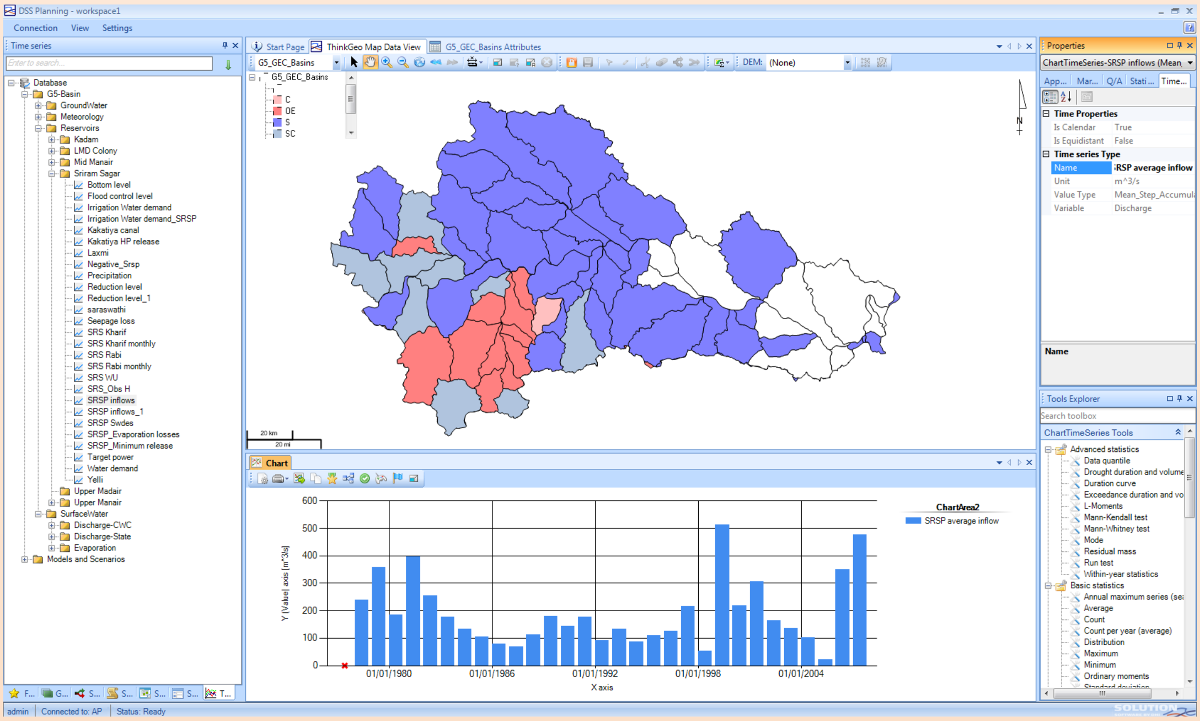
# INDIA: HYDROLOGY PROJECT-II




## PROJECT COMPLETION REPORT

## APRIL 2006 - MAY 2014

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## NATIONAL INSTITUTE OF HYDROLOGY

**ROORKEE – 247 667, UTTARAKHAND**

**July, 2014**

# Preface

Hydrology Project-I(HP-I) was taken up to develop Hydrological Information System (HIS) by creating facilities and standardized procedures for data collection, data compilation, processing and data storage for data use. HIS was established in nine states, viz. Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa & Tamil Naduand and six central agencies - Central Water Commission (CWC), Central Ground Water Board (CGWB), Central Water & Power Research Station (CWPRS), India Meteorological Department (IMD), Ministry of Water Resources (MoWR), National Institute of Hydrology (NIH). The Scientists of the Institute were trainind on, "Surface Water Data Entry Software (SWDES)", "Hydrological Modeling System (HYMOS)" and "Water Information System for Data On-line Management (WISDOM)" for Surface Water, "Ground Water Data Entry Software (GWDES)", "Groundwater Estimation and Management System (GEMS)", and WISDOM" for Ground Water. The Scientists further trained the engineers and officers of the various states on the afore-mentioned software.

Hydrology Project-II (HP-II) was the follow-up of HP-I. The EFC was approved on 22$^{nd}$ June, 2005 and the Cabinet Approval was obtained on 6$^{th}$ October, 2005. The Project started on 5$^{th}$ April, 2006 and the stipulated date of completion of the Project was 30$^{th}$ June, 2012, which was extended to May 31, 2014 and the project completed on 31, May, 2014. The HP-II was implemented in 13 States namely; Andhra Pradesh, Chhattisgarh, Goa, Gujarat, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Puducherry, Punjab & Tamil Nadu and 8 Central Organizations namely; Bhakra Beas Management Board, Central Ground Water Board, Central Pollution Control Board, Central Water Commission, Central Water & Power Research Station, India Meteorological Department, Ministry of Water Resources and National Institute of Hydrology. Roorkee.

Under HP-II, National Institute of Hydrology, Roorkee along with the DSS (P) consultants developed and implemented DSS (P) for Integrated Water Resources Development and Management in six central agencies and nine States. Eleven Purpose Driven Studies (PDS) were carried out and one hundred training programmes and workshops were organized on the specialized topics of hydrology, data processing, software and demand driven trainings for the State and Central implementing agencies at Roorkee and in various states, in which 2829 engineers/ officers participated. Seventeen Scientists received foreign trainings and one scientist undertook a study tour. Office and training equipments and vehicles were procured to strengthen various facilities in the institute. It is highly desirable that the achievements of the HP-II in general and DSS (P) in particular are sustained in all the implementing agencies, which require continuous support and capacity building to move forward for accomplishing integrated water resources development and management employing the DSS (P).

(R.D. Singh)
Director

**Director &**
**Project Coordinator** **Mr. R.D. Singh**

# Hydrology Project-II Cell

**Nodal Officer** **Dr. Rakesh Kumar, Scientist G & Head**

**Training Coordinator** **Dr. A.K. Lohani, Scientist F**

**Procurement Officer** **Dr. Sanjay Kumar, Scientist D**

# DSS (P) Core Group Members

| S.No. | Name of Scientist & Designation | State Represented |
|---|---|---|
| 1. | Dr. M.K. Goel, Scientist F | Kerala |
| 2. | Mr. D.S. Rathore, Scientist F | Maharashtra |
| 3. | Dr. A.K. Lohani, Scientist F | Tamilnadu |
| 4. | Dr. R.P. Pandey, Scientist F | Orissa |
| 5. | Dr. Sanjay Kumar, Scientist D | Maharashtra |
| 6. | Dr. Anupama Sharma, Scientist D | Gujarat |
| 7. | Dr. Surjeet Singh, Scientist D | Chhattisgarh |
| 8. | Dr. B. Venkatesh, Scientist F | Karnataka |
| 9. | Mr. Ravi Galkate, Scientist D | Madhya Pradesh |
| 10. | Dr. P.C. Nayak, Scientist C | Andhra Pradesh |

## Study Group for Purpose Driven Studies

**Coordinator** **Mr. C.P. Kumar, Scientist F**

**Procurement Officer** **Dr. Surjeet Singh, Scientist D**

## Principal Investigators of Purpose Driven Studies

| S.No. | Study Name | Principal Investigator |
|---|---|---|
| 1. | Integrated approach for snowmelt runoff studies and effect of anthropogenic activities in Beas basin (Lead agency: NIH) | Dr. Sanjay Kr. Jain, Scientist F |
| 2. | Impact of sewage effluent on drinking water sources of Shimla city and suggesting ameliorative measures (Lead agency: NIH) | Dr. V.K. Choubey Scientist F |
| 3. | Hydrological assessment of ungauged catchments (small catchment) – Mahanadi Sub basin (Lead agency: NIH) | Dr.P.K. Bhunya Scientist D |
| 4. | Urban hydrology for Chennai city – Storm water management in Cooum sub basin, Chennai Corporation, Chennai, Tamilnadu (Lead agency: NIH) | Dr. Y.R.S. Rao Scientist F |
| 5. | Groundwater management in over-exploited blocks of Chitradurga and Tumkur districts of Karnataka (Lead agency: NIH) | Dr. Sudhir Kumar Scientist G |
| 6. | Groundwater dynamics of Bist doab area, Punjab using isotopes (Lead agency: NIH) | Dr. M.S. Rao Scientist D |
| 7. | Coastal groundwater dynamics and management in the Saurashtra region, Gujarat (Lead agency: NIH) | Dr. Anupama Sharma Scientist D |
| 8. | A comprehensive assessment of water quality status of Kerala state (Lead agency: Kerala) | Dr. B.K. Purendra Scientist D |
| 9. | Assessment of effects of sedmentation on the capacity/life of Bhakra reservoir (Gobind Sagar) on river Satluj and Pong reservoir on river Beas (Lead agency: BBMB) | Dr. Sanjay Kr. Jain, Scientist F |
| 10. | Water availability study and supply-demand analysis in Seonath Sub-basin(Lead agency: Chhattisgarh) | Mr. Ravi Galkate Scientist D |
| 11. | Study of reservoir sedimentation, impact assessment and development of catchment area treatment plan for Kodar reservoir in Chhattisgarh state (Lead agency: Chhattisgarh) | Mr. R.K. Jaiswal Scientist C |

# Executive Summary

1. **Name of the agency** National Institute of Hydrology, Roorkee
2. **Web-site address** www.nih.ernet.in
3. **Financial targets and achievements**

| Allocation under project as per PIP (Rs. in Crores) | Revised allocation as per 2013 cost table (Rs. in Crores) | Total Expenditure from 2006-07 to 2014-15 (Rs. in Crores) |
|---|---|---|
| 48.45 | 48.1468 | 46,82,16,979 |

4. **Component wise physical progress**

**Component A: Institutional Strengthening**

- Organized 100 training programs and trained 2829 engineers/ officers on SWDES, specialized topics of hydrology (as per the needs of the IAs) and DSS(P) under awareness, dissemination and knowledge sharing.
- 11 scientists of NIH received foreign trainings on DSS(P) at DHI, Denmak; 5 on PDS at IHE, Netherlands and 1 in UK and 1 scientist visited South Africa and Denmark on study tour.
- Procured office and training equipments and vehicles under implementation support to strengthen various facilities in the institute.


**Component B: Vertical Extension**

I. **DECISION SUPPORT SYSTEM (PLANNING):** A Decision Support System (Planning) for integrated water resources development and management is developed and customized to the needs to the nine states for the pilot basins. DSS(P) applications are developed and demonstrated to solve various water resources problems identified by the states in their need assessment reports.

II. **PURPOSE DRIVEN STUDIES:** The institute has carried out eleven PDS viz. four on surface water and three on ground water as lead agency and four PDS with the states and central agencies. The major findings of these PDS are given below.

i. ***Integrated approach for snowmelt runoff studies and effect of anthropogenic activities in Beas basin (Lead agency: NIH):*** Snow melt, glacier melt and rainfall contributions are simulated using SNOWMOD model, developed at NIH and the isotopic techniques along with the future assessment of impact of climate change on stream flows.

ii. ***Impact of sewage effluent on drinking water sources of Shimla city and suggesting ameliorative measures (Lead agency: NIH):*** Water-borne diseases are caused by contamination of water with pollutants as water gets contaminated either at source or while passing through water pipes, which are poorly laid and maintained.

iii. ***Hydrological assessment of ungauged catchments (small catchment) – Mahanadi Sub basin (Lead agency: NIH):*** Methodologies are developed for estimation of water avilability, floods of various return periods and unit hydrographs for ungauged catchments and uncertainty bands are estimated.

iv. ***Urban hydrology for Chennai city – Storm water management in Cooum sub basin, Chennai Corporation, Chennai, Tamilnadu (Lead agency: NIH):*** The existing storm water drainage network with new modifications in Otteri Nullah sub basin of Chennai city is adequate for two years return period design storm runoff.

v. ***Groundwater management in over-exploited blocks of Chitradurga and Tumkur districts of Karnataka (Lead agency: NIH):*** The recharge to the hard rock aquifer for blocks of Chitradurga and Tumkur districts of Karnataka is limited to the valley portions only and the decline and recovery of groundwater decline is more dependent on rainfall rather than over exploitation. The irrigation tanks constructed for water harvesting are not recharging the groundwater.

vi. ***Groundwater dynamics of Bist doab area, Punjab using isotopes (Lead agency: NIH):*** Using isotopes, groundwater recharge conditions have been mapped and it is observed that over 60% of the groundwater recharge is taking place in Shiwalik-Kandi region and this recharge is taking a few decades for reaching to central Bist Doab region.

vii. ***Coastal groundwater dynamics and management in the Saurashtra region, Gujarat (Lead agency: NIH):*** Geochemical surveys and isotope based investigations are carried out to identify causes of groundwater salinity and establish the physico-chemical mechanism of mixing of freshwater-saltwater in the limestone coastal aquifer and a finite-difference based numerical model is developed to simulate the coastal groundwater dynamics.

viii. ***A comprehensive assessment of water quality status of Kerala state (Lead agency: Kerala):*** Water quality analysis of 15 river basins and groundwater quality investigations from 14 districts of Kerala showed that surface and ground water are having bacteriological contamination and iron concentration is very high in groundwater for most of the districts.

ix. ***Assessment of effects of sedmentation on the capacity/life of Bhakra reservoir (Gobind Sagar) on river Satluj and Pong reservoir on river Beas (Lead agency: BBMB):*** Sedimentation rates of Bhakra and Pong reservoirs are computed using remote sensing and sediment yields for the two basins are estimated using ArcSWAT model and found in good agreement with the observed sediment yields.

x. ***Water availability study and supply-demand analysis in Seonath Sub-basin(Lead agency: Chhattisgarh):*** MIKE 11 NAM model was applied for rainfall-runoff modelling and results were used in MIKE BASIN for water availability assessment, demand supply analysis to meet future water demands and generation of various scenarios for planning and management of water resources in Kharun river basin in Chhattisgarh state.

xi. ***Study of reservoir sedimentation, impact assessment and development of catchment area treatment plan for Kodar reservoir in Chhattisgarh state (Lead agency: Chhattisgarh):*** Rates of siltation and soil loss are estimated using remote sensing and GIS for Kodar reservoir and the developed catchment area treatment plan is being considered by district authority for taking up under MNREGA scheme.

**Component C: Horizontal Expansion**

- Organized SWDES trainings in the states of Himachal Pradesh and Goa.
- Organised PDS specific trainings in Himachal Pradesh, Punjab and Goa.

## 5. Major Physical Achievements

- Development and customization of DSS (P) software for the case study basins of the nine states as per their need assessment for the identified basins.

- Eleven PDS are carriedout to address hydrological problems of the study areas in the states.
- Domestic and foreign trainings for scientists of the institute involved in development of DSS(P) and foreign trainings of some of the scientists involved in carrying out PDS.
- Procurement of office and training equipments and vehicles for institutional strengthening.

**6. Post project plan for continuation of HP-II activities**

- AMC of the DSS(P) software for technical support and maintenance.
- Trainings for states and central agencies on DSS(P) for sustainability of DSS(P).
- Applications of DSS(P) in selected additional basins of the states.

**7. Lessons learnt**

- Technology advancement, adoption of the best practices and training and capacity building are essential for integrated water resources development and management.
- DSS (P) provides a very useful and efficient tool for generating and analysing various scenarios for taking apt decisions.
- Involvement of planning and design wings of the State Water Resources Departments along with the data centres may lead to larger applicability of the DSS (P) for IWRDM in future.
- Engineers/ Officers involved in development and implementation of DSS(P) should be retained as their continuity is essential for sustainability of the DSS(P) sofware.
- Data collection, processing, storage, retrieval and dissemination using the state-of-art knowledge in Information Technology should be encouraged.

**8. Dissemination of data and application of HIS/ Online and web application of DSS(P)**

- DSS(P) software is made online in 11agencies for 9 states by deploying the software on server.
- Online application for prediction of post monsoon drinking water scarcity situations was implemented for Maharashtra state.
- Online application for depicting current and historic reservoir water levels was developed for Maharashtra
- Dash Board functionality in the DSS (P) software may be used for dissemination of hydrological data and analysis results.

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# 1 INTRODUCTION

National Institute of Hydrology, Roorkee was entrusted important tasks under the World Bank funded Hydrology Project Phase-II (HP-II). Eight Central Agencies (MOWR, NIH, CWC, CGWB, CWPRS, CPCB, IMD and BBMB) and thirteen States (Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Kerala, Madhya Pradesh, Chhattisgarh, Odisha, Tamil Nadu, Himachal Pradesh, Goa, Pondicherry and Punjab) participated in the Project. The project commenced in June 2006 for a period of six years and subsequently extended for two years and completed in May 2014. Hydrology Project phase-II had activities under three major components viz. (i) Institutional Strengthening (ii) Vertical Extension and (iii) Horizontal Expansion.

Under HP-II, the National Institute of Hydrology, Roorkee was the nodal agency for development and implementation of Decision Support System (Planning) for Integrated Water Resources Development and Management implemented in six central agencies and nine States. NIH and the DSS (P) consultants (DHI Denmark) have completed development and implementation of the DSS (P) software in the participating IAs. The five components of DSS (P) are: (i) Surface water planning; (ii) Integrated operation of reservoirs; (iii) Conjunctive surface water and ground water planning; (iv) Drought monitoring, assessment and management; and (v) Management of both surface and ground water quality. During various stages of development and implementation of the DSS (P) the following tasks have been completed: (i) Preparation of Inception Report, (ii) DSS (P) Needs Assessment, (iii) DSS (P) Model Conceptualization, (iv) Database Development (v) Generic DSS(P) Development (vi) DSS (P) Customization (vii) DSS (P) Testing/ Refinement, (viii) DSS (P) Application and Demonstration and (ix) Preparation of final report.

The inception report provides a comprehensive road map for the development of the DSS (P) software during the project period. The DSS (P) needs of the States in their identified basins were assessed and the same have been compiled in one main need assessment repot and nine State specific NARs of the respective States. Based on the DSS (P) need assessment of the States the task of DSS (P) model conceptualization has been completed and accordingly the databases for the respective identified basins of each state have been created to develop the Generic DSS (P) for the pilot basin (Bhima Basin) of Maharashtra. The details of these databases and Generic DSS (P) software have been complied in the Database Development Report and Generic DSS (P) report. The Generic DSS (P) has been customized for the case study basins of all the state implementing agencies. The details of the customization task in the nine states have been complied in their customization reports. The outcomes of these reports were deliberated with the Implementing Agencies (IAs) in workshops organized by NIH and the Consultants as well as reviewed by the Review Committee constituted by the MoWR during fourteen meetings of the Review Committee at NIH, CWC, New Delhi and in the states. Based on the observations and comments of various IAs during the workshops and

Review Committee meetings customization of the DSS (P) software, its testing/ refinement, application and demonstration were further refined and final report was prepared. The consultants have conducted various training programs in the States as well as at NIH and NWA, Pune and in Denmark covering various aspects of development and implementation of DSS (P) as well as the Training of Trainers (ToT) at NIH. The Institute has also conducted various DSS (P) workshops and training programs on the DSS (P) software, specialized topics of hydrology, data processing software and demand driven trainings for the State and Central implementing agencies for knowledge dissemination and capacity building of the IAs.

The institute is working on a comprehensive plan to sustain the DSS (P) software by taking up studies on DSS (P) applications and proposes engaging of consultants for upgrading and maintenance of the software beyond project period. For this purpose, constitution of a Committee for AMC for DSS (P) was approved by the MoWR and two meetings of the committee were convened for finalization of the AMC. The AMC document has been finalised by the committee and submitted to MoWR for its consideration.

The Purpose Driven Studies (PDS) is another sub-component under the vertical component; wherein, the Institute actively participated with the States and Central Agencies in carrying out eleven PDS. These include four Surface Water and three Ground Water PDS, carried out by NIH. Apart from these, the Institute was associated in carrying out four other PDS with the States and Central Agencies. The PIs of the PDS have conducted field visits to the study areas and collected relevant data and information from the concerned states agencies. All the PDS have been completed and the reports of the studies are submitted to PCS, MoWR.

The Institute has conducted various DSS (P) workshops and training programs on the specialized topics of hydrology, data processing, software and demand driven trainings for the State and Central implementing agencies at Roorkee and in various states. Various equipments and hardware were procured to further strengthen the DSS (P) training activities under the project.

# 2 INSTITUTIONAL STRENGTHENING/ REFORMS

This component comprises of three sub-components, namely:

- Consolidation of HP-I activities in the existing states,
- Institutional support for awareness raising and knowledge dissemination, and
- Implementation support.

Under consolidation of HP-I activities, the project supported the existing Implementing Agencies (IAs) with continued/extended training in HIS data processing (SWDES). Training programs on the specialized topics were conducted for dissemination and knowledge sharing among the participating States and Central agencies. The details of these trainings workshops conducted are provided in section 5 under Capacity Building and Trainings. Various facilities (Training and Office equipments) were also developed under implementation support.

# 3 DEVELOPMENT OF DECISION SUPPORT SYSTEM (PLANNING) (DSS (P)) FOR INTEGRATED WATER RESOURCES DEVELOPMENT AND MANAGEMENT

The Institute was the nodal agency for the development of Decision Support System (Planning) for Integrated Water Resources Development and Management to be implemented in six Central agencies and nine States. To develop the DSS (P), Consultants were engaged through International Competitive Bidding (ICB) under World Bank Procurement guidelines. The contract for the DSS (P) consultancy was signed on 15$^{th}$ November, 2008 between NIH (Client) and DHI, Denmark (Consultants) at Roorkee. The DSS (P) Consultants have completed DSS(P) activities as per the scheduled tasks in the contract document and submitted the (i) Inception Report, (ii) DSS (P) Needs Assessment Report (NAR), (iii) DSS (P) Model Conceptualization Report, (iv) Database Development Report (v) Generic DSS(P) Development Report (vi) Customization Report of the Generic DSS(P) for the states of Maharashtra, Gujarat, Chhattisgarh (vii) Customization Report of Generic DSS(P) for the states of Karnataka, Madhya Pradesh, Orissa and (viii) Customization Report of Generic DSS(P) for the states of Kerala, Andhra Pradesh, Tamil Nadu (ix) DSS testing/refinement report, (x) DSS application and demonstration report and (xi) final DSS(P) report to NIH. The inception report provides a comprehensive road map for the development of the DSS (P) consultancy during the project period. The DSS (P) needs of the States in their identified basins were assessed by the Consultants during their visits to various States and the same have been compiled in one main NAR and nine State specific NARs of the respective States. Based on the DSS (P) need assessment of the States the task of DSS (P) model conceptualization has been completed and accordingly the databases for the respective identified basins of each state have been created to develop the Generic DSS(P) for the pilot basin (Upper Bhima Basin) of Maharashtra. The details of these databases and Generic DSS(P) software have been complied in the Database Development Report and Generic DSS(P) report. The Generic DSS(P) has been customized for the case study basins of all the state implementing agencies. The details of the customization task in the nine states have been complied in the customization reports. The outcomes of these reports were deliberated with the Implementing Agencies (IAs) in workshops organized by NIH and Consultants. The observations and comments of various IAs during the workshops were recorded and incorporated in the final reports further refinement and final demonstration of DSS(P) applications. A review committee (having representation from MOWR, NIH, CWC and CGWB) reviewed these final reports as per the scheduled deliverables/milestones in the contract. A DSS(P) Core Group comprising of ten Scientists was constituted and was associated with the DSS(P) consultants for proper implementation of DSS(P) software in the DSS(P) implementing agencies.

The development of decision support systems DSS (P), comprised of information systems linked to appropriate models, that provided support to promote the use of the data generated under HIS. The DSS(P) consists of five modules (i) Surface water planning; (ii) Integrated operation of reservoirs; (iii) Conjunctive surface water and ground water planning; (iv) Drought monitoring, assessment and management; and (v) Management of both surface and ground water quality.  DSS (P) for Integrated Water Resources Development and Management intended to support water resources decisions in all nine HP-I states. The details of the DSS(P) applications for each of the states for their pilot basins are discussed as follows.

# 3.1 DSS (P) APPLICATIONS - ANDHRA PRADESH STATE

The case study area selected by Andhra Pradesh is the G5 basin along the Godavari River. The Surface Water group has included areas outside this basin also, however, to include the full existing and planned command areas of the Sri Ram Sager Project (SRSP).

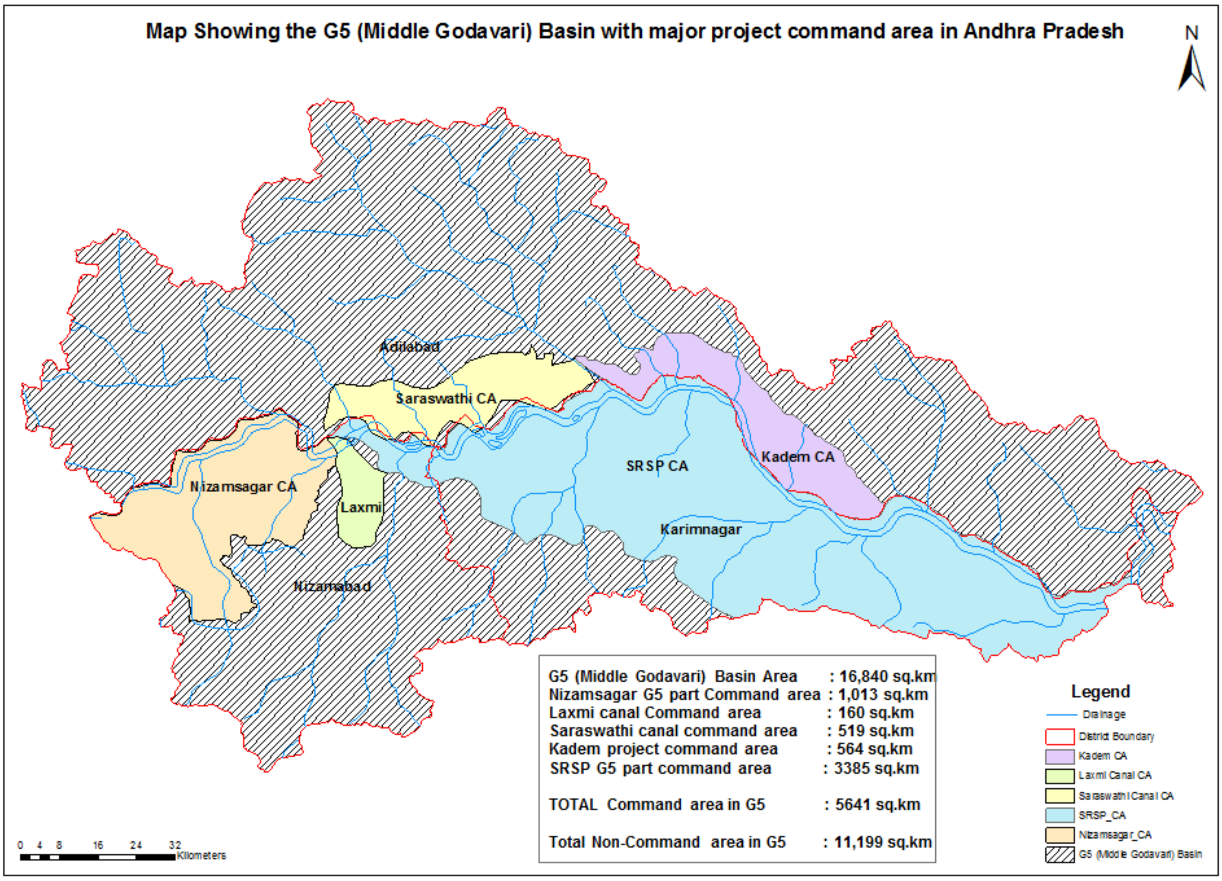



Figure 3.1: The Middle Godavari basin G5 and command areas

## 3.1.1 Scope of DSS Applications

The DSS applications for SRSP were planned at an early stage to target efficient water use within the command area, combined reservoir management and water transfer. A flood flow canal was created recently to transfer and store water in the SRSP area rather than letting it spill into the downstream Godavari. Additional storage is being constructed on the Manair River within the area along with extension of the command area with Stage II. In some areas within the SRSP command, excess water is being abstracted at the heed-end of ir-rigation canals, causing high ground water levels and leaving insufficient water for tail-enders, who are now often over-exploiting the local groundwater. DSS analysis of such areas may help identifying suitable solutions. The impacts of potential changes in the cropping pattern are also of interest in this area.

The groundwater applications prioritised by the state concern prediction of groundwater levels and the possibilities of increasing groundwater availability through artificial recharge.

## 3.1.2 Model Development

### 3.1.2.1 Surface water

The Surface Water group has developed a river basin model of the SRSP to enable testing of potential changes in water demand, system structure, reservoir operation, etc. The main Sri Ram Sager Dam is constructed across the Godavari river near Pochampad in the Balkonda Mandal of Nizambad district, Andhra Pradesh, India. The reservoir has a gross storage of 3172 MCM. The right bank canal (Kakatiya canal) runs for 284 km in stage I to the balancing reservoir Lower Manair Dam near Karimangar. The Stage II extension of Kakatiya Canal (from Km 284 to Km 346) is currently being constructed. The Sarswathi or left bank canal connects SRS with Kadam Dam, while the Laxmi canal (3.5 Km) and the Flood Flow Canal (120 Km) are also right bank canals from SRS. The Mid Manair Dam is under construction for local irrigation and stabilization of SRSP ayacut under stage-I and stage-II below Lower Manair Dam.

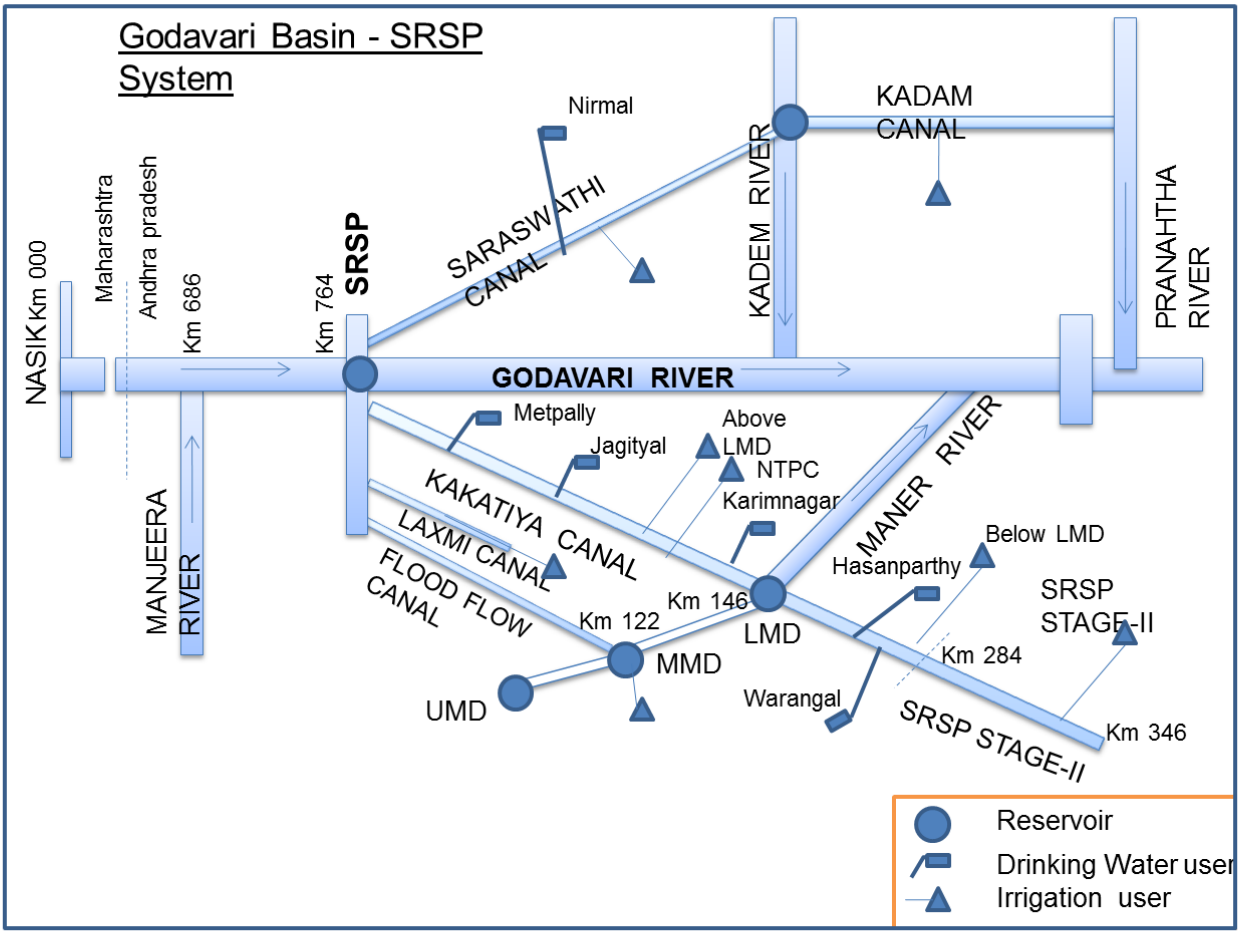



Figure 3.2: The Sri Ram Sager Project

A Flood Flow Canal was constructed a few years back to supplement water delivery in the right bank command. The canal transports 390 $m^3/s$ whenever SRS is about to spill and will feed the Middle Manair Dam (MMD) once this is completed upstream of LMD.

The total catchment area of Sri Ram Sagar Dam is 91,751 $km^2$. The availability of water was es-timated as 196 TMC out of which 145.35 TMC of water was proposed for Stage I. The sector wise utilization in the Stage I was planned as follows:

| | |
|---|---|
| Irrigation | 106.95 TMC |
| Domestic water supply | 5.50 TMC |
| Water supply to NTPC | 7.90 TMC |
| Evaporation losses | 25.0 TMC |
| Total | 145.35 TMC |

The cropping pattern adopted under SRSP was two thirds Irrigated dry and one third wet at the time of localization.

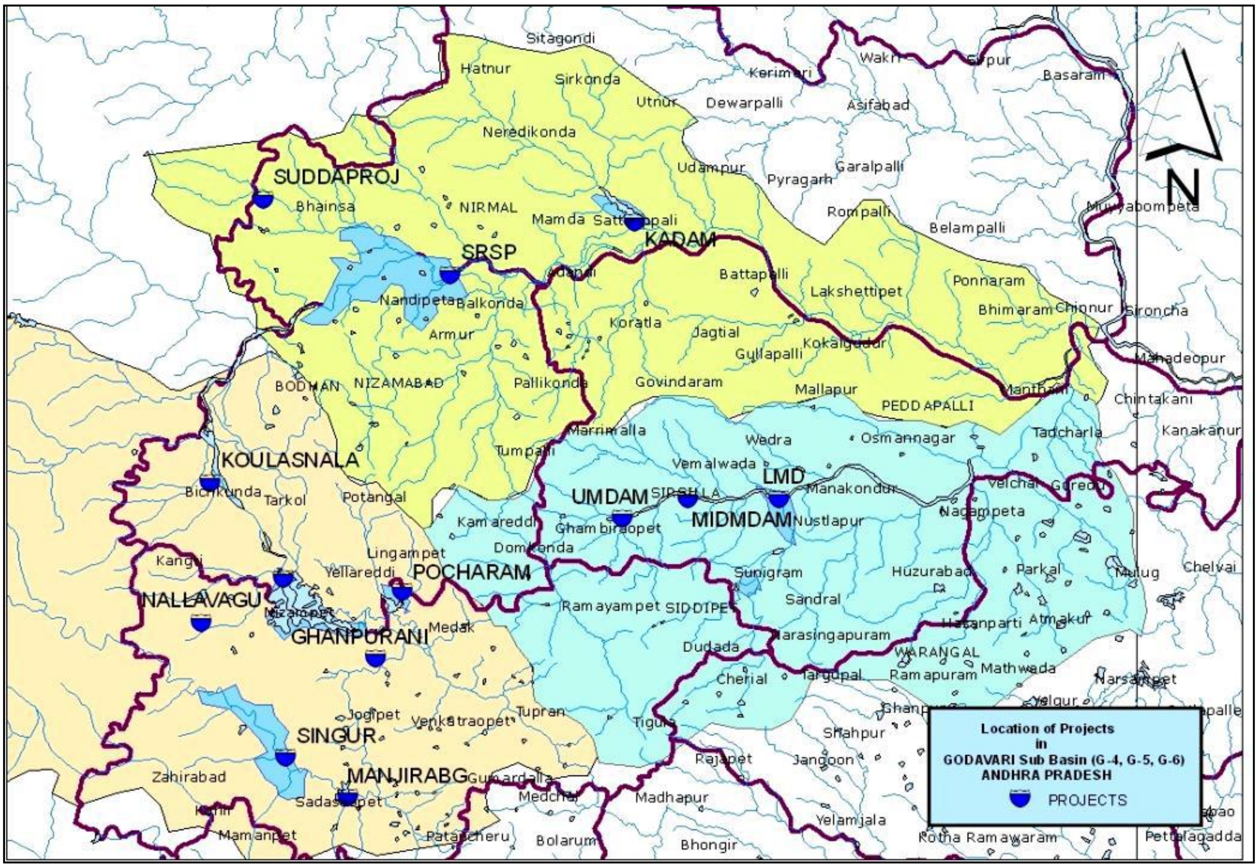


Figure 3.3: Map Showing Locations of Projects

### 3.1.3 Data

The Andhra Pradesh team has collected the required data of the SRS Project and within G5 in general in terms of meteorological and hydrological variables in the area. The data has been processed to enable construction of models, assessment of the availability of both surface and groundwater, and analysis of water management options.

Daily hydrological and meteorological data has been extracted from SWDES and processed along with the required time series of daily reservoir data, collected from the project authorities. This includes reservoir water levels, releases, spills, and estimated evaporation losses. The inflow to the reservoirs has been estimated on the basis of this information. The collected data also include salient features of the reservoirs such as area-elevation-volume tables and the characteristics of hydropower plants.

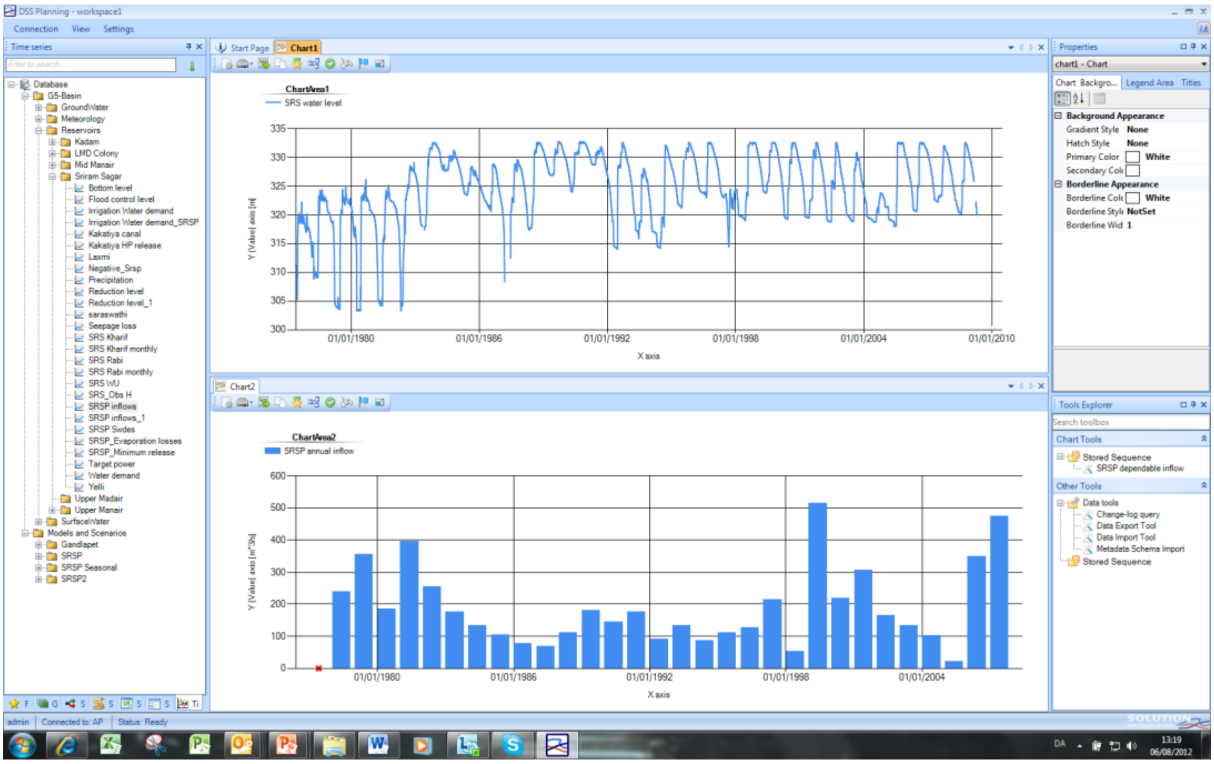



Figure 3.4: DSS screenshot with Sri Ram Sager water level and average annual inflow

### 3.1.4 The SRSP Model

A MIKE BASIN model has been set up for the Sri Ram Sager Project area to evaluate the impact of changes to the system, such as the recent construction of the Flood Flow canal, and to help in seasonal planning of water allocation. The model area is shown below.

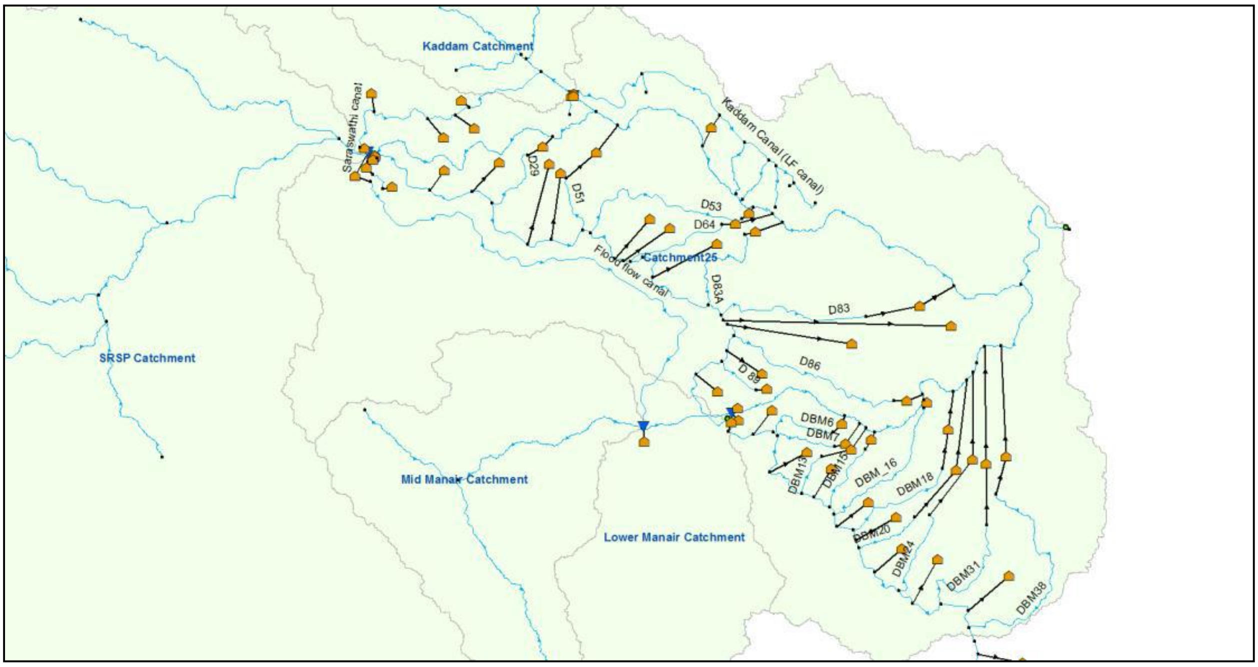



Figure 3.5: The SRSP model development

The Surface water model includes the whole Sri Ram Sager Project, which extends beyond G5 and includes the Manair and Kaddam catchments. Inflows to SRS, Kaddam and Lower Manair Dam have been derived from available data. Water is delivered from SRS through four canals, *i.e.* the Kakatiya canal, being the major canal which gets water through the hydropower releases, the Saraswathi canal which feeds Kaddam reservoir, the Laxmi canal, and the Flood Flow canal. Kaddam reservoir supplies water to the command area through two canals, Kaddam canal and Right flow canal. The model has been validated against observed data showing only minor deviations.

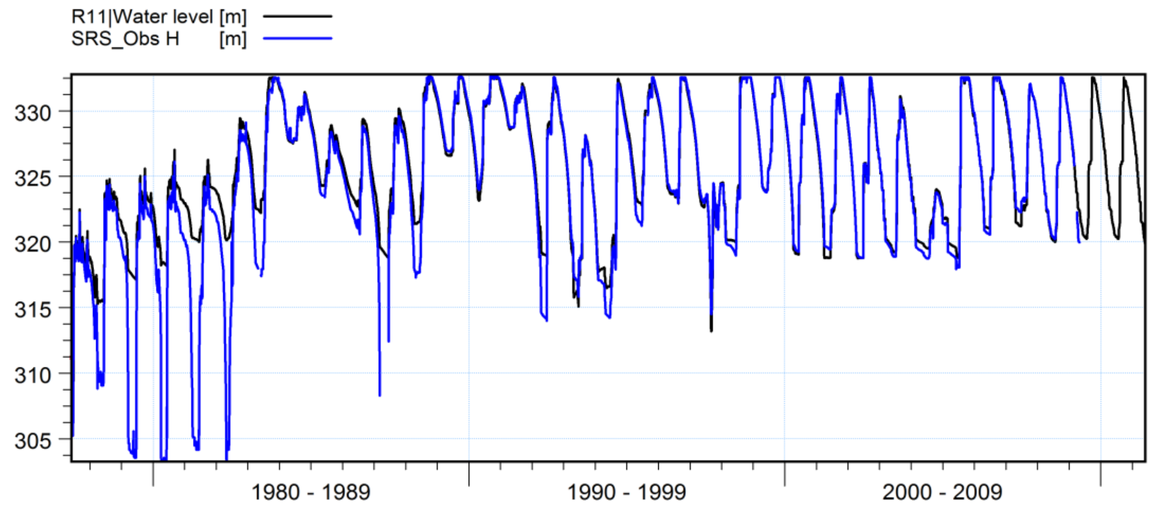



Figure 3.6: Comparison of simulated and observed water level in the Sri Ram Sager reservoir.

The Lower Manair Dam has a capacity of 24 TMC. Water balance sheets were available from Jan-2001 to April-2009, so that the inflow to the reservoir could be derived for this period. A rain-fall-runoff model was applied to extend the runoff series for the Manair catchment, in which the rainfall in these years ranges from 350 to 1400 mm with average rainfall of about 700 mm.

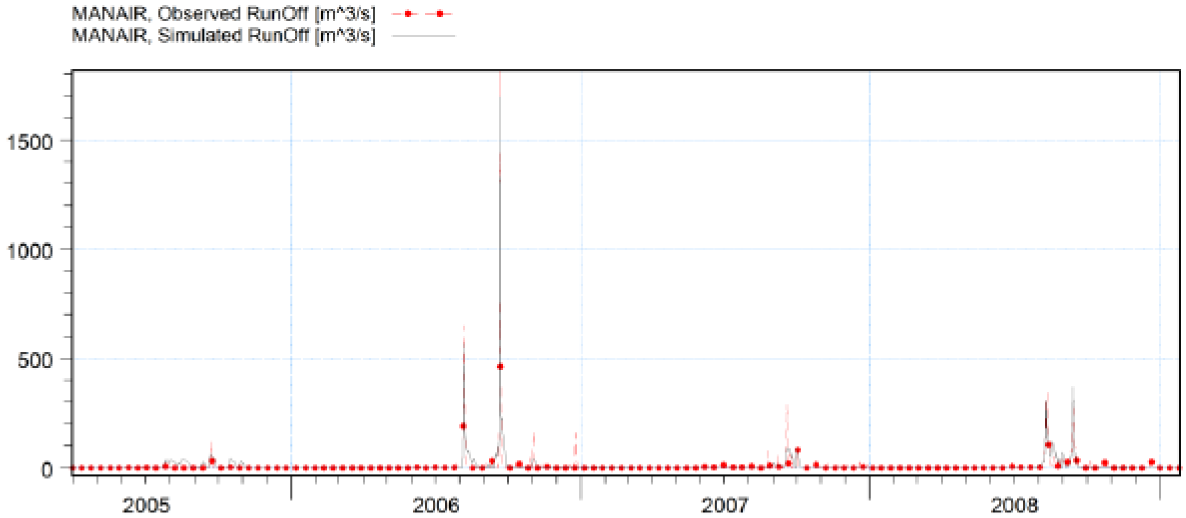



Figure 3.7: NAM calibration for Manair. $R^2$=0.855 and Water balance error = -0.6 %

The reservoir level variation of Lower Manair has been simulated as shown below for the full period of available rainfall data. The level matches the measurements well in most years.

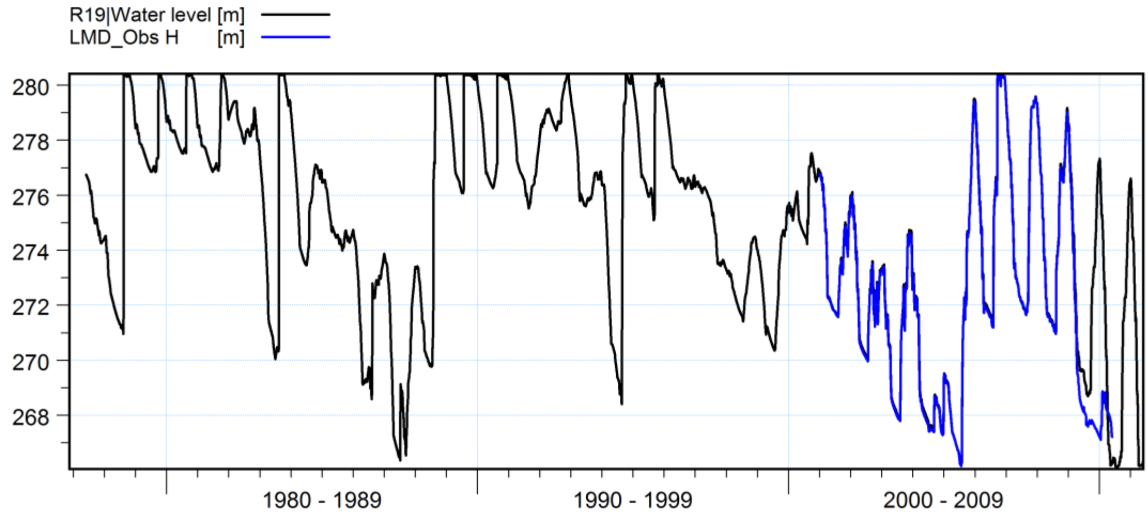



Figure 3.8: Validation of NAM generated inflow to Lower Maniar dam.

For the Kaddam dam, reservoir water level sheets were available from 1997 to 2009; Level data for the reservoir was available from 1970, but information on releases and spillway flow was in-sufficient to assess the inflow before 1997.

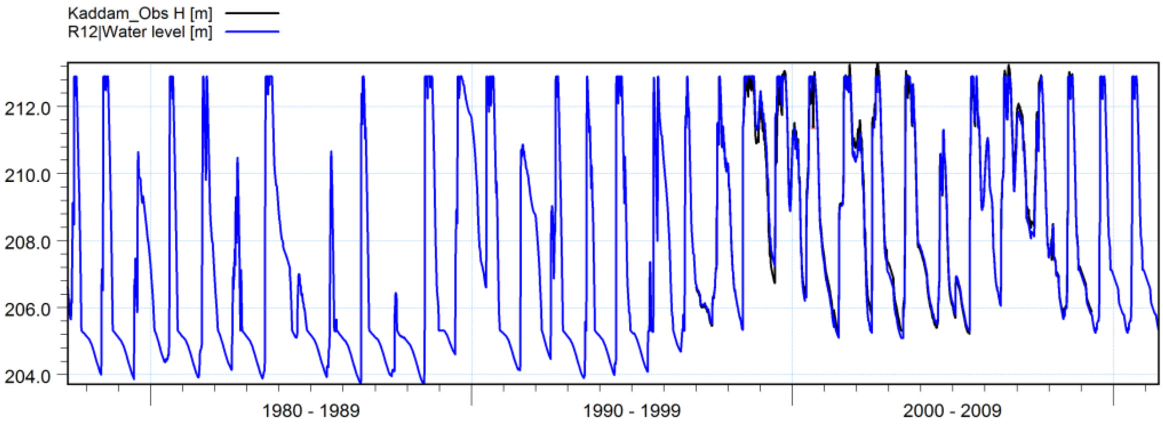



Figure 3.9: Kaddam WL-Observed vs. Simulated

The rainfall-runoff model was applied also to extend inflow to the Kaddam dam, see below.

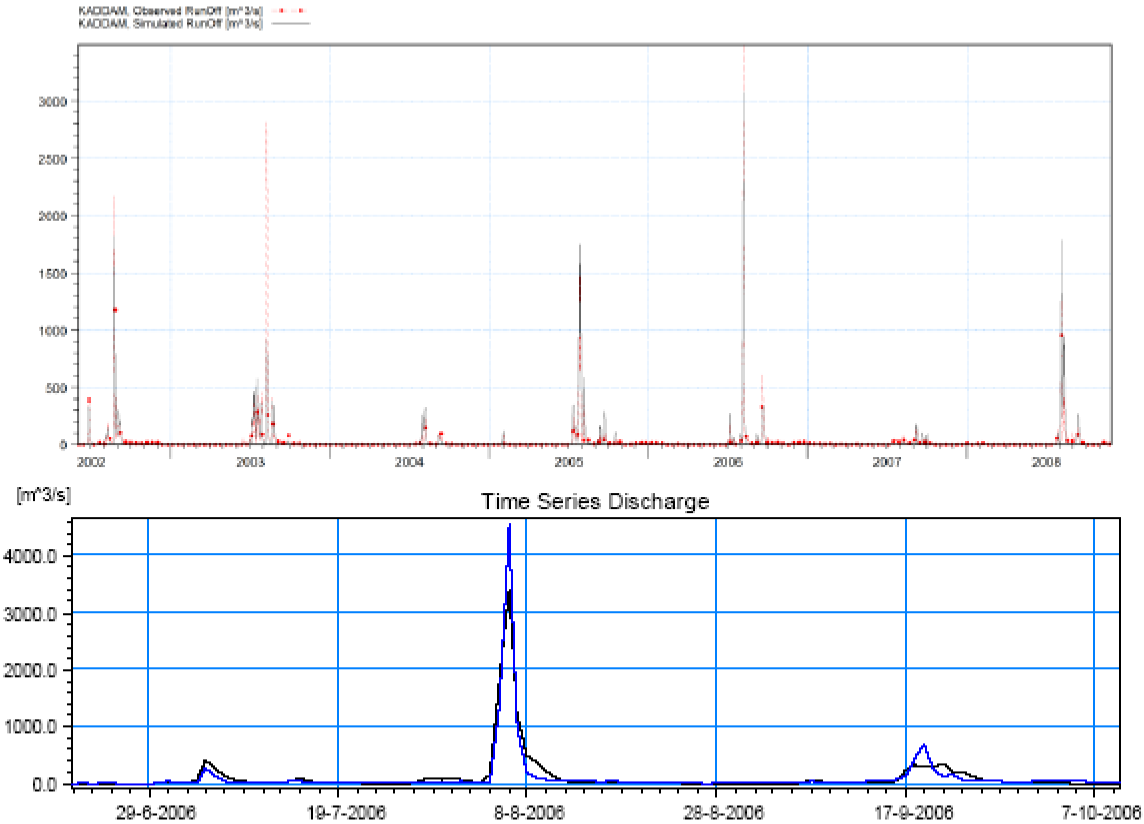



Figure 3.10: NAM calibration Kaddam catchment

The rainfall information was quite limited in this catchment. HP1-rainfall stations were available from 2002 to 2009, and the NAM model was calibrated using these (R2=0.75 and Water balance error=1.3%). A correlation was then established between the HP1 stations and rainfall at the nearby Adilabad station. An extended series of inflow was then generated for the period 1970- 1996 using this rainfall data. While the day-to-day accuracy of this extension may be low it rep-resents the best possible assessment of the variation of inflow to Kaddam over this period.

### 3.1.5 DSS Applications (SW)

The river basin model has been applied to analyse various scenarios, e.g. to assess the potential of supplying additional water below LMD.

#### 3.1.5.1 Increased demand below LMD

***Scenario 1:*** The situation before construction of the Flood Flow canal has been simulated for 31 years and statistics made on the results. It is seen that the average supply is significantly lower than the demand. The reliability of delivering full demand in a month is about 70% both below and above LMD.

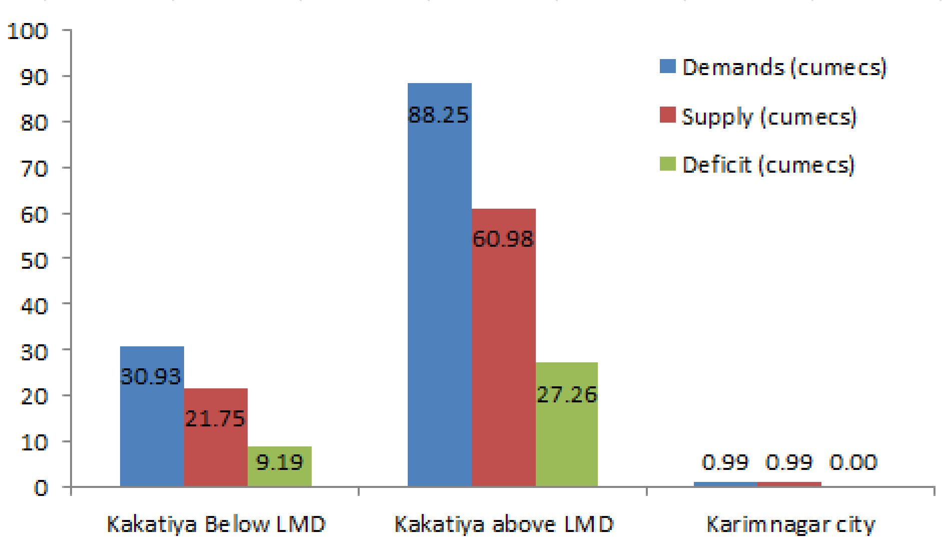



Figure 3.11: Statistics on results of scenario 1

***Scenario 2:*** This represents the future situation with the flood-flow canal, Mid Manair dam, and increased water demands below LMD, where Stage II is under construction. The system operation above LMD has been maintained, so that no additional deficit – or increased supply - is seen here. Additional water has been delivered below LMD, but not to the extent of the increased demands. The reliability below LMD is 65% in this case.

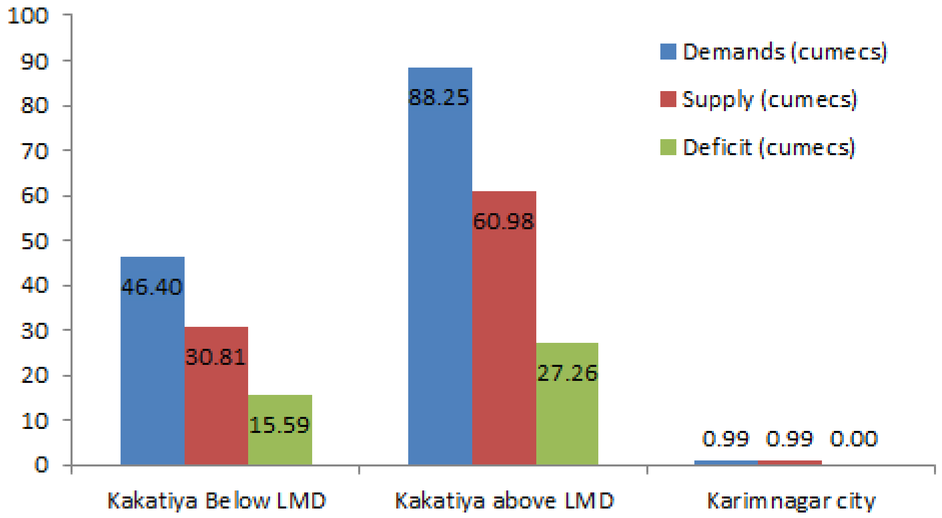



Figure 3.12: Statistics on model simulations of scenario 2

#### 3.1.5.2 Seasonal planning

The DSS has also been set up to provide seasonal predictions of the likely reservoir storage considering the planned water allocations and the current level and time of year. The predictions are made on the basis of the historical inflow, implicitly assuming that the statistical properties of the future inflow will correspond to the historical conditions. Below is shown the results of a seasonal planning simulation made on 4th July 2012. It is seen that while the reservoir may fill it will not do so if the 2012 monsoon inflow is low (75%) or very low (90%). The percentages may be changed in the DSS.

| **Next 12 months** | **90%** | **75%** | **10%** |
|---|---|---|---|
| Lowest expected Volume | 3.71 | 4.09 | 5.99 |
| Max expected Volume | 25.49 | 54.96 | 85.40 |

The corresponding results for the reservoir water level are shown below.

| **Next 12 months** | **90%** | **75%** | **10%** |
|---|---|---|---|
| Lowest expected level | 318.32 | 318.63 | 320.00 |
| Likely to fill | No | No | Yes |

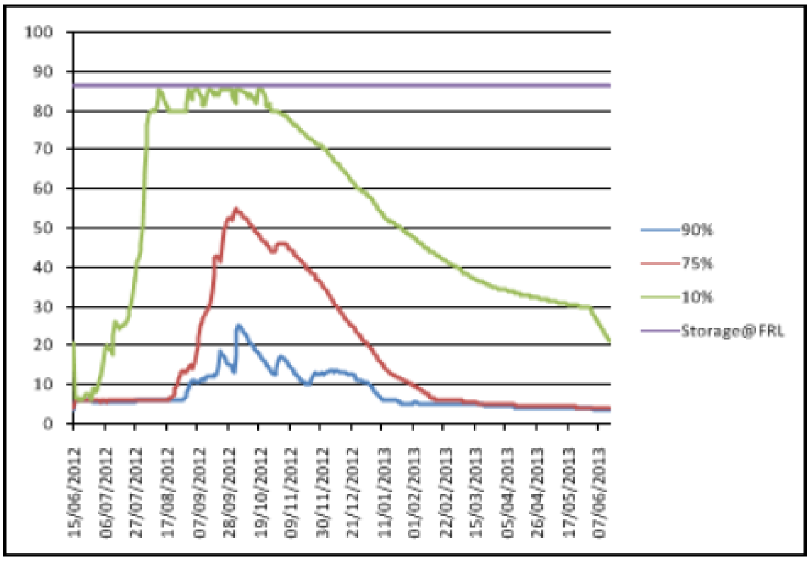



Figure 3.13: Likelihood of SRS storage exceedance

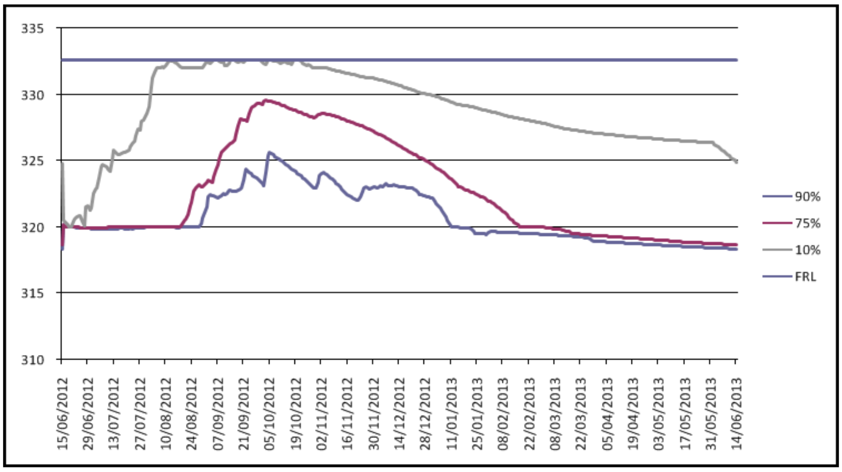



Figure 3.14: Likelihood of SRS water level exceedance

### 3.1.5.3 Irrigation demand

The DSS may be applied to assess the impact of changes to the cropping pattern within the command area. A facility has been developed to easily change irrigation demands as a function of the proposed combination of crops. The facility is available as a spreadsheet inside the DSS. Standard crops have been defined in the spreadsheet in terms of their total water requirements, fortnightly crop coefficients, and crop season, but users can easily add more crop types, if required.

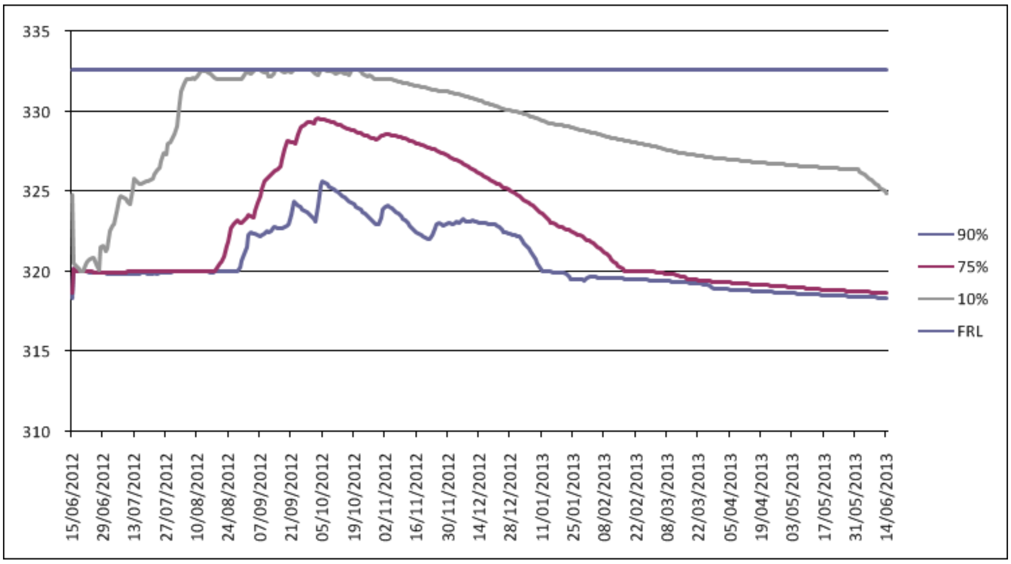
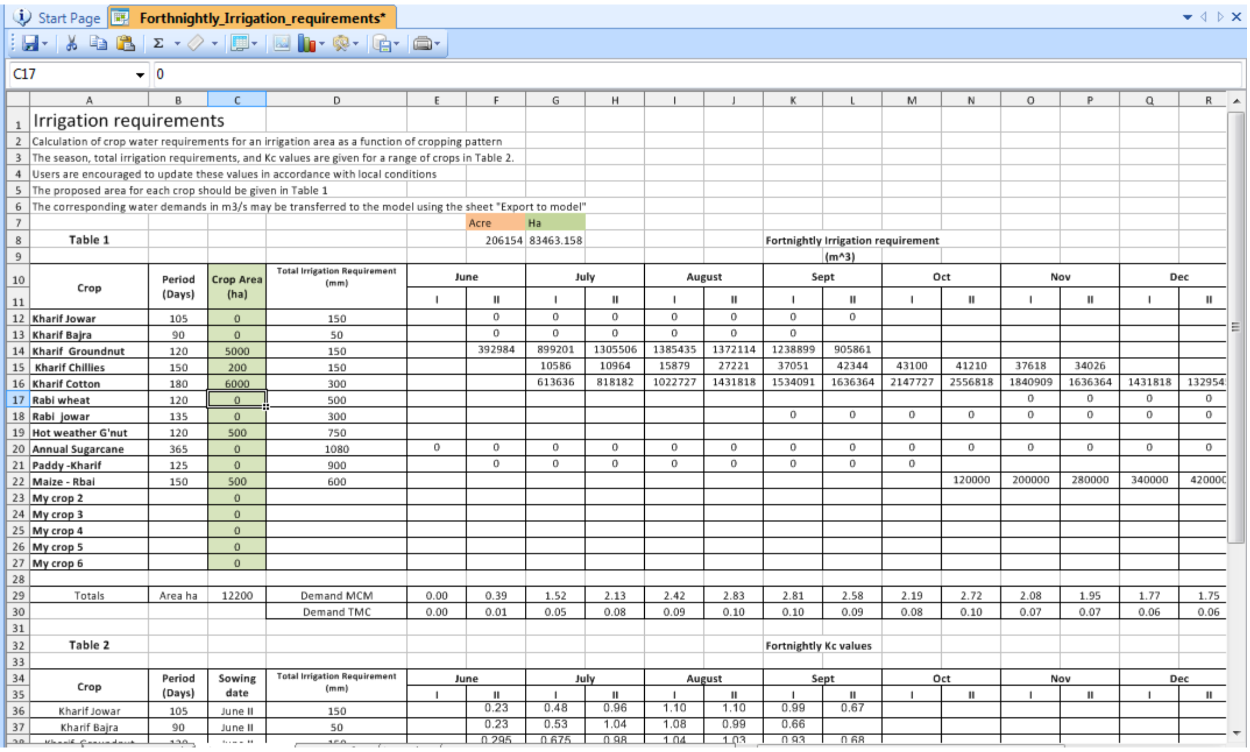



Figure 3.15: Likelihood of SRS water level exceedance




Irrigation requirements

Calculation of crop water requirements for an irrigation area as a function of cropping pattern
The season, total irrigation requirements, and Kc values are given for a range of crops in Table 2.
Users are encouraged to update these values in accordance with local conditions
The proposed area for each crop should be given in Table 1
The corresponding water demands in m3/s may be transferred to the model using the sheet "Export to model"

| Acre | Ha |
|---|---|
| 206154 | 83463.158 |

Table 1

Fortnightly Irrigation requirement (m^3)

| Crop | Period (Days) | Crop Area (ha) | Total Irrigation Requirement (mm) | June | | July | | August | | Sept | | Oct | | Nov | | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | I | II | I | II | I | II | I | II | I | II | I | II | I | II |
| Kharif Jowar | 105 | 0 | 150 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| Kharif Bajra | 90 | 0 | 50 | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| Kharif Groundnut | 120 | 5000 | 150 | | 392984 | 899201 | 1305506 | 1385435 | 1372114 | 1238899 | 905861 | | | | | | |
| Kharif Chillies | 150 | 200 | 150 | | | 10586 | 10964 | 15879 | 27221 | 37051 | 42344 | 43100 | 41210 | 37618 | 34026 | | |
| Kharif Cotton | 180 | 6000 | 300 | | | 613636 | 818182 | 1022727 | 1431818 | 1534091 | 1636364 | 2147727 | 2556818 | 1840909 | 1636364 | 1431818 | 132954 |
| Rabi wheat | 120 | 0 | 500 | | | | | | | | | | | 0 | 0 | 0 | 0 |
| Rabi jowar | 135 | 0 | 300 | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hot weather G'nut | 120 | 500 | 750 | | | | | | | | | | | | | | |
| Annual Sugarcane | 365 | 0 | 1080 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Paddy -Kharif | 125 | 0 | 900 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| Maize - Rbai | 150 | 500 | 600 | | | | | | | | | | 120000 | 200000 | 280000 | 340000 | 42000 |
| My crop 2 | | 0 | | | | | | | | | | | | | | | |
| My crop 3 | | 0 | | | | | | | | | | | | | | | |
| My crop 4 | | 0 | | | | | | | | | | | | | | | |
| My crop 5 | | 0 | | | | | | | | | | | | | | | |
| My crop 6 | | 0 | | | | | | | | | | | | | | | |
| Totals | Area ha | 12200 | Demand MCM | 0.00 | 0.39 | 1.52 | 2.13 | 2.42 | 2.83 | 2.81 | 2.58 | 2.19 | 2.72 | 2.08 | 1.95 | 1.77 | 1.75 |
| | | | Demand TMC | 0.00 | 0.01 | 0.05 | 0.08 | 0.09 | 0.10 | 0.10 | 0.09 | 0.08 | 0.10 | 0.07 | 0.07 | 0.06 | 0.06 |

Table 2

Fortnightly Kc values

| Crop | Period (Days) | Sowing date | Total Irrigation Requirement (mm) | June | | July | | August | | Sept | | Oct | | Nov | | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | I | II | I | II | I | II | I | II | I | II | I | II | I | II |
| Kharif Jowar | 105 | June II | 150 | | 0.23 | 0.48 | 0.96 | 1.10 | 1.10 | 0.99 | 0.67 | | | | | | |
| Kharif Bajra | 90 | June II | 50 | | 0.23 | 0.53 | 1.04 | 1.08 | 0.99 | 0.66 | | | | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | | 0.295 | 0.675 | 0.98 | 1.04 | 1.03 | 0.93 | 0.68 | | | | | | |

Figure 3.16: DSS spreadsheet to calculate water requirements for different cropping patterns

The resulting water requirements for the selected cropping pattern may be directly exported to the corresponding water user in the model as shown below.

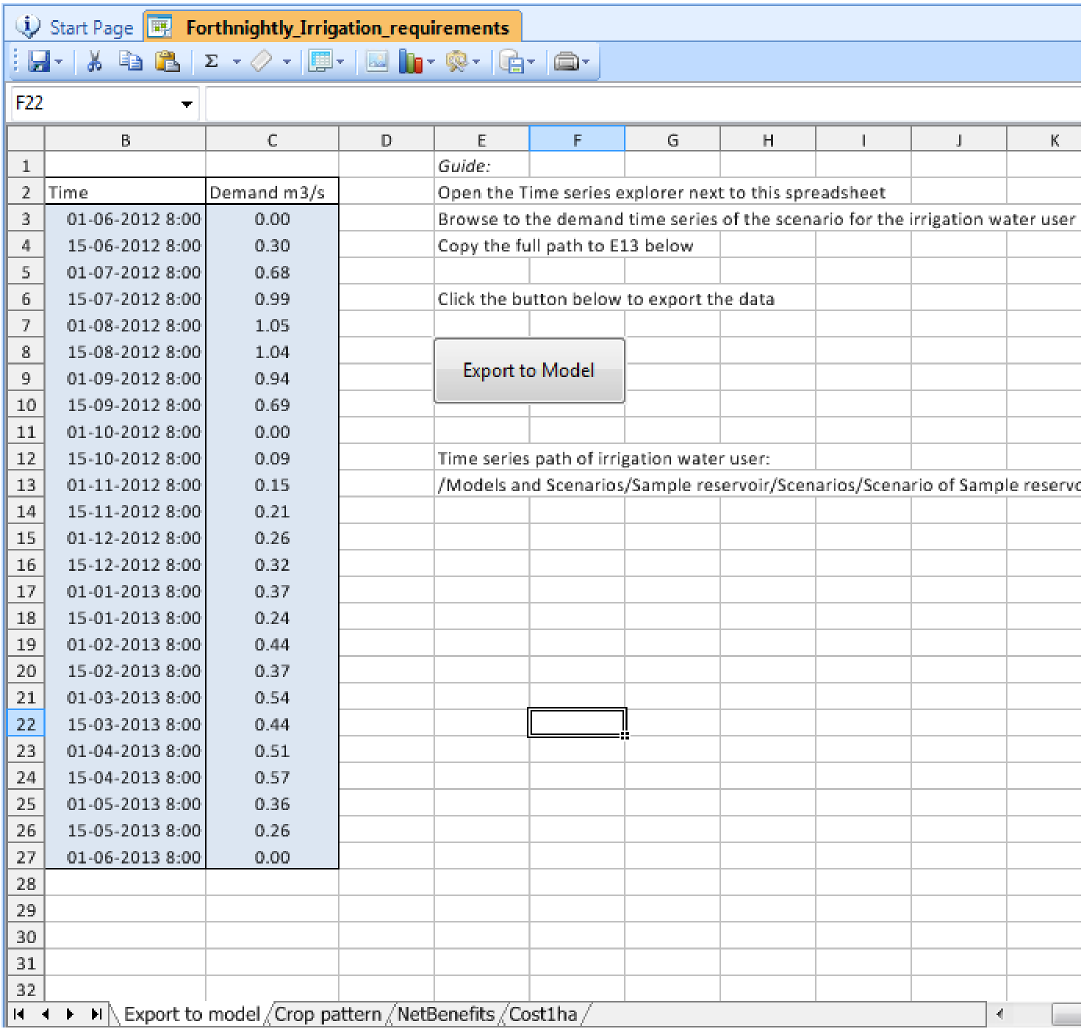



Figure 3.17: The irrigation requirements may be exported to the model

### 3.1.5.4 Ground Water in G5

The location of CGWB wells and state piezometers are further shown. The overexploited areas are mainly found within the Gandlapet catchment. This is also generally known as a drought prone area, and although the runoff from this catchment may exceed 1500 m3/s, these high discharges are of short duration, as illustrated by the graphs below. The hydrological model NAM has also been calibrated for three GEC watershed inside the SRSP area, viz. Madaram, Palakurthy and Kamanpur-Manthani based upon observed ground water level variations. Rainfall, evaporation and pumping/draft representing each watershed were given as input to the model.

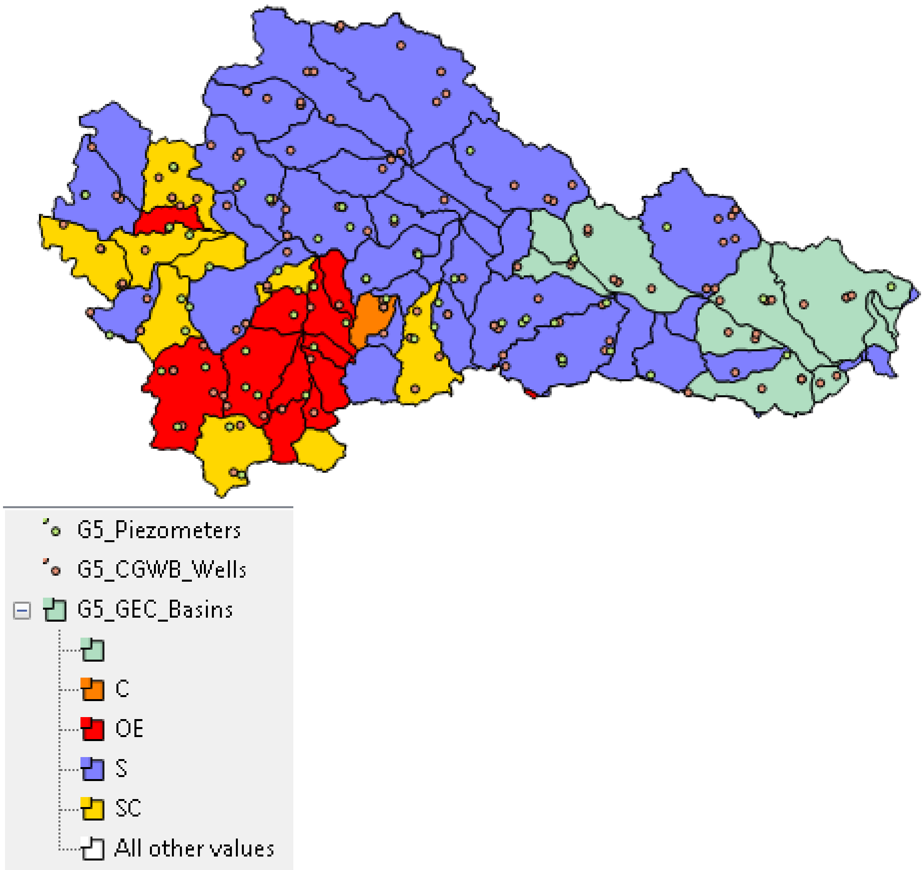



Figure 3.18: The G5 watersheds with indication of category (safe, semi-critical, critical, over-exploited).

### 3.1.5.5 Conjunctive surface and ground water use

Irrigation water requirements from reservoirs may be reduced if part of the water demands is met from groundwater and this can also help reducing the risk of water logging. Andhra Pradesh has already implemented this successfully in some command areas. The DSS (P) has been applied to model the impact of conjunctive use along a selected distributary within the Sri Ram Sager project in Andhra Pradesh, see below.

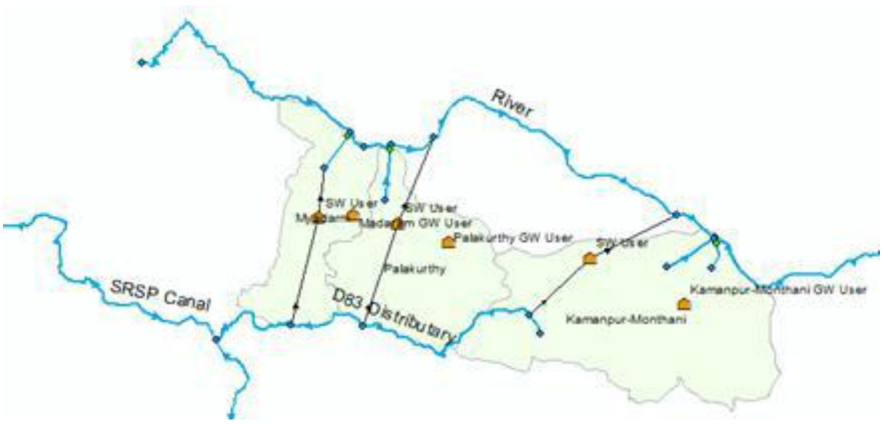



Figure 3.19: Plot showing model development for conjunctive use

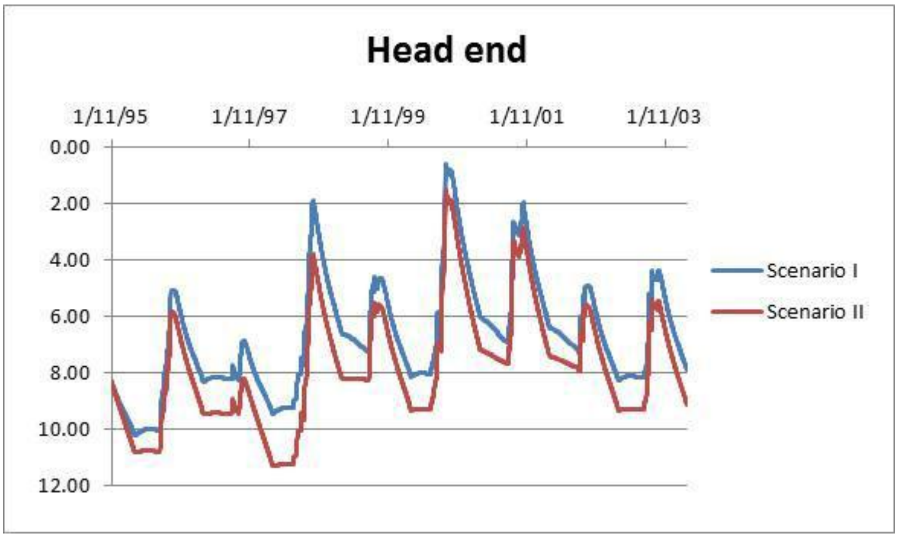
The command area is here divided in three separate areas representing the head, middle, and tail end reaches. Natural groundwater recharge has been generated for these areas using a hydrological model. The irrigation water users within each area are divided in groundwater users and surface water users, and the latter will automatically supplement with groundwater when-ever the available surface water is insufficient.

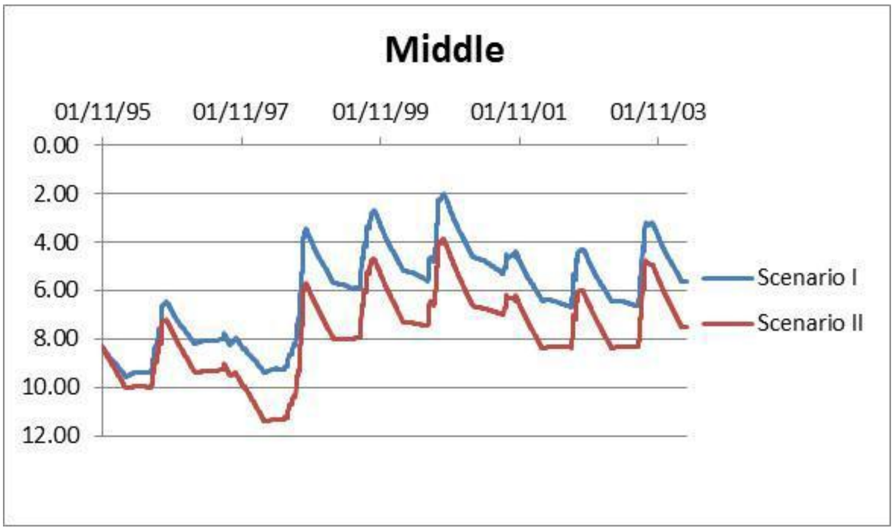
Two scenarios have been compared:

I. No restriction is imposed on the surface water use along the distributary. The head and middle end users have unlimited surfaced water available while the tail end users are required to supplement significantly with groundwater.

