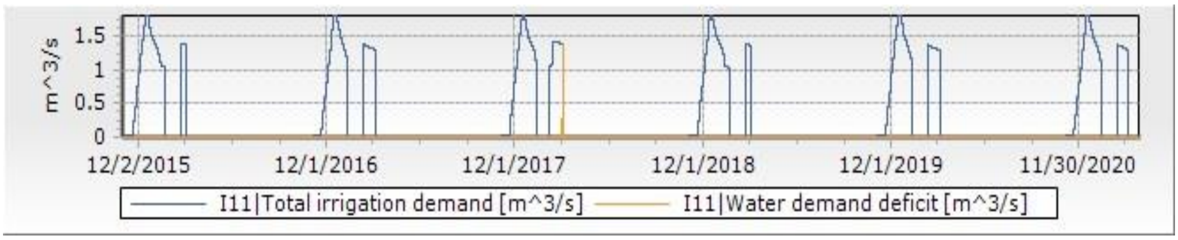
5.5.2.1 Overall efficiency 60% in flood irrigation

The results for the MIKE-HYDRO Basin simulation for the year 2015-2021 at 60% irrigation efficiency indicated that the average water deficit may be 0.45 MCM, suggesting that the irrigation demand was satisfactorily met in most of the years. However, the maximum water deficit reached 2.01MCM, signifying a substantial water shortage in the command area during the dry periods. These findings underscore the importance of optimizing irrigation practices and water management strategies to minimize water deficits and ensure sustainable agricultural water use in the region. **Figure 5.29 and Table 5.23** visually and quantitatively represent the variations in water deficits across the analyzed years, providing valuable insights for water resource planning and decision-making.

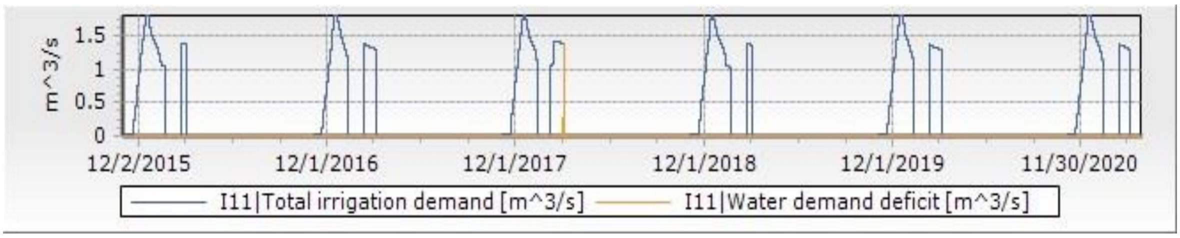
Table 5.23 Demand and Deficit at 60% irrigation efficiency (SCN-1)

Crop Year	Khajuri Samshabad WUA			Pipladhar WUA			Ravan WUA			Seu WUA			Total		
	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup
2015-16	8.06	0.00	12.60	9.59	0.01	14.96	12.96	0.18	19.96	19.48	19.48	12.64	43.24	0.37	66.99
2016-17	8.21	0.00	12.84	9.77	0.00	15.26	11.38	0.00	17.78	17.36	17.36	11.11	40.47	0.00	63.23
2017-18	9.07	0.21	13.84	10.79	0.26	16.45	12.81	0.72	18.90	18.25	18.25	12.50	45.17	2.01	67.44
2018-19	8.06	0.00	12.60	9.59	0.01	14.97	12.96	0.18	19.97	19.48	19.48	12.64	43.24	0.35	67.02
2019-20	8.21	0.00	12.84	9.77	0.00	15.26	11.37	0.00	17.77	17.36	17.36	11.11	40.47	0.00	63.23
2020-21	8.21	0.00	12.83	9.76	0.00	15.26	11.38	0.00	17.78	17.36	17.36	11.11	40.46	0.00	63.22
Average	**8.31**	**0.04**	**12.92**	**9.88**	**0.05**	**15.36**	**12.14**	**0.18**	**18.69**	**18.22**	**18.22**	**11.85**	**42.18**	**0.45**	**65.19**

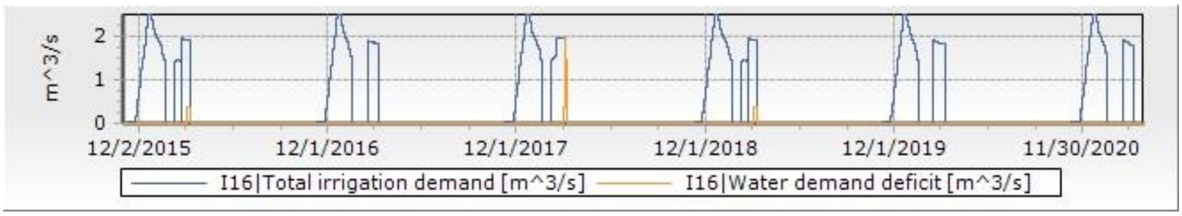
Maximum	**9.07**	**0.21**	**13.84**	**10.79**	**0.26**	**16.45**	**12.96**	**0.72**	**19.97**	**19.48**	**19.48**	**12.64**	**45.17**	**2.01**	**67.44**
Minimum	**8.06**	**0.00**	**12.60**	**9.59**	**0.00**	**14.96**	**11.37**	**0.00**	**17.77**	**17.36**	**17.36**	**11.11**	**40.46**	**0.00**	**63.22**



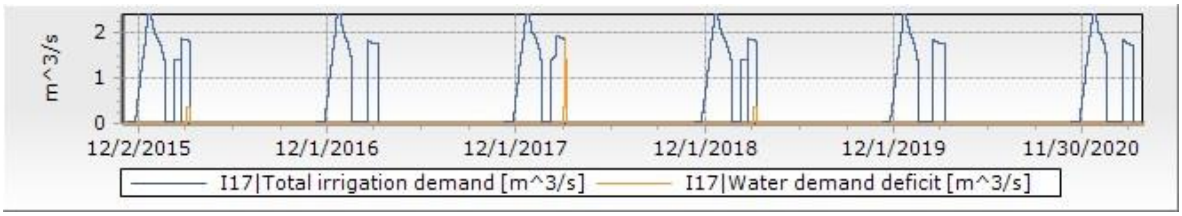
(a) Khajuri Samshabad WUA



(b) Pipaldhar WUA



(c) Ravan WUA

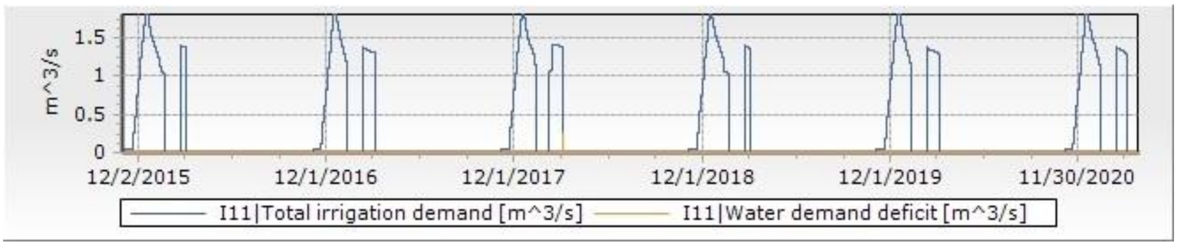


(d) Seu WUA

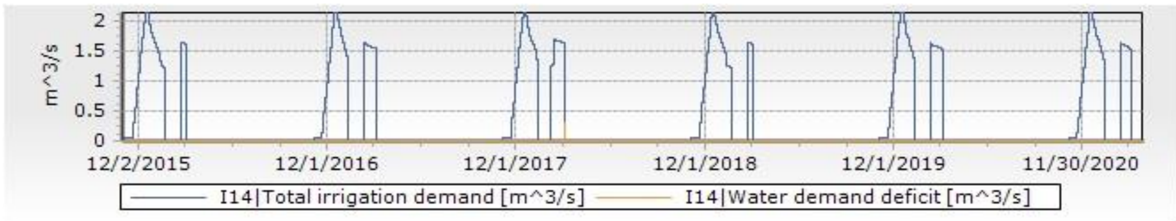
Figure 5.29 Simulation results from MIKE HYDRO basin for overall efficiency 60%

5.5.2.2 Overall efficiency 60% in flood irrigation with 5% groundwater (SCN-2)

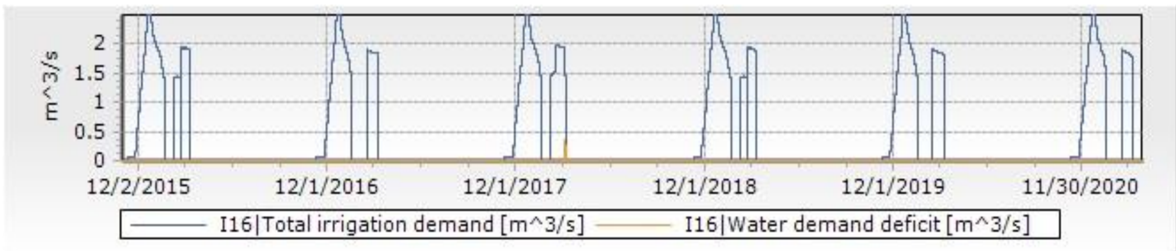
The results for the MIKE-HYDRO Basin simulation for the year 2015-2021 at 60% irrigation efficiency including 5% indicated that there may be no deficit and the irrigation demand was satisfactorily met in the given period except 2017-18. However, the maximum water deficit reached 0.27 MCM in the dry year period 2017-18. These findings underscore the importance of optimizing irrigation practices and water management strategies to minimize water deficits and ensure sustainable agricultural water use in the region. **Figure 5.30 and Table 5.24** visually and quantitatively represent the variations in water deficits across the analyzed years, providing valuable insights for water resource planning and decision-making.



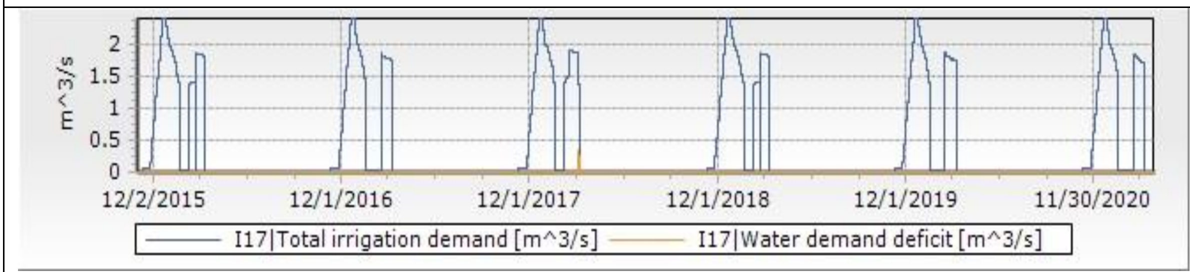
(a) Khajuri Samshabad WUA



(b) Pipaldhar WUA



(c) Rawan WUA



(d) Seu WUA

Figure 5.30 Simulation results from MIKE HYDRO basin for overall efficiency 60% and 5% GW use

Table 5.24 Demand and Deficit at 60% irrigation efficiency and 5% GW (SCN-2)

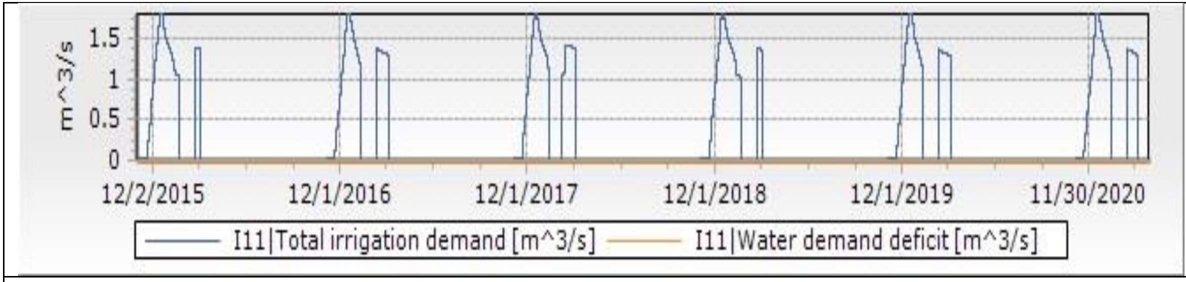
Crop Year	Khajuri Shamsabad WUA			Pipladhar WUA			Ravan WUA			Seu WUA			Total		
	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup
2015-16	8.06	0.00	11.97	9.59	0.00	14.23	12.96	0.00	19.23	12.64	0.00	18.76	43.24	0.00	64.19
2016-17	8.21	0.00	12.19	9.77	0.00	14.50	11.38	0.00	16.89	11.11	0.00	16.49	40.47	0.00	60.07
2017-18	9.07	0.02	13.43	10.79	0.03	15.97	12.81	0.11	18.84	12.50	0.11	18.39	45.17	0.27	66.63
2018-19	8.06	0.00	11.97	9.59	0.00	14.23	12.96	0.00	19.23	12.64	0.00	18.76	43.24	0.00	64.19
2019-20	8.21	0.00	12.19	9.77	0.00	14.50	11.37	0.00	16.88	11.11	0.00	16.49	40.47	0.00	60.07
2020-21	8.21	0.00	12.19	9.76	0.00	14.49	11.38	0.00	16.89	11.11	0.00	16.49	40.46	0.00	60.06
Average	8.31	0.00	12.32	9.88	0.00	14.65	12.14	0.02	17.99	11.85	0.02	17.56	42.18	0.04	62.54
Maximum	9.07	0.02	13.43	10.79	0.03	15.97	12.96	0.11	19.23	12.64	0.11	18.76	45.17	0.27	66.63
Minimum	8.06	0.00	11.97	9.59	0.00	14.23	11.37	0.00	16.88	11.11	0.00	16.49	40.46	0.00	60.06

5.5.2.3 Overall efficiency 75% in sprinkler irrigation (SCN-3)

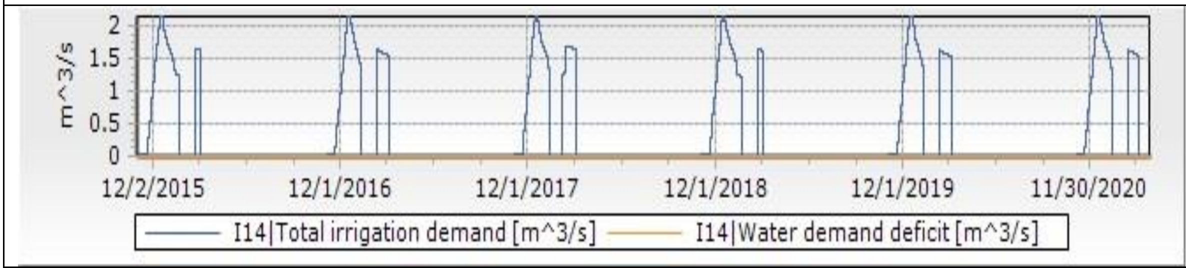
The study investigated various irrigation scenarios in the Mike Hydro Basin by considering different irrigation efficiencies for flood irrigation. In the present scenario, the sprinkler irrigation method was chosen for an overall efficiency of 75% and no groundwater use. The results of the analysis depicted in **Table 5.25 and Figure 5.31** covered the period from 2015 to 2021. The findings indicated that the application of a 75% irrigation efficiency for sprinkler systems resulted in promising outcomes with no deficit in the command. These results highlight the potential of improving irrigation practices and water management strategies to mitigate water deficits and enhance water availability in the command area.

Table 5.25 Demand and Deficit at 75% irrigation efficiency (SCN-3)

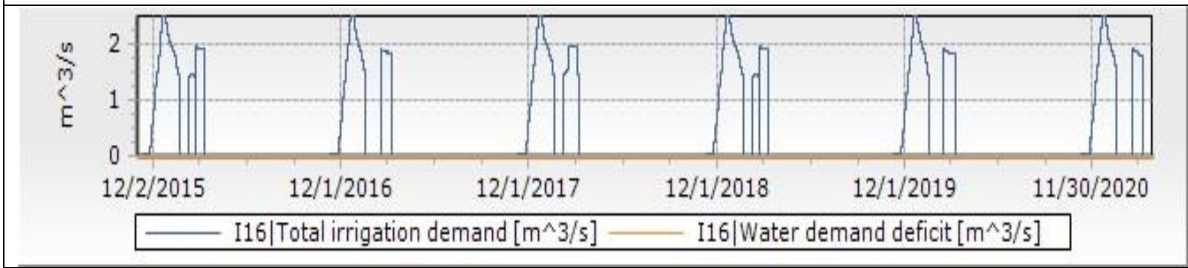
Crop Year	Khajuri Samshabad WUA			Pipladhar WUA			Ravan WUA			Seu WUA			Total		
	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup
2015-16	8.06	0.00	10.21	9.59	0.00	9.59	12.96	0.00	16.41	12.64	0.00	16.01	43.24	0.00	54.77
2016-17	8.21	0.00	10.41	9.77	0.00	9.77	11.38	0.00	14.41	11.11	0.00	14.08	40.47	0.00	51.26
2017-18	9.07	0.00	11.49	10.79	0.00	10.79	12.81	0.00	16.23	12.50	0.00	15.83	45.17	0.00	57.22
2018-19	8.06	0.00	10.21	9.59	0.00	9.59	12.96	0.00	16.41	12.64	0.00	16.01	43.24	0.00	54.77
2019-20	8.21	0.00	10.41	9.77	0.00	9.77	11.37	0.00	14.41	11.11	0.00	14.07	40.47	0.00	51.26
2020-21	8.21	0.00	10.40	9.76	0.00	9.76	11.38	0.00	14.41	11.11	0.00	14.08	40.46	0.00	51.25
Average	8.31	0.00	10.52	9.88	0.00	9.88	12.14	0.00	15.38	11.85	0.00	15.01	42.18	0.00	53.42
Maximum	9.07	0.00	11.49	10.79	0.00	10.79	12.96	0.00	16.41	12.64	0.00	16.01	45.17	0.00	57.22
Minimum	8.06	0.00	10.21	9.59	0.00	9.59	11.37	0.00	14.41	11.11	0.00	14.07	40.46	0.00	51.25



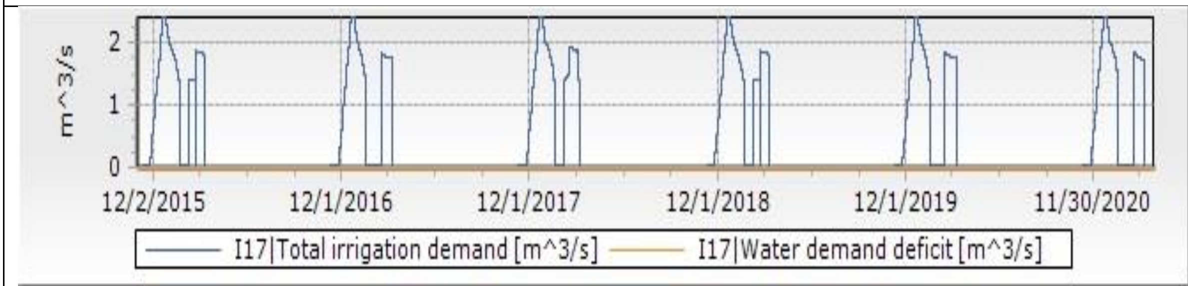
(a) Khajuri Samshabad WUA



(b) Pipaldhar WUA



(c) Ravan WUA

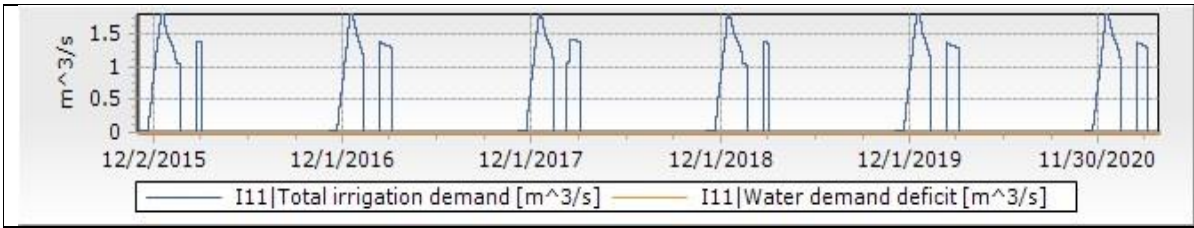


(d) Seu WUA

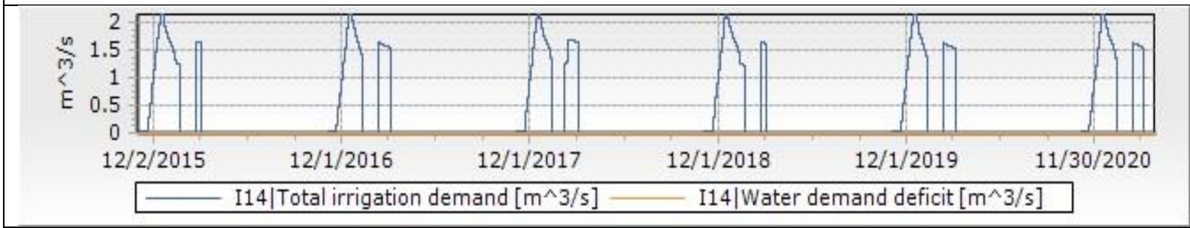
Figure 5.31 Simulation results from MIKE HYDRO basin for overall efficiency 75%

5.5.2.4 Overall efficiency 75% for sprinkler irrigation with 5% irrigation water

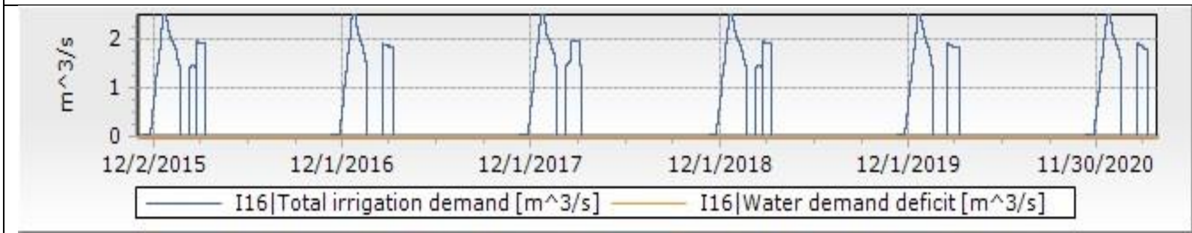
In the previous scenarios deficit was zero. This scenario has been run for future scenarios in the aspect of climate change. This scenario fulfils all the demands under the present climatic scenario. In the future, this scenario will be helpful for water resources for reservoir operation and planning management. The results of the analysis, depicted in **Figure 5.32 and Table 5.26** covered the period from 2015 to 2021.