II. The head and middle section users are limited to take only a fraction of their water requirements from the canal, so that the balance is abstracted from groundwater.

The plots below show the impact on the depth to groundwater in each area over a period of eight years.



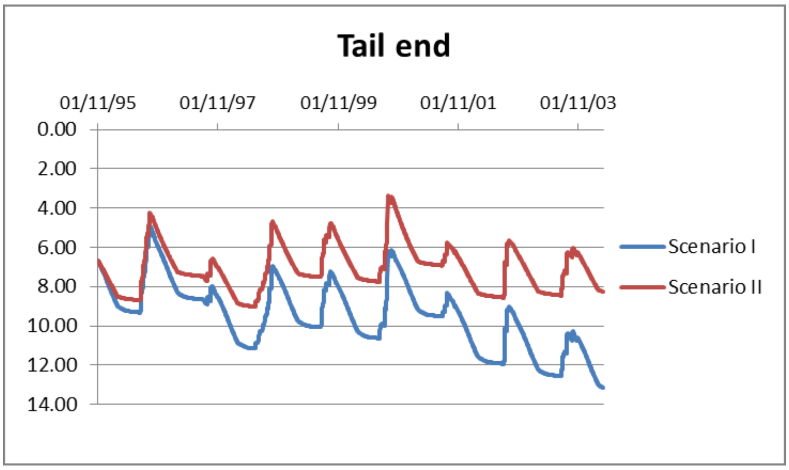



Figure 3.20: The simulated depth to groundwater (m) at head, middle, and tail end of D83

It is possible to increase groundwater use in the head and middle reaches without introducing a falling trend in the groundwater level here. The corresponding reduction in the abstraction from the canal to these areas allows for more water to continue down to the tail end, where the need for groundwater abstraction thereby is reduced, so that the falling trend in the groundwater level is eliminated.

### 3.1.6 DSS Applications (GW)

#### 3.1.6.1 Seasonal planning

The model has been set up to predict the groundwater depth over a dry season. This is tested for a range of years in the 1990s, with different initial values ranging from the dry 1991 to wet years in the 1994 and 1995. The predictions of groundwater levels are made in the models assuming a given abstraction by the local water users between October and June the following year. A fixed time series of expected abstraction has been applied in all years. The predictions are reasonably accurate and show how the level tends to fall considerably more after a wet monsoon than after a dry year.

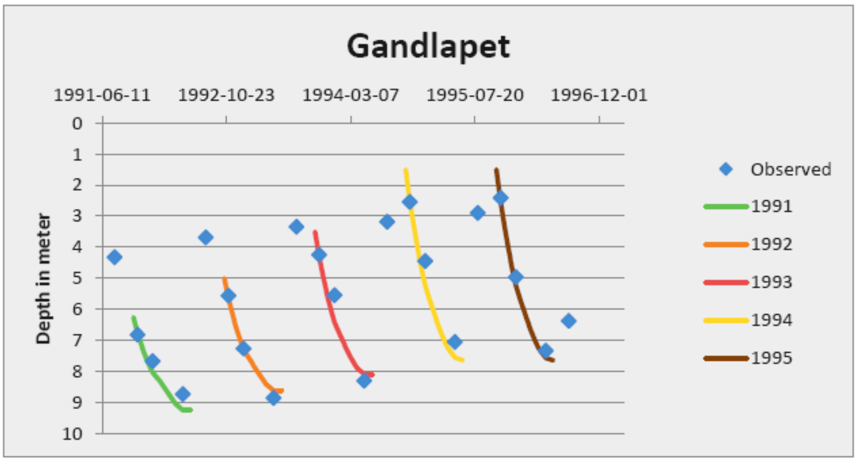



Figure 3.21: Test of groundwater predictions during the dry season for a range of hydrologically different years

This utility has also been set up for the Palakurthy watershed. The simulated level variation, starting at post monsoon level, is shown below for five years in comparison with observed level.

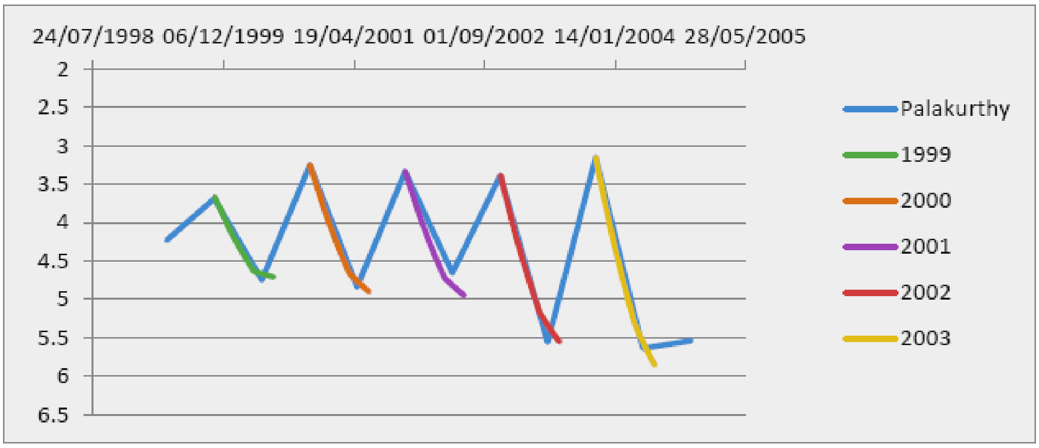



Figure 3.22: Palakurthy recession predictions

## 3.2 DSS APPLICATIONS – CHHATTISGARH STATE

The Decision Support System (Planning) was started in December, 2008 and Chhattisgarh State is one among the implementing agencies. In order to move ahead, DHI consultants have made different DSS tasks as below.

### 3.2.1 Needs Assessment:

The overall purpose of the Needs Assessment Visit was to assess the nature of water resource issues in the case study basin of Chhattisgarh, to make a preliminary assessment of the nature of the required DSS and its underlying models, to assess the required IT software and hardware needs and training needs, GIS training needs, and capacity building and training needs in the Surface and groundwater agencies of the State to enable Chhattisgarh to effectively contribute to the development and operation of the DSS. As part of this process, it was also necessary to assess the availability and adequacy of data required by the DSS models.

The DSS team from NIH, DHI consultants and the State visited the Chhattisgarh State during the period 27 April to 1 May 2009. The under-mentioned Table shows the details of activities undertaken during the visit:

| Day | Activity |
|---|---|
| 27th April, 2009 | Kick-Off Meeting, General discussions with State representatives |
| 28th April, 2009 | Inspection of State Data Centre and visit to gauging stations |
| 29th April, 2009 | Field Trip, Tandula tank command, Assessment and report writing, Consultant Team |
| 30th April, 2009 | Assessment and report writing, Consultant Team Meeting with State representatives |
| 01st May, 2009 | Wrap-up Meeting with State SW and GW representatives, Departure, Consulting Team |

### 3.2.2 DSS (P) Case Study Areas

The State had identified the Seonath River Basin in the upper Mahanadi Basin for application of DSS (Planning) for the following water resources issues in the basin:

- Conjunctive use of surface water and groundwater
- Drought management

The areas also include elements of surface water management and operation of reservoirs.

The Seonath River originates near village Panabaras in the Rajnandgaon District. The basin is located between latitudes $20^0$ 16’ N to $22^0$ 41’ N and longitudes $80^0$ 25’ E to $82^0$ 35’ E. The basin area of the river up to its confluence with the Mahanadi River is 30,860 km$^2$. The river traverses a length of 380 km. The main tributaries of Seonath river are the Tandula, Kharun, Arpa, Hamp, Agar and Maniyari Rivers. There are 22 major and medium tanks in the Seonath River Basin.

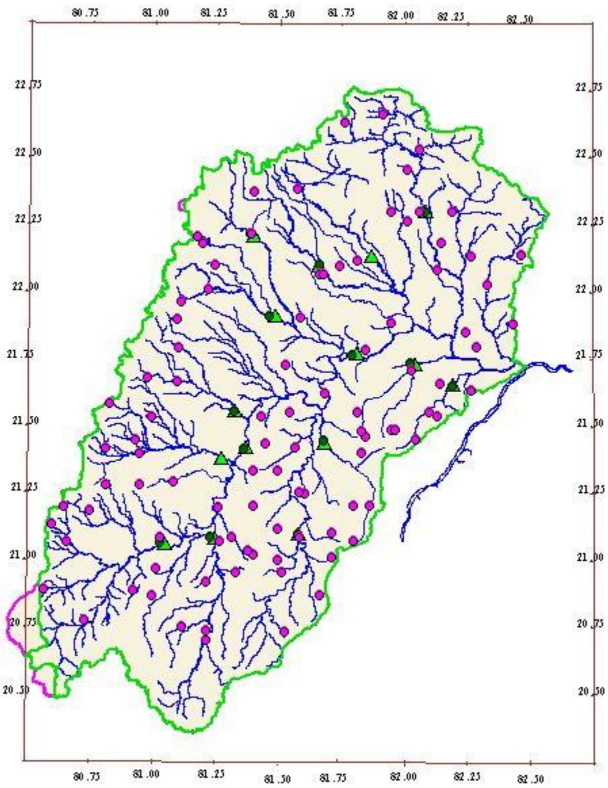


Figure 3.23: Seonath River Basin

### 3.2.3 Water Resources Issues of the State

Based on the discussions during the visit of consultants’ team to the State, the important water resources and related issues in the basin are:

- Making water available for irrigation and domestic water supply during the summer season.

- Estimation of inflows into the reservoirs.
- Improving the ground water availability in the semi critical blocks.
- Drought management in years of below normal monsoon rainfall.

At the end of the visit of consultants to Chhattisgarh, the command areas and catchment areas of the following small reservoirs within the Seonath River Basin were suggested for DSS (Planning) application:

- Tandula Tank in Durg District
- Mongara Barrage in Rajnandgaon District
- Madian Tank in Rajnandgaon District
- Saroda Tank in Kawardha (Kabirda) District

The corresponding functionalities of the DSS would mainly be:

- support decisions on tank operations in dry years
- support decisions on conjunctive use of surface and groundwater
- demonstrate benefits of changes in cropping pattern
- support decision on canal lining

### 3.2.4 Model Conceptualization

During this task, suitable modelling software was assessed and finalized by the consultants keeping in view the requirements of all implementing agencies. The main modelling software MIKE BASIN with NAM rainfall-runoff model was selected. The results of this modelling software will be used by the DSS front end to generate the scenarios.

The MIKE BASIN modelling package was provided and incorporated in the DSS in order to address the need of all states for river basin modelling software. MIKE BASIN includes the rainfall-runoff model NAM, which may be applied to assess the runoff and ground water recharge in sub-catchments within a basin and thereby generate time series, which represent the climatic variation of water availability. To facilitate the use of this software, the Consultant will provide a stand-alone version of NAM, which includes facilities to support the calibration process.

#### 3.2.4.1 MIKE BASIN (now MIKE HYDRO BASIN)

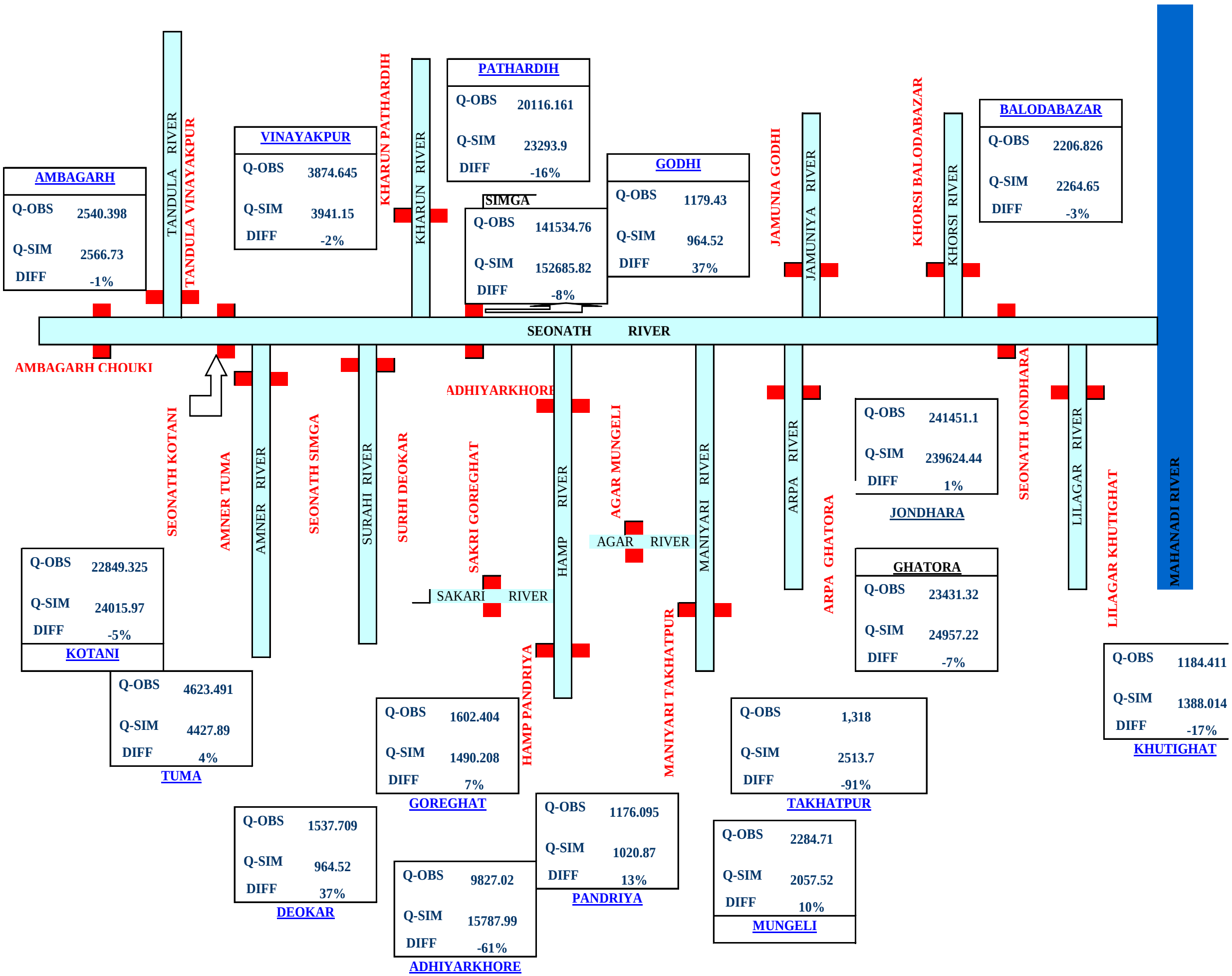
In brief, MIKE BASIN is a simulation model for water allocation representing the hydrology of the basin in space and time as well as modelling water quality and ground water related issues.

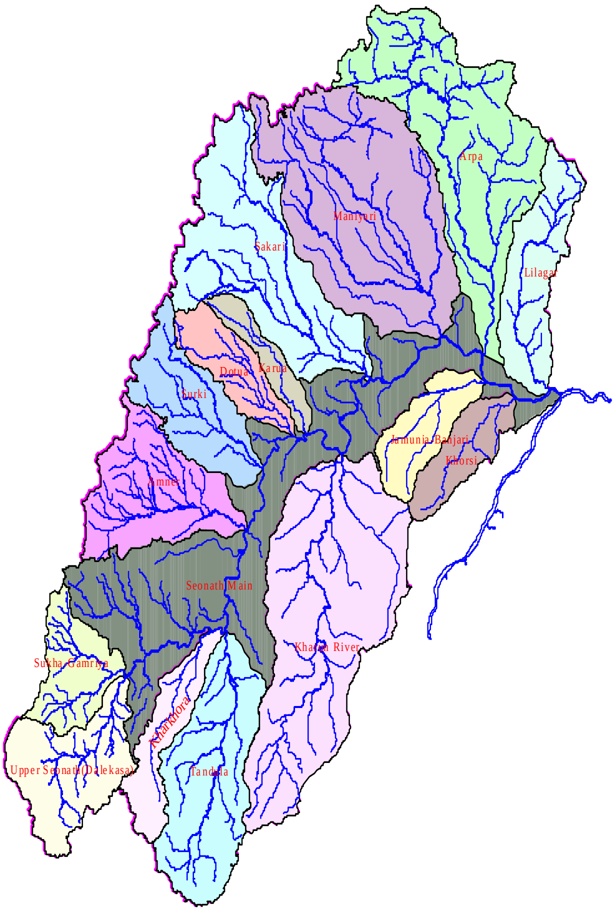
Technically, MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of reaches and nodes. The reaches represent individual stream sections while the nodes represent confluences, bifurcations, locations where certain water activities may occur, or important locations where model results are required. MIKE BASIN keeps track of water and water quality throughout a developed river network representing the river basin. MIKE BASIN adds time dimension to the spatial information stored in the GIS and is therefore a great package for data management as well.

### 3.2.4.2 Database Development

A geodatabase comprising essential GIS layers as well as links to relevant time series data has been established for the Seonath Basin. Various data required by the consultants viz. surface water time series, ground water time series, spatial data in the form of GIS layers were provided to the consultants. These data were given as input to the MIKE Basin software. Rainfall-runoff model calibration was done for 21 GD catchments and 20 reservoir catchments.

MIKE BASIN RESULT SIMULATION RESULT AT GD SITES UNDER SEONATH BASIN






| S.NO. | NAME OF THE RIVER | CATCHMENT AREA IN SQKM |
|---|---|---|
| 1 | ARPA RIVER | 3311.046 |
| 2 | AMNER RIVER | 1636.2 |
| 3 | DOTUA RIVER | 736.67 |
| 4 | LILAGER RIVER | 1348.23 |
| 5 | KARUA RIVER | 426.68 |
| 6 | JAMUNIA+ BANJARI | 761.43 |
| 7 | KHARUN RIVER | 4107.86 |
| 8 | KHARKHARA RIVER | 774.48 |
| 9 | KHORSI RIVER | 662.48 |
| 10 | SAKARI RIVER | 2673.97 |
| 11 | MANIYARI RIVER | 3938.61 |
| 12 | SUKHA+GAMRIYA | 831.32 |
| 13 | SURKI RIVER | 1235.95 |
| 14 | SEONATH MAIN | 4966.88 |
| 15 | UPPER SEONATH DALEKASA RIVER | 1390.22 |
| 16 | TANDULA RIVER | 2057.8 |
| | **TOTAL** | **30859.826** |

## NAM Simulated Results of GD and Tank Catchments

| Name of Tank | Data Peroid | Mike Basin Result | | | NAM Result | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Observed Accumulated discharge in MM3 | Simulated Accumulated discharge in MM3 | % diff | NAM Weigthage | NAM Coefficient of determination: R2 | Q_Sum Obs | Q_Sum sim | Water Balance | |
| 3 | 5 | 6 | 7 | 8 | 9 | 10 | | | 11 | 12 |
| Tandula Tank | 01/01/1995 to 23/06/2009 | 6073.200 | 6073.832 | 0% | 1 | 0.432 | 6644.9 | 7128.4 | -7.3 | |
| Gondli Tank | 01/07/1991 to 31/12/2008 | 2106.211 | 1934.380 | 8% | 1 | 0.447 | 8196.3 | 8465.6 | -3.3 | |
| Kharkhara Tank | 01/06/1995 to 21/09/2009 | 2603.988 | 2525.367 | 3% | 1 | 0.474 | 6815.1 | 7367.8 | -8.1 | |
| Kumhari Tank | 01/07/1987 to 31/12/2009 | 325.224 | 329.588 | -1% | 1 | 0.479 | 9377.3 | 9365.1 | 0.1 | |
| Khapri Tank | 01/01/1995 to 31/12/2009 | 404.059 | 288.144 | 29% | 1 | 0.526 | 10019.9 | 7064.7 | 29.5 | Return flow of Tandula canal |
| Matiamoti Tank | 01/06/2002 to 01/01/2010 | 253.042 | 236.670 | 6% | 1 | 0.554 | 2611 | 2814.2 | -7.8 | |
| Ruse Tank | 01/03/1997 to 01/01/2009 | 230.991 | 231.770 | 0% | 1 | 0.535 | 4521.2 | 4574 | -1.2 | |
| Surhi Tank | 01/09/1998 to 30/06/2009 | 364.229 | 346.801 | 5% | 1 | 0.468 | 2922.4 | 3030 | -3.7 | |
| Seonath Diversion | Being diversion scheme Seonath Diversion catchment as a part of Kotani Catch. | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Seonath_ Sahagaon | 01/01/2000 to 04/10/2008 | 13442.250 | 15344.68 | -14% | 1 | 0.363 | 10322.6 | 10330.2 | -0.1 | Disgarded Seonath Sahgaon |
| | Simga | 01/01/1980 to 31/12/2007 | 141534.760 | 152685.82 | -8% | | | | | | |
| 8 | Maniyari-Takhatpur | 01/08/2000 to 13/11/2008 | 1317.798 | 2513.7 | -91% | Data Disgarded & Apply nearest Agar_Mungeli_GD Site NAM Parameter | | | | | |
| 9 | Amner_Tuma | 01/08/2000 to 13/11/2008 | 4623.491 | 4427.89 | 4% | 1 | 0.451 | 2882.4 | 2907.4 | -0.9 | |
| 10 | Tandula_ Vinayakpur | 01/06/2001 to 13/12/2008 | 3874.645 | 3941.15 | -2% | 1 | 0.315 | 2023.9 | 2220.1 | -9.7 | |
| 11 | Jondhra | 01/01/1980 to 31/12/2007 | 241451.100 | 239624.44 | 1% | 1 | 0.165 | 11330.9 | 11330.9 | 0 | Disgarded Seonath Nandghat |
| | Seonath_ Nandghat | 19/07/2000 to 30/11/2008 | 59284.296 | 50936.84 | 14% | | | | | | |
| 12 | Kotani | 01/01/1995 to 31/12/2007 | 22849.325 | 24015.97 | -5% | 1 | 0.543 | 1818.9 | 1995.5 | -9.7 | Disgarded Seonath Singdai |
| | Seonath_ Singdai | 01/06/2001 to 12/10/2008 | 6320.740 | 9376.57 | -48% | | | | | | |
| 13 | Andhiarkhore | 01/01/1980 to 01/12/2007 | 9827.02 | 15787.99 | -61% | Data Disgarde | | | | | |
| 14 | Kharun_Pathardih<br>Kharun_Amdi | 01/06/1989 to 31/12/2007 | 20116.161 | 23293.900 | -16% | 1 | 0.74 | 7461.30 | 8078.30 | -8.3 | Disgarded Kharun Amdi |
| 15 | Arpa-Kota<br>Ghatora | 01/09/1979 to 31/03/2003 | 23431.320 | 24957.220 | -7% | 1 | 0.786 | 5478.9 | 7154.9 | -30.6 | Disgarded Arpa Kota |
| 16 | Ambagarh Chouki | 01/06/1988 to 01/05/1994 | 2540.398 | 2566.730 | -1% | 1 | 0.746 | 2777.900 | 3137.200 | -12.9 | |
| 17 | Lilager Khutighat | 16/06/1990 to 31/07/1994 | 1184.4109 | 1388.0135 | -17% | 1 | 0.345 | 973.100 | 1016.000 | -4.4 | |

Table 3.1: Groundwater available data

| S. N. | Particulars | No. of Stations | Period |
|---|---|---|---|
| 1 | Water level hydrograph stations | 262 | 1973-2009 |
| 2 | Water level of peizometers | 20 | 1997-2009 |
| 3 | Water quality of hydrograph stations | 262 | 2001-2009 |
| 4 | CGWB Water level data of peizometers | 37 | 1999-2009 |
| 5 | CGWB Water level data of Hydrograph stations | 137 | 1999-2009 |
| 6 | Block-wise water level assessment data | 67 Blocks | Based on GEC97 |

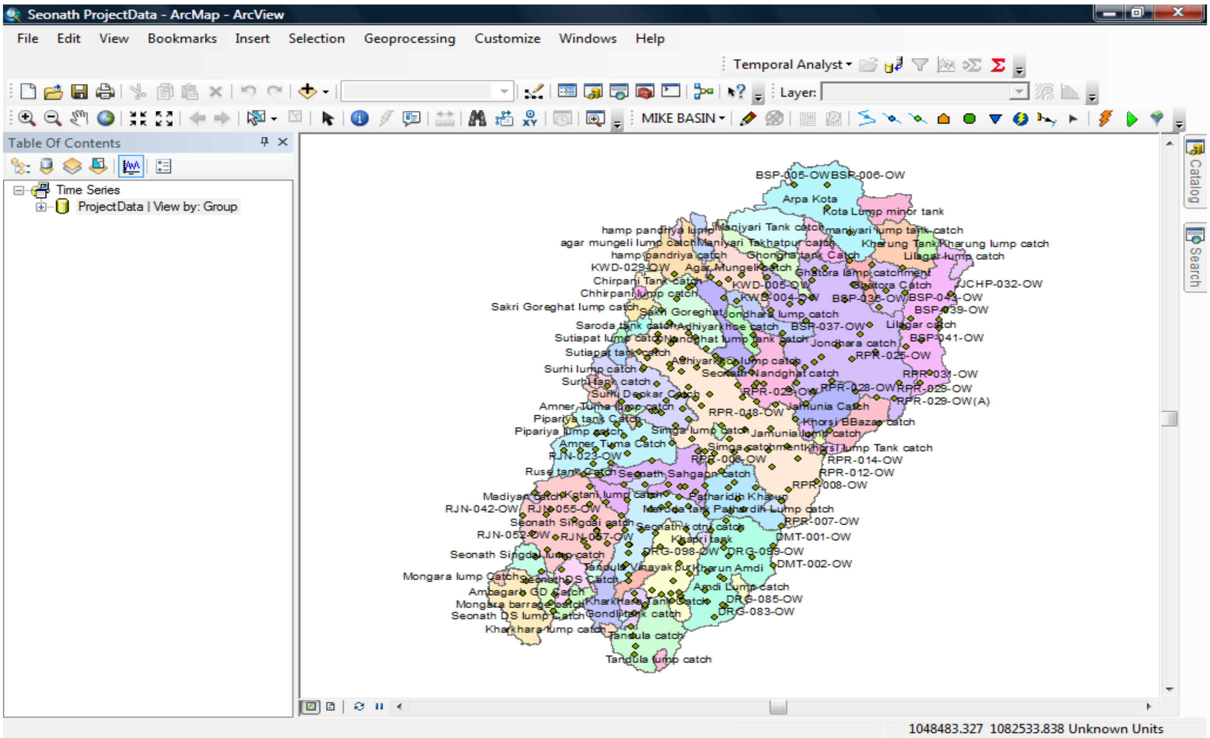



Figure 3.24: Groundwater Hydrograph Stations in Mike Basin Software

The following particulars for the State have been completed:

- Calibration of G&D and reservoir catchments using NAM Model.
- Calibration of Reservoirs Level.
- Mike Basin Setup for the basin.
- DSS Installation.
- Registration of Mike Basin model setup in the DSS software.
- Development of Mike Basin model for the conjunctive use.
- Demonstration of the conjunctive use interface in DSS(P).
- Installation in servers and configuration of DSS(P) through remote access.

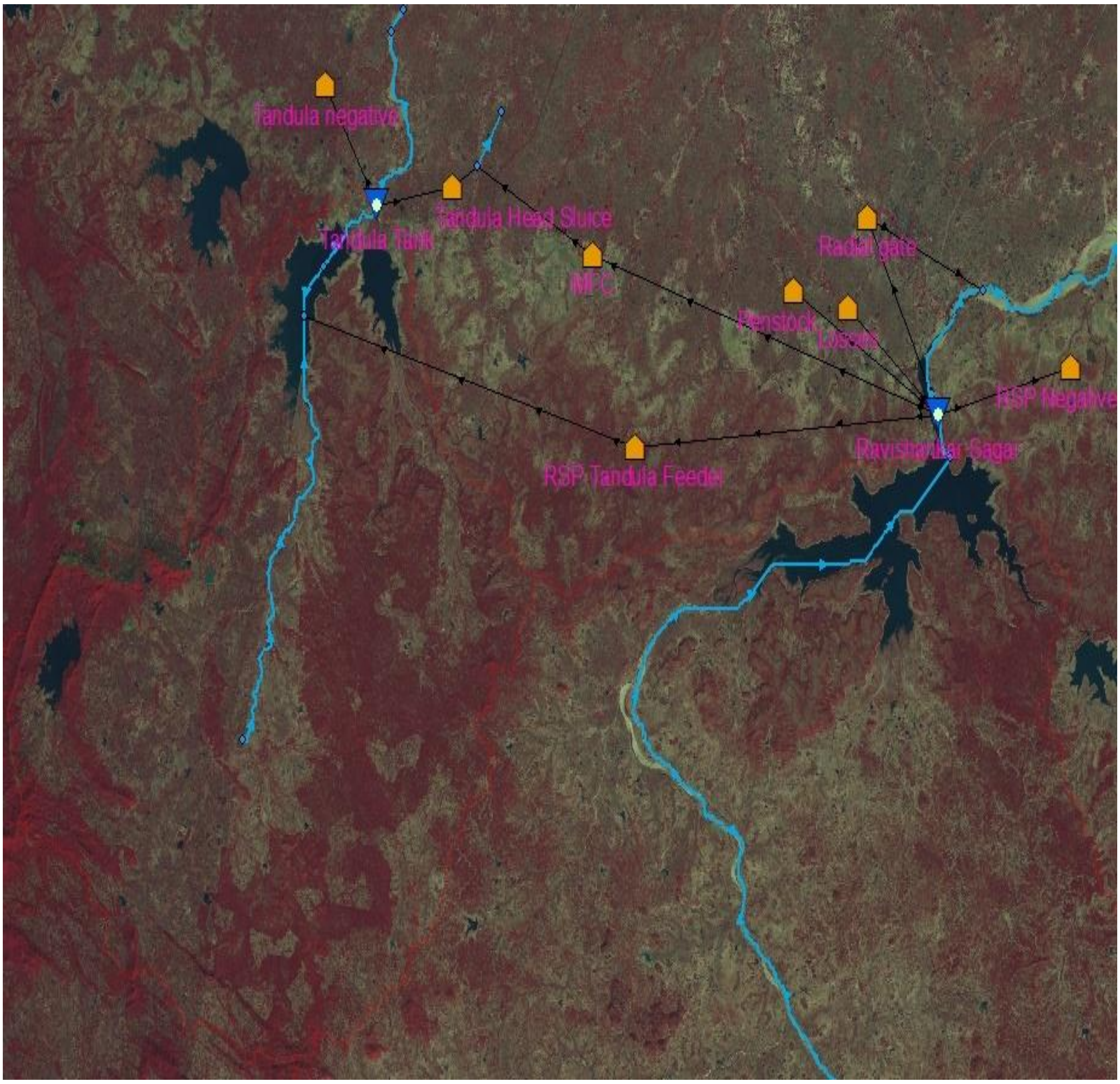


Figure 3.25: MIKE BASIN Network of the Ravishankar and Tandula Reservoirs System for Transferring Water from Tandula to RSP

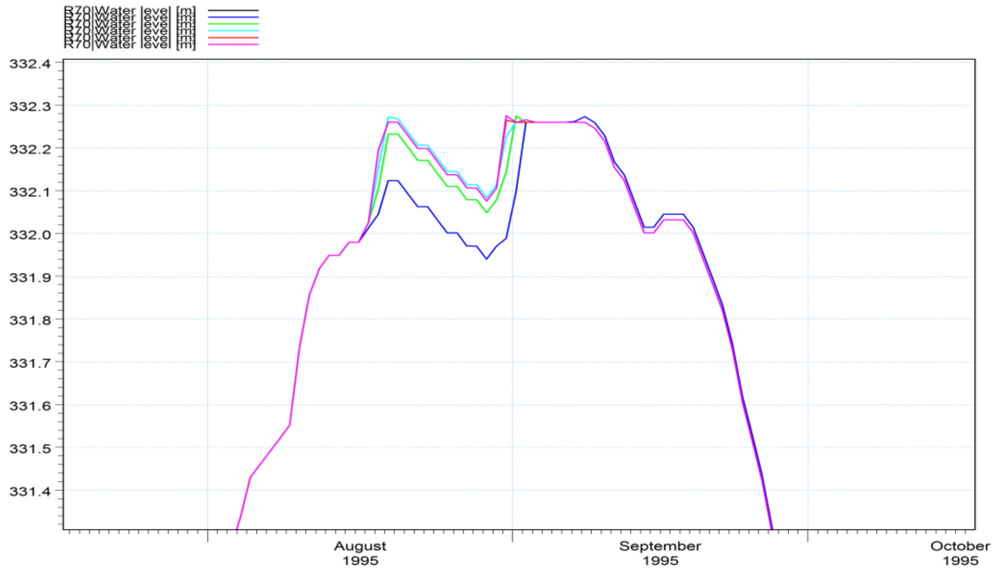



Figure 3.26: Simulated Water level of Tandula Reservoir under Different Scenarios

(Transfer water 0, 25, 50, 75, 100, 120 cumecs)

**PROPOSED RSP - TANDULA LINK CANAL**
**Simulation Period 01/01/1995 to 01/01/2010**

| S. No. | Description | Unit | Scenarios | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Transfer water RSP to Tandula | Cumecs | 0 | 25 | 50 | 75 | 100 | 120 |
| 2 | No of Year for Simulation | Year | 15 | 15 | 15 | 15 | 15 | 15 |
| 3 | Total No. of day when RSP Spilling in simulation period | Days | 100 | 86 | 76 | 68 | 53 | 43 |
| 4 | Total No. of day when Tandula Spilling in simulation period | Days | 96 | 121 | 139 | 142 | 144 | 145 |
| 5 | Total no. of day when RSP Spilling & Tandula Not Spilling in simulation period | Days | 75 | 43 | 27 | 25 | 21 | 20 |
| 6 | Total volume of water for Transfer to Tandula in simulation period | MCM | 0.000 | 152.707 | 277.436 | 385.981 | 467.322 | 511.666 |
| 7 | Average Yearly water transfer to Tandula | MCM | 0.000 | 10.180 | 18.496 | 25.732 | 31.155 | 34.111 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8 | Average Yearly No. of days when water transfer to Tandula | Days | 5 | 3 | 2 | 2 | 1 | 1 |

**PROPOSED RSP - TANDULA LINK CANAL**
**Simulation Period 01/01/2003 to 31/12/2007**

| S. No. | Description | Unit | Scenarios | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Transfer water RSP to Tandula | Cumecs | 0 | 25 | 50 | 75 | 100 | 120 |
| 2 | No of Year for Simulation | Year | 5 | 5 | 5 | 5 | 5 | 5 |
| 3 | Total No. of day when RSP Spilling in simulation period | Days | 89 | 76 | 66 | 59 | 48 | 40 |
| 4 | Total No. of day when Tandula Spilling in simulation period | Days | 68 | 93 | 110 | 111 | 112 | 113 |
| 5 | Total no. of day when RSP Spilling & Tandula Not Spilling in simulation period | Days | 70 | 39 | 24 | 23 | 21 | 20 |
| 6 | Total volume of water for Transfer to Tandula in simulation period | MCM | 0.000 | 128.947 | 231.511 | 318.456 | 383.097 | 418.800 |
| 7 | Average Yearly water transfer to Tandula | MCM | 0.000 | 25.789 | 46.302 | 63.691 | 76.619 | 83.760 |
| 8 | Average Yearly No. of days when water transfer to Tandula | Days | 14 | 8 | 5 | 5 | 4 | 4 |

#### 3.2.4.3 DSS(P) Development

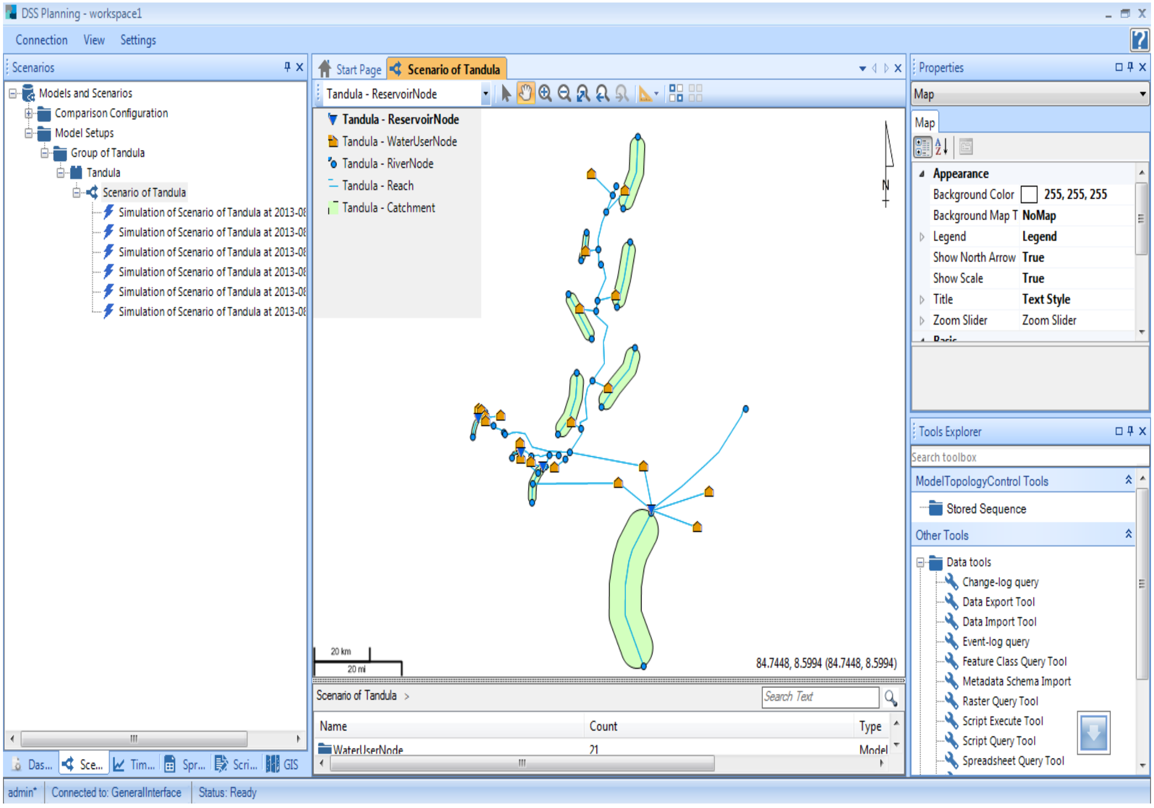
The DHI consultants have developed the DSS software which is recently upgraded to ver. 4.0. This version of DSS(P) is compatible with Mike Hydro Basin. Various functionalities of this software include GIS manager, Time Series manager, Scenario manager, Scripts manager, Spreadsheets manager, System manager, Dashboard manager, Tools explorer and Properties, etc. Tools explorer comprises of various operations like hydrological and statistical, import, export, etc linked to any particular time series or GIS layer.

### 3.2.4.4 DSS Customization

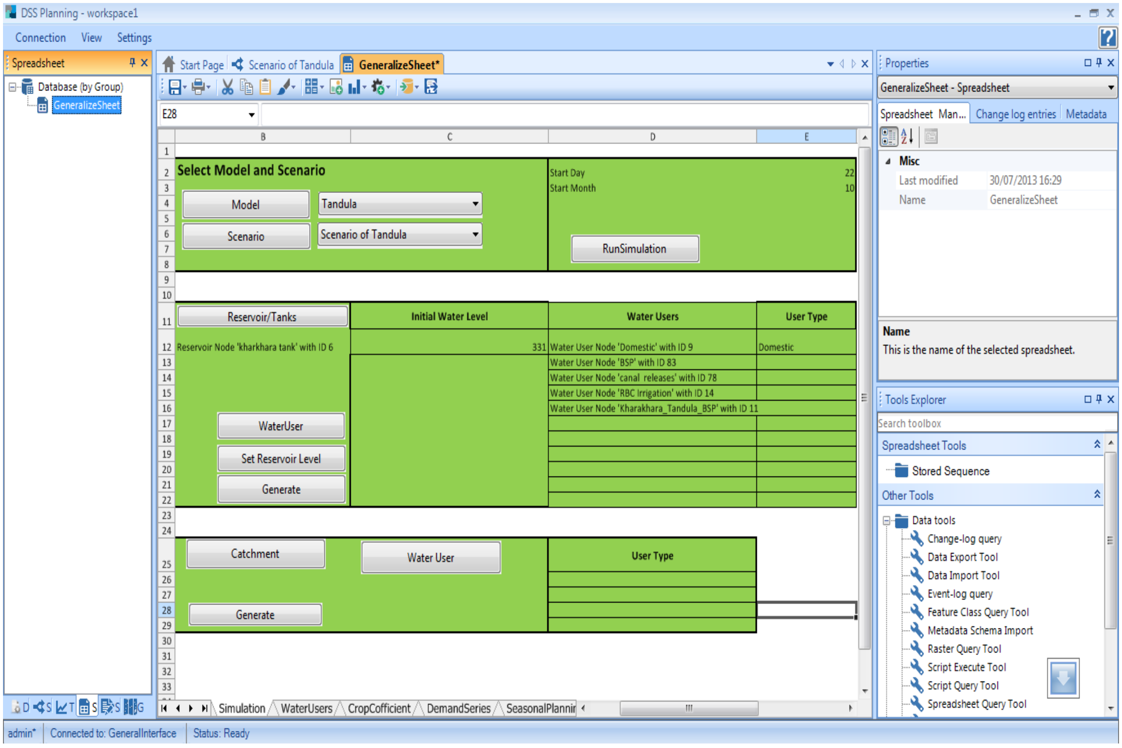
| S. N. | Sub-Task | Status | State Requirements |
|---|---|---|---|
| 1 | Customization of developed DSS(P) software | DSS(P) installed during 9th - 11th May, 2011. | Errors occurring while registering the model in the DSS software were resolved. |
| 2 | Demonstration of customized software to the State | Training given to 08 officers from SW & GW.<br>Training covered on: GIS features in DSS, Import of database into DSS, Data management, plotting of maps, deriving tables using Pilot basin (Bhima) database. | Detailed training and demonstration was required with the State own database for further modeling work which was held during January, 2012 at NIH Roorkee. |
| 3 | Preparation of Interim Report | 6th Review Committee meeting held on 14th Sept., 2011 at Raipur.<br>Report submitted. | Suggestions & observations were made and incorporated in the minutes. |

### 3.2.4.5 Conjunctive Use in Tandula Complex Command Area

Chhattisgarh state has developed a conjunctive use model for the Tandula complex command of the Seonath basin. This command area consists of four reservoirs viz. Tandula, Ravishankar, Kharkhara and Gondli. All these reservoirs operate in integrate manner. There are domestic, agricultural and industrial (Mainly Bhilai steel plant) demands in the command areas of these reservoirs. A schematic view of this complex command in DSS(P) is shown below:



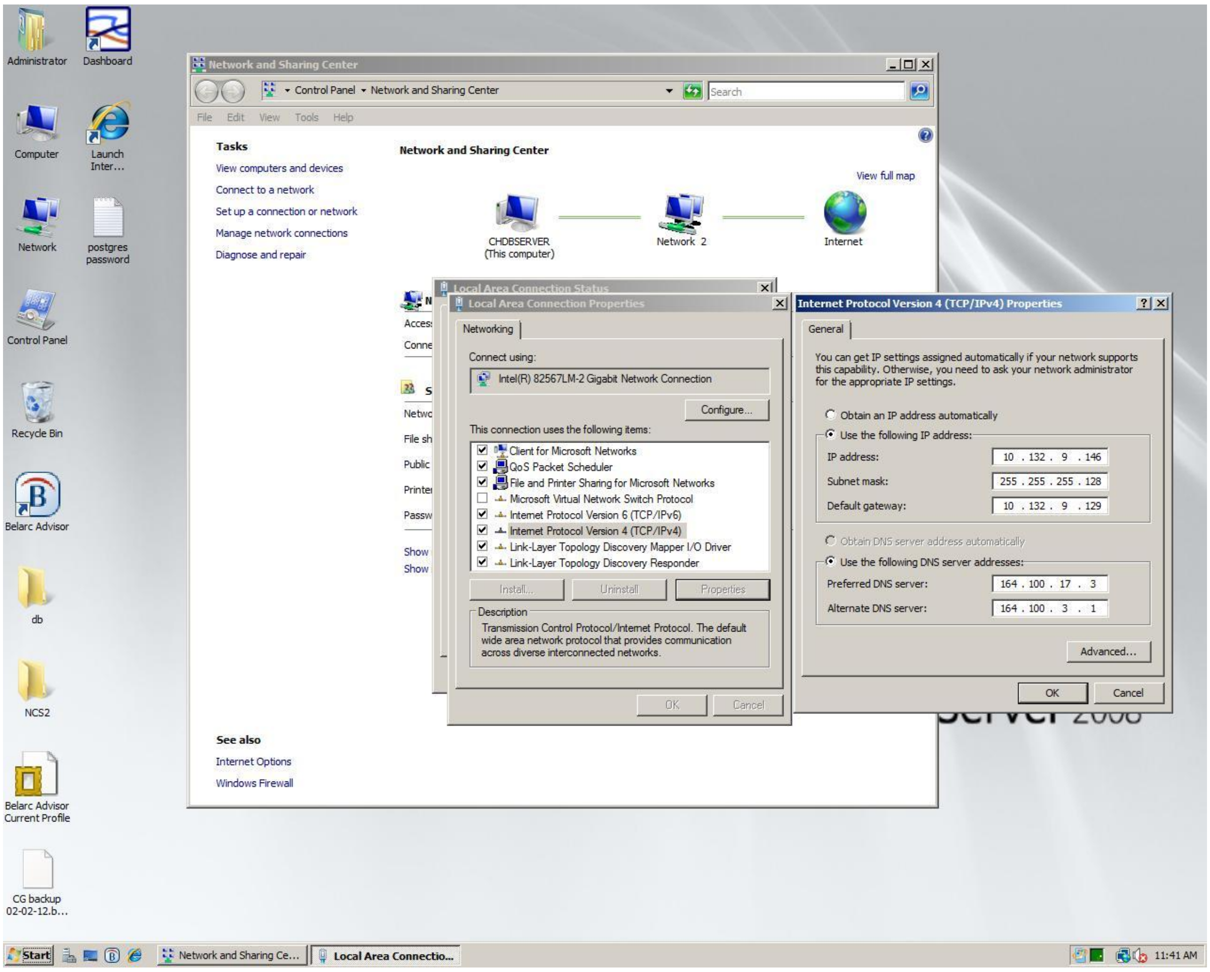

The outputs of this conjunctive use interface are in the form of estimation of water demands for various uses, surface and groundwater availability, allocation of surface water and groundwater, variation of reservoir and groundwater levels, groundwater recharge and abstraction, use of surface and groundwater in the command. The conjunctive use interface through spreadsheet is shown below for the Tandula command.




### 3.2.4.6 DSS(P) Server of the Chhattisgarh State:

The DSS Server of the State has NIC internet facility with following IP address:

- Internet protocol version 4 (TCP/IPv4)
- IP Address: 10.132.9.146
- Subnet Mask: 255.255.255.128
- Default Gateway: 10.132.9.129
- Preferred DNS Server: 164.100.3.1
- Alternate DNS Server: 164.100.17.3




Database installed in Server and the Server is in running condition.

## 3.3 DSS APPLICATIONS – GUJARAT STATE

To demonstrate the DSS technology, the Govt. of Gujarat (GoG) has selected the Mahi River Basin (basin portion falling in Gujarat).

### 3.3.1 Mahi River Basin

Mahi is a major west flowing inter-state river. It originates on the northern slopes of Vindhya mountain ranges at 500 m above m.s.l. in Madhya Pradesh and drains into the Gulf of Khambhat. Total length of Mahi river is 583 km. The river traverses through states of Madhya Pradesh, Rajasthan and Gujarat and drains a total area of 34,842 $km^2$ [Madhya Pradesh 6695 $km^2$ (19.22%); Rajasthan 16453 $km^2$ (47.22%); Gujarat 11694 $km^2$ (33.56%)]. The study area, covering the terminal reach of the Mahi River, extends from Kadana Reservoir to the Arabian Sea (Fig.6.1). The study area is 13,782 $km^2$, including only the portion of the basin that falls within the State of Gujarat. The average rainfall for the basin is 785 mm (90% rainfall during monsoon). Crops grown in three seasons are as follows: Kharif (June to October) - Paddy, Tobacco, Bajri; Rabi (November to February) - Wheat, mustard, sorghum, maize and potato; Hot weather (March to May) – Bajri

Twelve major and medium water structures control water flows for irrigation, drinking water and industrial use. Kadana Reservoir Project provides irrigation in command area of Mahi Right Bank Canal through Wanakbori pick up weir and provides water supply to Kadana Hydropower Station.

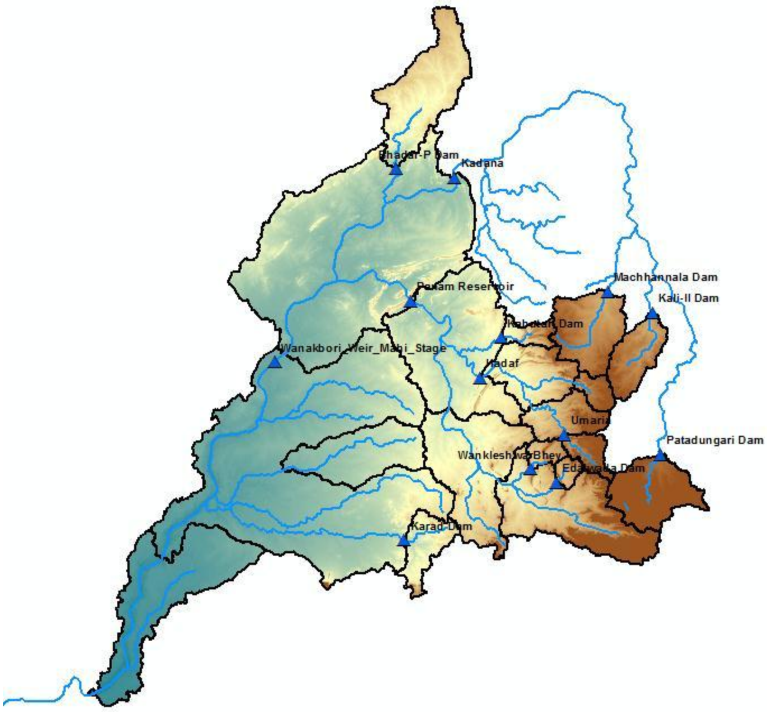



Figure 3.27: Study area in Mahi River Basin (Gujarat portion)

Groundwater occurs in both alluvial and hard rock formations (Fig. 6.2). The level of groundwater development is 61.25%. Net utilizable recharge is 1658.84 MCM/year. Total agriculture draft is 1016.00 MCM/year. Groundwater balance is 642.84 MCMC/year. As per Groundwater Resource Estimation Committee Report of 2002, 23 talukas are categorized as safe, 9 talukas are semi critical, 1 taluka is categorized as over exploited and one taluka of Bharuch district is categorized as saline taluka.

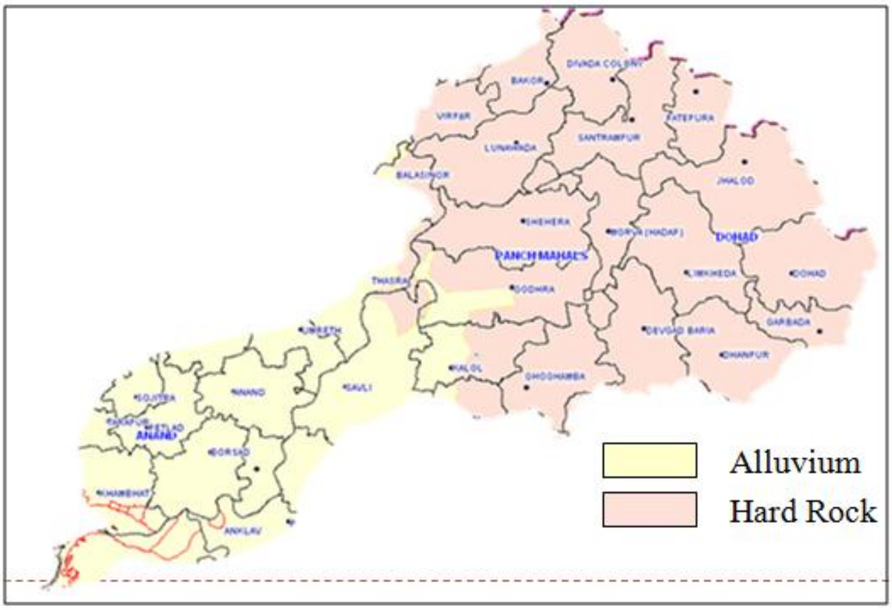



Figure 3.28: Geology of Mahi Basin

The specific issues associated with Mahi River Basin include:

- Managing the increasing demands for water resources for agriculture, domestic, industrial, and power generation purposes,
- Managing reservoirs and inter-basin transfer under normal, flood, and drought conditions. The command area of Mahi Right Bank Canal (MRBC) falls in the adjoining Sabarmati Basin, while the Sujalam Sufalam Canal from Kadana Dam has been constructed to transfer water by interlinking of rivers to the water-scarce North Gujarat region.
- The water use in command areas may be limited by changes in cropping pattern and reduced losses. Some areas suffer persistent inundation when heavy rain falls on irrigated land. Changes in drainage or irrigation scheduling may help in alleviating this problem. Some areas within the basin are drought prone,
- Pollution from villages and industries is seen in some areas, a minor but increasing problem. In addition, considerable variation is seen in the availability of water in this basin. Although efficient management is taking place in the basin it is believed that further improvement in the water management is possible.

In view of above, the DSS Planning applications developed for Gujarat State pertain to the following five categories: surface water planning, reservoir management, conjunctive use, drought monitoring and assessment, and water quality.

### 3.3.2 Mahi River Basin Model (Mahi RBM)

To develop the DSS applications, a River Basin Model (Fig. 6.3) of the Mahi Basin study area (Mahi RBM) has been developed using the MIKE BASIN software. The purpose of the model is to enable analysis of water management and climate change scenarios, describing potential changes in the water demands, surface water distribution, infrastructure operations, groundwater conditions, etc. In addition to providing a study area wide simulation of water conditions and use, the model provides the foundation for specific models which support targeted DSS Applications. Model construction consists of building a river network and compiling and populating the network features with parameters and time series data. The Mahi RBM network consists of polygons defining catchments for inflow and groundwater conditions, arcs defining river branches and link channels for connecting nodes, and nodes representing locations of computational interest or water use. Examples of nodes representing locations of computational interest include locations where stream channels merge, bifurcations in the channel, and inflow locations from catchments and water use nodes includes water users, irrigation users, reservoirs, and hydropower facilities.

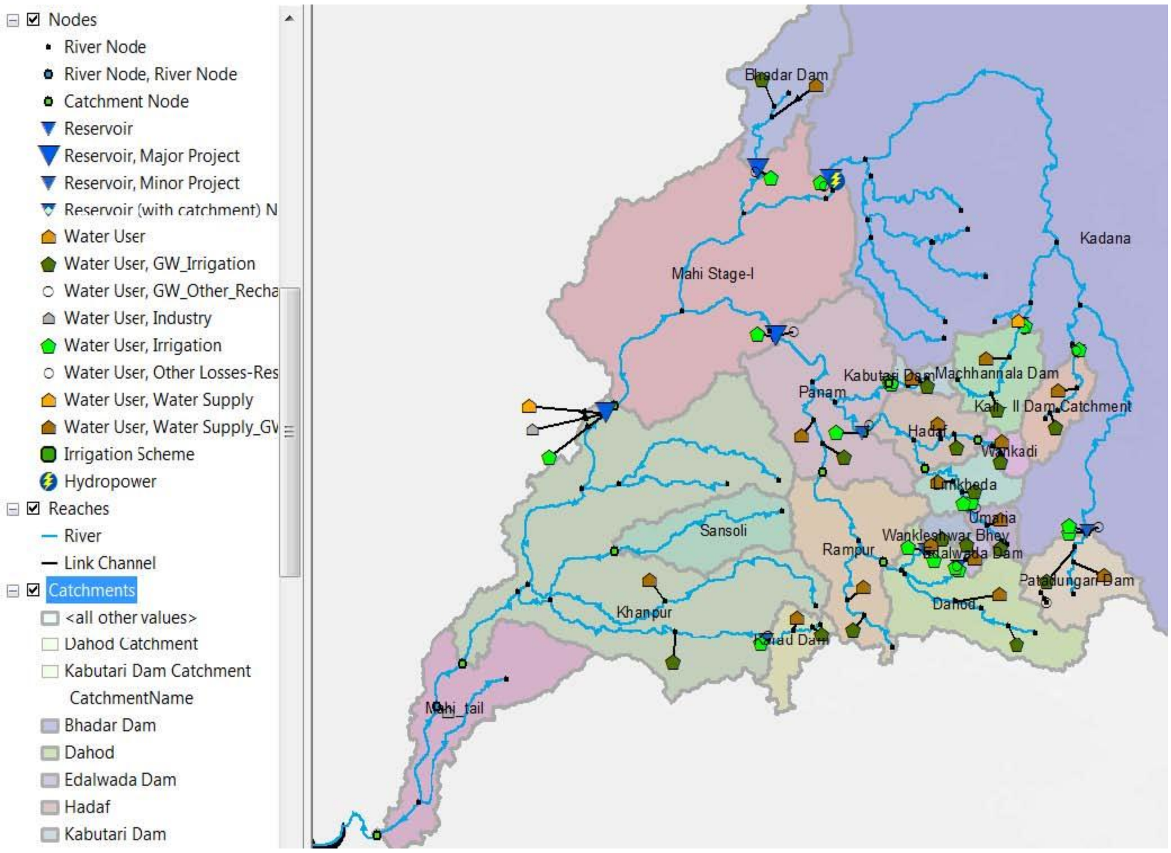



Figure 3.29: Illustration of Mahi RBM using MIKE BASIN software

Catchments outlets are locations in the model where water is introduced directly to the stream network. For the Mahi RBM, 12 upstream and 7 interior catchments were defined. Delineation of the catchments was from a DEM and with outlets occurring at stream measurements locations: stream gages and inflow records computed from major and mefium projects. Aside from the Kadana Dam catchment, which uses upstream gage discharge records, the surface runoff and groundwater recharge time series were determined from NAM modeling results. The 2-layer groundwater model was used in 14 catchments.

The reservoir purposes vary, but all have been built to support irrigation with 6 used as drinking water supply, 3 used as industrial/commercial supply, and 3 used for flood control. Water user nodes were connected to all reservoirs that represent these sectors. All reservoirs were designated as rule curve reservoirs and, for the majority, a standard spillway was implemented. In the Mahi RBM, water user nodes represent the drinking water, agricultural, and industrial/commercial sectors. Thirteen water user nodes represent drinking water with the primary source coming from groundwater. Additional water user nodes representing the Mahi_Pariej_Export and the surface water source from Machhannala Dam have also been included.

### 3.3.3 DSS Applications – Mahi Basin

Using the Mahi RBM, the major DSS Planning applications associated with the five categories viz., surface water planning, reservoir management, conjunctive use, drought monitoring and assessment, and water quality, are briefly described below. Fig. 6.4 shows the Mahi RBM on DSS platform.

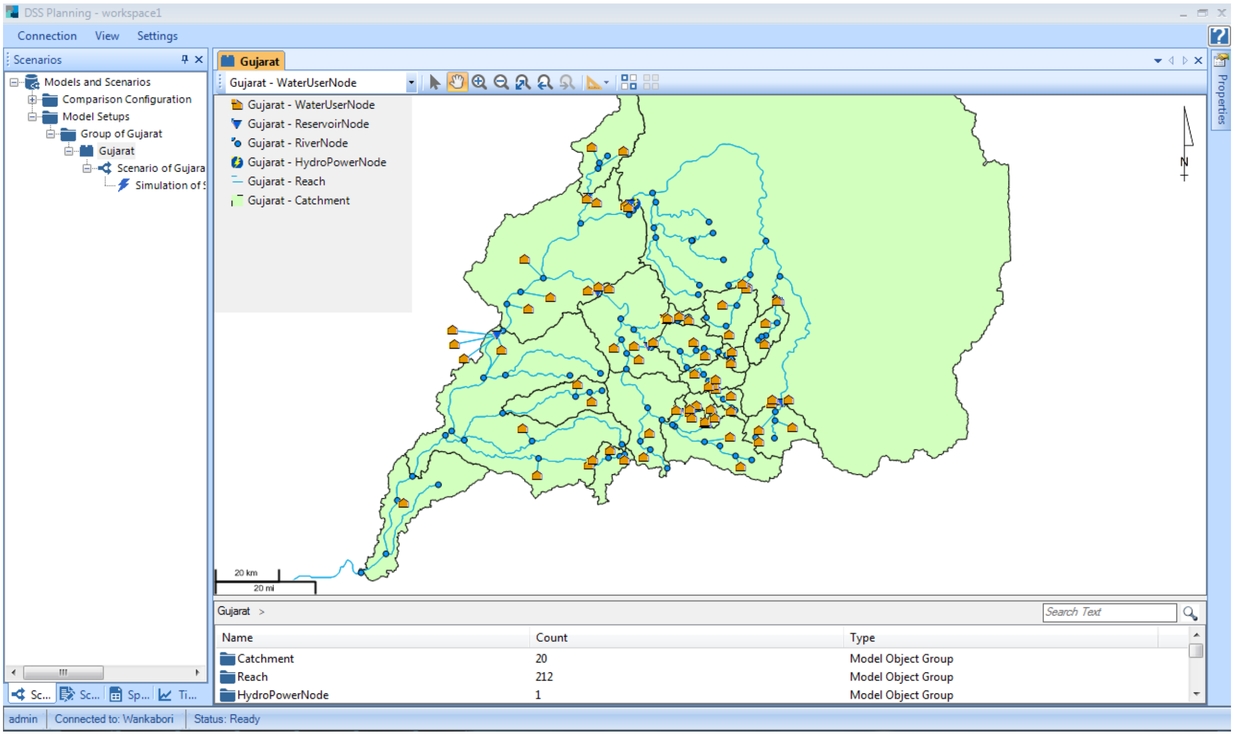



Figure 3.30: Mahi RBM registered on DSS platform

#### 3.3.3.1 Surface Water Seasonal Planning

The Seasonal Planning DSS Application allows the SWD (Surface Water Department i.e. the Central Design Organisation CDO) to test the impact of changing crop type and/or population on the projected reservoir elevations for one year duration given the 60%, 75%, and 90% reliability of inflow, using the Mike Basin model for the respective reservoir (Figure 3.31). This application allows reservoir managers to quickly test alternative deliveries to water users to predict the reservoir levels in the coming year. The output interface (Figure 3.32) of this DSS Application includes a predictive graph of reservoir water levels, given the reliability of inflows, that informs the user if the proposed operations will dry up reservoir, have additional storage that can be used, or if it is a balanced approach. Furthermore, the output interface tabularly displays the demand, supply, and deficit of the drinking water and irrigation water users to assess the effects on delivery.

The application can simulate current release strategies that can be adapted should the prediction indicate if releases are being too conservative such that additional storage can be released; or too aggressive, resulting in a depleted reservoir. In addition, the tool can be run for future conditions to examine how changing command area, crop type, or population may influence reservoir operations.

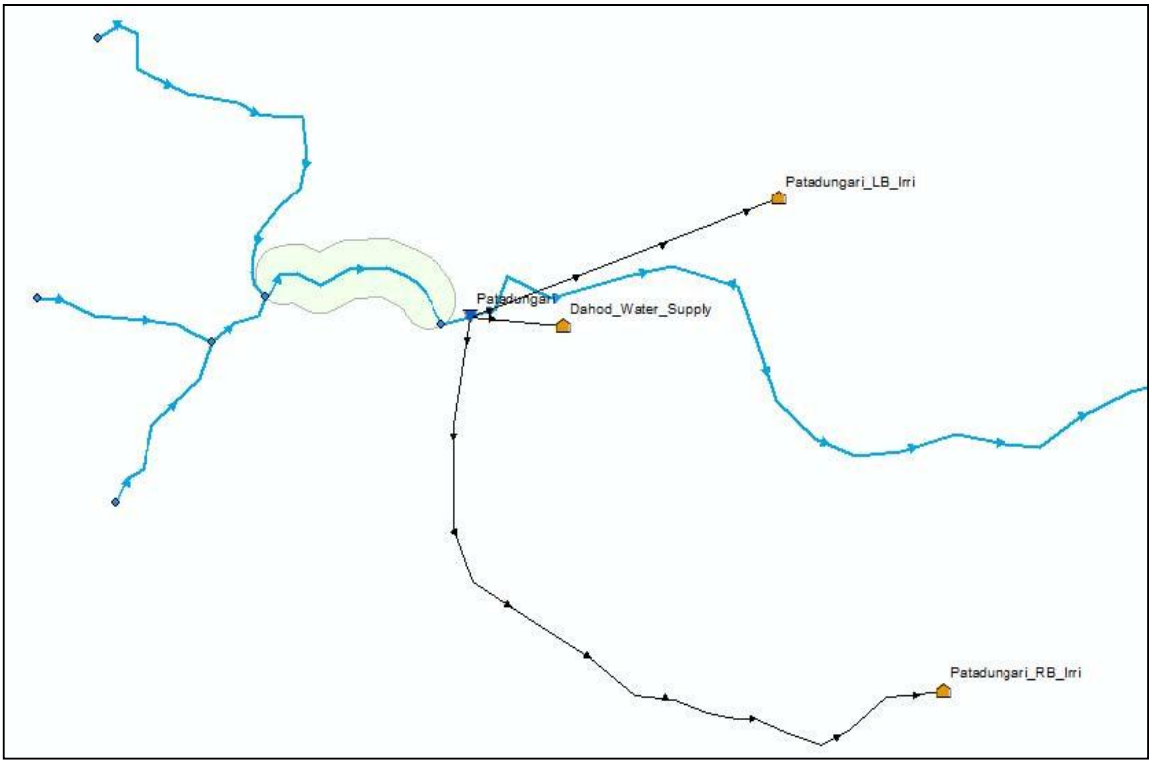



Figure 3.31: MIKE BASIN model of the Patadungari Reservoir

**Patadungari Reservoir Planning**

**Date**

| SYSTEMWIDE ANALYSIS | Demand | Supply | Defict |
|---|---|---|---|
| 90% Reliable Inflows | 54.17 | 50.84 | 3.32 |
| 75% Reliable Inflows | 54.85 | 46.64 | 8.20 |
| 60% Reliable Inflows | 54.63 | 41.21 | 13.43 |

Load Scenario

| Water User | Demand | Supply | Seepage Supply | Deficit | Projected Defict |
|---|---|---|---|---|---|
| **Dahod** | | | | | |
| 90% Reliable Inflows | 15.65 | 12.32 | 0.00 | 2.56 | 0.77 |
| 75% Reliable Inflows | 16.44 | 9.44 | 0.00 | 5.39 | 1.62 |
| 60% Reliable Inflows | 16.62 | 8.37 | 0.00 | 6.35 | 1.91 |
| **RBCA** | | | | | |
| 90% Reliable Inflows | 28.20 | 19.74 | 8.46 | 0.00 | 0.00 |
| 75% Reliable Inflows | 28.12 | 19.12 | 8.19 | 0.62 | 0.19 |
| 60% Reliable Inflows | 27.83 | 16.87 | 7.23 | 2.87 | 0.86 |
| **LBCA** | | | | | |
| 90% Reliable Inflows | 10.32 | 7.22 | 3.10 | 0.00 | 0.00 |
| 75% Reliable Inflows | 10.28 | 6.92 | 2.97 | 0.30 | 0.09 |
| 60% Reliable Inflows | 10.18 | 6.12 | 2.62 | 1.10 | 0.33 |

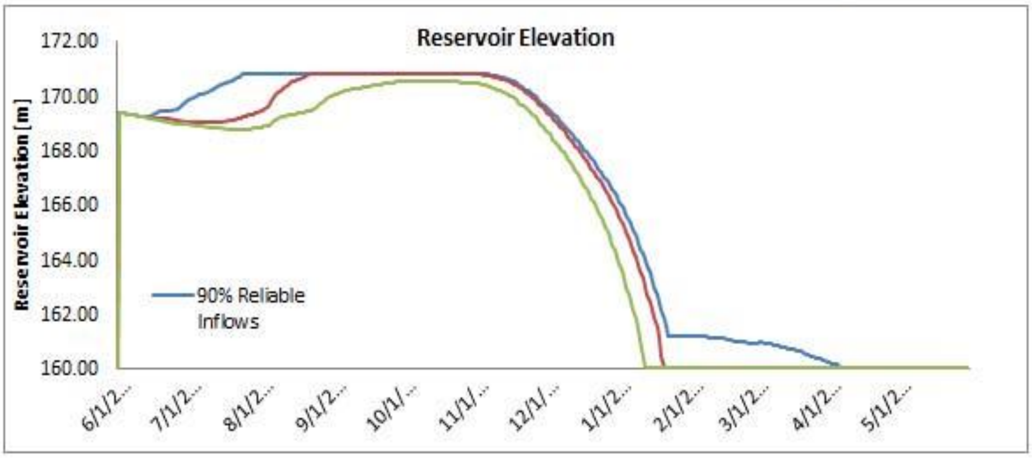



Figure 3.32: Output interface for the surface water seasonal planning DSS

### 3.3.3.2 Integrated Reservoir Operation

The Integrated Reservoir Operation DSS Application evaluates multi-reservoir operational strategies of the Kadana, Panam, and Bhadar Reservoirs for delivery of water to the irrigation, drinking water, industrial sectors as well as flood control in downstream reaches of the Mahi River. This DSS Application can be used to refine reservoir operations (flood control levels and operational rules); examine changes in water demand from command areas, drinking water users, and industrial areas influenced by the dam; and provide insight into operations given changing climate and upstream conditions (e.g. new structures along the Mahi River). Attributes of the water management that can be changed are initial reservoir levels, flood control levels, rule curve operations, irrigated area by crop type, and population and per capita drinking water use rate.

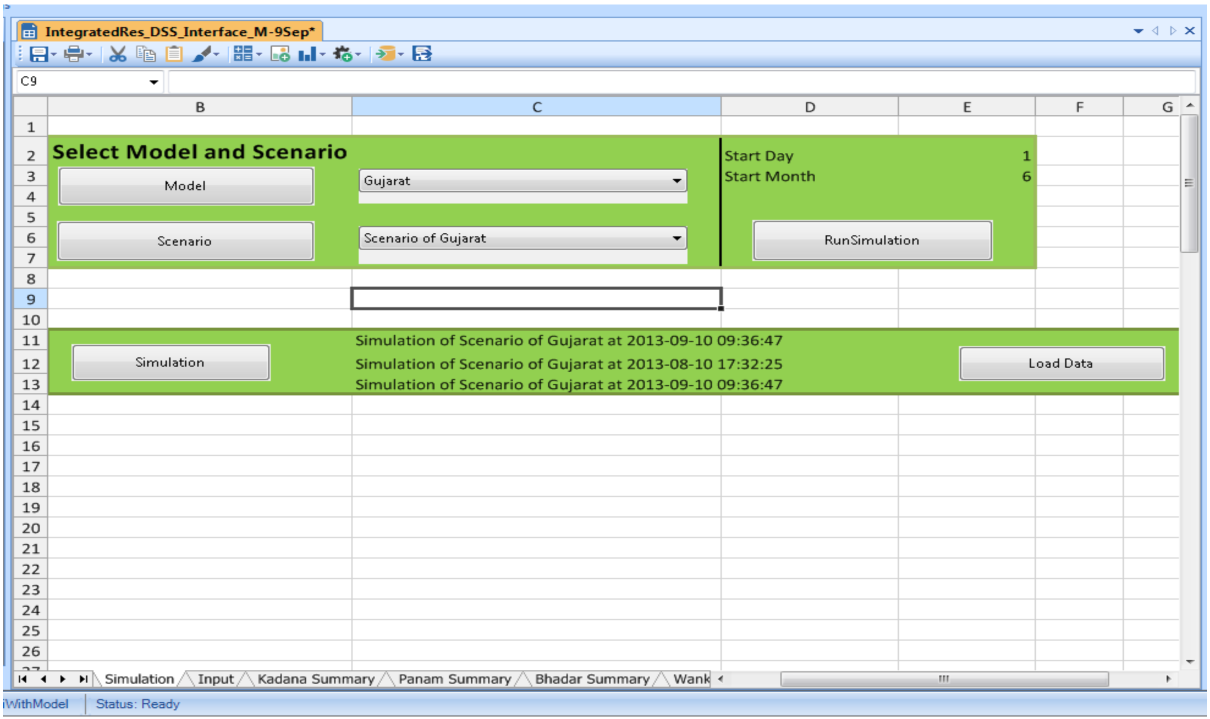



Figure 3.33: DSS User interface for integrated reservoir operation application

Output from this application allows reservoir managers to evaluate alternatives of reservoir operations and deliveries to water users that take into account the conditions and rules in the Kadana and Bhadar Reservoirs as well as water delivery to water users. The output interfaces present results from multiple scenarios for both facility and system-wide result presentation. The Integrated Reservoir Operations DSS Application output interfaces include:

Individual Facilities: Shows a predictive graph of each reservoir water level as well as tabular display of the demand, supply, and deficit of the drinking water and irrigation water users per reliability of inflow

System Results: Depicts graphs of water levels for reservoirs, water delivery by sector, and days above flooding.

The concept is to have managers investigate reservoir operations with regard to water demands or flood control restraints given a multiple reservoir system. Specifically, the DSS Application helps the managers to address:

- Refinement of flood control level time series in the Kadana, Panam, and Bhadar Reservoirs.
- Development of a release schedule based on weather and demand forecasts to recommend how much water each reservoir should release to support the Wanakbori Weir demand and minimize the downstream spill from the weir.
- Determining the operational curves and release schedule given changing downstream

water requirements.

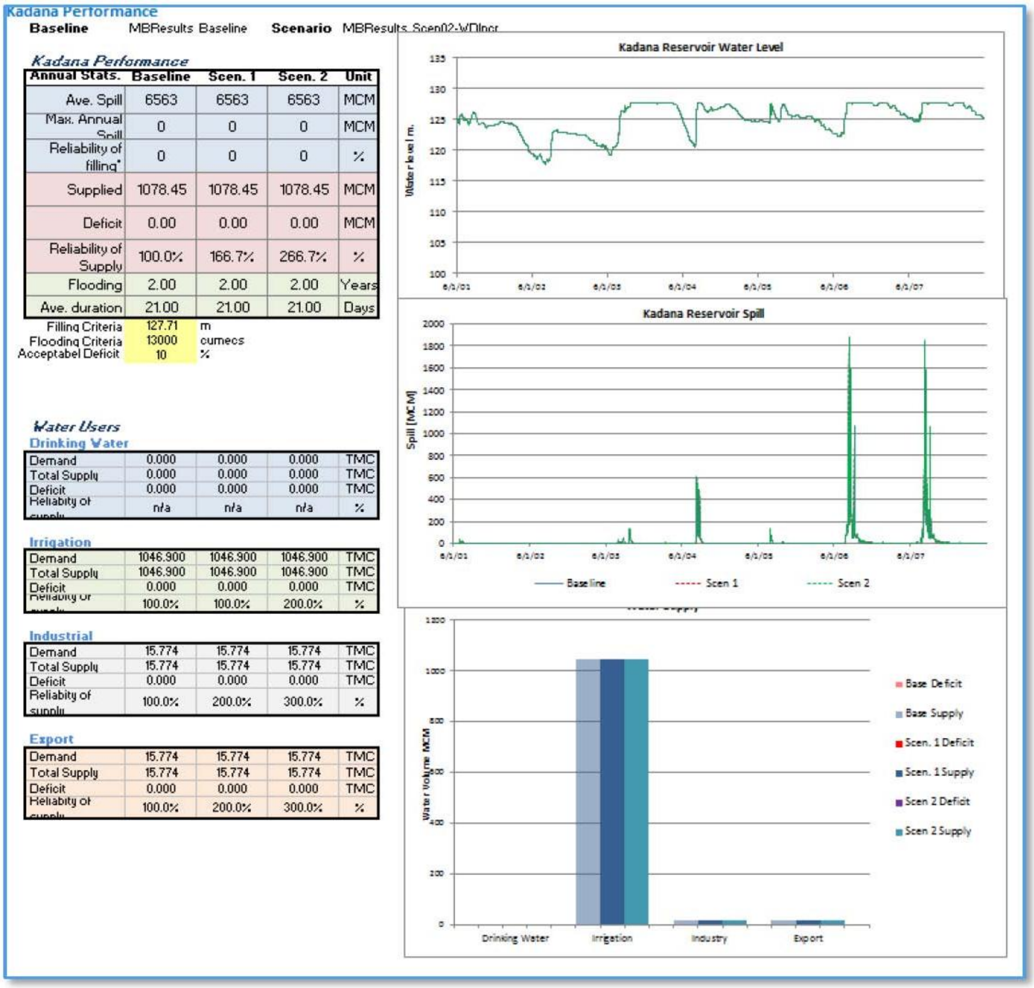



Figure 3.34: Reservoir summary for integrated reservoir operation DSS application

### 3.3.3.3 Conjunctive Water Management/ Groundwater Sustainability Planning

The conjunctive water management/groundwater sustainability planning DSS application evaluates the response to changes in catchment inflows/groundwater recharge, reservoir operations, and sector-wise water use within the study area over a longer period. The output interfaces for conjunctive use and groundwater planning are shown in Figure 3.35 and Figure 3.36.

Output from the Conjunctive Water Management/ Groundwater Sustainability Planning DSS Application interface allows the GWD (Groundwater Department i.e. GWRDC) to evaluate alternatives of management on a system-wide and catchment basis. For example, to evaluate the long-term sustainable groundwater draft, annual groundwater drafts were tested over the full simulation period in the Machhanala Catchment. Current abstraction drafts were tested then refined till the beginning and ending relative depth to groundwater were equivalent. The result is a quantum of water that can be safely abstracted without any detriment to the groundwater supply by excessive pumpage. These results can also be used by water managers to plan strategies for groundwater resources.

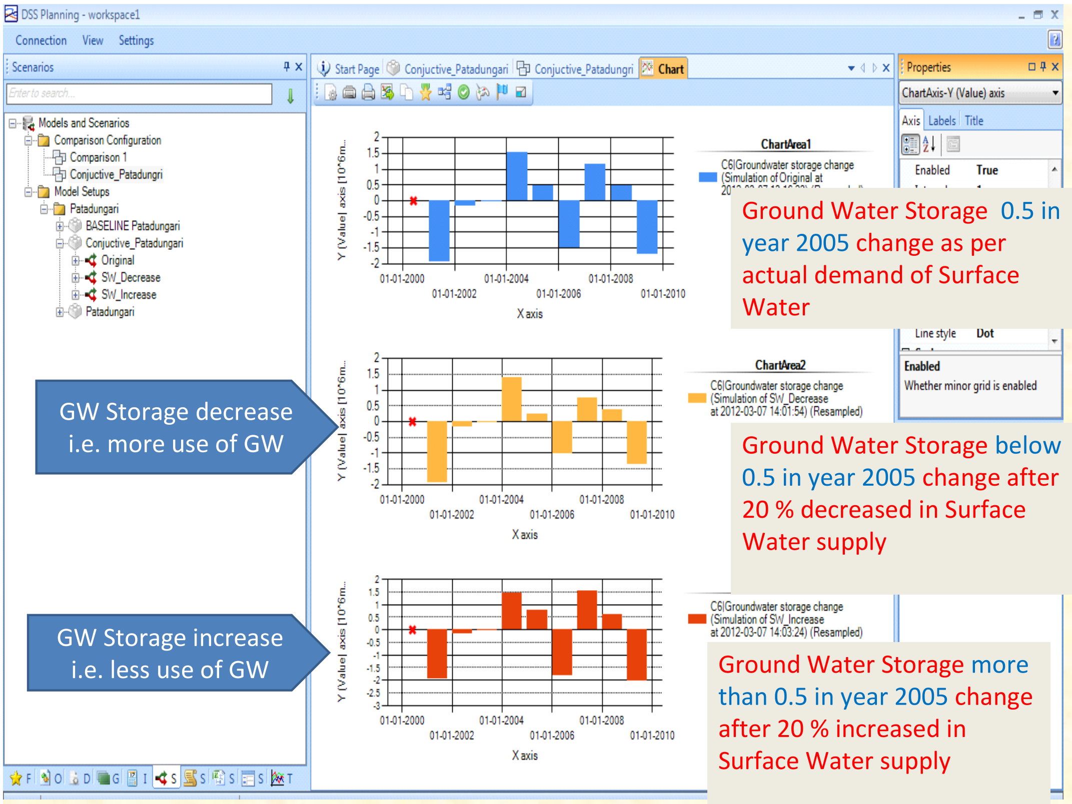



Figure 3.35: Illustration of output interface for conjunctive use application for Patadungari

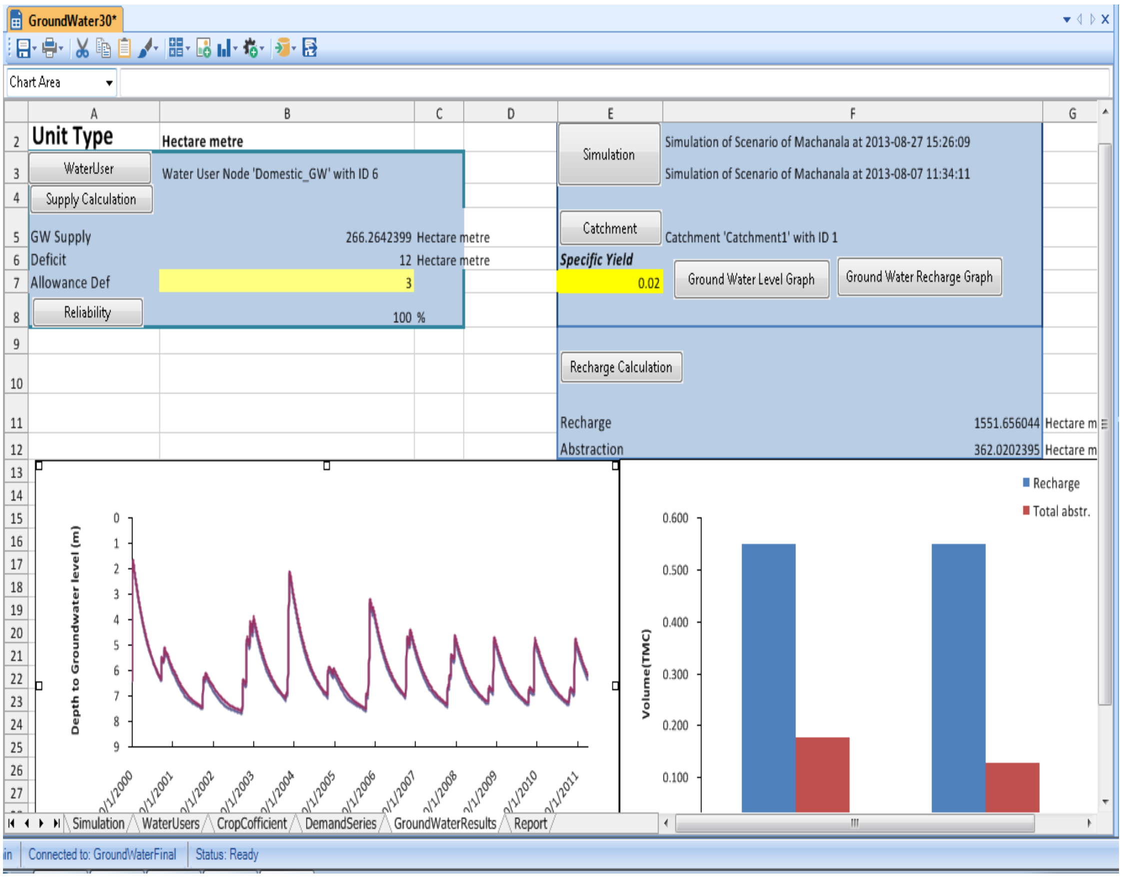



Figure 3.36: Illustration of output interface for groundwater planning for Machhanala

Figure 3.37 shows the simulated water levels for various stages of groundwater development in Patadungari using the DSS application developed for groundwater planning.