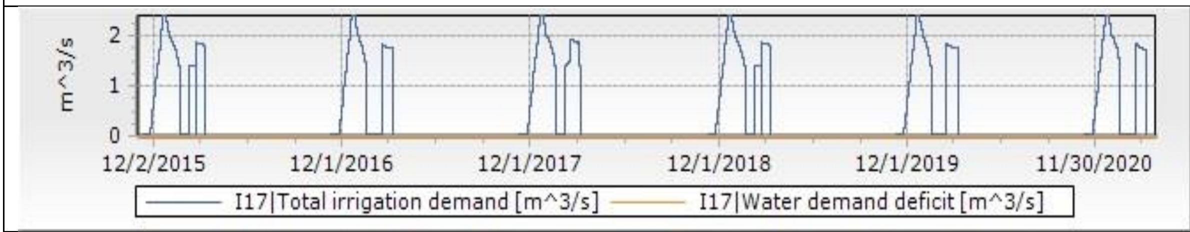
(a) Khajuri Samshabad



(b) Pipaldhar



(c) Ravan



(d) Seu

Figure 5.32 Simulation results from MIKE HYDRO basin for overall efficiency 75% with 5% GW use

Table 5.26 Demand and Deficit at 75% irrigation efficiency with 5% GW (SCN-4)

Crop Year	Khajuri Samshabad WUA			Pipladhar WUA			Ravan WUA			Seu WUA			Total		
	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup	ID	DD	Sup
2015-16	8.06	0.00	10.21	9.59	0.00	12.14	12.96	0.00	16.41	12.64	0.00	16.01	43.24	0.00	54.77
2016-17	8.21	0.00	10.41	9.77	0.00	12.37	11.38	0.00	14.41	11.11	0.00	14.08	40.47	0.00	51.26
2017-18	9.07	0.00	11.49	10.79	0.00	13.66	12.81	0.00	16.23	12.50	0.00	15.83	45.17	0.00	57.22
2018-19	8.06	0.00	10.21	9.59	0.00	12.14	12.96	0.00	16.41	12.64	0.00	16.01	43.24	0.00	54.77
2019-20	8.21	0.00	10.41	9.77	0.00	12.37	11.37	0.00	14.41	11.11	0.00	14.07	40.47	0.00	51.26
2020-21	8.21	0.00	10.40	9.76	0.00	12.37	11.38	0.00	14.41	11.11	0.00	14.08	40.46	0.00	51.25
Average	8.31	0.00	10.52	9.88	0.00	12.51	12.14	0.00	15.38	11.85	0.00	15.01	42.18	0.00	53.42

Maximum	9.07	0.00	11.49	10.79	0.00	13.66	12.96	0.00	16.41	12.64	0.00	16.01	45.17	0.00	57.22
Minimum	8.06	0.00	10.21	9.59	0.00	12.14	11.37	0.00	14.41	11.11	0.00	14.07	40.46	0.00	51.25

5.6 DSS PM for Sanjay Sagar Project

The Danish Hydrological Institute, Denmark (DHI) has developed a decision support system (DSS PM) for planning and management of water resources in the country. The DSS PM developed by DHI is based on MIKE along with HEC HMS, HEC RAS, NIH Re_SyP, and other software. The MIKE Hydro Basin model for the Sanjay Sagar project was brought into the DSS PM as shown in **Figure 5.33**. The DSS PM for the Sanjay Sagar project can be used for irrigation planning with future climate data available in the DSS PM and the development of scenarios with changed efficiencies, groundwater uses, and other options.

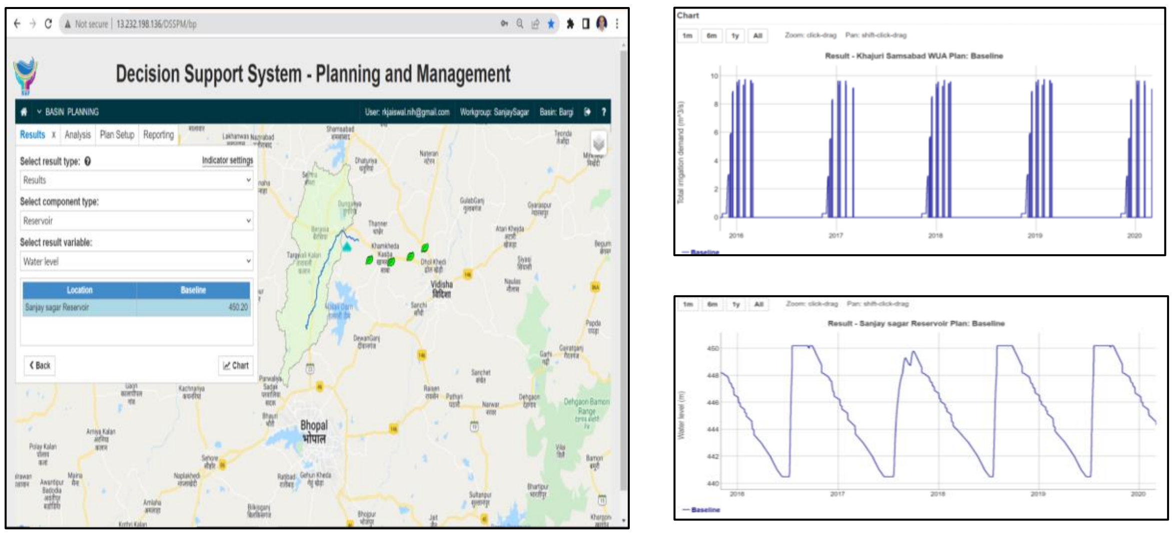


Figure 5.33 MIKE HYDRO Basin model of Sanjay Sagar Project in DSS(PM)

5.7 Climate Change Scenarios

Climate change is likely to affect almost all sectors of life and society and it is imperative to address the issue of changing climate change in a comprehensive manner considering present trends, future possibilities, harmful effects, uncertainties, complexity, response, and preparedness. The possible climate change may increase the concentration of carbon dioxide, population, urbanization, etc. leading to changes in precipitation and temperature regime will further affect evapotranspiration, crop water requirement, crop yield, and overall economy of many regions especially agrarian countries. Climate change can significantly affect the demand for irrigation command and the availability of water in reservoirs and other sources. It is desirable to carry out assessment studies where irrigation demand is computed using projected GCM data. The selection of the GCM climate model plays a vital role in the assessment of crop water requirement, demand, deficit, etc.

5.7.1 Performance Evaluation of GCM

The ability of the different GCMs to reproduce the rainfall, maximum and minimum temperature (T_{max} & T_{min}) of the study area concerning the observed dataset was assessed using four statistical indices including percentage bias (PBIAS), Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2), and root mean square error (RMSE). The value of the statistical indices of 13 GCMs for rainfall, T_{max}, and T_{min} were given in **Table 5.27**. Results show that, for rainfall, MPI-ESM1-2-LR gives the best results followed by BCC-CSM2-MR and EC-EARTH3-VEG respectively. The MPI-ESM1-2-LR performed best followed by EC-EARTH3-VEG, INM CM4-8, INM CM5-0, and MPI-ESM1-2-HR respectively for maximum temperature in the region. For minimum temperature, the MPI-ESM1-2-LR is found as best performing model. Based on the above results, MPI-ESM1-2-LR is selected to project future rainfall and minimum and maximum temperature.

Table 5.27 Performance metrics and ranking of different GCMs

GCM	Rainfall				Tmax				Tmin			
	Pbias	NSE	R^2	RMSE	Pbias	NSE	R^2	RMSE	Pbias	NSE	R^2	RMSE
ACCESS-CM2	-12.4	-0.13	0.25	162.33	0.26	0.49	0.54	3.36	1.3	0.86	0.86	2.21
BCC-CSM2-MR	-2.30	0.49	0.52	108.70	0.63	0.65	0.66	3.00	2.3	0.89	0.90	1.91
Can ESM 6	7.73	-0.72	0.01	199.86	-0.34	0.41	0.48	3.92	0.12	0.77	0.78	2.83
EC-EARTH3	-2.25	0.13	0.37	141.93	0.37	0.72	0.73	2.70	0.65	0.90	0.90	1.89
EC-EARTH3-VEG	1.83	0.35	0.50	122.08	0.42	0.71	0.78	2.43	1.3	0.91	0.91	1.82
INM CM4-8	-8.67	-0.00	0.49	152.92	0.55	0.71	0.78	2.44	1.8	0.89	0.89	1.97
INM CM5-0	5.30	-0.02	0.44	154.07	0.07	0.71	0.77	2.44	1.7	0.89	0.89	1.94
MPI-ESM1-2-HR	-0.85	0.16	0.43	139.14	0.77	0.71	0.76	2.57	2.23	0.92	0.92	1.6
MPI-ESM1-2-LR	**4.09**	**0.51**	**0.58**	**107.21**	**0.79**	**0.74**	**0.76**	**2.59**	**2.11**	**0.93**	**0.93**	**1.57**
MRI-ESM2-0	-1.12	-0.31	-0.23	174.39	0.85	0.53	0.58	3.50	1.8	0.91	0.92	1.74

NorESM-2-LM	-14.9	0.00	0.35	152.27	1.4	0.56	0.59	3.38	2.4	0.85	0.86	2.27
Nor ESM-2-MM	-10.8	0.16	0.37	138.81	1.29	0.67	0.68	2.94	2.59	0.88	0.88	2.07
ACCESS-ESM1-5	-10.0	-0.45	0.05	183.74	0.80	0.54	0.59	3.47	0.78	0.87	0.87	2.11

After selecting MPI-ESM1-2-LR as the best-performing future model, the concurrent rainfall from different scenarios of this GCM (SSP126, SSP245, SSP370, and SSP585) was compared with IMD rainfall and data from the Visual crossing website to identify the best-fit scenario under present climatic condition. The Visual crossing data provides 15 days of projected rainfall maximum and minimum temperature and can be uploaded through API for use in irrigation planning and reservoir operation. **Figure 5.34** shows the comparison of rainfall data during the period 2015 to 2022 from IMD, the visual crossing website, and different SSPs of MPI-ESM1-2-LR GCM. The analysis showed that SSP2.6 of MPI-ESM1-2-LR and data from the visual crossing website were found close to IMD Rainfall data and can be used for water resource planning, reservoir operation, and irrigation scheduling.

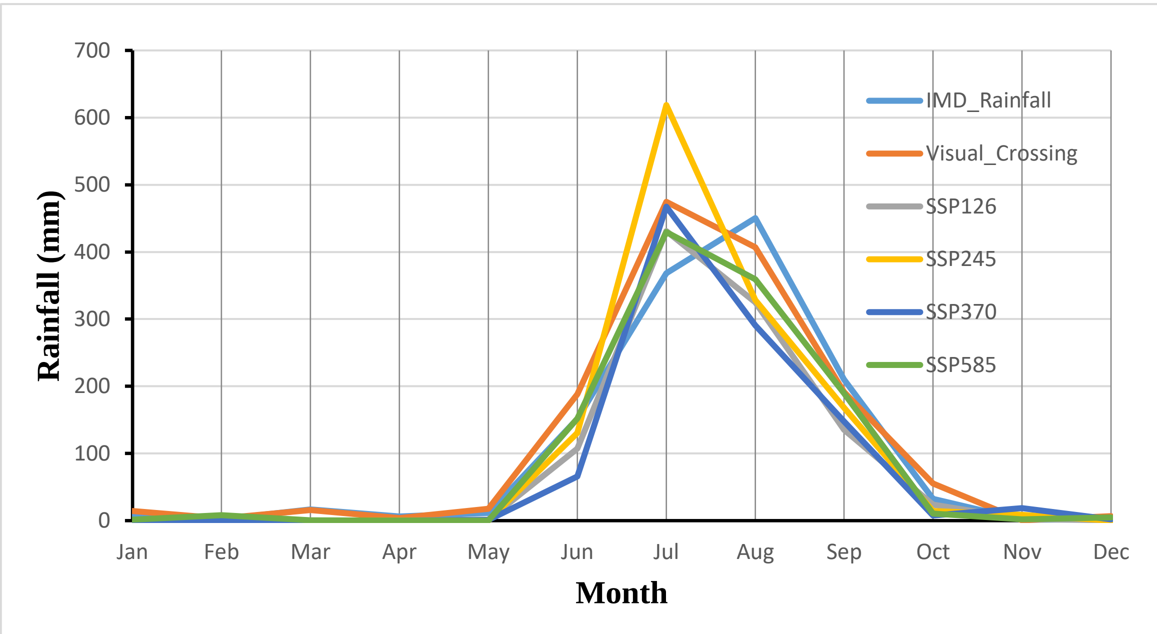


Figure 5.34 Comparison of IMD Rainfall, visual crossing with SSP scenarios

5.8 Excel-based decision support system for irrigation management

5.8.1 DSS program and dashboard

The development of a decision-making system utilizing Excel to facilitate the analysis of water balance calculations for the Sanjay Sagar dam's command area was made so that WR managers could use it easily. The system aimed to assist decision-makers in making informed choices by providing comprehensive insights into the surplus or deficit in the water supply. The Excel spreadsheet is constructed using data from multiple sources, including rainfall and temperature data obtained from the Indian Meteorological Department and other websites and GCMs. By considering temperature and location information, the water balance model accurately computes potential evapotranspiration using the Hargreaves method.

The Excel programming incorporated essential land parameter information, such as soil type, field capacity, and soil wilting point. Moreover, the crop water requirement, a crucial element in reservoir water balancing was considered based on forecast data from different websites. The system determines the amount of water to be supplied from the canal to achieve a balance between irrigation needs and water supply, thereby maximizing crop productivity, based on the current water availability in the reservoir. The Excel program has several interrelated sheets for computation of crop water requirement for wheat and gram crops, water balance of the reservoir for probable/actual supply based on efficiencies, canal capacity, available water in the reservoir, and inflow into the reservoir using the SCS CN model.

To address reservoir operation criteria, the water supply is reduced to user specified percentage after the reservoir level reaches a predetermined threshold, with the level of scarcity determined by the available water in the reservoir for a specific year. The information related to actual crop areas of wheat/gram and reservoir levels can be changed at any time of the crop season. The WR managers can also bring a 15-day future forecast of temperature and rainfall data from the visual crossing website using the MACRO function in the sheet.

The dashboard for the irrigation management program in Sanjay Sagar Dam is shown in **Figure 5.35**. In the dashboard, WR managers need to provide the area, showing dates of crops in different WUAs, and initial reservoir levels at the start of the canal. Once this information was filled in, the DSS automatically computed crop and irrigation water requirements of the crops, supplies, and deficits of water in different WUAs and the status of the reservoir at the end of the rabi season and depicted in the Result sheet. The results from the water balance are presented in **Figure 5.36**. The water demand, supply, and water scarcity are outlined in **Table 5.28**.

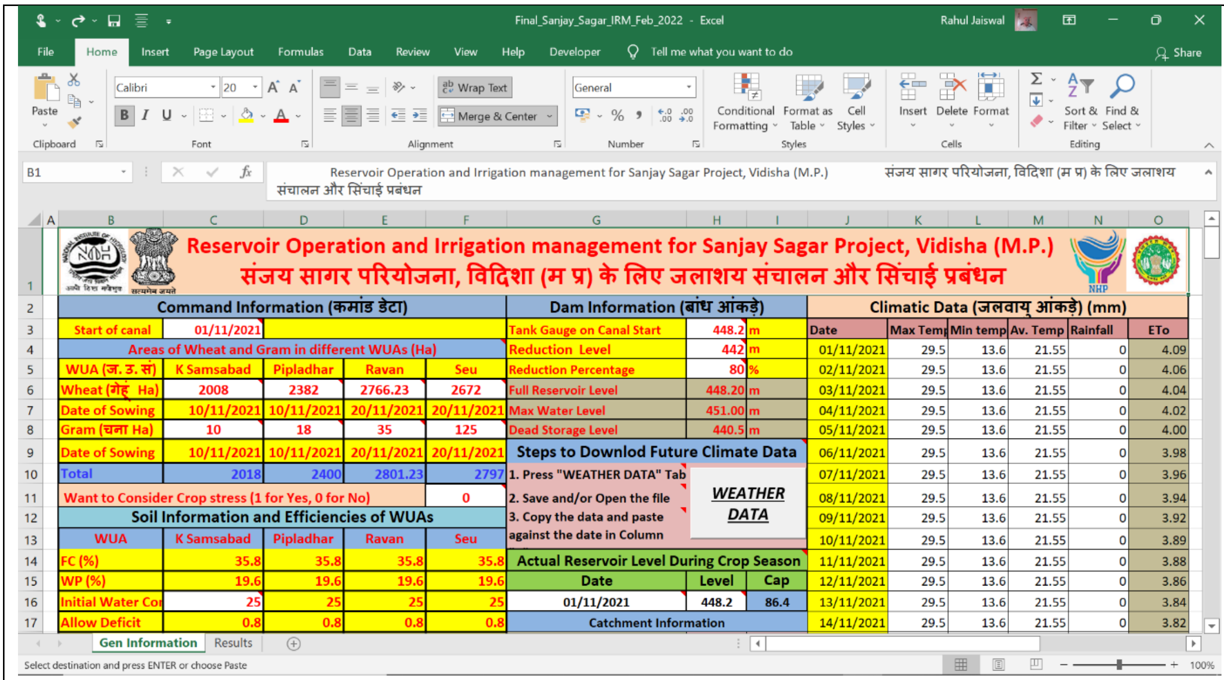


Figure 5.35 Dashboard for Excel-based reservoir Operation for Sanjay Sagar reservoir

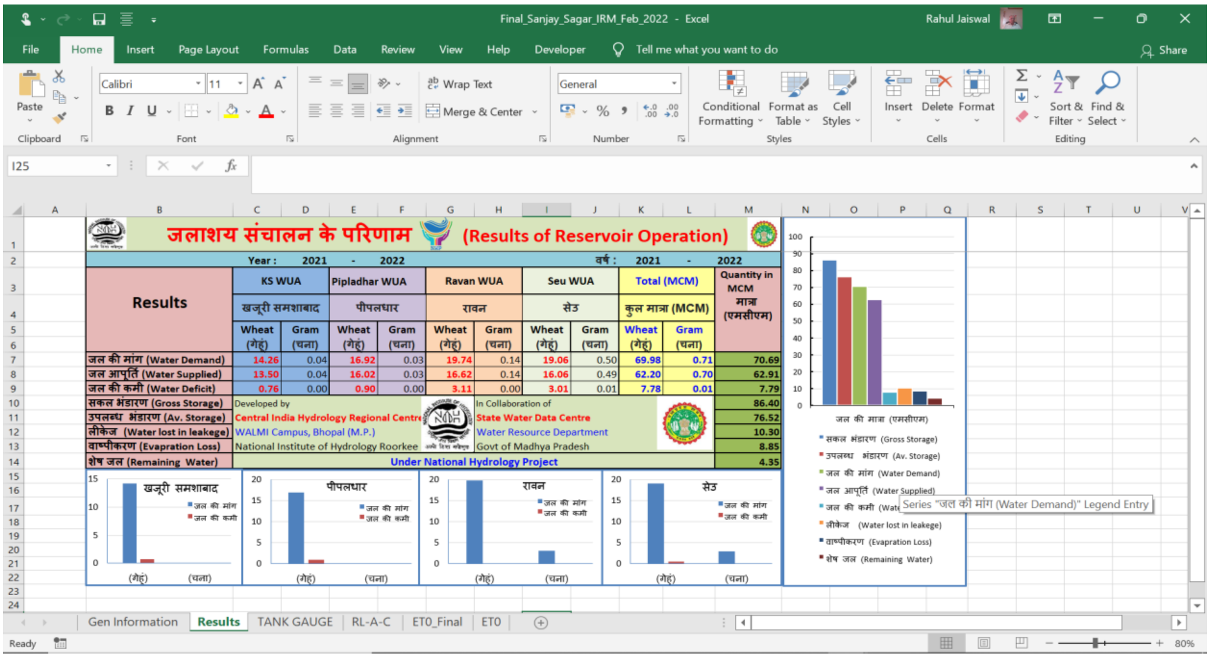


Figure 5.36 Results sheet of the dashboard for reservoir operation

Table 5.28 Results of excel-based DSS for Sanjay Sagar project

Results	Values (MCM)	KS WUA		Pipladhar WUA		Ravan WUA		Seu WUA		Total (MCM)	
		Wheat	Gram	Wheat	Gram	Wheat	Gram	Wheat	Gram	Wheat	Gram
Available Storage	76.38										

Water Demand		14.26	0.04	16.92	0.03	19.74	0.14	19.06	0.50	69.98	0.71
Water Supplied		13.50	0.04	16.02	0.03	16.62	0.14	16.06	0.49	62.20	0.70
Water Deficit		0.76	0.00	0.90	0.00	3.11	0.00	3.01	0.01	7.78	0.01
Water lost in leakage	3.6	-	-	-	-	-	-	-	-	-	-
Water lost through Evaporation	8	-	-	-	-	-	-	-	-	-	-

5.8.2 Optimization of crop areas

In the Excel-based programming, the water resource manager can also optimize the crop areas of different crops in WUAs using inbuilt macro through Solver in Excel. The macro was developed to optimize the percentage of crops for minimization of water deficit with constraints that the area of a crop in WUA should not be less than 10% and not be more than 80% of the total crop area. The GRG nonlinear optimization algorithm was used to optimize the crop areas using the following optimization function.

$$OF = Min \sum_{k=1}^{n} \sum_{l=1}^{m} Def_{k,l} \qquad (5.2)$$

Here, OF is the objective function, $Def_{k,l}$ is the deficit for k^{th} crop in l^{th} WUA. The constraints for different crops were assigned

$$CP_i^{\ j} \geq 10\% \qquad (5.3)$$

$$CP_i^{\ j} \leq 80\% \qquad (5.4)$$

Excel has three different solving methods for optimization including generalized reduced gradient (GRG) nonlinear, simplex, and evolutionary. The GRG nonlinear is mainly used to solve non-linear problems, the simplex method is used to solve linear problems, while the evolutionary can solve complex and non-smooth non-linear problems and provide global solutions. The GRG non-linear method examines the gradient or slope of the objective function as the input values (or decision variables) change and determines that an optimal solution has been reached when the partial derivatives equal zero. The solution of GRG nonlinear depends on the start value, the function should be smooth and sometimes it may stop on local optima, so the option of multi-start can be used to avoid these deficiencies. The simple LP is used to solve the optimum problem linearly and is least used in complex problems but always provides the global solution.

The evolutionary method is based on the theory of natural selection, which works well in the case of already-known best outcomes. The evolutionary solver begins with a random "population" of input value sets. These input value sets are fed into the model, and the results are compared to the target value. The GRG solver is used to look into robust and less time-consuming optimization techniques. The result of the model is demonstrated in the form of a bar chart for better visualization and understanding and tabular form. The result shows the demand for water in the command area based on the area of the crop and crop water requirement the amount of water supplied that has been required by the crop and eventually the deficit of water in the command due to insufficient availability of the water in the dam. The model is quite precise and very useful in the canal and reservoir operation.

5.9 Results of Web and Mobile Application

This application has been developed to provide information to the farmers about available water in the reservoir, demand, and deficit of water from different crops in WUAs, and optimized cropping patterns for minimization of deficit. There are several information tabs given in both applications. The description of all tabs is given below:

5.9.1 Home page view

In this user gets the basic information about the dam. The following information is listed below:

1. About Sanjay Sagar (Bah) Irrigation Project
2. Information about application
3. How is this application useful for farmers?

All this information is available in both languages (Hindi & English). The home page of Kisan Maitri has been presented in **Figure 5.37.**

5.9.2 User registration/login

On the registration login page, the user can register through his/her mobile number to use the services of the Application.

5.9.2.1 Registration process

1. The user needs to register himself by entering his name, and mobile number and setting the password as per his confidence.
2. The user is registered and ready to use the application.

5.9.2.2 Login process

1. Enter the mobile number given at the time of registration.
2. Enter the password chosen at the time of registration.

3. After login, the user must enter the relevant details under the given fields.

The farmer's registration form and login have been presented in **Figures 5.38(a) & 5.31(b)** where all the pages were given in Hindi language for easy understanding to farmers.

Figure 5.37 Homepage of Kisan-Maitri web application

Figure 5.38(a) Farmer registration tab

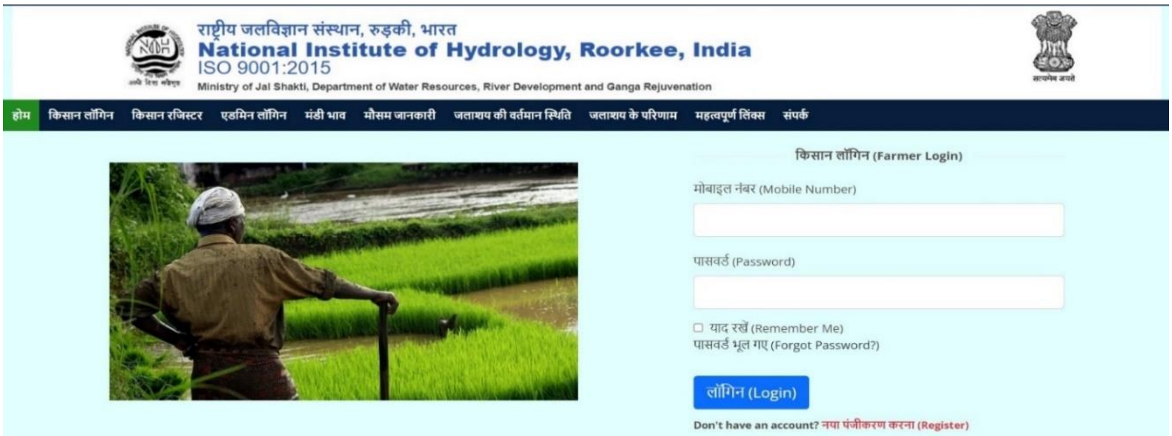


Figure 5.38(b) Farmer login tab

5.9.3 Dashboard information

After login, go to its dashboard. In the dashboard tab, the details of the reservoir, crop information, and complaints have been given. In this tab, two major pieces of information have been taken from farmers. The details are given below.

1. Crop Information: Farmers can enter crop details under a pre-defined crop name or by giving their crop name.
2. Information/Complaint: Through this option, farmers can raise any complaint/issue like water theft, non-availability of water/less water, canal breakage, etc. with photos and can also track the status of their complaint.

The dashboard overview and crop information are shown in **Figures 5.39(a) to 5.39(c).**

Figure 5.39(a) Farmer’s dashboard view

Figure 5.39(b) Entry of Crop Information by farmers

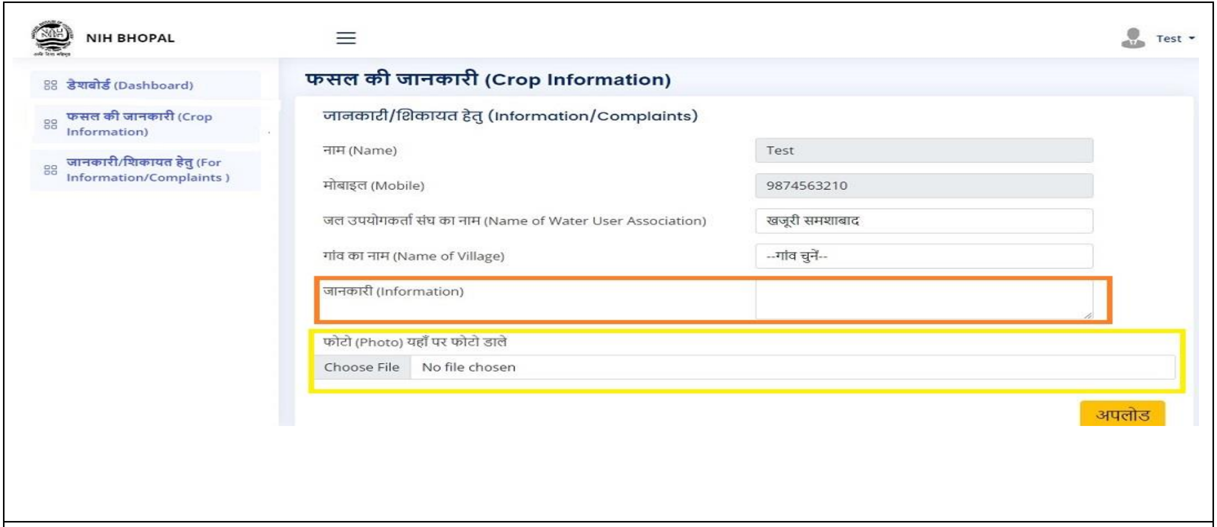


Figure 5.39(c) Information/Complaint

5.9.4 Weather tab

In this tab, Farmers can view 15 days' weather forecast and rainfall information of user location.

1. Real-time weather updates: The weather tab provides real-time updates on the current weather conditions like temperature, humidity, wind speed, and rainfall in the farmer's location.

The Weather forecast status is shown in **Figure 5.40.**

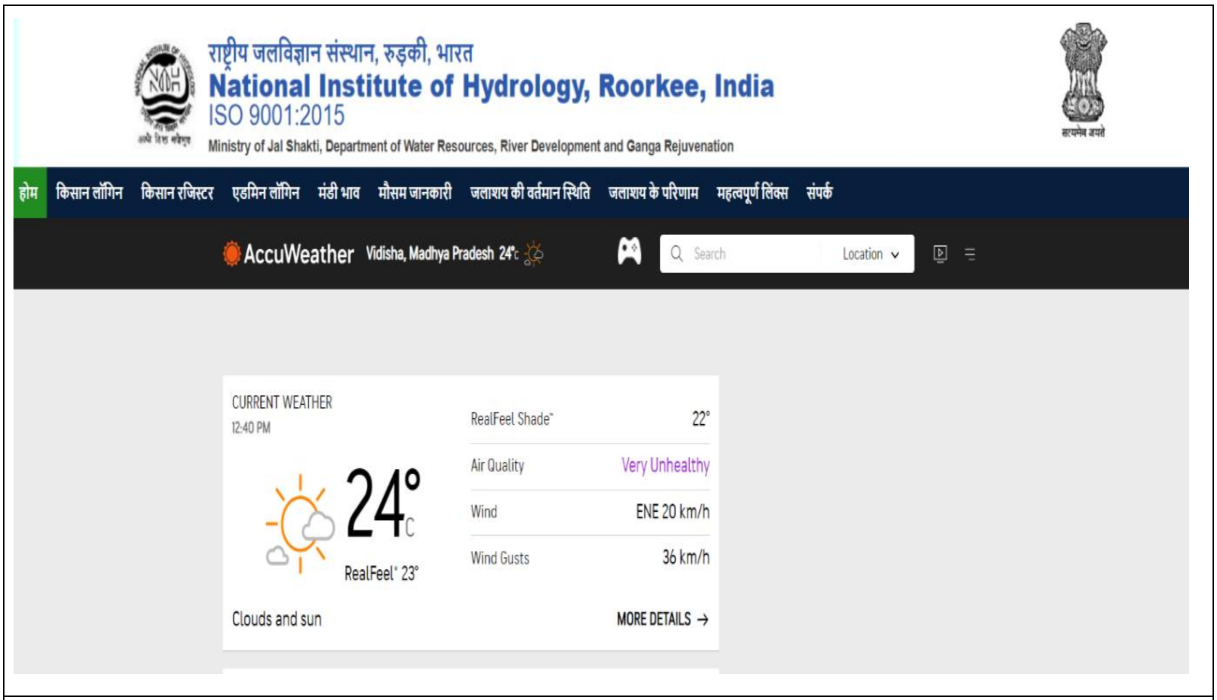


Figure 5.40 Weather Forecast Status

5.9.5 Current status of reservoir

In this tab, Admin has input dam data like reservoir level, the live capacity of the dam, and the gross capacity of a dam by pressing on the current location on the map.

1. Users can access and view the reservoir level and living capacity of the reservoir so that they can plan their harvest for the upcoming season.
2. In this tab, the user will also get information about the date of opening of the canal so that farmers can plan their irrigation programs accordingly.

The Reservoir's Current status window has been shown in **Figure 5.41.**

Figure 5.41 Current status of the reservoir

5.9.6 Mandi tab

This tab is Integrated with mandi API to provide accurate and timely information on mandi. State marketing boards provide real-time data about mandi prices and trading volumes.

1. Mobile applications can use the farmer's location to show nearby mandi’s and their prices. Farmers can also search for mandi’s based on the crop they want to sell. This feature can save time and effort for farmers by eliminating the need to physically visit multiple mandi’s to check prices.

The rate information of all mandi has been shown in **Figure 5.42.**

5.9.7 Result tab

This tab displays the graphical form of water demand, water supply, and water deficit based on the crop type in each command.

1. Demand-Supply Analysis – The results tab displays water demand and supply based on crop area, type, and crop water requirement in the command area. It provides a comprehensive analysis of the water requirements of various crops in the command area.

2. Crop-wise water requirement – The result tab displays the water requirement of different crops in the command area. It shows the amount of water required for each crop and the frequency at which it should be supplied.
3. Crop-wise deficit analysis – The result tab shows the shortfall in water supply to various water user associations in the command area. This reflects the shortage in water supply.

In the web/mobile-based applications, crop area information is taken from the farmers and based on the availability of water in the dam, future weather information, and soil moisture, water demand and difference are determined among different water user organizations. The Excel-based DSS explained earlier was used in the backend to facilitate the efficient allocation of water among different WUAs. The Results of excel Excel-based model and farmers' data have been shown in **Figure 5.43.**

Figure 5.42 Daily rate information of Mandi

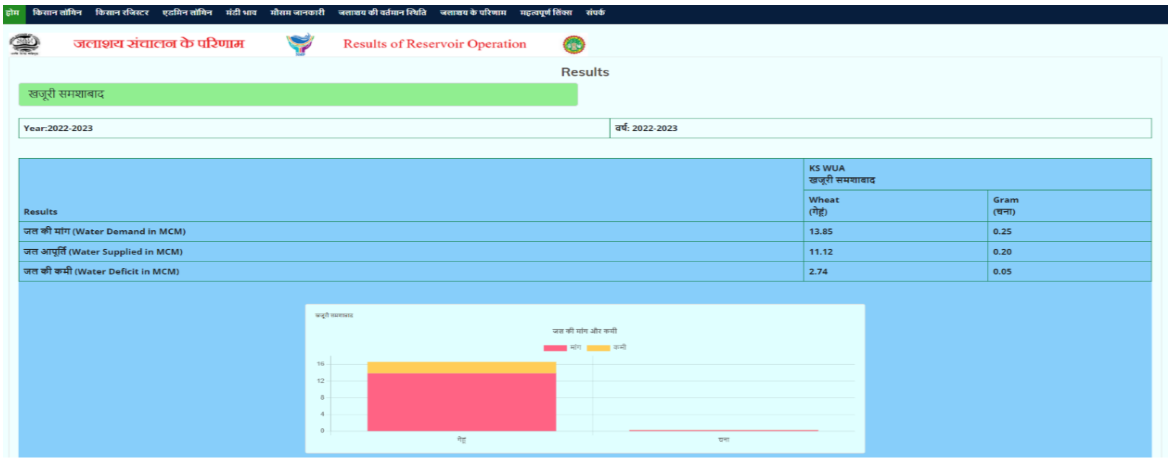


Figure 5.43 Results based on Model

5.9.8 Important features in the app

In this tab, the Admin has access to all applications like changing the information, editing, and running the model, checking the complaints and issues viewing the incident or uploaded photo to resolve the issues, and updating reservoir details.

User and Information Management

Only the administrator has the right to manage users and information.

- Admin can get information about crops filled by farmers.
- Admin can also change/delete/update crop data.
- Admin can run the model to calculate the water requirement of the crop.