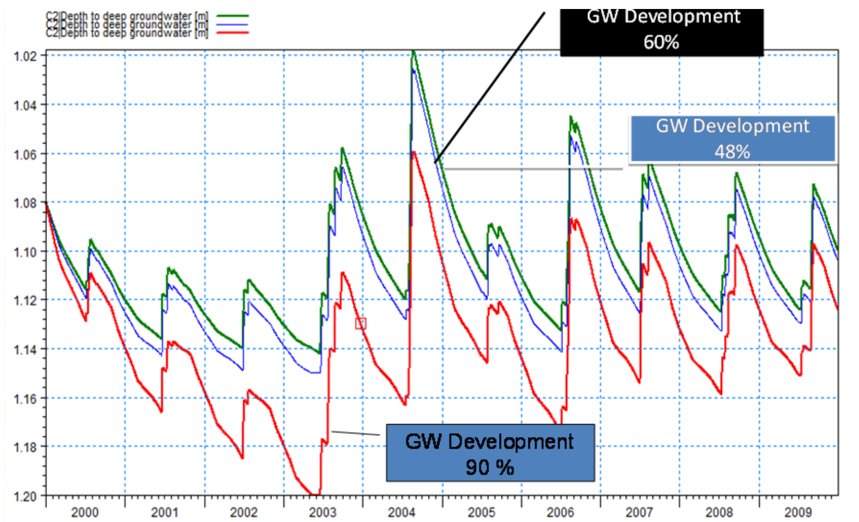



Figure 3.37: Simulated water levels for various stages of groundwater development

#### 3.3.3.4 Artificial Recharge

For mitigation of drought, one of the promising options is to increase water availability in drought prone areas by means of artificial recharge. Infiltration of surface water runoff can be increased during monsoon season through a series of check dams, abandoned wells, or tanks. The application has been developed in MIKE BASIN for Machhanala, for which time series of surface water runoff and natural recharge to groundwater were available. The variations in groundwater storage over this period of time were simulated with and without the proposed artificial recharge for given values of groundwater abstraction. Figure 3.38 shows how the groundwater depth would vary with and without artificial recharge for different rainfall years (dry, average and wet). Analysis of this type requires an overview of all potential structures within the area and an assessment of the total infiltration capacity of these structures.

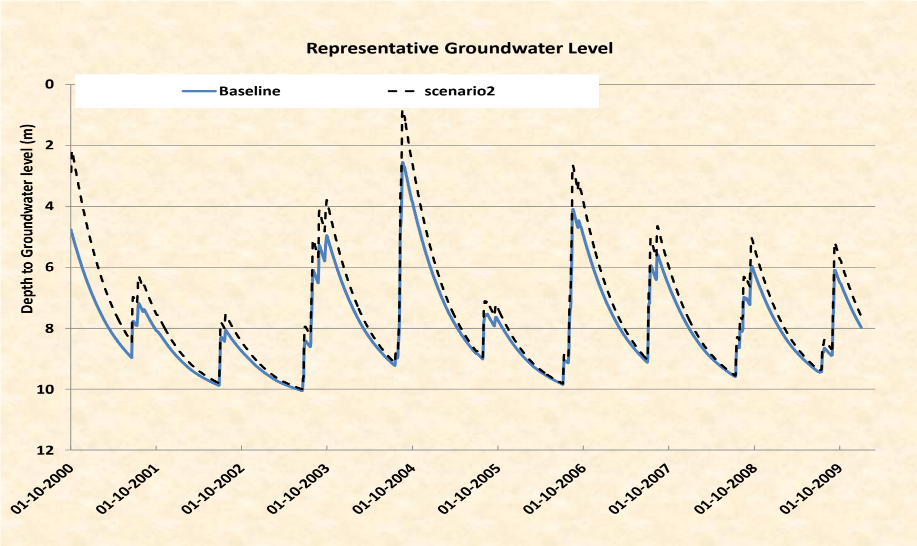



Figure 3.38: Variation in groundwater levels for baseline and recharge scenarios

### 3.3.3.5 Drought Monitoring and Assessment

A dashboard for display of drought affected talukas and drought severity was developed based on Standardized Precipitation Index (SPI) (Figure 3.39). Based on precipitation data, SPI is used for estimating wet or dry condition for a given region. It can provide early warning of drought and help in assessing the drought severity. The dashboard can be utilized to display on web the severity of drought in a location for a given year.

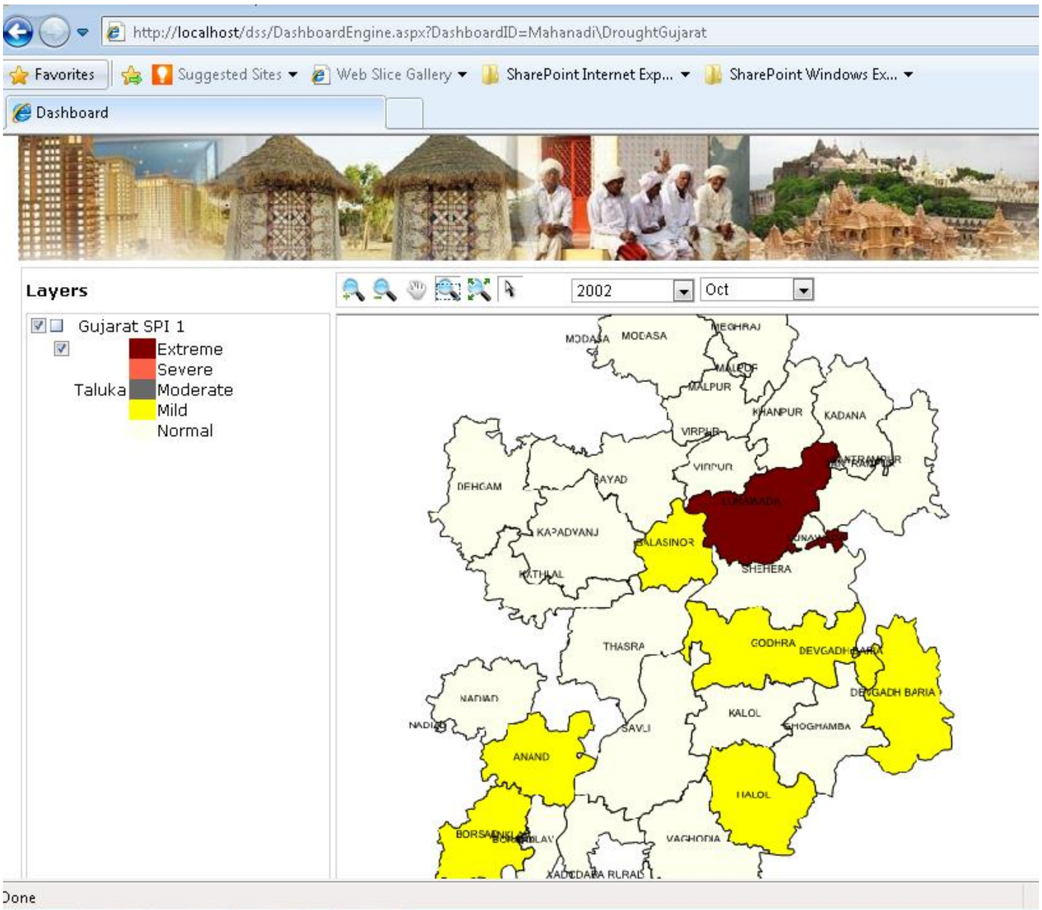



Figure 3.39: Illustration of dashboard for drought assessment

### 3.3.3.6 Water Quality Dashboard

Another dashboard for display of temporal variations in water quality of a well has been developed for the purpose of monitoring groundwater quality over the time scale (Figure 3.40)

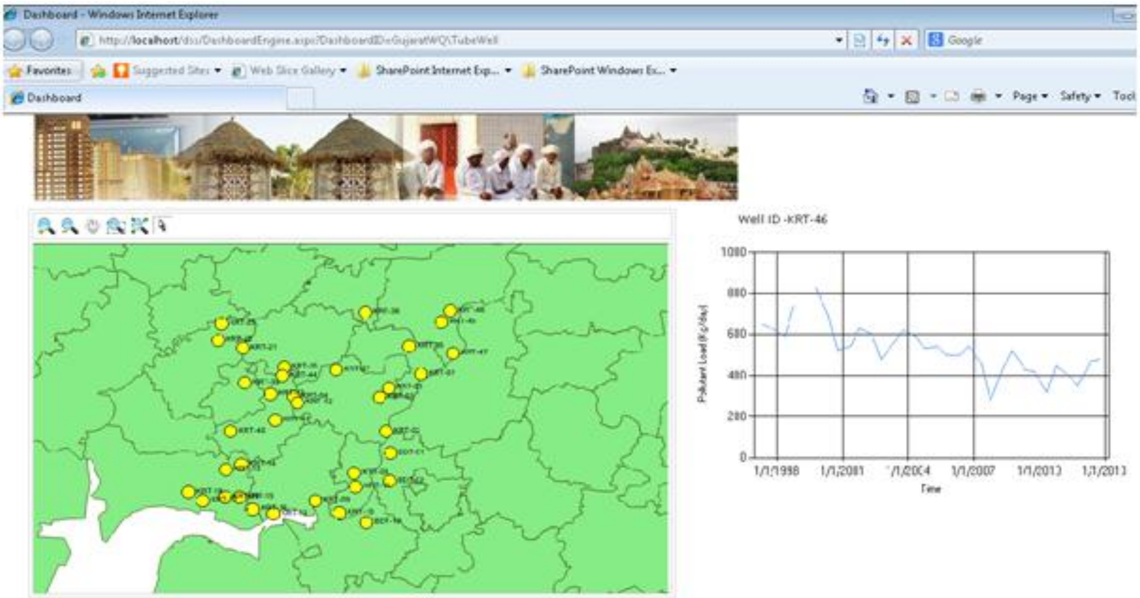


Figure 3.40: Illustration of dashboard for water quality monitoring

### 3.3.3.7 Additional Developed Interfaces

Additional interfaces developed on DSS Platform to facilitate applications for Gujarat include (a) Reservoir Working Table interface (Figure 3.41) and (b) Dependable year interface (Figure 3.42).

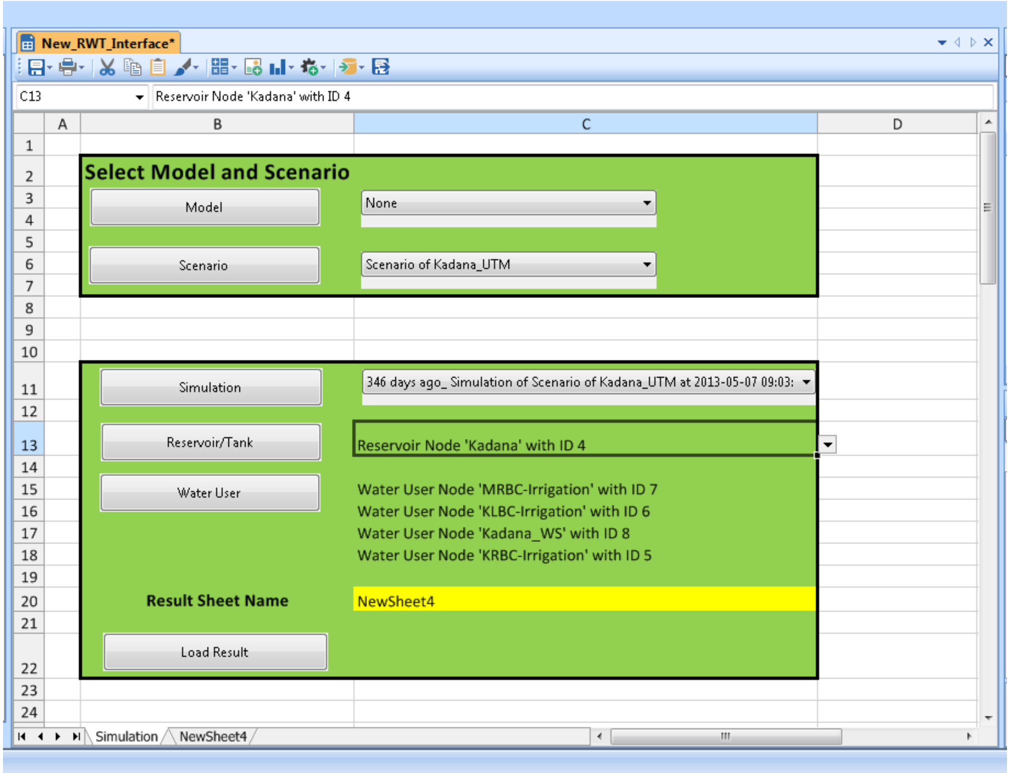



Figure 3.41: Reservoir Working Table interface

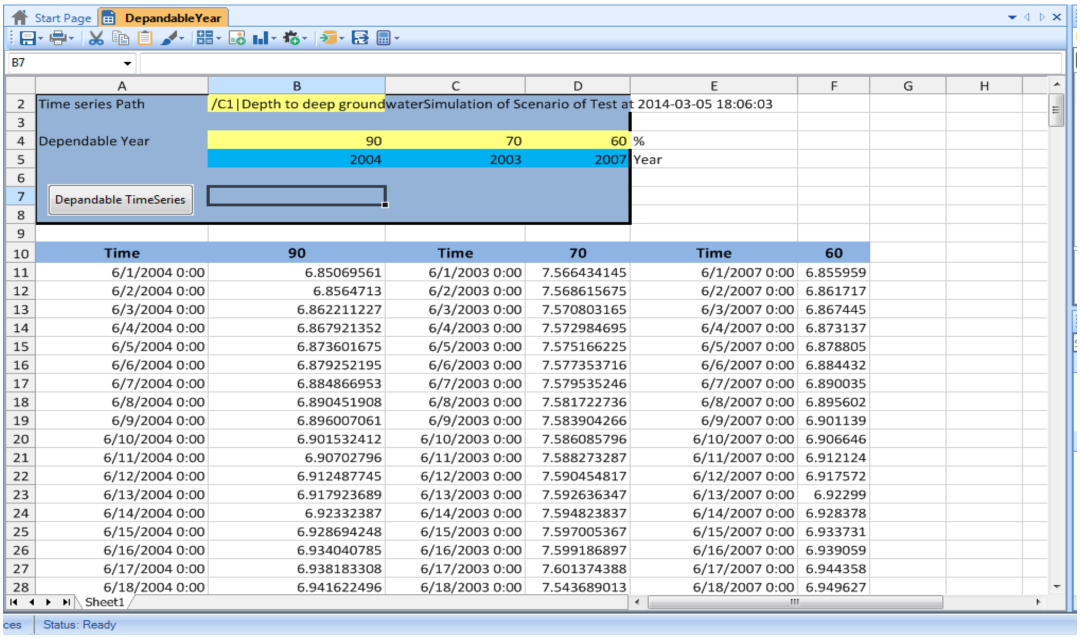



Figure 3.42: Dependable year interface

### 3.3.3.8 DSS Sustainability

In addition to developing DSS Applications, Gujarat has initiated in-house trainings for its officers on the usage of DSS Applications. Work has also been initiated for setting up of RBMs for five new basins. The output of the DSS can be further utilized in many ongoing projects in Gujarat such as the Sujalam Sufalam Yojana and in the Kalpasar project for computation of surplus water draining to the sea.

Primary users of the DSS are the Surface Water Department and Groundwater Department. Potential additional users of the DSS include Gujarat Agriculture Department, Participatory Irrigation Management (PIM) and Water User Associations (WUA) within command areas, NGOs and academic organizations. It is envisioned that the DSS can help law-makers, engineers, and public outreach efforts (both state and NGOs) for testing the effects of water management strategies within the command areas (e.g. cropping patterns/irrigation methods/conjunctive use strategies) and educational programs to help promote better water use.

## 3.4 DSS APPLICATIONS – KARNATAKA STATE

### 3.4.1 Palar Basin

The Palar basin is having geographical area of 2860 SqKm located between north latitudes 12° 51' 25'' to 13° 25' 12'' and east longitudes 77° 52' 44'' to 78° 34' 48''. The total population in this area is 9.5 lakhs (as per 2001 census).

The basin is predominantly is having rock types such as granites, peninsular gneisses and schists of Achaean age. These formations are fractured and jointed up to 250m-300m from surface giving room to ground water accumulation and flow. This hard rock is weathered at the top up to a thickness of 10-12m from surface. The weathered zone is overlain by red to brown sandy soil with thickness of about 2-3m. The large part of the area is gently undulating or plain flat terrain with very low slope. The Soil nature, climate with moderate rainfall and other geographical factors are favorable for agriculture and horticulture.

During 1980 decade open or dug wells were in large numbers and were the source for irrigation. Gradually as the ground water abstraction increased the water table declined below the phreatic zones. As a result of this, dug wells dried up and farmers began to sink bore wells which became popular and the number grew to very large extent extracting ground water more than normal annual replenishment. Ground water table decline*e continued resulting in drying up of shallow bore wells. Farmers as a result began to sink deeper bore wells in search of resource for retaining and saving perennial and horticultural crops. Thus overexploited situation of ground water resource has continued till the present time. This condition added adverse effect on tank storage also, as there is effluent situation throughout the time from surface to ground water resource.

### 3.4.2 Palar River

The Palar River, one of the west flowing rivers of peninsular India originates in Kolar district, Karnataka state. The total length of the Palar River course is 348km and it runs for 93km in Karnataka. Further enters Andhra Pradesh and Tamil Nadu and finally joins Bay of Bengal. The total catchment area is 17871SqKms The Palar basin in Karnataka covers an area of about 2860 SqKm. The normal annual rainfall in the basin 780mm. Bulk of rainfall occurs during southwest monsoon session. Thus Palar Karnataka's portion is essentially initial catchment area, dominantly ground water dependent with very little surface resources from the tanks.

In Palar basin there are 2138 minor to medium tanks. Most of the tanks remain dry in major part of the year except for few weeks during monsoon season. These tanks are ancient with the siltation up to 35 to 40% of their live storage. The surface flow in main course and the streamlets is limited to a few days soon followed by rainfall of considerable intensity. There are no major irrigation projects within the area.

Under well command Mulberry, Vegetables, Fruits and Coconuts as Horticultural and Plantation crops are being raised.

### 3.4.3 Palar Ground Water Mike Basin Modelling.

Developing the ground water model in Palar basin was carried out using available time series data such as rainfall, evapotranspiration, water levels and other GIS layers such outer boundary, drainage, land use land cover, geomorphology etc., Ground water abstraction time series were created using GEC data. The time series data were converted into dsfo format to be useful in Mike 11 and Mike basin modelling software.

Table 3.2: Data availability table

| Description | Number | Frequency | Data availability | | |
|---|---|---|---|---|---|
| | | | **From** | **To** | **Extended up to** |
| Observation wells | 45 | Monthly | 25-Jan-73 | 29-Oct-09 | 2010 |
| Rain Gauge Stations | 18 | Daily | 1990 | 2008 | 2010 |
| ET station at Kolar | 1 | Twice daily | 1-Sep-2003 | 31-03-29 | 2010 |

#### 3.4.3.1 Modelling Procedures

1. The DEM with 60m resolution was geoprocessed to trace rivers and to delineated catchments and boundaries in Mike basin.
2. The temporal data for rain gauge stations and observation wells were linked with their respective spatial data (point shape file).
3. Using weighted rain fall, ET time series and abstraction rate time series in Mike 11 NAM ground water option, runoff and recharge time series outputs were obtained by calibrating observed and simulated water levels
4. The obtained runoff and recharge time series for each individual catchment were used in MIKE BASIN ground water modelling.

Initially for training the model was built on 4 watershed catchments for the 5 years period from 2004-2008. Later this procedure was extended to all the delineated 20 catchments extending the calibration time from 1990-2010. MIKE BASIN model was set up for 20 sub basins with user nodes domestic, paddy irrigation and non-paddy irrigation. The catchment properties and the user nodes properties were given for all the catchments. Runoff and recharge time series for all the catchment as well as water user time series were loaded to respective nodes. The model was run and the simulated depths to deep groundwater level results were viewed with observed water level in each catchment. Further catchment has been calibrated till the observed and simulated groundwater level matched.

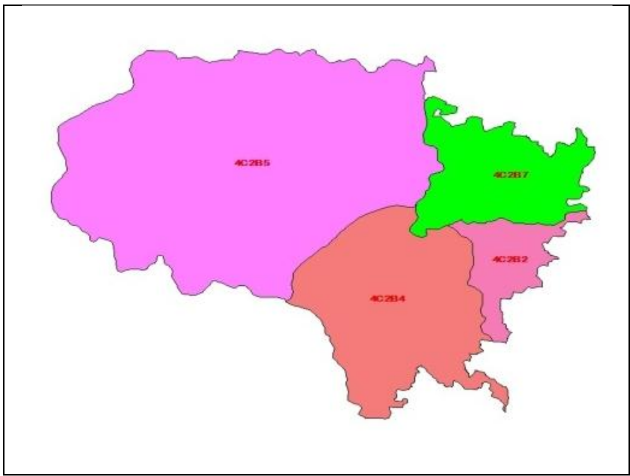



Figure 3.43: Palar Basin showing 4 catchments

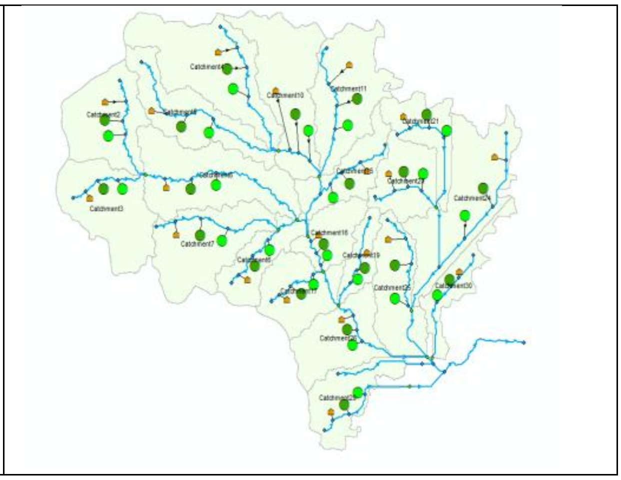


Figure 3.44: Palar Basin showing 20 catchments

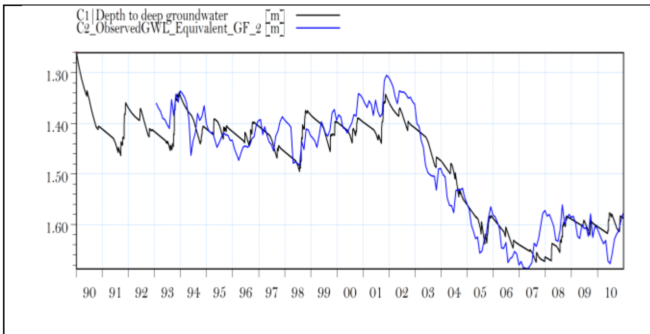



Figure 3.45: Calibration plot showing observed and simulated ground water levels for Catchment 2

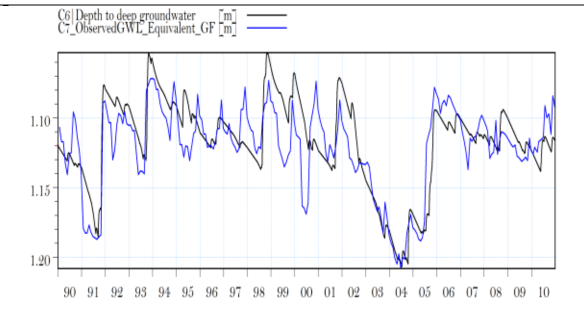



Figure 3.46: Calibration plot showing observed and simulated ground water levels for Catchment 7

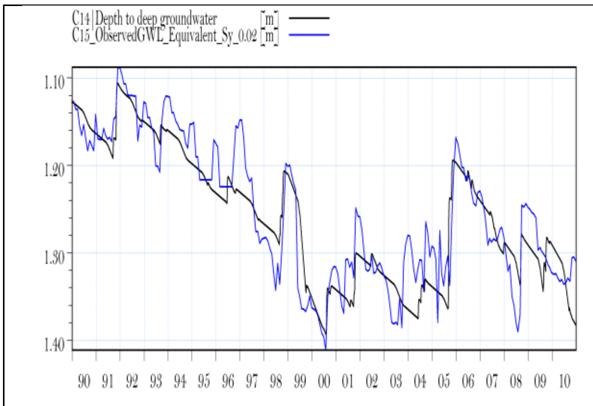



Figure 3.47: Calibration plot showing observed and simulated ground water levels for Catchment 15

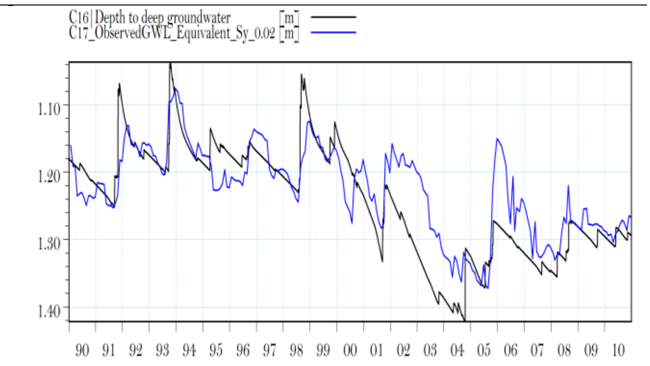



Figure 3.48: Calibration plot showing observed and simulated ground water levels for Catchment 17

### 3.4.3.2 Application of Model

The model is sensitive to a given Mike basin properties and can be applied to scenarios of what and if situations.

#### 3.4.3.2.1 Application of Model for estimation of sustainable rate of abstraction.

It is observed in most of the catchments water table is declining due to over abstraction particularly in the years of draught and a sustainable amount of abstraction advisable for long term has to be determined. Example of this application in the catchment no 2 is illustrated

- In catchment 2 there is a drop down in water level from 2002 to 2004 and in later years the water level is maintained and further it is slowly recovering from 2008 onwards ( Graph 1)
- The drop down of water levels in these years is because of less recharge in one hand and increase in irrigation abstraction on the other hand because of less rainfall than normal rainfall
- In order to determine sustainable level different rates of abstractions were applied in the model to observe the changes in the water levels from 1990 to 2010

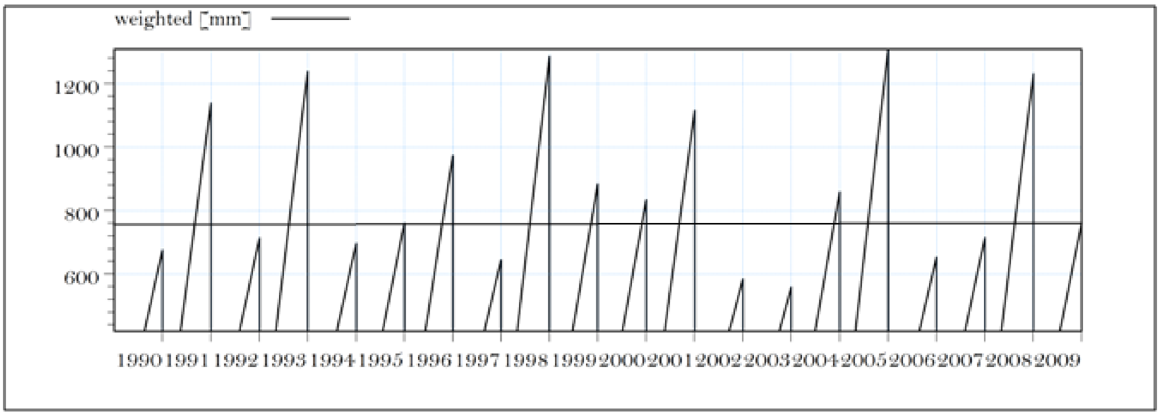



Figure 3.49: Graph showing Normal Annual Rainfall 785mm

- Abstraction rates of 2008 and 2009 were given for all the years from 1990-2010 and the simulation was simulated independently.
- The water level show gentle rise in both the cases
- Similarly abstraction rates of 2003 was given for the entire period to observe great decline in the water level

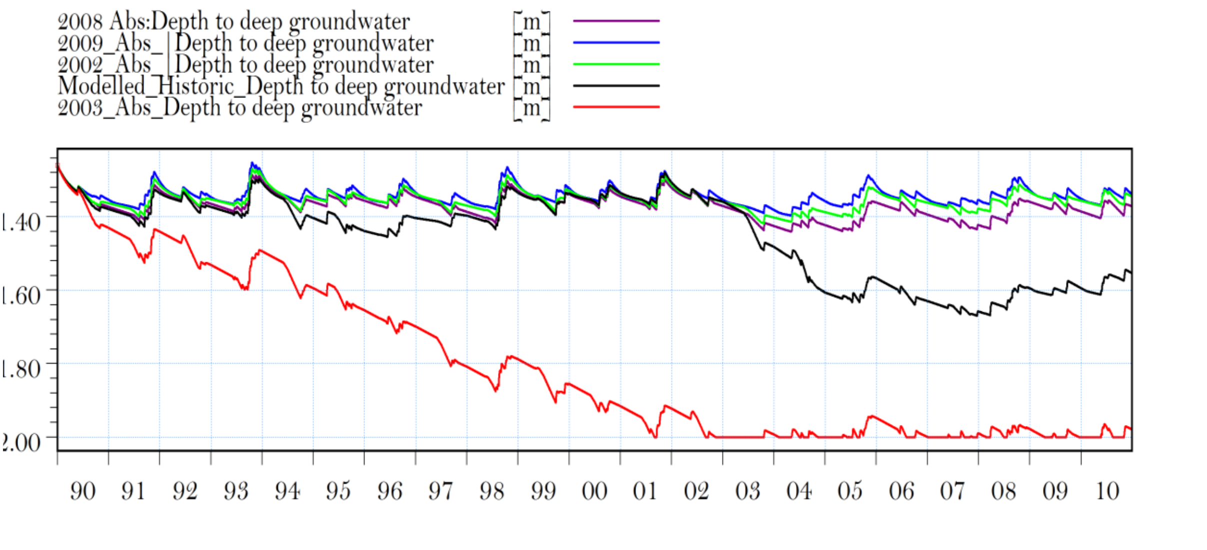



Figure 3.50: Simulated graph with different rates of abstractions

- The average rate of abstraction of 2003 and 2009 was taken for entire period (1990-2010), simulation was run with the initial level taken as that of 2008
- The water level plotted of this simulation showed gentle decline, suggesting the abstraction rate is slightly more than the sustainable rate
- Sustainable level was reached at 85% of the average rate of abstraction of 2003 and 2009

The levels of abstraction and the amount of variation for the years 2002, 2003, 2008 and 2009 are shown in the graph 6

Table 3.3: Table showing average annual abstraction and variation in abstraction from sustainable rate

| | Average Annual Abstraction Ham | Variation in Abstraction from Sustainable Rate Ham | Remarks |
|---|---|---|---|
| 2002 | 1113 | -80 | Nearer to sustainable |
| 2003 | 2428 | 1235 | Higher than sustainable |
| 2008 | 1331 | 138 | Higher than sustainable |
| 2009 | 907 | -286 | Nearer to sustainable |
| Sustainable Rate | 1193 | 0 | Rate recommended |

This application in catchment 2 shows the long term sustainable amount of abstraction useful at the time of implementation of rules pertaining to ground water legislation very recently passed by legislative houses of Karnataka State. The amount of abstraction for individual well owner can be calculated fixed and insisted at the time of well registration. (Well registration is an obligation on the part of well owner in the notified area as per rules of this bill)

### 3.4.4 Tungabhadra Command Area

The water resources issues identified for the TCA are water logging, water scarcity for tail end users, and increasing soil salinity. Common practice is for the head users of the canal to take the water first, flooding the fields and leaving irrigators at the tail end of the canal with limited irrigation water. For the head users, the excess water applied to fields raises groundwater levels that in turn leach salts from the black cotton soils towards the ground surface. Tail end users use groundwater to augment crop water requirements when surface water is short which creates declining groundwater levels. In the light of these problems in the command area, a DSS Application was developed to assist GoK SWD to evaluate the conjunctive use of surface and groundwater in the command area). It is envisaged to look for methods to solve water logging and reclaim the land and also to improve the groundwater levels in the tail end of the command area.

#### 3.4.4.1 Background

Supplying water to the TCA is the Tungabhadra Reservoir. The Tungabhadra Reservoir, constructed in 1958, is located at Munirabad in Bellary District, and has a catchment area of 28,177 km$^2$, a reservoir capacity of 3,751 Mm$^3$, and an annual yield of 11,528 Mm$^3$. The ex- tent of the TCA is 5,050 km$^2$ and lies in the Bellary, Raichur and Koppal Districts of Karna- taka. The right bank canals also service the command area in Andhra Pradesh. This multi- purpose reservoir provides service to the irrigation, domestic/municipal, and hydropower water use sectors. The combined installed capacity of the hydropower units is 63 MW.

Irrigation waters are released from the reservoir during the Kharif season (June to November) and the Rabi season (December to March). Water is released in four canals: the left bank lower canal (224 km in length), left bank high canal (15 km in length), right bank lower canal (349 km in length), right high canal (196 km in length). The left bank canals service the command area in the Koppal and Raichur Districts and the right bank canals service the command areas in the Bellary District. Water distribution in the left bank canals distributaries is controlled/measured by the SoK. For the right bank canals, the water distribution in the canals is controlled/measured by the SoK at the diversion off the main canals. The DSS for the TCA is to be developed to address the water resource issues in the left bank lower canal. Land use within the TCA is primarily agricultural.

Groundwater in the TCA is primarily extracted from black cotton soils (up to 10 m) for dug wells and late Achaean granites and gneisses with varying degree of weathering for bore wells. Red sandy/loamy soils are noticed in the elevated areas and along hill slopes. Associated with the black cotton soils are high salinity concentrations (5,000 - 10,000 ppm).

#### 3.4.4.2 Users of the TCA Application

The GoK SWD is responsible for monitoring precipitation, river discharge, and surface water quality; operating projects; and planning for future water projects and infrastructure. The TCA DSS Application has been specifically designed to assist GoK staff in assessing the con- junctive use of water as well as the impacts for changing agricultural practices and lining of canals the Tungabhadra Project. Using the application, the GoK SWD can evaluate conjunc- tive management strategies (e.g. promoting groundwater use in the upper basin) as well as supporting the education of the agricultural community on beneficial crop types and irriga- tion practices for the long term sustainability within the TCA.

In addition to regulation and planning, the GoK, research organizations, and NGOs are providing education on efficient water use. The GoK Department of Agriculture is educating farmers on better crop management methods. NGOs are assisting in Water User Associations (WUA) and educating farmers, households, and municipalities on better water use practices through education and community based planning. It is envisioned that the TCA DSS Application can be expanded for law-makers, engineers, and public outreach efforts (both State and NGOs) to appraise water management strategies and educational programs to help promote better water use within the command area.

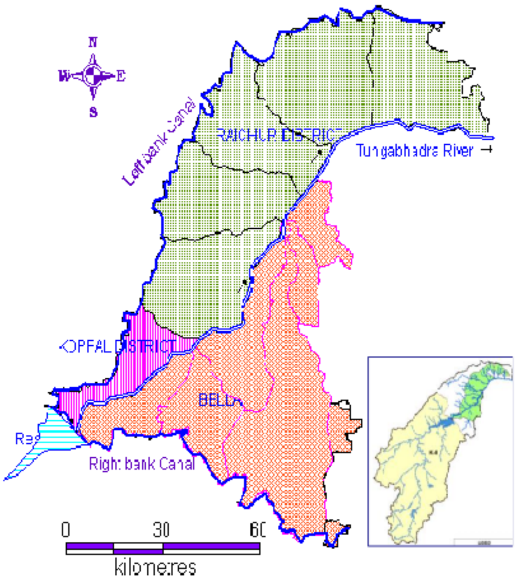



Figure 3.51: Study area

**Data**

The GoK SWD collected geographical and time series data to support the development of the TCA application. Important time series collected include precipitation, evapotranspiration, canal flows, inflows to Tungabhadra Reservoir, and groundwater levels. In addition, information on the salient features and land use-land cover and soils maps has been processed to enable construction of models, assessment of the availability of both surface and groundwater, and analysis of water management options. Daily hydrological and meteorological data has been extracted from SWDES and processed along with the required time series of daily reservoir data, collected from the project authorities. Groundwater levels have been collected from GWDES and used to define groundwater conditions underlying the TCA. Within the DSS, time series data have been linked to GIS information for quick reference. Below is an example of discharge information and a duration curve as produced in the DSS.

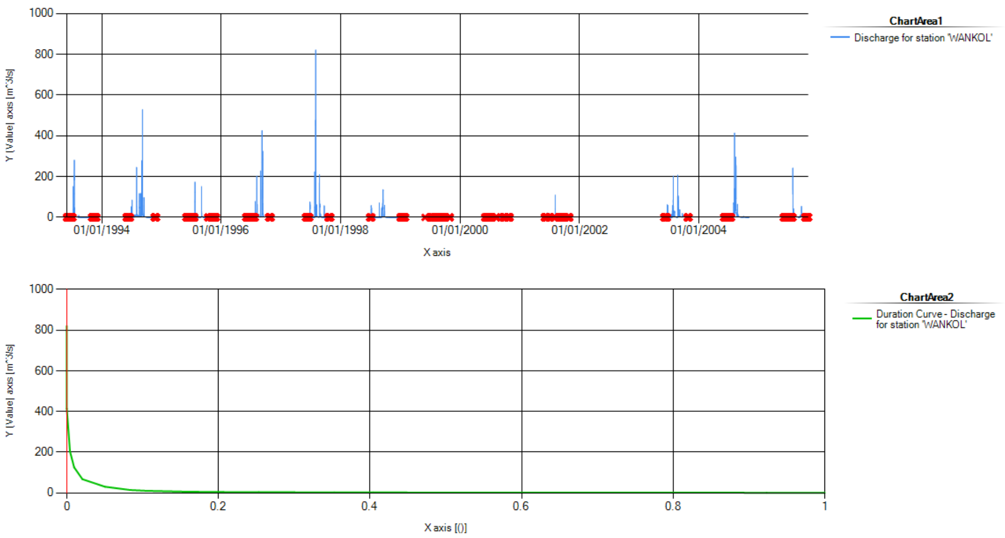



Figure 3.52: The discharge observed and corresponding duration curve for the gauging site at Wankol

**Model Development**

Supporting the TCA DSS Applications are River Basin Models (RBMs), that has been developed for the Tungabhadra Reservoir Left Bank Canal Command Area using MIKE BASIN. These models enable GoK SWD to evaluate possible changes in the water demands, water delivery strategies, and general water management etc. The work was carried out by the modelling teams GoK SWD with support from the Consultant and NIH.

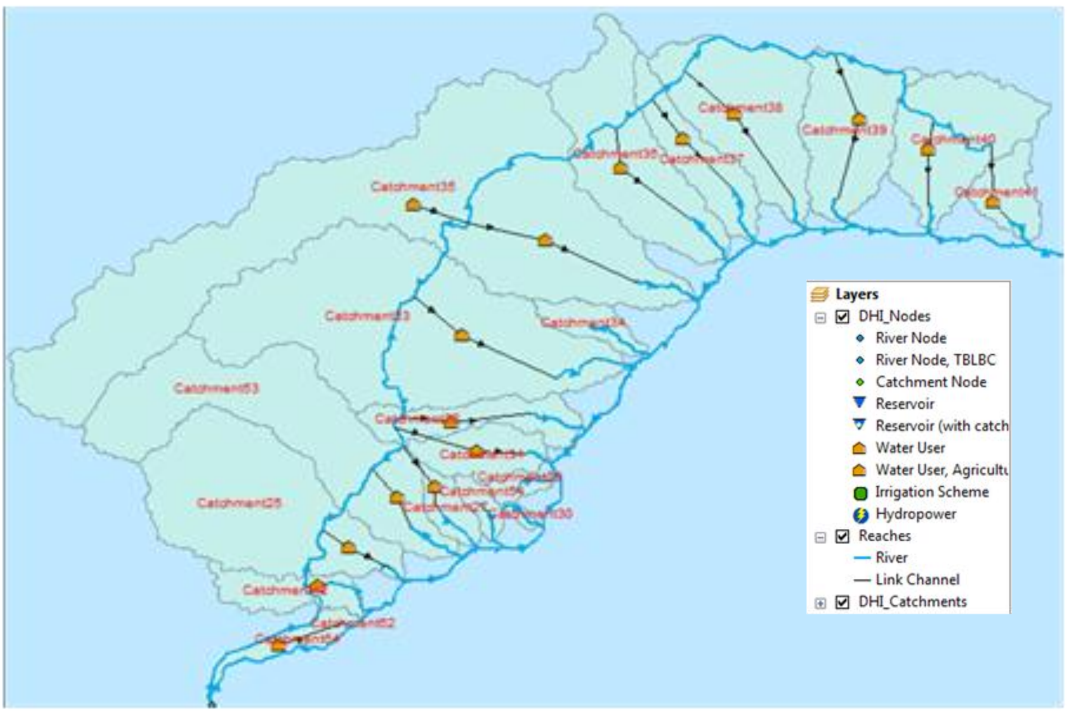



Figure 3.53: RBM setup for the Tungabhadra Reservoir LBC Command Area.

The Tungabhadra Command Area RBM is defined by 17 catchments each including water user nodes representing irrigation. Catchment runoff and ground water recharge were computed using the NAM model and imported to the RBM. All catchments employed MIKE BASIN's 2-layer model for simulating groundwater use and availability. Domestic water use was deemed insignificant in comparison to irrigation practices and thus excluded from the RBM.

The irrigation demand for the water use within each catchment in the command area was calculated by determine the areal extent of irrigation in the command area from landuse cover maps and applying literature values from GoK Department of Agriculture for crop water requirements per area. The 2004, 2007 GEC 97 data sets (for census of crop types and well counts) were used to validate the values. In the model, water supplied to each irrigation node can be delivered from both canals and groundwater. To regulated inflow from the canal, the ditch capacity associated with the inflow link channel is set to the desired amount delivered via the canal system with the balance being supplied by available groundwater. This allows the decision maker to change the quantity delivered by the canal to test conjunctive use alternatives in each catchment. Return flow quantities return to both the stream network and underlying groundwater catchment.

Using time series information from the TCA model, two additional models were constructed to demonstrate evaluation of conjunctive use management within the D25 Distributary and between the D25 and D54. These models were conceptually identical to the regional scale model in network configuration and methodology used to generate catchment inflow, groundwater recharge, and water demand time series. The exceptions are the network were developed as schematics of the system and, for the D25 Distributary, an additional node was introduced that represents GW pumped back to the stream network for use downstream. This addition was included to allow water managers to test this as a potential mitigation for lowering GW in the upper reaches of the distributary and supplying additional surface water flow to the lower reaches.

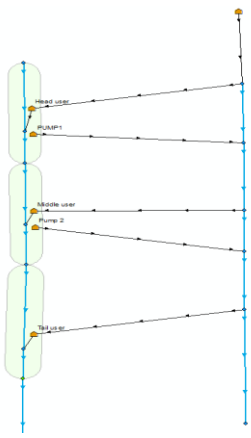



Figure 3.54: Schematic model of the T25 distributary in the TCA. The three polygons to the left represent the upper, middle, and lower portions of the distributary.

## DSS Applications

Three DSS Applications regarding conjunctive use of ground and surface water were undertaken in the TCA: i) for the D25 Distributary, ii) between the D25 and D54 Distributaries, and iii) throughout the LBC command area. The former two applications were used to refine and demonstrate the analysis with the latter application using finding from the first two examples in a systemwide analysis.

Each application consists of compared Baseline and Proposed Scenarios. For the Baseline Scenario, representing current conditions, users divert the maximum surface water necessary to fulfil their demand thus precluding downstream users from obtaining surface water supply. In contrast, the proposed scenarios restricts upstream users to divert only a portion their demand from surface water, thus letting canal water proceed downstream for other users. The demonstration objectives were to increase overall delivery of surface water, maintain or improve ground water levels, and increase delivery. Customized DSS interfaces were developed to support these analyses. Brief descriptions of the DSS Applications are presented below.

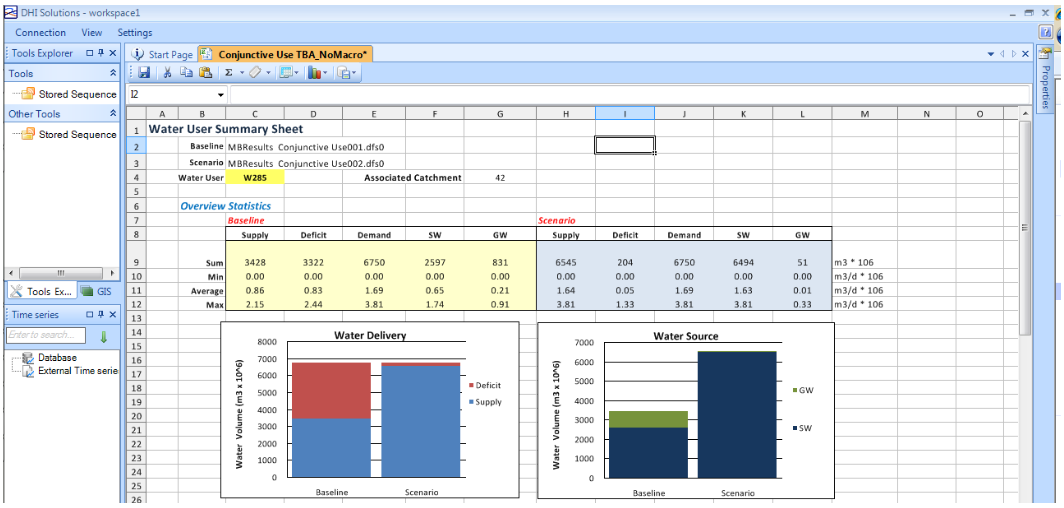



Figure 3.55: Example of output for an irrigation water use in the TCA DSS interface.

## Within the D25 Distributary Conjunctive Use Study

An analysis has been carried out in examining the issues of water logging and areas of critical water deficit zones within the TCA LBC D25 and D54 Distributaries. A schematic RBM has been set up for each of the D25 Distributary with the total command area for each of the distributaries has been divided into sub-command areas as Head, Middle and Tail Sub-Command Areas. The D25 and D54 Distributaries have command are- as of 132 $km^2$, which have been divided equally into the three sub-command areas of 44 $km^2$ (D25

Distributary).

Associated with each sub-command area is a water user node and for the Head and Middle Sub-Catchments, a node representing groundwater pumped back to the canal system. The total irrigation water demand for the command areas has been made available from GoK SWD. However, the demands for each of the sub-command areas within the distributaries are not available, therefore it was assumed the head, middle and tail user demands be allocated as 45%, 30%, and 25% of the total demand, respectively. For all users, surface water from the canal is taken first with the balance being supplied by groundwater. In both distributaries, the base condition is for the head user to withdraw the maximum water, leaving no or less water for the tail user.

Due to a discrepancy between the design crop and what is currently planted, a water deficit exists in all sub-command areas as the distributary capacity was designed for crops requiring less water. Therefore, groundwater is required in all sub-command areas to augment irrigation requirements. All the scenarios has been modelled with the assumption that there is a flow loss of 5% in the canal, and the return flow from the user is 40%, with 30% of the return flow lost through seepage. However for the tail user it is assumed that all the 40% of the return flow contributes as seepage loss.

Different scenarios have been modelled that partition available surface water from the canal network amongst the users and with different rates of abstractions of groundwater. The groundwater abstractions are tested to draft only the percentage of the fraction of the remaining demand (after surface water is supplied), to determine the groundwater depth. Pumping scenarios of ground water from the Head and Middle Sub-Command Areas, back to the distributary, to minimise the deficit at the Tail Sub-Command Area, has also been modelled. The goal is to maximize water delivery in the distributary while maintaining sustainable groundwater levels. The D25 and D54 Distributaries have been modelled separately.

**D25 Scenarios and Results**

Nine scenarios were simulated with varying degrees of groundwater supply and pump back to the stream. The description of the simulations and results are presented below.

**Baseline Scenario:** This scenario has been modelled using only the available surface water from the distributaries. No groundwater has been used in this scenario.

Baseline Scenario: No groundwater abstractions, uses only the surface
water from the Distributaries

**Scenario 1-5:** These scenarios have been modelled by using the available surface water from the distributaries, with various amount of groundwater abstraction. The abstraction has been carried out with various fraction of the percentage of the remaining demand after utilising the surface water.

- Scenario 1: With groundwater abstraction fraction (GWAF) of 1, i.e. abstracting 100% of the remaining demand from groundwater in all the sub-command areas
- Scenario 2: GWAF = 0.6, in all sub-command areas
- Scenario 3: GWAF = 0.65 (from Head), 0.55 (Middle), 0.4 (Tail)
- Scenario 4: GWAF = 0.70 (from Head), 0.50 (Middle), 0.30 (Tail)
- Scenario 5: GWAF = 0.90 (from Head), 0.50 (Middle), 0.30 (Tail)

**Scenario 6-9:** Same configuration as the above scenarios, but with varying amounts of pumping of groundwater from the Head and Middle Sub-Command Areas. The pumped water augments flows to down canal distributaries.

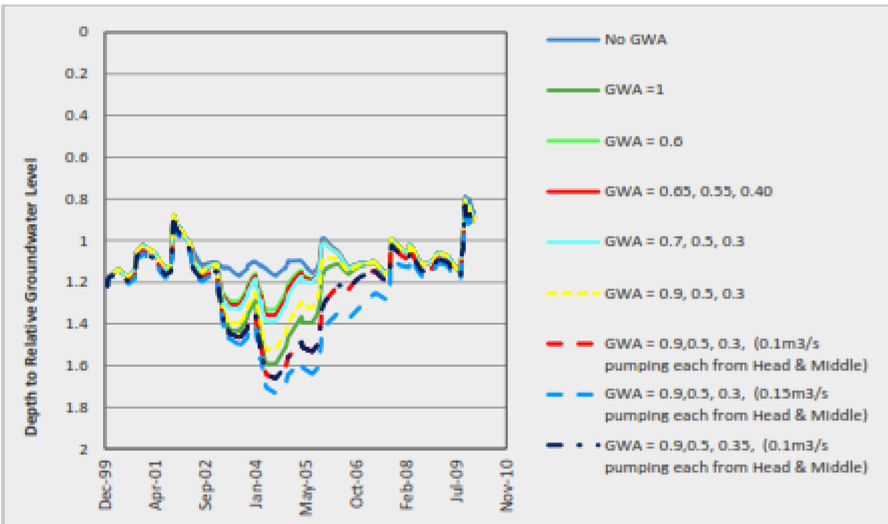
- Scenario 6: GWAF = 0.90 (from Head), 0.50 (Middle), 0.30 (Tail), 0.1 $m^3/s$ Pumping from each of Head and Middle Sub-Command Areas to the distributary
- Scenario 7: GWAF = 0.90 (from Head), 0.50 (Middle), 0.30 (Tail), 0.15 $m^3/s$ Pumping from each of Head and Middle Sub-Command Areas to the distributary
- Scenario 8: GWAF = 0.90 (from Head), 0.50 (Middle), 0.35 (Tail), 0.10 $m^3/s$ Pumping from each of Head and Middle Sub-Command Areas to the distributary
- Scenario 9: GWAF = 0.90 (from Head), 0.50 (Middle), 0.4 (Tail), 0.10 $m^3/s$ Pumping from each of Head and Middle Sub-Command Areas to the distributary

**Results:** Based on the overall delivery and sustainability of groundwater level in all the sub-command areas, Scenario 8 as the most favorable one. Iin the Head Sub-Command Areas, about 90 % of the remaining demand (0.26 TMC/year), after using surface water, can be safely extracted from groundwater. About 50 % and 35% of the remaining demand can be extracted safely from the Middle and Tail Sub-Command Areas respectively, which amounts to 0.38TMC/year and 0.46 TMC/year. This includes the pumping of groundwater 0.1 $m^3/s$ each from Head and Middle Sub-Command Areas back to the canal network for use downstream. Therefore the total safe abstractable groundwater in D25 is 1.11 TMC/year. The total sup- ply is 4.79 TMC/year with a deficit for Scenario 8 is 1.12 TMC. Scenario 9 is slightly large in supply (4.84 TMC/year), but the groundwater levels are unsustainable. Therefore, Scenario 8 is the best option for the D25 Distributary.

Table 3.4 Results from the Baseline and Scenarios 1-9 for the D25 Distributary. All results are in TMC/year.

| | ***Head*** | ***Middle*** | ***Tail*** | ***Head*** | ***Middle*** | ***Tail*** | ***Total*** |
|---|---|---|---|---|---|---|---|
| | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** |
| ***Demand*** | 2.66 | 1.77 | 1.48 | 2.66 | 1.77 | 1.48 | 5.90 |
| ***Surface*** | 2.50 | 1.17 | 0.08 | 2.50 | 1.17 | 0.08 | 3.75 |
| ***Groundwater*** | 0.00 | 0.00 | 0.00 | 0.16 | 0.60 | 0.83 | 1.59 |
| ***Pumping*** | | | | | | | |
| ***Supply*** | 2.50 | 1.17 | 0.08 | 2.66 | 1.77 | 0.91 | 5.34 |
| ***Deficit*** | 0.16 | 0.60 | 1.40 | 0.00 | 0.00 | 0.56 | 0.56 |
| | ***Head*** | ***Middle*** | ***Tail*** | ***Head*** | ***Middle*** | ***Tail*** | ***Total*** |
| | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TM*** | ***TMC*** |
| ***Demand*** | 2.66 | 1.77 | 1.48 | 2.66 | 1.77 | 1.48 | 5.90 |
| ***Surface*** | 2.50 | 1.24 | 0.17 | 2.50 | 1.17 | 0.08 | 3.75 |
| ***Groundwater*** | 0.09 | 0.32 | 0.79 | 0.10 | 0.33 | 0.56 | 0.99 |
| ***Pumping*** | | | | | | | |
| ***Supply*** | 2.59 | 1.55 | 0.96 | 2.60 | 1.50 | 0.64 | 4.74 |
| ***Deficit*** | 0.07 | 0.21 | 0.52 | 0.06 | 0.27 | 0.83 | 1.16 |
| | ***Head*** | ***Midldle*** | ***Tail*** | ***Head*** | ***Midldle*** | ***Tail*** | ***Total*** |
| | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TM*** | ***TMC*** |
| ***Demand*** | 2.66 | 1.77 | 1.48 | 2.66 | 1.77 | 1.48 | 5.90 |
| ***Surface*** | 2.50 | 1.16 | 0.07 | 2.50 | 1.16 | 0.07 | 3.73 |
| ***Groundwater*** | 0.11 | 0.30 | 0.43 | 0.15 | 0.30 | 0.43 | 0.88 |
| ***Pumping*** | | | | 0.00 | 0.00 | 0.00 | |
| ***Supply*** | 2.61 | 1.46 | 0.50 | 2.65 | 1.46 | 0.50 | 4.61 |
| ***Deficit*** | 0.05 | 0.30 | 0.98 | 0.01 | 0.30 | 0.98 | 1.30 |
| | ***Head*** | ***Midldle*** | ***Tail*** | ***Head*** | ***Middle*** | ***Tail*** | ***Total*** |
| | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | ***TM*** | ***TMC*** |
| ***Demand*** | 2.66 | 1.77 | 1.48 | 2.66 | 1.77 | 1.48 | 5.90 |
| ***Surface*** | 2.50 | 1.24 | 0.17 | 2.50 | 1.28 | 0.21 | 4.00 |
| ***Groundwater*** | 0.15 | 0.27 | 0.39 | 0.15 | 0.24 | 0.38 | 0.77 |
| ***Pumping*** | 0.11 | 0.11 | 0.00 | 0.17 | 0.17 | 0.00 | 0.34 |
| ***Supply*** | 2.65 | 1.51 | 0.56 | 2.65 | 1.52 | 0.60 | 4.76 |
| ***Deficit*** | 0.01 | 0.26 | 0.91 | 0.01 | 0.25 | 0.88 | 1.14 |

| ***Scenario 8: GWA with GWF = 0.90, 0.50, 0.35, 0.1,0.1 PUMPING*** | | | | | ***Scenario 9 : GWA with GWF = 0.90, 0.50, 0.4, 0.1,0.1 PUMPING*** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***Head*** | ***Middle*** | ***Tail*** | ***Total*** | | ***Head*** | ***Mid dle*** | ***Tail*** | ***Total*** |
| | ***TMC*** | ***TMC*** | ***TMC*** | ***TMC*** | | ***TMC*** | ***TMC*** | ***TM*** | ***TMC*** |
| ***Demand*** | 2.66 | 1.77 | 1.48 | 5.90 | ***Demand*** | 2.66 | 1.77 | 1.48 | 5.90 |
| ***Surface*** | 2.50 | 1.24 | 0.17 | 3.91 | ***Surface*** | 2.50 | 1.24 | 0.17 | 3.91 |
| ***Ground water*** | 0.15 | 0.27 | 0.46 | 0.88 | ***Ground water*** | 0.15 | 0.27 | 0.52 | 0.93 |
| ***Pumping*** | 0.11 | 0.11 | 0.00 | 0.23 | ***Pumping*** | 0.11 | 0.11 | 0.00 | 0.23 |
| ***Supply*** | 2.65 | 1.51 | 0.63 | 4.79 | ***Supply*** | 2.65 | 1.51 | 0.69 | 4.84 |
| ***Deficit*** | 0.01 | 0.26 | 0.84 | 1.12 | ***Deficit*** | 0.01 | 0.26 | 0.79 | 1.06 |



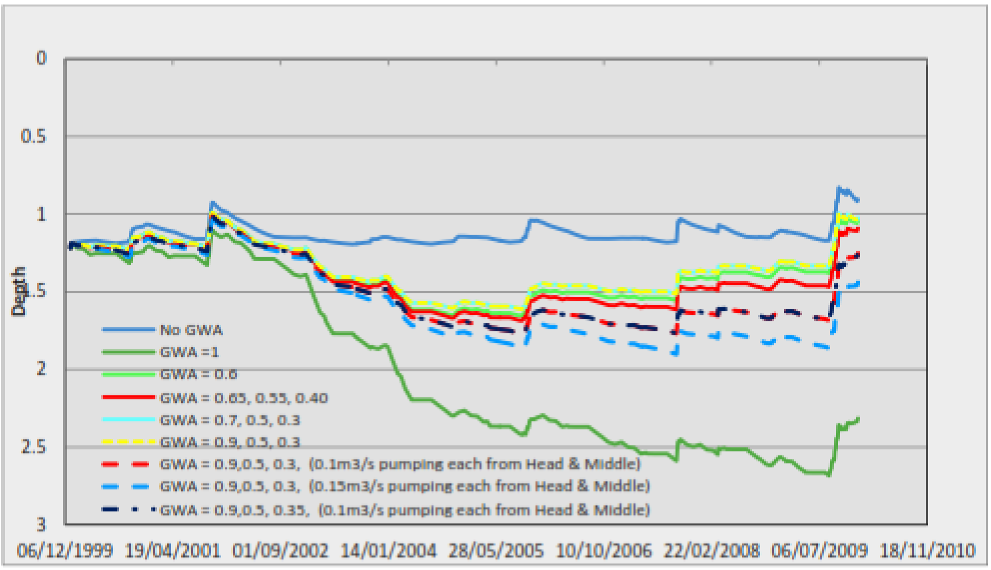




Figure 3.56: Simulated groundwater levels.

## 3.5 DSS APPLICATIONS – KERALA

Being one of the participating States in the Hydrology Project - II, Kerala has selected Bharathapuzha River Basin with its diverse hydrological and topographical characteristics as the pilot study basin for developing Decision Support System for water resource management.

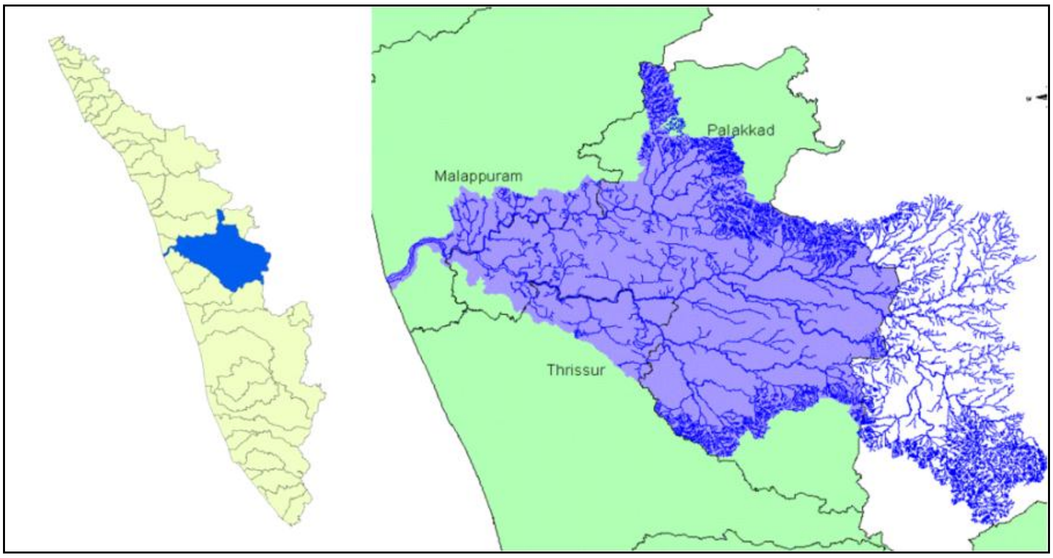



Figure 3.57: Bharathapuzha river basin

Kerala modelling team, comprising of officials from Irrigation Department & Ground Water Department, have developed the most number of applications than any other Implementing States in the DSS Project which are briefly summarized below:

### 3.5.1 Viability of artificial recharge

One of the application developed using the Bharathapuzha basin model is the effect of artificial recharge in different places of the basin. This DSS application is developed to assess the viability and quantity of groundwater to be recharged by artificial means. DSS application was developed to study the impact of check dam with a height of 2 m, with a water spread area of 15000 $m^2$ and having an anticipated upstream volume of 30000 $m^3$. Water spread area and the volume is assumed at the maximum condition with a river width of 50 m. Virtual check dam was placed in the calibrated and validated base model and different scenarios were generated.  Optimum simulation from 1978 to 2009 with the result re-sampled per year is shown in the bar graph.

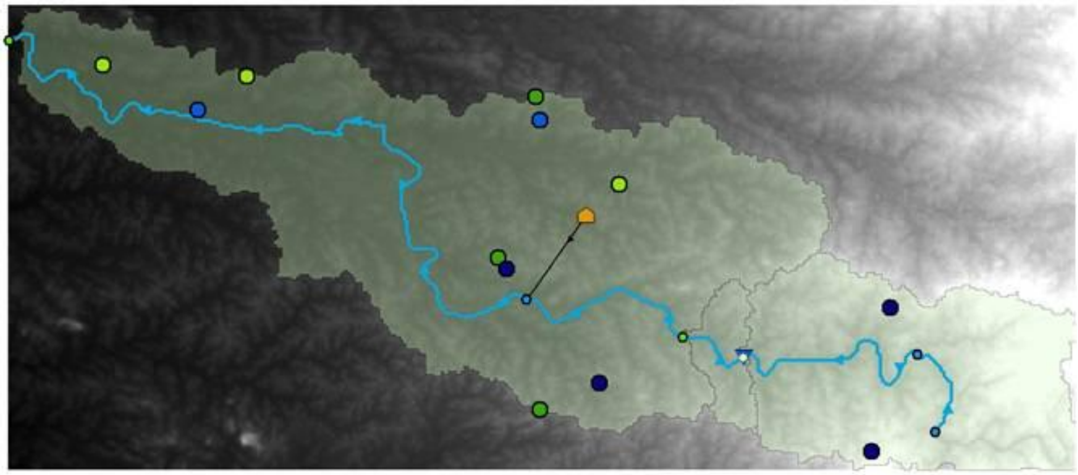


Figure 3.58: Pudur sub-basin

Table 3.5 Level-Area-Volume of virtual reservoir

| Level (M) | Area ($Km^2$) | Volume ($Km^3$) |
|---|---|---|
| 0 | 0 | 0 |
| 0.5 | 0.0025 | 0.00125 |
| 1 | 0.005 | 0.005 |
| 1.5 | 0.01 | 0.015 |
| 2 | 0.015 | 0.03 |

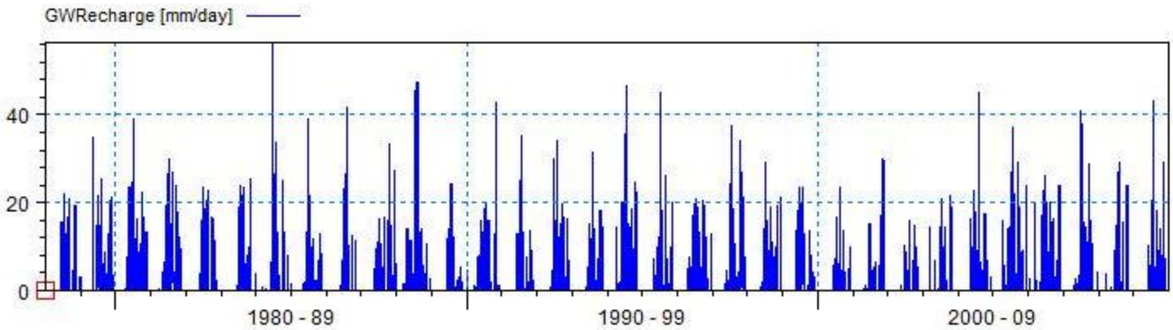



Figure 3.59: Plot of ground water recharge with check dams in Pudur sub-basin

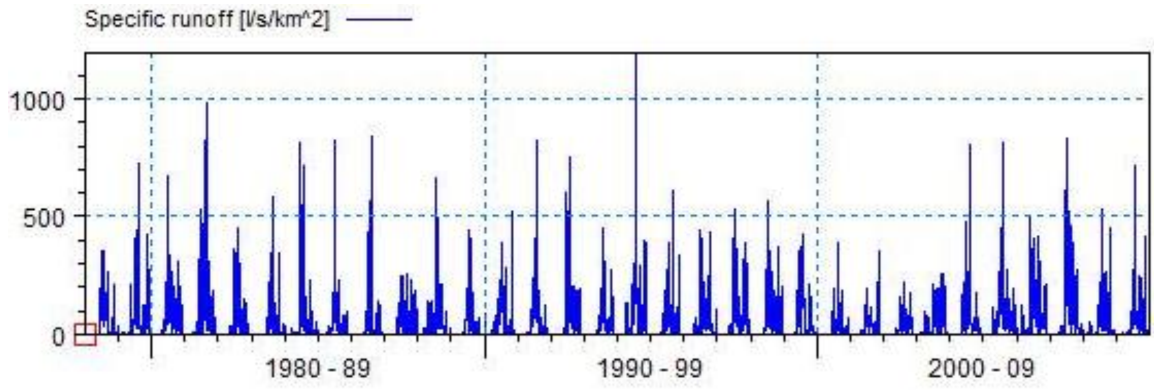



Figure 3.60: Plot of specific runoff of Pudur sub-basin

Results indicate that if the rainfall variation in the basin is same as in the period of simulation, the expected amount of recharge will be as above. The optimum simulation indicates that a minimum artificial recharge of 32650 $M^3$/ year can be generated from the check dam. The model simulated for check dam in Chittur area shows that check dams are feasible and will be highly beneficial for the groundwater recharge and rejuvenation of potential of groundwater in the area. Further, simulation will be run for all proposed check dams and their viability will be ascertained.

## 3.5.2 Conjunctive use

Conjunctive use of GW & Canal allocation for the Chittur area, an overexploited block which is also the command area downstream of Moolathara regulator was taken up for the application. The area was divided into three namely Head User, Middle User & Tail User. Crop water requirement of each area was calculated as per land use and the demands of major crops were calculated.

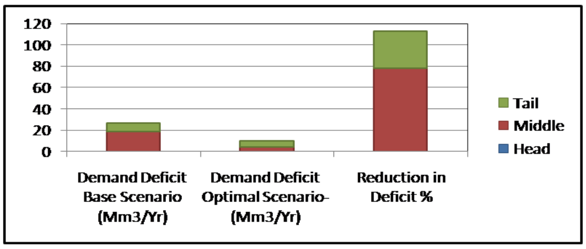



Figure 3.61: Comparison plot of demand deficit in base and optimal scenarios

| Scenario | User areas | Total Demand ($Mm^3/Yr$) | SW Abstraction ($Mm^3/Yr$) | GW Abstraction ($Mm^3/Yr$) | Demand Deficit ($Mm^3/Yr$) |
|---|---|---|---|---|---|
| Base | Head | 19.32 | 19.33 | 0 | 0 |
| | Middle | 32.34 | 7.9 | 6.32 | 18.2 |
| | Tail | 20.32 | 5.97 | 5.94 | 8.43 |
| Optimal | Head | 19.32 | 9.66 | 9.66 | 0 |
| | Middle | 32.34 | 23.45 | 4.89 | 4 |
| | Tail | 20.32 | 9.36 | 5.46 | 5.5 |

Figure 3.62: Comparison of base and optimal scenarios(quantified)

Many scenarios were generated (Water releases according to the GW extraction fractions as charted below) using Mike Basin for these users. Base scenario (with no use of ground water in the Head area and maximum in Tail area) scenarios were presented in slides for Paddy user areas. The Mike Basin results related to Surface water, Ground Water abstraction and Water demand deficits were analysed. Ground water depths (Mike basin results) were compared in each scenario. The application was developed as an Impact Assessment of Artificial Infiltration Structures in Pudur catchment. The recharge structure was modelled as a lumped single reservoir comprised of 20 mini storage structures like Check Dams. The corresponding water level rise and respective ground water recharge was compared and quantified. DSS modelling team prepared the same as an element, both for water storage and artificial infiltration. This can be a very useful tool in decision making, providing a viability analysis for such structures

### 3.5.3 Inter-subbasin transfer

This application was to study the viability of inter-subbasin water transfer during monsoon season to rain shadow regions of Kanjikode, Eruthempathy, Kozhinjampara and thereby to augment the ground resource of the area. Different scenarios were tested and the optimum scenario has given very encouraging results and it showed significant rise in the ground water level.

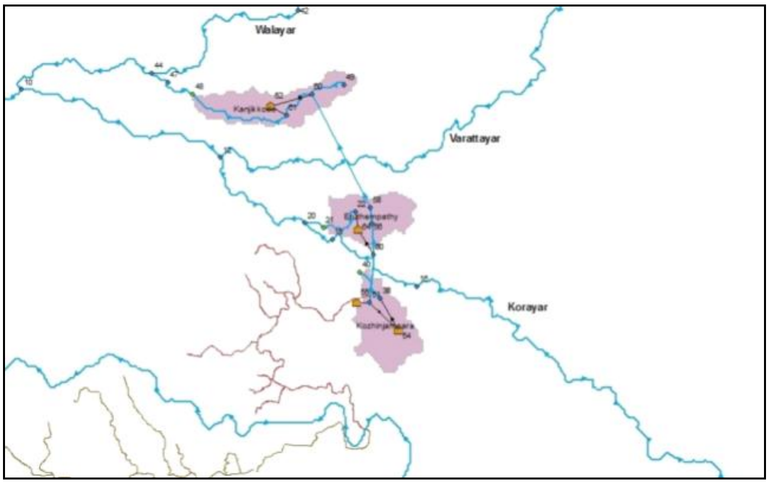



Figure 3.63: Plot of Kanjikkode, Erurthyampathy and Kozhinjampara sub-basins

### 3.5.4 Inter-basin transfer with hydropower module

Inter-basin transfer from Chalakudy basin was considered for the study which attempted a case of Hydropower. The hydropower potential of the project is around 60 MW, when operated only for peak hours (4 hours daily). The forest submergence comes to around 5 square km. Shifting the dam upstream for submergence has to be analysed. Assured supply of $4m^3$/sec of Irrigation water for three months in dry season can be made available as per the analysis. Being a forest area, this may be a point of decision making.

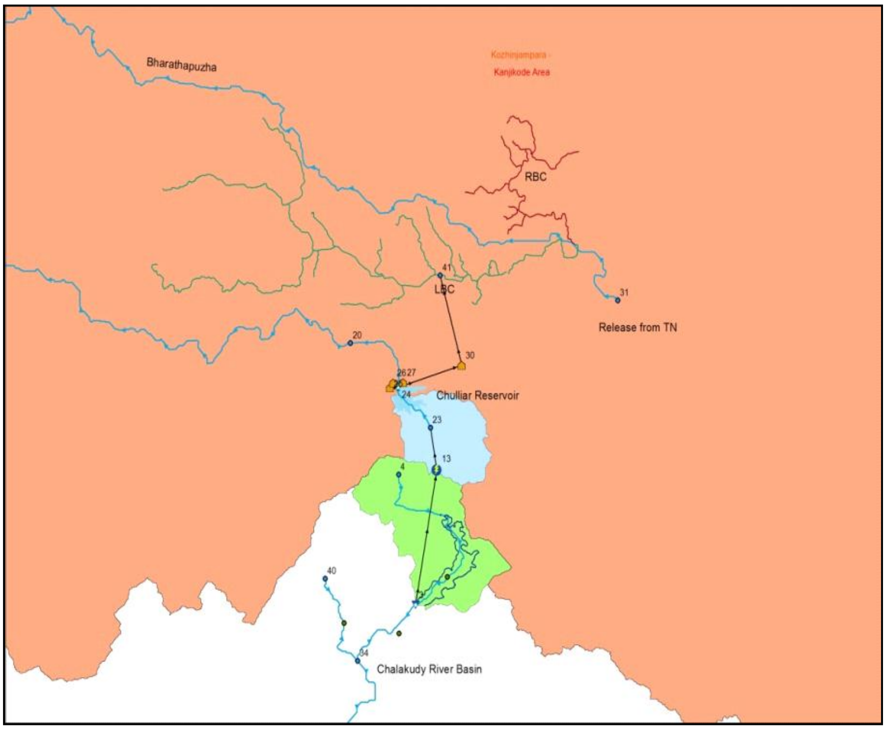



Figure 3.64: Schematic map showing the inter basin water transfer

### 3.5.5 Water quality module

Study basin doesn't pose much quality issues, but the application was developed to explore the capabilities of DSS Water quality tool in River basins. The BOD parameters were taken up for studies and the data of basin area according to the WQ stations of CWC were selected. Different scenarios were simulated with various discharges. The optimum quantum of environment flow to be released was simulated and it was found that a discharge of 2m$^3$/sec in the upstream will considerably reduce the BOD values at Kuttippuram which is the downstream point.

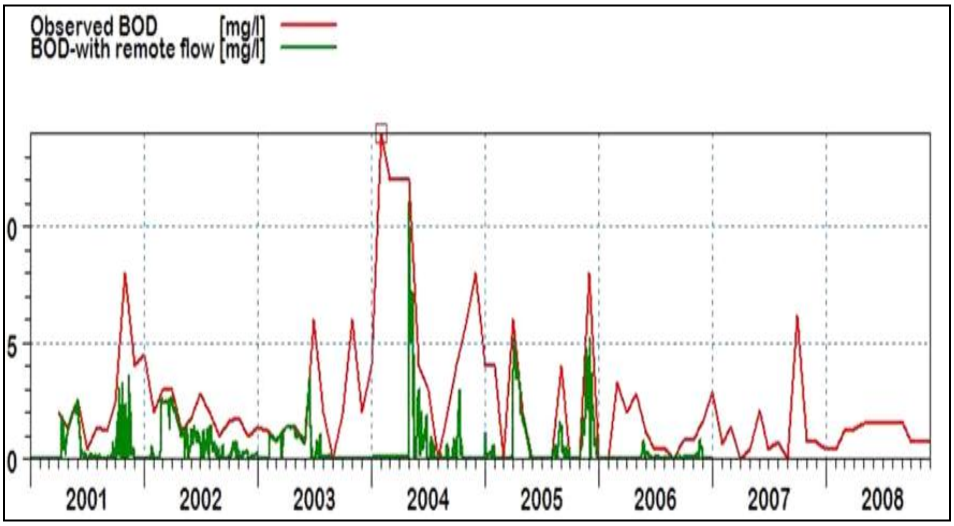



Figure 3.65: Plot showing observed BOD against BOD with remote flow

### 3.5.6 Yield of Bharathapuzha basin

Based on the locations of reservoirs and GD stations, the Bharathapuzha River Basin was delineated into 20 catchments. Tamil Nadu portion of the basin was not included for model development. The data from Manakkadavu Weir (jointly agreed by Tamil Nadu and Kerala under PAP agreement) was considered for the model simulation. Data analyzed using model tools indicate that the Specific runoff of the catchments varies from basin to basin. High specific runoff is noticed at Cheruthuruthy, Pulamanthole and Kuttippuram catchments and is substantiating the rainfall distribution in the area. The total yield of Bharathapuzha basin without any abstractions is analyzed for unit area, considering the ground water and surface water aspects, and the total yield is arrived as the discharge at the terminal point, at Kuttipuram, without any abstractions. Total yield of Bharathapuzha basin was calculated as 5964 MCM per year. The streamlined methodology can be replicated in other basins.

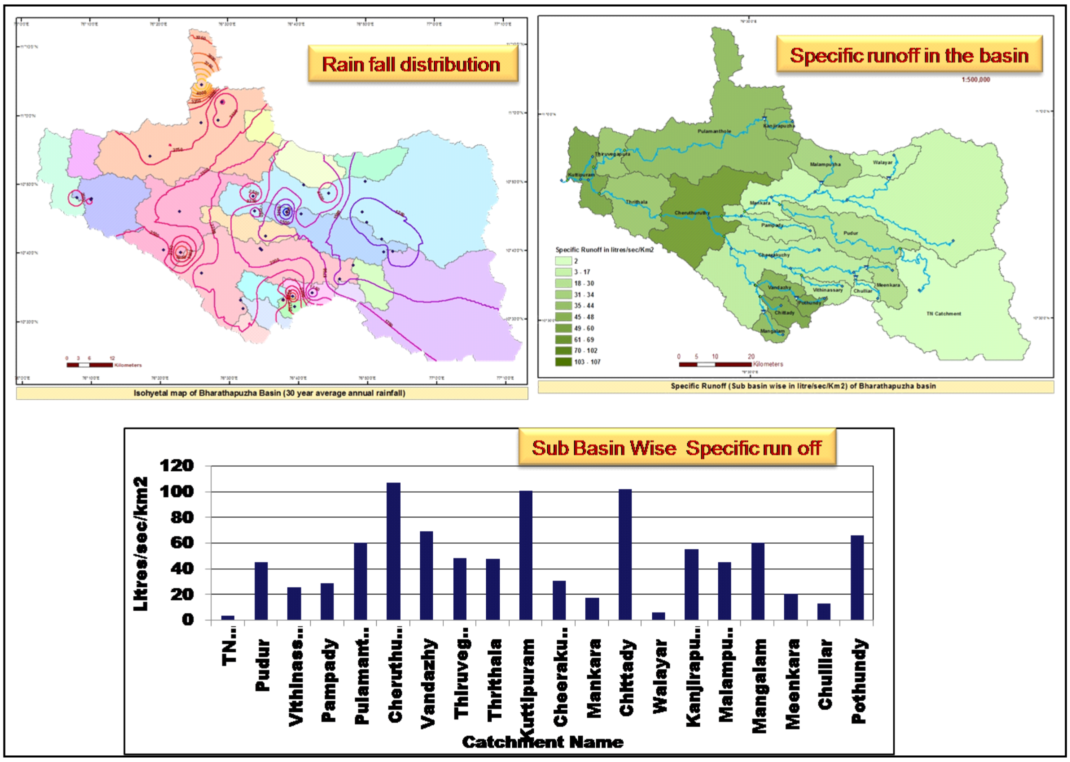



Figure 3.66: Rainfall distribution, specific runoff and subbasin-wise specific runoff

### 3.5.7 Inter-basin transfer

The application was developed for providing water for irrigation in KanjikodeKozhijampara area, as the water from main River is not sufficient. The project was conceived 2 decades ago but did not materialize due to objection from forest department. In the application, different scenarios were run for different levels of submergence using DEM. Mike basin was used to analyze the amount of water conveyed through tunnel and the hydropower generated.

Different scenarios were developed on varying tunnel capacities and generated hydropower was compared. Effect of additional water and hydropower from Karapara was also analyzed.

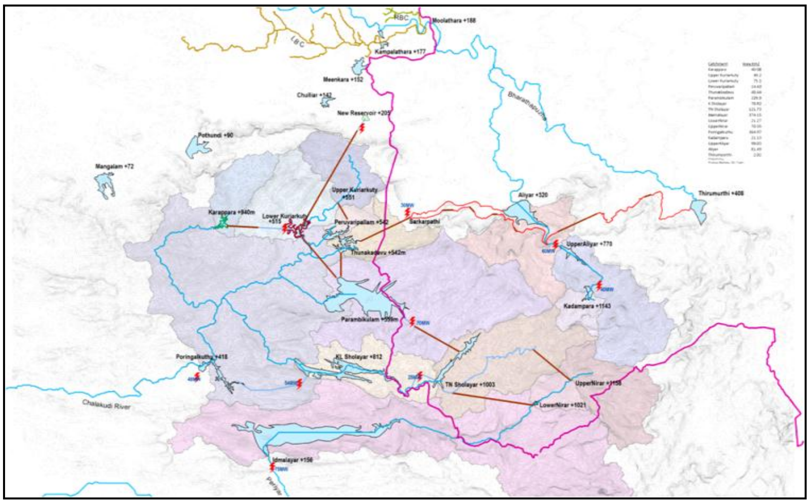


Figure 3.67: Schematic map showing the inter basin water

### 3.5.8 Inter-Subbasin transfer (Silent Valley to Malampuzha Reservoir)

Another application developed is for analyzing the inter sub-basin water transfer from Silent Valley area to Malampuzha reservoir. The water available in Malampuzha reservoir is not sufficient to cater the needs of the farmers in peak summer season and is affecting the crop production.

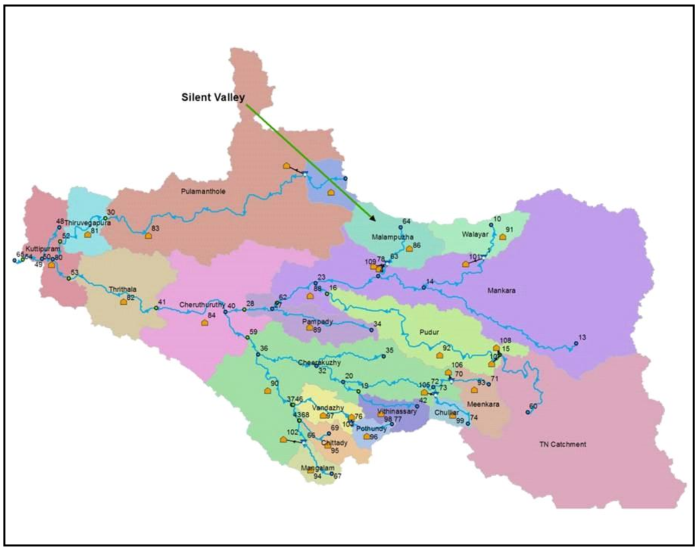



Figure 3.68: Water transfer link from Silent valley to Malampuzha

An option was tested using DSS tools to transfer the excess water from Silent Valley area to Malampuzha by constructing a diversion weir/tunnel. The application was tested for with no submergence of the forest area and also by not being affecting the downstream users.

Different scenarios have been tested with varying tunnel discharges and as per first estimates, the diversion will benefit the downstream users tremendously. However, elevation drop for gravity flow needs further investigation.

### 3.5.9 Reservoir operation

The inflow, outflow and various demands in each reservoir is schematized, charted and generated in the spread sheet component of DSS. In this exercise, we can compare the historical reservoir parameters for different reservoirs for a given particular period of water year. The export from DSS software to excel and similar applications help the field staff and decision makers to analyse the demands and releases of various reservoirs in an integrated manner. This will help in making decisions on new water consuming projects and thereby, for a better planning. The exercise is to be extended in other basins also.

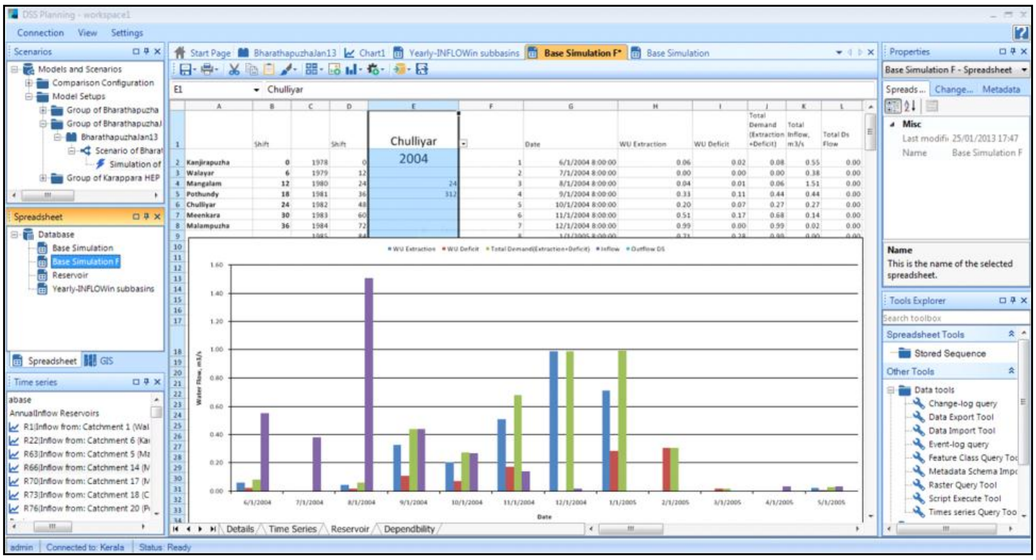



Figure 3.69: Reservoir Operation Dashboard

## 3.5.10 Applications Developed in other Basins

### 3.5.10.1 Viability of Pattisserry dam

Water availability study based on the representative catchment revealed that the proposal for supplementing the storage of Pattisserry dam is a viable option. The project has been included in the State plan budget.

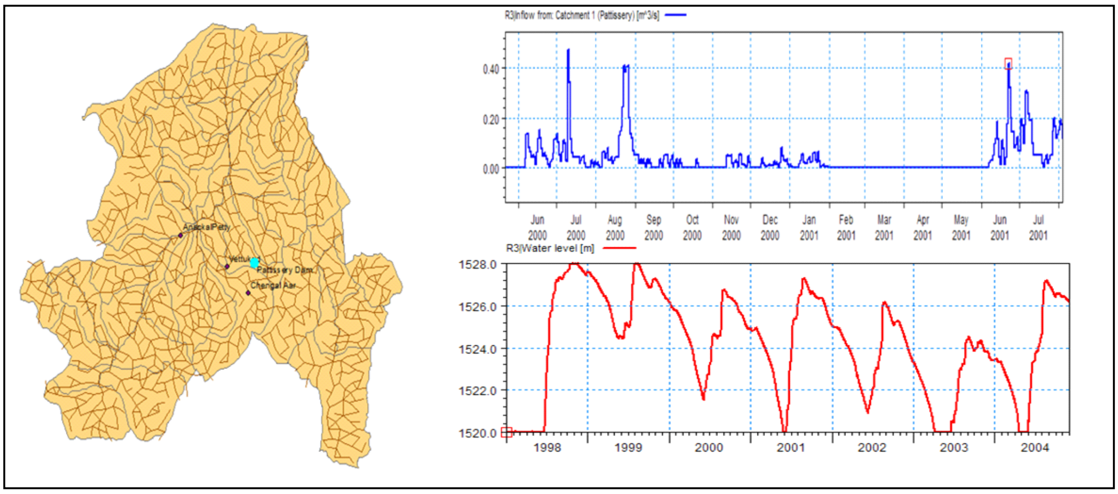



Figure 3.70: Location, anticipated inflow and water level of Pattissery Dam

***Viability analysis for storage structures***

DSS tools were extensively used for the viability study of storage structures in different basins other than Bharathapuzha basin. It helped to convince the decision makers on the advantages and disadvantages of the project. Area and extent of submergence, the expected amount of water accumulated in various periods were computed with reasonable accuracy. The analysis was done for check dams in Meenachil basin.

This study was conducted as a feasibility study of the proposal of 9 check dam locations in Meenachil basin. Seven locations were found to be feasible.

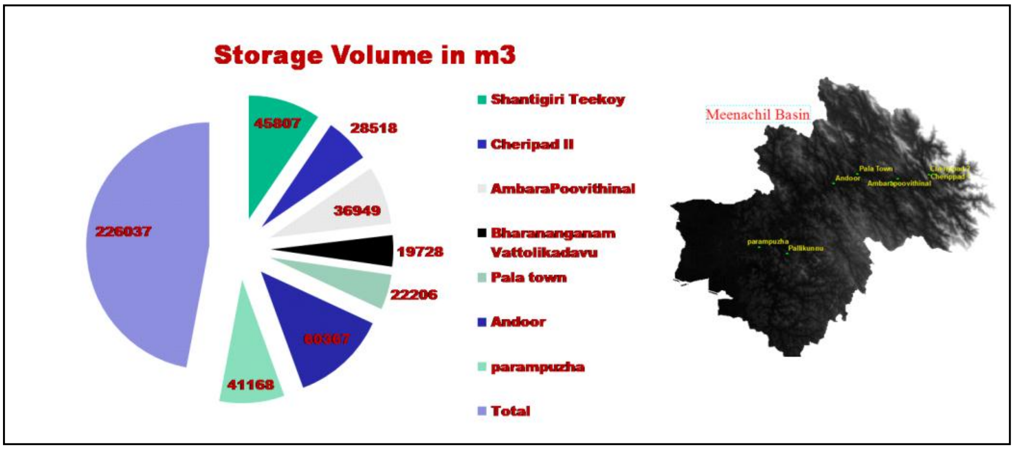



Figure 3.71: Anticipated storage volume of check dams in Meenachil basin

Contour area was calculated using ArcGIS to get the area of submergence due to the construction of each check dam. The field staff is conducting site investigation in each of the locations. Gauge station discharge was available in 4 locations in this river. Each check dam was given reservoir characteristics and water user for each check dam was specified including rough evaporation losses and recharge. DSS tools were used to compute the parameters.

Check dams in Chalakkudy basin were investigated because of prevailing drought condition in this area. The authorities including MLAs are demanding storage structures in this area. There is only one diversion weir in this place with very little capacity. In Chalakkudy basin, three locations for check dam has been studied using DSS tools and remote sensing data. All the three locations are in the forest area and field study is being done by irrigation department for finalizing the proposal based on the site conditions.

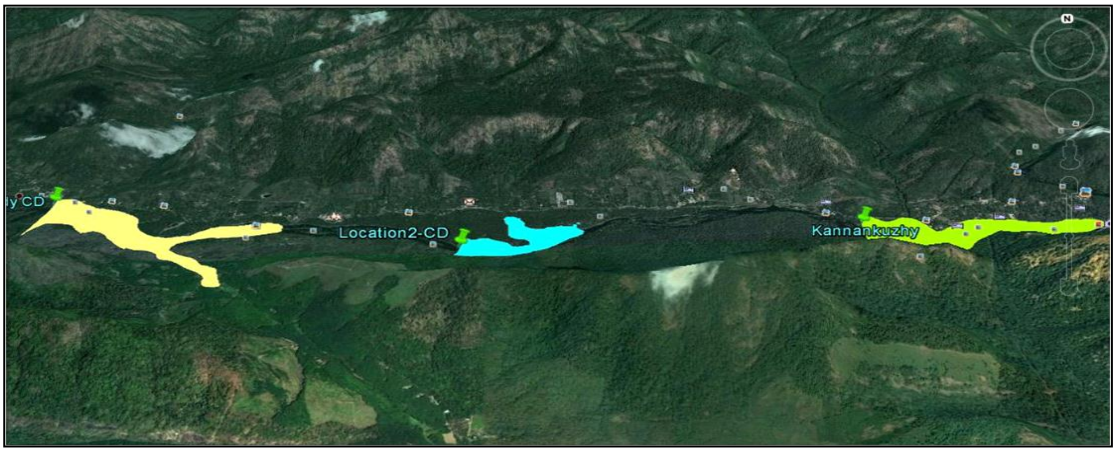



Figure 3.72: Locations of check dams in Chalakkudy basin

Similarly, three locations were identified for constructing check dams in Pambar basin. These locations are in the upstream side of Pambar referred also as Thalayar, i.e., upper reach of Pambar River.

1. Upper Chattamunnar
2. Lower Chattamunnar
3. Thalayar

The check dam locations received after site inspection was analysed using DSS tools and corresponding contours were plotted using ArcGIS. Resultant area of submergence was calculated to get the water spread area. It has been observed that the minimum storage volume is less in the case of Upper Chattamunnar, but it is better for Lower Chattamunnar. Thalayar location is best suited among the three locations when it comes to water spread and storage volume, and that too for a height of 2.5 - 3 m. The total storage comes to above 0.3 $Mm^3$ if all the check dams are in place. It may be noted that the location Thalayar itself can store more than half of the estimated storage capacity.

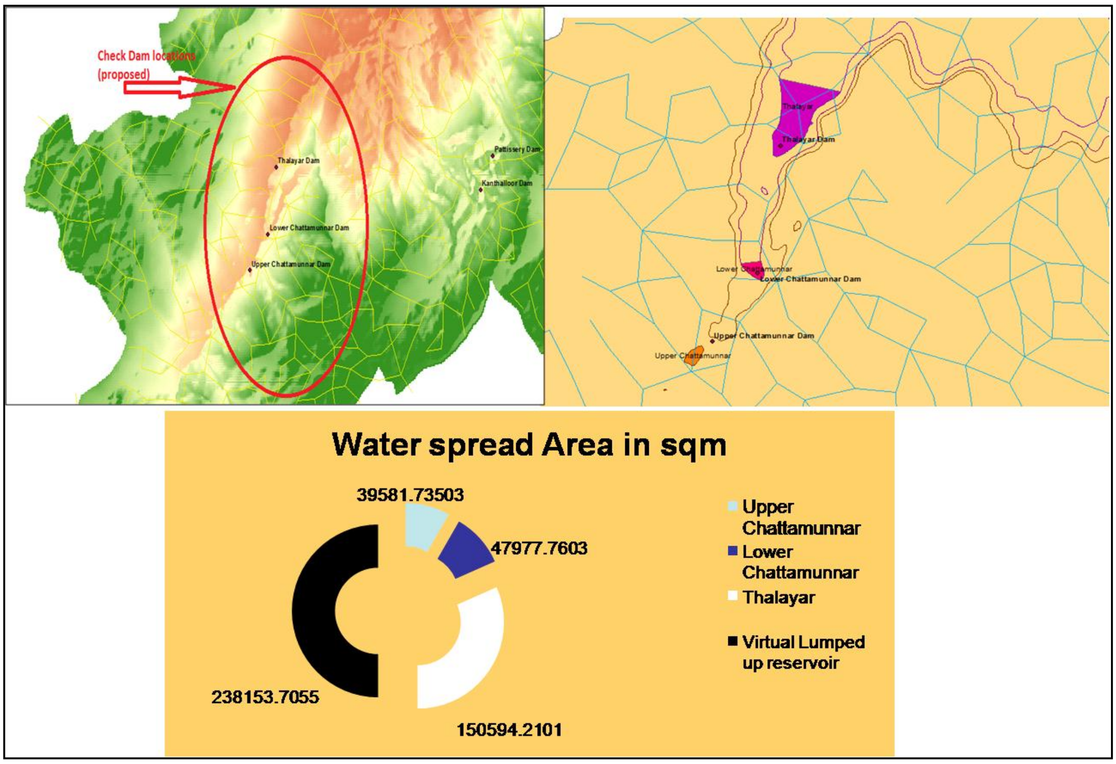



Figure 3.73: Locations of check dams in Pambar basin and anticipated storage

## 3.6 DSS APPLICATIONS – MADHYA PRADESH

The Government of India (GOI) Ministry of Water Resources (MOWR) has implemented the Hydrology Project Phase II (HP-II) in country, which was a follow-on Project to the Hydrology Project Phase-I (HP-I). The Hydrology Project II development objectives were to extend and promote the sustained and effective use of the HIS developed under HP-I by all potential users in India concerned with water resources planning and management. The HP-II project has three main components: Institutional strengthening, Vertical extension and Horizontal expansion. The participating states in the project are Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashatra, Orissa, Tamilnadu. Participating central agencies are National Institute of Hydrology (NIH), Central Water Commission (CWC), Central Ground Water Board (CGWB), Central Water and Power Research Station (CWPRS), Indian Meteorological Department (IMD) and Central Pollution Control Board (CPCB). The National Institute of Hydrology, Roorkee under the GoI MOWR, is the nodal agency for the development and implementation of DSS-WRPM. The DSS(P) software has been developed with the help of Danish Hydraulic Institute (DHI) Denmark for integrated water resources development and management of water resource systems to address the following five components of water resources planning and management:

- Surface water planning
- Integrated operation of reservoirs
- Conjunctive surface water and ground water planning
- Drought monitoring, assessment and management and
- Management of both surface and ground water quality

### 3.6.1 DSS in Madhya Pradesh

In Madhya Pradesh state DSS(P) was developed for the upper Wainganga River Basin. Wainganga Basin is a part of the Godavari valley which covers about 65,378 km$^2$ total areas running across Deccan plateau from the western to Eastern Ghats of Madhya Pradesh, Maharashtra, and Chhattisgarh. The area covered under Wainganga Basin in Madhya Pradesh is about 25480 km$^2$ as shown in Figure 1. The Basin receives most of its rainfall during the south-west monsoon (June to September). The area of the basin comes under humid region with mean annual rainfall varying between 1000 to 1600mm Wainganga flows 580 km south to join the Wardha River, a headwater of the Godavari. The length of the river in Balaghat District is about 98 km and width is about 250 m. The Madhya Pradesh part of Wainganga covers the districts of Betul, Chhindwara, Seoni, Balaghat and Mandla. Major tributaries of the Wainganga River within the State of Madhya Pradesh are the Pench, the Kanhan from its right, the Bagh from left while the Bijla, the Hirri, the Ha-lon, the Thanwar, the Bawanthadi, the Uskal (Nahara). The main crops grown in the basin are paddy, jowar, maize, wheat, pulses and oil seeds. The broad soil groups are shallow black soils with red soil and deep black soil in the eastern parts of the region. Arable land of the basin is 25 %, forest covers an area of 3.45 million ha in the basin and 2.55 million ha is a reserved forest.

### 3.6.2 Water Resources Issues in Wainganga Basin

a. Assessment of water resources availability to obtain a better basis for the water management and planning.
b. The water infrastructure has not been adequately maintained and considerable losses of water are seen. It would be useful to assess the impact of rehabilitating the infra-structure.
c. Identification of efficient use of water by the projects, which are existing and under construction. It may be possible to operate some reservoirs in combination to improve the efficiency. Any changes in water management must comply with the agreement with the downstream state.
d. Crop selection and the corresponding water requirements, particularly in dry years.


Figure 3.74: Watershed Map of MP showing location of Wainganga Basin

### 3.6.3 State's Expectation from DSS

Madhya Pradesh State worked on DSS for optimum allocation of water for present and future water use. The DSS therefore included assessments of the surface and groundwater availability and the various water demands. It also enabled analysis of multi-reservoir operation, irrigation scheduling, cropping patterns, conjunctive use, etc.

### 3.6.4 Data Availability

#### 3.6.4.1 Hydro-meteorological Data

There are a total of 35 non-recording rain gauge stations in the Wainganga Basin which have been established under HP-I. In addition there are many rain gauges of the Director of Land Records. The district wise number of rain gauges in Chindwara, Seoni and Balaghat are given below. There are a few FCS stations of IMD and CWC. Data have been computerized in SWDES at the State Water Data Centre at Bhopal.

#### 3.6.4.2 Hydrological Data

***Gauge and discharge sites***

Data of 14 G.D stations of state are available. The data of State GD sites have been computerised using SWDES. GD stations of CWC are located in the Madhya Pradesh and Maharashtra parts of Wainganga basin

***Groundwater data***

There are a network of 77 observation wells and 24 piezometers of Central Ground Wa-ter Board in Wainganga basin. Data of Ground Water Levels for 230 observation wells are available for the period 1974 or 2009. Data of 28 piezometers of state are available for the period 2000 to 2004. All the data have been entered through GWDES at the State GW Data Centre. GW quality data for 230 wells is available for the period 1985 to 2009.

**GIS data**

The state has prepared GIS data base with the help Madhya Pradesh Council of Science and Technology (MP-COST), Bhopal. The GIS data base include thematic layers on Catchment boundary, drainage network, roads network and villages, water bodies, etc.

**Water use data**

The abstraction of water for irrigation, domestic, industrial and other uses is a key data requirement for water resources planning. This information was collected by the state from various divisions in Wainganga basin. Irrigation demands were estimated with the available tools.

### 3.6.5 Needs Assessment Activity

The Needs Assessment activity for M.P. was carried out in May, 2009. The overall purpose of the Needs Assessment activity was to assess the nature of water resource issues in the case study basin of Madhya Pradesh to make a preliminary assessment of the nature of the required DSS and its underlying models to assess the required IT software and hardware needs and training needs, GIS training needs, and capacity building and training needs in the Surface and Ground water Agencies of the State to enable Madhya Pradesh to effectively contribute to the development and operation of the DSS.

#### 3.6.5.1 Issues identified under needs assessment activity

The demand for water is increasing in Madhya Pradesh and in view of the new developments taking place in Wainganga basin, the DSS should support decisions mainly on the following issues:

a. Assessment of water resources availability to obtain a better basis for the water management and planning.
b. The water infrastructure has not been adequately maintained and considerable losses of water are seen. It would be useful to assess the impact of rehabilitating the infra-structure.
c. Identification of efficient use of water by the projects, which are existing and under construction.
d. Crop selection and the corresponding water requirements, particularly in dry years.

To address these issues, the MIKE 11 NAM Model was applied for rainfall runoff modeling, MIKE BASIN software was used for development of various scenarios and DSS(P) software was used to analyze and examine the scenarios and output results to assess the impact of water management scenarios, multi-reservoir operations, conjunctive water use, and changes in cropping pattern.

### 3.6.6 Work Done Under DSS(P)

Various activities carried out for Madhya Pradesh state under DSS(P) are described in brief as given below:

#### 3.6.6.1 Development of Mike Basin Model of Wainganga

The Mike Basin Model was been developed for Wainganga basin as shown in Figure 8.2 and the details are given below:

a. All the database of SWDES and GWDES for Wainganga basin was converted to *dfso* files and uploaded in MIKE BASIN model.
b. Created a Geo-database incorporating all the relevant available spatial and temporal information.
c. With the help of DEM-90m of Wainganga basin, rivers were traced and catchments were delineated
d. Time series data on rainfall, runoff, groundwater levels, reservoir details, water bodies, etc. were imported in MIKE BASIN and linked to GIS features.
e. MIKE 11 NAM model calibrated for selected sub catchments and runoff time series were generated for remaining catchments.
f. The water demands at all user nodes were evaluated and data imported in MB model.

g. Reservoir Simulation done for three reservoirs.
h. Various scenarios are simulated in MB model.


Figure 3.75: MIKE BASIN Model of Wainganga basin and locations of GW OB wells

**DSS(P) Software**

a. DSS hardware: Database Server and Web server and workstation computers were procured and installed in State Data Centre, Bhopal
b. DSS(P) software was loaded in server and local personal computers in State Data Centre, Bhopal.
c. The officers of WRD department were trained by DHI to explore and use the different options of DSS(P) software.
d. The data base of Wainganga basin was uploaded in the local host PC.
e. Different Scenario generated for Waingangā basin using DSS(P).

**DSS(P) Customization**

a. All available GIS and time series data has been imported to the DSS database and a range of model applications performed (Fig. 8.3).
b. River basin modelling of reservoir and canal performance to assess the impact of canal maintenance.
c. Rainfall-runoff modelling to assess catchment runoff and groundwater recharge in sub-basins.
d. River basin model application to assess the performance of the Rajiv Sager project, currently under construction in the area.
e. Seasonal groundwater planning for Dhuty RBC command area.
f. These applications are developed by making use of the river basin model for the area.

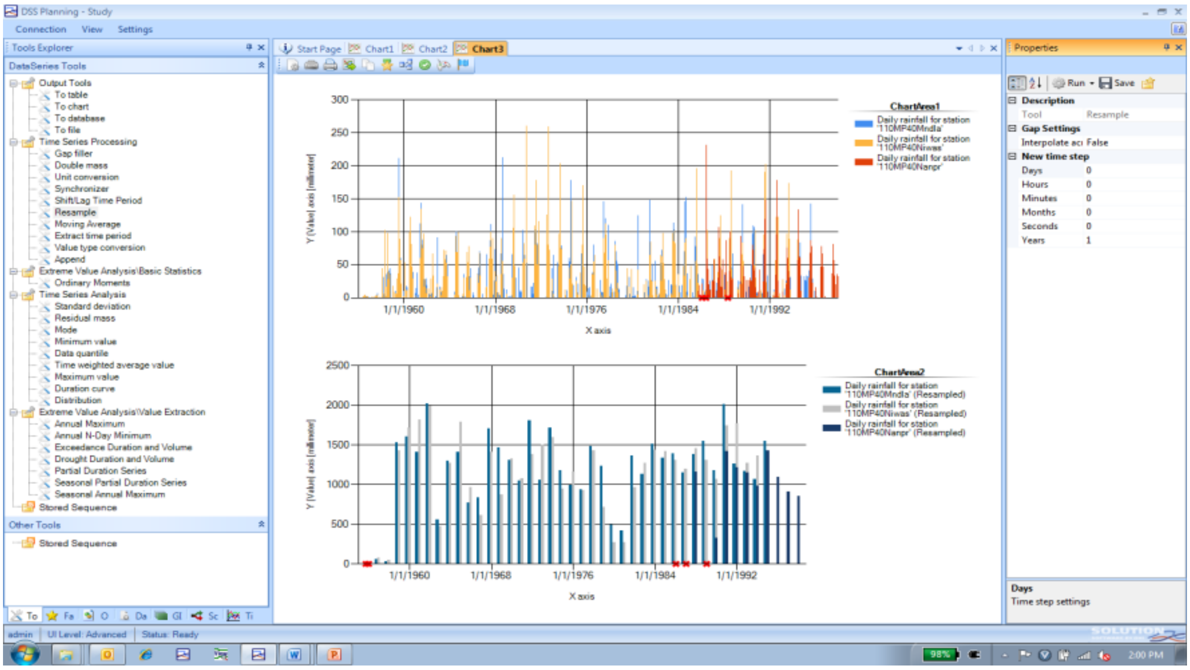



Figure 3.76: DSS(P) interface showing data processing

### 3.6.6.2 Water Availability Assessment in Wainganga Basin

Under this application, the Wainganga basin was sub divided into 22 sub-catchments the time series of surface runoff and ground water recharge were generated for different sub catchments (Figure 8.4) for 40 year period using MIKE 11 NAM Model.

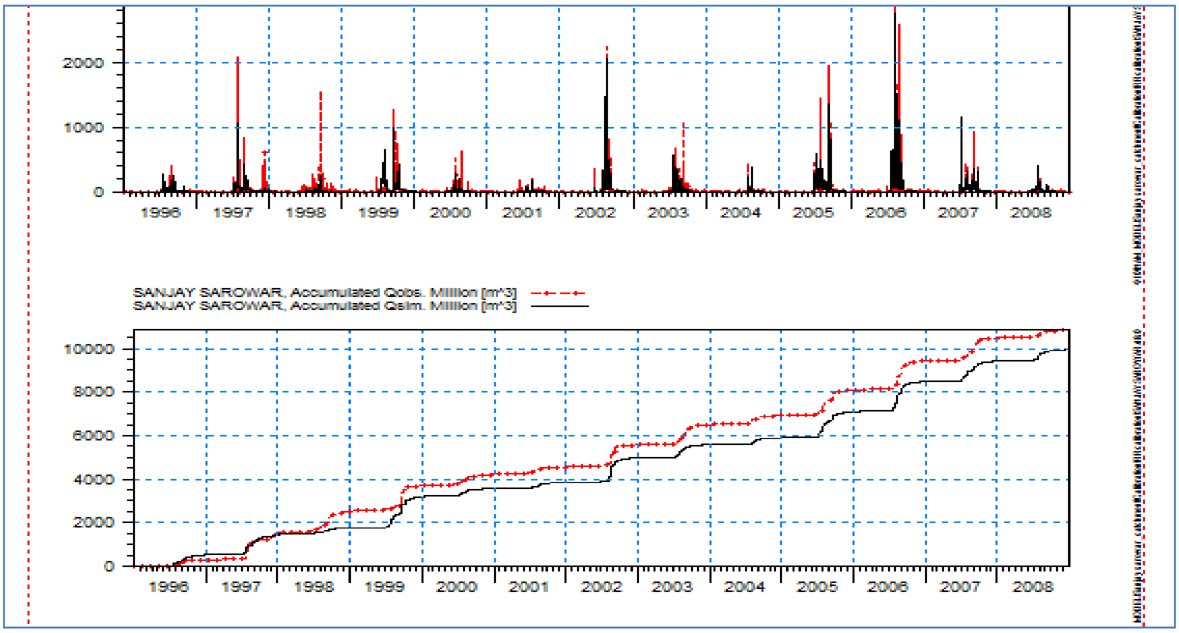



Figure 3.77: Comparison of observed and Simulated runoff

Table 3.6: Runoff Estimated in Different Sub Catchments of Wainganga Basin

| S.N. | Catchment | Catchment Area(Sq.Km) | Average Runoff in MCM/Year | 75% Dependable Runoff in MCM/Year |
|---|---|---|---|---|
| 1 | Balaghat | 375.74 | 111.06 | 72.38 |
| 2 | Bandol | 935 | 239.16 | 144.12 |
| 3 | Bawanthari | 1365 | 508.49 | 363.23 |
| 4 | Bonkatta | 610 | 358.17 | 222.57 |
| 5 | Chand | 971 | 98.15 | 53.29 |
| 6 | Chhindlai | 175.7 | 187.53 | 128.62 |
| 7 | Deoghat-Keolari | 510 | 286.45 | 181.99 |
| 8 | Deoghat | 452 | 253.87 | 161.29 |
| 9 | Dhuty Ugali | 628.71 | 189.49 | 140.64 |
| 10 | Hirnakheri | 2002 | 853.82 | 397.97 |
| 11 | Jam | 2284.76 | 229.67 | 109.16 |
| 12 | Khari | 1576.76 | 1925.6 | 1297.93 |
| 13 | Kumhari | 323.4 | 345.17 | 236.74 |
| 14 | Manpur | 738.81 | 788.55 | 540.84 |
| 15 | Pench | 1333 | 306.96 | 167.83 |
| 16 | Rajegaon | 5380 | 2668.19 | 1765.14 |
| 17 | Ramakona | 2437 | 495.8 | 194.47 |
| 18 | Rampalli | 750 | 279.34 | 155.86 |
| 19 | Ratanpur | 943 | 284.22 | 210.94 |
| 20 | Sanjay Sarowar | 1072 | 274.4 | 165.35 |
| 21 | Thanwar | 417 | 167.04 | 108.61 |
| 22 | Ugli-Keolari | 1774.37 | 534.78 | 396.9 |
| | **Total** | | **11385.91** | **7215.87** |

### 3.6.6.3 Seasonal planning of Sanjay Sarowar project

Sanjay Sarowar project is one of the major irrigation project of this basin on river Wainganga. The Dhuty wear at the downstream of Sanjay Sarovar supplies water for irrigation through its left and right bank canal system. The major water uses at Sanjay Sarvar are Sanjay Sarowar Irrigation User, Domestic Use of Seoni city and Dhuty releases 78MCM/Year. The model application was developed for seasonal planning of Sanjay Sarower. Main inputs used in the model were crops grown and its area, water user demands, initial reservoir Level. The results were shown in terms of variation in reservoir water level and storage at various probabilities, planning for crop selection and optimal utilization of available water

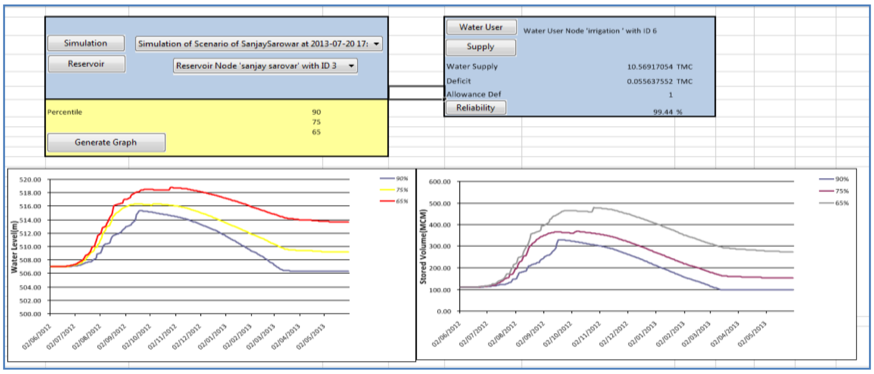



Figure 3.78: Water level and Stored volume in Sanjay Sarowar Reservoir

### 3.6.6.4 Impact assessment of infrastructure rehabilitation programme

The canals systems of Sanjay Sarowar scheme and Dhuty wear are in bad shape, their condition is deteriorated due to major cracks and damaged canal embankments and lining and it is assumed that major part of water supplied in command area is being lost through leakages and seepage. In such circumstances the major concern of the state WRD is to take up the rehabilitation programme to meet the challenge. This issue is being addressed through DSS(P) software. It is assumed that the present canal losses of the system are 30% and what will be the impact on additional water availability and additional crop yield if the canal water losses are reduced to 10% by appropriate rehabilitation measures. From the analysis it observed that around 65 MCM additional water is available if canal losses are reduced to 10% from 30%. The results are givan in Table 3.7 and Table 3.8 and Figure 3.66.

Table 3.7: Decrease in demand deficit when losses are reduces

**Scenario with 30% Losses**

| MCM/Year | Sanjay Sarowar Irrigation | Dhuty RBC | Dhuty LBC |
|---|---|---|---|
| Demands | 336.08 | 268.44 | 111.48 |
| Supply | 181.64 | 204.56 | 78.92 |
| Deficit | 154.43 | 63.88 | 32.56 |

**Scenario with 10% Losses**

| MCM/Year | Sanjay Sarowar Irrigation | Dhuty RBC | Dhuty LBC |
|---|---|---|---|
| Demands | 336.08 | 268.44 | 111.48 |
| Supply | 223.43 | 215.68 | 90.40 |
| Deficit | 112.65 | 52.76 | 21.08 |
| Additional Water available | 41.79 | 11.13 | 11.48 |

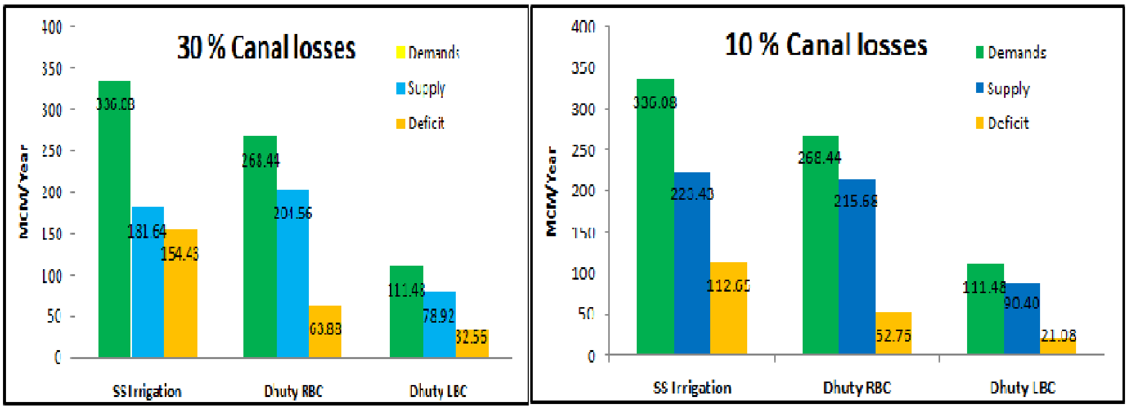


Figure 3.79: Bar graph showing decrease in water deficit if canal losses are reduced

Table 3.8: Increase in the crop production with the use of water saved

| Benefits From Additional Water Use (Annual) | | | | | |
|---|---|---|---|---|---|
| Crop | Expected Water Use (MCM) | Expected add. Yield(Ton) | Cost (Million Rs) | Input cost (Million Rs) | Benefits (Million Rs) |
| Wheat | 41.8 | 41800 | 334 | 201 | 133 |
| Paddy | 22.6 | 12556 | 129 | 78 | 51 |
| | | Total | **463** | **279** | **184** |

### 3.6.6.5 Reservoir Operation

An analysis has been carried out for the Sanjay Sarowar dam for improved flood control based on the forecast of the inflow to the reservoir. This would enable pre-release from the dam and thereby an increase in the available flood cushion before inflow starts increasing. This Analysis shows that the flood risk downstream of Sanjay sarowar may be significantly reduced if reliable inflow forecast are available. The simulated reservoir levels with and without inflow forecast for the two initial reservoir levels are shown below.

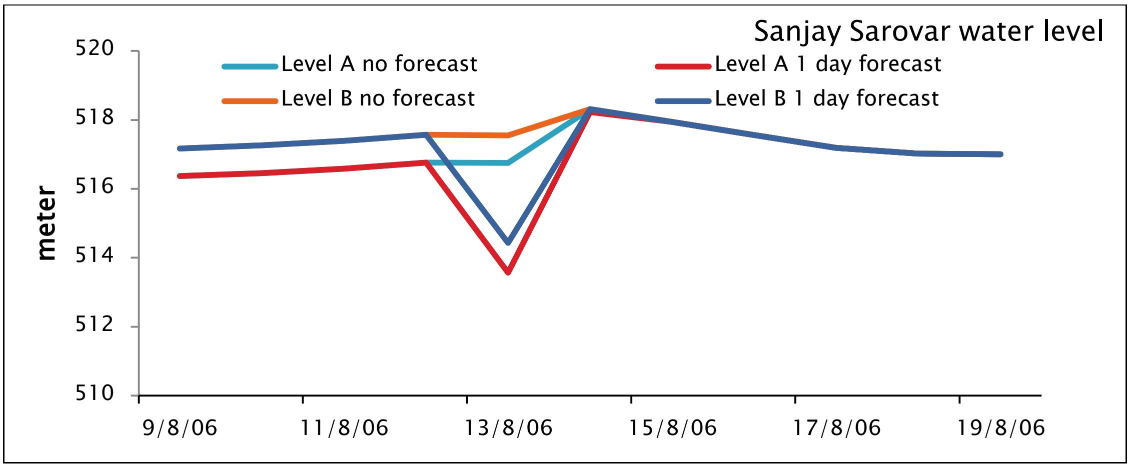



Figure 3.80: Simulated reservoir levels with and without inflow forecast for the two initial reservoir level

### 3.6.6.6 Performance Evaluation of Rajiv Sagar Project (Bawanthadi)

The Rajiv Sagar (Bawanthadi) Project is a joint venture between the states of Madhya Pradesh and Maharashtra, under construction on the river Bawanthadi as shown in Figure 7 in MIKE BASIN Model. The Dam site is near village Kudwa in Katangi tehsil of Balaghat district in M.P. and village Sitekasa of Tumsar tehsil of Bhandara district in Maharashtra. The construction of the dam and the Left Bank Canal is being carried out by Madhya Pradesh while the Right Bank Canal is constructed by Maharashtra. The cost of the dam is to be shared equally by the two states. On completion, the project is proposed to irrigate 18,615 Ha. of land in Balaghat district in M.P. by Left Bank Canal and 17,537 ha. of land in Bhandara district in Maharashtra by Right Bank Canal. At 158% Crop Intensity 29,412 Ha. land of Balaghat District and 27,708 Ha. land of Bhandara District will be irrigated. The performance of the Rajiv Sagar Project has been tested in the river basin model using the available catchment runoff series from 1976 to 2006 onwards.

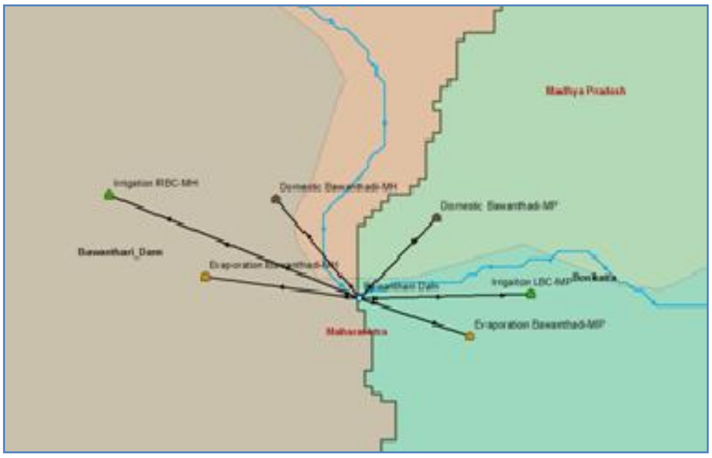



Figure 3.81: MIKE BASIN Model of Rajiv Sagar Project (Bawanthadi), Joint venture of GOI Madhya Pradesh and Maharashtra

From the analysis it can be inferred that out of 33 years selected for analysis, a significant deficits in Irrigation demands can be observed during three years only, i.e. 1987-1988, 1989-1990 and 2004-2005. Sufficient water will be available to meet the full water demands in approximately 90% of the years.

### 3.6.6.7 Seasonal Groundwater Planning For Dhuty RBC

The objective of this application to develop seasonal groundwater planning model in Dhuty RBC area to predict how much groundwater will be available at the end of May based on the groundwater level at the end of October. The MIKE BASIN Setup of GW seasonal planning is shown in Figure 8.9. Comparison between observed and simulated ground water depth is shown in Figure 8.10.


Figure 3.82: MIKE BASIN Setup of GW seasonal planning

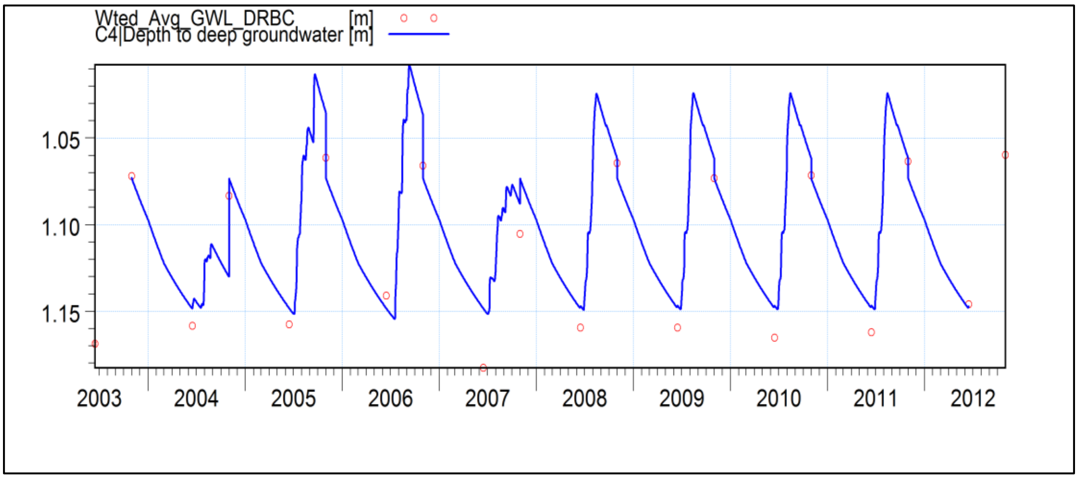



Figure 3.83: Comparison between observed and simulated ground water depth

The seasonal groundwater planning model tested for its accuracy in simulating GW levels for Dhuty RBC area and found efficient. The model can be used for predicting GW levels of May (pre-monsoon) using information on GW levels in October (post- monsoon) and it can be used to manage the GW demand in the study area

#### 3.6.6.8 Dashboard Manager

Dash board manager is a module for creating web pages for water resources application. The Dashboard manger can be used as a web page to display the monitored data and the results of the DSS for the public information. The applications of Dashboard are developed for Madhya Pradesh. It includes information of rain gauge sites, G/d sites and groundwater observation wells, its time series, graph etc.

## 3.7 DSS APPLICATIONS – MAHARASHTRA STATE

### 3.7.1 Reservoir Seasonal Planning

Single reservoir or reservoir complexes are utilized for meeting single or multiple water demands. Khadakwasla reservoir complex is one of the reservoir complexes in Upper Bhima basin, Maharashtra. The reservoir complex has four reservoirs, namely Panshet, Warasgaon, Temghar and Khadakwasla. The reservoir complex is used for irrigation, hydropower, urban water supply for Pune city and industrial purposes. Hydropower is generated in Panshet and Warasgaon reservoirs. Water supply is drawn from Khadakwasla reservoir. For this purpose, appropriate releases are made from upstream reservoirs. The period near end of summer season and prior to monsoon, when reservoirs again get water inflow, is critical for water supply point of view. To view the water availability during the critical period and reservoir filling status in next season, the reservoir complex operation was simulated. The reservoirs are operated jointly. For the simulation, historic records of 1970- 2009 were used. For water storage situation in the complex for given day and envisaged demands for the season, likelihood of total storage in the complex in the coming months was computed in DSS.

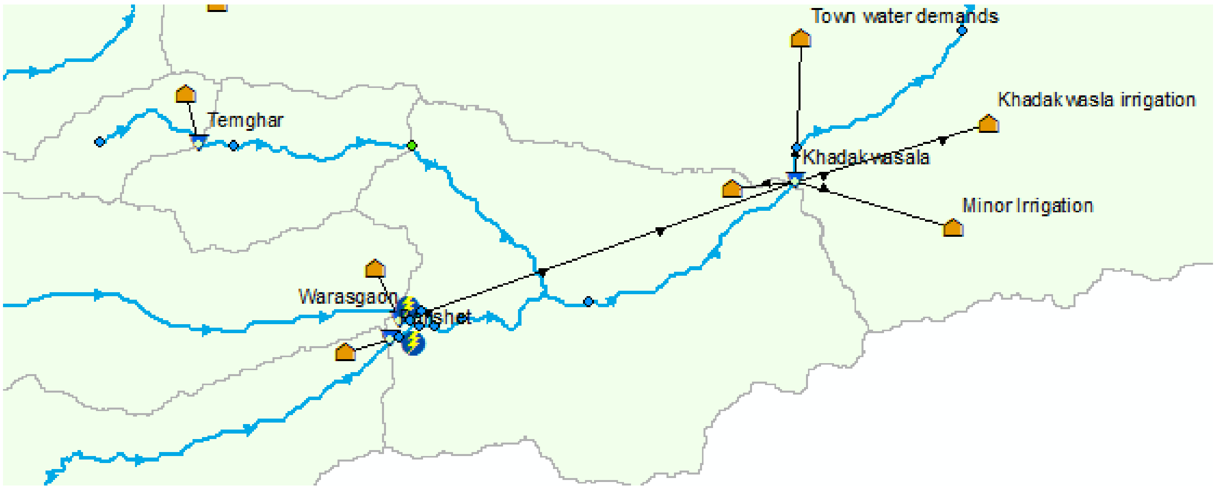
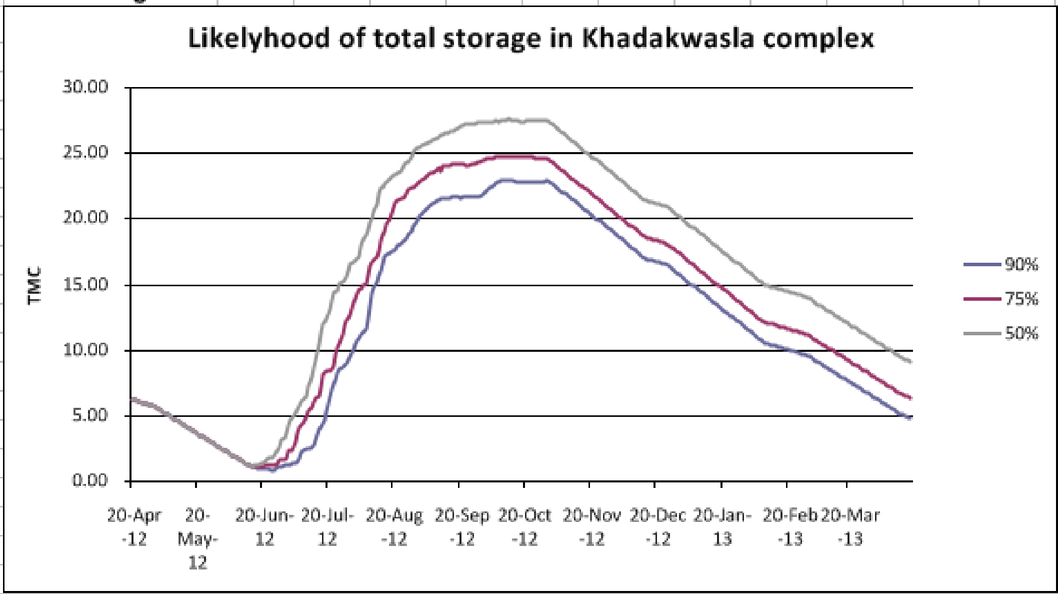



Figure 3.84: Model schematic for Khadakwasla reservoir complex

**Total storage**




| Next 12 months | 90% | 75% | 50% |
|---|---|---|---|
| Lowest storage TMC | 0.88 | 1.04 | 1.17 |
| Max storage TMC | 22.89 | 24.78 | 27.60 |

| Applied demand TMC | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec | year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation | 1.28 | 0.37 | 0.72 | 0.36 | 0.72 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 1.28 | 0.64 | 5.72 |
| Town water | 0.97 | 0.97 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.08 | 1.08 | 1.08 | 0.97 | 0.97 | 12.23 |
| Industry | 0.24 | 0.24 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.27 | 0.27 | 0.27 | 0.24 | 0.24 | 2.83 |
| Minor tanks | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.46 | 0.46 | 0.46 | 0.00 | 0.00 | 0.00 | 1.39 |

| Planned releases TMC | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec | year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation | 2.56 | 0.73 | 1.59 | 0.80 | 1.59 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 2.56 | 1.28 | 11.91 |
| Town water | 1.08 | 1.08 | 1.13 | 1.13 | 1.13 | 1.13 | 1.13 | 1.20 | 1.20 | 1.20 | 1.08 | 1.08 | 13.59 |
| Industry | 0.24 | 0.24 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.27 | 0.27 | 0.27 | 0.24 | 0.24 | 2.83 |
| Minor tanks | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.52 | 0.52 | 0.52 | 0.00 | 0.00 | 0.00 | 1.55 |
| | | | | | | | | | | | | | |
| **Total releases TMC** | 3.88 | 2.06 | 2.94 | 2.14 | 2.94 | 2.14 | 1.86 | 1.98 | 1.98 | 1.47 | 3.88 | 2.60 | 29.88 |

Figure 3.85: Seasonal planning for Mid- April 2012 in Khadakwasla reservoir complex

### 3.7.2 Conjunctive Use

Command areas are often affected by inequitable distribution of water between head and tail water users. The reasons for this could be water supply constraints, inefficient water management practices, higher dependence on surface water etc. The problem may be offset to some extent, by judicious use of both surface and groundwater. Use of groundwater will depend on power availability, infrastructure and associated costs. With the assumptions that the necessary arrangements are in place for utilization of both surface and groundwater, the scenarios may be developed and simulated for conjunctive use from these two water sources. The conjunctive use simulation was done in Khadakwasla Canal Command area in Upper Bhima basin. Conjunctive use scenarios were developed for irrigation water use in the command. Domestic demand in the command was met from groundwater source. Non project water utilizations were also incorporated in the scenario. These withdrawals are made along canals for non command area by lifting of water. Catchment wise sub division of the command was done. Conjunctive use was also simulated with different cropping scenarios. The application may be useful is further reducing water deficit, in particular will be useful in planning in drought situations.


Figure 3.86: Model Schematic for Khadakwasla canal command area

Table 3.9: Conjunctive use scenario for Khadakwasla canal command for catchment wise subcommands

| Conjunctive Use | BM51 | BM50 | BM49 | BM48 | BM61 | BM68 |
|---|---|---|---|---|---|---|
| SW supply | 65% | 70% | 80% | 65% | 80% | 100% |

Table 3.10: Water allocation summery from Khadakwasla canal command in base scenario

| Base | BM51 | BM50 | BM49 | BM48 | BM61 | BM68 | Total |
|---|---|---|---|---|---|---|---|
| Reliability | 100% | 100% | 99% | 99% | 75% | 11% | |
| Supply | 42.9 | 47.0 | 34.1 | 91.1 | 24.3 | 10.4 | 249.8 |
| GW | 0.6 | 1.9 | 2.5 | 12.9 | 7.9 | 10.4 | 36.3 |
| Deficit | 0.0 | 0.0 | 0.3 | 1.3 | 3.8 | 22.7 | 28.1 |

Table 3.11: Water allocation summery from Khadakwasla canal command in conjunctive use scenario

| Conj. use | BM51 | BM50 | BM49 | BM48 | BM61 | BM68 | Total |
|---|---|---|---|---|---|---|---|
| Reliability | 98% | 94% | 93% | 92% | 81% | 84% | |
| Supply | 42.6 | 46.4 | 33.7 | 88.9 | 25.9 | 30.6 | 268.1 |
| GW | 15.1 | 14.2 | 7.6 | 22.7 | 7.6 | 7.9 | 75.1 |
| Deficit | 0.3 | 0.6 | 0.6 | 3.5 | 2.2 | 2.5 | 9.8 |

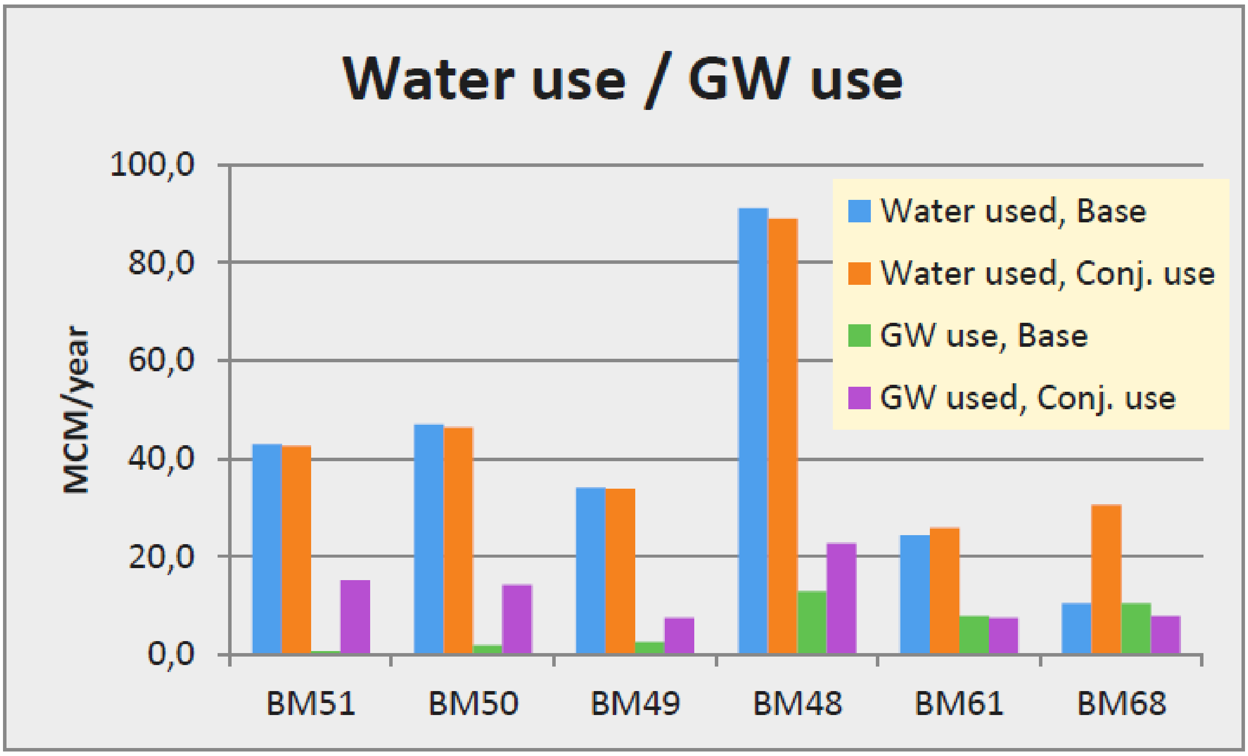



Figure 3.87: Water allocation comparison for base and conjunctive use scenario

Table 3.12: Water allocation summary in Sugarcane based cropping pattern in conjunctive use scenario of Khadakwasla canal command

| MCM/yr | BM51 | BM50 | BM49 | BM48 | BM61 | BM68 | Total |
|---|---|---|---|---|---|---|---|
| SW | 19.87 | 25.23 | 17.98 | 52.35 | 14.19 | 13.25 | 142.86 |
| GW | 9.46 | 7.88 | 5.68 | 11.04 | 2.84 | 9.78 | 46.67 |
| Total | 29.33 | 33.11 | 23.65 | 63.39 | 17.03 | 23.02 | 189.53 |
| Demand | 29.64 | 33.11 | 23.97 | 64.02 | 19.24 | 23.65 | 193.63 |
| Deficit | 0.32 | 0.00 | 0.32 | 0.63 | 2.21 | 0.63 | 4.10 |

Table 3.13: Water allocation summary in Non-Sugarcane based cropping pattern in conjunctive use scenario of Khadakwasla canal command

| MCM/yr | BM51 | BM50 | BM49 | BM48 | BM61 | BM68 | Total |
|---|---|---|---|---|---|---|---|
| SW | 11.98 | 14.82 | 12.30 | 33.74 | 11.67 | 11.04 | 95.55 |
| GW | 8.20 | 7.88 | 4.10 | 10.09 | 1.58 | 5.05 | 36.90 |
| Total | 20.18 | 22.71 | 16.40 | 43.84 | 13.25 | 16.08 | 132.45 |
| Demand | 20.18 | 22.71 | 16.40 | 43.84 | 13.25 | 16.08 | 132.45 |
| Deficit | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### 3.7.3 Groundwater Scarcity Prediction

For predicting groundwater scarcity at Talluka level, methodology was available. The methodology utilized post monsoon groundwater levels, preceding 5-year average groundwater level and percentage deviation of annual rainfall from long term average. Higher drop in groundwater levels compared to average level over preceding years and negative deviation in rainfall from long term mean, indicate scarcity situation. Different threshold levels were available for predicting beginning month, namely October, January, April or none, for groundwater scarcity. A dashboard application was developed for predicting groundwater scarcity at Talluka level.

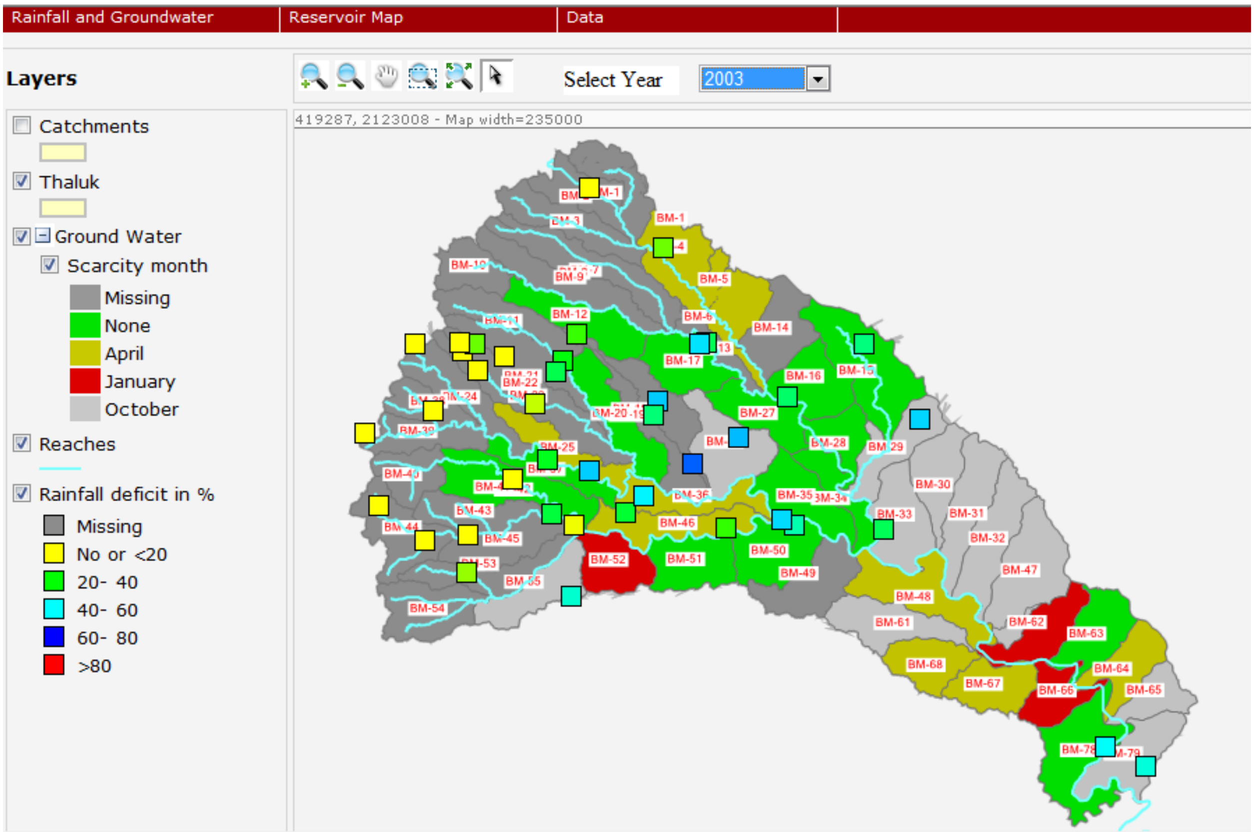



Figure 3.88: Groundwater scarcity in Upper Bhima basin at Talluka level for year 2003

## 3.8 DSS APPLICATIONS – ODISHA STATE

DSS (Planning) pertains to water resources planning, groundwater planning reservoir operation, irrigation management, drought management and conjunctive use of surface and ground water, etc. The distinguishing element of the DSS (Planning) is that they are intended to support decisions required at relatively infrequent time intervals such as one week, 10 days one month or longer planning horizons. As envisaged in the implementation plan of HP-II and proposals received recently from the states the generic DSS (planning) software were proposed to be developed and customized for Mahanadi basin and Tel Basin

A Decision Support System (DSS) provides the water Management Authorities a well-structured, user – friendly, practical and complete water resources management information system. It may assist the decision makers in taking the right decisions on the basis of good comparison of different strategies under various scenarios, and combine the benefits of Geographic information System, expert systems and simulation models Moreover, Modern visualisation techniques enable the managers to get a quick insight into the various options and trade-offs. In that respect a DSS can also be quite useful for priority ranking in master planning studies.

Decision Support System allow decision makers to analyze hydrologic data. run hydrologic simulation models, run basin water allocation models and study the effects of potential decision. A DSS is designed to access or display hydrologic data in an easily accessible manner, to model dynamic hydrologic condition, and to determine the ability of the river system to meet future demand based on operational and administrative use of storage. Often these DSS allow users to simulate and evaluate various "what if" scenarios for river operation alternatives. Operational plan addressed by DSS include the improvement of water use efficiency, exchanges between water users, the construction of new reservoirs or enlargement of existing facilities, the development of augmentation and replacement plans, as well as the development of additional beneficial uses, such as include accessibility, flexibility, learning, interaction and easy to use.

### 3.8.1 Report on Decision Support System (Planning) for the Odisha State

The activities related to development of the Decision Support System (Planning) (DSS(P) was started in Odisha Sate in the month December, 2008 along with other states and Central agencies. In order to proceed with systematic way the various activities of DSS development were divided into different set of tasks.

#### 3.8.1.1 Preparation of Inception report and Need Assessment:

Based on the documented information available in literature/reports the team of DHI Consultants prepared an inception report of project. This inception report covered the preliminary plan of the various technical methods, possible data availability with state plus concept and the approaches to achieve various tasks.

The primary objective of the Needs Assessment was to visit the state and discuss the water resources related issues and problems with the state officials and practicing field engineers of the respective state. The Team of DHI consultants visited the state of Odisha during the 30 March – 3 April 2009 to assess the prominent needs and the nature of water resource issues in the selected regions of the Odisha State. The preliminary assessment of the nature of the required DSS and its underlying models, to assess the required IT software and hardware needs and training needs, GIS training needs, and capacity building and training needs in the Surface water and groundwater department of the State to enable Odisha state officials to effectively contribute in the development and application of the DSS. As part of this process, it was also necessary to assess the availability and adequacy of data required by the DSS models.

During the visit of the Team of DHI Consultants to Odiaha State (30 March-03 April 2009 the details of activities undertaken are listed below:

| Day | Activity |
|---|---|
| 30th March, 2009 | Kick-Off Meeting, General discussions with State representatives |
| 31st Marchl, 2009 | Inspection of State Data Centre and site visitsto gauging stations |
| 1st April, 2009 | Field Trip to Visit lower Mahanadi basin, and Follow- up meetings, discussions on emerging problems, preparation of report |
| 02nd April, 2009 | Assessment and report writing, Consultant Team Meeting with State representatives |
| 03rd April, 2009 | Wrap-up Meeting with State SW and GW representatives, Departure, Consulting Team |

#### 3.8.1.2 Study Basin for DSS (P)

The State of Orissa lies on the east coast of India between latitudes 17049’ N to 22034’N and longitudes 81029’ E to 87029’ E. The State has a geographical area of 1,55,70 7km2. There are 30 districts in the State and a population of over 37 million. There are hilly regions and plateau regions in the State. The State can be broadly divided into four natural regions namely

- The hilly areas in the north and northwest
- The Eastern Ghats

- The Central and Western Plateau and
- The coastal plains

The hills in the coastal areas are not continuous ranges and are interspersed by the river valleys. They lie parallel to the coast at a distance of about 100 km from the coast. They are generally less than 800 m in height. The physiography influences the temperature and rainfall pattern in the State. The climate of the State is sub tropical and varies from semi arid to sub humid. In the eastern parts of the State the climate is humid or sub-humid. There are three well marked sea-sons in the State namely summer (March to May), rainy season (June to October) and winter (November to February). The average annual rainfall is 1503 mm. The rainy season is June to October and there is heavy rainfall in the month of August. During pre monsoon, monsoon and post mon-soon seasons cyclones affect the State bringing heavy rain fall. During winter there are thunder showers in the southern and western parts of the State.

Orissa state had decided to selected study areas within the Mahanadi Basin for DSS Planning Application under HP-II. The areas are: (1) the Hirakud Command Area, and (2) a drought prone area in upper Tel Basin. The tel River is one of the major tributary joining Mahanadi river system after Hirakund Reservoir.

### 3.8.2 Rivers and Water Resources

The State of Odisha is blessed with a number of rivers the biggest of them being Mahanadi. The other rivers are Subarnarekha, Baitarani, Brahmani, Rishikulya, Vamsadhara and Nagavali. Considerable irrigation takes place from the Hirakud Dam. Current status of Water Resources in the Odisha State is shown in Table 3.14.

The ground water utilisation in Orissa is around 20% of the replenishable amount, con-sidering the whole state, although large variations occur within the State. Quite inten-sive utilisation is seen in some areas, but these are not overexploited. An overview of the river basins is given below.

Table 3.14: Current status of Water Resources in the Odisha State

| Basin | Catchment Area | | | Average Annual flow (in BCM) | | |
|---|---|---|---|---|---|---|
| | Total (Sq.Km.) | Within Orissa | | Own | Outside State | Total |
| | | (Sq.Km.) | % to area of State | | | |
| Mahanadi | 141134 | 65628 | 42.15 | 29.90 | 29.255 | 59.155 |
| Brahmani | 39116 | 22516 | 14.46 | 11.391 | 7.186 | 18.577 |
| Baitarani | 14218 | 13482 | 14.46 | 7.568 | | 7.568 |
| Budhabalanga & Jambhira | 6691 | 6354 | 4.08 | 3.111 | | 3.111 |
| Subernarekha | 19277 | 2983 | 1.92 | 1.193 | 1.115 | 2.308 |
| Rushikulya | 8963 | 8963 | 5.76 | 3.949 | | 3.949 |
| Indravati | 41700 | 7400 | 4.75 | 6.265 | | 6.265 |
| Kolab | 20427 | 10300 | 6.61 | 11.089 | | 11.089 |
| Vamsadhara | 11377 | 8960 | 5.75 | 5.083 | | 5.083 |
| Nagabali | 9275 | 4500 | | 2.89 | 2.853 | 2.853 |
| Bahuda | 1118 | 890 | | 0.57 | 0.438 | 0.438 |
| Area draining directly in to the sea | | 3731 | | 2.40 | | |
| **Total** | **313296** | **155707** | **100** | **82.841** | **37.556** | **120.397** |

## 3.8.3 Mahanadi River Basin

In Orissa state, the DSS implementation has been carried out in two areas:

- Applications have been developed for seasonal water resources planning and consumptive use and reservoir operation in the Hirakud Command Area where the water demand exceeds the availability in the Rabi season.
- The upper Tel River Basin, which is drought prone part of the Mahanadi River Basin in Odisha.

The Khariff Area to be considered in the Hirakud Command Area is 163036 ha while the Rabi Area is 115481 ha. An assessment of the water availability in the basin has been made for seasonal planning and quantification of conjunctive use of Surface & groundwater.

The Mahanadi River Basin is spread over four states namely Chhattisgarh, Maharashtra, Jharkhand and Orissa. The Basin is situated between $19^{o}$ 20’ N and 23 $^{o}$35’ N latitude and between $80^{o}$ 30’ E and $84^{o}$50’ E longitude. Fig. 3.1 presents the basin Map of Mahanadi River System. The upper portion of the Basin is a square shaped depression known as Chhattisgarh. The Basin is circular in shape with a diameter of about 400 km and an exit passage of about 160 Km length and 60 Km breadth. The Basin is bounded by Central Indian hills on the north, Eastern Ghats on the east & south and Mikela Range lying in the northeast of Deccan Plateau

The Mahanadi off springs at an elevation of 442 meter above MSL. The Basin can be broadly divided into three distinct zones – the upland plateau, the central hill part flanked by Eastern Ghats and the delta area. The total length of the river from its origin till its outfall in to the Bay of Bengal is 851 km and the length of river in Orissa is 494 km. The major tributary rivers are Seonath, Hasdeo, Ib, Tel, Ong, and Salki and the ma-jor branches are Kathjori, Kuakhai, Birupa, Daya, and Bhargabi.

The Mahanadi Basin drains an area of 1,41,600 km$^2$. Most of which lies inside the states of Chhattisgarh and Orissa. The Catchment Area in Chhattisgarh is 75,136 km$^2$ and Orissa is Orissa 65,628 km$^2$. The catchment area upstream of Hirakud Dam is 83,400km$^2$. The catchment downstream of the Hirakud Dam at Delta Head (Naraj) is 48,700 km$^2$. The catchment receives 75% to 90% of total annual rainfall during south west monsoon. The average annual rainfall is 1420 mm.

Table 3.15: Completed water storage structures in Mahanadi Basin

| | |
|---|---|
| **Dams:** | |
| Major Dam | 1 |
| Medium Dam | 15 |
| Minor Dam | 55 |
| **Diversion Structures:** | |
| Barrages | 9 |
| **Ongoing WR structures:** | |
| Medium Dam | 3 |
| Barrages | 2 |
| **Proposed WR structures:** | |
| Dams and Barrages | 38 |

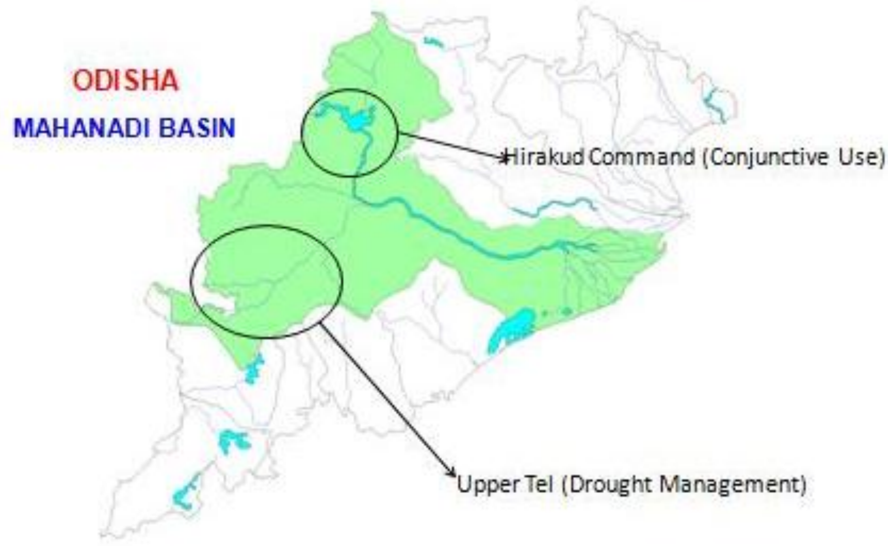



Figure 3.89: The Basin Map of Mahanadi River System.

#### 3.8.3.1 Water Management Issues in the Hirakud Command Area

The Hirakud Dam was originally constructed primarily for flood control, but is now applied mainly for irrigation, hydropower and industrial water supply. While sufficient water is available for paddy in the Kharif season from April to September most farmers in the middle and tail-end area are unable to produce a second crop of rice during the Rabi season from October to March. Ground water is applied in these lower areas, but sufficient resources are not available here for paddy.

Water logging is seen to occur in some areas within the command. Increased utilization of ground water is likely to alleviate this problem.

The main purpose of the DSS is to analyse, compare and visualise scenarios of conjunctive ground water and surface water use for various cropping patterns, particularly during the Kharif and Rabi cropping seasons. The aim is to increase water availability in scarcity areas, increase the Rabi command area, alleviate water logging and salinity problems, and identify optimal cropping pattern. It should be noted that while a DSS can help identifying more efficient ways of managing water, the implementation of these may require appropriate interpretation and execution of the scenario results.

#### 3.8.3.2 Drought & Water deficit issues in the Upper Tel River Basin

The major water resource issue in the upper Tel River Basin is water shortage. As noted above rainfall is highly erratic and surface runoff is not stored in the basin to meet and lean

season water demand for various purposes. The main water source is surface water. Ground water is scarce and difficult to extract. It occurs in hard rocks and is stored in fractured zones ('lineaments') and in isolated pockets of unconsolidated sediments that overlay bed rock. Often the local population has been forced to abandon the area some years when the monsoon has failed. Possible solutions for this area include creation of in situ water storage schemes, construction of minor reservoirs, and change in cropping pattern.
Water quality issues in Orissa have been covered by the CPCB study on the Brahmani River. Other issues are described below.

The corresponding functionalities of the DSS mainly are:

- support decisions on seasonal water planning and plan for tank operations in dry years
- support decisions on conjunctive use of surface and groundwater
- demonstrate benefits of changes in cropping pattern
- Support decision to enhance coverage of canal command areas.
- Regular monitoring & identification of drought events for appropriate planning and adjustment in the water utilization schedule during drought period

Particularly, the DSS should be designed to help taking decisions on the following issues in the Hirakud Command Area:

i. Analyse the impact of changes to the distribution of surface water inside the command area and to the conjunctive use. Scenarios of increased ground water abstraction in water logged areas and increased surface water irrigation in the middle and tail-end areas would be of particular interest.

ii. Assess the impact of changes in cropping pattern in terms of crop production and water use in order to identify promising alternatives to the present cropping.

iii. Analyse the water use by the various sectors to identify and help solving any conflicts or inefficiencies.

### 3.8.3.3 The issues for the Upper Tel catchment are:

i. Drought is occurring frequently in this area. The DSS should enable analysis of drought management options to help identify the best possible measures to miti-gate the impact of droughts.

ii. The farmers are very traditional in the choice of crop and generally reluctant to grow anything but paddy. It would be beneficial for the sustainability of water use in this drought prone area to convince farmers of growing crops, which are less demanding in water requirements. The DSS should therefore be able to as-sess the benefits of changes in cropping pattern by introducing cash crops such as gram, mustard, wheat, pulse, or vegetables. This is particularly important for the sustainable use of ground water.

iii. Surface water management, including analysis of possible inter-basin transfer of water and revised utilisation of available surface storages.

iv. The DSS should further be able to analyse the impact of conjunctive use of sur-face and ground water

### 3.8.4 Model Conceptualization

During this task, suitable modelling software was assessed and finalized by the consultants keeping in view the requirements of all implementing agencies. The main modelling software MIKE BASIN with NAM rainfall-runoff model was selected. The results of this modelling software would be used by the DSS front end to generate the scenarios. The MIKE BASIN modelling package was provided and incorporated in the DSS in order to address the need of all states for river basin modelling software. MIKE BASIN includes the rainfall-runoff model NAM, which may be applied to assess the runoff and ground water recharge in sub-catchments within a basin and thereby generate time series, which represent the climatic variation of water availability. To facilitate the use of this software, the Consultant will provide a stand-alone version of NAM, which includes facilities to support the calibration process.

The MIKE BASIN is a simulation model for water allocation representing the hydrology of the basin in space and time as well as modelling water quality and ground water related issues. Subsequently the MIKE BASIN is proposed to be replaced by the MIKE HYDRO Software to avoid licensing issues etc.

### 3.8.5 Database Development

Hydro-meteorological data series and geodatabase comprising of GIS layers as well as links to relevant time series data havebeen established for the Upper Mahanadi Basin up to Hirakund Dam, Hirakund Command and the Tel Basin. Various data required by the consultants viz. surface water time series, ground water time series, spatial data in the form of GIS layers were provided to the consultants. These data were given as input to the MIKE Basin software (Fig. 3.3). Rainfall-runoff model calibration was done for different GD catchments and reservoir catchments.

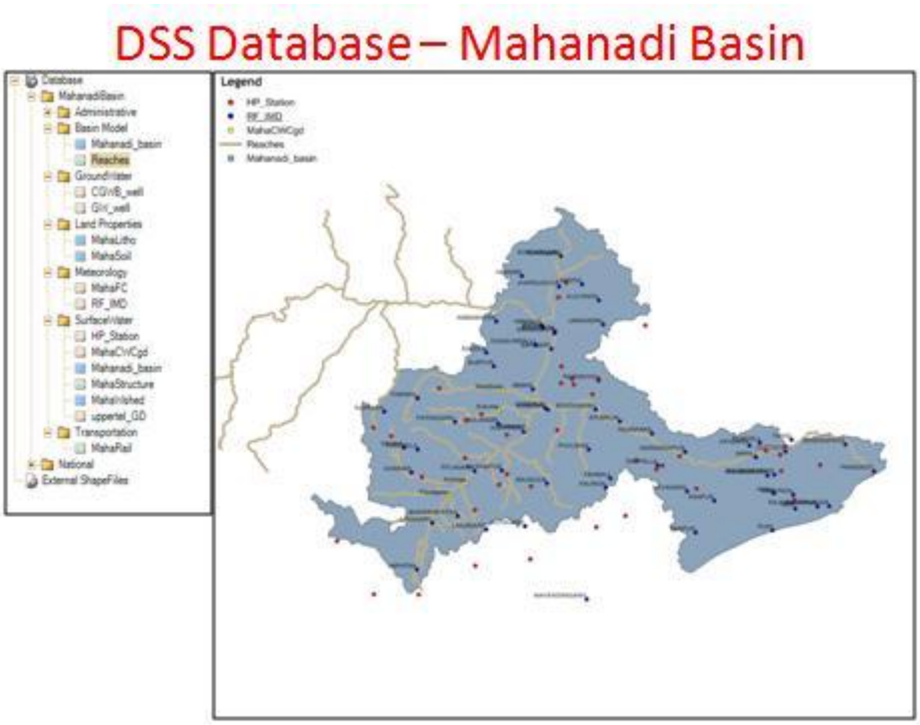



Figure 3.90: MIKE BASIN database development for Mahanadi Basin

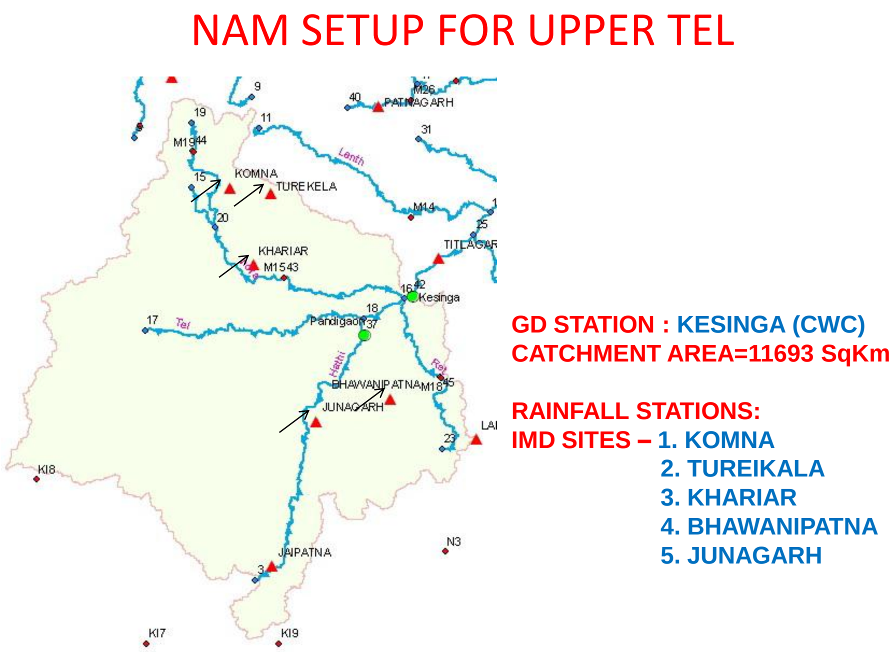



Figure 3.91: MIKE BASIN NAM Setup for Upper Tel Bsian

**The following particulars for the State have been completed:**

- Calibration of G&D and reservoir catchments using NAM Model as shown in Fig.3.4.
- Calibration of Reservoirs Level.
- Mike Basin Setup for the basin.
- DSS Installation.

- Registration of Mike Basin model setup in the DSS software.
- Customization and Development of Mike Basin model for the conjunctive use.
- Demonstration of the conjunctive use interface in DSS(P).
- Development of interface for drought monitoring and its demonstration

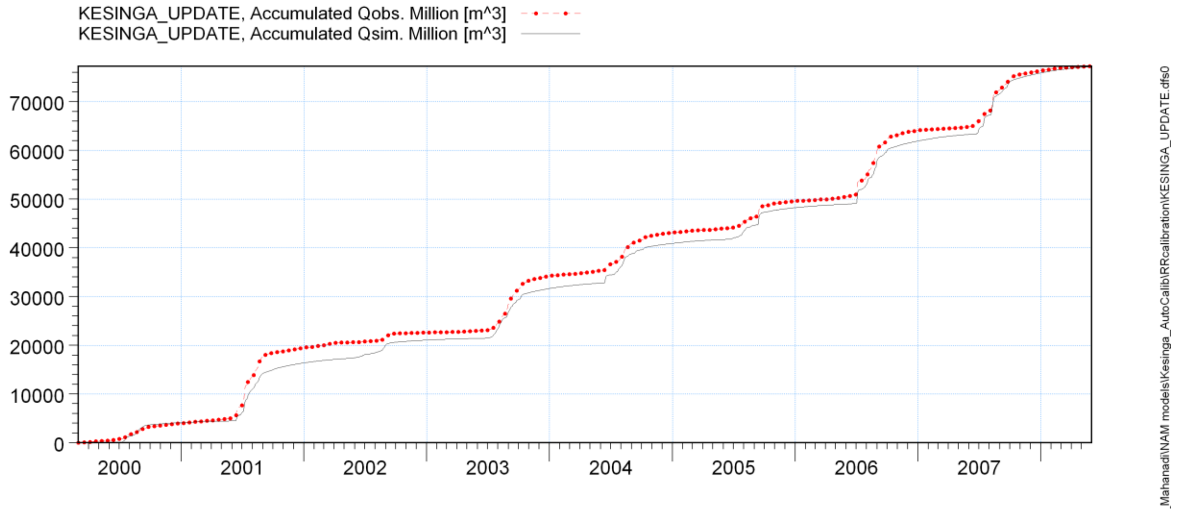



Figure 3.92: MIKE BASIN NAM Calibration for Upper Tel Bsian at Kesinga

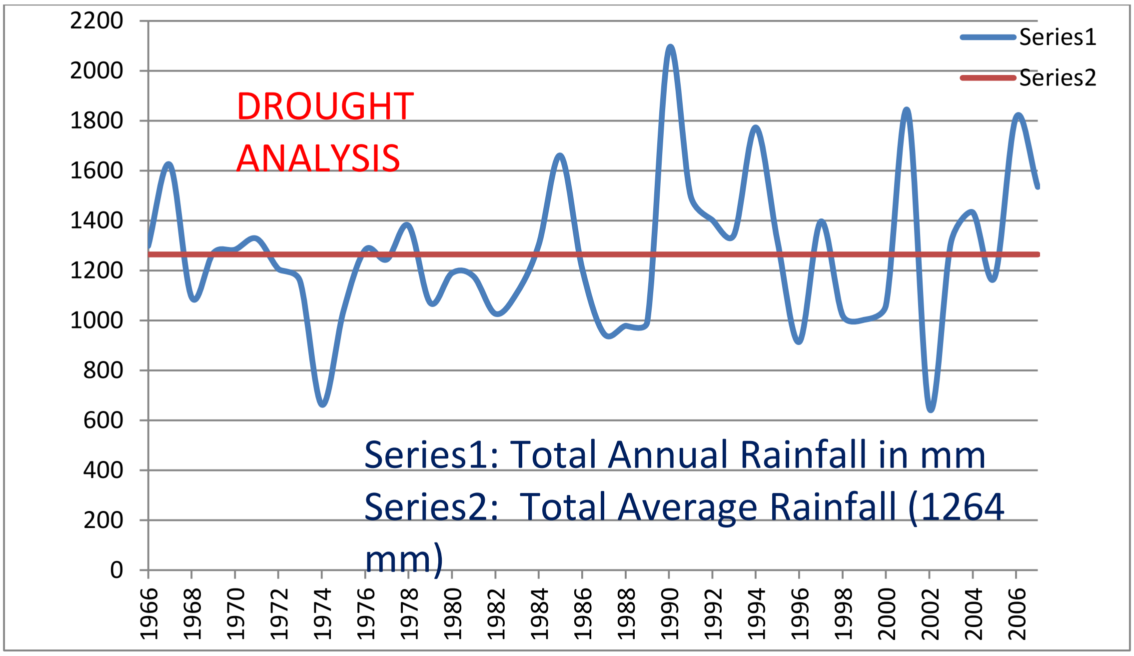



Figure 3.93: Plot of annual rainfall deviation from mean value

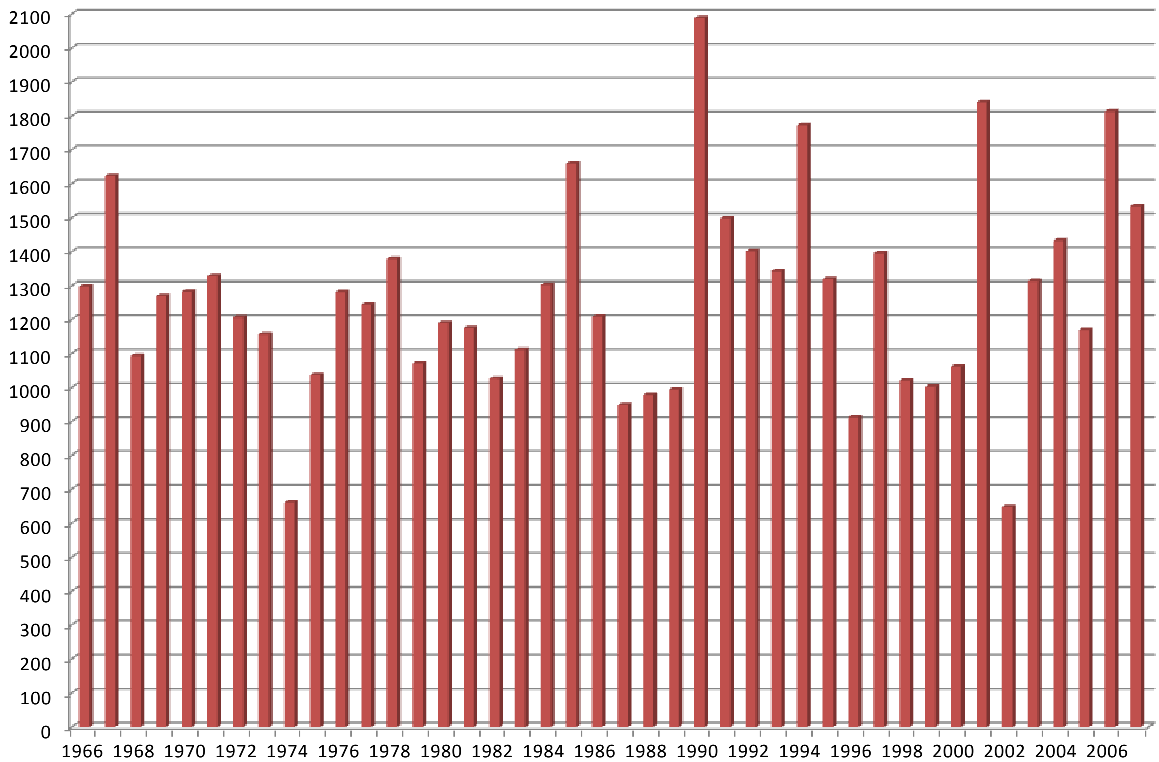



Figure 3.94: Plot of annual rainfall deviation from mean value

The Figure 3.93 and Figure 3.94 show total annual rainfall vs average annual rainfall from 1966 to 2007. The annual rainfall falling below the value of average annual rainfall of 1264 mm suffered drought from marginal to moderate. For example, 1974, 1996 & 2002 indicate "moderate drought" years.