The admin login on the web has been shown in **Figure 5.44(a).**

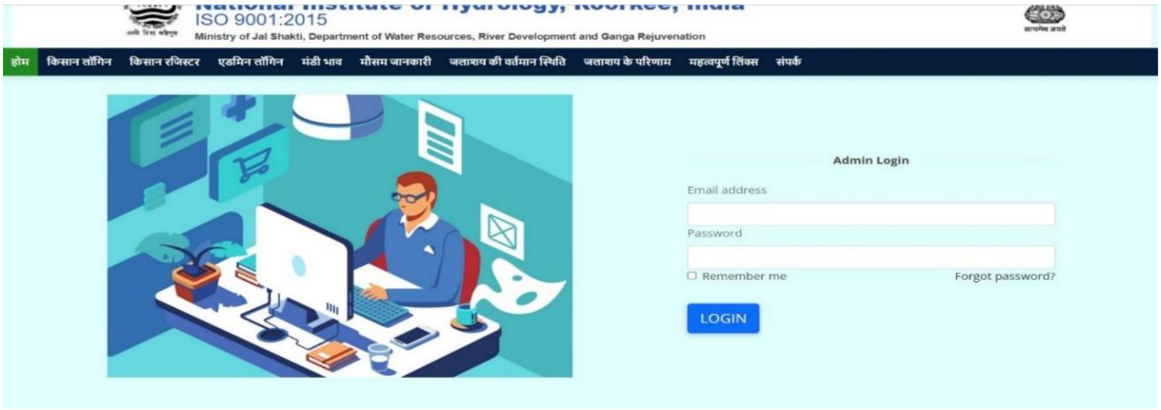


Figure 5.44(a) Web-based Admin Login View

The admin has the right to access the following functions in the admin panel shown in **Figure 5.44(b)**

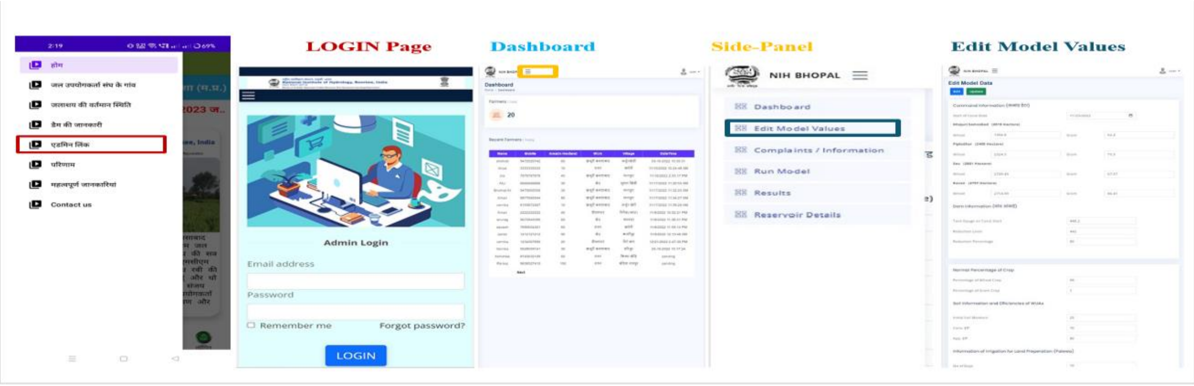


Figure 5.44(b) Functions for admin

After filling in all the required information, the admin can run the model and get the results shown in **Figure 5.44(c).**

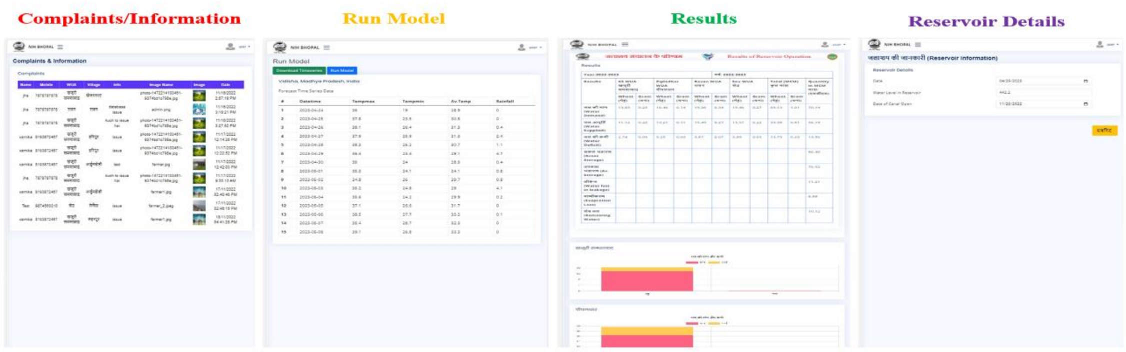


Figure 5.44(c) Final Results from mobile app

All the above functionality is the same for the Mobile Application. The user manual demonstrating all the important steps for using mobile applications has been prepared and given in **Annexure III**.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Water scarcity and increasing water demands pose significant challenges to sustainable development and agricultural productivity. The irrigation and reservoir operation, coupled with meticulous planning, are integral components of modern agricultural practices. Efficient irrigation ensures that crops receive an optimal supply of water, fostering growth and maximizing yields. Simultaneously, effective reservoir operation plays a crucial role in managing water resources, facilitating controlled release and storage to meet the demands of agriculture. In recent times, the convergence of technology and agriculture has given rise to innovative solutions, such as mobile application-based irrigation planning. This cutting-edge approach leverages the power of mobile technology to empower farmers with real-time data and insights about irrigation systems. Through the mobile application developed under the PDS, farmers can access weather forecasts, water availability, and personalized irrigation recommendations on their smartphones, enabling them to make informed decisions for water management. The integration of mobile applications into irrigation planning represented an innovative effort and transformative step towards precision, efficiency, and sustainability in agricultural practices while empowering farmers with accessible tools to optimize their water usage and crop productivity.

The study assessed the performance of existing irrigation systems, crop water requirements, and water distribution infrastructure. It has developed an irrigation planning framework that incorporates advanced technologies such as remote sensing, geographical information systems (GIS), hydrological modeling, and crop modeling to optimize irrigation scheduling, minimize water losses, and enhance water use efficiency. The study analyzed scenarios based on efficient management strategies through demand/supply assessment. It involves analyzing water demand patterns, efficiencies, and conjunctive use options to minimize deficits in water supply. The study considered crop water requirement based on the cropping pattern in the command and impact of climate change to estimate future water demands and evaluate the sustainability of systems and strategies to bridge the demand-supply gap for equitable water allocation.

The study adopted an integrated approach by considering the interdependencies and trade-offs between reservoir operation, irrigation planning, demand-supply challenges, and irrigation efficiencies. It emphasizes the need for collaboration among stakeholders, including water managers, policymakers, researchers, and local communities, to develop sustainable water resource management strategies. The study explored participatory approaches and decision support systems to facilitate informed decision-making to enhance the overall water governance framework

In the present study, three different modeling and measurement techniques i.e. water balance, isotopic analyses, and hydrological modeling were used to compute surface and sub-surface components of irrigation return flow in an irrigation command. The water balance technique was applied through monitoring and measurement after careful analysis of the system. More than 400 water samples from diverse sources including rainfall, dams, canals, rivers, open and bore wells, and hand pumps were analyzed for isotopic analysis. The end member mixing model was used to identify the contribution in open wells and rivers from rainfall and canal/dam water. The SWAT model was used as the third method, a well-proven model for analyzing large-scale hydrological processes in a basin. The model was initially calibrated and validated for virgin flow for the period of 1991-2013 and then two different runs were made with and without the dam and command for the period of 2014 to 2022 (After the construction of the dam in 2013). For running these scenarios, necessary changes were made in the model structure, and results were compared to compute return flow components. The water balance analysis confirmed that a major portion ranged from 12.3 to 35.9% with an average of 22.9% of supplied water to the command reaching the Bah River as regenerated flow, while 1.9 to 16% with an average of 10.2% of supplied water reached groundwater as recharge. The isotopic analysis provided qualitative results of contribution in open and confined wells and rivers from irrigation water with nearly 81 % and 9% contribution of canal water to open wells and bore wells respectively. The SWAT model results showed nearly 27.8% emerged as regenerated flow and 8.9% as recharge due to the application of irrigation in Sanjay Sagar’s command.

The irrigation return flow is a very complex phenomenon of the hydrological cycle in the command in conjunction with the supply system and river depending on several interdependent factors. A single method cannot be suggested for uniform application. A comparative analysis of these methods was made based on strengths, weaknesses, data availability, and skill requirements so that the researchers could apply suitable methods. The comparative analysis of three techniques applied in the PDS is presented in **Table 6.1**.

Table 6.1 Comparative analysis of techniques used for the computation of IRF

S.N.	Particulars	Assessment technique		
		Water balance technique	Isotopic analysis	SWAT model
1.	System analysis	Detailed system analysis is necessary to understand the inputs and outputs in the system. (H)	System analysis is not required. (L)	Some knowledge of the system is necessary (M).
2.	Data requirement	Extensive field measurement of inflows, outflows of rivers and canals, point inflow/outflow, climate data, land use, etc. (H)	Water sampling and analysis for isotopic components. (L)	Topography, soil, land use, and discharge data of a G/D site downstream of command for calibration/validation, crop data, reservoir details, supplies, etc. (M)
3.	Skill requirement	Knowledge of system analysis and identification of different components requires knowledge of hydrology. Skilled manpower is required for the measurement of flow. (L)	The skilled persons for isotopic analysis in the laboratory and analysis. Manpower is required for the collection of samples. (H)	Modeling knowledge and understanding of hydrology are prerequisites for this approach. (H)
4.	Advantage	A mass balance provides identified unknown components. Software knowledge is not necessary. Quantitative assessment is possible.	Only water samples and their analysis are required.	Provides quantitative assessment of different hydrological components. The impact of land and climate change and management can be studied.
5.	Drawbacks	Large manpower is required for monitoring flows and other data. Any change in the system needs to be addressed in water balance. (H)	Only provide a qualitative assessment of recharge and regenerated flow. (H)	Require software knowledge. A G/D site data is necessary for the calibration and validation of the model. (L)

The field data for soil samples were collected and analyzed for textural analysis and soil water retention properties. Soil water retention is an important characteristic of irrigation planning. The soil is mainly silty loam having field capacity and wilting point of 35.8 and 19.6% respectively. The NAM for the Bah River up to the G/D site was set up and the model was calibrated and validated for the period from 1991 to 2005 and validated from 2006 to 2013. The coefficient of determination (R^2) found during calibration and validation for daily modeling were 0.68 and 0.62 respectively. Which was a good match between observed and simulated. After successfully developing the NAM model, a MIKE HYDRO basin model for irrigation management of Sanjay Sagar command was prepared in which calibrated parameters of the NAM model were used to determine inflows and four water user associations (WUAs) as irrigation users. The soil testing results were used to define soil characteristics for WUAs. The cropping pattern in the study area is mainly wheat and very small areas of gram. The developed model was run from 2015 to 2021 and determined yearly demand and deficit for different WUAs. The model was run for four scenarios. The best result for maximum as well as the minimum deficit was 0 at 75% efficiency in the sprinkler irrigation method. The developed model has been brought in DSS (PM) developed under the National Hydrology Project by DHI for further planning and assessing the impact of climate and management-driven scenarios analysis.

An Excel-based reservoir operation and planning module was developed in which reservoir operation, demand, and deficit can be computed using forecast data of 15 days. The program automatically computes crop water requirements using crop coefficient and soil moisture accounting for crops in different WUAs. A daily water balance of the reservoir is made using inflows, reservoir level, losses (evaporation, seepage & leakage), crop water requirement with conveyance, and application losses. The different sheets of the Excel program were connected in such a way so that once all necessary information was filled up by users in Dashboard, automatically results were seen in the Results Sheet in the form of demand, the deficit for different WUAS and reservoir level at the start and end of cropping period. The future forecast data of temperature and rainfall for 15 days can be downloaded in the program through VBA programming to operate the reservoir.

A comprehensive web and mobile application (KISAN-MAITRI) based Decision Support System (DSS) has been developed to address water management challenges in agriculture, specifically focusing on irrigation planning and reservoir operation in the Sanjay Sagar command area. A mobile application complements the web platform, enabling farmers to access essential information like reservoir status, crop estimates, weather forecasts, market rates, etc. The web/mobile application developed under the PDS is site-specific and it is recommended that a generic version of a GIS-enabled web/mobile application may be developed with the involvement of IT firms where, WR managers can make their system of irrigation project to make efficient decision regarding irrigation supplies based on water availability, future climate, cropping pattern, soil information, etc. The farmers may benefit from timely information on demand/supply for the crops, water availability, reporting of grievances, suggested cropping patterns, market rates, and solutions to their problems from field experts.

The study examines the best GCM for future climate projection over the study area, the performance of 13 Global Climate Models (GCMs) of CMIP6 during 1991-2014 was evaluated against the observed dataset to identify the best climate model to reproduce rainfall and temperature time series. The MPI-ESM1-2-LR was selected as the model for projecting future rainfall and temperature. Once the future models were selected, their climate data was compared with IMD rainfall data using various Shared Socioeconomic Pathway (SSP) datasets and visual crossing website data. The analysis of the rainfall data from 2015 to 2022 revealed that SSP2.6 aligned well with IMD rainfall data. These findings have significant implications for various applications, including water resource planning, reservoir operation, and irrigation scheduling. The future projections based on the selected GCMs and SSP data can be utilized for informed decision-making and improved utilization of available resources.

6.2 Recommendations

The study conducted under this PDS was concentrated mainly on the computation of irrigation return flow which is an integral part of the command and development of a web/mobile-based informed decision system for efficient utilization of water in a reservoir project. The study was conducted for the Sanjay Sagar project situated on Bah River Falls in the Betwa system of Madhya Pradesh. In the study, three different techniques i.e. water balance, isotopic analysis, and hydrological methods were used to compute the rejuvenated and recharge part of IRF. A DSS was developed using MIKE 11 NAM and MIKE Hydro Basin incorporated in the DSS (PM) of NHP. The study further developed a fully functional web/mobile system for interaction among water resource managers, WUA members, and farmers for efficient irrigation using indigenously developed Excel-based DSS. The following are the recommendations from the PDS.

- The results of the analysis on IRF are site-specific and vary in the other commands based on several factors like topography, soil, geology, cropping pattern, application method, etc. It is recommended that the Water Resource Department, Govt of MP may carry out similar studies in a few other commands to arrive at a suitable percentage for rejuvenated flow and recharge.
- The present rate of rejuvenation flow through surface drainage is much higher than the standard rate considered by WRD MP, and hence there is a need to reduce these losses by lining canals, optimum releases and change in water application practice presently used in the Sanjay Sagar command.
- The MIKE Hydro Basin model with the MIKE 11 NAM model developed can be used for reservoir operation and it is suggested that enhancing efficiency to 75% may negate all the deficit in the command.
- The indigenously developed Excel-based irrigation planning and reservoir operation tool can

be developed for other commands for efficient irrigation using field-collected data and forecasted climate information.

- The web/mobile application developed under the PDS has the potential to develop a generic version where the water resource managers can develop a DSS for its command and constant interaction with farmers may become a reality for the suggestion of optimum cropping pattern, future climate, demand/deficit, water availability in the reservoir, canal running status, incidence reporting, etc.
- The web/mobile application developed in the PDS uses rainfall and climate data to save a significant amount of water in the event of timely information on future rains in the command.
- Presently, there is very limited interaction between WR managers and end users of water i.e. farmers in the command. The developed mobile application has an edge where farmers can report incidents of theft, and leakage and can see the status of reservoirs, and demand/deficit in the crops in their WUAs.
- There is a need to carry out a constant outreach program to the farmers of Sanjay Sagar and other commands for optimal use of water.

CHAPTER 7: REFERENCES

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ANNEXURE I: DETAILS OF BARRAGE D/S OF SANJAY SAGAR DAM

MANPURA BARRAGE

Tehsil: Berasia Distt. : Bhopal

I. Leading Details:

1.	Name of Project	:	MANPURA BARRAGE
2.	Tehsil	:	Berasia
3.	Name of River or Nalla	:	Bah River
4.	Location of Dam.	:	Near Village Manpura
5.	Longitude & Latitude	:	77° 32’42” 23°45’22”
6.	Basin	:	Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 240.25 sq. Km. or 92.76sq. mile
(a)	Average	:	120.31 MCM
(b)	Maximum	:	Abnormal
(c)	Minimum	:	19.87 MCM

III. Flood:

Maximum flood calculated by Dickens’s formula	:	1183.84 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	240.25 sq. km.
2.	Mean monsoon yield	:	120.31 MCM
3.	Gross storage capacity	:	0.405 MCM
4.	Live storage capacity	:	0.405 MCM
5.	Dead storage capacity	:	NIL
6.	Percentage of gross storage to average monsoon yield.	:	0.33 %

7. Percentage of dead storage to gross storage. : NA

V. Principal Levels:

L. S. L.	:	R. L. 99.00	M.
F. T. L.	:	R. L. 101.30	M.
M. W. L.	:	R. L. 101.30	M.
T. B. L.	:	R. L. 101.30	M.
Lowest river level	:	R. L. 97.70	M.

VI. Dam Details:

1.	Length of Barrage.	:	45.25 Meter
2.	Maximum height to stop Dam	:	3.30 Meter
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.066 M sqm.
6.	Water spread area at F. T. L.	:	0.1667 M sqm.
7.	Water spread area at M. W. L.	:	0.1667 M sqm.

VII. Benefits:

	Culturable command area	:	132.00 Ha	
	Area proposed for Irrigation	:	Design	Equivalent to
(a)	Hybrid wheat	:	20 Ha	40 Ha
(b)	Ordinary wheat	:	72 Ha	72 Ha
(c)	Gram	:	40 Ha	20 Ha
		Total	**132 Ha**	**132 Ha**

VIII. Cost per Hect. : **Rs.** 82682.00 **Rs.** 82682.00

X. Name of Village Benefitted By the Scheme.

(1) Manpura
(2) Berkheri Aheer

DOJAYI BARRAGE

Tehsil : Berasia — Distt. : Bhopal

I. Leading Details:

1.	Name of Project	:	DOJYAI BARRAGE
2.	Tehsil	:	Berasia
3.	Name of River or Nalla	:	Bah River
4.	Location of Dam.	:	Near Village Doyjai
5.	Longitude & Latitude	:	77° 33’45” 23°44’00”
6.	Basin	:	Chambal Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 97.49 sq. mile or 252.50sqkm.
(a)	Average	:	4465.46 Mcft.
(b)	Maximum	:	Abnormal
(c)	Minimum	:	737.80 Mcft.

III. Flood:

Maximum flood calculated by dickens’s formula	:	769.40 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	252.50 sq. km.
2.	Mean monsoon yield	:	4465.46 Mcft (126.44 MCM)
3.	Gross storage capacity	:	0.512 MCM
4.	Live storage capacity	:	0.512 MCM
5.	Dead storage capacity	:	NIL
6.	Percentage of gross storage to average monsoon yield.	:	0.40 %
7.	Percentage of dead storage to gross storage.	:	NA

V. Principal Levels:

L. S. L.	:	R. L. 99.00	M.
F. T. L.	:	R. L. 101.60	M.
M. W. L.	:	R. L. 101.60	M.
T. B. L.	:	R. L. 101.60	M.
Lowest river level	:	R. L. 97.60	M.

VI. Dam Details:

1.	Length of Barrage.	:	42.40 Meter
2.	Maximum height to stop Dam	:	4.00 Meters
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.034 M sqm.
6.	Water spread area at F. T. L.	:	0.175 M sqm.
7.	Water spread area at M. W. L.	:	0.175 M sqm.

VII. Benefits:

	Culturable command area	:	146.00 Ha	
	Area proposed for Irrigation	:	Design	Equivalent to
(a)	Hybrid wheat	:	42 Ha	84 Ha
(b)	Ordinary wheat	:	64 Ha	64 Ha
(c)	Gram	:	40 Ha	20 Ha
		Total	**146 Ha**	**168 Ha**

VIII. Cost per Hect. : **Rs.** 82377.00 **Rs.** 71589.00

IX. Name of village benefitted by this scheme. **:**
(1) Dojyai
(2) Khejara Parihar
(3) Khaikhera

KHAJURGHAT BARRAGE

Tehsil : Berasia Distt. : Bhopal

I. Leading Details:

1. Name of Project	:	KHAJURGHAT BARRAGE
2. Tehsil	:	Berasia
3. Name of River or Nalla	:	Bah River
4. Location of Dam.	:	Near Village Laharpur
5. Longitude & Latitude	:	77° 37’45” 23°42’55”
6. Basin	:	Chambal Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 200.29 sq. mile C.A. or 518.75 sq km.
(a)	Average	:	9174.08 Mcft.
(b)	Maximum	:	Abnormal
(c)	Minimum	:	1515.79 Mcft.

III. Flood:

Maximum flood calculated by dickens’s formula	:	2108.72 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	518.75 sq. km.
2.	Mean monsoon yield	:	9174.08 Mcft (259.78 MCM)
3.	Gross storage capacity	:	0.513 MCM
4.	Live storage capacity	:	0.513 MCM
5.	Dead storage capacity	:	NIL
6.	Percentage of Gross storage to average monsoon yield.	:	0.19 %
7.	Percentage of dead storage to gross storage.	:	NA

V. Principal Levels:

L. S. L.	:	R. L. 97.00	M.
F. T. L.	:	R. L. 98.80	M.
M. W. L.	:	R. L. 98.80	M.
T. B. L.	:	R. L. 98.80	M.
Lowest river level	:	R. L. 95.75	M.

VI. Dam Details:

1.	Length of Barrage.	:	51.45 Meter
2.	Maximum height to stop Dam	:	3.05 Meters
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.016 M sqm.
6.	Water spread area at F. T. L.	:	0.192 M sqm.
7.	Water spread area at M. W. L.	:	0.192 M sqm.