**Drought Management: Seasonal GW Planning**

One of the best ways to manage drought to use more ground water. The artificial infiltration is a key solution to harvest more ground water. Minor tanks in the area are assumed to act as one lumped artificial tank for infiltration. It is planned to analyse artificial recharge in Kalahandi District which is prone to drought. Small portion of Bhawanipatna Block, selected for this application was extracted from land use GIS layer by intersection tool in Arc Map. The delineated catchment area is 230 $km^2$ in which 53% of the total area is agricultural land (intersect from land use layer). The agricultural area used for Kharif and Rabi Paddy are approximately 20 and 8 percent respectively. During Rabi season 60% ground water is available and 40% surface water is required to be stored.

The MIKE BASIN setup for artificial recharge (Fig. 3.6) include irrigation User, Domestic user & Industry Users. Fig. 3.7 –presents Scenario -1 for dealing with irrigation demand using ground water.

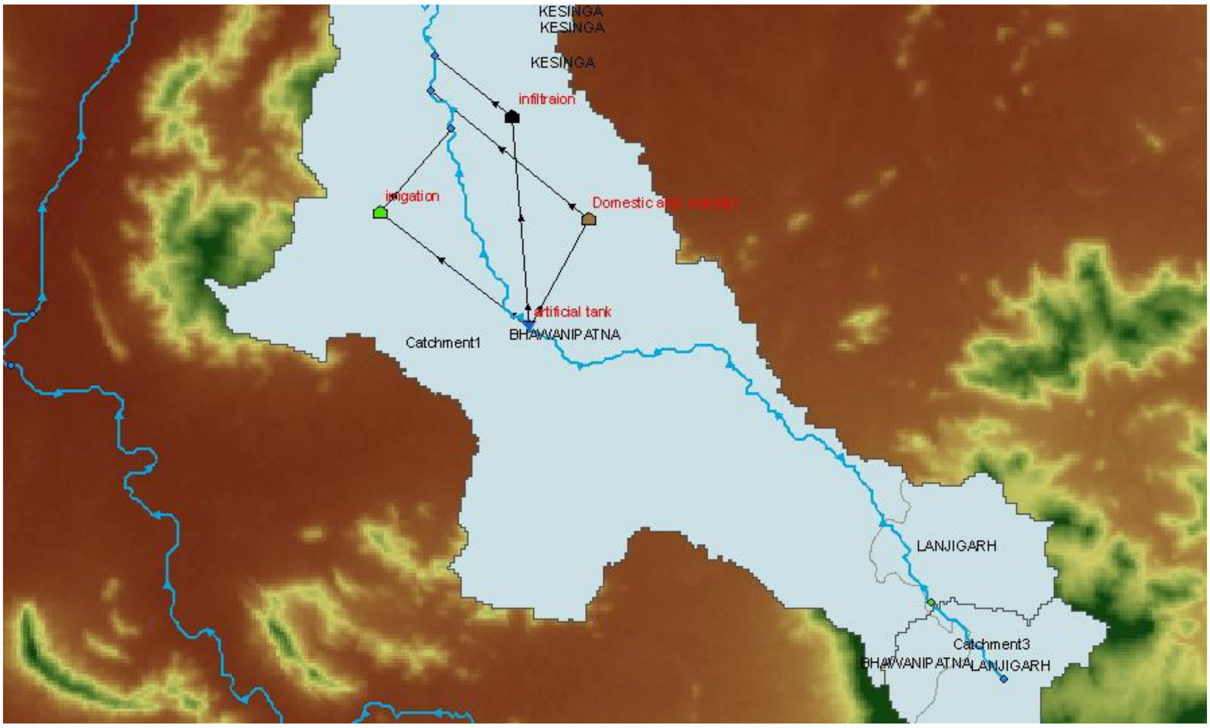



Figure 3.95: MIKE BASIN Setup for Artificial Infiltration -Bhawanipatna Block

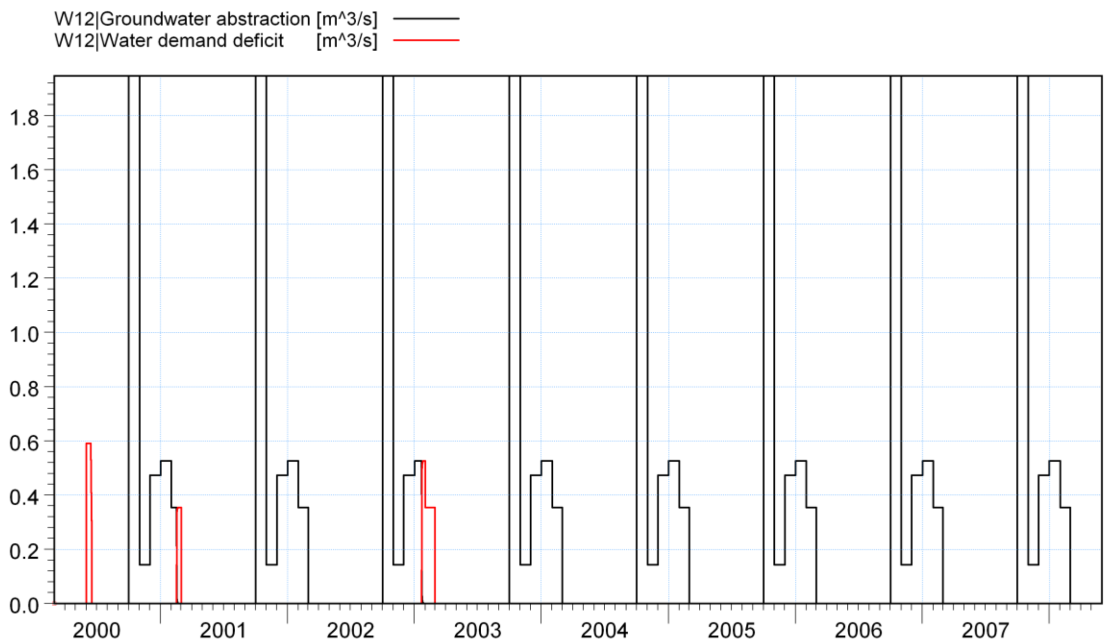



Figure 3.96: Irrigation Demand from GW --- Scenario 1

Figure 3.97 demonstrates the impact of infiltration by Lumped Artificial Tank -- *Red line:* GW level before infiltration and *Blue line*: GW level after infiltration

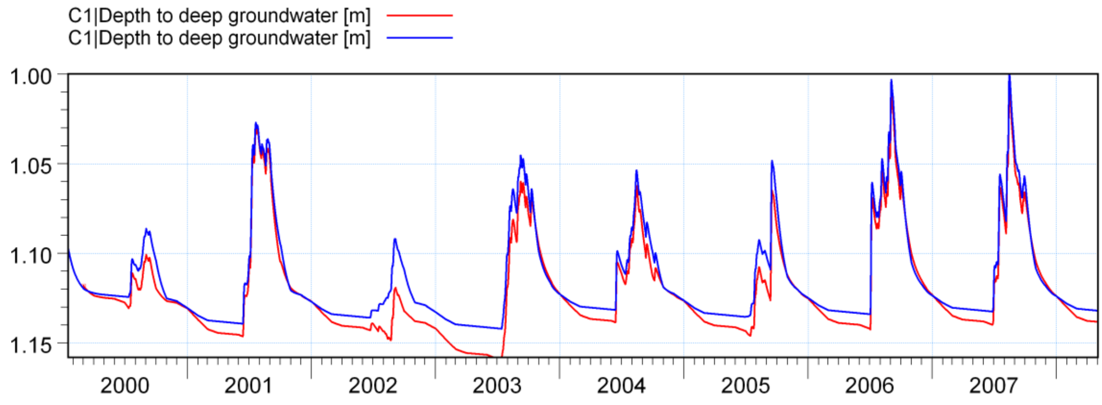



Figure 3.97: Change in Ground Water Level ------Scenario 2

## 3.8.6 DSS(P) Development

The DSS software which is compatible with MIKE HYDRO has been recently upgraded to ver. 4.0. Various functionalities of this software include GIS manager, Time Series manager, Scenario manager, Scripts manager, Spreadsheets manager, System manager, Dashboard manager, Tools explorer and Properties, etc. Tools explorer comprises of various operations like hydrological and statistical, import, export, etc linked to any particular time series or GIS layer.

### 3.8.6.1 The activities completed

- DSS server set up completed.
- DSS software version 3.2 installed in Server as well as in Desktop.
- DSS software customized for Conjunctive use planning in Hirakund Command, Seasonal water resources planning, and drought monitoring in Tel Basin.
- The System is presently functioning surface and ground water department Govt. of Odisha

## 3.8.7 DSS Customization

### 3.8.7.1 Conjunctive Use Hirakund Command Area

Odisha state has developed a conjunctive use model for the Hirakund command area There are domestic, agricultural and industrial demands in the command area
A schematic view of this complex command in DSS(P) in Figure 3.98 is shown below:

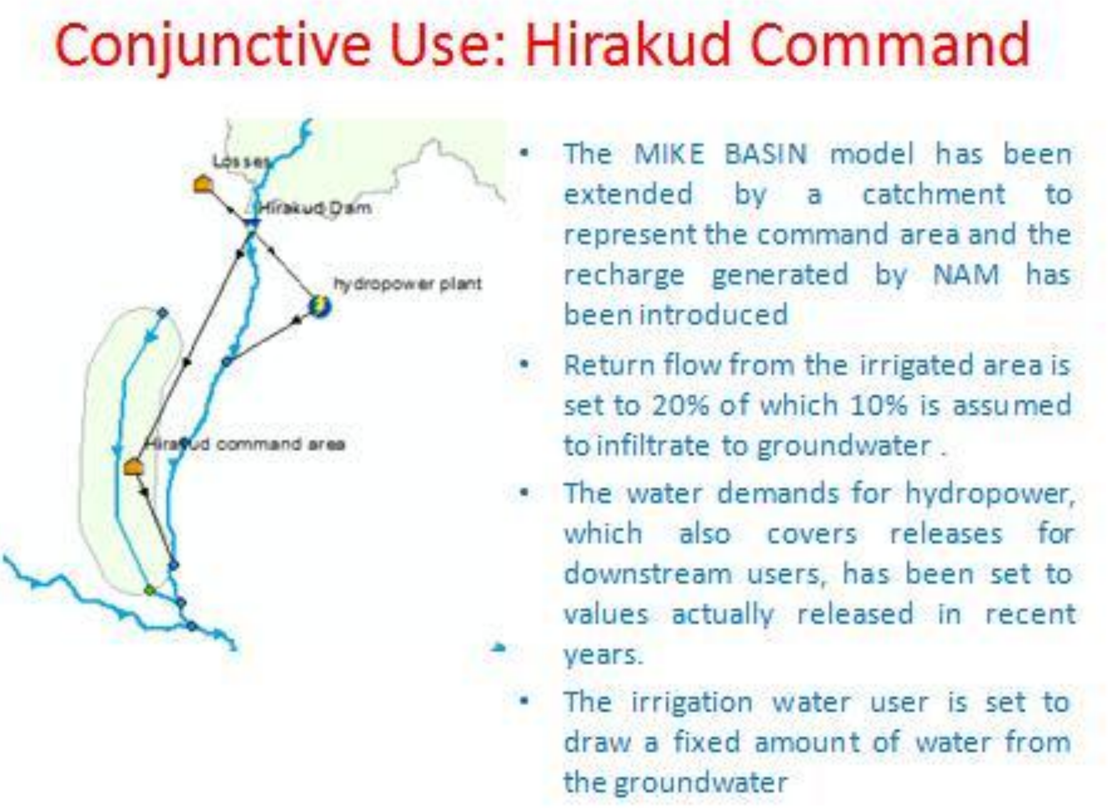



Figure 3.98: A schematic view of Hirakund command in for conjunctive use planning in DSS(P)


| | rabi | | | 15% | in rabi |
|---|---|---|---|---|---|
| | 85% | Deficit car | Groundwa | Groundwater use ab | |
| 01/01/2008 08:00 | 144.71 | 0 | 0 | 21.71 | |
| 01/02/2008 08:00 | 147.69 | 0 | 0 | 22.15 | |
| 01/03/2008 08:00 | 144.71 | 0 | 0 | 21.71 | |
| 01/04/2008 08:00 | 174.48 | 0 | 0 | 26.17 | |
| 01/05/2008 08:00 | 179.84 | 0 | 0 | 26.98 | |
| 01/06/2008 08:00 | 65.72 | 0 | 0 | 9.58 | |
| 01/07/2008 08:00 | 31.88 | 0 | 0 | 0.00 | |
| 01/08/2008 08:00 | 121.83 | 0 | 0 | 0.00 | |
| 01/09/2008 08:00 | 94.22 | 0 | 0 | 0.00 | |
| 01/10/2008 08:00 | 120.40 | 0 | 0 | 0.00 | |
| 01/11/2008 08:00 | 139.43 | 0 | 0 | 0.00 | |
| 01/12/2008 08:00 | 42.28 | 0 | 0 | 0.00 | |
| 01/01/2009 08:00 | | | | | |

Figure 3.99: Spread sheet for Hirakund command for conjunctive use planning in DSS(P)

The outputs of this conjunctive use interface are in the form of estimation of water demands for various uses, surface and groundwater availability, allocation of surface water and groundwater, variation of reservoir and groundwater levels, groundwater recharge and abstraction, use of surface and groundwater in the command. The conjunctive use interface through spreadsheet is shown in Fig. 3.10 for Hirakund command.

### 3.8.7.2 Development of DSS-Interface for Drought monitoring and management.

An Interface with DSS(P) software had been developed incorporating a new procedure developed by NIH for identification of Meteorological Drought in monthly time stem has been incorporated in the in addition to Standardized Precipitation Index (SPI) for three month Time-Scale. The stepwise procedure is given below.

**Step 1: Get Mean Monthly values (June, July, .... May)**

i. Take monthly value of a given month (Say June) for all the years from available record.

ii. Arrange above data for said month in ascending or descending order. Discard 5% upper and 5% lower values from the data set.

iii. Get average of the remaining values—it will be mean value of the said month.

Similarly, get mean values for other months of the water-year (i.e. July, Aug.. ...., May

**Step 2: Get Mean Seasonal (June –sept or June-Oct.) and Annual values (June -May)**

i. Using same procedure as in step-1, calculate mean seasonal and annual values.

ii. Repeat step-1 and step-2 for all the stations in the study basin.

**Step 3: Identification of drought onset.**

It is drought month (start) or else no drought.

i. If rainfall in first month (say June) < 50% of corresponding month's mean rainfall value – it is drought month (start) or else no drought.

ii. If rainfall of 2$^{nd}$ month (i.e. July) < 50% of corresponding month's mean rainfall value

*OR*

If rainfall of 1$^{st}$ +2$^{nd}$ month is < 75% of corresponding mean rainfall value.

iii. If rainfall of 3$^{rd}$ month (i.e. Aug) < 50% of corresponding month's mean rainfall value

*OR*

If rainfall of 1$^{st}$ +2$^{nd}$ +3$^{rd}$ month is < 75% of corresponding mean rainfall value.

iv. If rainfall of 4$^{rd}$ month (i.e. July) < 50% of corresponding month's mean rainfall value

*OR*

If rainfall of 1$^{st}$ +2$^{nd}$ +3$^{rd}$ +4$^{th}$ month is < 75% of corresponding mean rainfall value. (Also it is seasonal drought)

v. And so on .......

vi. For 12-month (annual) – if rainfall of 1$^{st}$ +2$^{nd}$ +3$^{rd}$ +4$^{th}$ + .......+ 12$^{th}$ month is < 75% of corresponding mean rainfall value.

Application of above methods have been customized and demonstrated for the state of Odisha

**Simple drought Index (SDI):** The Estimation of Weighted Departure of Rainfall

- The percentage rainfall departure from mean value of given month was estimated and it is multiplied by the weight of corresponding month's mean rainfall. Finally a dashboard has been developed for near real time drought monitoring as given in Fig. 3.11.

## Comparison of SDI with SPI & EDI

| Year | Month | Rainfall | Monthly Av. RF | SDI-Identification | Weighted Departure | SPI 3 Month | EDI Monthly |
|---|---|---|---|---|---|---|---|
| 2006 | Jan | 0 | 20 | Drought-50 | -2.13 | -1.99 | 0.57 |
| 2006 | Feb | 20 | 22 | Drought-2m | -0.21 | -0.43 | 0.48 |
| 2006 | Mar | 34.2 | 11 | 1 | 2.47 | 0.31 | 0.85 |
| 2006 | Apr | 23.8 | 7 | 1 | 1.79 | 1.17 | 1.18 |
| 2006 | May | 25 | 22 | 1 | 0.32 | 1.19 | 0.62 |
| 2006 | Jun | 42.5 | 132 | Drought-50 | -9.54 | -0.4 | -0.69 |
| 2006 | Jul | 435.6 | 322 | 1 | 12.11 | 0.27 | 0.37 |
| 2006 | Aug | 171.5 | 314 | 1 | -15.19 | -0.39 | -0.63 |
| 2006 | Sep | 44.9 | 202 | Drought-50 | -16.75 | -0.64 | -1.29 |
| 2006 | Oct | 11.5 | 33 | Drought-50 | -2.29 | -1.57 | -1.31 |
| 2006 | Nov | 0.6 | 12 | Drought-2m | -1.22 | -1.71 | -1.46 |
| 2006 | Dec | 0 | 5 | Drought-2m | -0.53 | -0.86 | -1.44 |
| 2007 | Jan | 0 | 20 | Drought-50 | -2.13 | -1.74 | -1.78 |
| 2007 | Feb | 71.2 | 22 | 1 | 5.25 | 0.75 | -0.67 |
| 2007 | Mar | 25 | 11 | 1 | 1.49 | 1.04 | -0.5 |
| 2007 | Apr | 1.8 | 7 | 1 | -0.55 | 1.52 | -0.67 |
| 2007 | May | 2.9 | 22 | Drought-50 | -2.04 | 0.08 | -0.87 |

$$W_j = \frac{\overline{MR_j}}{\overline{AR}} \quad \text{..............................} \quad (4.19)$$

$$WMD_j = W_j \{ \frac{(MR_{i,j} - \overline{MR_j})}{\overline{MR_j}} \} X100 \quad \text{........................} \quad (4.20)$$

Where, $W_j$ = Weight of the j[th] month rainfall w.r.t. annual rainfall

$\overline{MR_j}$ = mean rainfall of j[th] month, (j= 1,2,.....12)

AR = mean annual rainfall

$MR_{i,j}$ = monthly rainfall (i=1,2,3, .........n)

n = number of years of rainfall records

$WMD_j$ =Weighted monthly rainfall departure in %.


Figure 3.100: A view of DSS(P) dashboard for drought management in Tel Basin

## 3.9 DSS APPLICATIONS – TAMIL NADU STATE

Tamil Nadu has proposed developing for three study areas for the development of DSS (P): the Agniyar Basin, the Tamirparani Basin, and the Vaippar Basin (Figure 3.102). For each study area, Tamil Nadu has collected and formatted spatial and time series data. For the Tamirparani and Vaippar Basins, the data included and linked to in the databases is described in the following sections.

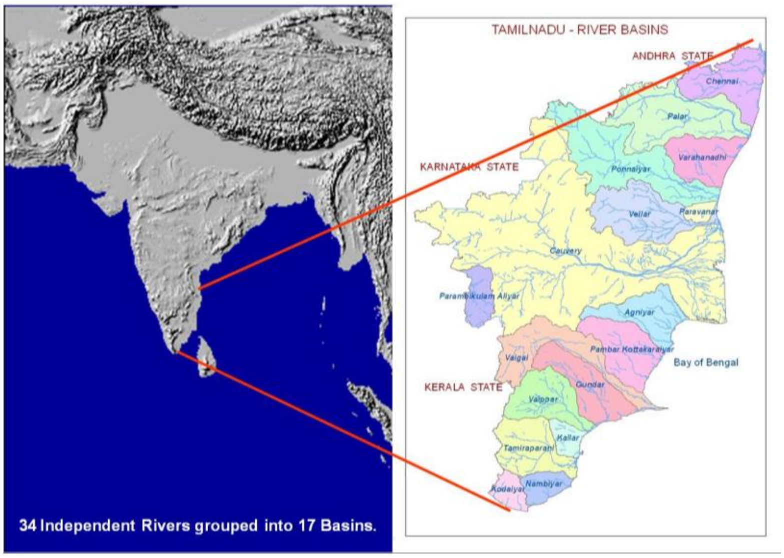



Figure 3.101: Rivers basins of Tamilnadu

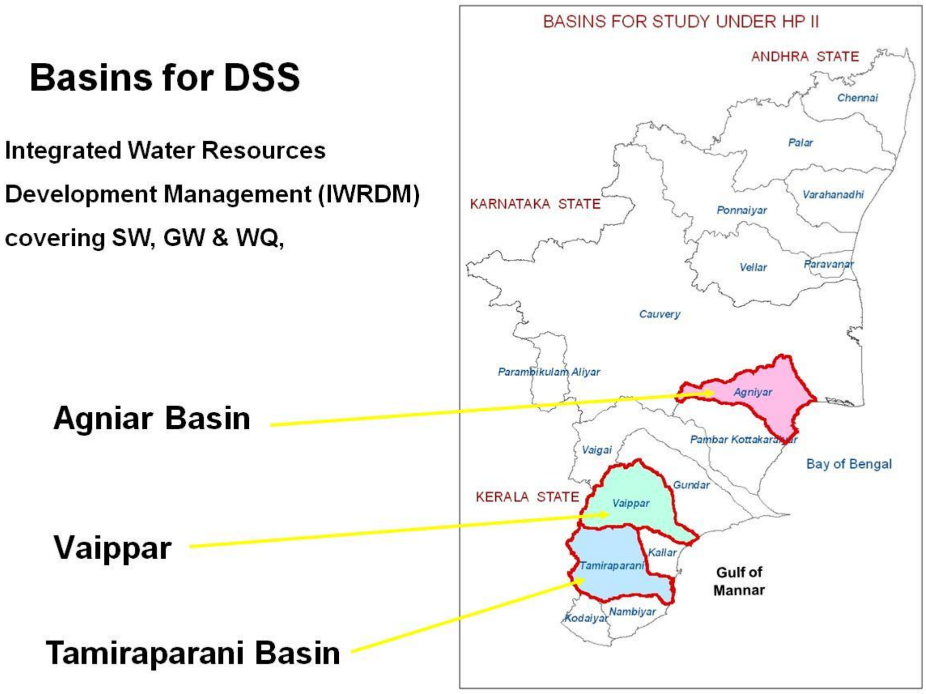



Figure 3.102: Rivers basins proposed for DSS(P) development by Tamilnadu

### 3.9.1 Spatial Data: Tamirparani Basin

Spatial data incorporated into the geodatabase includes the locations of stream network, rain gauges and wells as well as stream, digital elevation model, lithology, soils, settlements, villages, administrative boundaries, roads, geology, landuse, watersheds, and geomorphology. This spatial information has been projected into the WGS_1984_UTM_Zone_44N and a datum of D_WGS_1984.

### 3.9.2 Surface Water Data: Tamirparani Basin

Twenty seven rain gauges and 3 full climatic stations are available to characterize precipitation within the Tamirparani Basin. State and IMD data are available from 1999 and 1972 respectively. Stream gauge data is available from 8 gauge discharge sites within the basin with data reported from 1999. Additional stream gauge information is available from dam outlet for major project.

### 3.9.3 Ground Water: Tamirparani Basin

Within the Tamirparani Basin, 84 dug well and 36 piezometer ground water level data is available from 1999 and 1972, respectively. This data has been collected and formatted into DFS0 format for the mike basin model. Ground water data of the basin is available in the GWDES format.

### 3.9.4 Spatial Data: Vaippar Basin

As with the Tamirparani Basin, the spatial data incorporated into the geodatabase includes the locations of stream network, rain gauges and wells as well as stream, lithology, digital elevation model, soils, settlements, villages, administrative boundaries, roads, geology, landuse, watersheds, and geomorphology.

### 3.9.5 Surface Water Data: Vaippar Basin

Twenty seven rain gauges and 2 full climatic stations are available to characterize precipitation within the Vaippar Basin. State and IMD data are available from 1999 and 1972, respectively. The data available in SWDES format has been transferred into mike basin. Stream gage data is available from 3 gauge discharge sites within the basin with data reported from 1999. Reservoirs have been added to the database and the properties associated with the reservoirs have been added in the MIKE BASIN model setup of the basin.

### 3.9.6 Ground Water Data: Vaippar Basin

Within the Vaippar Basin, ground water level data is available for 87 dug wells and 36 tube wells. This data has been collected and formatted into DFS0 format, and loaded into the geodatabase supporting the Vaippar Basin. The period of record for the water level time series in the database ranges from 2000 to the present. The data is available in GWDES format.

### 3.9.7 Customization of the DSS Planning

The customization of the DSS Planning software to meet the requirements of Government of Tamilnadu.  DSS Planning software has been developed to support decisions in water resources development and management and share data and information within the user organization. The main elements of the system are:

- Database and associated tools to display, manage, and analyse GIS and time series data and provide easy access to this information for water managers and professionals at all levels within the user organisation.
- Modelling tools to analyse water management options and extract key results for decision makers. Comprehensive support has been provided to the state modelling team to set up and calibrate models for the case study area to address the identified issues in the basin.
- Web tools to easily upload data and information on the water resources situation, water management plans, etc. to external stakeholders.

The case study areas selected by Tamil Nadu for application of the DSS are the Agniyar, Tamiraparani, and Vaippar Basins. Though all three have been selected, the primary focus for implementing the DSS is the Vaippar Basin.

### 3.9.8 State Issues

The DSS Planning address in general five major issues: surface water planning, reservoir management, conjunctive use, drought management, and water quality. Within the State of Tamil Nadu, all five water issues exist in one to three of the case study basins. Though the Vaippar Basin is listed for all five major issues, the dominant issues identified during the model development include drought, over exploitation of ground water, and deterioration of water quality. The specific issues associated with the Vaippar River Study Area include:

- The annual discharge/yield from several streams in the basin is insufficient for supplying all demands. Therefore, there is need for assessment of water resources and decision for allocation of water among various sectors. ossibility of additional water resources development by way of transfer of surplus water from Periyar Reservoir. Integrated operation of reservoirs is needed. In the Arjuna subbasin, water does not reach the downstream users. An investigation is needed to examine conjunctive use solutions of available surface and ground water resources to meet water demand deficiencies.

- Vembakottai and Anaikuttam Reservoirs meant for irrigation have become drinking water supply schemes for Sivakasi and Virudhnagar respectively. Investigation on how to supply irrigation water to the Vembakottai and Anaikuttam Reservoir command areas.
- Rainfed tanks feed 55% of command area. Flood waters do not reach these tanks. Most of the irrigation tanks are heavily silted up. Investigate impacts of connecting the tanks to surface water networks and siltation management of tanks.
- River is polluted due to effluents from industries and sewage from households being let off into the river directly causing water quality problems.
- Drinking water sources in the coastal regions of the Vaippar Basin are experiencing saltwater intrusion

### 3.9.9 Interaction with the State of Tamil Nadu

The Consultant and NIH have cooperated with state representatives during state visits for needs assessment, general modelling support, and DSS installation. An additional exercise embarked upon by the GoTN staff is the development of a MIKE SHE model for the Vaippar Basin. The team has spent some time and effort collecting and formatting data for this model. While implementing MIKLE SHE, it was anticipated that the hydrologic data generated by the MIKE SHE model will eventually be used as input data for the MIKE BASIN model. DHI has provided some guidance and instruction on the development of the MIKE SHE model to the officers of Tamilnadu.

### 3.9.10 DSS Customization for Tamil Nadu

The customization of the DSS has been carried out in cooperation with the GoTN Surface Water and Groundwater Departments and focused on the Vaippar basin. All available GIS and time series data has been imported to the DSS database and two model applications developed. While these applications make use of the river basin model for the area, the DSS is also available to provide overviews and information on water related issues internally in the government as well as to the general public. Following an introduction to the study area, these applications are described below.

### 3.9.11 River Basin Model

To provide an overview of water distribution of water supply and demand within the Vaippar Basin, a river basin model in MIKE BASIN has been developed (Fig. 7.3). The model consists of 9 major catchments, 10 major reservoirs, and 7 major rivers. The catchments were delineated on a combination of stream gauge location and administrative criteria. The surface runoff and groundwater recharge time series are calculated by NAM for the interim, but will be linked to the MIKE SHE results of the Vaippar Basin once that model is complete. Each catchment calculates both surface runoff and groundwater availability as model results. GoTN expects the delineation to be refined further in the future. Ten major reservoirs are included in the model setup. All reservoirs include at least a node representing an irrigation command area and 6 include nodes representing domestic and industrial users. In addition to major reservoirs, four sub-catchments employ a reservoir node representing the cumulative impact of the large number of tanks within that sub-catchment. Within each sub-catchment are water use nodes representing domestic, irrigation, and industrial use. Demand for each node was develop using population statistics and consumption rates for domestic use, and GEC 97 information from irrigation and industrial use. Each water user node is able to draw water from either the surface network or groundwater catchment. Though nodes representing industrial use are included for each catchment, the demand time series is set to 0 m3/s for those that currently have insignificant industrial water use. However, these nodes have been included in the model so that future conditions of industrial expansion can readily be tested. In a similar manner, the water user nodes representing domestic uses can be changed to represent population expansion in any catchment.

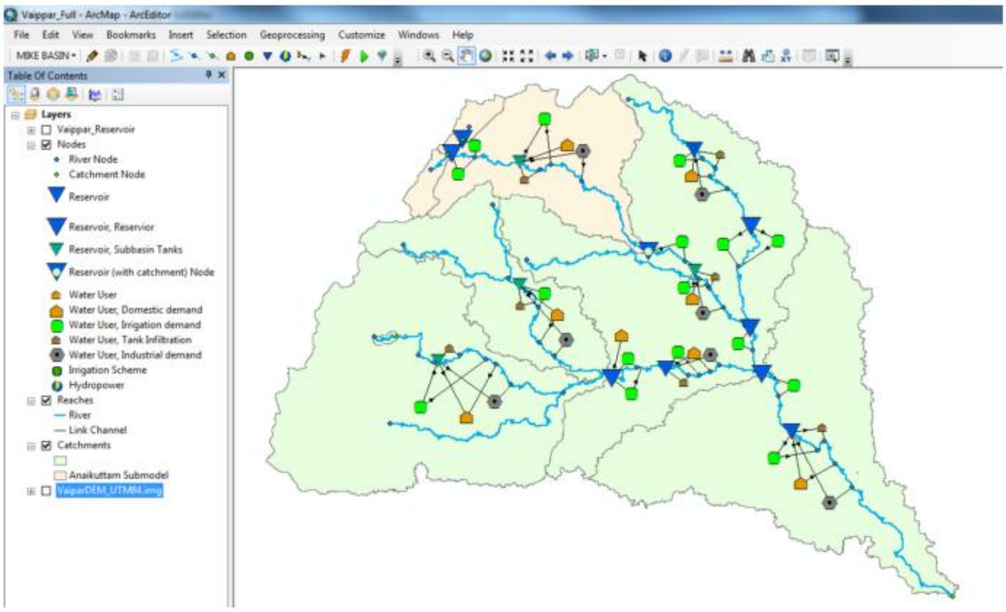



Figure 3.103: MIKE BASIN model setup for the Vaippar Basin for Tamil Nadu.

The highlighted catchment shows the location of the Periyar Reservoir Seasonal Planning and Anaikuttam Sub-Basin Conjunctive Use DSS Applications.

## 3.9.12 DSS Applications

To demonstrate DSS capabilities, two case studies were undertaken: i) seasonal planning for Periyar Reservoir and ii) assessing the sustainable groundwater abstraction within the Anaikuttam Sub-catchment. Below is a description of both applications.

### 3.9.12.1 Seasonal Planning for Periyar Reservoir

Following the monsoon, reservoir operators determine the quantity of water the reservoir can release during an irrigation season. These schedules are often based on the original design and do not include changes in irrigation needs in the command area, demands to domestic and industrial users, changes in inflow hydrology, or reservoir capacity due to storage. To improve reservoir planning, a tool has been developed allowing operators to input new irrigation demands and calculate, based on current reservoir conditions, the expected reservoir storage given historic inflow hydrology. For this application, the tool runs the last 11 years of inflow records into Periyar Reservoir, simulating current reservoir rule curves and user demands to statistically determine the reservoir storage in the coming year. While the data used in this application is particular to the Periyar Reservoir, the DSS application can be adopted to reservoirs throughout Tamil Nadu.

Supporting the Periyar Reservoir DSS Application is a MIKE BASIN model of the reservoir, the command area represented by a water user node, and the inflow catchment. Salient features defining the reservoir geometry and operations have been loaded to the model to represent current conditions. The water user node has the current irrigation required on a daily basis. Baseline Scenario (blue) and a 30% Increase in Water Demand Scenario (purple) for the Periyar Command Area. Units are in cubic meters/second.

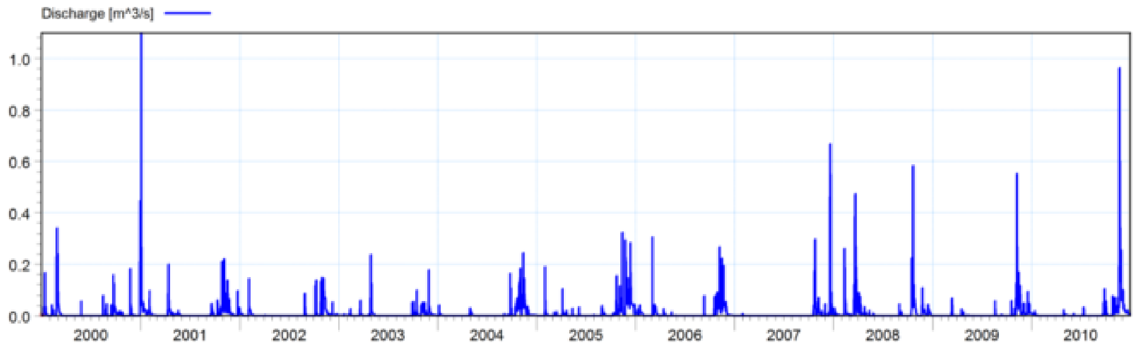



Figure 3.104: Historic inflows to Periyar Reservoir.

Though annual reservoir operations and water demand is specified, the model simulates 11 years of historical inflows to the reservoir (Fig. 7.4). This simulation is run stochastically such that the reservoir level is reset to an elevation of 195.7 ft at the start of each year. The annual results are then extracted from the full period and the probability of reservoir levels, likelihood to empty and fill results, and percentage deficit computed. For demonstration of this application, two scenarios were tested: a Baseline Scenario and an 30% Increase in Agricultural Demand Scenario. The simulation was run startingin January 1, 2000 through Dec 31, 2010. Figure 7.5 and Figure 7.6 depict the reservoir elevations and the likelihood of the reservoir level if run stochastically

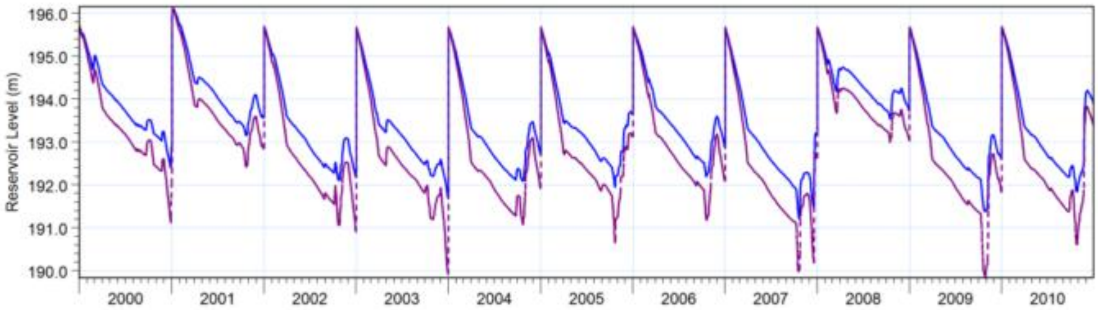



Figure 3.105: Periyar Reservoir water levels for the Baseline (blue) and 130% Demand Scenarios (purple).

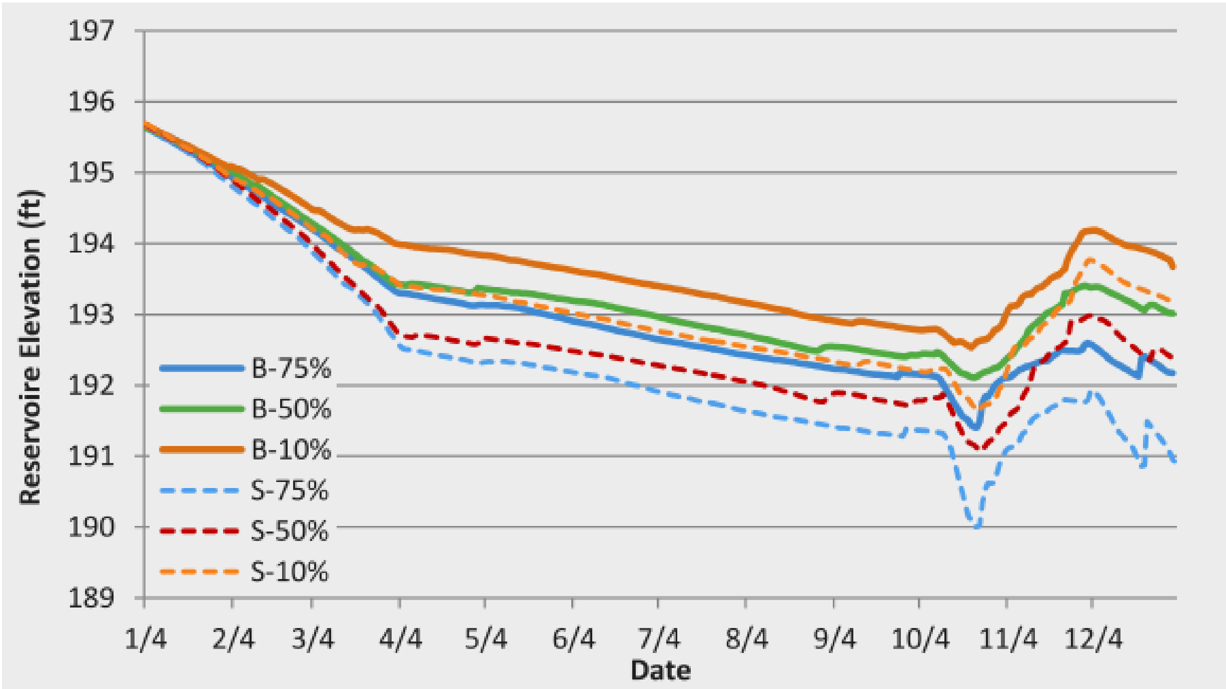



Figure 3.106: 75%, 50%, and 10% likelihood of exceedence in the Periyar Reservoir water level for the Baseline (B) and 1.5 Increase in Agricultural Demand (S) Scenarios.

Given the 11 years of historic record, the irrigation demand, and a reservoir level of 1957 ft, the likelihood that the reservoir level will exceed this 75%, 50%, and 10% levels is depicted in Figure 7.6. With the current and proposed irrigation rates, the model predicts that the reservoir will not return to the original elevation but on average return to a maximum of 193.4 ft in late December . In 25 % of the hydrologic years simulated and increasing irrigation by 3 0 %, the reservoir elevation will also get as low as 190 ft in late October. Of the 11 years , the irrigation node experienced nod eficiencies for the Base line Scenario and for the 130% Demand Scenario. The deficit periods lasted for 3 days , 3 days , and 5 days with an average daily deficit of 67 %, 87%, and 71%, respectively. The water deficiency occurred towards the end of the 12 day irrigation cycle occurring in October with a quantum of water delivered being 78%, 83%, and 84% of the total demand for that period.

#### 3.9.12.2 Sustainable Groundwater Abstraction in the Anaikuttam Sub-basin

Of concern to the GoTN Groundwater Department is the sustainability of groundwater given abstractions from water users and the infiltration associated with tanks. The sub-catchment upstream of Anaikuttam Reservoir was used to demonstrate how the DSS could be used to evaluate the problem. The specific question asked for this case study was twofold: i) what is the impact of increasing non-command area irrigation ground water abstraction by 25% and ii) what is the impact of increasing the tank infiltration capacity in addition to increasing irrigation demand. The metrics for determining was the assessing the sustainability of groundwater abstraction within the Anaikuttam Sub-catchment and reliability of delivery to users.

To test these alternatives, a MIKE BASIN model of the basin was developed which included subcatchments representing the sub-catchments upstream of the Kovilar, Periyar, and Anaikuttam Reservoirs; reservoir nodes and associated command areas representing the Kovilar and Periyar Reservoir Systems; a tank representing all the tanks in the Anaikuttam Sub-catchment; and water users nodes representing drinking water, irrigation, and industrial demand within the Anaikuttam Sub-catchment (Fig. 7.7). Inflow and groundwater recharge rates were determined from NAM calibration of the basin and outflow records from the Periyar and Kovilar Reservoirs. Though in the model, historic releases were used for the two upstream reservoirs. Time series of demand for all user nodes was determined for current water use as indicated by population and crop statistics within the basin. The domestic user received all of its water from groundwater, the industrial node’s demand was set to nil, and the irrigation node’s demand could take water from either ground or surface water sources.

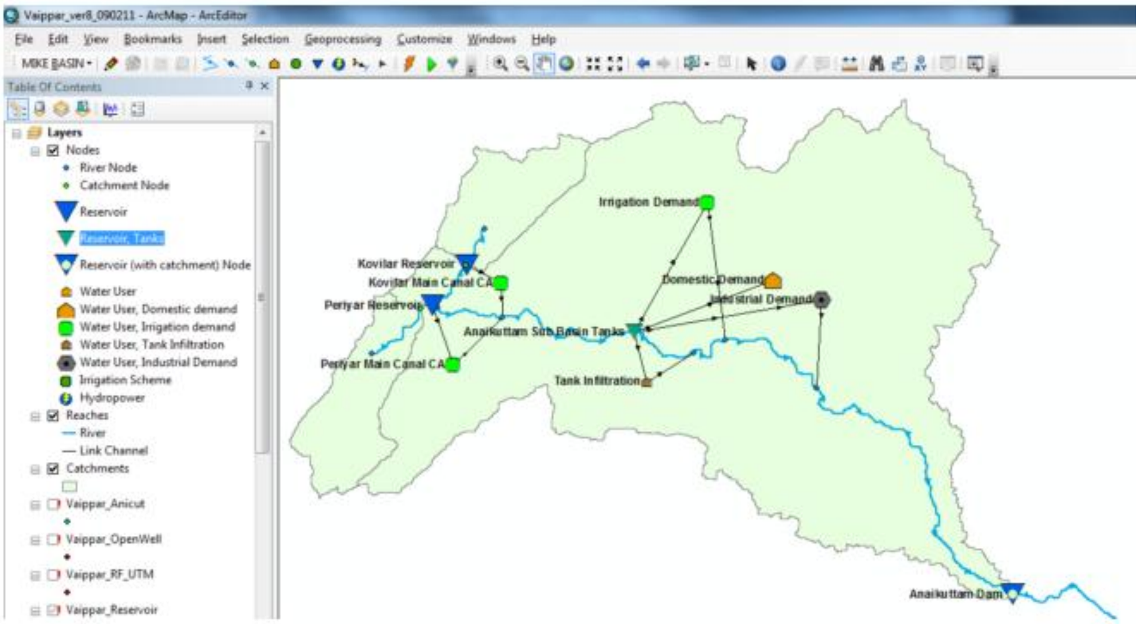



Figure 3.107: MIKE BASIN model setup used to evaluate sustainable groundwater abstraction for the Anaikuttam Subcatchment. The Anaikuttam Sub-catchment is a catchment in the MIKE BASIN model of the Vaippar Basin, Tamil Nadu

The baseline model simulated hydrologic conditions for January 2000 – December 2008 on a daily time step. For the increased groundwater abstraction for irrigation scenario, the water user node representing the tanks and associated irrigation command area was increased by 25% (25% GW Abstr. Increase). For the tank maintenance scenario, the tank seepage was increased while maintaining the increase of 25% for the irrigation node (Increase Tank Infil + 25% GW Abstr Increase).

For the 25% GW Abstraction Increase Scenario, the basin groundwater volume was slightly lowered which was most pronounced during the dry period in 2003 – 2004 (Fig. 7.8). When the infiltration capacity of the tank was increased, the effects of the increased abstraction were mitigated.

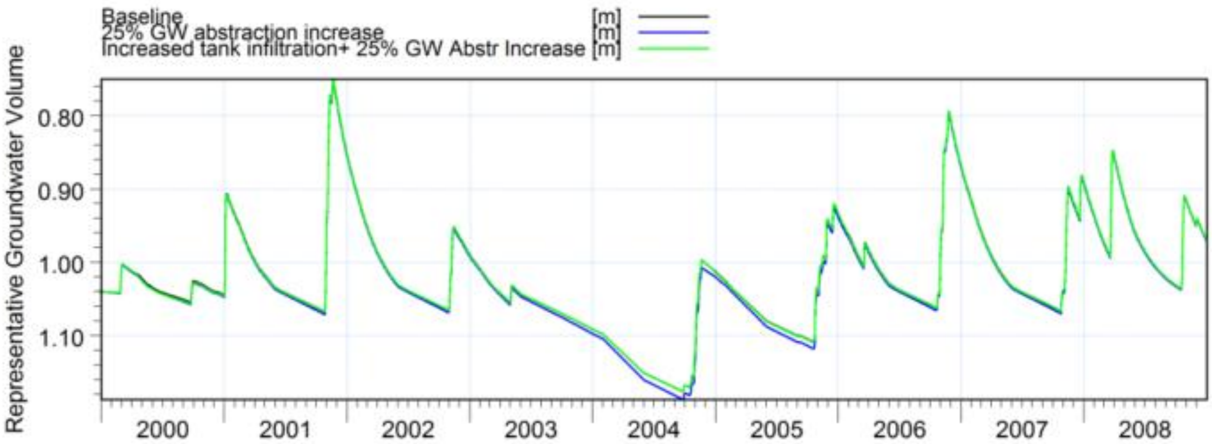



Figure 3.108: Representative groundwater volumes for the Anaikuttam Sub-catchment.

However, it is observed that when the pumping rates are increased, water is left in the reservoir that is then evaporated . In addition, the source of the water used by the irrigation node can also be determined. In this case, increasing the groundwater abstraction increased the amount taken by the irrigation node from the groundwater but which is offset by changes in infiltration rates from the tank.

# 4 PURPOSE-DRIVEN STUDIES (PDS)

The Purpose Driven Studies (PDS) was another subcomponent under the vertical component wherein the Institute has actively participated with State and Central Agencies in carrying out eleven PDS. The PCS and World Bank approved four Surface Water (SW) and three Ground Water (GW) PDS of NIH. Apart from these, the Institute was associated in carrying out four other PDS with the States and Central Agencies. The procurement of various software, goods and equipments was completed under these PDS. The PIs of the PDS conducted the field visits to the study areas and collected relevant data and information from the concerned States Agency. The model development and analysis of the results was completed for these PDS studies.

The Purpose Driven Studies (PDS) was a vertical component, wherein the Institute has actively participated with State and Central Agencies in carrying out eleven PDS. The PCS and World Bank had approved four PDS pertaining to Surface Water (SW) and three PDS pertaining to Ground Water (GW) with a total of seven PDS assigned to NIH. Apart from these, the Institute has also been associated in carrying out four other PDS with the States and Central Agencies.

Suitable project staff was appointed for supporting these PDS. Various software, satellite imageries and equipment were procured under these PDS. The Principal Investigators of these PDS made extensive field visits to the study areas and collected relevant data and information from the concerned States Agencies. Depending upon the methodology for respective PDS, laboratory investigations, analysis of observed and collected data, model development and simulations, analyses of results, recommendations etc. were made for each PDS. The following Purpose Driven Studies were undertaken by National Institute of Hydrology.

**I. PDS for which NIH was the lead agency**

1. Integrated approach for snowmelt runoff studies and effect of anthropogenic activities in Beas basin
2. Impact of sewage effluent on drinking water sources of Shimla city and suggesting ameliorative measures
3. Hydrological assessment of ungauged catchments (small catchment) – Mahanadi Sub basin
4. Urban hydrology for Chennai city – Storm water management in Cooum sub basin, Chennai Corporation, Chennai, Tamilnadu
5. Groundwater management in over-exploited blocks of Chitradurga and Tumkur districts of Karnataka
6. Groundwater dynamics of Bist doab area, Punjab using isotopes
7. Coastal groundwater dynamics and management in the Saurashtra region, Gujarat

**II. PDS for which NIH was supporting agency with the States and Central agencies**

8. A comprehensive assessment of water quality status of Kerala state
9. Assessment of effects of sedmentation on the capacity/life of Bhakra reservoir (Gobind Sagar) on river Satluj and Pong reservoir on river Beas
10. Water availability study and supply-demand analysis in Seonath Sub-basin
11. Study of reservoir sedimentation, impact assessment and development of catchment area treatment plan for Kodar reservoir in Chhattisgarh state

Extended summary of these Purpose Driven Studies is presented as follows.

## 4.1 INTEGRATED APPROACH FOR SNOWMELT RUNOFF STUDIES AND EFFECT OF ANTHROPOGENIC ACTIVITIES IN BEAS BASIN

*Principal Investigator :* *Dr. Sanjay Kumar Jain*

Purpose driven study under HP-II on "Integrated approach for snowmelt runoff studies and effect of anthropogenic activities in Beas basin" was carried out in Water Resource Division of National Institute of Hydrology, Roorkee from 2010-2013. The main aim of the project described in this report was to estimate the contribution of different component i.e. rainfall, snow/glacier melt water, base flow in Beas River up to Pandoh dam, Himachal Pradesh.

The Report has been structured in ten chapters which include (i) Introduction, (ii) Review of Literature (iii) Study area, data used and field investigation (iv) Trend Analysis, (v) Snowmelt runoff modelling, (vi) Major ion chemistry of Beas River, (vii) Snow and glacier melt separation using Isotope, (viii) Climate change modelling ix) Stream flow/Snowmelt runoff under changed climate scenarios (x) Conclusion.

**Chapter 1** has been mainly devoted to the background information related to Himalayan snow cover and glacierzed region as well as brief note on different techniques used in this study. The Himalayan water system is highly dependent on snow storage and hence has great potential to suffer from the effects of global warming. This potential risk has fueled a vast number of research activities in the last 20 years in the field of climate change and its resulting impacts on water resources. The methodologies have two major steps involved: 1) Determining changes in temperature, precipitation and other climatologic variables such as evapotranspiration and; 2) Using these changes to determine the resulting changes in stream flow.

The extent of snow cover area (SCA) largely depends on the climate i.e. precipitation, temperature and solar radiation. During the past four decades, satellite remote sensing has provided valuable information on hemispheric-scale snow extent. SCA has decreased in most regions, especially in spring and summer. Northern Hemisphere (NH) SCA observed by satellite over the 1966 to 2005 period decreased in every month except November and December, with a stepwise drop of 5% in the annual mean in the late 1980s. Since the early 1920s, and especially since the late 1970s, SCA has declined in spring and summer, but not substantially in winter despite winter warming. Recent declines in SCA in the months of February through August have resulted in (1) a shift in the month of maximum SCA from February to January; (2) a statistically significant decline in annual mean SCA

**Chapter 2** deals with the review of literature on trend analysis, snowmelt runoff modelling, Isotope studies and impact of climate change. It is a challenge to the scientific community to understand the complicated processes involved in climate change and alert the society to tackle the problem. Precipitation or rainfall shows different trend in different parts of the world with a general increase in high and mid-latitudes and most equatorial regions but a general decrease in the subtropics (Carter et al., 2000). Temperature on the other hand is the driving force for all the climatic variability. Increasing temperatures will decrease snowfall because of which snow may cease to occur in areas where snowfall currently is marginal (Bown and Rivera, 2007). Increased temperatures in the winter may lead to early snowmelt events and a shift in runoff from the spring to late winter with a corresponding decrease in runoff in the summer period (Burn and Elnur, 2002).

A number of studies relating to changes in rainfall over India have been carried out. In these studies as such no clear trend of increase or decrease in average annual rainfall over the country have been reported (Lal, 2001). The Himalayan region, including the Tibetan Plateau, has shown consistent trends in overall warming during the past 100 years (Yao et al. 2007). Various studies suggest that warming in the Himalayas has been much greater than the global average of 0.74°C over the last 100 years (IPCC, 2007).

Since a long time hydrologists have relied on remote sensing techniques to obtain the information on the spatio-temporal extent of snow-cover. Snow was observed in the first image obtained from the TIROS-1 (Television and Infrared Observation Satellite) following its April 1960 launch (Singer and Popham, 1963). The revolutionary role of remote sensing in snow study is discussed elaborately by Rango (1996), Singh and Jain (2003), Hall et al, (1995). Nevertheless, field measurements are still required to validate the satellite data (Saraf et al., 1999).

Effects of climate change on water resources are attracting the attention of many investigators. According to previous studies, a 10 % change in precipitation will result in 15–25 % change in runoff, while a 2 degree rise in temperature will cause a 5–12 % decrease in runoff.

In **Chapter 3**, study area, data used and field investigations have been discussed. Beas River originates from the eastern slopes of Rohtang pass of Himalayas at an elevation of 3900 m and flows in nearly north-south direction up to Larji, where it takes a nearly right angle turn and flows towards west up to the Pandoh dam. The length of the river up to the Pandoh dam is 116 km. The catchment of the Beas basin up to Pandoh dam is 5384 $km^2$ out of which only 780 $km^2$ is under permanent snow.

The hydrometeorological data was collected on daily basis for the whole year from Bhakra Beas Management Board (BBMB), Sudernagar.In this study, Terra/Aqua- Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data have been used for SCA estimation. The Shuttle Radar Topography Mission (SRTM) data is used for elevation information of the area. Field investigation was also the part of the study for isotopic signature. To investigate the isotopic signatures, samples of rainfall, snow and streamflow were collected on daily and weekly basis of the study area from April 2010 to March 2013. These samples have been analysed for $\delta^{18}O$ and $\delta D$ and also for water quality analysis

**Chapter 4,** Trend analysis of annual mean temperature indicates rising trend at Bhuntar, Larji and Pandoh and deceasing trend at Manali station. None of these trends is found statistical significant. During pre-monsoon season, all the stations indicated rising trend with rising trend at Bhuntar and Pandoh statistically significant at 95% confidence level. During monsoon, post monsoon and winter seasons two stations (Bhuntar and Larji) experienced rising trend and remaining two stations (Manali and Pandoh) experienced decreasing trend. The rising trend at Larji during monsoon season was only statistically significant at 95% confidence. Seasonal analysis of rainfall trends shows that all stations during pre-monsoon, post-monsoon and winter season experienced decreasing trend whereas all stations experienced increasing trend in monsoon season.

**In Chapter 5,** Snowmelt runoff modelling is discussed along with model variable and parameters. In this chapter computation of different component, efficiency criteria, calibration and simulation of the model is being discussed. In the last of the chapter, estimation of the snowmelt runoff and rainfall runoff have been computed.

**Chapter 6** deals with the ion chemistry of Beas River. In the present study, the water quality of River Beas has been analysed during the year 2011 (from Beas Kund to Pandoh Dam Site) in terms of important water quality parameters to better understand the major ion chemistry of this important snow-fed perennial river.

Three sets of water samples were collected at  in polyethylene bottles from Manali, Dhundhi, Kothi, Beas at Bhunter, Parwati at Bhunter and Pandoh sites during February, May and July 2011 by dip (or grab) sampling method. Some parameters like pH and electrical conductance were measured on the spot by means of portable meters (HACH, USA). For other parameters like sulphate, sodium, calcium, etc samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at 4oC for chemical analysis.  An overall precision expressed as relative standard deviation (RSD) was obtained for all the samples. Overall data reproducibility for cations and anions was within ±5. The cationic and anionic charge balance (<5%) is an added proof of the precision of the data. The charge balance (calculated by the formula: [(TZ+ - TZ-) / (TZ+ + TZ-) x 100] between cations and anions and ratio of TDS/EC are within acceptable limits, confirming the reliability of the analytical results.

In **Chapter 7**, Isotope approach is being used to separate out the different components in river Beas at Manali and Bhunter. River Parwati, tributary of Beas is also studied at Bhunter to get the different component in river Parwati during 2010-2011. The sampling strategy was developed on the basis of contribution of different component. During ablation period, samples for river and precipitation were collected on daily basis at Manali and Bhunter for isotope analysis. While groundwater samples were collected during premonsoon and post monsoon basis. Since the river runoff during the winter is mainly sustained by baseflow/subsurface flow. Therefore, during the winter season, samples for river were collected on weekly basis whereas sample from rain and snow have been collected as and when event occurred.The $\delta^{18}O$ and $\delta D$ of the collected samples have been analysed in National Institute of Hydrology, Roorkee and pH and EC was measured in-situ during sampling.

An annual average of 51% of snow/glacier melt water is observed to river Beas at Manali. Parwati River samples at Bhunter shows that it receive 33% annual average of snow/glacier melt water to the streamflow whereas river Beas after the confluence of river Parwati at Bhunter receives 40% snow/glacier melt contribution to the streamflow.

In **Chapter 8,** climate change modelling have been discussed. The primary objective of the present study is to develop downscaling models to obtain future projections of precipitation and temperature at sites in Beas River basin on daily time scale for different climate change scenarios. In this study, transfer function based on statistical multi site spatial downscaling models were developed to arrive at required future projections of precipitation and temperature from simulations of third generation Canadian Coupled Global Climate Model (CGCM3).

**In Chapter 9**, stream flow/snow melt runoff was computed under changed climate scenarios using the SNOWMOD model.

In the last chapter, complete study has been concluded. There is a growing need for an integrated analysis that can quantify the impacts of climate change on various aspects of water resources such as precipitation, hydrologic regimes, drought, dam operations, etc. Despite the fact that the impact of different climate change scenarios is forecasted at a global scale, the exact type and magnitude of the impact at a small watershed scale remains untouched in most parts of the world. Hence, identifying local impact of climate change at a watershed level is quite important. This gives an opportunity to define the degree of vulnerability of local water resources and plan appropriate adaptation measures that must be taken ahead of time. Moreover this will give enough room to consider possible future risks in all phases of water resource development projects.

## 4.2 IMPACT OF SEWAGE EFFLUENT ON DRINKING WATER SOURCES OF SHIMLA CITY AND SUGGESTING AMELIORATIVE MEASURES

*Principal Investigator :* *Dr. V.K. Choubey*

### 4.2.1 Introduction

The provision of clean drinking water has been given priority in constitution of India, with Article 47 conferring the duty of providing clean drinking water and improving public health standards to the State. The government has undertaken various programmes since independence to provide safe drinking water. But inspite of the huge expenditure, availability of safe and secure drinking water to citizens is in question. This is due to high population growth through these years. The average availability of water is reducing steadily with the growing population and it is estimated that India will become water stressed country by 2025.

The health burden of poor water quality is enormous. Water-borne diseases are caused by contamination of water with pollutants. Water gets contaminated either at source or while passing through water pipes which are poorly laid and maintained, or in the homes when it is not stored properly. This study was undertaken keeping in mind the mass level Jaundice in parts of Shimla City during 2007.

### 4.2.2 Study area

Shimla City is situated in south of the river Satluj in the state of Himachal Pradesh (Figure 4.1) at $31^0$6' North latitude and $77^0$13' East longitude, its mean elevation is 2130 m above mean sea level. The climate of Shimla City may be divided into four seasons of about three months each. Beginning in January, the first quarter is rough, snowy and stormy. The second quarter is dry and sunny, with gradually increasing dust and heat. The third is rainy, damp and the fourth bright, clear and bracing. Temperature varies from 15 to $27^0$C in summers and in winters it is in the range of 0 to $17^0$C. Shimla region consists of a thin soil layer (0.15 m on ridges to 7 m deep in valleys), an intervening layer of detritus (mix of soil and fragments of weathered bedrock); and hard bedrock.

### 4.2.3 Objectives of the PDS

i) Analysis of hydrological, water quality and basin characteristics of the study area.
ii) Assessment of water quality variables in drinking water sources, natural drains and sewage effluent.
iii) Analysis of pollutant / source identification (location) of sewage influx in drinking water.

iv) Impact assessment of sewage effluent in drinking water sources and suggesting possible remedial measures for its removal.
v) Dissemination of knowledge and findings to field engineers and common people through preparation of manual, leaflets, booklets and by organizing workshops / training.

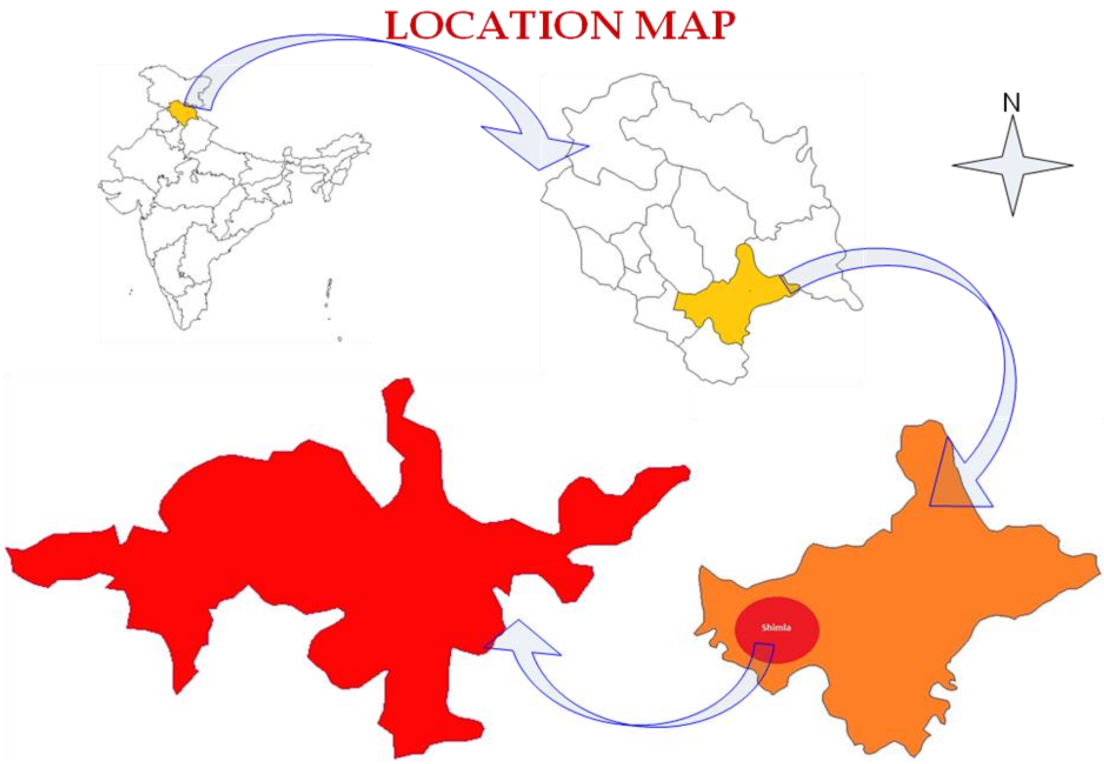



Figure 4.1: Location Map of Shimla City

### 4.2.4 Study Methodology

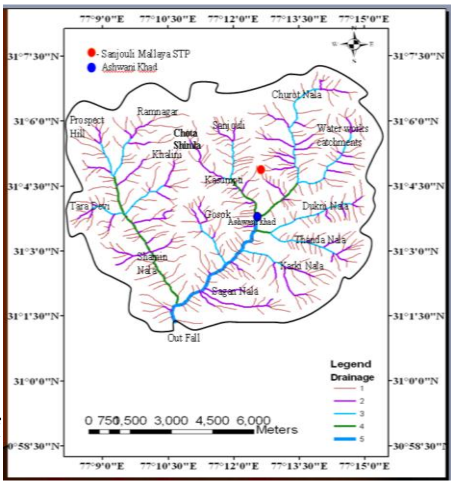
Samples of groundwater, surface water, treated water from water treatment plant (WTP) and sewage treatment plant (STP) were collected in the pre- and post-monsoon season of year 2010 & 2011. Based on the results obtained in 2010-11, field observations and suggestions made by experts of PCS/TAMC, sampling from water treatment plant, sewage treatment plant, open drains, break points in water transmission lines and user points was carried out on monthly basis during 2011-12. The samples were preserved as per standard procedures and were analyzed for physico-chemical as well as bacteriological parameters in the NIH water quality laboratory and I&PH Laboratory at Dhalli as per APHA (1995).

### 4.2.5 Results and Discussions

#### 4.2.5.1 Analysis of hydrological and basin characteristics of Shimla City

Drainage area of Shimla city consisting of part of Satluj and Yamuna sub-basins was digitized and prepared a digital elevation model (Figure 4.2 to Figure 4.5). The Shimla city lies partly in Satluj river basin and partly in Yamuna river basin. Morphological characteristics of stream (linear, aerial and relief aspect) of study area were analyzed and are shown in Tables 1. The Yamuna sub-basin of Shimla city is having 91.97 sq-km drainage areas with fifth order stream and drainage density of 3.25.

Figure 4.2: Drainage Map of Shimla City falling partly in Satluj (above) and partly in Yamuna Basin (below)



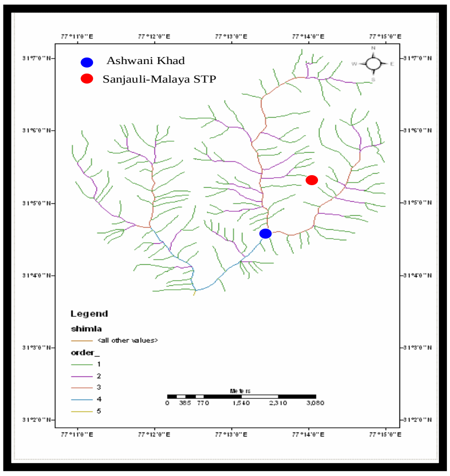



Figure 4.3: Drainage Map of Yamuna Sub-basin for Shimla City

Figure 4.4: Drainage Map of Yamuna Sub basin for Sanjauli-Malyana Region

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Table 4.1: Morphometric characteristics of stream of study watersheds

| **Parameters** | **Watershed (Yamuna basin)** | **Sub-watershed (Sanjauli-Malyana)** |
|---|---|---|
| Total no. of streams | 465 | 166 |
| Total length of streams (Km) | 298.8 | 80.9 |
| Watershed area ($Km^2$) | 91.97 | 30 |
| Drainage density ($Km/Km^2$) | 3.25 | 2.67 |
| Total relief (m) | 1000 | 600 |

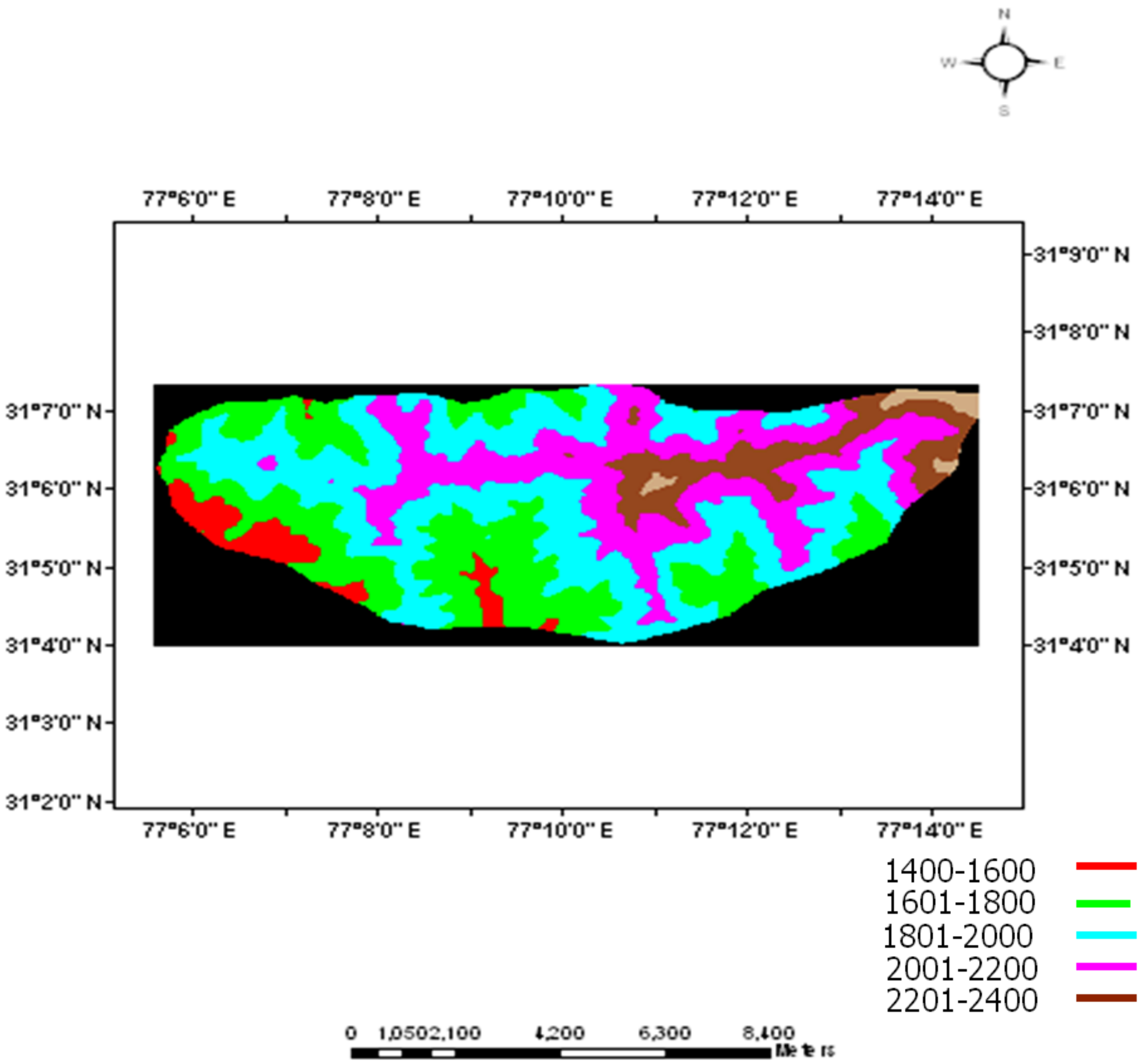


Figure 4.5: Digital Elevation Model of Shimla City

#### 4.2.5.2 Application of SewerCAD Software

SewerCAD is a powerful design and analysis tool for modeling sanitary sewage collection and pumping systems. In this study, SewerCAD software is utilized for understanding the efficacy of the existing sewerage system and find out the faults if any (Figure 4.6). The conclusions drawn from the software and field survey are:

1. The existing sewerage network is sufficient for designed sewage load and the elevation profile indicated smooth flow of sewage.
2. At present, only 25-30% habitation is connected to sewerage system and hence the possibility of the overflow is ruled out.
3. Some manholes were found overflowing due to blockage of pipes by poly bags / jute bags, which may lead to contaminate the drinking water.
4. Leakages were observed in the drinking water supply line. This may leads to ingress of contaminated water in the supply line during non supply periods.

5. Temporary arrangements for arresting the leakages lead to ingress of contaminated water.

As per I&PH officials, 70-75% habitation is not connected by sewerage lines and the domestic waste from these habitations finds its way to natural drainage / streams directly or via age old septic tanks which may be the main reason for contamination of groundwater.

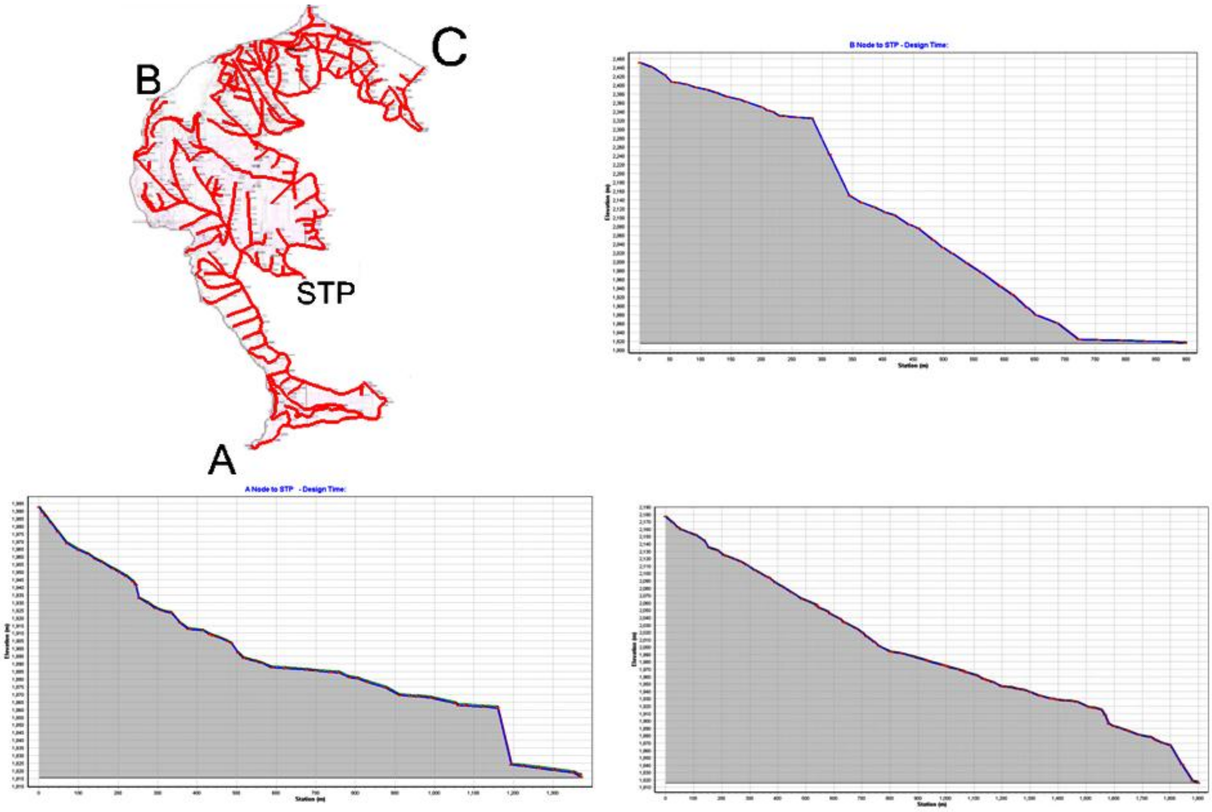


Figure 4.6: Sewerage map of Sanjauli Malyana region divided in three sections

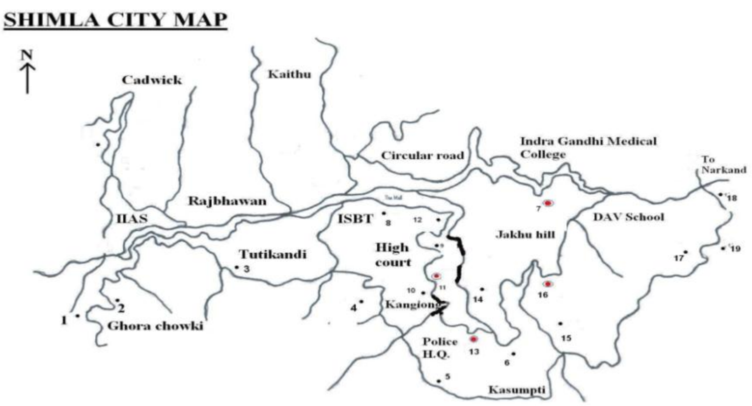


Figure 4.7: Map showing groundwater sampling locations

### 4.2.5.3 Groundwater quality

Groundwater samples were collected from 19 locations covering study area of Shimla city (Fig. 2.7). The groundwater of Shimla city was found to be of Ca-Mg-$HCO_3$ type having temporary hardness. 25% ground water samples were high in total dissolved solids, hardness, and nitrate. $NO_3$ concentration ranges from 0-66 mg/L in pre-monsoon samples and 0-29 mg/L in post monsoon season. Although, the $NO_3$ concentration in most of the ground water sample were well within the permissible limit set by Bureau of Indian Standards for drinking water but the concentration is enough to produce methamoglobinemia (blue baby syndrome) in infants. Samples of Bharari, Cart road to Mall road, Circular road and New Shimla (Sector-3) were positive in E-coli. Presence of nitrate and E-coli in groundwater indicates contamination with sewage. This is due to improper sanitation facilities in the city.

### 4.2.5.4 Sewage treatment plant and open drains

Jaundice cases were noted mainly from the localities receiving water from Ashwani Khad water supply system. The natural stream supplying water to Ashwani Khad WTP receives treated water from Sanjauli-Malyana STP and three natural drains viz. Housing board colony (Sanjauli) drain, Sanan open drain, and Shivmandir (Malyana) drain which are contaminated with sewage from nearby localities.

Samples from the STP as well as open drains were collected and analyzed to understand the extent of contamination. STP is based on extended activated sludge process (EASP) and the capacities of treatment units are sufficient to take care of the designed load. The treatment plant consists of bar screen, grit chamber, aeration tank, secondary clarifier, solids contact clarifier, and chlorine contact tank for disinfection. The treated water from STP is expected to have BOD less than 30 mg/L and TSS less than 50 mg/L. Analysis result of STP indicates partial treatment of sewage which is polluting the natural stream. The inferences drawn from the field observations and analytical results are:

1. The duration and extent of settled biomass recycling to aeration tank is not sufficient. This leads to septic conditions in the secondary clarifier, which reduces the performance of the system. This condition leads to de-nitrification of nitrate in the secondary clarifier leading to floating muck on the surface of the clarifier. The duration of settled biomass of the recycling and recirculation flow needs to be increased to prevent the septic condition in the secondary clarifier.

2. Chemical dosing in clarifier is manual and hence the desired quality is not achieved. Metering pumps for dosage of alum as well as polyelectrolyte should be installed along with proper chemical preparation tanks. The chemical dosage should be based on Jar test. Proper operation of clarifier will improve the quality of treated water by entrapping the solids / organics escaping from the secondary clarifier by sorption on the chemical sludge.

3. The organics as well as the biomass which is escaping from the system is oxidized by hypochlorite. This leads to formation of trihalomethane (THM's) which are carcinogenic in nature. This can be avoided by compliance of step 1 & 2.

4. Proper operation of STP will minimize the disease outbreaks. This can be achieved by proper training of the operators and valuing their critical role.

Water quality analysis of open drains leads us to following conclusions:

1. Presence of organics (COD: 100-400 mg/L) and nitrate (15-40 mg/L) in the open drains indicates heavy contamination with sewage. The contamination results from the human defecation in open and absence of sewerage lines in the areas like Dhingoo, Engine ghar etc.

2. Kitchen & bathroom drain (grey water) is not connected to sewage drain.

3. Water quality deterioration of the open drains was also due to malpractice of throwing the garbage in the drains which slowly degrades and provides media for micro-organisms growth.

4. Although Shimla Municipal Corporation has set up a full-fledged solid waste management plant, but most of the solid is dumped without any treatment near the plant itself without any engineered structure. The leachates from this facility find its way to the natural stream and contaminate it.

#### 4.2.5.5 Water treatment plants, intermediate storage reservoirs (lifting stations) and user point

Samples were collected from the inlet and outlet of water treatment plants (Dhalli & Ashwani khud), lifting stations and user points to trace the location or cause of contamination during treatment and supply.

Dhalli WTP receives water from Churat Nalla (2 MLD) and Sayog catchment (0.1 MLD). Water from Sayog catchment which is dense forest area is expected to be pathogen free and without any contaminants. This water is treated through slow sand gravity filters followed by chlorination and is supplied for drinking. Water from Churrat nalla is chemically treated with the aid of alum and lime. The chemical sludge and sediments are settled in sedimentation tank and the clear water is filtered through rapid sand filters. The water after chlorination is supplied to consumers.

Ashwani Khud WTP was installed in 1992 wherein the water is received from a natural stream. The stream water is treated by chemical coagulation, flocculation and sedimentation followed by filtration and disinfection with chlorine. The WTP also receive water from bore wells to full fill the demand. Bore well water is supplied directly after disinfection. The chlorinated water is pumped to Kawalag storage plant and then to Kusumpti tank where it is re-chlorinated and distributed.

Ashwani Khud, source of WTP has six main tributeries namely – Malyana Nallah, Sanan Nallah, Housing Board Nallah, Jagroti Nallah, Koti Nallah, and Bharandi Nallah. Out of these nallah, the Malyana (STP) Nallah, Housing Board Nallah, and Sanan Nallah which originates from densely populated areas have some contamination. The water coming from these nallah has chances of being contaminated due to outflow of numerous domestic septic tanks, solid waste, and STP treated water. WTP is designed to treat 10 MLD water. The water is treated through flocculator and sedimentation tank with the aid of alum and lime. Chemically treated water is filtered through rapid sand filter. Filtered water is blended with ground water and supplied to consumers after chlorination at WTP (clear water tank) and Kusumpti reservoir. Following conclusions can be drawn from the field survey and laboratory results:

1. Inlet water to Dhalli from Cherot and Jagroti as well as Ashwani Khud WTP is contaminated with organics as well as bacteria.

2. Dhalli and Ashwani Khud water treatment plants are designed for removal of turbidity from surface water. The technology needs to be upgraded for present scenario.

3. During lean period (summer), the proportion of effluent from densely populated area and STP increases in Ashwani Khud water due to general reduction of base flow making the situation worse.

4. For such type of waters (contaminated with human waste), solids contact clarifier is desired with an option for in built sludge recirculation system. A sludge blanket from metal hydroxide flocs is created in the clarification zone of the clarifier through which the water is filtered. The sludge blanket acts like a dynamic filter as well as adsorbent and if properly operated, able to remove organics as well as microbe. Treated water from this system is crystal clear and requires minimal chlorine dosing for disinfection.

5. Presence of organics and fecal coliform requires continuous operator attention and free residual chlorine at the user end. Absence of residual chlorine at any moment from treatment to supply will lead to disaster due to presence of low molecular weight organic compound and nutrients produced by action of chlorine that can be assimilated by bacteria and promote bacterial growth.

6. Installation of Ultra Filtration (UF) membranes which are physical barrier for bacteria and viruses is recommended for final polishing of treated water from Ashwani Khad WTP.

7. Trials with strong oxidizing agents like ozone, chlorine dioxide etc. in order to get rid of organics as well as microbes is suggested.

8. During interaction with residents, it was brought to the notice that after spells of rain, the water supply is muddy. This indicates leakage in the water supply through which storm water enter during non supply period and contaminates the potable water.

User point samples were collected from the affected area based on the transmission lines as indicated by I&PH officials. Three samples were collected from each line. Following conclusions can be drawn from the water analysis and field observations:

1. The profile of free residual chlorine from water treatment plant to user point (reduces from 25 mg/L at WTP to 1 mg/L at user point) clearly indicates high chlorine demand of water due to presence of organics (Fig. 2.8).

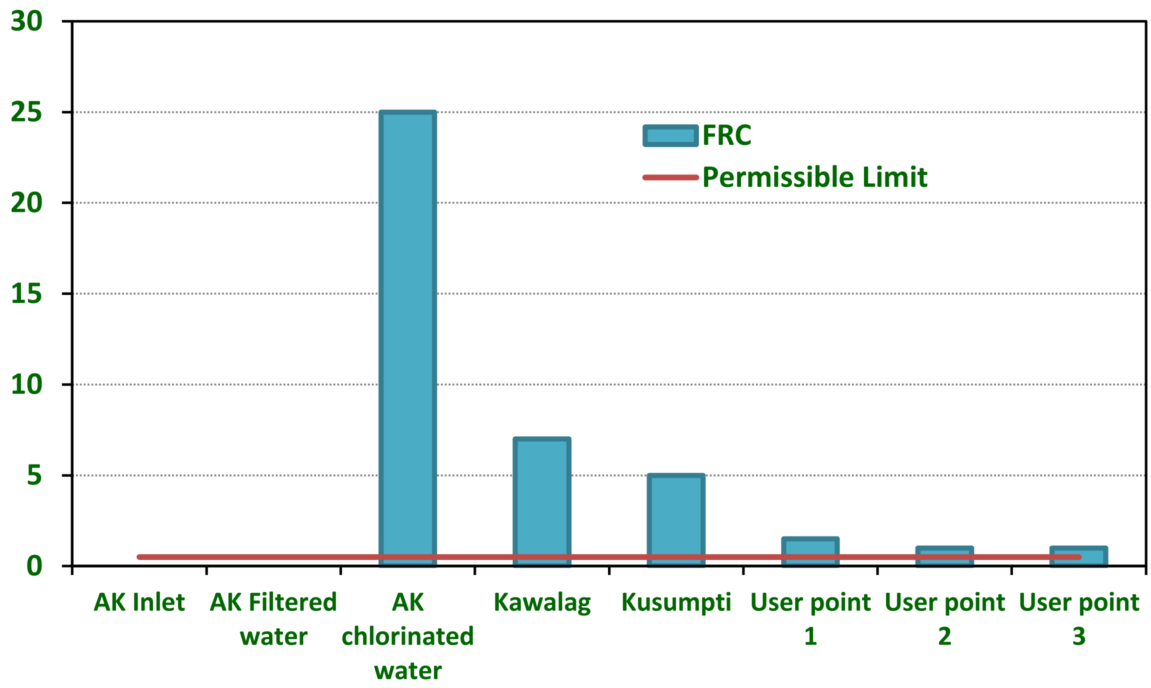


Figure 4.8: Free residual chlorine profile from WTP to user point

2. Reduction in COD from 35-50 mg/L (filtered water) to 15-25 mg/L (after chlorination) indicates about 50 mg/L consumption of chlorine at WTP. If we add 25 mg/L residual, chlorine dosage comes out 65-75 mg/L. Although, this high dosage results in pathogen free water, it also leads to formation of organic halides which was confirmed by IR Spectra.

3. Samples collected from Dinu Bhojnalaya (New Shimla-Phase 3, Part 2) which receives water from untreated Bawadi water was found to be contaminated with organics as well as fecal coliform indicating immediate need to isolate such sources.

### 4.2.6 Conclusion and Recommendations

1. Sewerage network installed in Sanjauli Malyana region is sufficient for designed sewage load and elevation profile indicates smooth flow of sewage.

2. Contamination of natural stream supplying water to Ashwani Khad WTP is due to
   a. Poor connectivity of habitation with the sewerage network.
   b. Discharge of kitchen and bathroom drain (grey water) to natural streams.
   c. Human defecation in open
   d. Malpractice of throwing garbage in drains
   e. Dumping of solid waste without any engineered structure
   f. Reduced efficiency of Malyana STP. This may be due to less recycling of settled biomass from secondary clarifier to aeration tank.

3. Ashwani Khad WTP is designed to treat water free of organics and pathogens. It is designed to remove suspended solids. The WTP needs modification to provide safe water.

4. It is recommended to install solids contact type Clarifier / Actiflow to get rid of organics and microbes during pretreatment.

5. WTP should also consider installation of physical barrier such as ultra filtration membrane which guarantees 99.9% removal of bacteria and viruses. This will also help in removal of organics.

6. I&PH should explore the possibility of using ozone for destruction of organics present in Ashwani Khad WTP outlet. Piloting for a minimum of six months at site is required before installation of full scale plant.

7. Response time for attending leakage in supply line needs to be reduced and temporary arrangement for arrest of leakage should be avoided.

8. Presence of free residual chlorine at the user end should be ensured.

9. The sludge handling system of STP and WTP should be improved to prevent chances of biological and chemical sludge being disposed of in the natural open drains.

10. Shimla Municipal Corporation should ensure that 100% habitation is connected with sewerage system.

11. Facility for transportation of sludge in the septic tank does not exist and hence it finds its way to open drains in the monsoon season. In view of this aspect, Septic tank system should be discouraged and sewerage facility should be provided.

12. Civil equipment sizing of Malyana STP is sufficient to take care of designed load. A separate detailed study is required to understand the reasons behind the

underperformance of the STP and the measure for improvement. The study will involve

a. DO profiling in aeration tank and secondary clarifier
b. Mixed liquor SVI and zone settling velocity study
c. Specific oxygen uptake rate
d. Identification of mixed liquor fauna

13. Anoxic tank for removal of nitrate should be considered in order to reduce the nitrate concentration in drinking water supplied from Ashwani Khad WTP.

14. Minimum 1 mg/L dissolved oxygen is required in the treated water from secondary clarifier. To achieve this, it is recommended to continuously recycle the settled sludge along with periodic removal of biomass from the system. This will improve the performance of the system as well as clarity of the treated water and chlorine demand.

15. STP treated water quality can be improved by operating the clarifier in proper way, so that the organics and microbes escaping from the secondary clarifier are entrapped here by sorption on the chemical sludge.

16. Proper operation of WTP & STP will minimize the disease outbreaks. This can be achieved by proper training of the operators and valuing their critical role.

17. Performance evaluation / audit of WTPs as well as STPs should be done in order to improve the performance.

## Photos and Images

Sampling from open drain

Ashwani Khud WTP

Solid waste dumping on roadside

STP Malyana

Manhole overflow

Oxidation by bleaching powder at STP Malyana

## 4.3 HYDROLOGICAL ASSESSMENT OF UNGAUGED CATCHMENTS (SMALL CATCHMENT) – MAHANADI SUB BASIN

*Principal Investigator :* *Dr. P.K. Bhunya*

Many hydrological variables that are of interest from hydrologic point of view are difficult to observe routinely and unambiguously. Among the hydrological variables, *streamflow* is one such variable that can be measured at a gauging site of a catchment with some confidence. Hence, from practical point of view, the definition for an *ungauged catchment* is usually limited to the catchments with inadequate streamflow measuring facilities at the project site and also with scanty or no stream flow records. And due to economic and geographical (inaccessibility)constraints, detailed hydrological and meteorological investigations at every new site on large scale and on long term basis for a large country like India is not feasible. Thus, there is a need for methods that can be utilized for realistic estimation of such hydrological variables for ungauged catchments. So this study entitled 'Hydrological Assessment of Ungauged Catchments' was part of the Purpose Driven Studies (PDS) (programmed for years 2009- 2013) focuses on prediction of flood or runoff in ungauged catchments where little or no information is available.

For ungauged catchments, the need for developing a suitable methodology for realistic estimation of hydrological variables of interest is hardly over-emphasized. This study was taken up with the specific objective of design flood estimation in such catchments. For this study, about thirty six small catchments in Mahanadi region is are considered as test catchments for application. The present study pertains to the basin that is inside the state of Orissa. And the catchment area up to confluence with bay-of Bengal sea i.e. *Nimapara* is 65628 Sq. km. It also is popularly conveyed as Mahandi-Brahmani-Rushukulya River Basin. Four different approaches were studied, and methodologies developed for both limited data and no data situations. The developed methods were checked for their workability taking two types of data i.e. short-term and annual maximum series data from real catchments. Thus, the work of this study is organized in six sections, it is accordingly summarized and concluded, and finally the limitations are discussed as follows:

### 4.3.1 Processing and Analysis of Hydro-Meteorological Data

The daily mean rainfall for the year 2008 is given in the report and the mean monthly rainfall for few raingauges has been calculated using two methods: (i) Arithmetic mean (AM) and (ii) Thiessen Polygon (TP). In this study, three types of runoff data are used: (i) monthly runoff series, (ii) Annual maximum series (AMS), and (iii) short –term (ho urly) data. The short term data, i.e., the hourly runoff data are used in this study are few and selected, and they have been used in unit hydrograph analysis. The annual peak runoff of twenty five bridge catchments was taken from CWC report and Appendix-2 in the report shows fourteen CWC gauging sites with daily flows and the period. Consistency of a rain gauge station and double mass curves analysis are used to cross check the significant change during the period of record and to check trends or non-homogeneity between flow records. The study area data has no such error. Both of these tests along with t- and F- distribution tests are done for the flow series that gives the crucial ratio between-group to the within-group variance estimates. From the flow data used in this study, it is noticed that between-group estimate of the population variance is sufficiently bigger than the within-group estimate of the population variance which are always positive numbers. It means that the samples have been collected without bias. The performance of AR models are done for randomly selected paired stations i.e. for *Altuma and Anandpur, Kantamal and Salebhata, Pamposh and Champua* and *Gomlai and Jaraikela* and the results seen to be independent and normally distributed with a common variance. Lastly, residual flow series given in Annexure 3 is the simplest a means of identifying anomalies between stations is the plotting of comparative time series with respect to lag times from rainfall to runoff or the wave travel time in a channel.

### 4.3.2 Rating Curve (RC)

When developing rating curves based on existing data the traditional power curve model may not be the best choice. Depending on the situation, a polynomial or quadratic power curve model may provide a fit that statistically better than the power curve model. The power curve model tends to perform better when data points are closely spaced and no data points lay far from the main cluster. The results show that there was no back water correction for any sites and any steep or mild slope in the curve. The Rating curve for both Monsoon and Non-Monsoon were almost a straight line. The Value of R2 for monsoon range from a maximum of 0.946 that is for Tikerpada and a minimum of 0.582 that was Talcher. Similarly for Non-Monsoon the value of R2 range from 0.902 to 0.342. Regardless of the sign of the expected bias associated with traditional approaches (underestimation or overestimation) our study clearly points out that bias and overall uncertainty associated with rating-curves can be dramatically reduced by constraining the identification of rating-curve with information resulting form simplified hydraulic modeling, with significant advantages for practical applications.

### 4.3.3 Regional Flow Duration Curves (RFDC)

Sometime, either adequate flow records for gauged catchments are not available or numbers of gauged catchments are limited. It makes the development of regional flow duration curve using method of regionalizing the parameters of chosen probability distribution sometimes erroneous. In the present study, the results presented in this section used two seasonal periods i.e. monsoon (July-Sept) and Non-Monsoon (Oct-June) periods to construct regional flow-duration curves. Regional flow duration curve in Mahandi basin were developed using flow data for fourteen catchments. Data in monthly steps were not available in twenty three catchments, so was not considered in this case. The mean monthly flows from both monsoon and non monsoon separate were fitted in flow exceedance points by a probable fitting equation (viz: second degree and power) which on logarithm tic transformation becomes linear that is popularly adopted. From the results as seen earlier, most ephemeral catchments have poorer RFDC fits than the perennial catchments, and during monsoon period, probability of more than ninety seven percent > 300 cumecs , flow exceeding 1000 cumecs has a probability of fifty percent and 3000 cumecs flow exceedance comes to around ten percent probability. The curve have a steep slope throughout and a flat slope towards the end that indicates a highly variable stream with flow largely from direct runoff and large amount of storage. In regards to uncertainty in RFDC results, the individual catchments are averaged for two bands i.e. lower (nearly 5 % exceedance) and upper (nearly 97 % exceedance ) and the corresponding runoff values are related with catchment area dealing with uncertainty. The RFDC as per standard procedure, and it can be seen from the results (Table 6.2 - 6.3 and figures in Annexure 6) with $R^2$ values exceeding 0.9382 (Weibull), 0.9182 (Blom), 0.913 (Gringorton) and 0.9163 (Cunnane) respectively. This is fairly a good fit as $R^2 > 0.9$ for monsoon and non-monsoon. In general for the Mahanadi region, the curve has a steep slope throughout that denotes a highly variable stream with flow largely from direct runoff. The slope of the lower end of the duration curve shows a flat slope that indicates a large amount of storage; and at the upper end is a steep slope that indicates a negligible amount.

### 4.3.4 Synthetic Unit Hydrograph Methods

The probability distribution functions (*pdf*) that has similar shape to unit hydrograph (UH) are generally used for formulating Synthetic unit hydrograph (SUH) methods. Few methods frequently used in such cases are Nash model similar to two parameter- Gamma distribution Clark's and geomorphological instantaneous unit hydrograph (GIUH) methods. This study reported herein focused on two aspects i.e. the traditional methods of SUH derivation, e.g., GIUH based Nash and Clark's approach, Snyder's method, and SCS-curve number (CN) and conventional methods using events data. Among the four pdfs analyzed in this study, the Clark's and geomorphological instantaneous unit hydrograph models are more flexible in description of unit hydrograph SUH shape as they skew on both sides similar to a unit hydrograph, and on the basis of their application to field data. In case of SCS- Curve Number (CN) method for computing UH, the variable CN for a catchment has to be ascertain talking updated land use index or else there occurs a large error in determining the peak flow ($q_p$) and time to peak ($t_p$) along with W50 , W75 (width of UH joining 0.5 and 0.75 peak flow ordinates) and time to base. In the present study some catchments with area more than 100 $km^2$ gives erroneous results. In case of Nash model that is similar to a Gamma distribution (in a limiting case), and the results shows that it should be a preferred method for deriving SUH. Parameters are highly sensitive to peak flow of the UH in case of Nash model (when □ i.e. product of $q_p t_p$ is low). Any overestimation in parameter estimates increases the peak flow of the UH and the trend is reverse at large □□values. the variance□□ of a positively skewed UH was observed to be more sensitive to time to base ($t_B$) than $t_p$, implying that the □□-ratio for any two catchments approximately varied in proportion to the corresponding $t_B^2$-ratio. Figure 3 shows the results of flood hydrographs derived using four of the above methods in catchments in Mahanadi basin..

### 4.3.5 Regional Unit Hydrograph Analysis

In this case, eleven catchments in Mahanadi basin with relevant data are used for regional analysis, and in a nutshell is briefed hereby. Regional unit hydrograph for lower Mahanadi region based on Nash and Clark approach yielded the model parameters with the basin as follows: nk and $LL_c/S^{0.5}$ with $R^2 = 0.57$, K and L with $R^2 = 0.63$ and time of concentration (Tc) and $LL_c/\sqrt{S}$ with $R^2 = 0.99$. Data of unit hydrograph derived from stream flow and rainfall records in basins adjoining the basin under study should be used to estimate the constants for use to any regional unit hydrograph study. The results give $R^2$ mostly more than 0.6 and a fair fit.

### 4.3.6 Flood Frequency Analysis Techniques

The understanding of floods plays a key role in many hydrological studies, especially in the design of hydraulics structures such as dams, culverts, bridges and others. Extreme hydrological events are not only important in the design of water resource projects but also in the management of water resources. Flood frequency estimation remains an important topic for such design purposes, and flood data constitute the main source of information for this analysis. Single stations analyses were carried out for 37 hydrometric stations located in the Mahandi watershed. *Maximum daily discharges* ($m^3/s$) or Annual Maximum Series (AMS) for 25 years for 23 small catchments and about 35 years for 14 gauging sites were analyzed using seven distributions viz. EV1, GEV, PT3, LP3, GP, GL and WAK. Three parameter estimations methods were applied for this case and they are method of moments (MOM), method of maximum likelihood (ML) and method of probability weighted moment (PWM). A regional flood frequency analysis was also carried out for the same study area and is given in next section. Since new data are available, the goal of the present study was to update those flood frequency analyses previously analyzed. As such, results presented in this document will better reflect our current state of knowledge regarding the high flow regimes throughout the Mahanadi region. In general, the results of the present study are consistent with those from early studies, although it can be seen that updating the flood information resulted, for many stations, in an improvement of flood estimates.

Results of the 36 single station high flow frequency analyses are provided in Appendix 9 (b) and (c ) for the estimated parameters and the flood for recurrence intervals of 20, 50, 100, 200 , 300 and 500 years. From the single station or at-site analysis results, it is clear that for the majority of the single analysis both the LP3 and GEV fitted the data almost similar. However, at the high recurrence intervals, it is evident that GEV adjusts better to the observational data than LP3 and GP. Results of the R.M.S. error statistics favor GEV over

LP3 approximately 64% of the time. For the 36 GD sites, the corresponding return period flood are estimated separately and the goodness-of-fit assessments suggested the GEV model to be the overall most appropriate distribution function. These findings were also strengthened by extreme value theory, which suggests that the annual maxima (such as flood data) be modeled as realizations of random variables distributed according to a member of the *generalized extreme value* (GEV) family of distributions. Based on such considerations, the GEV was therefore be accepted for the estimation of at-site floods as a function of annual maximum runoff for various recurrence intervals (i.e., 20, 50, 100, 200, 300 and 500). In all cases, the fitted model were consistent with the calculated T-year flood events, such that they could be applied to predict floods for ungauged basins (within their range of application).

### 4.3.7 Regional Flood Frequency Analysis

Screening of the data conducted using the annual maximum peak flood data of the Mahanadi Sub zone 3(d) employing the Ddiscordancy measure ($D_i$) test reveals that 22 out of the 23 Br-catchments (gauging sites) are suitable for regional flood frequency analysis. However, based on the heterogeneity measures, `H(j)'; the annual maximum peak flood data of other 13 GD sites are considered to constitute a homogeneous region. So, in a total, 36 catchments (with gauging sites) are used for regional flood frequency analysis. Various distributions viz. EV1, GEV, GL, PT3, LP3, GNO, GP, and WAK have been employed. Based on the L-moments ratio diagram and $|Z_i^{dist}|$ –statistic criteria, the GNO distribution has been identified as the robust distribution for the study area.

The developed regional flood frequency relationships may be used for estimation of floods of desired return periods for gauged and ungauged catchments of the study area. As the regional flood frequency relationships have been developed using the data of catchments varying from 19 to 1,150 $km^2$ in area; hence, these relationships are expected to provide estimates of floods of various return periods for catchments lying nearly in the same range of the areal extent. Further, the relationship between mean annual peak flood and catchment area is able to explain 83.4% of initial variance ($R^2$ = 0.834). Hence, in case of ungauged catchments the results of the study are subject to these limitations. However, the regional flood frequency relationships may be refined for obtaining more accurate flood frequency estimates; when the data for some more gauging sites become available and physiographic characteristics other than catchment area as well as some of the pertinent climatic characteristics are also used for development of the regional flood frequency relationships.

### 4.3.8 Peak over Threshold Techniques

In some regions, annual maximum floods observed in dry years may be very small, and inclusion of these events can significantly alter the outcome of the extreme value analysis. In contrast, the peak over threshold (POT) model avoids all these drawbacks by considering all flood peaks above a certain threshold level; hence more than one flood per year may be included, and exceptionally low annual maximum values that may cause problems in parameter estimation are not included. POT model. are often used for flood frequency analysis when there is a paucity of data. The analysis presented in this study focused on the choice of generalized Pareto (GP) distribution for computation of flood exceedance in POT model, when the occurrences of peak exceedances are fitted with a PD distribution. The reliability of the expressions for $\mathrm{Var}[\hat{q}(T)]$ derived using the analytical procedure was checked using the Monte Carlo simulation method. Next, a ratio between the $\mathrm{Var}[\hat{q}(T)]$ of analytical and simulation procedures denoted as $R_1$ was used to check the reliability of these expressions. Results showed $R_1$ to be asymptotically reaching 1 for AMS and PDS models, especially for higher record length i.e., at N=50. The difference between the simulated and the analytical results becomes more prominent with increase in T years, with a significant difference e.g., $R_1$ = 0.92 for AMS/PD-GP model for a 300 years return period, when a 10 years sample was used. The difference is sometimes caused by an error in evaluation of the parameter estimates variances and covariance, when based on the expected information matrix.

For the AMS model the variance of quantiles derived using analytical expressions are overestimated while the PDS models underestimate the same. This is evident for POT/PD-GP and AMS/PD-GP, respectively where the $R_1$ values lies below one for most of the cases. The above referred figure shows the change of $R_1$ values with T in case of PDS models, and $R_1$ lies over one for all cases in the range of 10 to300 years return period. To check the effect of choice of initial parameters selected for the simulation on the overall results of the ratios of variances, a different set of test was carried out with a new threshold, but the outcome was found to be similar. Hence, the choice of initial values of parameters in simulation was found not to affect the results of $R_1$.

The advantages of the Poisson distribution over negative binomial distributions have been dealt in the past by ÖnÖz and Bayazit (2001). On the basis of a detailed study they reported that the flood estimates and their corresponding variance based on the binomial and negative binomial distribution when combined with ED for the magnitudes of the peaks are almost identical to those obtained using PD. The above conclusions were in agreement with the findings of Kirby (1969) and Cunnane (1979). However, most of these studies focused on exponential distribution in POT models, and no such study have been reported in literature so far as to where PD distribution is used with GP distribution for modeling the flood exceedances in POT. From the overall results it can be observed that the Poisson distribution performs slightly better when the difference between mean and variance is small e.g. when $\mu = 1$ and $\sigma^2$=1.2.

### 4.3.9 Confidence Intervals and Uncertainty of Predictions

To estimate the uncertainty in the regional Flow Duration Curves (RFDC), flood hydrograph using Unit Hydrographs (UH) and recurrence flood using flood frequency analysis, it needs the methods of statistics and probability for the quantification of uncertainty in the hydrologic predictions. A set of thirteen small watersheds distributed throughout Mahanadi basins are considered for this case. These watersheds cover a range of watershed characteristics including soil type, topography and land use, as well as time series of daily precipitation, and streamflow for about 10-35 years period.

Identifying the characteristics of the minimum flow duration distribution and deciding on appropriate uncertainty probabilities (the median plus the ensembles equaled or exceeded >3%, >50% and 97% of the time for example) shows approximately >3% probability and the graph is exponential, >50% probability graph is straight line and >97% probability graph is scattered based on FDC using the median hydrology ensemble. . The conclusion is therefore that yield assessments based on a probabilities of exceedence of between about >3% and >97% would not be affected by including hydrological uncertainty. Using the unstructured sampling program (no stochastic daily flow inputs), it is clear that the high flow exceedance probabilities i.e. < 3 % sampling has resulted in much lower uncertainty compared to low flow exceedance i.e. > 96 % in the basin.

The mean errors were estimated for computed unit hydrographs with the conventional methods using four different methods, and the results show different degree of errors ranging from minimum 2.32 to maximum 30.56. In similar way, the calculation of confidence band has been illustrated for one of the catchment (Br-No 7). The approximate expressions for the *T*-year event estimation corresponding to a probability of non-exceedance, and its Root Mean Square Error (RMSE) using seven different pdf provides the variance of return period flood and show that GEV, LP3 and WAKEBY models yields less variance of $q$(T) than others for different return periods and is consistent.

### 4.3.10 Study Benefits/Impacts

The study shall give a field engineer and other field staffs dealing with hydrological projects with circumstance where the basins are either ungauged or partially gauged. The report may give referred users a friendly platform and part-guide for developing a suitable methodology for realistic estimation of hydrological variables. With this background as a backdrop, this study was taken up with the specific objective of design flood estimation in such catchments. Four different approaches were studied, and methodologies developed for both limited data and no data situations. The developed methods were checked for their workability taking two types of data i.e. short-term and annual maximum series data from real catchments. Thus, the work of this study is organized in six sections, that is accordingly summarized and concluded in the above discussions. The future scope in this topic and the limitations are discussed in the following section.

### 4.3.11 Future Plan

In future, it is envisaged to add a few more physiographic parameters using remote sensing imageries and GIS, which are sometime difficult to interpret from the Survey of India toposheets or might have changed due to natural and human activities in the region. CWC has already stipulated design return periods for different schemes depending on their size (small, medium, and large) along with the specification for using either PMF or SMF for design flood computation. Therefore, it is envisaged to analyses various distributions and recommends a standard statistical distribution for flood frequency analysis in the region. This shall include also the uncertainty bands and the robustness of used models for these cases. The theoretical analysis shall include all the recent developments in the topic and the latest available data of the region. For future scope, a margin has to be kept for climate change scenario, and its effect on flood impacts in river regions.

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## 4.4 URBAN HYDROLOGY FOR CHENNAI CITY – STORM WATER MANAGEMENT IN COOUM SUB BASIN, CHENNAI CORPORATION, CHENNAI, TAMILNADU

*Principal Investigator :* *Dr. Y.R.S. Rao*

The available historical hydrological data which is suitable for urban hydrological studies have been evaluated in the Chennai city. No flood inundation maps, short terms rainfall and water level data is available for the study area. However historical hourly rainfall nearby study area at Nungambakkam (maintained by IMD) has been collected and analyzed. The hourly rainfall computed for 2, 5, 10, and 25 years return periods using Gumbel's distribution are 48.89, 64.10, 74.08, and 87.24 mm respectively. During the project period five tipping bucket rain gauges and two automatic water levels recorders have been installed in the study area. The present DEM and landuse cover maps have been prepared from DGPS survey and satellite data respectively. The storm water drainage network details and Otteri Nullah longitudinal profiles/cross section details at every 30 m were collected and GIS database has been prepared. Using thematic layers of DEM, drainage network and road network, total 88 micro watersheds have been delineated in the Otteri Nullah sub basin. Using these thematic layers, the study area has been schematized using 121 nodes and 120 links in the XP-SWMM model. Based on measured rainfall and water level data in the study area, the SWMM model performance has been evaluated in terms of runoff computation in the study area. After successful testing of the model, the design storm for 2, 5 10 and 25 years return periods have been considered as input into the model and found that the present storm water drainage network is not even sufficient to drain two year return period storm. Few scenarios also developed for on going renovation activities proposed by PWD, Chennai in the Otteri Nullah sub basin. The data monitored in the sub basin may act as benchmark dataset for further research and to explore other flood mitigation measures in the study area.

### 4.4.1 Introduction

Present growth of urban settlements has put tremendous pressure on urban services like water supply, sanitation, drainage and solid waste disposal. These urban metamorphosis leads to flash floods, inundation of public places and environmental problems. According to United Nations projections, 60% of the World's population will live in cities by 2030. During rainy seasons, urban area is subjected to flooding due to non-provision/insufficient storm water drains to convey storm water safely to a suitable water body. If the water stagnates then there is a likelihood of spreading water borne diseases, which may affect the health of the people. To tackle these situations scientifically, short duration rainfall, water levels, discharge measurements and smaller interval topographical details are of at most important in urban watersheds especially which are located in coastal regions. Observed data of coastal inundations are very rare, yet are essential for testing the performance of simulation models for this significant natural hazard. In this paper, we therefore examine the extent to which observed data can constrain predictions of a flood inundation model and potentially providing a bench mark data set for comparative model analysis. The Purpose Driven Study (PDS) make use of the existing hydrological database, which were computerized in Hydrology Project-I and also additional data on short interval rainfall/water levels monitored during project period. This study also demonstrates the application of hydrological model for better management of storm water flooding in urban watersheds.

### 4.4.2 Study Area

Chennai (earlier called as Madras) was established in 1639, as one of the East India company's earliest trading ports and later became the center for the company's control over southern India. The Chennai Metropolis is expected to become one of the Mega Cities in the world with more than 10 million populations, in the next 10 years. The Chennai city Corporation with 176 sq. km area may have to accommodate about 59-lakh population while rest of the metropolitan area with the extent of 1013 sq. km will accommodate about 66 lakh population by 2026. The sub basin boundaries in Chennai Corporation and location of study area are shown in Figures 4.1. Mean annual rainfall in Chennai metropolitan is about 1200 mm and mean rainy days are about 52 days. The storm water drains and sewer lines are separate in the study area. Entire town drains the storm water into the Bay of Bengal mainly through two major rivers namely Cooum and Adyar Rivers. The entire Chennai Corporation is divided into 12 watersheds based on the natural barriers like rivers, channels, drains, roads, railway lines and contours (Figure 4.1). These watersheds have different characteristics of their own having different types of land use pattern that affect the runoff. These sub basins has different soil characteristics, different permeability and flood absorption characteristics. Among these watersheds the Otteri Nullah sub basin has been chosen for micro level urban storm water modeling in consultation with Tamilnadu State Government. This sub basin is the largest sub basin among the sub basins of Chennai Corporation.

### 4.4.3 Otteri Nullah sub basin

Otteri Nullah sub basin is located on the Northern part of Chennai city and it is the largest among the other sub basins. It is surrounded by Kolattur watershed on western part, Cooum watershed in southern part, North Buckingham canal watershed on eastern side, Captain Cotton canal watershed on the Northern side. This watershed is in the Northern part of the Cooum River and a Macrodrain Otteri nullah is passing through this watershed. This watershed covers Perembur, Konnur, Villivakkam, Ayanavaram, Purasavakkam, Kilpauk North, Mogapper, part of Kolattur, a part of Anna Nagar, Pulianthope and a part of Thattankulam. Micro closed drains like Anti Malarial Drain, Bricklin Road Drain, Sivagami street Drain, Konnur High Road Drain, 3$^{rd}$ Main Road Drain and Millers Road Drain join Otteri Nullah at different locations in addition to some road side drains that join directly

Otteri Nullah. A closed Sivagami street drain joins open Ekangipuram channel and then finally drains into major Otteri Nullah. The total catchment area of Otteri Nullah is 30.63 Sq.Km. The synoptic view of the study area (Satellite data) is shown in Figure 4.2.

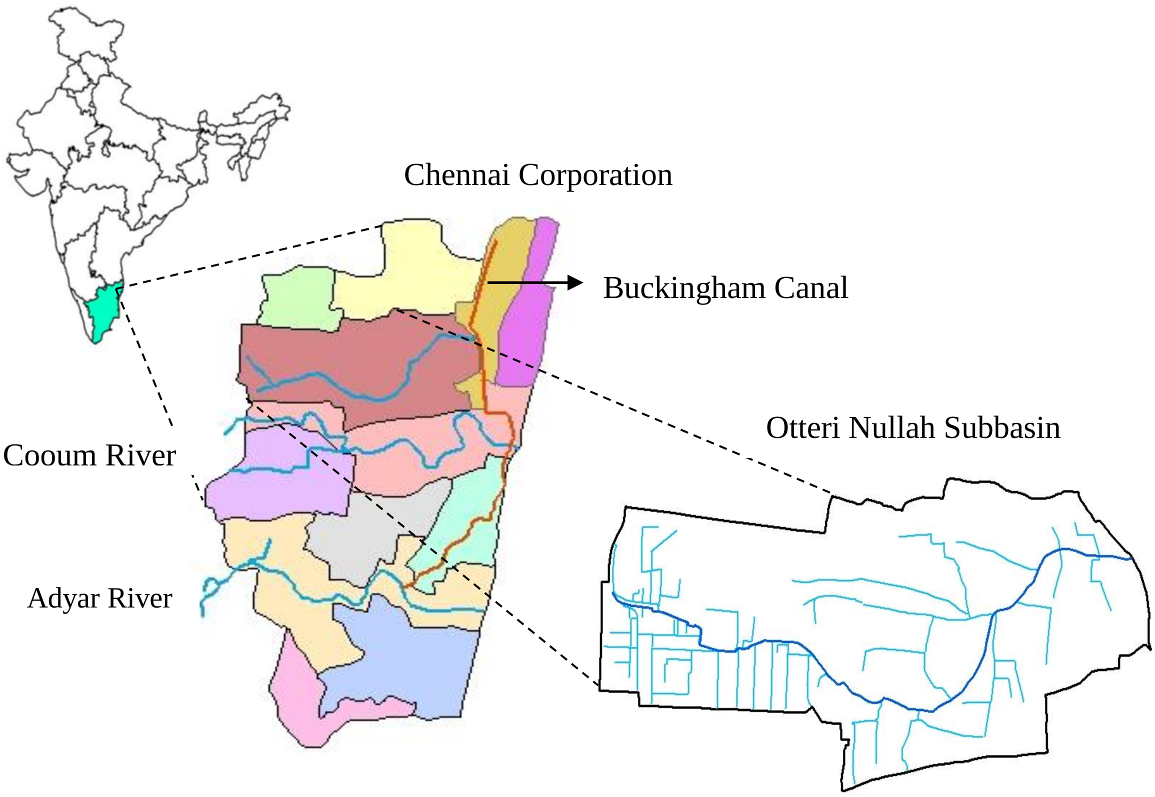



Figure 4.9: Location of Otteri Nullah Sub basin in Chennai Corporation

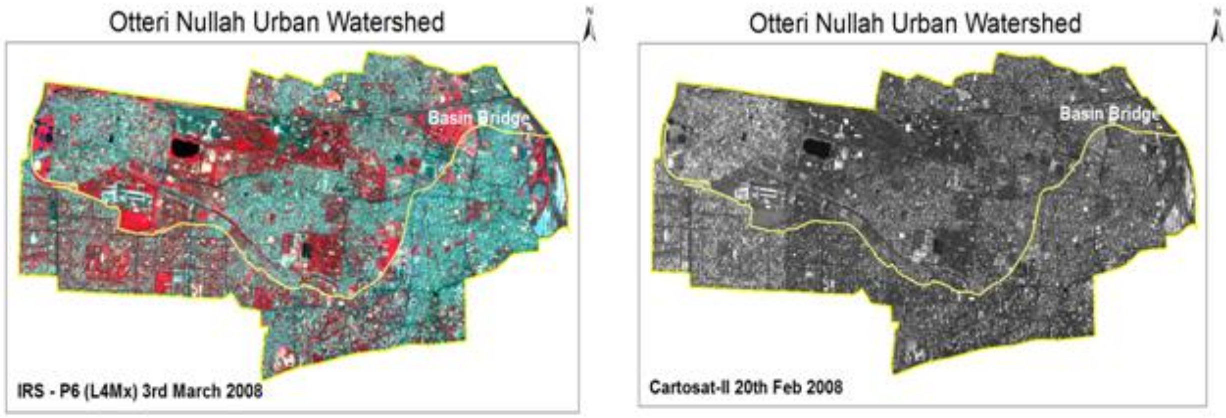



Figure 4.10: Synoptic view of the study area (FCC: 5.8 m and PAN: 2.5 m resolution).

### 4.4.4 Importance of the Project

Data of coastal inundations due to storm water flooding are very rare and yet to be studied about this significant natural hazard. In this paper, we therefore examine the extent to which observed data can constrain predictions of a flood inundation model and potentially providing a bench mark data set for comparative model analysis. Especially due to non-availability of short duration (15 minute) rainfall, water levels and 0.25 m topographical details, it is always difficult to undertake any scientific urban hydrological studies in the coastal areas for conceptualizing mathematical model and its calibration and validation. Purpose Driven Study (PDS) has provided an opportunity to install field equipments for measuring short interval rainfall and water levels in the project area and also to make use of the entire existing hydrological database, which were computerized in Hydrology Project-I. The main objectives of the PDS are given below.

### 4.4.5 Objectives

1. Evaluation of existing storm water drainage network in the study area using mathematical model
2. To find out the inflow-outflow hydrographs at various outlets and the water surface profile along the drains.
3. Feasibility of improvement of the existing drainage network and additional network if possible to mitigate urban storm water flooding in the study area.
4. Dissemination of results of the project through workshops/brain storming sessions/awareness programmes with the help of NGO's/Govt., departments /Academic Institutions in the study area and elsewhere.

### 4.4.6 Methodology

The Storm Water and Waste Water Management Model (SWMM) is comprehensive mathematical model for simulation of urban storm water and combined sewer system. The SWMM is one of the most widely used models for analysis of urban runoff in quantity as well as quality. The SWMM transforms rainfall excess to runoff hydrograph using Manning's equation and a nonlinear runoff flow routing procedure. It is also capable of predicting and routing quantity and quality constituents of urban storm water runoff. Runoff hydrographs are predicted based on the input hyetograph and the physical characteristics of the sub catchment: including area, average slope, degree of impervious, overland resistance factor, surface storage and overflow distance. Rossman (2005) provided more details on SWMM.

In the present project, a dynamic rainfall-runoff simulation model XP-SWMM (Graphical Interface of SWMM 1-D and 2-D) used for single event or long-term simulation of storm water runoff quantity in the study area. The runoff component operates on a collection of sub-catchment areas that receive precipitation and generate runoff. The routing portion includes runoff through system of pipes, channels, storage/treatment device, pumps and regulators.

Model tracks the quantity of runoff generated within each sub-catchment and flow rate, flow depth in each pipe or channel during a simulation period consisting of multiple time steps. Catchment information build up in GIS/image processing softwares like ERDAS/ARC-GIS and the same are transformed for developing the necessary inputs for mathematical model to simulate surface runoff processes. The following coverages (Thematic maps) were developed and used in the study.

1) Sub basin and micro watershed boundaries
2) Digital Elevation Model
3) Land use and soil map
4) Storm water drainage network map
5) Drain exit points for all micro watersheds

The above coverages in turn define the model parameters like area of sub-catchment, length and slopes of channel/drains. The model further routes the runoff collected from sub-catchments through the drainage network using St. Venant's equation (fully dynamic wave equation). The inputs required for developing runoff depth from each micro watershed using SWMM model is shown in Figure 4.3. Similarly the information required to generate runoff hydrograph is shown in Figure 4.4.

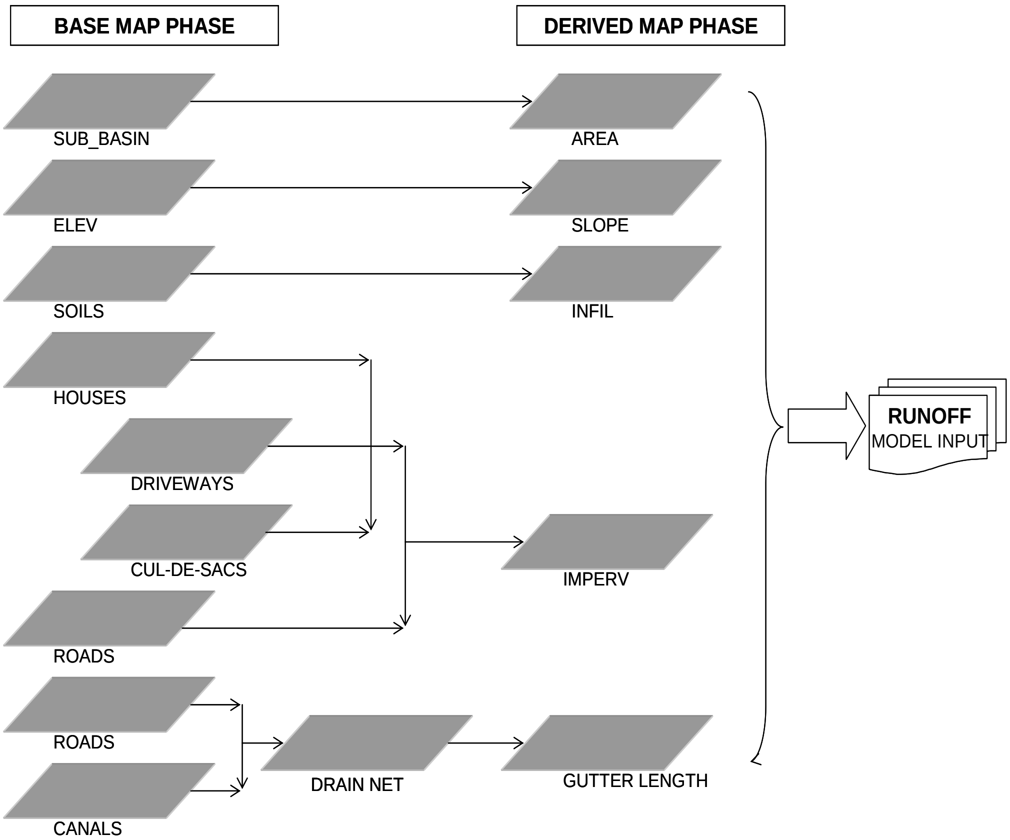



Figure 4.11: Flow chart showing model inputs for generating Runoff

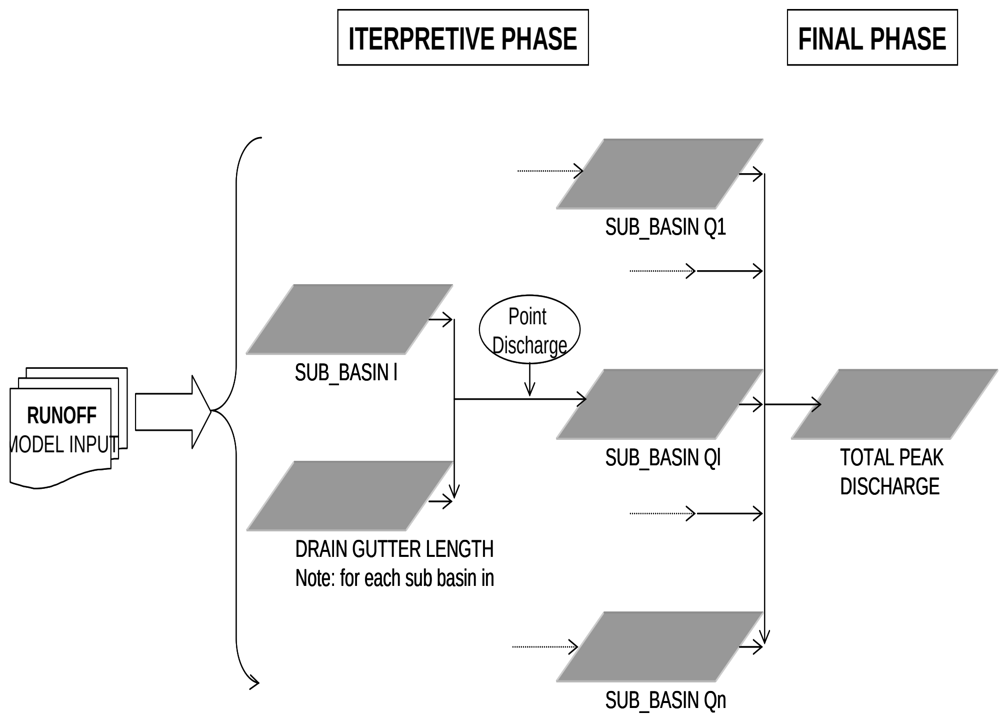



Figure 4.12: Flow chart showing model inputs for generating Runoff Hydrograph

## 4.4.7 Results and Discussions

### 4.4.7.1 Data collection tools and methods

Five tipping bucket rain gauges and two Automatic water level recorders have been installed in the study area to collect short interval rainfall and water levels. The date of installation of equipments and its data availability is given in the Table 4.1 and their locations are shown in Figure 4.5. The collected data has been processed and validated. The response of the spatial variations of rainfall pattern within the study area is observed in measured water levels. Differential Global Position System (DGPS) is used in field survey and prepared the DEM of the study area. The cross sectional details of Otteri Nullah drain at every 30 m, storm water drainage network in the sub basin and its cross sections, bed levels were obtained from Chennai Corporation. The nearest available Indian Meteorological Department (IMD) rain gauge is at Nungambakam and its hourly rainfall has been obtained from IMD, Chennai for a period of thirty years (1980 to 2009).

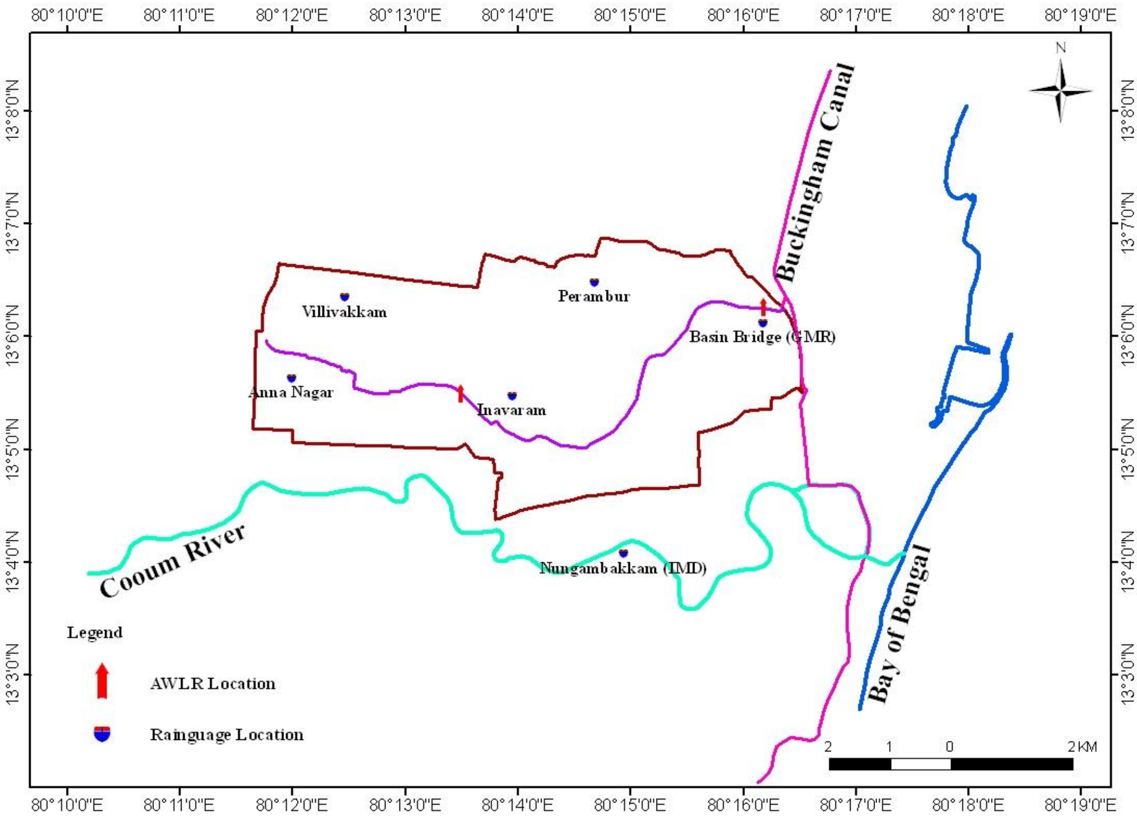



Figure 4.13: Location of Tipping bucket rain gauges and AWLR's in the study area

Table 4.2: Details of equipments installed in the study area

| S.No | Name of the Equipment | Location | Date of Installation | Data Processed and analyzed |
|---|---|---|---|---|
| 1 | Tipping Bucket Raingauges | Anna Nagar | 19-09-2010 | 19-01-2014 |
| 2 | | Villivakkam | 08-09-2011 | 19-01-2014 |
| 3 | | Inavaram | 08-09-2011 | 19-01-2014 |
| 4 | | Perambur | 09-07-2011 | 19-01-2014 |
| 5 | | Basin Bridge (GMR) | 09-07-2011 | 19-01-2014 |
| 6 | Automatic Water Level Recorders (Bubbler type) | Anna Nagar (L block) | 29-09-2011 | 23-01-2014 |
| 7 | | Basin Bridge (GMR) | 09-07-2011 | 22-01-2014 |

#### 4.4.7.2 Historical Rainfall Data Processing and Analysis

The analysis of 30 years (1980 to 2009) hourly rainfall data at Nungambakkam (Monitored by IMD) has been carried out and Intensity Duration Frequency (IDF) curves have been prepared using Gumbell distribution. The highest annual rainfall observed during this period is 2489 mm in the year 2005. The maximum daily rainfall observed during this period is 394 mm on 27$^{th}$ October 2005. The maximum numbers of rainy days observed are 83 in the year 1997. The Intensity Duration Frequency (IDF) curves prepared for Nugambakkam raingauge stations are given in Figure 4.6. The design storm of 24 hours with a return period of 2,5, 10, and 25 years are given in Figure 4.7.

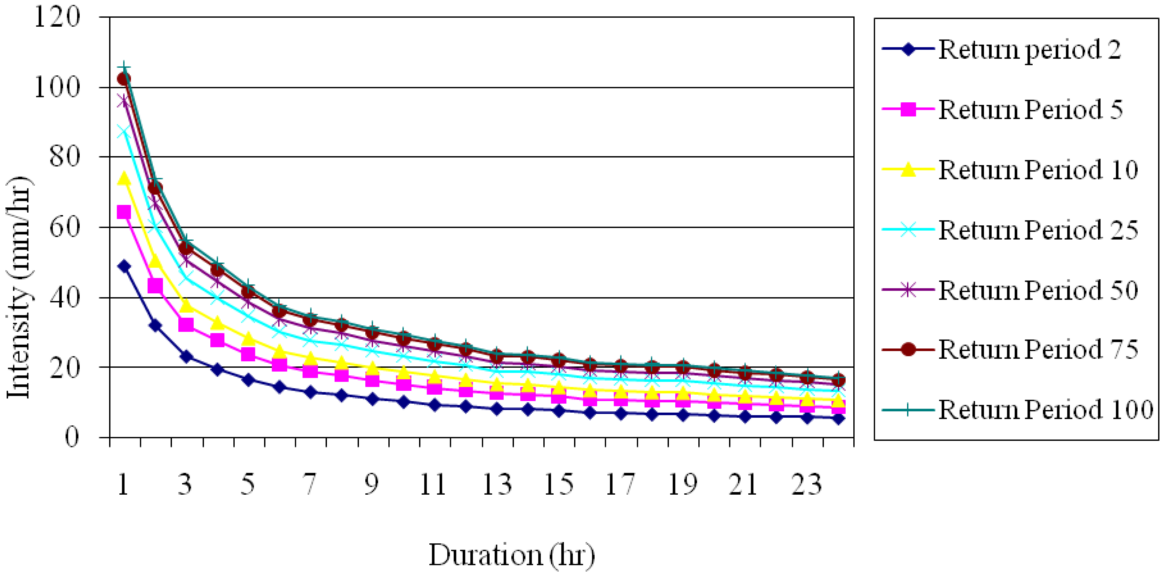



Figure 4.14: Intensity Duration Frequency (IDF) curves for Nungambakkam Raingauge station (IMD)

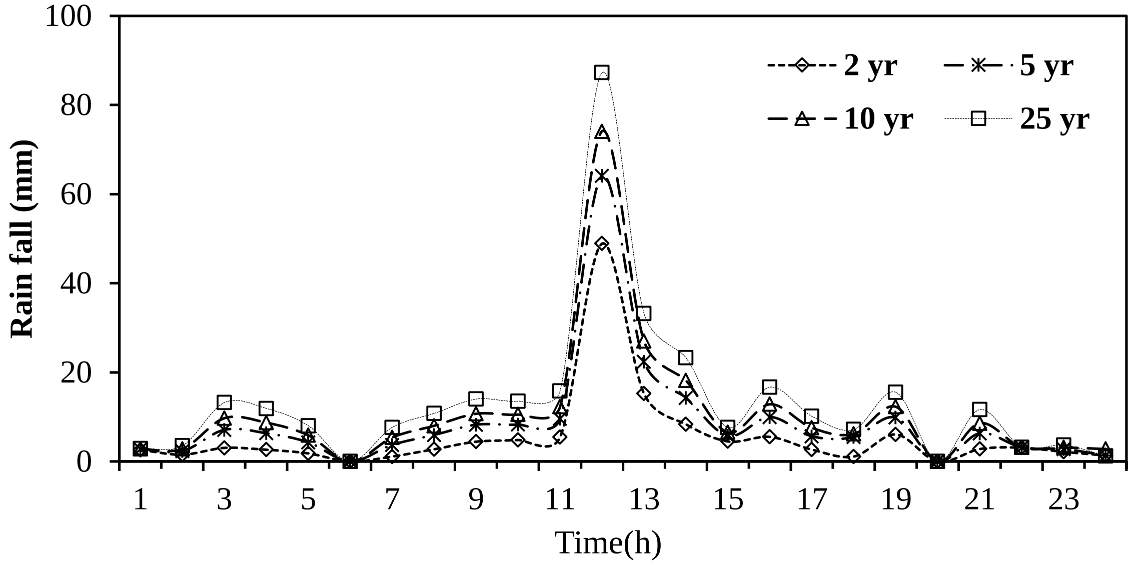



Figure 4.15: Design storms for various return periods in the study area

### 4.4.7.3 Model Setup and Results

The study area has been descritised in the form of nodes, conduits and micro watersheds for setting up SWMM model and these details are given in Figure 4.8. Total 121 nodes, 120 conduits and 88 micro watersheds have been delineated in the study area using drainage network, topography and slopes. Among 121 nodes, 29 nodes are located on Otteri Nullah drain and rest of the nodes (92) is marked on storm water drains. Total 88 micro watersheds are connected to 85 nodes in the study area. Among 88 micro watersheds 52 micro watersheds are above Anna Nagar gauging station and rest of the micro watersheds are above Basin Bridge gauging station. The catchment area above Anna Nagar gauging station is 6.2 sq km where as the total catchment area of Otteri Nullah is around 30 sq km. The total sub basin is having 67% of impervious and 33% of pervious area. Total length of storm water drains considered in the study area is 58871 m. The total length of major Otteri Nullah is around 10 Kms. There are only three major soil types observed in the study area. They are sandy (Group A), clay (Group D) and sandy clay (Group D), and they have occupied 13.32%, 41.62% and 45.06% areas respectively in the study area. These soils are considered as Group A and D as per the SCS Hydrological soil groups (SCS, 1986). The major land uses observed in the study area are open land, residential, roads, vegetation, and water body. They occupy 3.3%, 56%, 10.9%, 28.9% and 0.6% respectively and shown in Figure 4.9. The range of curves number is 61 to 84 for 88 micro watersheds in the study area.

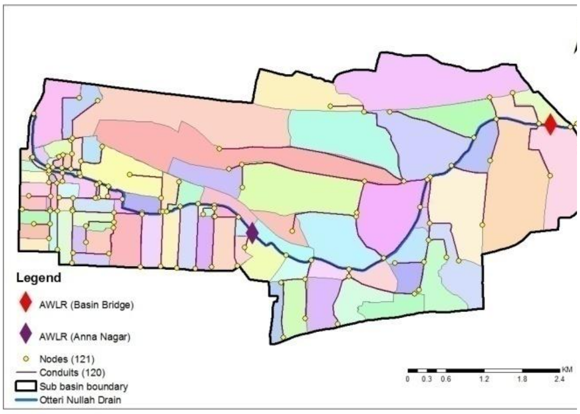



Figure 4.16: Watersheds delineation of study area

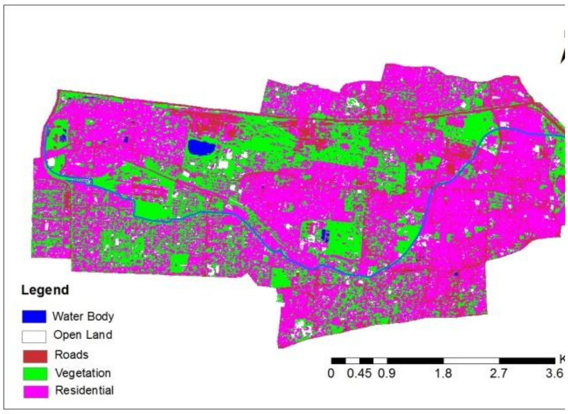



Figure 4.17: Study area land use classification

In order to test SWMM with field input parameters, two events (25th October 2011 and 4th November 2011) of observed hourly rainfall and water level data have been considered for model performance at Anna Nagar. Similarly continuous observed hourly rainfall period (25-29 October 2011) is also considered to test SWMM performance at Anna Nagar and Basin Bridge. Results indicated that the model predicted water levels for two events at Anna Nagar (correlation coefficient 0.81 and 0.80) are in good agreement with observed water levels and the same are shown in Figures 4.10 and 4.11 respectively. Continuous hourly rainfall period-simulated water levels are reasonably matched with shape of the observed stage at Anna Nagar (correlation coefficient 0.84) as shown in Figure 4.12 but at Basin Bridge there is less peak and time lag observed in the Figure 4.13. This is mainly due to drain blocking with garbage, floating material and improper interconnectivities between storm water drains.

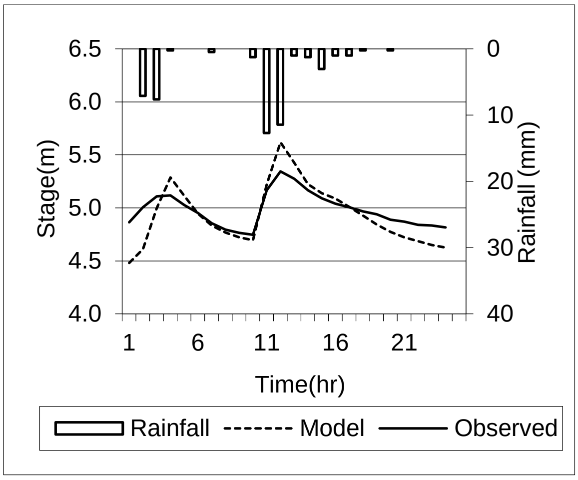



Figure 4.18: Comparison between observed and modelled stage at Anna Nagar (25th Oct. 2011)

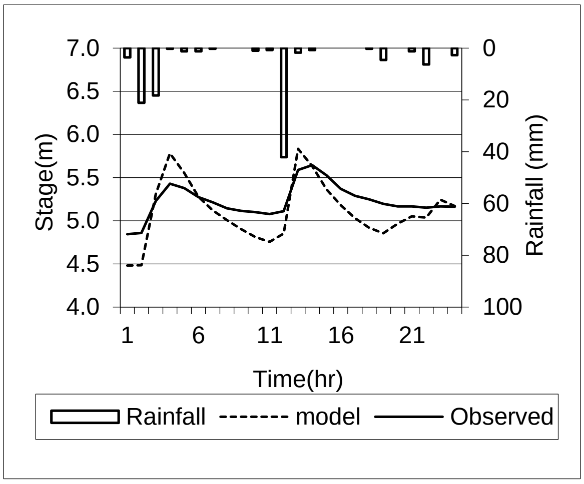



Figure 4.19: Comparison between observed and modeled stage at Anna Nagar (4th Nov. 2011)

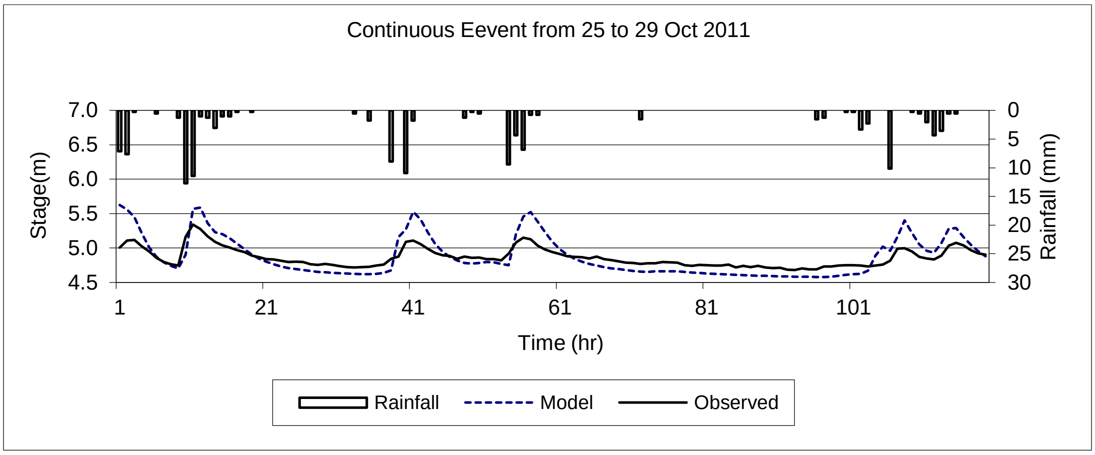



Figure 4.20: Comparison between observed and simulated water levels at Anna Nagar

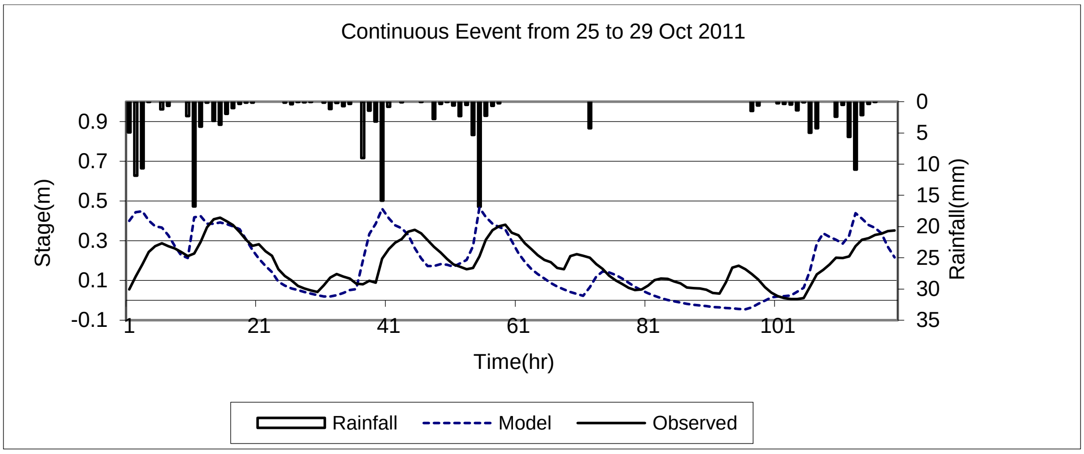



Figure 4.21: Comparison between observed and simulated water levels at Basin Bridge

Present storm water drainage network of Otteri Nullah sub basin is evaluated for different return period design storms, which are computed from IDF curves of the basin (Figure 4.6). The application of model with different return period storms indicated that the present networks of storm water drains are not adequate to drain off the runoff generated from the sub basin. The PWD is proposed to modify the longitudinal profile of Otteri Nullah drain as a part of flood mitigation measures in the sub basin. The proposed longitudinal profile is incorporated in the model and tested the adequacy for storm water drainage network for different return period of storms. It was observed that the proposed longitudinal profile is adequate to drain off only 2-years return period storm in the basin. The computed water surface profiles with flooding nodes with existing and proposed longitudinal profile are shown in figures 4.14 and 4.15 respectively. The outfall hydrographs for various return periods are also computed with existing and proposed longitudinal profile of Otteri Nullah drain and the same are shown Figures 4.16 and 4.17 respectively. The flood peak, system inflow and outflow volume and percentage of error are shown in Table 4.2. The minimum error indicated that the inflow volume and generated runoff volume are similar. The comparison between outfall hydrographs for various return period storms indicated that only 2 years return period flood peak is passing at basin outfall with proposed longitudinal profile and rest of the hydrographs indicate flooding in the sub basin.

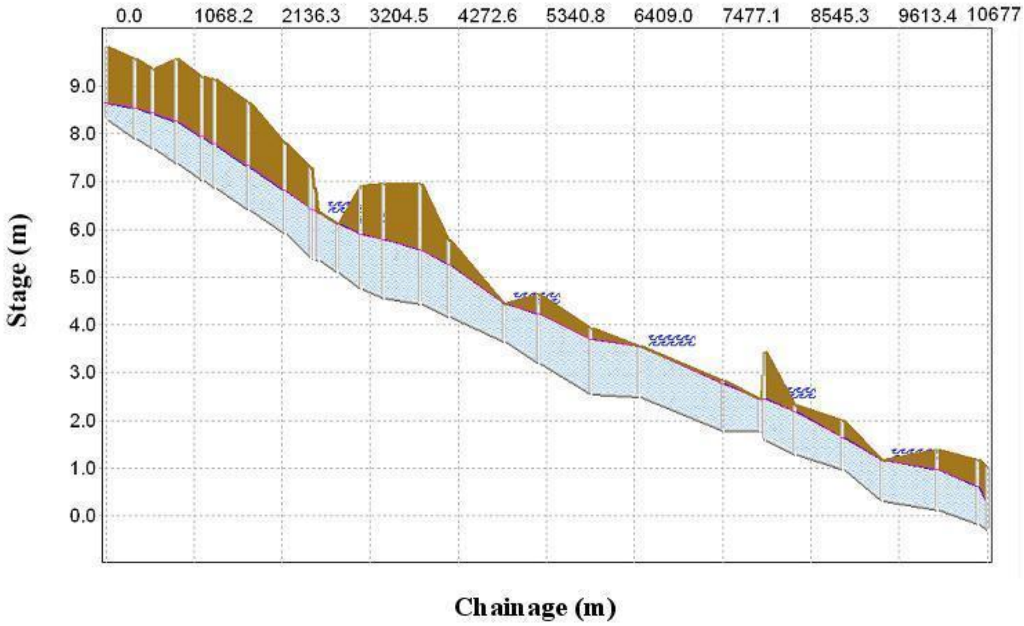



Figure 4.22: The computed water surface profiles with flooding nodes with existing longitudinal profile

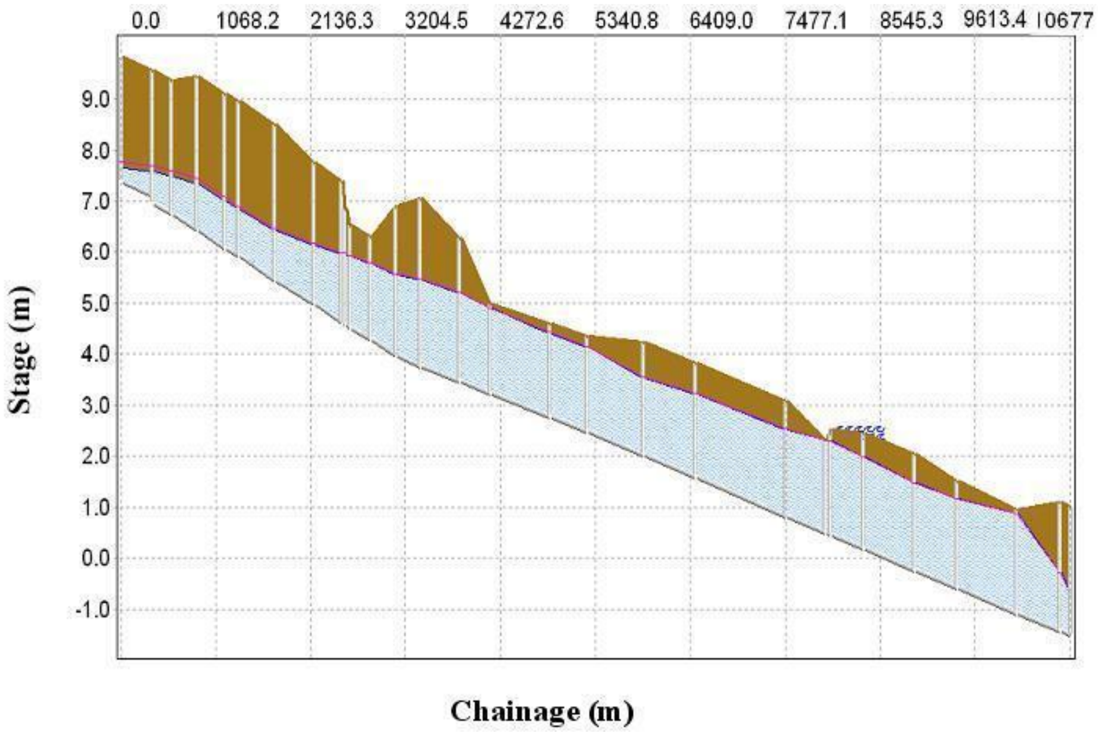



Figure 4.23: The computed water surface profiles with flooding nodes with proposed longitudinal profile

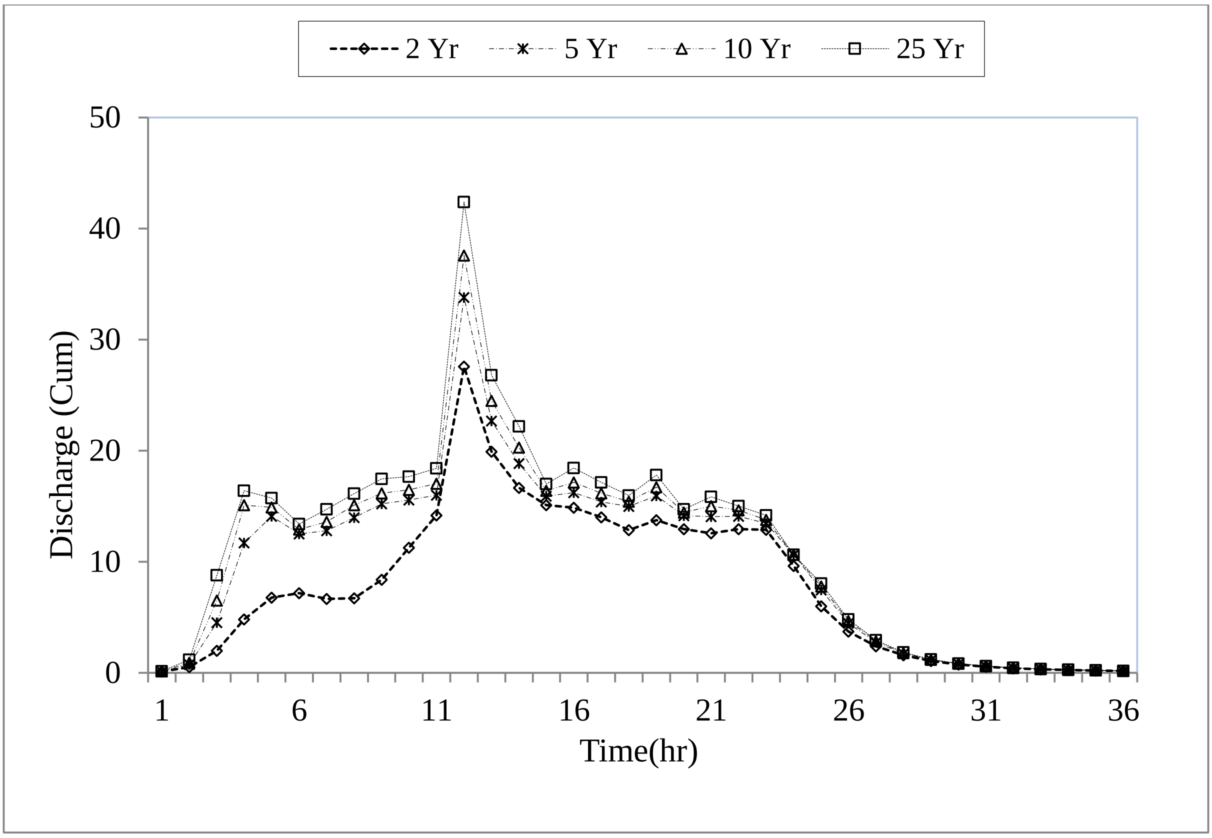



Figure 4.24: Outflow hydrographs for existing longitudinal profile of Otteri Nullah .

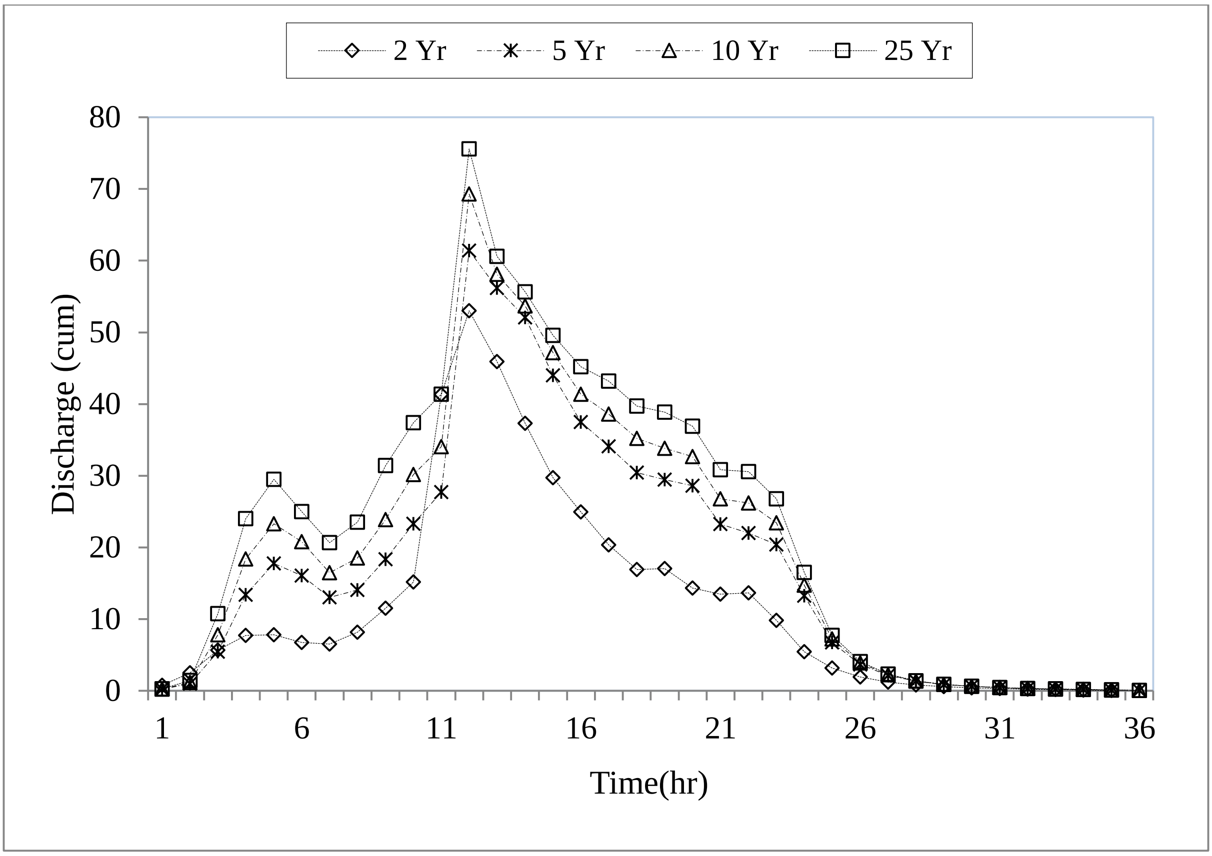



Figure 4.25: Outflow hydrographs for proposed longitudinal profile of Otteri Nullah. .

Table 4.3: Inflow and outflow hydrographs properties of the Otteri Nullah sub basin

| 24 hr design storm return period | Peak ($m^3/s$) | | System Inflow ($m^3$) | | System Outflow ($m^3$) | | ± % Error | |
|---|---|---|---|---|---|---|---|---|
| | Existing | Proposed | Existing | Proposed | Existing | Proposed | Existing | Proposed |
| 2 | 27.57 | 53.00 | $2.7463*10^6$ | $2.7463*10^6$ | $2.7429*10^6$ | $2.7538*10^6$ | 0.065 | -0.323 |
| 5 | 33.80 | 61.40 | $4.6879*10^6$ | $4.6879*10^6$ | $4.6817*10^6$ | $4.6931*10^6$ | 0.065 | -0.110 |
| 10 | 37.58 | 69.31 | $5.9395*10^6$ | $5.9395*10^6$ | $5.9345*10^6$ | $5.9411*10^6$ | 0.031 | -0.050 |
| 25 | 42.37 | 75.60 | $7.6090*10^6$ | $7.6091*10^6$ | $7.6056*10^6$ | $7.6092*10^6$ | 0.005 | -0.001 |

### 4.4.8 Conclusions

The present storm water network in Chennai city especially in the Otteri Naullah sub basin has been studied. Historical hourly rainfall data (1980-2009) nearby study area at

Nungambakkam (maintained by IMD) has been collected and analyzed. The hourly rainfall computed for 2, 5, 10, and 25 years return periods using Gumballs distribution are 48.89, 64.10, 74.08, and 87.24 mm respectively. Due to non availability of 15 minutes rainfall and water level data in the study area, five tipping bucket rain gauges and two automatic water level recorders have been installed in the field. Further, DGPS survey has been conducted to prepare Digital Elevation Model (DEM) for the study area in addition to available information from SOI maps. The present land use/land cover map has been prepared using IRS P6 LISS III satellite data. The storm water drainage network details and Otteri Nullah longitudinal profiles/cross section details at every 30 m were collected and GIS database has been prepared. Using thematic layers of DEM, drainage network and road network, total 88 micro watersheds have been delineated in the Otteri Nullah basin. Using these micro watersheds, storm water drainage network and Otteri Naullah cross sections the study area has been schematized using 121 nodes and 120 links in the XP-SWMM model. Model parameters like Node/link characteristics, pervious/impervious area, soil type, average width/slope and SCS-CN have been computed for each micro watershed in the study area using GIS data base. Based on measured rainfall and water level data in the study area few events have been selected for SWMM model performance in terms of runoff computation in the study area. After successful testing of the model, the 24 hrs design storm for 2, 5 10 and 25 yrs return periods have been considered in the model to check the storm water drainage network efficiency in the study area. It was found that the present storm drainage network is not even sufficient to drain storm water runoff for two year return period storm. The hydrographs at outfall of the sub basin has been developed for various return period design storms and this information is very useful for best management practices (BMP).

Few scenarios also developed for ongoing renovation activities proposed by PWD in the Otteri Nullah sub basin. The 2, 5, 10 and 25 return period storms are once again considered for modified longitudinal profile of Otteri Naullah in XP-SWMM model and found that modified longitudinal profile is capable of draining two year return period storm. Flood water diversion link with proposed cross sectional area are incorporated in the SWMM model and found that the reduction of the flood peak at diversion link (above AnnaNagar) is 38% in Otteri Nullah basin. The data monitored in the sub basin may act as benchmark dataset for further research and to explore other flood mitigation measures in the study area. The outcome of the project has been disseminated to user agencies through interaction workshops and training programs during the project period.

## PHOTO'S AND IMAGES







## 4.5 GROUNDWATER MANAGEMENT IN OVER-EXPLOITED BLOCKS OF CHITRADURGA AND TUMKUR DISTRICTS OF KARNATAKA

*Principal Investigator :* *Dr. Sudhir Kumar*

### 4.5.1 Objectives

(1) To analyze groundwater productivity at specific study sites including artificial recharge structures

(2) Model for management and regulation of identified over-exploited blocks on an operational basis

Rainfall and groundwater data has been compiled. Required toposheets (SOI), satellite data and geological maps have been procured. Raingauges and automatic GWLR have been procured. ORGs, soil moisture sensors, evaporation pan and automatic GWLR have been installed. Hydro-meterological data has been collected from May 2010 and analysed. GIS data base (lithology, geomorphology, soil type, landuse / land cover, drainage, and tanks) and DEM have been prepared. Land use - land cover classification has been done using Liss-4 data. Geological sections have been prepared for two watersheds. Infiltration tests have been conducted at various locations. Resistivity survey has been conducted at 18 sites. Pump tests have been conducted at 4 locations. Water samples were collected from a tank and surrounding groundwater sources to understand the interaction of tank with groundwater. Socio-economic survey has been conducted in the two watersheds. Isotopic analysis of water samples has been done. Morphometric analysis has been carried out. Estimation of surface runoff has been estimated by SCS method.

# 4.6 GROUNDWATER DYNAMICS OF BIST DOAB AREA, PUNJAB USING ISOTOPES

*Principal Investigator :* *Dr. M. S. Rao*

## 4.6.1 Introduction

Punjab state is one of the most productive agricultural regions in the country and is supported by its dense network of canals spanning over 14500 kms of length that distributes its source water from the rivers Satluj, Ravi and Beas and also through extensive groundwater extraction (by over 33 BCM) through millions of its state and private owned pumps. The era of sharp agricultural growth with intensive irrigation support begun with Green Revolution and this ultimately earned the name- *'Bread Basket of India'* to the state. The state occupies only 1.57% geographical area of India but, contributes more than 50% of the grain in the central grain pool. In particular, it contributes about 55% of wheat and 42% rice to the central pool. The state has 86% cropped area and 98% of this is under irrigation that uses nearly 84% of the state's water resources. The extensive water use is resulting in falling ground water level (except in south-western region of the state), soil & water quality deterioration and also water logging in some parts (mostly in south-western region). Hydrogeologically and also socio-culturally, Punjab is broadly divided into three regions, Bist-Doab (the region between river Beas & Satluj), Majha (region between the river Ravi and Beas) and Malwa- (the region south of the river Satluj). Depending upon the hydrogeology, these regions are facing different type's water resource problems. In the present study, this is investigated in detail for the Bist Doab region.

The specific objectives of the project are (i) to identify the recharge sources and recharge zones of groundwater (ii) investigating the groundwater flow regime (iii) groundwater quality issues and (iv) suggesting the steps to improve the groundwater conditions. The objectives were attained through collating and analyzing the existing data and chemical & isotopic analysis of groundwater.

## 4.6.2 Study Area & Demography

The Bist- Doab is a triangular shaped region bounded by the hill range of Shivalik in the north-east, the river Beas forming its northern & western boundary and the river Satluj as its southern boundary. The region ends to its south west corner at Harike Barrage at village Harike where the two rivers Beas and Satluj confluence. The area spans over 9060 km$^2$ and contains four districts Hoshiarpur, Jalandhar, Kapurthala and Shahid Bhagat Singh Nagar (abbreviated as SBS Nagar, formerly Nawanshahar). The demographic characteristics of these districts are given below –

Table 4.4: Demographic data of Bist-Doab region districts

| District Name | Area ($km^2$) | Population (census 2011) | % increase w.r.t. to 2001 | Population Density (number/sq km) |
|---|---|---|---|---|
| Hoshiarpur | 3386 | 1586625 | 7.1 | 683 |
| Jalandhar | 2632 | 2181753 | 11.16 | 831 |
| Kapurthala | 1633 | 754521 | 8.37 | 492 |
| SBS Nagar * | 1258 | 614362 | 4.58 | 479 |

***** SBS Nagar- Formerly Nawashahar

### 4.6.3 Surface Water Resource

As per the name Bist Doab, the region is enclosed between the two perennial rivers Beas and Satluj. The inside of the region is drained by the tributaries of rivers Satluj and Beas (mainly Kali Bein & White Bein). The discharge in the river Beas is controlled at Maharana Pratap Sagar reservoir (also known as Pong reservoir). The reservoir is situated in Kangra District of Himachal Pradesh. It's gross storage capacity is 8570 MC. Shah Nahar canal and Kandi canal of Beas river off-takes at Mukerian Hydel serves the irrigation needs in Kandi (foot-hill) area of Bist Doab. While Shah Nahar ensures 395 MCM usage of Beas water in the northern region of Bist Doab, the Kandi canal runs all along the foot hills of Shivalik over 130 km length from north east (Talwara) to south east (Balachaur) to serve the water needs of the Kandi region. The irrigation needs of Kandi region is also supported through a series of 16 small dams developed on ephemeral streams at higher reaches between Mukerian to Rupnagar (former name-Ropar) in addition to the two major dams Bhakra and Pong on the rivers Satluj and Beas, respectively.

Bhakra dam constructed on Satluj river is located at Bhakra village in Bilaspur of Himachal Pradesh. Its reservoir (name- Gobind Sagar) stores up to 9.34 BCM of water. At Rupnagar headworks, the two canals: Sirhind Canal and Bist Doab Canal off-takes from the river Satluj, while Sirhind canal command is spread in Malwa region (southern Punjab), the Bist Doab Canal, over 805 km of its length, serves the need of southern half of the Doab region. The canal has an authorized capacity of 1452 Cs. and culturable command area of 1.99 lac hectares. Over the years, the carrying capacity of the canal has got reduced to 1000 Cs.