VII. Benefits:

	Culturable command area	:	153.00 Ha	
	Area proposed for Irrigation	:	Design	Equivalent to
(a)	Hybrid wheat	:	40 Ha	80 Ha
(b)	Ordinary wheat	:	65 Ha	65 Ha
(c)	Gram	:	48 Ha	24 Ha
		Total	**153 Ha**	**169 Ha**

VIII. Cost per Hect. : **Rs.** 85183.00 **Rs.** 77118.00

X. Name of village benefitted by this scheme. :
(1) Laharpur
(2) Berkhedi Ghat

BARKHERA YAKUB BARRAGE

Tehsil : Berasia | Distt. : Bhopal

I. Leading Details:

1.	Name of Project	:	BARKHERA YAKUB BARRAGE
2.	Tehsil	:	Berasia
3.	Name of River or Nalla	:	Bah River
4.	Location of Dam.	:	Near Village Barkhera Yakub
5.	Longitude & Latitude	:	77° 37’45” 23°42’55”
6.	Basin	:	Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 140.00 sq. Km. C.A.
(a)	Average	:	73.90 Mcum.
(b)	Maximum	:	Abnormal
(c)	Minimum	:	11.59 Mcum

III. Flood:

Maximum flood calculated by dickens’s formula	:	895.15 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	165.50 sq. km.
2.	Mean monsoon yield	:	73.90 MCM
3.	Gross storage capacity	:	0.40 MCM
4.	Live storage capacity	:	0.40 MCM
5.	Dead storage capacity	:	NIL
6.	Percentage of Gross storage to average monsoon yield.	:	0.54 %
7.	Percentage of dead storage to gross storage.	:	NA

V. Principal Levels:

L. S. L.	:	R. L. 97.60	M.
F. T. L.	:	R. L. 99.60	M.
M. W. L.	:	R. L. 99.60	M.
T. B. L.	:	R. L. 99.60	M.
Lowest river level	:	R. L. 96.60	M.

VI. Dam Details:

1.	Length of Barrage.	:	43.25 Meter
2.	Maximum height to stop Dam	:	3.00 Meters
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.012 M sqm.
6.	Water spread area at F. T. L.	:	0.16 Msqm.
7.	Water spread area at M. W. L.	:	0.16 M sqm.

VII. Benefits:

	Culturable command area	:	115.00 Ha	
	Area proposed for Irrigation	:	Design	Equivalent to
(a)	Hybrid wheat	:	25 Ha	50 Ha
(b)	Ordinary wheat	:	50 Ha	50 Ha
(c)	Gram	:	40 Ha	20 Ha
			Total **115 Ha**	**120 Ha**

VIII. Cost per Hect. : **Rs.** 69708.00 **Rs.** 66800.00

IX. Name of village benefitted by this scheme. **:**

(1) Barkhera Yakub
(2) Arjun Kheri
(3) Hingoni
(4) Khajuri Rani

BABACHIYA BARRAGE

Tehsil : Berasia — Distt. : Bhopal

I. Leading Details:

1. Name of Project	:	BABACHIYA BARRAGE
2. Tehsil	:	Berasia
3. Name of River or Nalla	:	Bah River
4. Location of Dam.	:	Near Village Babachiya
5. Longitude & Latitude	:	77° 36’45” 23°42’15”
6. Basin	:	Chambal Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 178.00 sq. Km. C.A.
(a)	Average	:	Mcft.
(b)	Maximum	:	Abnormal
(c)	Minimum	:	Mcft.

III. Flood:

Maximum flood calculated by dickens’s formula	:	943.36 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	178.00 sq. km.
2.	Mean monsoon yield	:	Mcft (Mcum)
3.	Gross storage capacity	:	0.21463 MCM
4.	Live storage capacity	:	0.21463 MCM
5.	Dead storage capacity	:	NIL
6.	Percentage of gross storage to average monsoon yield.	:	NA
7.	Percentage of dead storage to gross storage.	:	NA

V. Principal Levels:

L. S. L.	:	R. L. 99.00	M.
F. T. L.	:	R. L. 101.40	M.
M. W. L.	:	R. L. 101.40	M.
T. B. L.	:	R. L. 101.40	M.
Lowest river level	:	R. L. 98.07	M.

VI. Dam Details:

1.	Length of Barrage.	:	34.80 Meter
2.	Maximum height to stop Dam	:	2.40 Meters
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.075 M sqm.
6.	Water spread area at F. T. L.	:	0.161 M sqm.
7.	Water spread area at M. W. L.	:	0.161 M sqm.

VII. Benefits:

	Culturable command area	:	70.00 Ha	
	Area proposed for Irrigation	:		-
(a)	Hybrid wheat 15 ha.	:	30 Ha	
	(equivalent to)		28 Ha	
(b)	Ordinary wheat	:	12 Ha	
(c)	Gram	:		
		Total	**70 Ha**	

VIII. Cost per Hect. : **Rs.** 66914.00

X. Name of village benefitted by this scheme. **:** (1) Babachiya
(2) Khejraghat
(3) Arjunkhedi

JHANAKPUR BARRAGE

Tehsil : Berasia | Distt. : Bhopal

I. Leading Details:

1.	Name of Project	:	JHANAKPUR BARRAGE
2.	Tehsil	:	Berasia
3.	Name of River or Nalla	:	Bah River
4.	Location of Dam.	:	Near Village Jhanakpur (Hingoni)
5.	Longitude & Latitude	:	77° 34’30” 23°43’00”
6.	Basin	:	Chambal Betwa Basin

II. Hydrological Data:

1.	Mean Rainfall	:	Annual Average Rainfall (mm) 1187
2.	Runoff calculated by Binnie’s	:	Table for 157.25 sq. miles. C.A.
(a)	Average	:	2434.87 Mcft.
(b)	Maximum	:	Abnormal
(c)	Minimum	:	385.91 Mcft.

III. Flood:

Maximum flood calculated by dickens’s formula	:	871.35 Cumecs

IV. Reservoir Data:

1.	Catchment area	:	157.25 sq. km.
2.	Mean monsoon yield	:	Mcft (Mcum)
3.	Gross storage capacity	:	0.2816 MCM
4.	Live storage capacity	:	0.2816 MCM
5.	Dead storage capacity	:	-
6.	Percentage of gross storage to average monsoon yield.	:	NA
7.	Percentage of dead storage to gross storage.	:	NA

V. Principal Levels:

L. S. L.	:	R. L. 99.30	M.
F. T. L.	:	R. L. 101.70	M.
M. W. L.	:	R. L. 101.70	M.
T. B. L.	:	R. L. 101.70	M.
Lowest river level	:	R. L. 98.30	M.

VI. Dam Details:

1.	Length of Barrage.	:	32.60 Meters
2.	Maximum height to stop Dam	:	2.40 Meters
3.	Length of Waste-weir	:	--
4.	Quantity of earthwork	:	--
5.	Water spread area at L. S. L.	:	0.043 M sqm.
6.	Water spread area at F. T. L.	:	0.173 M sqm.
7.	Water spread area at M. W. L.	:	0.173 M sqm.

VII. Benefits:

	Culturable command area	:	101.375 Ha	
	Area proposed for Irrigation	:	Design	Equivalent to
(a)	Hybrid wheat	:	20 Ha	40 Ha
(b)	Ordinary wheat	:	34 Ha	34 Ha
(c)	Gram	:	22 Ha	11 Ha
			Total 76 Ha	**85 Ha**

VIII. Cost Per Hect: **Rs.** 69632.00 **Rs.** 62259.00

IX. Name of village benefitted by this scheme. **:**
(1) Jhanakpur
(2) Haripur
(3) Ghatkhedi

Annexure II: RESULTS OF TEXTURAL ANALYSIS (NIH ROORKEE)

NATIONAL INSTITUTE OF HYDROLOGY (SOIL WATER LABORATORY) ROORKEE

Project: Sanjay Sagar Project in Madhya Pradesh / INDENT DATE : 07/01/2021 | Net wt. of oven dried sample (G)= 400.00 gm

Analysed by: S.L.Srivastava, C.S. Chowhan ,Dinesh Kumar,Alok Kumar, Siddharth Shreye

SL. No.	Sample Code	Depth (cm)	Sample collected on 75 µ sieve after washing and oven drying: Wt of soil & container (gms.) (A)	Container wt. (gms.) (B)	Weight retained on each sieve above 75µby dry sieving (gm): 4.75mm (R)	2.00mm (S)	1.40mm (T)	0.85mm (T)	0.43mm (V)	0.250mm (W)	0.212mm (X)	0.075mm (Y)	Total coarser above 75µ (C=R+S+T+U+V+W+X+Y)	Dry sample retained on pan (D)	Finer soil below 75 µ (F=G-C)	wt of dry soil retained after sieving (gm) (C+D)	wt of dry soil before sieving(gm) (A-B)
1	PDS-IRF-TA-1		172.56	151.26	6.25	4.83	5.24	2.86	0.98	0.18	0.19	0.76	21.29	0.46	378.71	21.75	21.3
		% Finer by Master Sizers															
			Actual % Finer		98.4375	97.23	95.92	95.205	94.96	94.915	94.8675	94.6775					
2	PDS-IRF-TA-2		148.63	136.78	0.00	0.13	1.40	2.15	1.90	0.76	0.61	3.83	10.78	0.77	389.22	11.55	11.85
		% Finer by Master Sizers															
		Actual % Finer			100	99.9675	99.618	99.08	98.605	98.415	98.2625	97.305					
3	PDS-IRF-TA-3		176.90	148.17	0.00	3.38	8.47	8.83	4.60	0.85	0.35	1.35	27.83	0.29	33.00	28.12	28.73
		% Finer by Master Sizers															
		Actual % Finer			100	99.155	97.038	94.83	93.68	93.4675	93.38	93.0425					
4	PDS-IRF-TA-4		160.84	140.54	3.01	2.62	5.30	4.28	2.28	0.34	0.38	1.26	19.47	0.63	380.53	20.1	20.3
		% Finer by Master Sizers															
		Actual % Finer			99.2475	98.5925	97.268	96.1975	95.6275	95.5425	95.4475	95.1325					
5	PDS-IRF-TA-5		158.90	141.93	1.19	4.55	5.06	3.42	1.38	0.30	0.22	0.84	16.96	0.25	383.04	17.21	16.97
		% Finer by Master Sizers															
		Actual % Finer			99.7025	98.565	97.3	96.445	96.1	96.025	95.97	95.76					
6	PDS-IRF-AT-6		177.07	153.58	2.74	5.80	6.90	4.08	1.84	0.42	0.28	1.42	23.48	0.31	376.52	23.79	23.49
		% Finer by Master Sizers															
		Actual % Finer			99.315	97.865	96.14	95.12	94.66	94.555	94.485	94.13					
7	PDS-IRF-TA-7		179.69	135.08	12.04	6.16	10.80	8.76	4.29	0.74	0.04	1.14	43.97	0.52	356.03	44.49	44.61
		% Finer by Master Sizers															
		Actual % Finer			96.99	95.45	92.75	90.56	89.4875	89.3025	89.2925	89.0075					
8	PDS-IRF-TA-8		170.12	140.90	2.20	6.58	8.88	5.95	3.34	0.62	0.21	1.34	29.12	0.58	370.88	29.7	29.22
		% Finer by Master Sizers															
		Actual % Finer			99.45	97.805	95.585	94.0975	93.2625	93.1075	93.055	92.72					
9	PDS -IRF-TA-9		185.16	148.07	6.62	3.88	7.95	7.49	4.92	0.82	0.14	4.07	35.89	1.13	364.11	37.02	37.09
		% Finer by Master Sizers															
		Actual % Finer			98.345	97.375	95.388	93.515	92.285	92.08	92.045	91.0275					
10	PDS-IRF-TA-		202.45	151.97	3.64	10.34	14.21	8.86	4.01	0.82	0.45	6.51	48.84	1.19	351.16	50.03	50.48
		% Finer by Master Sizers															
		Actual % Finer			99.09	96.505	92.953	90.7375	89.735	89.53	89.4175	87.79					
11	PDS-IRF-TA-1		165.45	137.48	1.34	2.56	5.92	5.46	3.46	0.97	0.26	5.62	25.59	2.56	374.41	28.15	27.97
		% Finer by Master Sizers															
		Actual % Finer			99.665	99.025	97.545	96.18	95.315	95.0725	95.0075	93.6025					
12	PDS-IRF-TA-1		186.32	131.86	8.57	9.25	14.56	8.76	4.23	0.68	0.36	6.09	52.5	1.84	347.50	54.34	54.46
		% Finer by Master Sizers															
		Actual % Finer			97.8575	95.545	91.905	89.715	88.6575	88.4875	88.3975	86.875					

NATIONAL INSTITUTE OF HYDROLOGY (SOIL WATER LABORATORY) ROORKEE

Project: Sanjay Sagar Project in Madhya Pradesh / INDENT DATE : 07/01/2021 | Net wt. of oven dried sample (G)= 300.00 gm

Analysed by: S.L.Srivastava, C.S. Chowhan ,Dinesh Kumar,Alok Kumar, Siddharth Shreye

SL. No.	Sample Code	Depth (cm)	Sample collected on 75 µ sieve after washing and oven drying: Wt of soil & container (gms.) (A)	Container wt. (gms.) (B)	Weight retained on each sieve below 75µby dry sieving (gm): 1.94500 µm	2.31200 µm	62.23000 µm	% Clay	% Silt	% Sand	% Gravel
1	PDS-IRF-TA-1	0	172.56	151.26							
		% Finer by Master Sizers			17.75	20.92	92.23				
		Actual % Finer			16.805	19.807	87.321	18.31	69.02	9.91	2.77
2	PDS-IRF-TA-2	0	148.63	136.78							
		% Finer by Master Sizers			15.62	18.06	90.87				
		Actual % Finer			15.199	17.573	88.421	16.39	72.03	11.55	0.03
3	PDS-IRF-TA-3	0	176.90	148.17							
		% Finer by Master Sizers			17.6	20.86	92.38				
		Actual % Finer			1.452	1.721	7.6214	1.59	6.03	91.53	0.84
4	PDS-IRF-TA-4	0	160.84	140.54							
		% Finer by Master Sizers			17.06	21.35	95.23				
		Actual % Finer			16.23	20.311	90.595	18.27	72.32	8.00	1.41
5	PDS-IRF-TA-5	0	158.90	141.93							
		% Finer by Master Sizers			22.38	27.82	96.32				
		Actual % Finer			21.431	26.64	92.236	24.04	68.20	6.33	1.44
6	PDS-IRF-AT-6	0	177.07	153.58							
		% Finer by Master Sizers			19.55	24.61	97.02				
		Actual % Finer			18.402	23.165	91.325	20.78	70.54	6.54	2.14
7	PDS-IRF-TA-7	0	179.69	135.08							
		% Finer by Master Sizers			23.45	27.40	96.55				
		Actual % Finer			20.872	24.388	85.937	22.63	63.31	9.51	4.55
8	PDS-IRF-TA-8	0	170.12	140.90							
		% Finer by Master Sizers			13.07	16.03	91.60				
		Actual % Finer			12.119	14.863	84.932	13.49	71.44	12.87	2.19
9	PDS -IRF-TA-9	0	185.16	148.07							
		% Finer by Master Sizers			24.58	29.77	96.94				
		Actual % Finer			22.375	27.099	88.242	24.74	63.51	9.13	2.63
10	PDS-IRF-TA-1	0	202.45	151.97							
		% Finer by Master Sizers			23.03	28.10	97.61				
		Actual % Finer			20.218	24.669	85.692	22.44	63.25	10.81	3.50
11	PDS-IRF-TA-1	0	165.45	137.48							
		% Finer by Master Sizers			14.60	19.01	94.94				
		Actual % Finer			13.666	17.794	88.866	15.73	73.14	10.16	0.97
12	PDS-IRF-TA-1	0	186.32	131.86							
		% Finer by Master Sizers			23.46	28.81	98.26				
		Actual % Finer			20.381	25.029	85.363	22.70	62.66	10.18	4.46

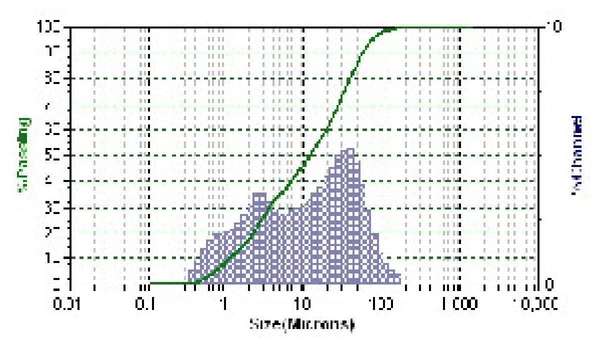
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal — **Data Acquired: 09/06/2021 - 11:42**

PDS-IRF-TA01 — **Calculated: 09/06/2021 - 11:42**



Summary

Data	Value
MV(um):	22.08
MN(um):	0.635
MA(um):	3.33
CS:	1.802
SD:	21.50
Mz:	19.45
σi:	21.80
Ski:	0.612
Kg:	0.983

Percentiles

%Tile	Size(um)
95.00	73.64
90.00	56.06
80.00	39.18
60.00	19.09
50.00	11.86
40.00	6.70
30.00	3.64
20.00	2.204
10.00	1.099
5.00	0.714

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	3.22	31.20
1184	0.00	100.00	3.27	3.53	27.98
995.6	0.00	100.00	2.750	3.53	24.45
837.2	0.00	100.00	2.312	3.17	20.92
704.0	0.00	100.00	1.945	2.89	17.75
592.0	0.00	100.00	1.635	2.32	15.06
497.8	0.00	100.00	1.375	2.13	12.74
418.6	0.00	100.00	1.156	2.05	10.61
352.0	0.00	100.00	0.972	2.02	8.56
296.0	0.00	100.00	0.818	1.93	6.53
248.9	0.00	100.00	0.688	1.72	4.80
209.3	0.00	100.00	0.578	1.57	3.08
176.0	0.30	100.00	0.486	0.94	1.51
148.0	0.55	99.62	0.409	0.57	0.57
124.5	0.82	99.07	0.344	0.00	0.00
104.7	1.26	98.25	0.2890	0.00	0.00
88.00	1.92	96.99	0.2430	0.00	0.00
74.00	2.84	95.07	0.2040	0.00	0.00
62.23	3.09	92.23	0.1720	0.00	0.00
52.33	4.02	88.34	0.1450	0.00	0.00
44.00	5.27	83.82	0.1220	0.00	0.00
37.00	5.22	78.25	0.1020	0.00	0.00
31.11	5.01	73.03			
26.16	4.57	68.02			
22.00	4.18	63.45			
18.50	3.84	59.27			
15.56	3.84	55.43			
13.08	3.29	51.89			
11.00	3.12	48.60			
9.25	3.00	45.48			
7.78	2.89	42.48			
6.54	2.77	39.60			
5.50	2.74	36.83			
4.62	2.89	34.09			

Peaks

Dia(um)	Vol%	Width
23.92	68.8	48.08
1.687	31.2	2.26

Project:- Hydrilogical Modeling for Evaluation of return flow and irrigation planning for optimal utilisation of water resources in the command of Sanjay Sagar Project inMadhya Pradesh.
Sample code :- PDS-IRF-TA01
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0376
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.924
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.606%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3764	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(2)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\MHDatabase 2016.MDB				

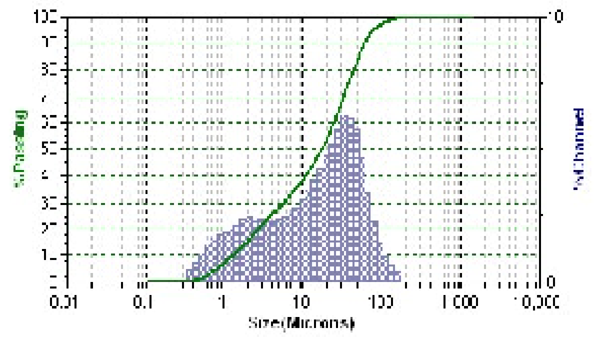
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 14:18**

PDS-IRF-TA-2 | **Calculated: 09/06/2021 - 14:18**



Summary

Data	Value
MV(um):	25.30
MN(um):	0.642
MA(um):	3.90
CS:	1.538
SD:	23.43
Mz:	22.61
σi:	23.39
Ski:	0.470
Kg:	0.931

Percentiles

%Tile	Size(um)
95.00	77.86
90.00	60.03
80.00	43.48
60.00	24.41
50.00	16.97
40.00	10.70
30.00	5.65
20.00	2.658
10.00	1.254
5.00	0.785