### 4.6.4 Topography and Land Use

The topographic slope divides the Bist Doab region into three units: Plain (elevation range 212-245 m and slope ~ 0.4 m/km), Kandi region (elevation range 245 m to 355 m and slope ~ 4m/km) and hilly region (elevation > 355 m range and slope 30 m/km). Maximum width of these regions is; Plain- 85 km, Kandi- 30 km and Shiwalik ~ 6 km.

In the Bist Doab region, in the order of their decreasing area, land distribution under various uses is agriculture (80.78 %) > forest & hill area (7.19 %) > Build up area (6.45 %) > water channels & water bodies (2.91 %) > waste land (2.67 %). Agricultural statistics show that during the Green Revolution, over a period from 1961-1991, cultivable land increased by a few thousand hectares due to reasons like land leveling, mechanized farming, intensive irrigation practices etc. However, in post 1995 period a minor decrease in the agricultural area is observed due to land use conversion for industrial and urban development. Area occupied by different crops in the region is wheat 39.88 %, Rice 28.63 %, Maize 10.61 %, Sugar Cane 3.94 %, Cotton Seed 0.04 % and others 16.90 %. Based on the productivity & crop based virtual water use, the water utilized for various food grains computed using agricultural data for the year 2006 comes out to be 3.5 $Mm^3$ for rice, 3.4 $Mm^3$ for wheat, 0.5 $Mm^3$ for maize, 0.05 $Mm^3$ for sugarcane and 0.003 $Mm^3$ for cotton.

### 4.6.5 Precipitation

In general, in the study region, the rainfall decreases in the direction along the the river Satluj course from Rupnagar in the east to Harike in the west. District-wise, the lowest rainfall occurs in Kapurthala district. The long term rainfall data (>50 years) shows that 80 % of the annual rain is received during monsoon period i.e. June to October. The minimum rainfall (< 10 mm) occurs mainly during November. In all seasons, hilly region especially the southern side receive high rains (> 700 mm/year). This region falls in sub-humid climate. The central plains receive moderate rains (~ 500-600 mm/year). The western boundary especially the south-west region receives very low rains (<450 mm/yr). This region falls in semi-arid climate zone. District wise comparison of normal annual rainfall is SBS Nagar (long term average = 600.3 mm) > Hoshiarpur district (long term annual average= 571.9 mm) > Jalandhar (long term annual average= 534.4 mm) > Kapurthala district (long term annual average= 386.1 mm). The rainfall pattern analyzed at district level for various seasons over the period from 1901- 2011 shows high variability in its temporal distribution. For example, rainfall at Kapurthala in the year 2007 was 365.5 mm, in the year 2009 it was 756.5mm, the monsoon (June, July August) rainfall of 2007 was just 147 mm whereas it was 330 mm in 2008, on 5/10/1955 the single day (24 hours) rainfall was 339.1 mm.

### 4.6.6 Groundwater conditions

The groundwater flow direction in shallow and deep aquifers is examined using the data collected for the period (1999-2009). The result show that groundwater flow in the upper half of the Doab region is diagonally along NE (Shivalik-Kandi) to SW direction (towards the confluence region of the rivers Beas and Satluj at Harike) and along east-west direction in the southern part of the study area parallel to the River Satluj. The surface water and groundwater flow accumulate towards the confluence zone resulting into large water spread at Harike (Harike wetland, a Ramsar site). Groundwater is at shallow depth (closed to surface) at this region. Groundwater fluctuation analyzed for the period 2002-08 shows highest groundwater fall (upto 8m) in the shallow aquifer in the area between Hoshiarpur and Garhshankar while for the same period (2002-08) in the deeper aquifer major fall in the groundwater head (upto 8m) is observed around the area between Jalandhar to Adampur. Thus, the groundwater fall (maximum) pattern is not the same in the shallow and deep aquifers. The groundwater fall (in both shallow and deep aquifer) is very low in the northern region of Doab. In the northern region (for example, at Mukerian) groundwater occurs at shallow depths (<5 m) where as it occurs at deep depths in the southern zone (for example at Nakodar it is at 35 m). Thirty years groundwater data (1972-2004) at village Shankar in the block Nakodar at the south west of Jalandhar city analyzed shows a continuous decline in water table at a rate of 0.53 m/yr. Response to groundwater level due to monsoon was monitored using automatic water level recorder recorded at 6 hourly intervals (6 nos. of 150 m deep piezometers were installed for this purpose) shows very high rate of groundwater recharge at Bhogpur (3 m rise between 8$^{th}$ to 15$^{th}$ September 2011). However, at discharge site such as at Sultanpur the rise was less than 50 cm during this period.

The groundwater balance analyzed at block level indicates, over exploitation in almost the entire region except at Kandi region and at flood plain zone. This is due to low population density and marginal use of groundwater for irrigation at these regions. Among all the blocks of the region, groundwater use is lowest in the Talwara block (stage of groundwater development is about 45%) and it is highest in the Lohian block (stage of groundwater development is 418%). Over exploitation of groundwater is observed mainly in the plains (especially around Jalandhar) due to high population density and intensive groundwater use in agriculture. District-wise comparison of the net groundwater availability (for the data of 2006) of Bist-Doab is Kapurthala (62,156ha m) < SBS Nagar (66,480ha m) < Hoshiarpur (91,817ha m) < Jalandhar (113,203ha m). Whereas, the net groundwater availability for future irrigation development is in the order: Hoshiarpur (+12,640 ha m) > SBS Nagar (-49,971 ha m) > Kapurthala (-65,354 ha m) > Jalandhar (-1, 75,217 ha m).

### 4.6.7 Groundwater Quality

In order to investigate groundwater quality 111 samples (50 Shallow groundwater, 52 deep groundwater, 2 from Kandi canal, 2 from Bist-Doab canal, 3 from Dholbaha Reservoir, 1 from Kali Bein and 1 from Labbar stream of Kandi region) were collected and analysed for major ions. The analyzed data interpreted using Piper tri-linear diagram, Gibb's diagram, Wilcox diagram and Chadha's diagram and on this basis the following important conclusion were drawn.

Groundwater chemistry of Bist-Doab region is dominated by $Mg^{2+}$ and $Na^{+}$ ions in the surface and groundwater, respectively. The canal water is $Mg^{2+}Ca^{2+}$ $HCO_3^-$ type of composition and shallow & deep groundwater is $Ca^{2+}Mg^{2+}$ $HCO_3^-$ and $Na^{+}HCO_3^-$ type of composition. High amount of $Mg^{2+}$ in groundwater is from Kandi region and in adjoining areas of canals. Calcite and dolomite present as kankar in the region might be the source for $Ca^{2+}$ and $Mg^{2+}$ in groundwater. This is also seen in the plot between Ca+Mg vs $HCO_3$. Gibb's plot also indicates water–rock interaction and silicate weathering influencing the water chemistry in some areas of the Bist Doab. Enriched $Na^+$ in groundwater in some areas of Bist Doab is also seen. The Na/Cl vs Cl, factor analysis and stable isotope data indicates $Na^+$ and $HCO_3$ enrichment due to dissolution of sodic-rich and carbonate minerals and also due to evaporation during the recharge process. Isotope data indicates that deep aquifers are recharged mainly in Kandi region whereas; shallow aquifers are recharged both at Kandi and in plains. The slow rate of recharge in plains (for the case of shallow aquifer) compared to that at Kandi region has led more salt dissolution and the concentration of this further increased with evaporation during the recharge. The observed higher nitrate and sulphate concentration in shallow aquifers (in plains) is also due to recharge from agricultural contaminated water in plains. The deep groundwater quality is fairly good at in the entire Bist Doab (as the recharge of deep aquifer is mainly from Kandi region). As the groundwater quality of deep aquifer is good throughout the region, the deep aquifer need protected (from contamination & over-drafting) for present and future drinking needs. A list of locations where groundwater contamination is reported is listed below.

Table 4.5: Groundwater contaminated sites (concentration above desirable limit as per BIS and WHO standards) Bist-Doab region

| **Ions & desirable limit (mg/l)** | **Site name** | |
|---|---|---|
| | **Shallow aquifer** | **Deep aquifer** |
| *$Ca^{2+}$ (> 75)* | Rahon and Badesaron | All samples within permissible limit |
| *$Mg^{2+}$ (> 30)* | Goraya, Noormahal, Rahon, Saidpur Jhinni, Nakodar and Nawanpind | |
| *$Na^+$ (> 200)* | Phillaur, Sadiqpur | |
| *$K^+$ (> 10)* | Begowal, Maliyakalan | |
| *$NO_3^-$ (> 45)* | Nussi, Nakodar, Goraya and Nawanpind | |
| *$F^-$ (> 1)* | Busowal, Darwesh, Jandiala, Khurdpur and Jalandhar | Arjanwal, Behram, Darwesh, Malliankalan and Phillaur |
| *Se (0.01)* | Nawansahar district (Panam, Nazarpur, Simbli, Mehendpur, Jainpur, Barwai and Bhanmazara) | All samples within permissible limit. |

## 4.6.8 Isotopic Analysis

For isotopic analysis, samples were collected regularly for precipitation from 13 locations, river water from 11 locations, shallow groundwater from 21 sites and deep groundwater from 26 sites. The stable isotope range and isotope characteristic of recharge sources observed during the study period is given below:

Table 4.6: Characteristic isotopic values of the recharge sources in Bist Doab

| Recharge Sources | Parameter of characteristic isotopic equation ($\delta^{18}O$ vs. $\delta D$) | | $\delta^{18}O$ (‰) | | $\delta D$ (‰) | |
|---|---|---|---|---|---|---|
| | Slope | D-excess | Min | Max | Min | Max |
| **Precipitation** | | | | | | |
| **At Kandi** | 7.85 | 5.82 | -16 | 5 | -128 | 38 |
| **In Plains** | 7.87 | 5.07 | -14 | 1 | -107 | 02 |
| **River Beas** | 7.57 | 8.56 | -7.3 | -6.6 | -44.0 | -41.0 |
| **River Satluj** | 6.75 | -2.61 | -11.0 | -10.0 | -74.0 | -69.0 |

For the interpretation of the isotopic data, the isotopic composition of surface water sources was compared with the corresponding values for the shallow and deep groundwater and accordingly, the recharge water sources for the shallow/deep groundwater were identified. The important inferences drawn from the comparison are given below-

- Compared to the river Beas, river Satluj water is more depleted in its isotopic composition ($\delta^{18}O$ & $\delta D$). Both the rivers originate at similar altitudes (river Satluj originates at 4570m above MSL from Lake Rakshastal whereas, river Beas originates at 4361m. above MSL from Beas Kund). The difference in isotopic composition develops as they receive discharge from their tributaries. River Beas gets inflows from several tributaries in the lower altitude before entering into the Bist Doab region and this alters its original (depleted) isotopic value. On the contrary, river Satluj receives relatively less discharge from low altitude tributaries and therefore, not much altering in its initial isotopic composition is seen. The difference in isotopic composition between the two rivers observed at the point of entry into the Bist Doab region (and also all along their stretch in the Bist Doab region) is effectively utilized in the present study to distinguish their contribution to the groundwater. Although, isotopic composition ($\delta^{18}O$ & $\delta D$) of precipitation and river Beas has an overlapping range, their D-excess substantially differs (as their moisture vapour traverse history from the point of the moisture origin is different). This difference in D-excess between the river Beas and precipitation is effectively used in differentiating their contribution to the groundwater.
- Shallow groundwater in the study area is formed mainly (approx. 90 %) through local precipitation.
- The river Beas recharges the groundwater during its flooding over a distance upto 3 km. The groundwater recharge through the river Satluj is negligible (in-fact, the river Satluj receives groundwater as base flow in most of its course in the region). Overall, about 9 % of the total study area falling along the eastern bank of river Beas contributes recharge to local groundwater.
- Although Bist Doab canal occupies the entire southern region of Doab, the effective canal occupied area that contributes recharge to groundwater is ~1% of the total study area.

In addition to stable isotope composition, environment tritium in groundwater is measured in groundwater to estimate the age of the groundwater. Environment tritium activity in the rain water was 9.2 TU, river water was 8 TU, average tritium in shallow groundwater was 5 TU (range: 2 to 8 TU) and average tritium in deep groundwater was 1 TU (range: 7.6 to 0 TU).

For estimating groundwater age, value of initial tritium activity was taken as the tritium activity of groundwater observed in the Kandi region (recharge zone). The important results and conclusion drawn from the tritium analysis are summaries below.

- In case of shallow groundwater; 17% of the study area (mainly in the northern region and along the Beas flood plain) occupies recent groundwater (age < 8 yrs.), 48% of the study area (mainly in the central region) occupies sub-modern (8-16 yrs. old) groundwater, 32% of the study area (Phagwara to Phillaur region) occupies moderately old (16-32 yrs.) groundwater and 3% of the study area (area close to Phillaur) occupies old (age > 32 yrs.) groundwater.
- In case of deep groundwater; 1 % of study area is occupied by recent groundwater (age < 10 years), 18% of the study area is occupied by sub-modern (10-20 yrs old) groundwater, 39% of the study area is occupied by moderately old groundwater (20-40 years age) and 42% of the study area is occupied by old groundwater (age >45 years).
- Age distribution of deep groundwater: Recent deep groundwater is mainly distributed at Ropar and Harike; sub-modern deep groundwater is distributed in parts of Kandi region (locations near Sansarpur and Dholbaha), in the central region (at Khurdpur) and near Harike; moderately old deep groundwater is distributed in 15-25 km width all along NW-SE direction along the foot hill and also in the central Doab around Jalandhar; and old deep groundwater is distributed in South central to end of SW of Bist Doab region and in the Kapurthala district.
- The age data and stable isotope data indicates that the river Beas is interacting with groundwater over a distance upto 2 km from its river bank. Recharge from Kandi region covers one third of the recharge area (~ 3000 sq km). This is a regional recharge zone for the Bist Doab region.
- The deep groundwater recharge zone occupies 5 % of the Kandi region (a few 100 sq km area).
- The groundwater leakage from shallow to deep aquifer is seen in the south eastern parts and at Khurdpur in central part of Bist-Doab. The shallow-deep groundwater interaction in area other than Kandi and Harike occupies <1% of the total Bist-Doab region. Therefore, withdrawal from deeper aquifer is not supported by means of connectivity with overlying shallow aquifer.

### 4.6.9 Isotopic Hydrochemistry

The observations drawn on the prevailing groundwater conditions using isotopic data also resembles with the groundwater chemical faces. The groundwater type in the recharge zone (Kandi region) in shallow aquifer is $MgHCO_3$ type. As this water moves southward, to Satluj flood plains, the groundwater age increases and it becomes $NaHCO_3$ type. At few locations close to the river Beas, it is $CaHCO_3$ type. Similar to shallow aquifer, deeper aquifer groundwater is $MgHCO_3$ type in the recharge zone (Kandi region) on increasing with age and approaching to central plains becomes $CaHCO_3$ type and with further increase in age towards river (Beas & Satluj) flood-plains becomes $NaHCO_3$ type.

### 4.6.10 Groundwater: Its Use and Management

The groundwater usage for irrigation in Bist-Doab region is taking place at a rate much higher than the recharge occurring both in shallow and deep aquifer. The groundwater recharge zones are distributed mainly in Kandi region. In the remaining area the recharge is taking place only in few patches. Except at few locations (other than Kandi region), the deep aquifer is not getting recharged from surface sources or shallow aquifers. Moreover, deeper groundwater in more than 60% of the region is older than 30 yrs. Therefore, if the exploitation of deeper aquifer continues, the groundwater reserve in the deeper aquifer may get exhausted. Thus, the present scenario of groundwater withdrawal is expected to risk the drinking water needs of the growing population. The groundwater in deeper aquifer is of good quality in entire Bist-Doab. Therefore, deeper aquifer groundwater needs to be protected from contamination (as the overlying groundwater has already showing signs of contamination) and this should be preserved for present and future drinking needs (otherwise this may go dry in few decades due to over-mining). Wherever possible, it should be rejuvenated. The variability in precipitation in space and time is very high and therefore, surface water reserve is also required to be created to protect the groundwater for drinking needs and surface water to save the crops. The topography and the available surface water sources (rivers, ponds, dams etc.) provide ample opportunity to reduce the growing pressure on groundwater resources if managed properly. Towards this, possibility of developing link canals connecting river Beas with Bist-Doab canal through Kali Bein and also interlinking Kandi Kanal with Bist-Doab canal exist to redistribute the river Beas water in the central Doab region where water demand is very high. After redistribution and use of surface water the remaining reach to its downstream at Harike Barrage through the available surface water links for its further convey to southern region and to Rajashtan through the Rajasthan feeder canal. The water resources can also be augmented through check dams to collect water discharge from ephemeral streams of Kandi region. (The possible canal link map and surface water storage locations are provided in the report). These along with artificial recharge measures and use of advance agriculture technology and soil water management measures can help to improve the overall quantity and quality of groundwater of Bist-Doab region. At government level, various steps can be taken up like; release of vision document & water policy, mass awareness programmes and online & real-time monitoring of groundwater resource etc. With long term management measures it is possible to rejuvenate the groundwater of Bist Doab region to its pristine quality and quantity.

Towards, intellectual output, the project has brought out publications in journals & conferences (2 in International Journals and 16 in conferences). During the project period under capacity building 1 Training Course, 1 Brain Storming Session, 2 Mass Awareness Programmes and one Regional Workshop was conducted, and through engaging project staff, trained 3 senior level and 3 junior level officers. The project has developed a strong link with the state water resource department and also with Punjab University, Chandigarh. The output from the project envisages a much broader scope in programme implementation, micro-detail analysis and conducting the similar R&D work in other parts of Punjab.

# 4.7 COASTAL GROUNDWATER DYNAMICS AND MANAGEMENT IN THE SAURASHTRA REGION, GUJARAT

*Principal Investigator :* *Dr. Anupma Sharma*

The work under the Research and Development Project has been carried out as per the details given below.

## 4.7.1 Objectives of the Project

Major objectives of the project are:

1. To characterize the various hydrologic components and establish their quantitative inter-relationships in the coastal aquifer system.
2. To identify causes of increasing groundwater salinity and its far reaching consequences on the coastal aquifer system.
3. To establish the physico-chemical mechanism of mixing of freshwater-saltwater in the coastal aquifer system of Saurashtra region.
4. To simulate the transport of saltwater in the coastal aquifer system through numerical modeling and study impact of existing aquifer management practices on the groundwater regime.
5. To develop a trade-off model for planning sustainable groundwater development program for different management strategies and evolve guidelines for optimal design of possible remedial measures.
6. To evaluate the impact of anticipated climate change on groundwater recharge and dynamics of coastal aquifer system and suggest suitable remedial measures.
7. Analysis of effect of water quality degradation due to saltwater intrusion on the socio-economic growth.
8. Rollover of project output to State Departments in Gujarat and concerned users in terms of technology transfer of technical know-how gained during the project for implementation of program for sustainable development of coastal groundwater resources.

## 4.7.2 About the Study Area

In the study, the coastal groundwater dynamics and saltwater intrusion phenomenon in the Minsar river basin (Figs. 7.1-7.2) of coastal Saurashtra has been under detailed investigation The river Minsar originates from the hills near village Jamvadi of Jamnagar district. It flow downwards and after covering 24 km meets the Dai river and 7.60 km from this junction meets the Bileshwari river near village Rana Khirasara. The catchment area of this river is partially hilly and partially plain. During the period 2001-2009, the maximum discharge of river Minsar has been 1387 $m^3/s$. The river is ephemeral carrying water mainly during monsoon season. In the upper catchment of the river, four reservoirs are present which store water for irrigation and drinking needs. These are, namely, Fodarna, Khambala, DaiMinsar and Kalindri.

The study area can be divided into (1) Barda Hills (2) Low lying flat mud land i.e. the Ghed area, and (iii) the coastal ridges. The geomorhological feature of Ghed area is such that it forms inland basin in shape of a saucer, due to relatively higher elevations of coastal ridge topography all along the coast line. During monsoon, heavy flood water comes from upstream area of Minsar river and accumulates in Ghed area. The Ghed area remains inundated and cut off from other parts of the region during monsoon. The reservoir formed due to construction of bandhara (solid masonary concrete walls) on Kerly Creek, stores fresh water and prevents seawater from encroaching landwards. These two schemes namely Kerly Tidal Regulator and Kerly Reservoir Scheme are shown in Fig. 7.1. On the other end of the study area, the region comprising Barda Sagar (refer Fig. 7.1) has been included in the region under investigation although this area falls beyond the watershed of Minsar river. This has been mainly done because the groundwater table contours near the coast continue into this extended region. The construction of a weir on Barda Sagar has led to availability of freshwater for irrigation in adjacent areas. Similarly the construction of spreading channels between Medha to Kindri creek (channel length 7.96 km) and Kindri to Kerly creek (channel length 21.06 km) have enhanced the recharge of groundwater and has made available the surface water to farmers for lift irrigation. The coastal ridge is considered as the deposition feature of beach sand and miliolitic limestone along the coast. The beach sand is recent deposition along the coast extending only about 50 m inland. The topography is generally undulating with ridges occurring parallel to sea coast. These ridges are exposed at a distance of upto 1-3 km inland from the coast. The height of these ridges with reference to msl varies between 4.5 m at Kantela village to about 12 m at Tukda village. Near the coast at higher elevations, where the ridges make stony waste lands, heights above msl vary between 11-29 m. The study area comprises of parts of five talukas: Rananav, Porbandar, Kutiyana, Jamjhodhpur and Bhanvad (Fig. 7.2). The geology of the region mainly comprises of milliolitic limestone, Gaj formation, laterites and alluvium in the coastal plains. The low-lying Ghed area is having channel fill deposits while in the upper inland areas weathered/ hard Deccan Trap is present.

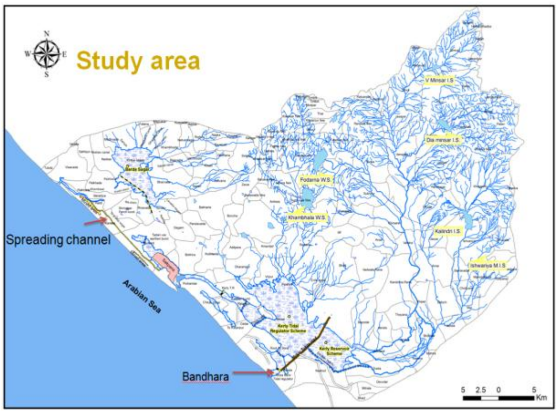


Figure 4.26: Drainage network in Minsar

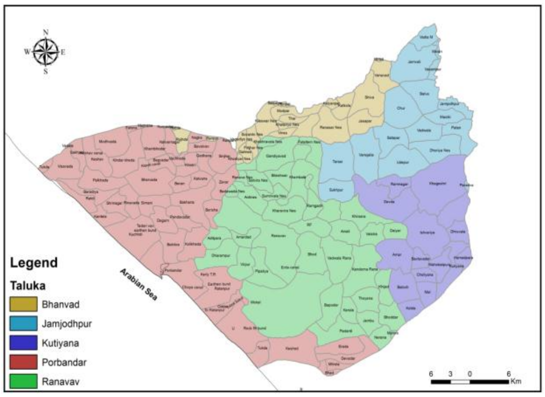


Figure 4.27: Taluka and village River Basin boundaries in study area

## 4.7.3 Study Methodology

### 4.7.3.1 Data Collection Tools and Methods

The massive data collection program was initiated by preparing a list of required data and related maps and reports to be collected from various departments. A total of nine Survey of India toposheets were obtained on 1:50,000 scale as follows: 41G/5, 41G/9, 41G/10, 41G/13, 41G/14, 41G/15, 41K/1, 41K/2, 41K/3. Satellite data IRS P6 (LISS III/ LISS IV) was procured from National Remote Sensing Centre (NRSC), Hyderabad, for the years 2004, 2009, 2010, 2011, 2012 and 2013 corresponding to the months January/February, March/April and October/November. Landsat imageries available on the net were also utilized. Long term meteorological data comprising daily rainfall, maximum and minimum temperature, relative humidity, wind speed and duration of sunshine hours were obtained from India Meteorology Department (IMD), Pune, for the years 1969-2005, and also from the State Water Data Centre (SWDC), Gandhinagar for the years 2006-2013. Data pertaining to irrigation schemes and land reclamation schemes, spreading channel, check dams, land use etc. were collected from various State Departments such as GWRDC, SIPC (Salinity Ingress Prevention Circle, Rajkot & Porbandar), CGWB (Central Ground Water Board, Ahmedabad), GSI (Geological survey of India, Gandhinagar), CDO (Central Design Organisation, Gandinagar) etc.

A total of 376 lithologs of dug wells, bore wells and piezometers were collected from GWRDC and CGWB. In addition, geophysical surveys were also carried out by GWRDC to gain additional information pertaining to geology and map the fresh/saline groundwater zones. Field experiments for estimation of parameters such as infiltration rates using double ring infiltrometer, saturated hydraulic conductivity using Guelph permeameter, pump tests etc. were performed in the field keeping in view the varying geological formations. Soil samples (both undisturbed and disturbed) and water samples of groundwater and surface water bodies for chemical and isotope analyses in the laboratory were also collected.

### 4.7.3.2 Frequency of Data Collection

An intensive monitoring program of groundwater level and water quality was launched in Minsar River Basin (Fig. 7.3). Initially 40 wells were selected for monitoring on quarterly basis and 26 wells were demarcated for monthly monitoring. Subsequently, the observation network was modified to monitor a total of 114 locations every third month that included collection of water samples from open wells, piezometers and surface water bodies such as spreading channel, creeks, reservoirs and Arabian Sea. Rainwater samples were also collected. Sites for installation of 16 piezometers were selected at strategic locations to monitor the groundwater level and water quality. The installation of these 16 piezometers by

GWRDC was completed in February 2011. These piezometers which were part of the observation network were regularly monitored.

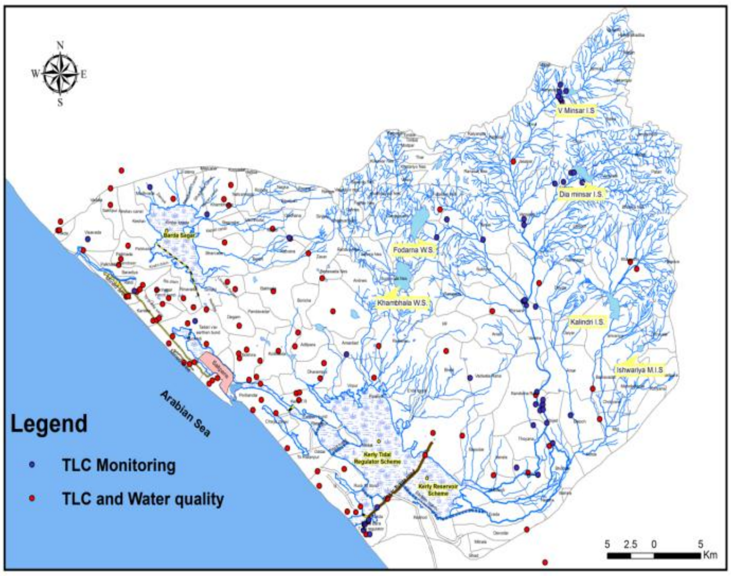



Figure 4.28: Observation network in Minsar River Basin

#### 4.7.3.3 Water Sampling Techniques

For evaluation of groundwater and surface water quality, groundwater samples and samples from surface water bodies including Arabian sea and fresh rainwater were collected. Samples were collected in 1-litre capacity polythene bottles. Prior to sampling, these bottles were thoroughly washed with diluted $HNO_3$ acid and then with distilled water and also rinsed thrice with the respective groundwater to be sampled. Each sample collected was recorded and identified with a unique sample number marked on each bottle. The samples were analysed for following parameters: physical parameters - pH, EC, TDS; chemical parameters - sodium ($Na^+$), potassium ($K^+$), total hardness (TH) as $CaCO_3$, calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), chlorides ($Cl^-$), sulphates ($SO_4^{2-}$), nitrates ($NO_3^{2-}$), flourides ($F^-$), alkalinity, carbonates($CO_3^{2-}$), and bicarbonates ($HCO_3^{2-}$). Portable pH and EC meters were employed to measure physical parameters, such as pH and EC, on site. Chemical parameters were analysed in the Water Quality Laboratory at NIH Roorkee. $Na^+$ and $K^+$ were determined by Flame Atomic Absorption Method; alkalinity, $CO_3^{2-}$, $HCO_3^{2-}$, TH, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$ were analyzed by EDTA titration method; $SO_4^{2-}$ was estimated by turbidity method; whereas $F^-$ and $NO_3^-$ by spectrophotometer in the laboratory. Analytical precision for measurements of cations and anions, indicated by the ionic balance error (IBE), was computed on the basis of ions expressed in meq/l. The value of IBE was observed to be within a limit of ±5%. The precise locations i.e. longitudes and latitudes of sampling points were also determined in the field through Global Positioning System (GPS). In addition, two portable TLC meters were utilized to monitor the salinity profiles inside individual wells. To collect high frequency data of groundwater levels, CTD divers (data loggers) were installed in three piezometers located in a profile perpendicular to the coast to monitor the impact of tides on groundwater levels. The nearest piezometer was located only 50 m from the coastline and exhibited the maximum impact of tides on the groundwater level

#### 4.7.3.4 Socioeconomic Surveys

In addition, surveys were carried out to investigate the impact of groundwater salinity and the water conservation measures introduced in the area on the socio-economic conditions of the local population and farmers in the coastal belt of Minsar Basin. For this purpose, a questionnaire sheet was worked out for carrying out the socio-economic survey.

### 4.7.4 Data Analysis

#### 4.7.4.1 Development of Base Maps and DEM

An integrated database of the study area has been developed on ArcGIS 9.3. Initially, the Minsar River Basin was demarcated and digitized from toposheets of scale 1:50,000. Subsequently, the drainage network, coastline and existing water bodies such as creeks, reservoirs, marshy areas, percolation tanks etc., locations of bandharas, embankments, checkdams etc. were digitized (refer Fig. 7.1). All the administrative boundaries i.e. the taluka and village boundaries were also digitized (Fig. 7.2). A digital elevation model (DEM) was developed by using SRTM data and digitizing elevation contours and spot heights from toposheets of scale 1:50,000 (Fig. 7.4). Daily rainfall for the period 2001-2013 was collected for 11 raingauge stations for the study area. To compute the average rainfall over the study area, Thiessen polygons were drawn and monthly average rainfall values were computed.

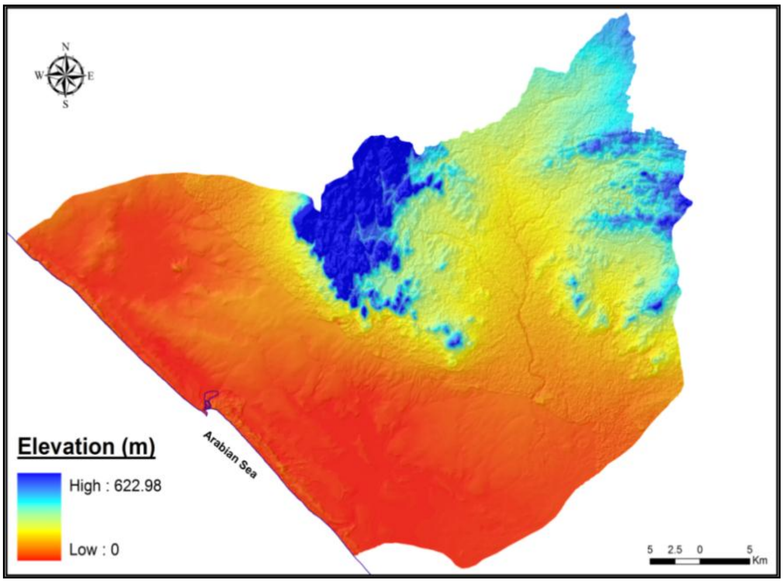



Figure 4.29: DEM of Minsar River Basin

### 4.7.4.2 Land Use Classification

The satellite data procured from NRSC was employed to study the total area under cultivation during Kharif and Rabi seasons. The main Kharif crops are groundnut, jawar, cotton, bajra, while the main rabi crops are wheat, jeera, jawar, maize, cotton. Figure 7.5 shows the general landuse pattern in the study area. The figure also illustrates the low-lying area near Kerly creek that gets flooded during monsoon season. Figure 7.6 illustrates the crop area under Kharif and rabi seasons.

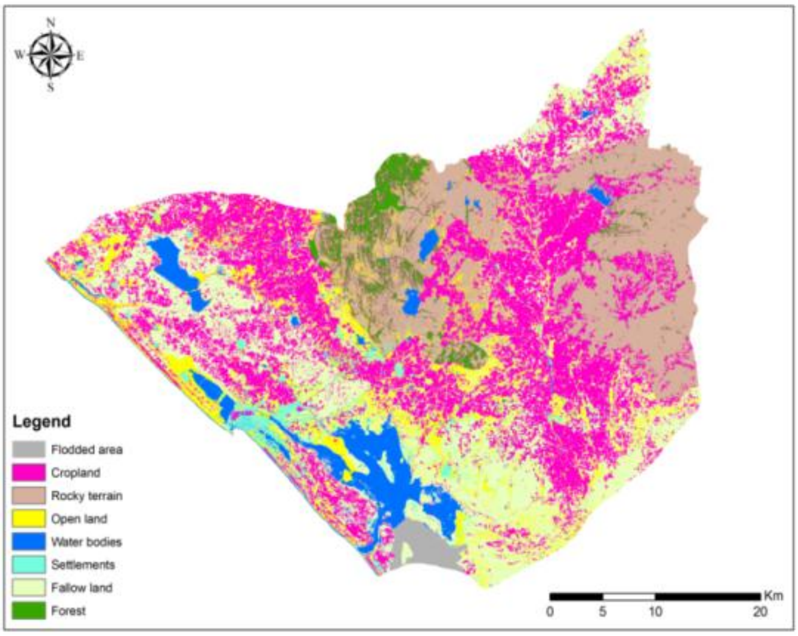



Figure 4.30: General landuse in the study area

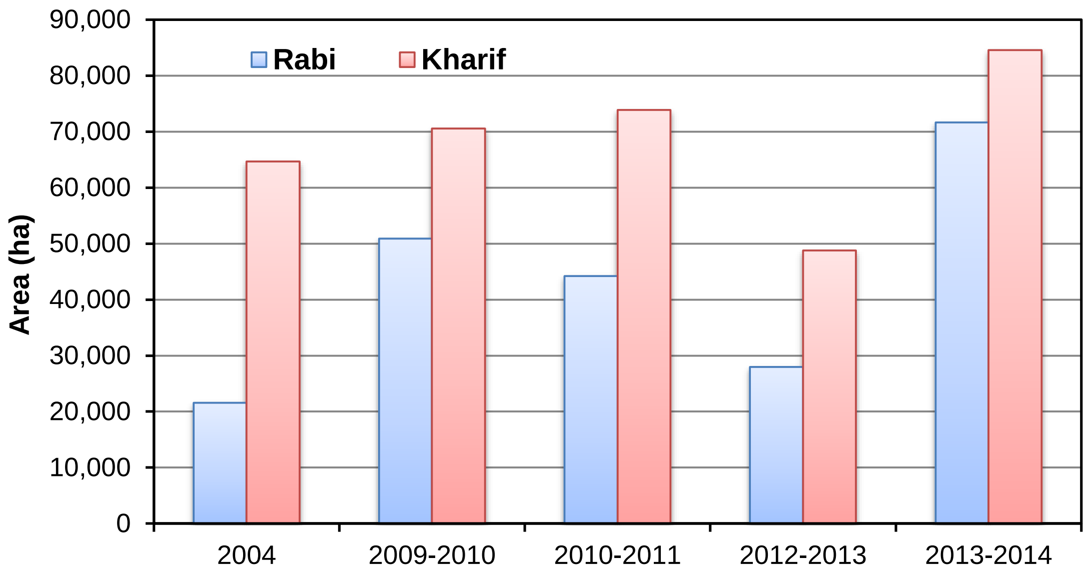



Figure 4.31: Crop area under Kharif and Rabi seasons

The satellite data was further used for ascertaining the water spread area of different reservoir schemes in study area. Figures 7.7(a)-(b) show the variation in water spread area of reservoirs namely Kerly, Barda Sagar, Fodarna, Khambala, Dia Minsar and Kalindri. These figures illustrate that during the pre-monsoon season (Fig. 7.7(a)), the water spread area of all reservoirs is minimum. Water spread area of Barda Sagar reservoir is almost nil. During post-monsoon 2009, the satellite data shows maximum water spread area of reservoirs.

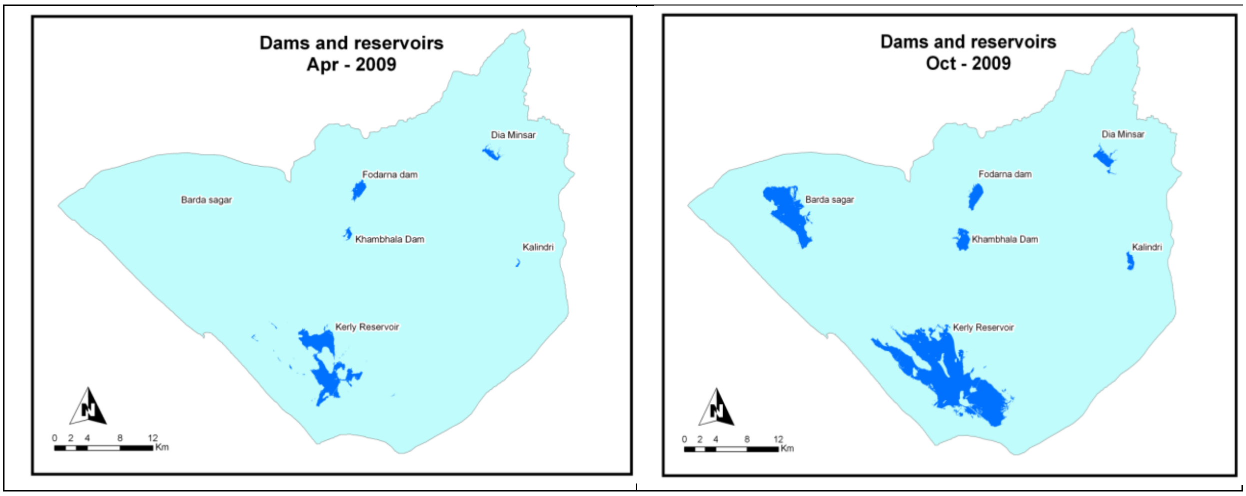



Figure 4.32: Reservoir water spread area in (a) Apr 2009 (pre-monsoon) (b) Oct. 2009 (post-monsoon)

### 4.7.4.3 Geology of Minsar River Basin

The geological formations range from Deccan trap lava flows of Paleocene to Cretaceous age to recent alluvial and windblown deposits. The geological formations are broadly igneous lava flows, marine deposits and alluvial deposits. The area is covered by milliolitic limestone of Pleistocene age all along the coastal line and alluvium of recent age (locally the Ghed area). Gaj limestone and clay underlying these formations are not exposed anywhere except around Pipaliya village where these are directly overlying Deccan basalts. Exposures of Gaj formations are also seen between Porbandar and Kindari Creek along the coast.

### 4.7.4.4 Development of Fence Diagram

Geology of the area has been broadly categorized as: Deccan traps, limestones, Gaj formations and alluvial deposits. A total of 376 lithologs of dug wells, bore wells and piezometers were collected from GWRDC and CGWB. These were processed and analyzed using the Rockworks software. The generated fence diagram is shown in Fig. 7.8. The principal source of groundwater is the unconfined milliolite limestone aquifer, which supplies water for settlements along the coastal belt. In the coastal belt, open and shallows bore wells are suitable structures for groundwater development as salinity is encountered at depth. Alluvial deposits include soil, coastal sand, and sand dunes, marshy lands, and, mud, gravel and kankar beds. The mud is restricted to the depressions and creeks where the water remains stagnant. The Gaj formation in the area is formed from intercalation of clay layer in limestone. In general, groundwater in this formation is brackish due to the inherent salinity of the formation.

Geological cross-sections constructed parallel to the coast reveal that all along the coast, milliolite limestone, with a thin cover of top soil, is underlain by Gaj limestone formations. Farther away from the coast the limestone is underlain by weathered trap and hard trap. In the inland area of Minsar basin, the limestone formations are relatively thinner and the weathered trap and hard trap are encountered below the limestone formations at comparatively shallower depths. In some areas the limestone formations are missing and weathered trap is encountered below the top soil cover. Cross-section constructed perpendicular to the coast shows the variation in thickness of limestone formation from seaward side to landward side, in general. The reported maximum thickness of limestone is 45m.

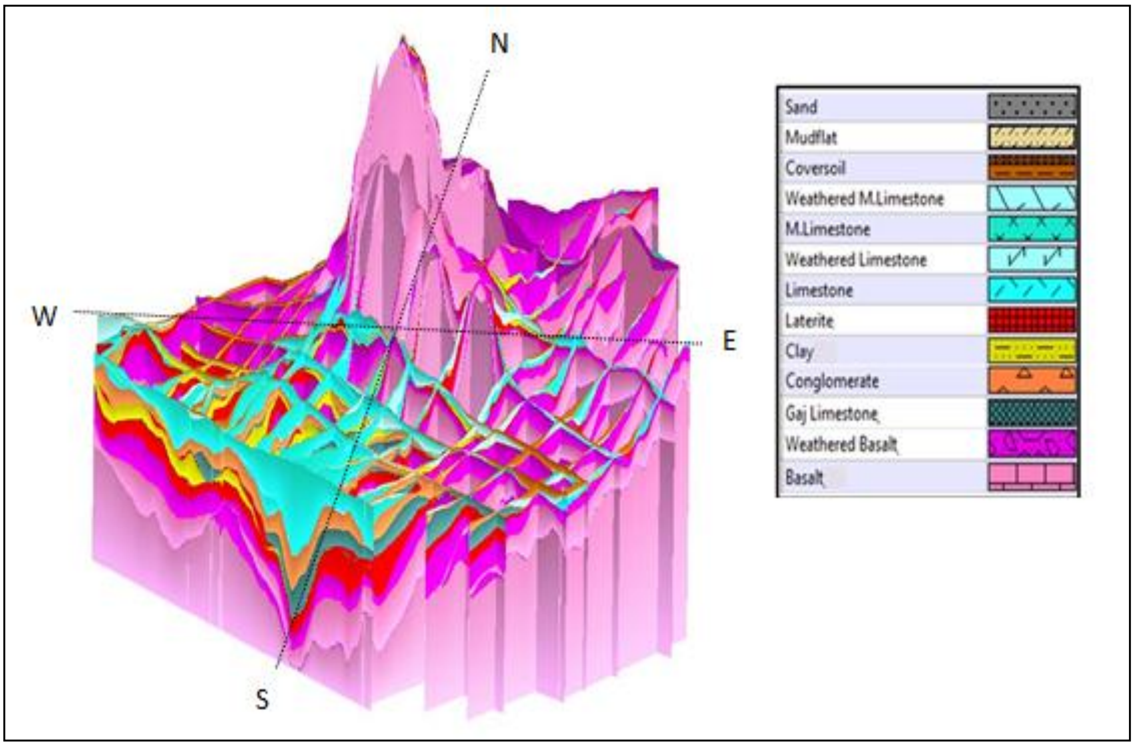



Figure 4.33: Fence diagram of study area

#### 4.7.4.5 Groundwater Levels and Groundwater Movement

Maps of water table elevation between 1985 and 2013 drawn using water level measurements in open wells and piezometers indicate that groundwater in the aquifer system during both pre- and post-monsoon generally flows from the upland areas towards the seaward side (Fig. 7.9(a)-(b)). During pre-monsoon, there is significant decline in the water table in areas near the sea coast. Due to scanty rainfall in the year 2012, the decline in water table of pre-monsoon 2013 was more severe (Fig. 7.9(a)). Due to the lowered water table near the coast, a reversal of gradient is observed in the coastal strip during the pre-monsoon period, and leads to flow of seawater in the landward direction

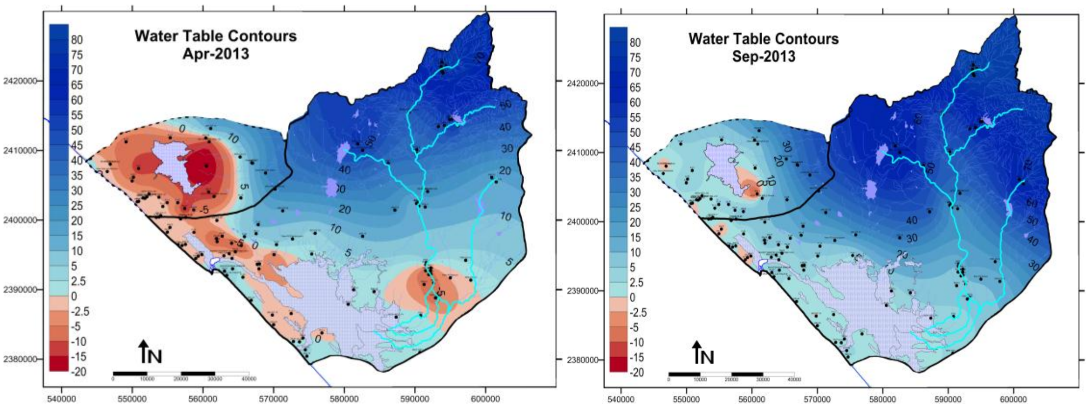



Figure 4.34: Water table contours 9a) April 2013, (b) Sept. 2013

### 4.7.4.6 Groundwater Recharge and Discharge

Recharge to the aquifers occurs primarily as infiltration of precipitation and streamflow from Minsar River and its tributaries. The foothills of Barda hilly area are a major zone of groundwater recharge. As a result of agricultural and urban development, groundwater pumping is an important source of discharge from the study area. Most of the wells are less than 30 m deep except in upland area. Groundwater pumping in excess of recharge causes decline in water levels and salinewater ingress in the coastal belt. In hard rock areas, groundwater availability is limited and is confined to weathered zone, cracks and fractures only. The creeks in the coastal belt are subject to tides twice a day so that tidal water encroaches inland resulting in wells near these tidal creeks to turn saline due to ingress of tidal waters. As a result of over-withdrawal of fresh water in the region, larger number of wells turned saline affecting agricultural land and crop production. To prevent the tidal ingress into the coastal land, bandharas across the mouths of these creeks have been constructed. The cut off of these structures is taken to relatively impervious strata to prevent tidal ingress/ seawater seepage into coastal land and contaminate fresh groundwater. The freshwater reservoir created behind the structures is used for irrigating the adjacent land through lift irrigation. It also results in increased recharge to groundwater through the command area. The reservoir water not only improves the water quality of wells in surrounding areas but also aids the leaching out of salts in saline soils through use of freshwater for irrigation.

### 4.7.4.7 Groundwater Balance

The estimation of groundwater balance of a region requires quantification of all individual inflows to or outflows from a groundwater system and change in groundwater storage over a given time period. The basic concept of water balance is:

*Input to the system - outflow from the system = change in storage of the system*
*(over a period of time)*

Water balance for the whole study area was carried out by dividing the area into a number of zones as per the village boundaries. The study area comprises of 138 villages in five talukas. The average rainfall for the study area is around 650 mm. Water balance on monthly scale for the study area has been carried out for both normal rainfall years (2010-2011, 2011-2012, 2013-2014) and drought year (2012-2013). Different hydrologic components computed for water balance are as follows:

- ***Inflow components***
  - Recharge from rainfall
  - Recharge from surface water bodies (checkdams, percolation tanks, spreading channel, reservoirs/irrigation schemes)
  - Irrigation return flow (from surface water and groundwater irrigated areas)

- ***Outflow components***
  - Groundwater draft
  - Evapotranspiration from shallow water table
  - Base flow
  - Submarine discharge

The detailed water balance computations were based on GEC norms. For the purpose of computing recharge from surface water bodies, following data pertaining to study area was taken into account: 5 irrigation schemes, 2 water supply schemes, 113 checkdams, 67 small and medium percolation tanks and 22 km long spreading channel. These structures provide ample opportunity for groundwater recharge. During water balance calculations, each structure was considered for recharge computations. For computing groundwater draft, the data for the total number of electrified wells in each village with capacity of electric motors was utilized. This data was obtained from Gujarat Electricity Board (GEB). In addition, crop water and irrigation water requirement were also computed for each crop grown in different seasons.

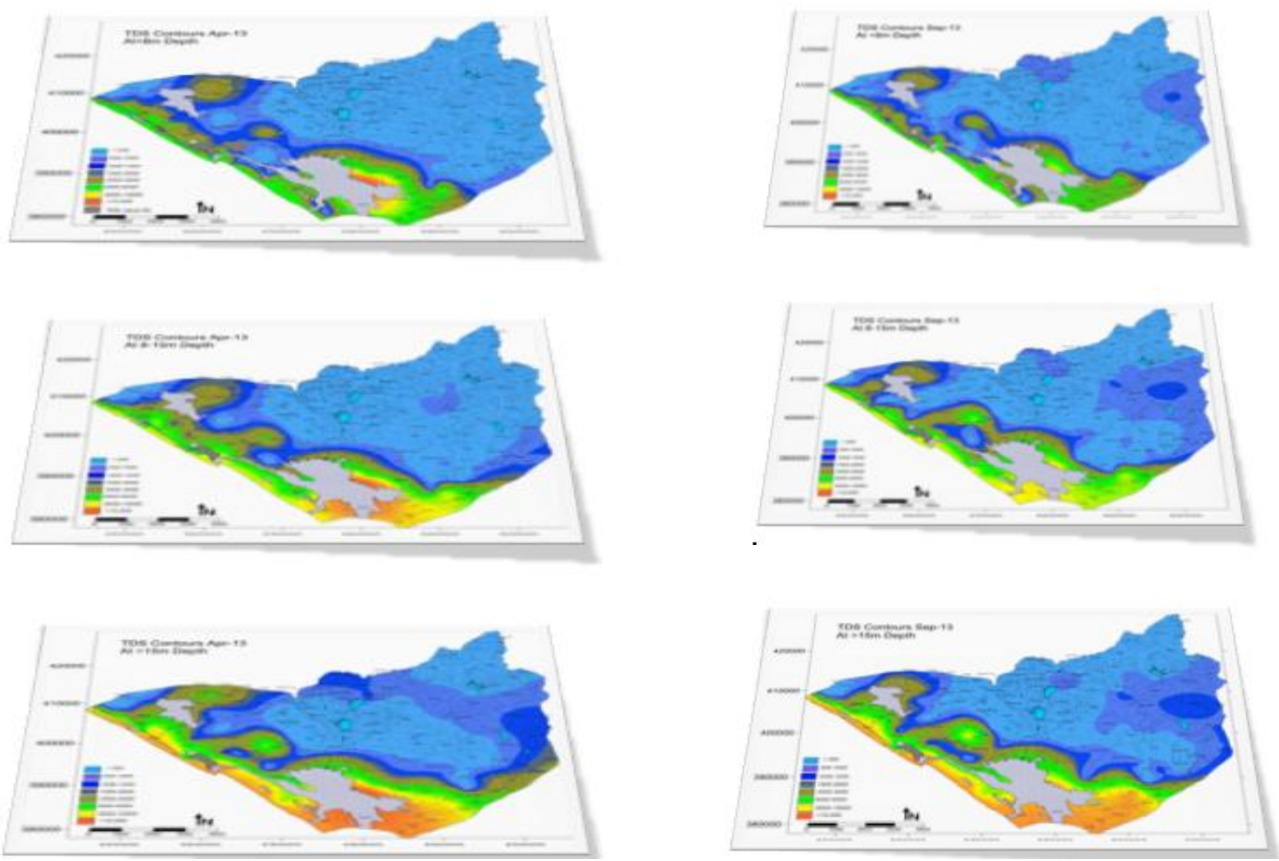
#### 4.7.4.8 Groundwater Chemistry

The chemistry of water in aquifers underlying the Minsar Basin is controlled by several factors, including the chemistry of the natural recharge water and the geochemical reactions that occur within the aquifer system. Intruding seawater, mixing with water from surrounding and underlying deposits, or mixing with water from estuarine deposits near Arabian Sea, also may alter groundwater chemistry, increase chloride concentrations, and degrade the quality of groundwater. In this study, groundwater chemistry is evaluated on the basis of major-ion data to determine native groundwater quality, the sources of high-chloride water to wells, and the geochemical reactions that occur within aquifers underlying the Minsar Basin. Most samples collected as part of this study were from domestic or irrigation well discharges and piezometers installed during the study. These samples from wells integrate, usually in unknown proportions, water that entered the well throughout the entire screened interval into a single sample, except for piezometers in which the screen has been kept short.

The TDS data recorded at different depths in the observation wells and peizometers indicates that the TDS varies depth wise in the region. At increasing depths, TDS was found to increase and vice versa (Fig. 7.10(a)-(b)). Pockets of fresh groundwater are present near the seacoast due to flushing/ displacement of saline water by percolating rain water. Groundwater circulates through porous limestone; however, its downward movement is arrested by impervious Gaj sediments and Deccan traps.

### 4.7.4.9 Physico-Chemical Mechanism of Mixing of Freshwater-Saltwater

Geochemical processes occurring within the groundwater and reactions with aquifer minerals have significant impact on water quality. These geochemical processes are responsible for the seasonal and spatial variations in groundwater chemistry. In the present study, 117 monitoring locations were spread over the four zones of the region viz. Zone I, Zone II, Zone III and Zone IV for monitoring of groundwater salinity. For water quality analysis, 70 locations spread over the study area (Fig. 7.11) were selected.



(a) Pre-monsoon 2013 (b) Monsoon 2013

Figure 4.35: Spatial distribution of TDS in pre-monsoon and monsoon season at different depths

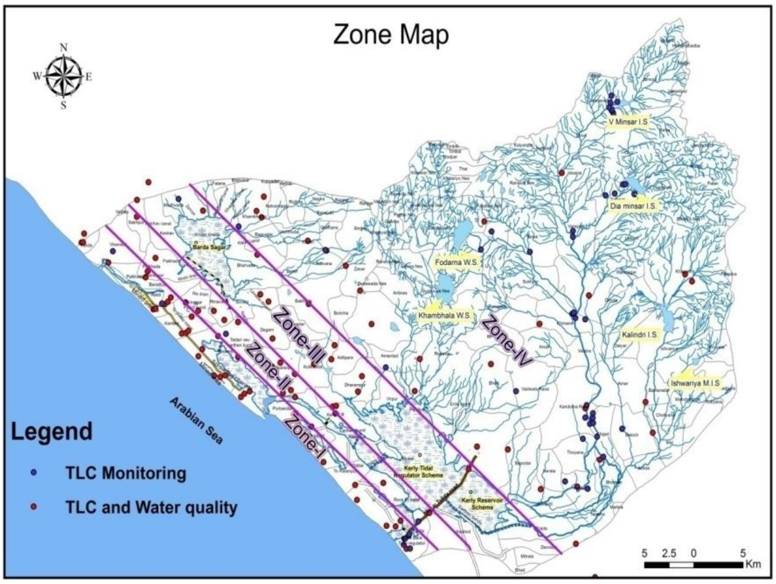
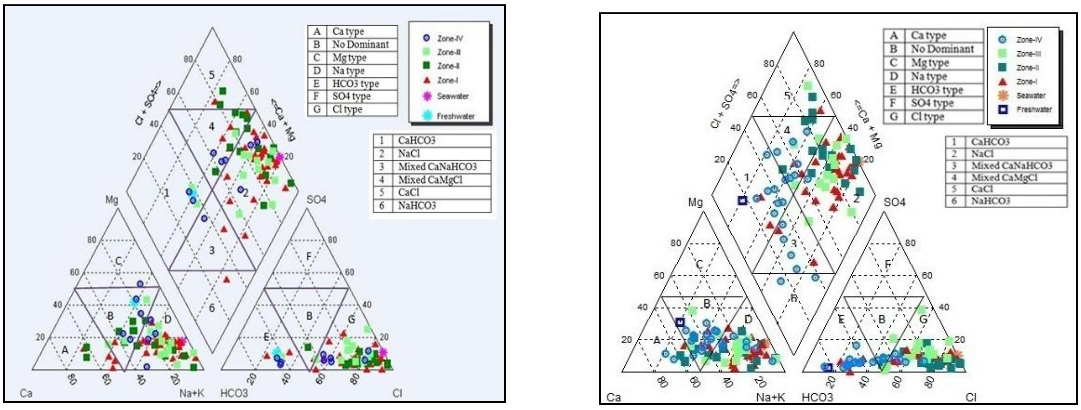



Figure 4.36: Zones demarcated in study area for studying water quality changes

Chloride concentrations in groundwater ranged from 78 to 20,714 mg/L. For comparison, the chloride concentration of seawater is about 19,000 mg/L. High chloride concentrations are not unusual in shallow groundwater along the coast. These high chloride concentrations result from evaporative concentration of seawater in shallow creeks prior to deposition or from the dissolution of chloride salts remaining after the evaporation of seawater or discharging ground water. Most of the sampled wells (about 85%) have chloride concentrations greater than desirable limit of 250 mg/L. Water from some wells having high chloride concentrations may also result from mixing with high-chloride water from underlying partly consolidated deposits or from mixing with high-chloride water from estuarine deposits. Nitrate concentration in water from wells was detected on the higher side mostly in wells located in cultivated lands, near Porbandar city or populated areas. The order of dominance of the cations of the study area in general is is Na > Mg > Ca > K and of the anions is Cl > HCO3 > SO4 > $NO_3$.

The results from the water analysis were used as a tool to identify the sources and operative mechanisms in the study area. The average concentrations of TDS, Na, Ca, Mg, and Cl ions decrease with the distance from the sea coast. Other parameters like $HCO_3$, $SO_4$, $NO_3$ and F concentrations have not followed any increasing or decreasing trend from the sea coast. Piper diagram (1994), used to identify the facies of groundwater as well as the geochemical processes along the flow path of groundwater, was plotted by taking the concentration of different ions from the study area (Fig.7.12).




**(a) Pre-monsoon 2013** **(b) Monsoon 2013**

Figure 4.37: Piper trilinear diagram of pre-monsoon and monsoon season of study area

The plots shows that most of the samples for Zone I and II analyzed during pre-monsoon and monsoon seasons fall in the field of mixed Na-Cl and Ca-Mg-Cl type with minor representations from mixed Ca-Mg-$HCO_3$, Ca-Na-$HCO_3$ and Ca-Cl type while for Zone III samples fall in the field of Na-Cl and Ca-Mg-Cl type with minor representations from mixed Ca-Cl and Ca-$HCO_3$ type. For Zone –IV samples found to be fall in the field of mixed Ca-Mg-Cl and Na-$HCO_3$ type with minor representations from Na-Cl and Ca-Na-$HCO_3$ type during pre monsoon season while in monsoon season, samples fall in the field of mixed Ca-Mg-Cl, Ca-HCO3 and Ca-Na-$HCO_3$ type which shows freshening of water due to dilution effect of rainfall.

#### 4.7.4.10 Numerical Model of Coastal Aquifer System

The numerical model of the coastal aquifer system has been developed using the finite-difference based SEAWAT2000 ver 4 model of the USGS, which accounts for variable density flow. The flow model has been developed using the shapefiles and data generated during extensive data processing in ArcGIS, Excel and Surfer software described in previous sections. The stratigraphic layers were prepared using the fence diagram developed in Rockworks software. The top elevation of the uppermost layer coincides with the DEM of the study area. The aquifer parameter values were initially assigned using the parameter values computed by analying pump test data using the AquiferTest software (Fig. 7.13). Initially the calibrated model with coarse grid was used to generate flow patterns for the Minsar River basin (Fig. 7.14). Subsequently, SEAWAT2000 has been employed to simulate saltwater transport in the coastal zone of the Minsar River basin with a finer grid. To evaluate the management alternatives, the impact of the two irrigations schemes in coastal area, namely Kerly and Barda, and pumping from public supply wells (Fig. 7.15) was also studied.

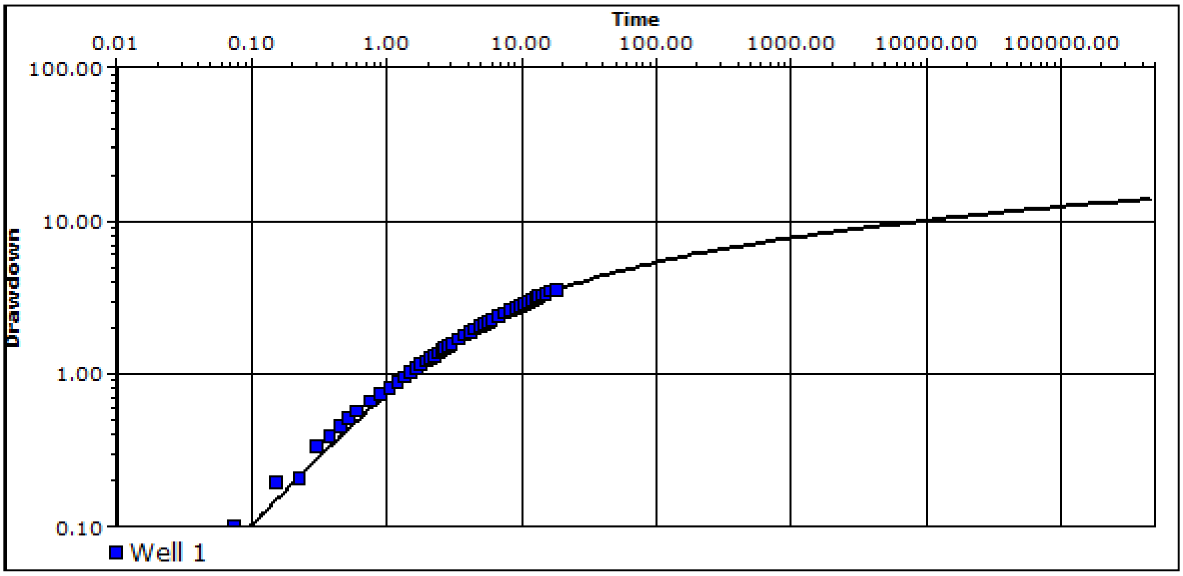



Figure 4.38:Analysis of pump test data for village Aniali using Papadopulos and Cooper's method

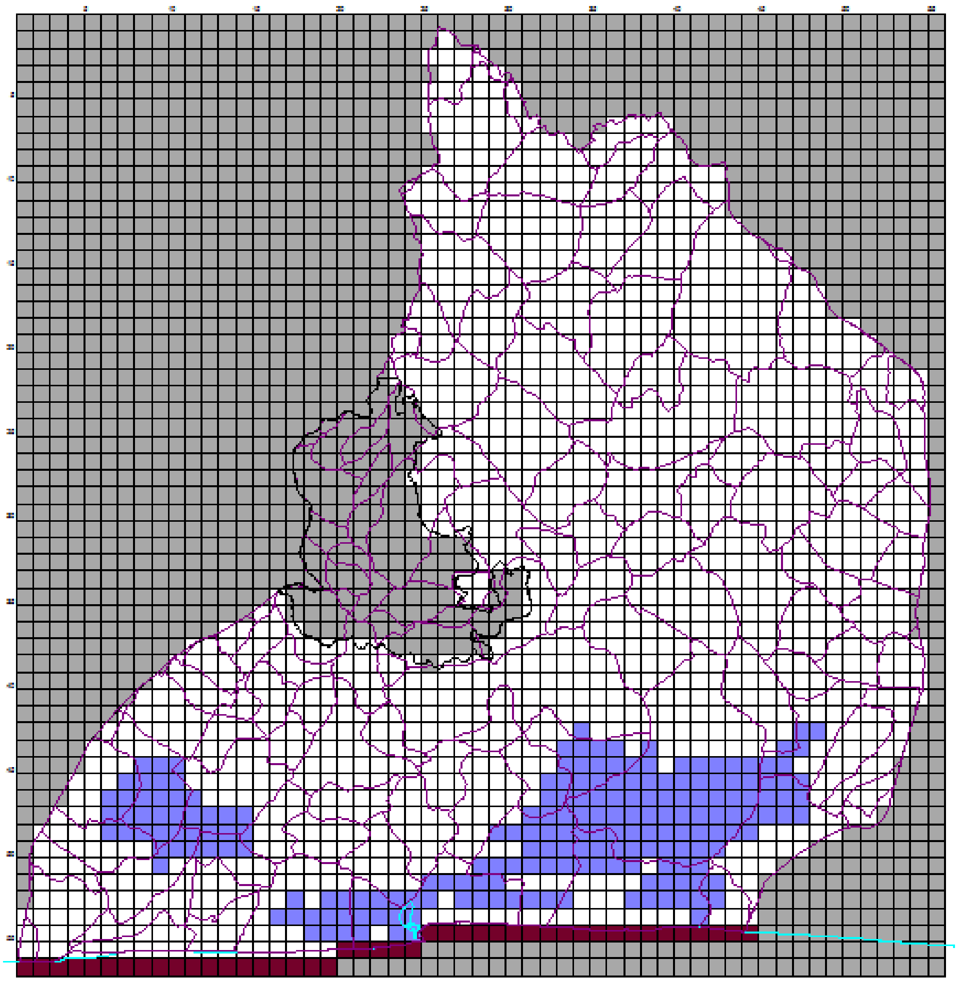


Figure 4.39: Numerical modeling of groundwater flow in Minsar River Basin

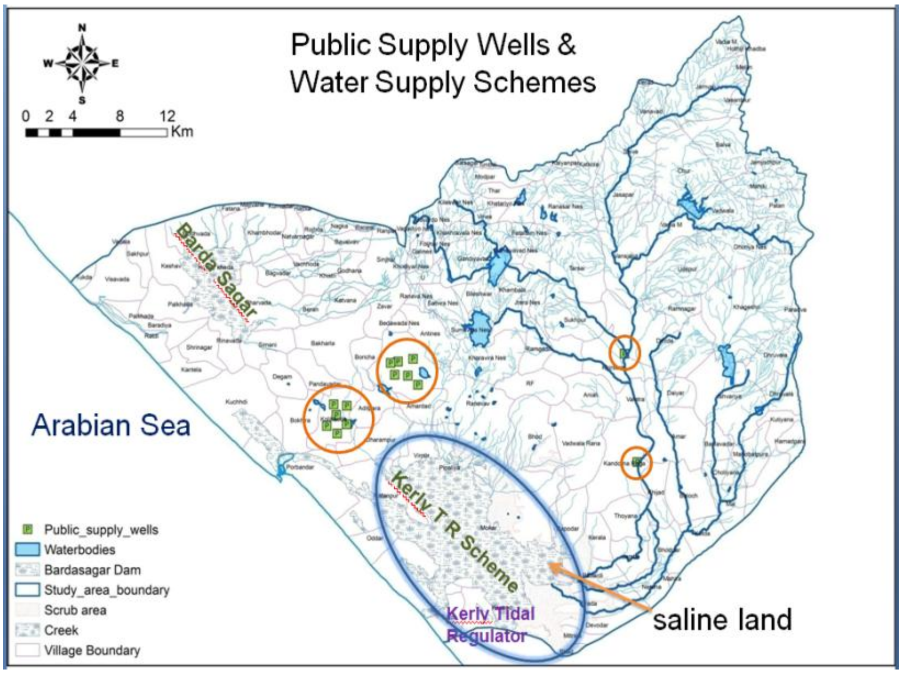



Figure 4.40:Irrigation and public water supply schemes in Minsar River Basin Impact

Anticipated Climate Change on Groundwater Recharge and Dynamics

Climate change impacts on the Minsar River Basin can be categorized into two sub-components:

- Impacts on surface water: This includes variation in surface runoff, stream-flow and water storage in different reservoirs.
- Impacts on groundwater: This includes change in inter-relationship between surface and groundwater and resulting changes in groundwater recharge pattern.

Therefore, these impacts have been studied as per the following methodology:

1. Preparation of observed climatic data series for base line period (1960-1990)
2. Downloading of GCM (General Circulation Model) data for the study area.
3. Developing inter-relationship between local observed and global climatic data through statistical techniques using SDSM (Statistical Downscaling Model) package. This includes calibration and validation of the developed statistical model.
4. Using the developed statistical model, downscaling of future climatic variables for the study area under different future scenarios (low emission and high emission scenarios)
5. Application of numerical groundwater model to study the impact of changes in climatic variables.

Base line period is considered for years 1961-1990. Figures 7.16-7.17 show the observed and modeled daily mean precipitation using the statistical model and the projected precipitation under A2 scenario of HadCM3 GCM.

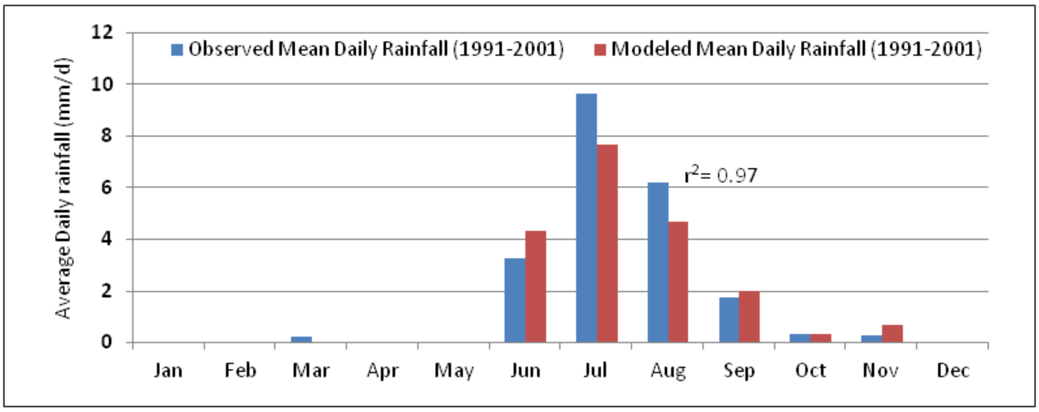



Figure 4.41: Graph showing observed and modeled daily mean precipitation

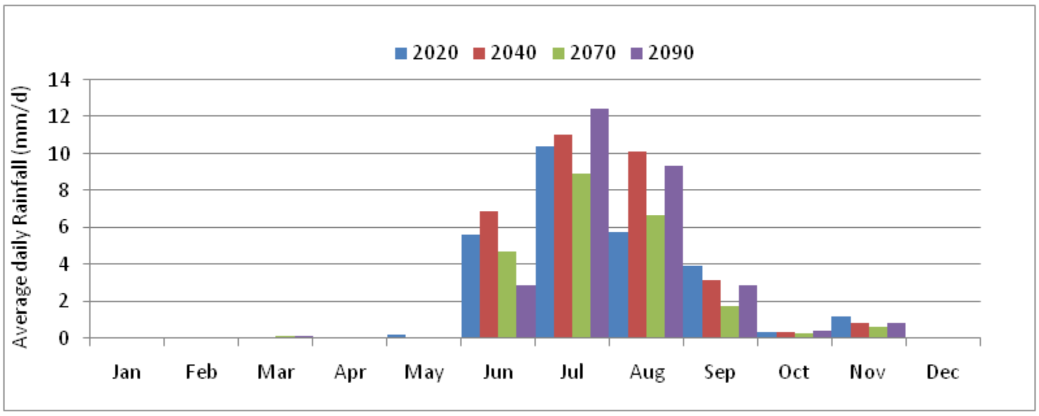



Figure 4.42: Projected precipitation under A2 scenario of HadCM3 GCM

The projected variables have been applied to the groundwater numerical model to study the impact on groundwater recharge in the coastal aquifer.

#### 4.7.4.11 Effect of Water Quality on the Socio-Economic Growth

To investigate the effect of water quality degradation in the coastal zone and the impact of salinity prevention schemes during the last decade, socio-economic surveys were carried out. This study involved the integration of remote sensing techniques and socio-economic survey within a GIS framework. Total geographical area covered in this report is 1749 km$^2$ in which 138 villages of 5 talukas are covered. To evaluate the impact of salinity on socio-economic and environmental status of the study area, a survey was conducted within a distance of 20 km from coast (refer Fig.7.18). Detailed socio-economic survey was conducted in coastal villages with the help of a structured schedule and personal interviews with the local people in the study area and the following details were collected

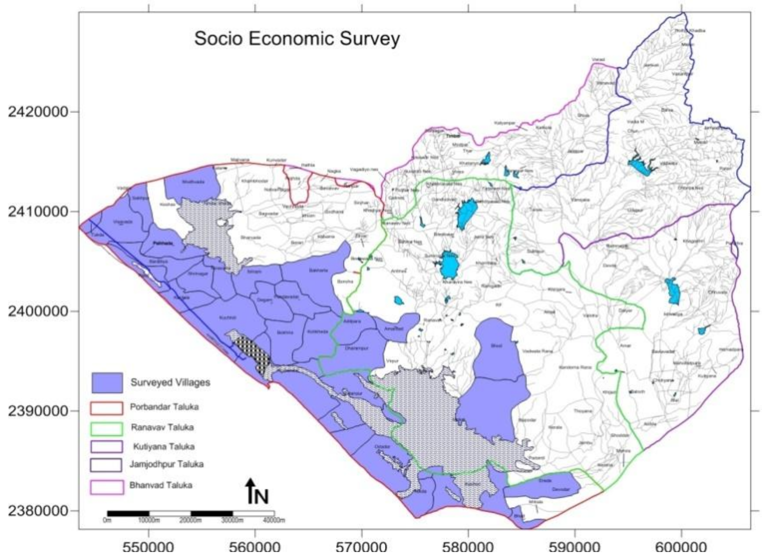



Figure 4.43: Villages covered under socio-economic survey

The coastal villages have both surface and groundwater resources which are used for agriculture production and drinking water but the surface water resources are limited up to the monsoon season. It was noted that open wells are still an important source of water for majority of the households near the coast line villages despite groundwater salinity.

In 1970's, the coastal villages were worst affected by the saltwater ingress from the sea as well salinity in the inland Ghed areas which was reflected by reduction in agricultural activity. Effect of salinity was so severe that people were migrating from rural areas to nearby urban areas and depended less and less on agricultural land for their livelihood. To avoid such socioeconomic imbalance in the area, Government of Gujarat implemented several mitigation measures to combat the problem. The salinity ingress prevention cell (SIPC) set up by the Government of Gujarat under the irrigation department invested in building structures like tidal regulators, bhandharas, checkdams, spreading channels and reservoirs for recharging groundwater and controlling the salinity.

#### 4.7.4.12 Changes in cropping pattern

As an outcome of improvement in groundwater salinity and additional availability of surface water on account of salinity prevention schemes, cropping pattern in the study area has changed during the last three decades. Food grain crops were important in 1970s, but later on non-food grain crops have become dominant. In the cultivated area, coarse cereals like jowar and bajra have been replaced by cash crops such as oil seeds (castor, groundnut), cotton, spices (jeera) and horticultural crops (brinjal, chilly, onion, etc.). Major expansion in irrigation, water management, implementation of drip and sprinkler irrigation, providing

Kisan Credit Cards and Soil Health Cards for farmers in the past years have spearheaded agriculture economy towards inclusive growth.

### 4.7.5 Technology Transfer Activities

During the project, three training courses targeted on the subject of coastal aquifers have been organized jointly by NIH Roorkee and GWRDC Gandhinagar at following locations:

- Anand (Gujarat) in November 2010 for State Department Officers from coastal HP-II states
- Rajkot (Gujarat ) in March 2013 for State Department Officers from Gujarat
- Ahmedabad (Gujarat) in March 2014 for State Department Officers from coastal HP-II states.

### 4.7.6 Conclusions

Extensive field tests and surveys, laboratory experiments, and data monitoring were carried out in Minsar River Basin to investigate the dynamics of the coastal aquifer system. These investigations were supplemented by numerical modeling exercises utilizing the database generated during the study and historical records collected from various agencies. Groundwater is a major source of irrigation in the study area; however severe levels of salinity exist at deeper depths in the coastal zone in proximity to the Arabian Sea. It was found that groundwater salinity occurs both on account of lateral ingress of saltwater from the sea and inherent salinity of the Gaj formations. Further landward movement of salinity is curtailed by the larger gradient of groundwater head in the upland area directed towards the sea. This gradient existing in both pre- and post-monsoon seasons effectively limits the freshwater-saltwater interface in the coastal zone. The salinity mitigation measures adopted in the region during the last two decades have been successful in enhancing the socio-economic growth of the region.

# 4.8 A COMPREHENSIVE ASSESSMENT OF WATER QUALITY STATUS OF KERALA STATE

*Principal Investigator :* *Dr. B.K. Purandara (from NIH)*

## 4.8.1 Introduction

The development and management of the water resources of a region has to be evolved together with that of land and biomass, giving due weightage to the specific socio-economic and environmental features. Kerala is having both abundance and scarcity as far as water resources is concerned. Though it has 44 so called rivers, most of them are monsoon fed and dry up during summer. Kerala is having the maximum density of open wells, but several of them do not yield during summer.

Salinity propagates not only to the downstream reaches of rivers but also into the groundwater aquifers of the thickly populated coastal belt. The estuaries near the industrial areas and thickly populated towns and cities are facing pollution problems, which becomes all the more severe by the reduction in summer flows.

The groundwater issues of the aquifers of the State are location specific and time variant. Hence, in order to achieve sustainable utilization and management of groundwater resources in terms of both quality and quantity, it is essential to establish a groundwater information system with all relevant components for easy visualization, access, retrieval and utilization.

Topographically, Kerala is divided into three distinct geomorphic zones. The highland zone is defined as the area covered by the altitudinal zone with elevation greater than 75 m above mean sea level. The midland region falls between altitudinal zones between 7.5 and 75 m. The coastal land is characterised by lagoons and ancient or modern dunes with altitudes upto 7.5 m above mean sea level.

The total land area is geologically more or less monotonous. The highland zone i.e., western ghat zone-is formed by the oldest rocks of Pre-cambrian age, belonging to the granulite facies of metamorphism. Charnockite, geneisses, basic dykes, quartz and pegmatitie veins are typical of the Pre-cambrian rocks. Most of these rocks are very rich in elements like O, Si, Al, Fe, Ca, Na, K, Mg in the order of abundance.

These rocks have undergone weathering and have transformed themselves into laterite. Laterite in Kerala coastal belt has also formed out of the transformation of sedimentary rocks of Tertiary age, and occurs as cappings. Further weathering of laterite has given rise to lateritic soil. Laterite is very rich in either oxides of iron or aluminium, and in the latter case sometimes qualifies as an ore of Aluminium. In the midland zone large and extensive outcrops of laterite derived from the Precambrian rocks as well as laterite derived form the sedimentary rocks of Teritary age have been noticed.

The coastal zone on the other had is the result of the late tertiary and quaternary processes of sedimentation, and dispersal of sediments. Effects of Neotectonics are also noticed in this tract. The coastal land zone is characterised by the presence of lagoons which link the river channels with the Laccadive sea.

#### 4.8.1.1 Relevance of the study

The major groundwater quality problems reported in Kerala are due to the presence of excess salinity, iron, fluoride, hardness and coliforms. The causes of contamination can be attributed to sea water intrusion, domestic sewage, mineralogical origin and agricultural and industrial activities.

The water quality problems in the coastal areas are mainly because of the presence of excess chloride.

Along the midland region, concentration of iron and chloride were found to be on higher side in bore wells. Abnormal values of pH and electrical conductivity were also noticed in few wells. However, about 50 % of the wells are contaminated by coliforms. Palghat region is reported to have fluoride contamination along with high concentration of iron and calcium.

The highland zone mostly yields good quality water. However, high concentration of iron and coliform are reported from Idukki district.

However, the above studies were conducted in isolation, covering smaller study areas. Necessary data on water quality status on a State scale are not available for proper planning and management of the groundwater resources. Vulnerability of water resources to pollution, needs to be addressed in a regional scale. By considering the above facts, the State Government of Kerala has proposed the present project with the coordination of the National Institute of Hydrology under the ongoing Hydrology Project (Phase II):

- to identify the regional water quality problems
- to develop quality indices
- to evolve strategies to protect the existing water bodies by conducting public awareness programmes
- to adopt appropriate preventive and remedial measures

On the serious issue of water quality, more investigations are required to assess the real situation in order to device remedial measures and management options. Vulnerability of precious sources of water to pollution needs to be addressed in a regional scale. Any investigations without addressing quality issues in the right perspective may not yield sustainable results. Keeping in view of the above facts, the objectives of the proposed 3-year Purpose Driven Study are listed as below:

- To ascertain the existing pollution level of rivers, lakes, ponds, streams, wells, water taps and other water bodies in Kerala.
- To evolve water quality index for the surface water bodies and quality modeling for the selected river reaches.
- To develop vulnerability index for groundwater resources and to carry out quality modeling for selected blocks.
- To create awareness among the people about the locations & causes of pollution and thereby to initiate proper pollution control practices.

Considering the significance of water quality issues, Kerala State Irrigation Department and Kerala State Ground Water Department is collaborating with the Regional Centre, National Institute of Hydrology (NIH), Belgaum, Karnataka, for this PDS. The project is being carried out jointly by the collaborating agencies as per the guidelines on PDS for the HP II.

It is noted from various studies that the pollution levels in the water bodies and drinking water sources of the State of Kerala have gone up at an alarming rate. However, necessary data on hydrologic and water quality status for the entire State are not available for proper planning and management of the water resources. The present project was conceived in this direction to identify the type of quality problems existing in different regions of the State, to develop quality indices and to evolve strategies to protect the existing water bodies.

### 4.8.2 Methodology

The State Irrigation Department also identified about 480 sampling locations covering all regions of the State and major river basins. The monitoring locations include rivers, ponds, lakes and tap water. The water samples were collected and the analyses were conducted during the period from 2008 to 2012.

The State Ground Water Department identified about 990 monitoring points to collect ground water samples. These locations cover open wells, dug wells and bore wells from all the 14 districts of Kerala. The water sample collection and its analyses were done by using standard methods during 2008 to 2010.

#### 4.8.2.1 Water quality index

The significance of the WQI can be appreciated as the resources play a crucial role in the overall environment and this index has also been recognized as one of the 25 environmental performance indicators of the holistic Environmental Performance Index (EPI). The EPI is based on well-established policy categories covering both environmental public health and ecosystem vitality which focus on climate change, water quality and quantity, air pollution, biodiversity, land-use changes, deforestation and sustainability of agriculture and fisheries (EPI 2010). The major statistical look to WQI indices was given by Landwehr (1974), whose doctoral work culminated in the classification of the water based on the numerical values of indices as follows: very bad: 0-20; bad: 21-45; medium: 46-75; good: 76-90; very good/Excellent: 91-100. He also concluded that a multiplicative water quality index was a more visible and unbiased estimator of water quality that best reflected the consensus of the experts (Landwehr and Deininger 1976; Landwehr 1979). Water quality of many Indian rivers has been comprehensively studied, analyzed and reported according to their suitability for various beneficial uses (Bhargava 1983c, 1994).

**Calculation of $WQI_{BA}$**

The parameters used for the calculation of the $WQI_{BA}$ indices were: colour, pH. $BOD_5$, DO, temperature, hardness, TDS, sodium, chloride, EC, magnesium and calcium.

Bascaron Water Quality Index ($WQI_{BA}$), Equation (Bascaron, 1979):

$$=K \sum C_i P_i / \sum p_i$$

Where

$C_i$= percentage value corresponding to the parameter.

$P_i$= parameter weight.

K= constant of adjustment in function of the visual aspect of the water, as follows; 1.00 for clear water no apparent contamination; 0.75 for water with slightly unnatural colour (colour red and colour blue) and with foam; 0.50 for polluted appearance water with odour between moderate and strong; 0.25 for dark water that presents fermentation and strong odour (Bascaron, 1979).

**Calculation of CCME WQI**

In the formulation of water quality index, the importance of various parameters depends on the intended use of water and water quality parameters are studied from the point of view of suitability for human consumption. The BIS for drinking water specifications (IS 10500) have been quoted. Conceptually CCME WQI comprises three factors and is well documented (CCME 2001).