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	2.26	25.05
1184	0.00	100.00	3.27	2.32	22.79
995.6	0.00	100.00	2.750	2.41	20.47
837.2	0.00	100.00	2.312	2.44	18.06
704.0	0.00	100.00	1.945	2.35	15.62
592.0	0.00	100.00	1.635	2.18	13.27
497.8	0.00	100.00	1.375	2.01	11.09
418.6	0.00	100.00	1.156	1.88	9.08
352.0	0.00	100.00	0.972	1.79	7.20
296.0	0.00	100.00	0.818	1.66	5.41
248.9	0.00	100.00	0.688	1.44	3.75
209.3	0.00	100.00	0.578	1.10	2.31
176.0	0.42	100.00	0.486	0.75	1.21
148.0	0.63	99.58	0.409	0.46	0.46
124.5	0.96	98.95	0.344	0.00	0.00
104.7	1.48	97.99	0.2890	0.00	0.00
88.00	2.27	96.51	0.2430	0.00	0.00
74.00	3.37	94.24	0.2040	0.00	0.00
62.23	4.66	90.87	0.1720	0.00	0.00
52.33	5.79	86.21	0.1450	0.00	0.00
44.00	6.19	80.42	0.1220	0.00	0.00
37.00	6.29	74.23	0.1020	0.00	0.00
31.11	5.79	67.94			
26.16	5.22	62.16			
22.00	4.74	56.93			
18.50	4.31	52.19			
15.56	3.89	47.88			
13.08	3.47	43.99			
11.00	3.09	40.52			
9.25	2.79	37.43			
7.78	2.58	34.64			
6.54	2.43	32.06			
5.50	2.32	29.63			
4.62	2.26	27.31			

Peaks

Dia(um)	Vol%	Width
16.97	100.0	48.86

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-2
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0546
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.906
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.599%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	55 %
#Channels:	50	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3760	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\MHDatabase 2010.MDB				

10.5.4

S3000/S3500

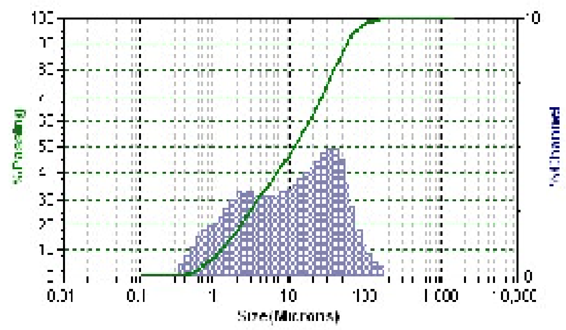
- Particle Size Analysis -

PDS RC Bhopal

PDS-IRF-TA-3

Data Acquired: 09/06/2021 - 14:33

Calculated: 09/06/2021 - 14:33



Summary

Data	Value
MV(um):	21.61
MN(um):	0.661
MA(um):	3.45
CS:	1.740
SD:	20.94
Mz:	18.87
σi:	21.53
Ski:	0.633
Kg:	1.034

Percentiles

%Tile	Size(um)
95.00	73.73
90.00	55.33
80.00	37.94
60.00	17.73
50.00	11.19
40.00	6.58
30.00	3.76
20.00	2.211
10.00	1.185
5.00	0.765

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	3.15	30.60
1184	0.00	100.00	3.27	3.26	27.45
995.6	0.00	100.00	2.750	3.33	24.19
837.2	0.00	100.00	2.312	3.26	20.86
704.0	0.00	100.00	1.945	2.99	17.60
592.0	0.00	100.00	1.635	2.80	14.61
497.8	0.00	100.00	1.375	2.29	11.90
418.6	0.00	100.00	1.156	2.06	9.69
352.0	0.00	100.00	0.972	1.92	7.63
296.0	0.00	100.00	0.818	1.77	5.71
248.9	0.00	100.00	0.688	1.53	3.94
209.3	0.00	100.00	0.578	1.17	2.41
176.0	0.42	100.00	0.486	0.78	1.24
148.0	0.59	99.58	0.409	0.46	0.46
124.5	0.85	98.99	0.344	0.00	0.00
104.7	1.25	98.14	0.2890	0.00	0.00
88.00	1.94	96.89	0.2430	0.00	0.00
74.00	2.87	95.05	0.2040	0.00	0.00
62.23	3.65	92.18	0.1720	0.00	0.00
52.33	4.51	88.73	0.1460	0.00	0.00
44.00	4.93	84.22	0.1220	0.00	0.00
37.00	4.89	79.29	0.1020	0.00	0.00
31.11	4.75	74.40			
26.16	4.45	69.65			
22.00	4.20	65.20			
18.50	3.99	61.00			
15.56	3.78	57.01			
13.08	3.56	53.23			
11.00	3.37	49.67			
9.25	3.24	46.30			
7.78	3.17	43.06			
6.54	3.11	39.89			
5.50	3.09	36.78			
4.62	3.09	33.69			

Peaks

Dia(um)	Vol%	Width
11.19	100.0	41.88

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-3
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0081
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.923
Low Edge(um):	0.096	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.881%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3762	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

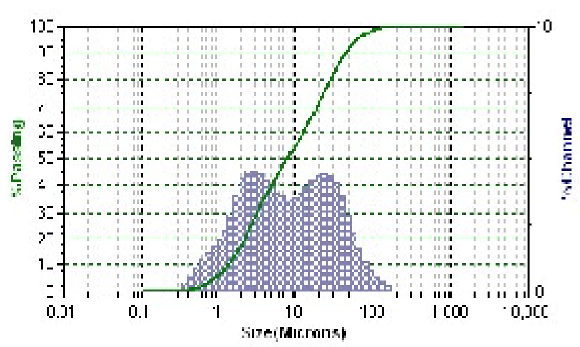
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal — **Data Acquired: 09/06/2021 - 14:47**

PDS-IRF-TA-4 — **Calculated: 09/06/2021 - 14:47**



Summary

Data	Value
MV(um):	16.98
MN(um):	0.719
MA(um):	3.40
CS:	1.766
SD:	15.71
Mz:	14.26
σi:	16.97
Ski:	0.701
Kg:	1.197

Percentiles

%Tile	Size(um)
95.00	61.00
90.00	43.82
80.00	28.29
60.00	12.45
50.00	7.67
40.00	4.82
30.00	3.22
20.00	2.194
10.00	1.325
5.00	0.852

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	4.44	34.88
1184	0.00	100.00	3.27	4.61	30.44
995.6	0.00	100.00	2.750	4.60	25.83
837.2	0.00	100.00	2.312	4.29	21.33
704.0	0.00	100.00	1.945	3.83	17.05
592.0	0.00	100.00	1.635	2.89	13.43
497.8	0.00	100.00	1.375	2.31	10.54
418.6	0.00	100.00	1.156	1.92	8.23
352.0	0.00	100.00	0.972	1.69	6.31
296.0	0.00	100.00	0.818	1.60	4.62
248.9	0.00	100.00	0.688	1.28	3.12
209.3	0.00	100.00	0.578	0.84	1.86
176.0	0.22	100.00	0.486	0.60	0.92
148.0	0.41	99.78	0.409	0.32	0.32
124.5	0.58	99.37	0.344	0.00	0.00
104.7	0.81	98.79	0.2890	0.00	0.00
88.00	1.14	97.98	0.2430	0.00	0.00
74.00	1.61	96.84	0.2040	0.00	0.00
62.23	2.22	95.23	0.1720	0.00	0.00
52.33	2.93	93.01	0.1450	0.00	0.00
44.00	3.60	90.08	0.1220	0.00	0.00
37.00	4.10	86.48	0.1020	0.00	0.00
31.11	4.36	82.38			
26.16	4.43	78.02			
22.00	4.35	73.59			
18.50	4.19	69.24			
15.56	3.96	65.05			
13.08	3.73	61.09			
11.00	3.56	57.36			
9.25	3.61	53.80			
7.78	3.50	50.29			
6.54	3.75	46.71			
5.50	3.95	42.96			
4.62	4.17	39.05			

Peaks

Dia(um)	Vol%	Width
20.24	57.0	37.44
2.326	43.0	3.06

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-4
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0475
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.907
Low Edge(um):	0.096	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.577%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	85 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3766	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\WHDatabase 2010.MDB				

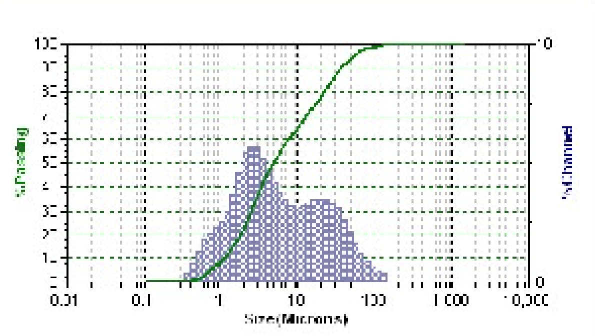
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 15:00**

PDS-IRF-TA-5 | **Calculated: 09/06/2021 - 15:00**



Summary

Data	Value
MV(um):	13.55
MN(um):	0.707
MA(um):	2.742
CS:	2.189
SD:	12.58
Mz:	11.00
σi:	14.33
Ski:	0.792
Kg:	1.469

Percentiles

%Tile	Size(um)
95.00	53.79
90.00	37.00
80.00	21.78
60.00	7.59
50.00	4.81
40.00	3.37
30.00	2.474
20.00	1.788
10.00	1.073
5.00	0.732

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	5.21	44.32
1184	0.00	100.00	3.27	5.65	39.11
995.6	0.00	100.00	2.750	5.64	33.46
837.2	0.00	100.00	2.312	5.44	27.82
704.0	0.00	100.00	1.945	4.63	22.38
592.0	0.00	100.00	1.635	3.69	17.75
497.8	0.00	100.00	1.375	2.95	14.06
418.6	0.00	100.00	1.156	2.50	11.11
352.0	0.00	100.00	0.972	2.26	8.61
296.0	0.00	100.00	0.818	2.06	6.35
248.9	0.00	100.00	0.688	1.76	4.29
209.3	0.00	100.00	0.578	1.31	2.53
176.0	0.00	100.00	0.486	0.80	1.22
148.0	0.39	100.00	0.409	0.42	0.42
124.5	0.51	99.61	0.344	0.00	0.00
104.7	0.68	99.10	0.2890	0.00	0.00
88.00	0.90	98.42	0.2430	0.00	0.00
74.00	1.30	97.52	0.2040	0.00	0.00
62.23	1.50	96.22	0.1720	0.00	0.00
52.33	2.10	94.72	0.1450	0.00	0.00
44.00	2.62	92.62	0.1220	0.00	0.00
37.00	3.06	90.00	0.1020	0.00	0.00
31.11	3.32	86.94			
26.16	3.42	83.62			
22.00	3.44	80.20			
18.50	3.40	76.76			
15.56	3.31	73.36			
13.08	3.21	70.05			
11.00	3.15	66.84			
9.25	3.22	63.69			
7.78	3.44	60.47			
6.54	3.79	57.03			
5.50	4.22	53.24			
4.62	4.70	49.02			

Peaks

Dia(um)	Vol%	Width
22.04	39.5	38.78
2.492	60.5	3.91

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-5
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0367
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.913
Low Edge(um):	0.096	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.670%
Residuals:	Disabled	Part. Ref. Index:	1.51			Flow:	85 %
#Channels:	86	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3770	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

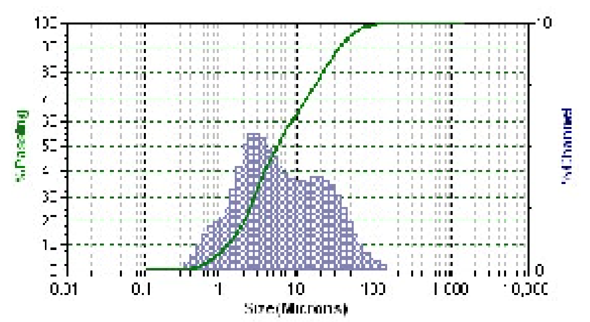
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 15:16**

PDS-IRF-TA-6 | **Calculated: 09/06/2021 - 15:16**



Summary

Data	Value
MV(um):	13.14
MN(um):	0.721
MA(um):	2.978
CS:	2.015
SD:	11.90
Mz:	10.85
σi:	13.36
Ski:	0.750
Kg:	1.386

Percentiles

%Tile	Size(um)
95.00	49.70
90.00	34.84
80.00	21.13
60.00	8.24
50.00	5.38
40.00	3.77
30.00	2.738
20.00	1.977
10.00	1.199
5.00	0.788

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	5.36	40.96
1184	0.00	100.00	3.27	5.46	35.60
995.6	0.00	100.00	2.750	5.53	30.14
837.2	0.00	100.00	2.312	5.06	24.61
704.0	0.00	100.00	1.945	4.19	19.55
592.0	0.00	100.00	1.635	3.30	15.36
497.8	0.00	100.00	1.375	2.59	12.06
418.6	0.00	100.00	1.156	2.17	9.49
352.0	0.00	100.00	0.972	1.93	7.32
296.0	0.00	100.00	0.818	1.75	5.39
248.9	0.00	100.00	0.688	1.48	3.64
209.3	0.00	100.00	0.578	1.11	2.16
176.0	0.00	100.00	0.486	0.69	1.04
148.0	0.21	100.00	0.409	0.36	0.36
124.5	0.40	99.79	0.344	0.00	0.00
104.7	0.54	99.39	0.2890	0.00	0.00
88.00	0.76	98.85	0.2430	0.00	0.00
74.00	1.07	98.09	0.2040	0.00	0.00
62.23	1.40	97.02	0.1720	0.00	0.00
52.33	1.99	95.64	0.1450	0.00	0.00
44.00	2.64	93.65	0.1220	0.00	0.00
37.00	3.04	91.01	0.1020	0.00	0.00
31.11	3.42	87.97			
26.16	3.67	84.55			
22.00	3.70	80.88			
18.50	3.77	77.18			
15.56	3.80	73.33			
13.08	3.60	69.65			
11.00	3.59	66.05			
9.25	3.71	62.46			
7.78	3.94	58.75			
6.54	4.25	54.81			
5.50	4.61	50.56			
4.62	4.99	45.95			

Peaks

Dia(um)	Vol%	Width
5.38	100.0	23.80

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-6
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0487
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.911
Low Edge(um):	0.096	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.578%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	NA
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	NA
Filter:	Enabled	DB Record:	3774	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

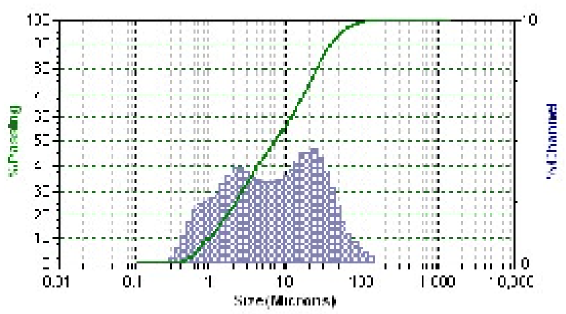
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 15:28**

PDS-IRF-TA-7 | **Calculated: 09/06/2021 - 15:28**



Summary

Data	Value
MV(um):	14.94
MN(um):	0.614
MA(um):	2.664
CS:	2.253
SD:	13.97
Mz:	12.52
σi:	14.93
Ski:	0.678
Kg:	1.147

Percentiles

%Tile	Size(um)
95.00	53.09
90.00	38.29
80.00	25.09
60.00	11.39
50.00	6.96
40.00	4.16
30.00	2.591
20.00	1.654
10.00	0.913
5.00	0.643

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	3.55	38.66
1184	0.00	100.00	3.27	3.76	35.11
995.6	0.00	100.00	2.750	3.95	31.35
837.2	0.00	100.00	2.312	3.95	27.40
704.0	0.00	100.00	1.945	3.68	23.45
592.0	0.00	100.00	1.635	3.27	19.77
497.8	0.00	100.00	1.375	2.89	16.50
418.6	0.00	100.00	1.156	2.66	13.61
352.0	0.00	100.00	0.972	2.57	10.95
296.0	0.00	100.00	0.818	2.48	8.38
248.9	0.00	100.00	0.688	2.22	5.90
209.3	0.00	100.00	0.578	1.72	3.68
176.0	0.00	100.00	0.486	1.12	1.96
148.0	0.34	100.00	0.409	0.63	0.84
124.5	0.45	99.66	0.344	0.21	0.21
104.7	0.61	99.21	0.2890	0.00	0.00
88.00	0.85	98.60	0.2430	0.00	0.00
74.00	1.20	97.75	0.2040	0.00	0.00
62.23	1.71	96.55	0.1720	0.00	0.00
52.33	2.38	94.84	0.1445	0.00	0.00
44.00	3.13	92.46	0.1220	0.00	0.00
37.00	3.84	89.33	0.1020	0.00	0.00
31.11	4.37	85.49			
26.16	4.68	81.12			
22.00	4.52	76.44			
18.50	4.54	71.92			
15.56	4.24	67.38			
13.08	3.88	63.14			
11.00	3.62	59.26			
9.25	3.45	55.63			
7.78	3.38	52.18			
6.54	3.35	48.80			
5.50	3.37	45.45			
4.62	3.42	42.08			

Peaks

Dia(um)	Vol%	Width
15.67	64.9	32.04
1.458	35.1	1.86

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-7
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0350
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.919
Low Edge(um):	0.096	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.570%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3770	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

10.5.4

S3000/S3500

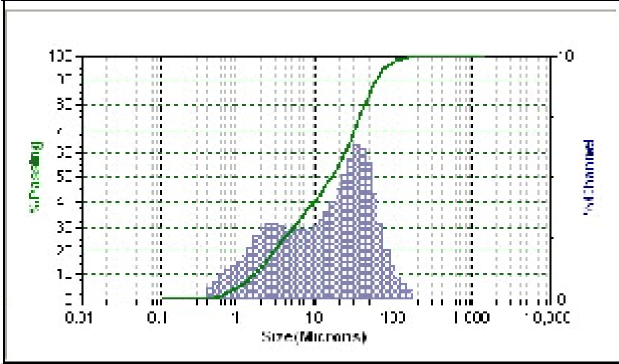
- Particle Size Analysis -

PDS RC Bhopal

PDS-IRF-TA-8

Data Acquired: 09/06/2021 - 15:40

Calculated: 09/06/2021 - 15:40



Summary

Data	Value
MV(um):	24.43
MN(um):	0.771
MA(um):	4.44
CS:	1.351
SD:	22.45
Mz:	21.75
σi:	22.56
Ski:	0.503
Kg:	0.937

Percentiles

%Tile	Size(um)
95.00	75.82
90.00	58.06
80.00	41.99
60.00	23.43
50.00	15.75
40.00	9.37
30.00	5.15
20.00	2.883
10.00	1.582
5.00	0.987

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	3.02	25.27
1184	0.00	100.00	3.27	3.10	22.25
995.6	0.00	100.00	2.750	3.12	19.15
837.2	0.00	100.00	2.312	2.96	16.03
704.0	0.00	100.00	1.945	2.62	13.07
592.0	0.00	100.00	1.635	2.20	10.45
497.8	0.00	100.00	1.375	1.82	8.25
418.6	0.00	100.00	1.156	1.56	6.43
352.0	0.00	100.00	0.972	1.37	4.87
296.0	0.00	100.00	0.818	1.21	3.50
248.9	0.00	100.00	0.688	1.02	2.29
209.3	0.00	100.00	0.578	0.76	1.27
176.0	0.42	100.00	0.486	0.51	0.51
148.0	0.61	99.58	0.409	0.00	0.00
124.5	0.90	98.97	0.344	0.00	0.00
104.7	1.35	98.07	0.2890	0.00	0.00
88.00	2.05	96.72	0.2430	0.00	0.00
74.00	3.07	94.67	0.2040	0.00	0.00
62.23	4.36	91.60	0.1720	0.00	0.00
52.33	5.61	87.24	0.1450	0.00	0.00
44.00	6.19	81.63	0.1220	0.00	0.00
37.00	6.34	75.45	0.1020	0.00	0.00
31.11	5.79	69.11			
26.16	5.10	63.32			
22.00	4.49	58.22			
18.50	4.00	53.73			
15.56	3.61	49.73			
13.08	3.20	46.12			
11.00	3.05	42.94			
9.25	2.92	39.79			
7.78	2.80	36.87			
6.54	2.88	33.99			
5.50	2.90	31.11			
4.62	2.94	28.21			

Peaks

Dia(um)	Vol%	Width
15.75	100.0	44.89

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-8
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0615
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.896
Low Edge(um):	0.086	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.593%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3702	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(2)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\WIHDatabase 2010.MDB				

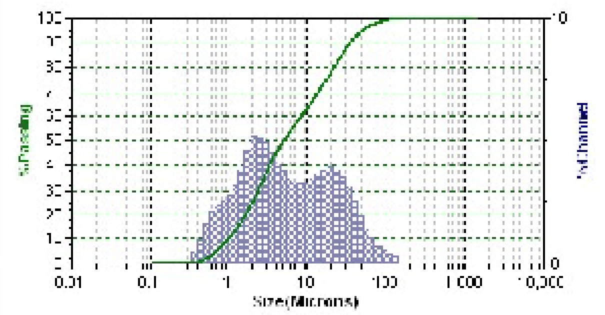
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 15:51**

PDS-IRF-TA-9 | **Calculated: 09/06/2021 - 15:51**



Summary

Data	Value
MV(um):	13.12
MN(um):	0.682
MA(um):	2.580
CS:	2.317
SD:	12.20
Mz:	10.60
σi:	13.53
Ski:	0.765
Kg:	1.316

Percentiles

%Tile	Size(um)
95.00	49.76
90.00	34.84
80.00	21.52
60.00	8.18
50.00	4.96
40.00	3.29
30.00	2.330
20.00	1.637
10.00	0.961
5.00	0.679

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	4.81	44.37
1184	0.00	100.00	3.27	4.80	39.06
995.6	0.00	100.00	2.750	5.11	34.00
837.2	0.00	100.00	2.312	5.19	29.77
704.0	0.00	100.00	1.945	4.81	24.50
592.0	0.00	100.00	1.635	3.83	19.97
497.8	0.00	100.00	1.375	3.10	16.14
418.6	0.00	100.00	1.156	2.78	12.96
352.0	0.00	100.00	0.972	2.59	10.18
296.0	0.00	100.00	0.818	2.42	7.59
248.9	0.00	100.00	0.688	2.11	5.17
209.3	0.00	100.00	0.578	1.58	3.06
176.0	0.00	100.00	0.486	0.87	1.48
148.0	0.32	100.00	0.409	0.61	0.61
124.5	0.41	99.68	0.344	0.00	0.00
104.7	0.55	99.27	0.2890	0.00	0.00
88.00	0.75	98.72	0.2430	0.00	0.00
74.00	1.03	97.97	0.2040	0.00	0.00
62.23	1.43	96.94	0.1720	0.00	0.00
52.33	1.94	95.51	0.1450	0.00	0.00
44.00	2.54	93.57	0.1220	0.00	0.00
37.00	3.12	91.03	0.1020	0.00	0.00
31.11	3.57	87.91			
26.16	3.83	84.34			
22.00	3.92	80.51			
18.50	3.84	76.59			
15.56	3.67	72.75			
13.08	3.46	69.08			
11.00	3.31	65.62			
9.25	3.27	62.31			
7.78	3.34	59.04			
6.54	3.50	55.70			
5.50	3.75	52.20			
4.62	4.08	48.45			

Peaks

Dia(um)	Vol%	Width
18.11	47.8	32.17
2.049	52.2	2.06

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-9
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0380
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.916
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.582%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	85 %
#Channels:	50	Particle Shape:	Irregular	Cell ID:	1792	UIsonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Uisonic Time:	N/A
Filter:	Enabled	DB Record:	3796	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	D:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

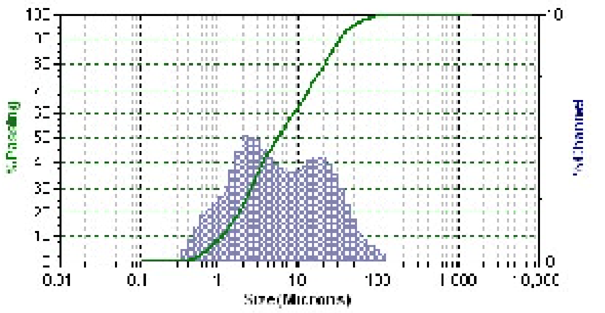
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 16:00**

PDS-IRF-TA-10 | **Calculated: 09/06/2021 - 16:00**



Summary

Data	Value
MV(um):	12.39
MN(um):	0.692
MA(um):	2.713
CS:	2.211
SD:	11.31
Mz:	10.28
σi:	12.43
Ski:	0.726
Kg:	1.265

Percentiles

%Tile	Size(um)
95.00	45.42
90.00	32.17
80.00	20.33
60.00	8.48
50.00	5.31
40.00	3.52
30.00	2.469
20.00	1.735
10.00	1.026
5.00	0.709

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1400	0.00	100.00	3.89	4.55	42.94
1184	0.00	100.00	3.27	4.96	38.09
995.6	0.00	100.00	2.750	5.09	33.13
837.2	0.00	100.00	2.312	5.07	28.10
704.0	0.00	100.00	1.945	4.40	23.03
592.0	0.00	100.00	1.635	3.89	18.55
497.8	0.00	100.00	1.375	3.09	14.66
418.6	0.00	100.00	1.156	2.81	11.03
352.0	0.00	100.00	0.972	2.39	8.22
296.0	0.00	100.00	0.818	2.20	6.03
248.9	0.00	100.00	0.688	1.89	4.63
209.3	0.00	100.00	0.578	1.41	2.74
176.0	0.00	100.00	0.486	0.87	1.33
148.0	0.00	100.00	0.409	0.46	0.46
124.5	0.37	100.00	0.344	0.00	0.00
104.7	0.40	99.63	0.2890	0.00	0.00
88.00	0.65	99.15	0.2430	0.00	0.00
74.00	0.89	98.50	0.2040	0.00	0.00
62.23	1.24	97.61	0.1720	0.00	0.00
52.33	1.72	96.37	0.1450	0.00	0.00
44.00	2.31	94.65	0.1220	0.00	0.00
37.00	2.95	92.34	0.1020	0.00	0.00
31.11	3.53	89.39			
26.16	3.96	85.86			
22.00	4.20	81.90			
18.50	4.23	77.70			
15.56	4.09	73.47			
13.08	3.97	69.38			
11.00	3.70	65.61			
9.25	3.62	61.91			
7.78	3.65	58.19			
6.54	3.76	54.64			
5.50	3.94	50.78			
4.62	4.20	46.84			

Peaks

Dia(um)	Vol%	Width
16.83	49.2	28.55
2.111	50.8	2.99

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-10
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0349
Up Edge(um):	1400	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.910
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.601%
Residuals:	Disabled	Part. Ref. Index:	1.81			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3790	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

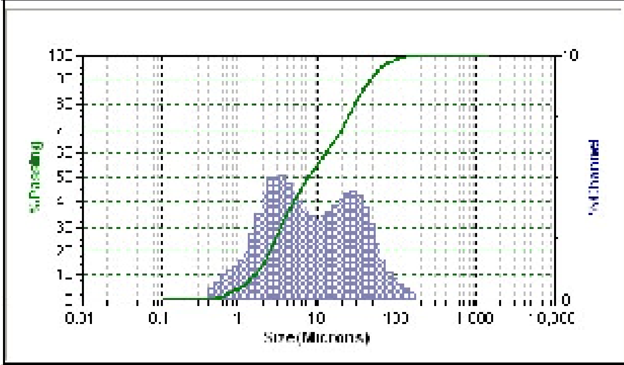
10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal | **Data Acquired: 09/06/2021 - 16:12**

PDS-IRF-TA-11 | **Calculated: 09/06/2021 - 16:12**



Summary

Data	Value
MV(um):	17.50
MN(um):	0.830
MA(um):	3.73
CS:	1.608
SD:	16.18
Mz:	14.64
σi:	17.42
Ski:	0.730
Kg:	1.184

Percentiles

%Tile	Size(um)
95.00	62.58
90.00	45.02
80.00	29.39
60.00	12.39
50.00	7.42
40.00	4.82
30.00	3.38
20.00	2.395
10.00	1.533
5.00	0.996

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	5.07	34.15
1184	0.00	100.00	3.27	5.04	29.08
995.6	0.00	100.00	2.750	5.03	24.04
837.2	0.00	100.00	2.312	4.41	19.01
704.0	0.00	100.00	1.945	3.52	14.60
592.0	0.00	100.00	1.635	2.66	11.08
497.8	0.00	100.00	1.375	2.01	8.42
418.6	0.00	100.00	1.156	1.62	6.41
352.0	0.00	100.00	0.972	1.38	4.79
296.0	0.00	100.00	0.818	1.20	3.41
248.9	0.00	100.00	0.688	1.00	2.21
209.3	0.00	100.00	0.578	0.74	1.21
176.0	0.35	100.00	0.486	0.47	0.47
148.0	0.46	99.65	0.409	0.00	0.00
124.5	0.59	99.19	0.344	0.00	0.00
104.7	0.85	98.60	0.2890	0.00	0.00
88.00	1.16	97.75	0.2430	0.00	0.00
74.00	1.65	96.59	0.2040	0.00	0.00
62.23	2.30	94.94	0.1720	0.00	0.00
52.33	3.08	92.64	0.1450	0.00	0.00
44.00	3.81	89.56	0.1220	0.00	0.00
37.00	4.29	85.75	0.1020	0.00	0.00
31.11	4.45	81.46			
26.16	4.34	77.01			
22.00	4.12	72.67			
18.50	3.86	68.55			
15.56	3.60	64.69			
13.08	3.40	61.09			
11.00	3.32	57.69			
9.25	3.40	54.37			
7.78	3.64	50.97			
6.54	4.00	47.33			
5.50	4.40	43.33			
4.62	4.78	38.93			

Peaks

Dia(um)	Vol%	Width
24.84	49.0	38.12
2.890	51.0	4.04

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-11
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

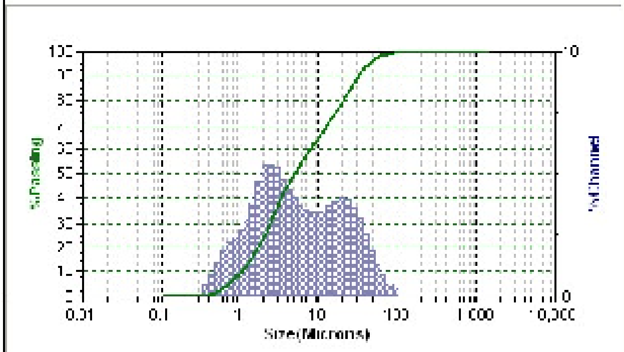
Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0435
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.914
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.573%
Residuals:	Disabled	Part. Ref. Index:	1.51			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1792	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3794	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\MHDatabase 2018.MDB				

10.5.4

S3000/S3500

- Particle Size Analysis -

PDS RC Bhopal	**Data Acquired: 09/06/2021 - 16:23**
PDS-IRF-TA-12	**Calculated: 09/06/2021 - 16:23**



Summary

Data	Value
MV(um):	11.85
MN(um):	0.704
MA(um):	2.680
CS:	2.239
SD:	11.42
Mz:	10.22
σi:	12.22
Ski:	0.750
Kg:	1.226

Percentiles

%Tile	Size(um)
95.00	43.71
90.00	32.17
80.00	20.42
60.00	7.87
50.00	4.92
40.00	3.34
30.00	2.403
20.00	1.717
10.00	1.030
5.00	0.715

Size Percent

Size(um)	%Tile

Size(um)	%Chan	%Pass	Size(um)	%Chan	%Pass
1408	0.00	100.00	3.89	4.77	44.18
1184	0.00	100.00	3.27	5.24	39.41
995.6	0.00	100.00	2.750	5.36	34.17
837.2	0.00	100.00	2.312	5.36	28.81
704.0	0.00	100.00	1.945	4.68	23.45
592.0	0.00	100.00	1.635	3.83	18.77
497.8	0.00	100.00	1.375	3.12	14.94
418.6	0.00	100.00	1.156	2.67	11.82
352.0	0.00	100.00	0.972	2.42	9.15
296.0	0.00	100.00	0.818	2.21	6.73
248.9	0.00	100.00	0.688	1.88	4.52
209.3	0.00	100.00	0.578	1.38	2.64
176.0	0.00	100.00	0.486	0.83	1.26
148.0	0.00	100.00	0.409	0.43	0.43
124.5	0.00	100.00	0.344	0.00	0.00
104.7	0.56	100.00	0.2890	0.00	0.00
88.00	0.54	99.44	0.2430	0.00	0.00
74.00	0.84	98.90	0.2040	0.00	0.00
62.23	1.29	98.06	0.1720	0.00	0.00
52.33	1.68	96.77	0.1450	0.00	0.00
44.00	2.55	95.09	0.1220	0.00	0.00
37.00	3.19	92.54	0.1020	0.00	0.00
31.11	3.67	89.35			
26.16	3.95	85.68			
22.00	4.02	81.73			
18.50	3.91	77.71			
15.56	3.71	73.80			
13.08	3.51	70.09			
11.00	3.40	66.58			
9.25	3.41	63.18			
7.78	3.53	59.77			
6.54	3.73	56.24			
5.50	3.99	52.51			
4.62	4.34	48.52			

Peaks

Dia(um)	Vol%	Width
18.84	43.8	28.79
2.262	56.2	3.43

Project:- Hydrological Modeling for Evaluation of return flow and irrigation planning for optimal utilization of water resources in the command of Sanjay Sagar Project in Madhya Pradesh.
Sample code :- PDS-IRF-TA-12
Analyzed By:- SLS & C.S.CHOWHAN

SOP Name: None(*)

Distribution:	Volume	Run Time:	30 Sec	Fluid:	CURRENT CARRIER		
Progression:	Standard	Run#:	Avg of 3	Fluid Ref Index:	1.333	Loading Factor:	0.0361
Up Edge(um):	1408	Particle:	SOIL PARTICLE	Above Residual:	0	Transmission:	0.916
Low Edge(um):	0.095	Transparency:	Transparent	Below Residual:	0	RMS Residual:	0.723%
Residuals:	Disabled	Part. Ref. Index:	1.51			Flow:	65 %
#Channels:	56	Particle Shape:	Irregular	Cell ID:	1702	Usonic Power:	N/A
Analysis Mode:	S3000/3500			Multi Run Delay:	0 Min.	Usonic Time:	N/A
Filter:	Enabled	DB Record:	3790	Recalc Status:	Original	Serial Number:	S4947
Analysis Gain:	Default(3)	Database:	C:\Program Files\Microtrac FLEX 10.5.4\Databases\NIHDatabase 2018.MDB				

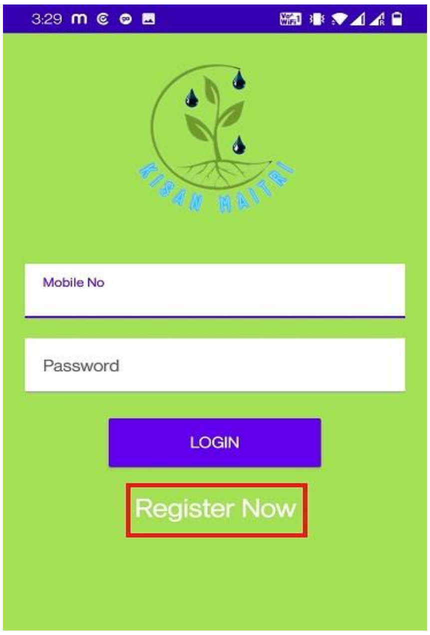
ANNEXURE III: USER MANUAL OF KISAN-MAITRI MOBILE APP

Information

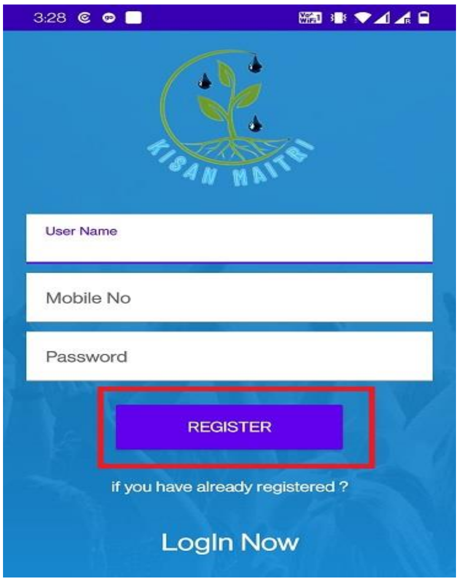
This application has been created to provide information to the farmers about the water problems they face during farming or some other necessary information. It is expected from all of you that you will cooperate with us in this new beginning for you.

The order of what you have to do is as follows -

Step 1 – First of all the farmer has to register himself. For this, first of all the farmer has to press the login button and then go to the register**.**



- Farmers have to register by entering their name, mobile number and password in the farmer registration form.

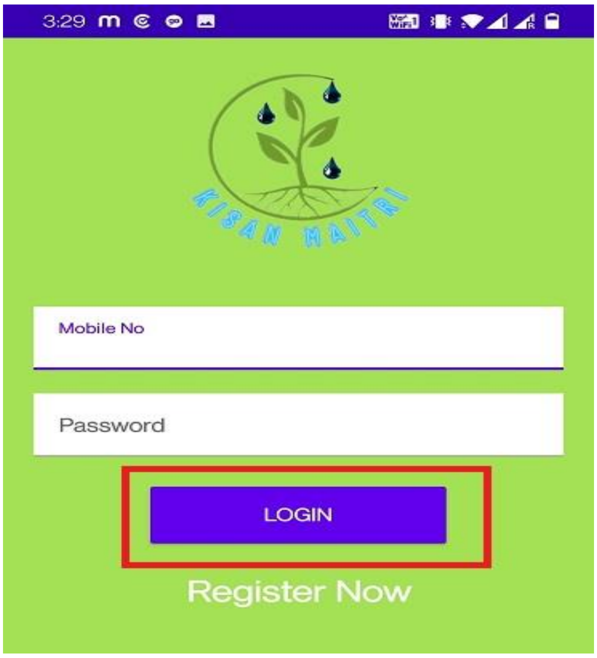


- After that farmer's registration will be done.

After Registering

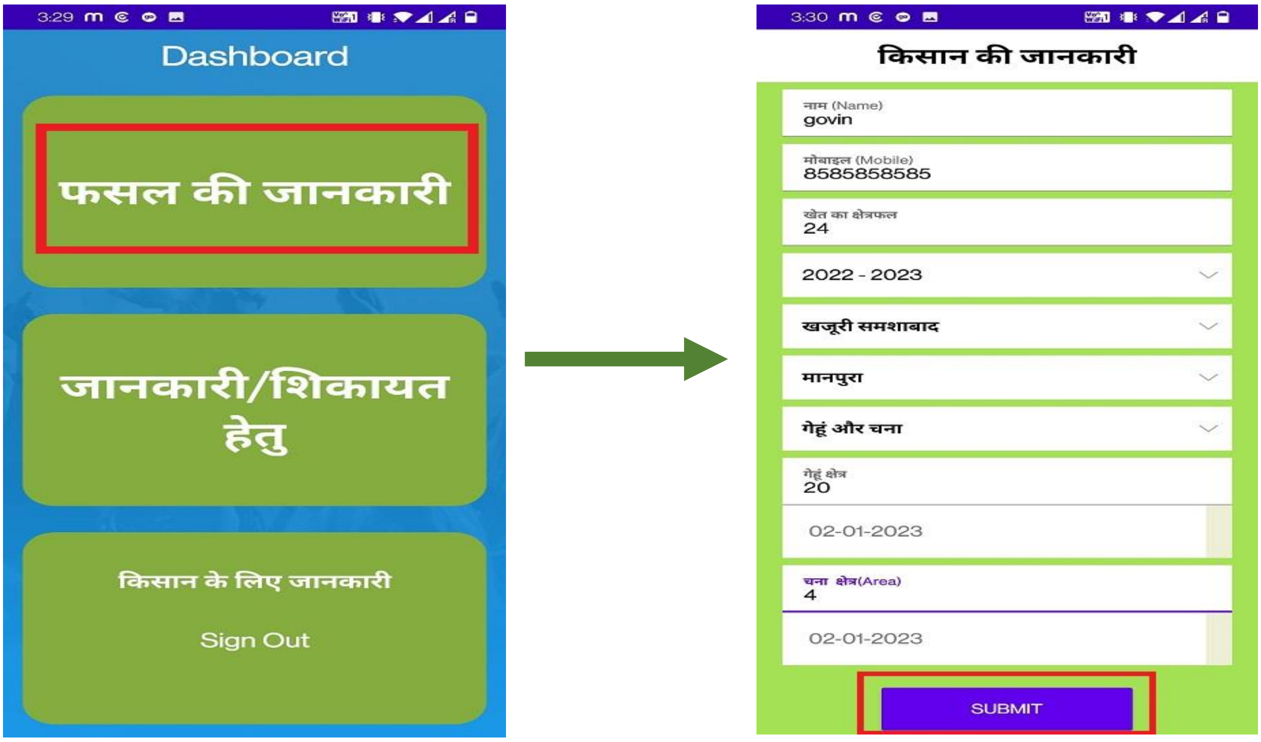
Step 2 - After registering, the farmers will have to go to the login page and give information about the crop to be sown.

- To login, Farmers have to enter the same mobile number and the same password which you had filled at the time of registration. Then press the login button.



After Login

- After logging in, Farmers have to press the crop information button. In this form, the farmer has to select the name of his water user association. As you select the name of the association, at the same time a box for selecting the village will open there from which you have to select your village. And then you have to give information about yourself and only that crop area in which you are going to sow the crop in this session. You will have to give the name of the crop and the date of its sowing and then press the submit button.



To obtain information or make a complaint

Step 3 - You can go to the information/complaint page to ask to administration something or to make a complaint. (For information/complaint) then a form will appear on your screen.

- After this, you have to select the name of water user association or village, if you have any question then write your question in the information. And if you have any complaint then write the complaint in the information. And if there is a photo, select it and press the upload button.


4:55
जानकारी/शिकायत हेतु
नाम (Name)
tiwari
मोबाइल (Mobile)
9595959595
जल उपयोगकर्ता संघ
गांव का नाम
जानकारी (Information)
SUBMIT

ANNEXURE IV: PHOTOGRAPHS

(A) Measuring the depth of the main canal.

(B) Training to field staff

(C) Canal water is going directly into the river.

(D) Sowing of wheat in farmer's field.

(E) Field data collection for crop identification.

(F) Initial stage of wheat crops.

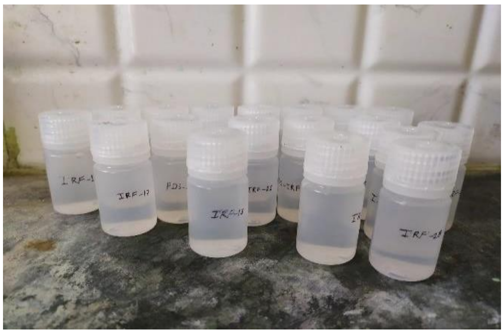
	
(G) Pumping of canal water for irrigation.	**(H)** Marking for level measurement.

	
(I) Collection of the canal water sample	**(J)** 20ft long pipe (each) uses for irrigation

	
(K) Collection of water sample from the barrage	**(L)** One month after opening the canal, water Spread at the G/D site.

(M) Irrigation in the wheat field

(N) Wheat crop in the command



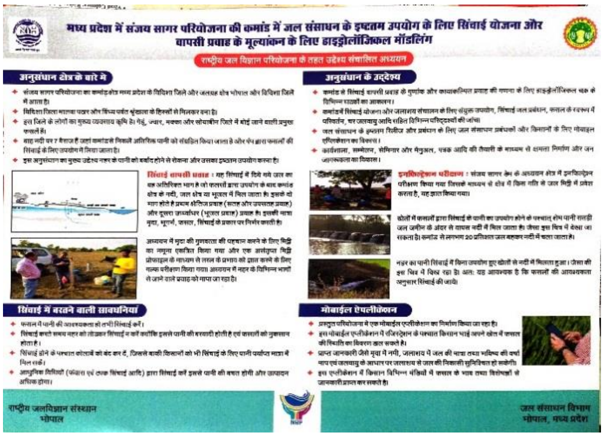
(O) Water samples for tracer analysis

(P) Soil samples from four different fields

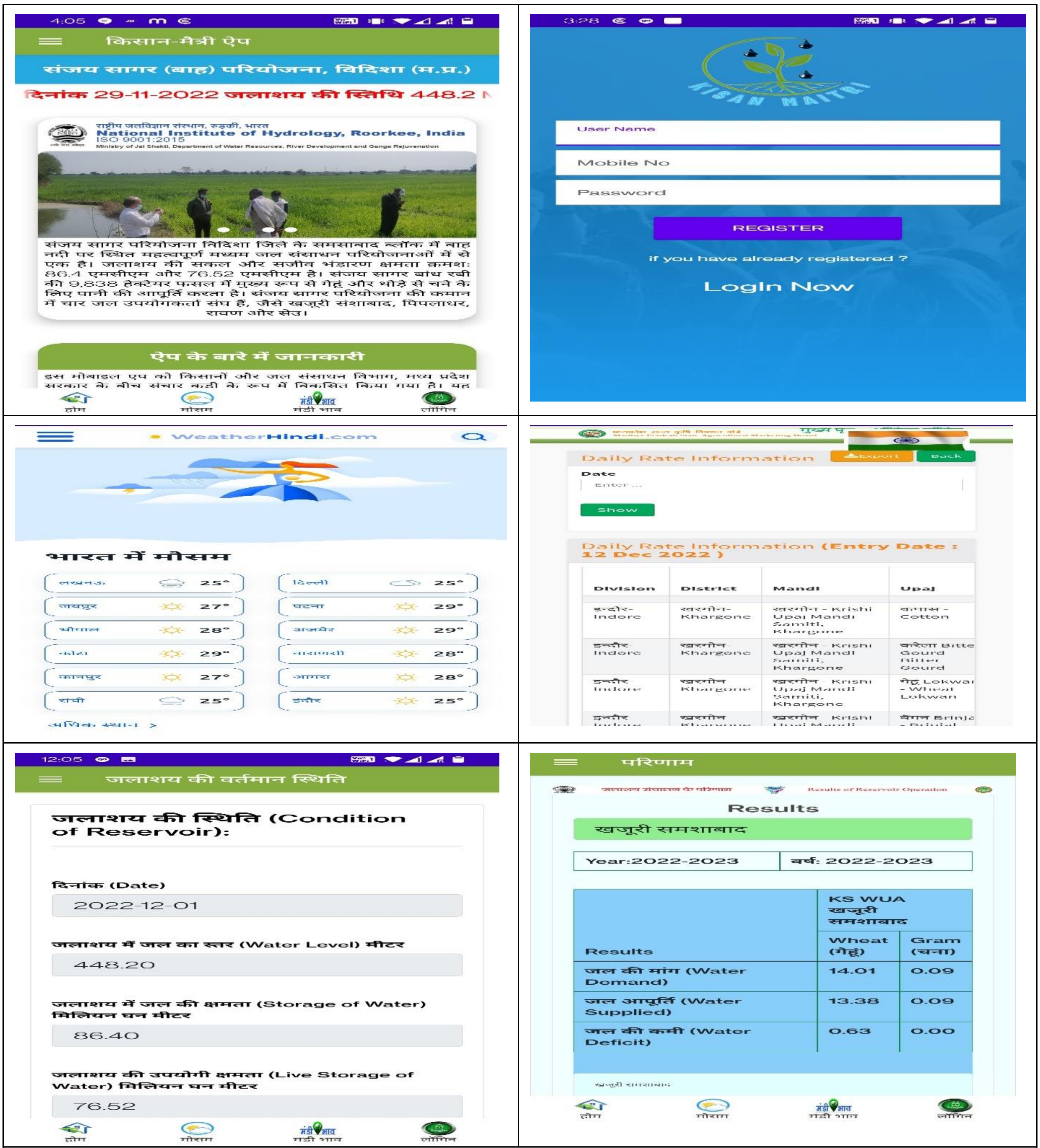
(Q) Demonstration of KISSAN-MAITRI App.

(R) Demonstration of Mobile app. functions

(S) Geology of the command area (Vidisha district)




(T) During Mass Awareness program on command of Sanjay Sagar Dam (Bah)



(U) Kissan-Maitri Mobile Application Tab

Study Group

Director	:	Dr. M.K Goyal
Coordinator	:	Dr. Anil Kumar Lohani, Scientist-G
NIH Regional Centre Bhopal		
Principal Investigator	:	Dr. Rahul Kumar Jaiswal, Scientist-F
Co-Principal Investigators	:	Dr. Ravi V. Galkate, Scientist-F
	:	Dr. T. Thomas, Scientist-F
	:	Mrs. Shashi P Indwar, Scientist-C
	:	Shri Kuldeepak Pal, JRF
	:	Shri Jani Mohit Deepesh Bhai
	:	Shri Ram Lakhan Singh Thakur
	:	Shri Shohrat Ali
	:	Shri Sukant Jain, Research Scientist
NIH Roorkee		
Co-Principal Investigators	:	Dr. Anil Kumar Lohani, Scientist-G Dr.
	:	Sudheer Kumar, Scientist-G
	:	Dr. Surjeet Singh, Scientist-F
Water Resources Department, Govt. of Madhya Pradesh		
Principal Investigator	:	Director, Hydrometeorology, WRD MP
Co-Principal Investigators	:	S. E., GW circle, Bhopal
	:	S. E., Sanjay Sagar Bah Project, Bhopal
	:	Deputy Director (D B Admin)
	:	E. E., Sanjay Sagar Irrigation Project
	:	E. E., Hydrometeorology Div 1, Bhopal

APPENDIX-A: Project summary

Table A.1: Summary

Project objectives		
Objectives as per project document	Revised objective	Reasons for revision
• Assessment of different components of hydrological cycles for computation of irrigation return flow coefficient and rejuvenated flow from the command • Investigation of various scenarios including conjunctive use, irrigation water management, cropping pattern changes, variable climate, etc. for irrigation planning and reservoir operation in the command • Development of a mobile application for WR managers and farmers for optimal release and management of water resources • Capacity building and development of public awareness through workshops, conferences, seminars, and preparation of manuals, leaflets, etc.	-	-

***Manpower* deployed (against sanctioned manpower)**			
Sanctioned		Deployed	
Designation	Person months	Designation	Person months
JRF	Sh.Kuldeepak Pal June 2019 to June 2021 (24 months)	JRF	Sh.Jani Mohit Deepesh Bhai September 2021 to April 2022 (7 months)
JRF	Sh. Ram Lakhan Singh Thakur	JRF	Sh.Shohrat Ali

	June 2022 to August 2022(2 months)		Septemeber 2022 to September 2023 (12 months)
Field Assistant	Sh. Gopilal Yadav (20 months)	Field Assistant	Sh. Prakash Singh (20 months)
Field Assistant	Sh. Sandeep Kushwah (20 months)	Field Assistant	Sh. Shaitan singh (15 months)
Field Assistant	Sh. Raghuveer Singh (5months)		

Infrastructure/ equipment		
Planned (as per project proposal)	Developed/ procured	Reasons for deviation
Dell Laptop	Procured	-
Remote sensing data		
Water sample bottles		
Soil sample container		
Field work		
Planned (as per project proposal)	Completed	Reasons for deviation
Soil testing and measurement of flow in the canals, water sample of different source (well, BRB, Hand pump etc.)	Yes	-
Workshop/ Capacity building/ technology transfer		
Planned (as per project proposal)	Organized	Reasons for deviation
Mass awareness programme on Feb 27, 2021 at Sanjay Sagar Bah Dam site	Yes	-

Study area	
Planned	Extended
Irrigation return flow assessment using different techniques, reservoir operation and management plan and Mobile and web application development.	Only the Sanjay Sagar canal was considered

New data generated in the project		
Planned (as per project proposal)	Achievement	Reasons for deviation
-	-	-
Envisaged contribution to the project		
Planned (as per project proposal)	Contribution made	Reasons for deviation
Assessment of return flow using three different techniques, water balance, hydrological modelling, and isotopes.	Hydrological modeling was found more promising due to less requirement of data.	
Development of a decision support for irrigation planning	A decision support using the MIKE suite of software was developed	-
Development of a mobile application for interaction between the water resources department and end users	Web and mobile applications were developed to collect information from farmers for real-time	-

	reservoir operation and irrigation planning	
How research outcome benefited the end user department and society		
Planned (as per project proposal)	Benefit derived	Reasons for deviation
• Decision support developed under the PDS can be helpful in appropriate decisions for irrigation planning • The web/mobile-based application enables interaction between farmers and WR managers • Farmers can get knowledge of water availability and deficit in advance • Farmers can inform issues of canal breakage or other problems for timely intervention.	• Decision support developed • Web/mobile application is developed • The application is working properly • The application is working properly	- - - -
End-of-project deliverables		
Planned (as per project proposal)	Achieved	Reasons for deviation

Outsourcing (>1 lakh)/ consultancy (All)			
Consultant (name and qualifications), organization / outsource agency	Work assigned	Estimated cost Rs	Actual cost Rs
Development of a Mobile application for the planning of reservoir release and irrigation	Cloud Soft Technology Pvt Ltd		

Financial achievement

Water Resource Department Govt. of Madhya Pradesh, Bhopal					
S No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.				
2	Traveling Expenditure				
3	Infrastructure/Equipment				
4	Experimental Charges/Fieldwork/Consumables				
5	Capacity building/Technology transfer				
6	Contingency				
7	Outsourcing/ consultancy				
	Total				

Central India Hydrology Regional Centre, National Institute of Hydrology, Bhopal					
S No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation

1	Remuneration/Emoluments for Manpower etc.			2017882	
2	Traveling Expenditure			342506	
3	Infrastructure/Equipment			353204	
4	Experimental Charges/Fieldwork/Consumables			129161	
5	Training/Workshop/HON.			78400	
6	Capacity building/Technology transfer			0	
7	Contingency			0	
8	Outsourcing/ consultancy			80000	
	Total			3001153	

Table A.2: Quantitative outcome

i. Research papers published/ submitted		
S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/ seminar)	Impact Factor for Journal
1.	Jaiswal R.K., Ali S., Jain S., Galkate R.V, Krisanh G., Lohani A.K., Kumar S., Monitoring, and modelling approaches for quantitative assessment of irrigation return flows for management of water resources in a command, J Earth Environ. Sci. (Accepted)	3.119
2.	Ali. S, Bharti. B, Singh, H.P & Jaiswal, R.K (2023). Assessment of Spatial and Temporal Trends of Diurnal Temperature Range for Vidisha District, Madhya Pradesh, India. *IJEP 43(7):* 599-611.	0.3
3.	Ali. S, Bharti. B, Singh, H.P & Jaiswal, R.K (2023).Application of SWAT Model for Water Balance Component Analysis: The case of Bah River Basin, Madhya Pradesh, India. *IJEP 43(11):* 972-986.	0.3
4.	Ali. S, Bharti. B, Singh, H.P & Jaiswal, R.K (2023). Runoff Estimation by Integration of GIS and SCS-CN Method for Bah River Watershed, Madhya Pradesh, India. *VVIJOURNAL 11(12):* 109-126.	0.2
5.	Saini, S., Varnika, Jaiswal, R.K., Galkate, R., Lohani, A.K (2023) कृषि में सिंचाई के लिएजल संसाधनों के इष्टतम उपयोग एवं जल प्रबंधन हेतू वेब आधारित निर्णय समर्थन प्रणाली. *जलवायु परिवर्तन एवं जल प्रबंधन विषय पर राष्ट्रीय जल संगोष्ठी-2023 राष्ट्रीय जल विज्ञान संस्थान रूड़की.* दिनांक-17-18 Aug 2023.	-
6.	Ali. S, Bharti. B, Singh, H.P & Jaiswal, R.K (2022). Assessment of Trends of Diurnal Temperature Range for Vidisha District, Madhya Pradesh, India. National Symposium *TROPMET 2022,* November 29-December 2022	-
7.	Jaiswal R.K., Pal, K., Jain, S., Galkate, R.V., Lohani, A.K. (2021). Computation and comparison of satellite based crop	-

	evapotranspiration with climate data in a command, *International Conference on Recent Advances in Civil Engineering for Sustainable Development (RACESD-2021)*, Feb 13-14, 2021 (Online)	
8.	Tripathi, S., Tiwari. H.L., Jaiswal, R.K. (2021). Hydrological modeling using open-source application, *International Conference on Water and Environment (ICWE-2021)*, March 22-23, 2021 (Online)	-
9.	Jaiswal R.K., Pal, K., Galkate R.V., Lohani A.K. (2019) Quantative assessment of regenerated flow and irrigation management in a command, 2nd International Conference on Sustainable Management, Pune, Nov 6-8, 2019.	-

Reports/Monographs/Internal publications brought out

S. No.	Reports/Monographs/Internal publications
1.	Yearly and quarterly progress Reports on PDS
2.	Working manual for mobile application

ii. New techniques/models/ software/ knowledge developed, if any

- SWAT model has been developed for irrigation return flow assessment
- Decision support system for reservoir operation in MIKE DSS
- Excel-based decision support for irrigation planning
- Web/mobile-based application for interaction between WR managers and farmers

iii. Web site/ application developed

Name	Web address	Server location	Launch date	Details of information available
Web/Mobile application for interaction between WR managers and farmers	For Web Application: http://117.252.14.232:86 For Mobile App: https://play.google.com/store/apps/details?id=com.gov.kisanmaitri	-	Nov 2021	Applications are working properly

iv. Patents filed/awarded, if any

v. Workshop/ conferences/ seminars/capacity building programs organized

S. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)

1.	Inception workshop for IRF study	Apr 24, 2019, 1-day, 25	N
2.	Farmers awareness workshop at Samshabad	Feb 27, 2021, 1-day, 80	N
3.	Mass awareness workshop in Majhera village of Sanjay Sagar command	April 28, 2022, 1-day, 40	N

v. Stake holders feedback and action taken on constructive feedback

S N.	Feedback received	Action taken
1.	Feedback from WR engineers regarding development of DSS	An excel-based DSS has been developed
2.	Feedbacks from regarding mobile application	Applaiction has been developed in hindi

vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)

S No	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring	Number (planned)	Numbers (measured)
1.	Soil texture and soil water retention testing	12 sites	12 sites
2.	Collection of water samples from canals, dam, hand pumps, open wells, rain fall, bore wells, and river, etc.	30 sites	40 sites

vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.)

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown

viii. Equipment/ software purchased

a. Equipment purchased

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown
1.	PH Meter (Eco Tester PH2 w ATC)	1	-	100	

2.	Electrical Conductivity meter (Eco Tester-EC Low Tester)	1	-	100	

b. Software purchased

S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown

ix. Plans for utilizing the equipment facilities in future

S. No.	Installation/ equipment	Planned future use

x. Data dissemination policy for data generated in the project

xi. Number of post-graduate/doctoral candidates completed their courses (Please give a list of such candidates)

Post-graduate student

1. M. Tech thesis of Sachin Tripathi Scholar No: 192111715 of MANIT, Bhopal (2020-21) titled “Hydrological Response Analysis under Climate Change using SWAT”
2. M. Tech thesis of Priya Singh Scholar No: 202111702 of MANIT, Bhopal (2021-22) titled “Estimation of Evapotranspiration through SEBAL Model using satellite data”

Ph.D. Student

1. Shohrat Ali, Research Scholar of Central University of Jharkhand titled “Assessment of Climate Change Vulnerability using SWAT under RCP4.5 and RCP8.5 Scenario in Bah River Basin, Madhya Pradesh, India - Ongoing

xii. Foreign deputation/visit of PI/Co-PIs/students, if any: Nil

A.3 Activity chart

Include activity chart/ modified activity chart, and reasons for modification of activity chart.

Particular of works	First Year				Second Year				Third Year				Fourth Year			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV

Meetings of partner organizations and field staff for project activities	■	■			■					■				■		
Field visit and recognizance survey	■	■			■				■				■			
Collection and analysis of meteorological, hydrological, command, groundwater data	■	■	■	■												
Hiring of JRF for the study	■	■														
Review of literature and finalization of methodology	■	■	■													
Digital image analysis of high resolution RS data for land use detection/ purchase of land use data		■	■	■												
Selection of measuring points in river and canals and field plots	■	■														
Development of GIS data base		■	■													
Selection of field plots, instrumentation and measurement of flows, meteorological parameters and soil moisture			■	■			■	■			■	■			■	■
Collection and analysis of water samples for tracer analysis			■	■			■	■			■	■			■	■
Evaluation of Soil properties		■	■			■	■									
Measurement of groundwater data and pump tests			■	■			■	■			■	■				
Water balance model of river for computation of rejuvenated flow				■	■	■	■	■	■	■						
Application of hydraulic and water balance model for computation of IRF							■	■	■	■	■	■				
Application of MIKE HYDRO Basin model for irrigation releases								■	■	■	■					
Scenarios based assessment under variable climate, efficiency, crops, conjunctive use conditions											■	■	■	■		
Development of mobile based application for transfer of information among users and managers									■	■	■	■				
Demonstration of developed application to users/govt. officials													■	■		
Preparation of Status/Interim/Final Report				■				■				■				■
Inception/dissemination/capacity building/mass awareness workshops	■	■			■	■			■	■		■	■		■	■

Appendix-B: Supplementary results

Provide supplementary results here, if any