Factor 1 (F1) deals with scope that assesses the extent of water quality guideline noncompliance over the time period of interest.

$$F1 = \left[\frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters}\right] \times 100$$

Factor 2 (F2) deals with frequency i.e. how many occasions the tested or observed value was off the acceptable limits or the yardsticks.

$$F2 = \left[\frac{Number\ of\ failed\ tests}{Total\ number\ of\ test}\right] \times 100$$

Factor 3 (F3) deals with the amplitude of deviation or the amount by which the objectives are not met. F3 represents amplitude: The extent (excursion) to which the failed test exceeds the guideline. This is calculated in three stages. First, the excursion is calculated,

$$Excursion = \left[\frac{failed\ test\ value}{Guideline\ value}\right] - 1$$

Second, the normalized sum of excursion (nse) is calculated as follows:

$$nse = \left[\frac{\sum excursion}{Total\ number\ of\ testes}\right]$$

F3 is then calculated using a formula that scales the nse to range between 1 and 100:

$$nse = \left[\frac{nse}{0.01\ nse + 0.01}\right]$$

The index value is computed using the following formulation:

$$CCME\ WQI = 100 - \left[\frac{\sqrt{F^2 1 + F^2 2 + F^2 3}}{1.732}\right]$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. The above formulation produces a value of CCME WQI between 0 and 100 and gives a numerical value to the state of water quality. Note a zero (0) value signifies very poor water quality. Whereas a value close to 100 signifies excellent water quality. The assignment of CCME WQI values to different categories is somewhat subjective process and also demands expert judgment and public's expectations of water quality. The water quality is ranked in the following five categories:

1. Excellent (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions are very close to natural or pristine levels.
2. Good (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
3. Fair (CCME WQI Value 65-79) – water quality is protected, but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
4. Marginal (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
5. Poor (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels (Canadian Council Ministers of the Environment (CCME) 2001).

The WQI software has been prepared in Visual Basic by CCME, which can be implemented in MS Excel for computational purpose. Instructions for the implementation are well described in the Calculator Version 1.0 (Canadian Council Ministers of the Environment (CCME) 2001. The output is available in the form of a table displaying the values of F1, F2, F3, WQI, number of sample, number of variables tested, total number of variables, total tests, failed tests, passed tests and tests below detection level. A frequency histogram of F1, F2 and F3 is also given (Lumb et al. 2006).

### 4.8.3 Study Area


Figure 4.44: Study Area Map

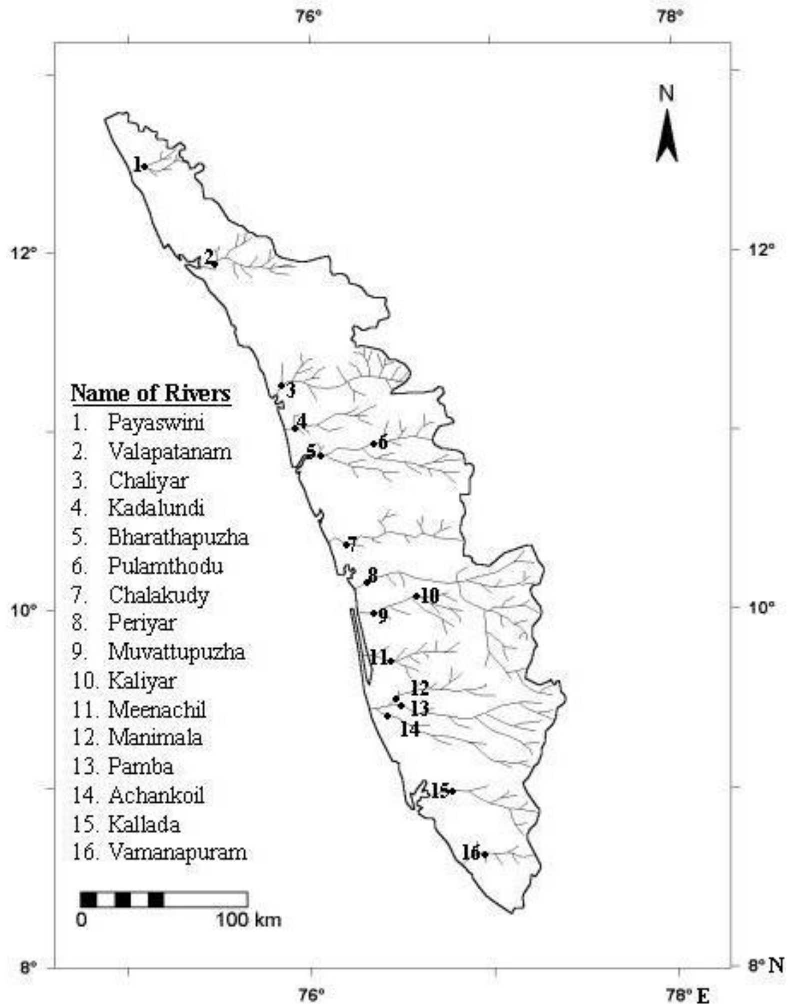


Figure 4.45: River Basins Selected for the Analysis

## 4.8.4 Results and discussion

### 4.8.4.1 Surface Water Quality

Kerala is one among the most thickly populated region in the world and the population is increasing at a rate of 14%per decade. As a result of the measures to satisfy the needs of the huge popualtion, the rivers of kerala have been increasingly polluted from the industrial and domestic waste and from the pesticides and fertilizer in agriculture. Industries discharge hazardous pollutants like phosphates, sulphides, ammonia, fluorides, heavy metals and insecticides into the downstream reaches of the river. The river Periyar and Chaliyar are very good examples for the pollution due to industrial effluents. It is estimated that nearly 260million litres of trade effluents reach the Periyar estuary daily from the Kochi industrial belt.A list of major industries situated here and the nature of their outputs indicates the type of chemicals that are likely to find their way into the river Periyar is given in the table

The major water quality problem associated with rivers of Kerala is bacteriological pollution. The assessment of river such as Chalakudy, Periyar, Muvattupuzha, Meenachil, Pamba and

Achenkovil indicate that the major quality problem is due to bacteriological pollution and falls under B or C category of CPCB classification. There are local level quality problems faced by all rivers especially due to dumping of solid waste, bathing and discharge of effluents.

**Northern Region**

In Northern districts of Kerala, it is found that the water is slightly saline in few locations particularly, close to the coastal belts. The maximum EC was observed at Paika (2170 µS/cm). Other areas affected are Uppala (1920 µS/cm) and Bambrane (1001 µS/cm). The corresponding TDS values also showed a similar trend. Chloride concentration also varied considerably from place to place and the variation was significant in the above mentioned locations (Paika-837 mg/l, Uppsala–540 mg/l and Bambrane-260 mg/l). COD is one of the most important parameter which indicates the level of contamination. In Kasaragod area, few locations recorded high COD values, viz. Karuvankayam (23 mg/l), Pallathaduka (20 mg/l), Bambrane (21 mg/l), Paliyathadukka (18 mg/l) and Pallangode (16 mg/l). Total coliform and E.coli were also reported to be very high in some of the locations. The Pre-monsoon analysis showed the contamination of water at Thaniyadi. The electrical conductivity (2070 µS/cm), Chloride (1200 mg/l) and TDS 1325 mg/l were much higher than the permissible limits.

In the Payyannur area, the observations showed the presence of highly saline water. In many areas, electrical conductivity exceeded 30000 mg/l, particularly at Perumba and Kariyamkode. This high salinity was also indicated through other parameters such as Chloride (exceeding 13000 mg/l) calcium 300 mg/l, magnesium 600 mg/l and also sulphate which exceeded 1600 mg/l indicating the influence of sea water in these regions.

In Thalassery, Moolakadavu showed a very high electrical conductivity (5670 µS/cm). The corresponding TDS observed was 3629 mg/l. The hardness of the water was also considerably high (800 mg/l). Apart from this very high concentration of Chloride (1552 mg/l) and sulphate (2900 mg/l) were also recorded in this area. All the higher concentration of the said parameters indicates the presence of salt water in this part of the study area.

In Malappuram, the water quality parameters are all within the permissible limits. However, the toal coliform was in considerably distributed throughout the study area. In addition, COD was observed at Areacode (25 mg/l) and Kallukayam (24 mg/l). One of the interesting characteristics of the region is the presence of acidic water in many of locations and it was significant at Perinthalmanna (5.82) and Makkaramparambu (5.92).

In the rivers basins of Kozhikode region, showed very high electrical conductivity at number of locations. Maximum value was observed was 42100 µS/cm at Elathur followed by Beypore (38000 µS/cm), Canoly canal (30900 µS/cm), Faroke (25700 µS/cm) and Kottakadavu (18300 µS/cm). Similar trend was observed in the case of TDS distribution.

Apart from this chloride, Ca, Mg and sulphates were also significantly high in this part of the study area. Bacteriological analysis showed that DO drops to 2.6mg/l at Karaparambu bridge. BOD was also considerably high in few locations and the maximum observed was at Canoly canal (18.9 mg/l) followed by (13.3 mg/l) during the post-monsoon. COD was also very high at Beypore estuary (30 mg/l) and Canoly canal (171 mg/l).

**Eastern Region**

In Wyanad (North eastern district of Kerala) and adjoining areas, the surface water quality parameters showed wide variations. However, only at very few stations the anions and cations exceeded the permissible limits. It is found that in some of the locations COD showed a significant concentration, particularly, Vellamunda (100 mg/l), Thindumal (66 mg/l), Valad (52 mg/l) and Padinzhavathara (84 mg/l). A notable quantity of phosphate was observed in Sulthan Batheri area (21.8 mg/l). Apart from this at Sulthan Batheri, bacteriological contamination was noticeably high. Significant numbers of E. coli were observed in places like Kodal kadavu, Mananthavady, Edavaka, Kottikulam, Bavali, Thindummal, Valad and Koodamkunnu.

Surface water quality observations in Palakkad region (Bharathapuzha and Bhavani River basins) showed a drastic change in certain water quality parameters particularly, the electrical conductivity. The maximum electrical conductivity observed was 1110 µS/cm at Kanjikode followed by Chullimada (1050 µS/cm). Similar variation was also found in the case of Total Dissolved Solids. Turbidity values also increased in some of the locations. The maximum turbidity observed was at Plazhy (% NTU). Further, it was observed that, water was acidic in few of the locations (maximum was observed at Chulliyar). Significant quantities of chlorides were also present in some of the places. Highest concentration was observed at Chullimada (310 mg/l). It is very important to high light the presence of fluorides in surface water. The maximum concentration was observed at 1.95 mg/l at Meenakara. Vithanassery also showed a higher concentration of fluoride (1.85 mg/l). Phosphates were also appeared in many locations. The maximum was observed at Chulliyar (0.4 mg/l). During the Post-monsoon, though there was a dilution effect on various parameters, the variation from Pre-monsoon to Post-monsoon was marginal. Total coliforms were also considerably high in this region.

**Central Regions**

The surface water quality data pertaining to Bharathapuzha, Keechery and Puzhakkal River basins showed considerable variations from Pre-monsoon to Post-monsoon seasons. In all locations, the water was colorless except at Thrithala and Pattambi under Bharathapuzha basin. It was found that the major cause of concern is the concentration of sediments for the change in color. The acidity and alkalinity results of the analysis indicated that both the parameters observed were well within the permissible limits. The bacteriological report showed that the total coliform was the major problem in most of the sampling locations. The total coliform count exceeded more than +1100 in many places. It was also observed that iron is one of the important constituent in rivers waters of Bharathapuzha and Keecheri basins. The concentration of iron varied between 0.6 mg/l and 3.44 mg/l. The presence of Phosphates was also noticed in some of the locations particularly at Puzhakkal and Kanjirapudu. Most significant observation in this region is about the presence of Fluoride in surface water at Pattambi during Post-monsoon season. The concentration was more than 3 mg/l.

The chemical analysis data of Chalakudy River basin indicated that the entire area of the basin is dominated by acidic type of rocks. The acidic rocks might have contributed to the lower pH in the waters of the region. In all stations it is found that the pH is less than 7. Further, it is interesting to note that during the post-monsoon season, in-spite of heavy rainfall and dilution, there was no significant change in pH value. It was also observed that, coliforms are also of concern as the count showed more than +1100 in many of the locations.

In Thrissur region (Karuvannur and Puzhakkal River basin), all major anions and cations were far above the permissible limits. The cause for such drastic variation could be due to the presence of artificial canal. The electrical conductivity was enormously high and the maximum was found to be 56910 µS/cm at Enamakkal and 48450 µS/cm at Thriprayar. The corresponding TDS observed in the said stations were 24930 mg/l and 21270 mg/l respectively. Hardness of the water was also found to be very high. 5765 mg/l was observed at Enamakkal and 4573 mg/l at Thriprayar. Similarly, those stations were marked by very high concentration of Chloride (17594 mg/l and 14595 mg/l) and also certain anions such as sulphate and phosphates. Apart from this, Iron is one of the important elements which were widely distributed in the surface waters of this region. The maximum concentration of Iron observed was 4.4 mg/l. The bacteriological analysis also showed considerable variations. The DO level has showed a drop up to 2.4 mg/l which was observed at Pillathode.

The major river basins of central Kerala (Periyar, Muvattupuzha, Pamba, Achenkoil, Minacil and Manimala) showed significant variations from season to season and year to year. Periyar and Muvattupuzha showed signs of pollution in some of the locations. Pamba river also showed a sign of degradation particularly during festival seasons. Apart from this, in few of the locations the acidity was very high and alkalinity was also found to be marginally high. The maximum acidity was observed at Mararikulam (750 mg/l) followed by Kalathu (710 mg/l). The maximum alkalinity observed was 382 mg/l at Ambalapuzha and a value of 260 mg/l was noted at Pazhavayadi. Total hardness was within the permissible limits except at aroor (840 mg/l). Similarly at Aroor chloride concentration was 2880 mg/l and Magnesium concentration was 168 mg/l which is considerably higher than the permissible limits. The maximum concentration of calcium (85 mg/l) was observed at Ambalapuzha. Iron concentration was also above the permissible limits in many of the locations. It is also interesting to note that the observations made in certain tap water also showed higher concentration of Iron.

Dissolved oxygen and total coliform counts also varied significantly from place to place. The minimum DO of 2.3 mg/l was observed at Alleppey. DO was also less at Mararikulam (2.5 mg/l) and Thanneermukkam (2.8 mg/l).

The water quality parameters were within the permissible limits for the river basin, except pH and coliform contamination. The river water was found to be acidic (with pH less than 6.5) in many places. At Kumarakom, which is located at the downstream side of the basin and near to estuarine region, some of the quality parameters showed large values during the pre-monsoon season of 2009; Electrical Conductivity (2.64 x $10^6$ µS/cm), Total Dissolved Solids (2.337 x $10^6$), Total Hardness (270 mg/l) and Magnesium (46.70 mg/l). Also DO level showed lower values during the same season at many monitoring stations.

**Southern Region**

The major river basins falling under this sub-division are Vamanapuram, Karamana, Ithikkara and Neyyar. In Thiruvananthapuram and surrounding area, the surface water quality parameters showed wide variations. Places like Ittikkara, Chittumala, Chavara and Tiruvallar temple area, etc. showed very high electrical conductivity values. It was maximum at Ittikkara (19100 µS/cm) followed by Chittumala (6200 µS/cm), Thiruvallar temple (3950 µS/cm and Chavara (1170 µS/cm). In some of the locations turbidity was the major problem. A turbidity of 103 NTU was observed at Sooranad south, followed by Neyyar (95 NTU), Ayathikode (36 NTU), Tasvalayillakulam (31 NTU) and Ottashekharamangalam (25 NTU). pH of the waters showed considerable variations in the region varying from highly alkaline (9.58) to Acidic (5.2). Total hardness was high only at Chittumala (620 mg/l). At Chittumala chloride concentration was also markedly high (2740 mg/l). Thiruvallur (768 mg/l) and Ittikkara (486 mg/l) also showed high chloride content. One of the major observations made in this area is about the presence of Fluoride. Fluoride concentration was 17 mg/l at Puttkulam. Apart from this nitrate concentration up to 48.5 mg/l was recorded at Pandarakula. In addition, iron and coliform contamination was also observed in most of the locations.

### 4.8.4.2 Statistical interpretation of River Water Quality Data

The WQI obtained by the application of CCME for 15 river basins, showed that the over all rating varies between 53.33 and 78. Minimum was observed in Kabini and maximum was in Chandragiri river which is the northern most river basin of Kerala under study. The drinking water rating varied between 49 & 83. Minimum was observed in two basins viz., Kabini and Karamana. In the case of aquatic rating, it varies from 41 to 73. Minimum was observed in Achankovil and maximum in Pamba. However, it is noticed all river basins shows very good quality water for recreation, irrigation and livestock purposes. Figure 8.2 shows the average water quality indices determined by CCME method. Water Quality indices were developed station-wise and presented in the original report.

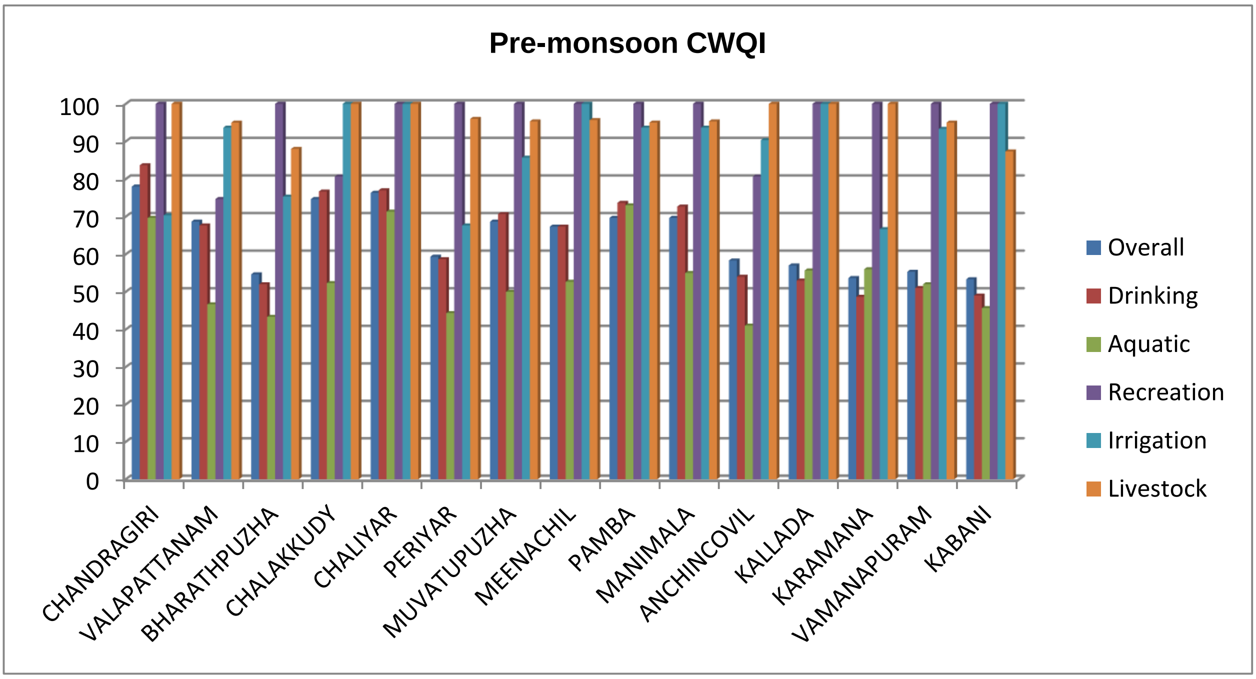



Figure 4.46: WQI estimated using CCME for selected river basins of Kerala

During the Post-monsoon, overall rating varied between 47 and 78.5 (Fig. 8.3). The minimum was noted in Bharathapuzha and maximum in Chaliyar. The rating for drinking water showed a variation between 41 to 80.5. For aquatic purposes the rating varied between 35 and 64.The water is quite useable for recreation, irrigation and livestock population.

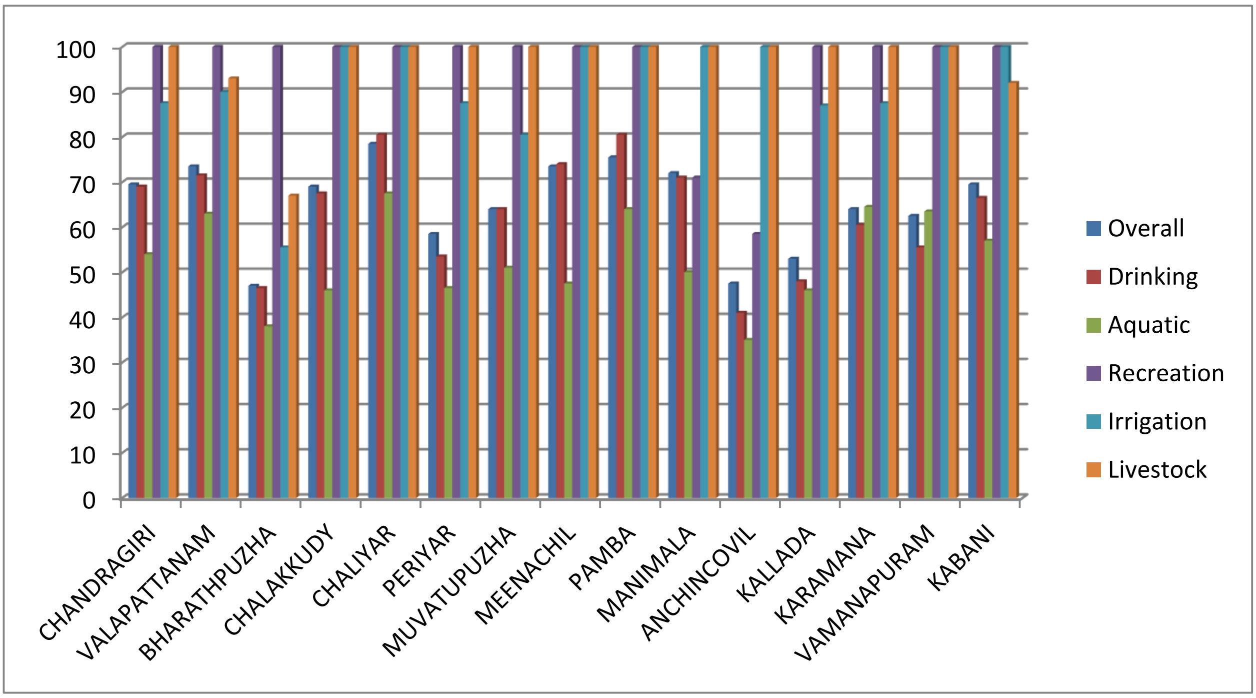


Figure 4.47: WQI during Post-monsoon season Calculated using CCME WQI method

### 4.8.4.3 Groundwater Quality

The Kerala state is known for its highest density of population in India, particularly along the coastal tracts. It is also reported that dug wells are the most common type of abstraction structures in Kerala. In Kerala, 65% of the urban and 44% of the rural population are getting protected water. The rest still depends on groundwater sources for domestic purpose. The major groundwater quality problems in Kerala are due to the presence of excess salinity, iron, fluoride, hardness and coliforms. The causes of contamination can be attributed to sea water intrusion, domestic sewage, mineralogical origin, agricultural and industrial activities.

Kerala State Ground Water Department has monitored about 1000 sampling stations during pre and post monsoon seasons of 2008 and 2009. Using these data, a preliminary water quality data screening was carried out for all the districts and probable areas of contamination are identified. Initial analyses were conducted on all 14 districts.

**Kasaragod District**

Kasaragod district, with major part covered by midlands, the water quality problems are highly varying. Keeping this in mind, 80 samples were collected and analysed. It is found that pH values are acidic. Lower values varied from 5.01 (Bekal) and 5.19 (Uduma) to 6.48 (Kasaragod and Panathur). Bela showed high concentration of Sodium (536 mg/l). Apart from the pH variation, other water quality problem encountered in the district was the presence of Iron content in majority of the wells. More than 80% of the wells were having the Iron concentration which exceeds the permissible limit. Higher values were observed at Badiyaka (9.21 mg/l), Beemanady (8.68 mg/l), Panayal (5.70 mg/l) and Kooliyad (4.67 mg/l). It was also observed that the Endosulphane content was reported and many villagers were affected physically due to the chemical contamination.

**Kannur District**

Sampling was conducted at 77 locations during 4 seasons. It was observed that all the water quality parameters are within permissible limits in all stations and all seasons. Marginally high value of Electrical Conductivity (760 µS/cm) was observed at Kottiyoor. Iron concentration was 2.36 mg/l for Chavassery and 2.24 mg/l for Kottiyoor.

**Kozhikode District**

In Kozhikode district, the water quality problems were reported mainly due to excess of chloride along the coastal tracts. The chloride concentration > 250 mg/l was detected from many stations and also high concentrations of iron and TDS. The borewell samples in

Kozhikode city have high concentration of chloride (20200 mg/l), iron (0.40-0.90 mg/l), total hardness (9000 mg/l – 10600 mg/l) and sulphate (2200 mg/l – 2300 mg/l). During the present investigation, 78 samples were collected from Kozhikode district and analysed. The values of pH indicated more acidity with minimum pH recorded at Kallanode (4.53), Vadakara (4.68) and Villiappally (4.91). It was observed that the Electrical Conductivity value was very high at Cheruvannur (2452 µS/cm). The Total hardness was also found to be marginally higher in Cheruvannur (335 mg/l). The chloride (463.6 mg/l) and sodium concentration (171 mg/l) were also noted to be on higher side. Potassium concentration was high in the district at Quilandy (25 mg/l). The Iron concentration was much higher than the permissible limit. The maximum concentration observed was 8.9 mg/l at Maniyur and 7.11 mg/l at Arikulam.

**Wyanad District**

The State Ground Water Department has identified about 60 stations in this district and water sampling and analyses were done for 4 seasons in 2008 and 2009. It was observed that pH values are generally less than 7 which represent the acidic nature of water. Majority of the tested parameters were under permissible limits except for few stations. Higher values of EC were observed for Thakarappadi (1470 µS/cm) and Sulthanbatheri (1030 µS/cm). Thakarapadi also showed a large value of Magnesium, 109.84 mg/l and Pulpally recording 45.87 mg/l. Potassium concentration was high at Sulthanbatheri (29.8 mg/l), Ambalavayal (24.2 mg/l) and Pozhuthana (21.8 mg/l). Many regions showed high Iron concentration; Thirunelli (9.27 mg/l), Vythiri (8.55 mg/l), Kalpetta (4.27 mg/l), Korom (2.89 mg/l).

**Palakkad District**

The analysis carried out for 84 monitoring stations showed that water quality is a major constraint in the district. Various parameters such as Total Hardness, Chloride, Sodium, Fluoride, Iron, pH and Electrical Conductivity showed marked variations in various parts of the district. The highest value of pH was observed at Ambalapara (8.90) and the lowest at Cherpulacherry (5.18). The Total Hardness value at Kannimari was observed as 1410 mg/l. Chloride concentration showed a maximum value of 1025 mg/l at Kannimari. Fluoride concentration was also found to be very high in villages like Nattukal (2.87 mg/l), Panangattiri (2.80 mg/l), Tharur (2.80 mg/l), Chempanthode (2.90 mg/l) etc. Ion content of 41 mg/l was noticed at Kongad village. Iron concentration was also high at Pudukode (11.25 mg/l), Cherpulacherry (9.62 mg/l), Vallapuzha (9.28 mg/l), Pattambi (9.27 mg/l), Ambalapara (9.75 mg/l), Pulapetta (9.38 mg/l), etc. The variation of pH was between 5.2 (Ottappalam) and 8.5 at Chittur. Electrical Conductivity, the maximum observed was at Kannimari (3200 µS/cm). EC value recorded at Kozhinjampara was1980 µS/cm, Chullinada (1570 µS/cm), Venthapalayam (1550 µS/cm) and Thavalam (1520 µS/cm). Higher values of Sodium was observed at Kodakad (636 mg/l), Mannarkad (237 mg/l), Venthapalayam (232 mg/l) and Chittur (207 mg/l).

**Malappuram District**

Water quality monitoring was conducted for pre and post monsoon seasons of 2008, and 2009 for 70 stations within this district. Presence of Iron was emerged as the major water quality problem. Few stations recorded higher levels of EC, TH, Cl and Na. Low pH values (< 7) were observed at Thirur (4.57), Pandikadu (4.85), Kalachal (4.90) and Parannekad (4.98). High value of Electrical Conductivity was observed at Puduponnani (40000 µS/cm) and the values of Total Hardness (5300 mg/l) Chlorine (18130 mg/l) and Sodium (8650 mg/l) were high for the water sample from the same location. It was also observed that the Iron concentration at many of the places is in excess of the desirable limit. Higher values were recorded at Poroor (10.24 mg/l), Paloor (8.77 mg/l), Melmuri (8.80 mg/l), Kadavanad (7.37 mg/l), Kuttipuram (5.74 mg/l), Edavanna (4.38 mg/l), etc.

**Thrissur District**

The State Department has selected 80 stations for water quality monitoring. The major parameters were within the limits in majority of stations except pH and Iron concentration. pH values were less than 7 in most of the stations; minimum values were at Cherpu (4.62), Koratty (4.64), Ollur (4.66), Puthukad (4.68) and Aalur (5.12). High concentration of Iron was noticed at Mulamkunnathukavu (9.98 mg/l), Kondazhy (9.23 mg/l), Kunnamkulam (9.32 mg/l), Elanad (9.07 mg/l), Tholur (6.78 mg/l), etc. Chittilappally recorded a value of 1100 µS/cm for Electrical Conductivity and Chavakkad recorded 940 µS/cm. Chittilappally also showed high values of Total Hardness (320 mg/l) and Chlorine (300 mg/l). High concentration of Sodium was observed at Guruvayoor (112 mg/l) and nearby Chavakkad (109 mg/l).

**Ernakulam District**

The major water quality problem reported from the district, from the monitoring of 76 stations, was due to excess of iron content in most of the sampling locations. The maximum concentration observed was 10.4 mg/l for the bore well within the Revenue tower, Kochi. High values were also recorded as 8.59 mg/l for open well and 9.4 for bore well at Edayar, Kodungallur. pH values were less than 4 for bore well samples of Edayar and Mookannur and dug well samples from Pookattupadi and Pallickara. However a pH value of 8.7 was recorded at Vazhappilly, for a bore well sample. It was observed that the Electrical Conductivity value is very high at Revenue Tower, Kochi (4300 µS/cm) and Edayar (3600 µS/cm). The Total hardness was also found to be high in these samples; 1740 mg/l for Revenue Tower and 800 mg/l, for Edayar. The Chloride concentration was also high (1355 mg/l) for the samples from the Revenue Tower. Also the same water sample shows a high Sodium concentration (682 mg/l).

**Idukki District**

Sampling was done at 57 bore/dug wells in Idukki district. Water quality parameters, except pH and Iron concentration, were within permissible limits. Generally, most of the samples showed pH value less than 7, with sample from Mattupetty and Kanjar recorded the lowest values; 3.58 and 4.56 respectively. Iron content was also on higher side in most of the sampling stations. High values are recorded at Vandamattom (10.46 mg/l), Kanthalloor (5.98 mg/l), Udumbannur (4.5 mg/l), Vazhithala (4.35 mg/l) and Kulamavu (4.0 mg/l).

**Kottayam District**

The State Department has identified 60 stations for water quality monitoring for the District. Most of the parameters were within permissible limits at all stations. Some stations recorded large values of pH; Nattokom (3.90), Vadavathur (4.70), Kumarakom (8.60), Uzhavoor (8.70) and Chingavanam (8.80). Higher values for Electrical Conductivity were recorded at Vaikom (845 µS/cm) and Kanam (803 µS/cm). Also Iron content was on the higher side at Madappalli (14.00 mg/l) and Kumarakom (9.62 mg/l).

**Pathanamthitta District**

Groundwater samples were collected from 68 stations and were subjected to laboratory analyses. The water quality parameters were within desirable limits for most of the stations. However, pH was found to be less than 7 in many of the stations. Adur and Pandalam samples recorded a minimum value of 4.00. The pH value for Mallappalli was 4.10, 4.60 for Vallicode and 4.70 for Pathanamthitta. Kuttoor recorded a moderately high value of 325.50 mg/l for Total Hardness. Iron concentration showed high values at Enathimangalam (6.66 mg/l), Naranamoozhi (3.5 mg/l), Konni (3.28 mg/l) and Pathanamthitta (2.79 mg/l).

**Alappuzha District:**

In the present study, 71 ground water samples were collected from the entire Alappuzha district during 4 seasons in the year 2008 and also 2009. Physico-chemical parameters were determined. The data showed that in most of the locations, the EC, Cl and Na found to be considerably high. Apart from this, the pH in the district also showed wide variations (4.2 to 8.7). The minimum was reported from Puliyoor and maximum was at Arattuvazhy and Chambakulam. The maximum EC (6940 µS/cm) was observed at Karumady. Chanthirur recorded 3820 mS/cm and Kainakary 3760 µS/cm. Total hardness was also very high in Karumady which exhibited a maximum value of 1030 mg/l. Along the coastal zone, the Chloride concentration showed a maximum value of 1927 mg/l at Karumadi followed by Chanthirur (997 mg/l) and Kainakari (897 mg/l). Sodium concentration also showed a high value (752 mg/l) at Karumady and 636 mg/l at Chanthirur. Fluoride showed a maximum concentration of 1.77 mg/l at Arattuvazhy. However, the iron concentration is highly unpleasant and showed a concentration of 21.65 mg/l at Moncombu, 14.60 mg/l at Eera and 8.24 mg/l at Karuvatta.

**Kollam District**

Water quality monitoring was done at 67 sampling sites for 4 seasons. At many of the places, the pH values were highly acidic. Vilakudy recorded a low value of 3.5, followed by Kizhakumbhagam (3.60), Sasthamkotta (4.00), Anchalammodu (4.00), Kadakkal (4.10), Veliyam (4.50), Pallimukku (4.50), etc. Electrical Conductivity showed large values at Vilakudy (1320 µS/cm), Eravipuram (899µS/cm), Ochira (831 µS/cm) and Aavaneeswaram (803 µS/cm). Sodium was present in excess at the samples from Vilakudy (117.60 mg/l). High Iron concentrations were observed at Chavara (10.16 mg/l), Kummil (6.85 mg/l), Edappallikota (6.20), Mukhathala (5.81 mg/l) and Ayoor (4.69 mg/l).

**Thiruvanathapuram District**

87 sampling stations were identified within the district for water quality monitoring. The parameters pH, EC, Total Hardness, Chlorine, Sodium and Iron showed above permissible values in many stations. pH was generally less than 7 in most of the stations. pH value at Parakulam was 3.90 and at Veli was 9.90. Mnay stations recorded pH values less than 5, such as Nemom (4.00), Balaramapuram (4.00), Peyad (4.20), Malayankeezhu (4.20), etc. Electrical Conductivity values were more than permissible limits at Attingal (4290 µS/cm), Kaliyikavila (1840 µS/cm) and Poovar Ward (1960 µS/cm). Attinagl recorded a maximum Total Hardness of 706 mg/l whereas Poovar recorded 362. 70 mg/l. Chlorine concentration was more at Attingal (677 mg/l), Kaliyikavila (462 mg/l) and Poovar (304 mg/l). Sodium was also in excess at these stations; Attingal (514.70 mg/l), Kaliyikavila (220 mg/l) and Poovar (234 mg/l). It was noticed that Iron is present in most of the stations in excess of the permissible limits, large values were recorded at Attingal (11.10 mg/l), Madathilnada (7.26 mg/l), Parakulam (5.66 mg/l), etc. The Water Quality Index developed for 14 districts of Kerala, clearly demonstrated that there is gradual deterioration of water quality in different parts of the state. Alappuzha and Palakkad districts were severely affected due to various reasons. The eastern district like Wyanad, Idukki and Kottayam showed a constant variation over the years.

## 4.8.5 Groundwater Impact Analysis using VLEACH Model

### 4.8.5.1 Model Conceptualization

In the model, one-dimensional finite difference scheme was employed for solving the vadose zone transport equation, and a mass balance principle was used for the mixing calculation in the saturated aquifer underneath the soil columns. Ravi and Johnson (1993) developed one dimensional transport program called VLEACH, which handles only vertical migration of pollutant in a homogeneous soil column. VLEACH calculates the equilibrium distribution of contaminant mass between the liquid, gas, and sorbed phases. Transport processes are then simulated. Liquid advective transport is calculated based on values defined by the user for infiltration and soil water content. The contaminant in the vapor phase migrates into or out of adjacent cells based on the calculated concentration gradients that exist between adjacent cells. After the mass is exchanged between the cells, the total mass in each cell is recalculated and re-equilibrated between the different phases. These steps are conducted for each time step, and each polygon is simulated independently. At the end of the model simulation, the results from each polygon are compiled to determine an overall area weighted ground water impact for the entire modeled area.

#### 4.8.5.1.1 Analysis of VLEACH Results

To understand the soil heterogeneity effect in the column the homogeneous soil columns were simulated. Note that, for homogeneous soil, uniform soil property was used. Two types of soil are found in majority of the study area in Kerala. Two major physiographic units were considered for the study, the upland areas dominated by Sandy and sandy clay loams and lowland areas and coastal areas dominated silty sands and clayey soils. Accordingly attempt were made to simulate the impact of water quality parameters on groundwater under different recharge conditions both in upland and lowland regions of Kerala. The results of VLEACH contain mass balance and ground water impact information. In particular the calculated mass in the vadose zone. The mass is calculated in g/sq.ft. The components of the changes in mass are described as advection from the atmosphere, advection from water table, diffusion from atmosphere, diffusion from water table, total inflow at boundaries, and mass discrepancy. A positive value in the mass change indicates mass loss from the system. The total ground water impact is defined in terms of total mass and cumulative mass.

The application of VLEACH model and the sensitivity analysis carried out in the study area, indicated that the organic carbon partition coefficient (Koc), infiltration velocity (q), and fraction organic carbon ($f_{oc}$) have the greatest impact on both soil contaminant concentration and ground water loading. Bulk density (ρb) and porosity have significant effect only on the soil contaminant levels. The other parameters are found to have no significant impact on either soil contaminant level or groundwater loading. The application VLEACH shows that the higher recharge in the study area may result in speedy distribution of contaminants to the ground water. This is well demonstrated in the coastal areas where high rainfall accompanied by higher recharge rates were estimated and found that this is major cause of contaminant transport in coastal areas. Further, the density of population is very high all along the coastal belts, sewage and water drained through the soak pits (toilet) passes directly into the water table and results in water contamination. A detailed study is required to understand the phenomenon more systematically.

### 4.8.6 Application of Soil Water Infiltration Movement Model (SWIM Model)

SWIM model was applied for a period of 10 years (1996-2005). Monthly rainfall and evaporation were used for the analysis. Significant variation in rainfall was observed over the years. The annual rainfall varied between 2990 mm to 4100 mm during the study period, mostly occurring in the monsoon season (June - October). From the available rainfall, evaporation and soil hydraulic data, soil moisture profiles were simulated for three geomorphic zones in the district.

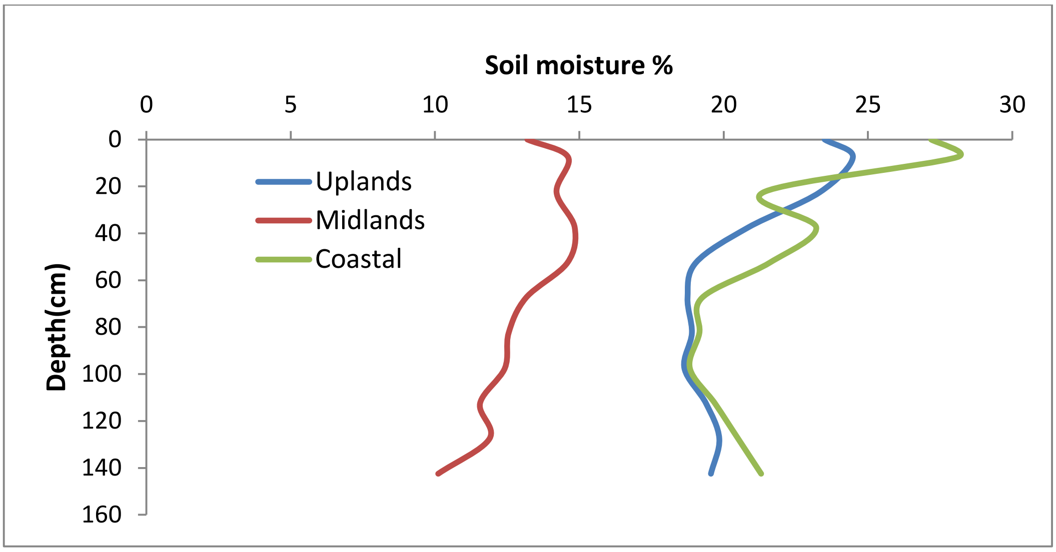



Figure 4.48: Simulated Soil Moisture profiles using SWIM model for Calibration

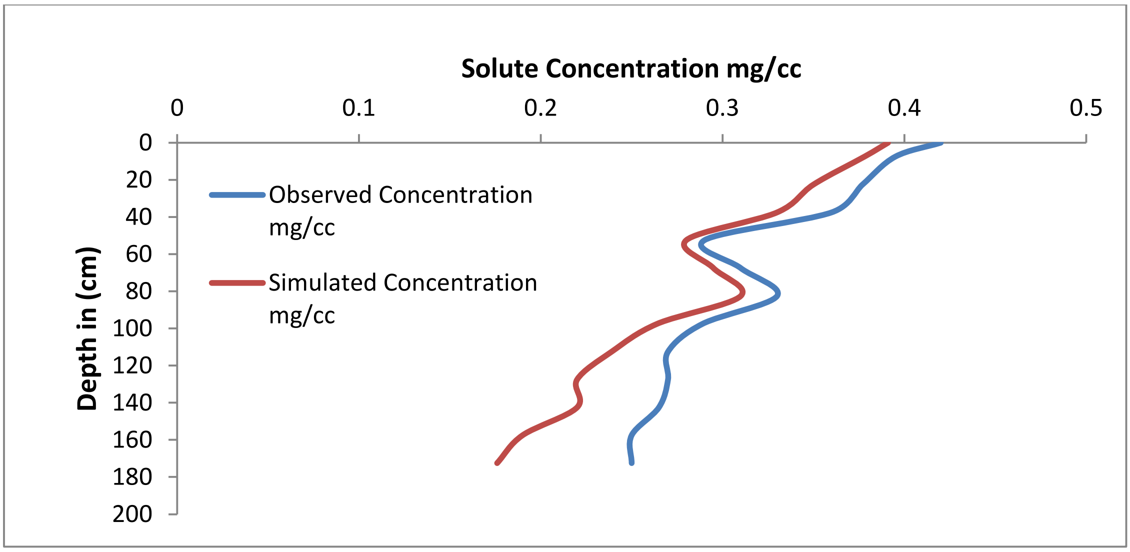



Figure 4.49: Simulated Solute concentration in an agriculture field (low-land and coastal areas)

### 4.8.7 Questionnaire survey

Opinion was sought from the owners of the wells regarding the use of water and prevalence of any water-borne disease in the area. Though the contamination in terms of nitrate and faecal coliforms was significant in some of the riparian belts and as well as in few districts viz., Ernakulam, Kasaragod, Kollam, Malappuram and Alappuzha districts. However, during the interviews, it was found that the public were not exactly aware about the incidence of diseases were due to water problem or any other reasons. This is because in majority of the cases isolated incidents were reported.

### 4.8.8 Conclusions

1. The surface and groundwater studies carried out in Kerala showed that the major cause of pollution is due to bacteriological contamination. As far as total coliform is concerned, majority of the samples were contaminated in pre-monsoon as well as in post-monsoon. As per the BIS guidelines, faecal coliforms should be absent in order that the water can be considered safe for drinking.

2. In both surface and groundwater, iron concentration is much higher than the permissible limit of 0.3 mg/l. However, ions such as nitrates which are the indicators of groundwater contamination were significantly lower than the permissible limits. Seasonal variations in some of the parameters are found including fluorides.

3. Heavy metal observations showed that elements such as copper, cadmium, nickel and zinc are found in some of the locations. However, the concentrations were below the desirable ranges. Arsenic and mercury were found to be absent in all places. Orthophosphates were found to be present in some of the locations.

4. The presence of shallow water table (10–20 m) in pre-monsoon and 5–10 m in post-monsoon coupled with the presence of fractures in the underlying rocks renders the water source vulnerable to pollution from the on-site sanitation systems. It is also observed that the density of septic tanks in the coastal areas are too high and does not have adequate distance between the septic tanks and abstraction points which resulted in excessive bacterial contamination in coastal areas.

5. Detailed observations and few investigations on soil hydraulic properties indicated that there are large scope for preferential flow paths in typical lateritic terrains of Kerala state resulting in leakage of contaminated water from soak pits and other industrial areas which will ultimately lead to surface and groundwater contamination.

6. An analysis of the available lithologs close to the study area indicates that there is a thick clay layer in coastal areas above the water-bearing horizon. The presence of this clay layer is likely to act as an adsorbant for the contaminants which percolate from the pit latrine. Therefore, some of the chemical contaminants, such as nitrates are likely to be adsorbed on the intervening clay layer. This is evident from the observations where the concentrations of nitrates were much below the permissible ranges.

7. DO-BOD monitoring and modelling showed that though the rivers like Pamba, Periyar, Muvattupuzha etc are affected due to human interference in certain parts of the river course which was indicated by DO-BOD concentrations, due to higher self

purification capacity of the rivers, the river maintains the DO level at the accepted limits.

8. The study revealed the impact of land use and cropping pattern, geology, soil and also on the distance from the coastal/estuarine area and the density of population has a direct impact on surface water quality and indirect affect on groundwater quality.

9. The application of VLEACH model and the sensitivity analysis carried out in the study area, indicated that the organic carbon partition coefficient (Koc), infiltration velocity (q), and fraction organic carbon ($f_{oc}$) have the greatest impact on both soil contaminant concentration and ground water loading. Bulk density ($\rho b$) and porosity have significant effect only on the soil contaminant levels. The other parameters are found to have no significant impact on either soil contaminant level or groundwater loading. The application VLEACH shows that the higher recharge in the study area may result in speedy distribution of contaminants to the ground water. This is well demonstrated in the coastal areas where high rainfall accompanied by higher recharge rates were estimated and found that this is major cause of contaminant transport in coastal areas.

10. Application of SWIM model also demonstrated that there is a greater possibility of groundwater contamination in coastal/lowland areas due to higher moisture movement and agriculture activities in low land areas of Kerala.

11. The study conclusively reveals that the impact of the on-site sanitation system has pronounced effect on shallow unconfined aquifers in lateritic and hard rock areas as compared to confined aquifer. The effect will be same for both chemical and bacteriological contaminants.

### 4.8.9 Recommendations

1. On-site sanitation program should be discouraged in highly permeable lateritic terrains with shallow water table. This will result in bacteriological contamination. If off-site sanitation cannot be provided, best engineering design should be ensured and operation and maintenance (O&M) should be an integral part of the low-cost sanitation program.

2. Critical parameters like the depth of the water table, soil characteristics, and rock strata need to be considered in any program on installation of on-site sanitations where groundwater is used for drinking purpose.

3. A systematic lithological mapping and hydrogeological mapping need to be carried out in any area which is going to be served by on-site sanitation facilities. If a confined aquifer with sustainable yield exists in the study area, this may be preferred to the shallow aquifer.

4. A systematic monitoring of surface and groundwater needs to be carried out in areas served by on-site sanitation systems. The monitoring needs to be carried out for

indicator parameters like nitrate, chloride, and faecal coliforms by agency responsible for water supply and sanitation.

5. Design of surface water as well as groundwater monitoring network system should be decided based on the following factors such as land use/land cover changes, geology of the region, soil types, distance from the coast or estuarine or standing body of water, depth of the monitoring wells, static water levels in the region, population density and type of interference by man/animals, extent of forest covers or plantations etc.

6. A systematic soil hydraulic properties and soil quality need to be assessed from time to time which will help in understanding the movement of contaminants to groundwater.

7. Regular monitoring of DO-BOD should be done for the specific which are under severe threat due to human interference like tourism, industrial growth, mining activities and intensive agriculture belts.

## 4.9 ASSESSMENT OF EFFECTS OF SEDMENTATION ON THE CAPACITY/LIFE OF BHAKRA RESERVOIR (GOBIND SAGAR) ON RIVER SATLUJ AND PONG RESERVOIR ON RIVER BEAS

*Principal Investigator :* *Dr. Sanjay Kumar Jain (from NIH)*

The information on discharge and sediment yield at basin scale is required for planning, design, installation and operation of hydro-power projects, including management of reservoirs. The western Himalayas that constitute head water catchments for many major rivers are the major contributors of runoff and sediment yield in these rivers due to large degradation in forest cover and other anthropogenic activities. Reliable runoff and sediment yield data is scarcely available for remote and inaccessible areas of Himalayan catchments.

In this study, three aspects for Saluj and Beas rivers have been covered and these are (i) Sediment yield using rating curves (ii) Sedimentation in reservoirs using remote sensing and (iii) runoff and sediment modelling using ArcSWAT model.

### 4.9.1 Sediment Yield using Rating Curves

For preparation of rating curves there a number of techniques, in this study sediment rating curves have been prepared using regression approach as well as using Fuzzy techniques. The whole period of 1996-2005 was divided in two parts (1987-1996 and 1997-2005), one for developing a relation and other for checking the results obtained. The relationship has been developed for four sites, three on Satluj and one on Beas. The relationships have been developed for daily and monthly values for monsoon as well as for non-monsoon period using Sediment Rating (SRC), ANFIS-Grid Partitioning and Cluster techniques. For all the techniques, coefficient of determination have been computed. The results for four sites (Kasol, Suni, Rampur and Nanduan) of Satluj and Beas basin using these three techniques are comparable however the results obtained using soft computing techniques are slightly better. Through figures, it can be observed that most of the time, the cluster and grid methods are giving better results than rating curve equation.

### 4.9.2 Sedimentation in Reservoirs

Satellite remote sensing based survey gives the information on the capacities in the water level fluctuation zone or in other words in live zone of the reservoir. In the dead zone, the information on the capacity could be taken from the most recently conducted hydrograhic survey. Use of satellite remote sensing technique enables a fast and economical estimation of live storage capacity loss due to sedimentation. In the present study remote sensing data of the years 2008-09 have been used for both the reservoirs i.e. Pong and Bhakra reservoir. The sedimentation rate in live zone using remote sensing comes out to be 19.77 $Mm^3$ per year for Pong and 18.08 $Mm^3$ for Bhakra reservoir. While using hydrographic survey it was found that the sedimentation rate in live zone for Pong reservoir is 19.87 $Mm^3$ per year (15.73 ha-m/100 $km^2$/year) for Pong and 22.00 $Mm^3$ (5.93 ha-m/100 $km^2$/year) for Bhakra reservoir. It can be seen that results using remote sensing are comparable for Pong reservoir while it is underestimated for Bhakra reservoir. For Bhakra reservoir, the zone of assessment for the two approached is different. Also the sedimentation studies carried using hydrographic survey is for the year 2006-07 and using remote sensing data it is for the year 2008-09. Based on this study it can be recommended that it would be appropriate if hydrographic surveys are conducted at longer interval and the remote sensing based sedimentation surveys are carried out at shorter interval to make both surveys complementary to each other.

### 4.9.3 Runoff and Sediment Modelling using ArcSWAT

SWAT model was calibrated and validated to examine its applicability for simulating daily flow and sediment concentration from intermediate catchments of Satluj and Beas river basins. The observed daily flow and sediment concentration from upstream catchments were given as input using the concept of inlet watershed and these were routed through main channel along with those simulated from the study areas. The coefficient of determination ($R^2$) and Nash–Sutcliffe efficiency ($E_{NS}$) were used for performance evaluation. The model simulated the daily discharge of Satluj catchment with a high degree of accuracy with $R^2$ and $E_{NS}$ values as 0.92 and 92.25% during calibration and 0.91 and 89.73% respectively during validation. The $R^2$ and $E_{NS}$ values for sediment concentration were obtained as 0.85 and 84.15% during calibration and 0.73 and 69.95% respectively during validation. These results indicated a very good performance of SWAT in simulating the discharge and sediment concentration from Satluj River. In Beas river basin, the model simulated the discharge with $R^2$ and $E_{NS}$ values as 0.79 and 71.64% during calibration and 0.75 and 70.83% respectively during validation indicating reasonably good performance of the model. However, the simulated results of sediment concentration in Beas basin were not very encouraging as the $R^2$ and $E_{NS}$ were 0.49 and 42.54% during calibration and 0.41 and 40.80% respectively during validation. The simulated mean annual water yield and sediment yield at Kasol gauging site on Satluj river and Nadaun gauging site on Beas river were comparable to observed values. The overall results of the study indicated that the simulation of daily discharge was better than that of sediment concentration in both the basins. Although, the model underestimated and overestimated daily discharge and suspended sediment for some flood events, predictions were within acceptable limits despite some inconsistency in observed data and possible inaccuracies in derivation of model input parameters in view of remote and inaccessible areas. In General, the results of the study indicated that the SWAT model performed well on both the study catchments and hence can be used as a useful tool for estimation of runoff and sediment yield from Himalayan catchments.

# 4.10 WATER AVAILABILITY STUDY AND SUPPLY-DEMAND ANALYSIS IN SEONATH SUB-BASIN

*Principal Investigator :* *Mr. Ravi Galkate (from NIH)*

## 4.10.1 Introduction

Chhattisgarh, a newly born state is exploiting its water resources to meet domestic, irrigation and industrial water demands. However, the state is facing the problem of water scarcity in rural as well as in urban areas to meet various water demands. Most of the rivers of the state gets dried by mid winter season and the rural as well as urban areas under the sub-basins are subjected to severe water crisis during the summer season. Therefore, assessment of water demand for various uses and study of supply scenarios are the essential elements for planning of water resources management of the region. Thus the present PDS study has been carried out to address hydrological issues of water resources management in Kharun sub-basin of Seonath basin such as rainfall runoff modeling, water availability study and study of supply and demand scenario. The study also aims to understand the hydrological behavior of river basins to harness the available water resources optimally. The research oriented approach adopted in the present PDS would be helpful in tackling the water resources problem highlighted in Seonath basin. The methodologies developed during the course of the study would be useful in resolving hydrological issues in the other similar sub-basins of Chhattisgarh state. Kharun river is one of the important tributary of Seonath river in Chhattisgarh state. The Kharun river basin is situated between 20$^{o}$ 38' N to 21$^{o}$36' N Latitude and 81$^{o}$ 20' to 81$^{o}$55' E Longitude. The index map showing location of Kharun river in Chhattisgarh is shown in Figure 10.1. The catchment area of Kharun river basin is 4112 km$^2$. Kharun flows to the west of Raipur town and supply water to Raipur city through small storage Bhatagaon anicut and also provide water supply to major industrial area near Raipur city. It is supplemented from Ravishankarsagar reservoir situated at Dhamtari on Mahanadi.

The present PDS has been carried out with the following objectives:

- Assessment of drought situation in Kharun basin
- Development of rainfall-runoff model for Kharun river
- Water availability study
- Assessment of supply-demand scenario
- Optimal utilization of water resources by planning for storage sites (Through Consultancy)
- Evaluation infiltration characteristics of soil
- Dissemination of knowledge, findings and application of the developed model to field engineers and common people through preparation of Manual, leaflets, booklets and by organizing workshops/ seminars every year.

### 4.10.2 Assessment of Drought Situation

Drought is generally viewed as a sustained and regionally extensive occurrence of appreciably below average natural water availability, either in the form of precipitation, surface water runoff or ground water. The meteorological and hydrological drought situation in Kharun river basin was assessed through departure analysis of annual rainfall and low flow analysis of stream flow data. From the analysis, it was observed that the Kharun river basin experiences two drought years in every 10 years period with 20% frequency. All drought events observed in the basin were of moderate nature i.e. rainfall deficit was 25 to 50% of normal rainfall. The Kharun river has experienced low flow epoch for 23 times over the period of 18 years period (1989-2007) indicating 1 or 2 low flow condition every year. The severity of low flow in the river varied from 0.13 to 80.26 MCM and duration of low flow epoch ranged from 13 to 177 days.

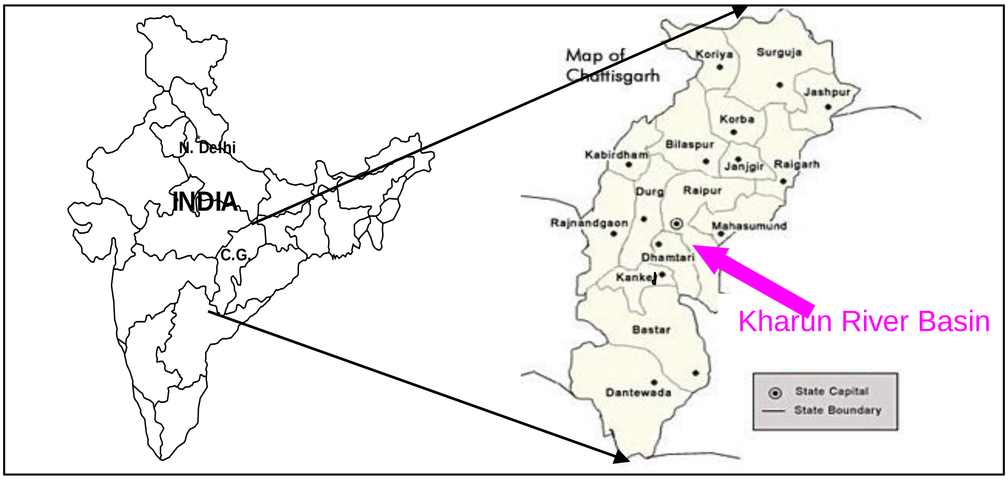



Figure 4.50: Index map showing location of Kharun river in Chhattisgarh

### 4.10.3 Development of Mike Basin Model of Kharun River

The flow regime in Kharun is strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir into the river and its supply for various usages through the series of anicuts. The water from Kharun River has been diverted to meet the domestic water demand Raipur city, industrial water demand of Silthara and Urla industrial area, water supply for railways and other water demands through series of anicuts. Therefore the MIKE BASIN model of Kharun as shown in Figure 10.2 was developed and used for estimation of virgin flow at desired location in Kharun river, water availability study at various location under virgin and regulated condition and deriving information for supply demand analysis.

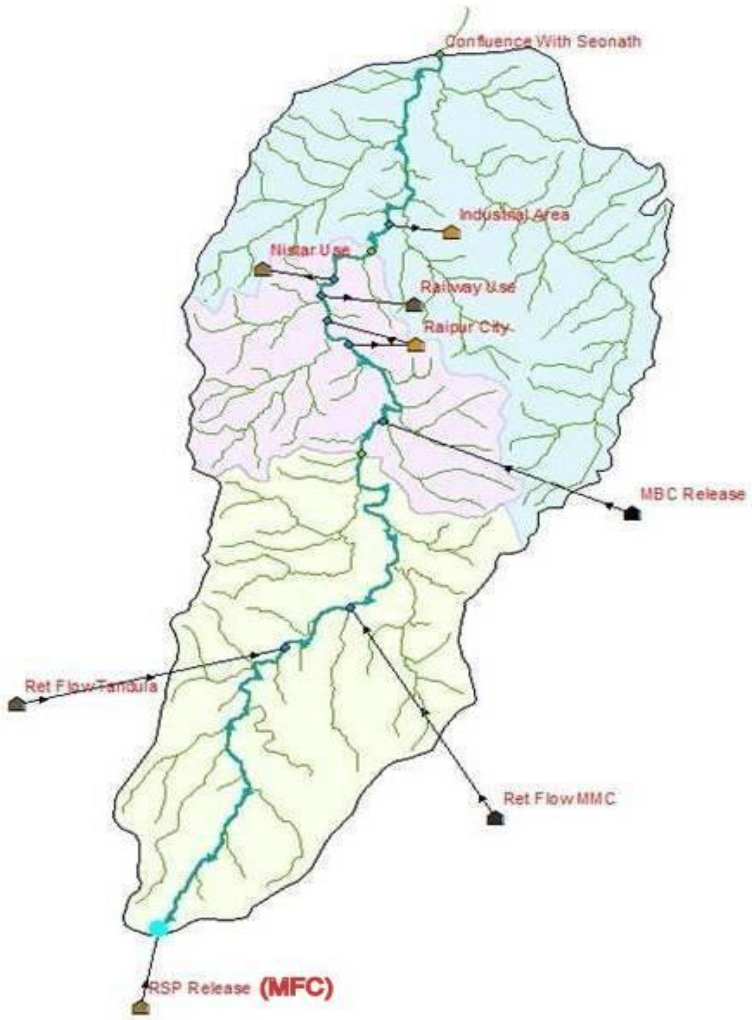



Figure 4.51: Kharun River Basin Model in MIKE BASIN

#### 4.10.3.1 Rainfall Runoff Modeling

Rainfall runoff modeling forms an important component of hydrological studies and plays an essential character in water resource planning and management of river basins. The rainfall-runoff modeling in Kharun river was carried out by MIKE 11 NAM Model using 15 years observed flow data of Patherdihi G/D site. The catchment area of Kharun river basin up to Patherdihi is 2442 $km^2$. After the calibration and validation of model, its capability to simulate the runoff for the extended period of time was verified. Accuracy of the model was examined on the basis of coefficient of determination ($R^2$), Efficiency Index (*EI*) and Sum of Square of Error (*SSE*). The sensitivity analysis was also carried out to identify most influencing model parameter. The coefficient of determination ($R^2$) value of model calibration was observed as 0.858, indicating the good agreement between the simulated and observed catchment runoff in terms of the peak flows with respect to timing, rate and volume. The resultant hydrograph shown in Figures 10.3 illustrates good match between the observed and simulated runoff.

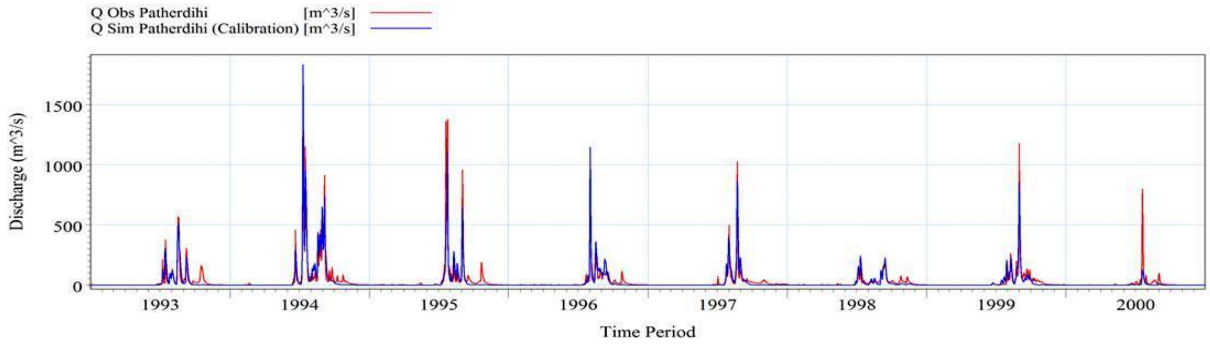



Figure 4.52: Comparison between observed and simulated discharge for calibration

The coefficient of determination for the validation process of the model was observed as 0.764, indicating good agreement between the simulated and observed catchment runoff. It could be broadly concluded that, the MIKE 11 NAM model has been suitable for Kharun basin and it can be used for predicting runoff for the extended time period in the Kharun basin and for predicting runoff of another basin of similar characteristics using the rainfall data.

### 4.10.4 Water Availability Assessment in Kharun River

The water availability study of a Kharun river can play an important role in Kharun river basin planning, on the basis of which development of water resources of a river for various beneficial uses is thought of. The virgin and regulated flow time series of the Kharun river were simulated at basin outlet by using MIKE BASIN model of Kharun River. Water availability analysis in Kharun basin was carried out by estimation of dependable flow volumes at various probability levels using Flow Duration Curve technique.

The analysis indicated that the estimated average annual rainfall in Kharun basin is 1147 mm producing 1802.88 MCM average annual runoff. The river has sufficient annual water yield but due to lack of big storage structures on river, the water demands in the basin cannot be fulfilled by the river under virgin flow condition. It was also concluded that, the Kharun river is originally a intermittent river having ample flow during monsoon season and low flow for 2-3 months thereafter. Under the natural virgin condition, the river has no flow during January to May at even at 60% probability.

The Ravishankarsagar reservoir and other sources add around average 116.22 MCM water in the river which is being supplied to Raipur city, railways and industrial area through the series of anicuts and the average annual regulated flow in Kharun becomes 1919.1 MCM. Under regulated condition, it was observed that the Kharun river has considerable flow during January to May even at 90% probability. Figure 10.4 illustrate the increase of monthly dependable flow volume or water availability in Kharun river at 90% probability when water is added to river from Ravishankarsagar reservoir.

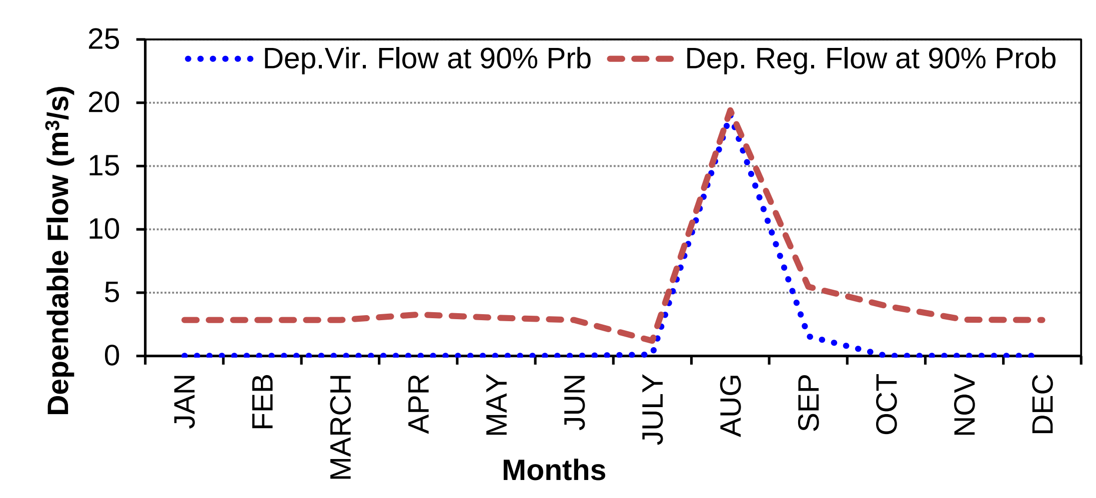



Figure 4.53: Water availability in Kharun river under virgin and regulated flow condition

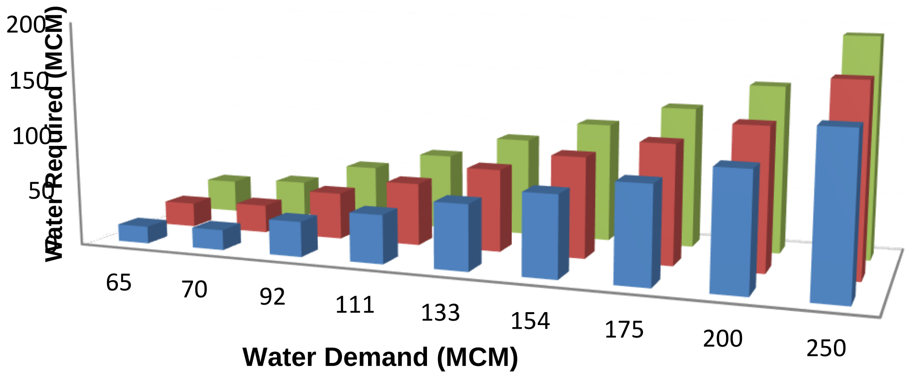
### 4.10.5 Supply Demand Analysis

The water supply demand analysis in Kharun basin was carried out using the observed flow data of Patherdihi G/D site by estimating the surplus or deficit volumes in the river on ten-daily basis at various probability levels. The water available in river was considered as a supply. The most important water demands which are to be met from Kharun River were domestic water demand of Raipur city, demand of Silthara and Urla industrial area, railway water demands and other demands like nistari and recreational activities. The present and projected water demands for next 5 decades were estimated considering the demographic and industrial growth in the basin. The calculations and analysis of estimation of surplus or deficit for each Ten-Daily period was carried out using the following logic.

*If Supply > Demand then Supply – Demand = Surplus*

*If Demand > Supply then Demand – Supply = Deficit*

The domestic water supply and industrial water supply are two main water demands on the Kharun river. The total water demand in year 2010-11 was 65.21 MCM which will become 174.56 MCM by the year 2050-51. On comparison of water demand on river and deficit periods, it is observed that, as the water demand increases the deficit period also increases, the river experiences the deficit much earlier if the demands are increased. From the analysis it could be seen that the deficit period at any probability level and even at higher demand ends in the month of July and August. At 90% probability level, when water demand is 65 MCM the water deficit is 22 MCM. When the demand will increases to 133 MCM (in 2030-31) and 175 MCM (in 2050-51) the water deficit will become 73.56 MCM and 105.33 MCM respectively. In year 2050-51, the additional 105.33 MCM water will be required in Kharun river to fulfill the total demand. It could also be concluded that water deficit increases with increase in demand and increase in probability level. The graph illustrating amount of additional water required to meet various demand is shown in Figure 10.5. The water supplemented from Ravishankarsagar reservoir to the Kharun river was found of great help to increase the water availability in the river to meet the various demands.




| | 65 | 70 | 92 | 111 | 133 | 154 | 175 | 200 | 250 |
|---|---|---|---|---|---|---|---|---|---|
| 75% | 15.41 | 18.13 | 31.33 | 43.12 | 57.97 | 71.60 | 85.24 | 101.86 | 137.75 |
| 90% | 22.00 | 25.32 | 41.99 | 56.06 | 73.56 | 89.45 | 105.33 | 124.53 | 165.23 |
| 95% | 29.71 | 33.67 | 52.94 | 68.94 | 88.38 | 106.49 | 124.91 | 148.00 | 193.76 |

Figure 4.54: Additional water supply required to meet the deficit at Patherdihi

**Measures to be adopted to meet additional water demand**

- The systematic approach of water resources management and water conservation measures can be adopted in Kharn basin to meet the future water demands.
- Construction of water storage structures i.e. small dams in the upstream of Raipur city on Kharun river will be helpful to meet the future demand to great extent. This approach has been studied under this PDS in next section. Small dams should be planned to achieve maximum storage with minimum submergence.
- The water from Ravishankarsagar reservoir can directly be added to Kharun river near Raipur city through pipe or canal instead of adding water through Deorani Jethani nala. This arrangement may help in minimizing the seepage, percolation and evaporation losses and increase the water availability in river.
- The future domestic demand of Raipur city and industrial demands could also be managed from Ravishankarsagar reservoir by giving priority over irrigation.
- Systematic approach towards artificial recharge and development of groundwater in Raipur city and nearby areas would help to meet the major part of domestic water demands from groundwater.
- The regular monitoring and assessment of surface as well as groundwater quality would be important components in water resources development for future water demand fulfilment.

### 4.10.6 Planning for Storage Sites

The water demands in Kharun basin are increasing due to rapid urbanization and industrialization leading to water scarcity and over exploitation of the available water resources. Thus there is need of systematic planning for water resources development of Kharun river basin for providing assured water supply to meet the increasing water demands. To study was carried out for identification of possible storages sites on Kharun river, assessment of submergence area and possible storage capacity at these sites. The Digital elevation model (DEM) was generated for study area and interpolated at 1m contour interval for sites R1 (Amdi), R2, R3 and R4 as shown in Figure 6. Sites were located keeping in view availability of high banks, narrow width and wide storage of water. The elevation-area-capacity relationships were developed for each site and storage volumes were estimated using trapezoidal rule.

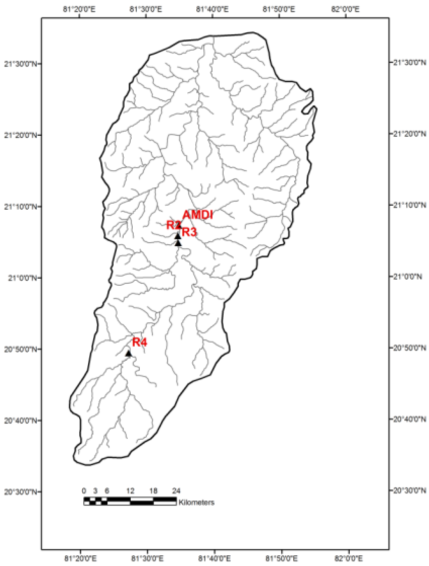



Figure 4.55: Drainage map and potential reservoir sites in Kharun river basin

From the analysis of elevation-area-capacity relationships developed at all four locations on Kharun river, the possible areas under submergence and its corresponding storage capacities at different dam heights are shown in table below.

Table 4.7: Possible submergence and storage capacity at proposed sites

| Site | Bed Level (m) | Max Water Level (m) | Height of Dam (m) | Area of Submergence (sq. km.) | Storage capacity (MCM) |
|---|---|---|---|---|---|
| R1 | 272 | 281 | 9 | 3.44 | 2.75 |
| | | 282 | 10 | 5.74 | 4.59 |
| | | 283 | 11 | 8.97 | 7.35 |
| | | 284 | 12 | 13.71 | 11.34 |

| | | | | | |
|---|---|---|---|---|---|
| R2 | 274 | 283 | 9 | 3.26 | 2.55 |
| | | 284 | 10 | 5.59 | 4.42 |
| | | 285 | 11 | 8.91 | 7.25 |
| | | 286 | 12 | 13.11 | 11.01 |
| R3 | 275 | 284 | 9 | 3.26 | 2.65 |
| | | 285 | 10 | 5.03 | 4.15 |
| | | 286 | 11 | 7.49 | 6.26 |
| | | 287 | 12 | 10.70 | 9.10 |
| R4 | 301 | 310 | 9 | 15.30 | 11.78 |
| | | 311 | 10 | 25.14 | 20.22 |
| | | 312 | 11 | 38.95 | 32.04 |
| | | 313 | 12 | 55.56 | 47.25 |
| ***Total of all sites*** | | | ***9*** | ***25.26*** | ***19.73*** |
| | | | ***10*** | ***41.50*** | ***33.38*** |
| | | | ***11*** | ***64.32*** | ***52.90*** |
| | | | ***12*** | ***93.08*** | ***78.70*** |

#### 4.10.6.1 Evaluation of Infiltration Characteristics of Soil

Infiltration test were conducted in Kharun river basin using Double Ring Infiltrometer at nine sites namely, Raipur, Bhilai, Selud, Patan, Bargaon, Dharsiwa, Pindrawan Tank, Gurur and Arkar which were well distributed over the basin. The infiltration tests sites were grouped according to their soil types and the infiltration rates estimated are given in Table 10.2. The infiltration contour map indicating spatial variability of infiltration rate over the study area is given in Figure 10.7.

Table 4.8: The infiltration rate and average infiltration rate in the different soil

| S. No. | Name of the site | Soil details | Infiltration rate (cm/hr) | Average infiltration rate (cm/hr) |
|---|---|---|---|---|
| 1 | Raipur | Kanhar | 1.5 | 1.0 |
| 2 | Bhilai | Kanhar | 1.1 | |
| 3 | Patan | Kanhar | 0.4 | |
| 4 | Dharsiwa | Matasi | 3.6 | 2.4 |
| 5 | Gurur | Matasi yellow soil | 3.1 | |
| 6 | Pindrawan Tank | Matasi | 0.6 | |
| 7 | Bargaon | Sandy Murrum soil | 4.3 | 3.7 |
| 8 | Selud | Murram | 3.5 | |
| 9 | Arkar | Sandy soil | 3.2 | |

The analysis indicated that the Kharun river basin has mainly three main types of soil i.e. Kanhar, Matasi and Sandy Murrum or sandy soil. Kanhar is the dark brown to black clay and low land soil, slightly heavier than Matasi. Wheat and Paddy are grown in this soil and average infiltration rate observed in this soil type was 1.0 cm/hr. Matasi is the yellow, loam to clay loam or loamy clay soil generally found in upland or level lands yielding good paddy.

The average infiltration rate observed in this soil type was 2.4 cm/hr. In Sandy Murrum or sandy soil the average infiltration rate observed in this soil type was 3.7 cm/hr.

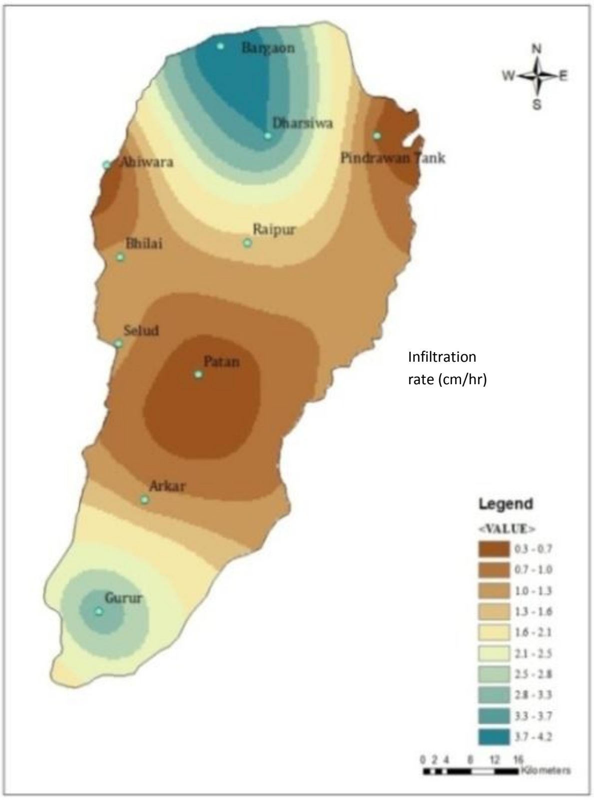



Figure 4.56: Spatial variability of infiltration rate over the study area

### 4.10.7 Recommendations and Applications

Chhattisgarh state has been experiencing rapid population and industrial growth which have increased the water demands and are expected to boost up in next few decades. Though the state experiences moderate droughts, the water crises in rural as well as urban areas during every summer have become common. Hence there is an urgent need of long term planning to undertake appropriate water resources development and management strategies in river basins of state for the optimum utilization of water which is being drained down the rivers without being tapped causing more dependence on groundwater. It is recommended that the state WRD should maintain adequate network for hydrometeorlogical data monitoring which is key for long term planning of water resources. To meet the future water demands state WRD should plan for series of small dams on rivers such that submergence affects are minimized, adequate runoff is available from catchment and topography permits adequate storage. The water resources planning should includes issues such as demand management in the river basin, planning of water supply at appropriate level of probability and providing assured water supply to meet demands. The surface and groundwater quality are the key issues of water resources management and need to be given due emphasis. WRD should adapt scientific approach like hydrological modeling and use of modern softwares for planning purposes and to achieve it the capacity building of field officers/officials is equally important. There is a need to undertake regular awareness programs for various water users and stakeholders for judicious use of precious water resources.

### 4.10.8 Dissemination of Knowledge

Under the present PDS programme the leaflets and booklet in the form of 'Executive Summery' were prepared by WRD, Raipur and it was widely circulated amongst all the line departments like WRD, Field offices, Agricultural Department, Raipur Corporation, etc. in the state, to the stakeholders and to most of the beneficiaries. Two workshops were organized at State Water Data Centre, WRD, Raipur on 9th December, 2011 and 28th June, 2013 for dissemination of knowledge among filed engineers and various stakeholders and beneficiaries.

### 4.10.9 Gist of Conclusions

- Kharun river is one of the important tributary of Seonath river in Chhattisgarh state. It is prime source of water supply to Raipur city and nearby industrial area.
- The frequency of occurrence of droughts in Kharun river basin was observed 20% and most of the droughts were of moderate nature. The Kharun river was found experiencing on an average 1 or 2 low flow epoch (hydrological droughts) every year.
- The flow regime in Kharun was found strongly influenced by regulation operations associated with water transfer from Ravishankarsagar reservoir into the river and its supply for various usages (domestic, industrial, etc.) through the series of anicuts.
- The MIKE 11 NAM model was found suitable for Kharun basin and it can be used for simulating runoff for the extended time period in the Kharun basin and also for simulating runoff of another basin in Chhattisgarh of similar characteristics using the rainfall data.
- Water availability analysis indicated that the Kharun river is an intermittent river having ample flow during monsoon season and marginal flow for 2-3 months thereafter. The estimated average annual rainfall in Kharun basin was observed 1147 mm producing 1802.88 MCM average annual runoff. To fulfill the various water demands during lean period, the Ravishankarsagar reservoir and other sources add around average 116.22 MCM water in the river and which is being supplied to Raipur city, railways and industrial area through the series of anicuts.
- The total water demand to be met from Kharun in year 2010-11 was 65.21 MCM which will become 174.56 MCM by the year 2050-51. When water demand will increases to 133 MCM (in 2030-31) and 175 MCM (in 2050-51) the water deficit will become 73.56 MCM and 105.33 MCM respectively.
- To meet the future water demands, four possible sites were identified and proposed on Kharun river for construction of small dam.
- The infiltration rates observed in three main types of soil i.e. Kanhar, Matasi and Sandy Murrum or sandy soil were 1.0, 2.4 and 3.7 cm/hr respectively
- Two workshops on PDS outcomes were organized at State Water Data Centre, WRD, Raipur on 9th December, 2011 and 28th June, 2013 for dissemination of knowledge among filed engineers and various stakeholders and beneficiaries.

**Photos and Images**



Bhatagaon anicut for water supply to Raipur city at Bhatagaon Anicut

Field visit to Kharun river basin for hydrological investigations


Pump house at Murethi anucut for water supply to Silthara industrial area

Engg-In-Chief, WRD, CG addressing the First PDS Workshop at Raipur in Dec, 2011

## 4.11 STUDY OF RESERVOIR SEDIMENTATION, IMPACT ASSESSMENT AND DEVELOPMENT OF CATCHMENT AREA TREATMENT PLAN FOR KODAR RESERVOIR IN CHHATTISGARH STATE

*Principal Investigator :* *Mr. R. K. Jaiswal (from NIH)*

### 4.11.1 Introduction

The process of sedimentation embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction of sediment. The study of erosion and sediment yield from catchments is of utmost importance as the deposition of sediment in reservoir reduces its capacity, and thus affecting the water availability for the designated use. Negative effects of sedimentation tend to become more and more relevant on a global scale due to population growth, the increasing vulnerability of many territories, and more severe climatic conditions, which facilitate more and more soil erosion. Amongst several causes of soil erosion and loss of nutrients, the major ones are improper and unwise utilization of watershed resources without any proper vision, which is observed more in developing countries (FAO, 1985). An effective catchment area treatment (CAT) plan of a water resources project is a key factor to make the project eco-friendly and sustainable. For CAT studies, the sub-watersheds can be prioritized on the basis of slope, geomorphic characteristics, soil erosion and sediment yields, land use/land cover etc. In the prioritization and identification of suitable measures of soil and water conservation, the GIS may be considered as the most effective and viable tool for considering the interaction between the spatially distributed resources.

In the present study, sub-watersheds have been prioritized using Saaty's analytical hierarchical process (Saaty, 1980) considering nine different erosion hazards parameters (EHPs). The Analytical Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. It involves building a hierarchy (Ranking) of decision elements and then making comparisons between each possible pair in each cluster (as a matrix) and gives a weighting for each element within a cluster (or level of the hierarchy) with a consistency ratio (useful for checking the consistency of the data). The hydrologic behaviors of watershed play an important role in its effective management (Shin-Min et al. 2002). In the present study, Soil and Water Analysis Tool (SWAT) has been used for runoff/ sediment modeling and impact assessment analysis of CAT plan.

### 4.11.2 Study Area

The Kodar reservoir has been selected for the systematic and scientific study of reservoir sedimentation, sediment yield from catchment areas, prioritization of catchment for soil conservation measures, sediment modeling in the inflowing rivers and impact assessment analysis on runoff and sediment inflows in the reservoir. The Kodar reservoir is constructed across river Kodar, a tributary of river Mahanadi and first impounded in 1976-77. The catchment area of the river up to dam site is 317.17 sq. km. and mean annual rainfall in the catchment area is about 1433.1 mm. The dead storage capacity and gross storage capacity of reservoir are 11.33 MCM and 160.35 MCM respectively. The base map showing location of Kodar reservoir has been given below.

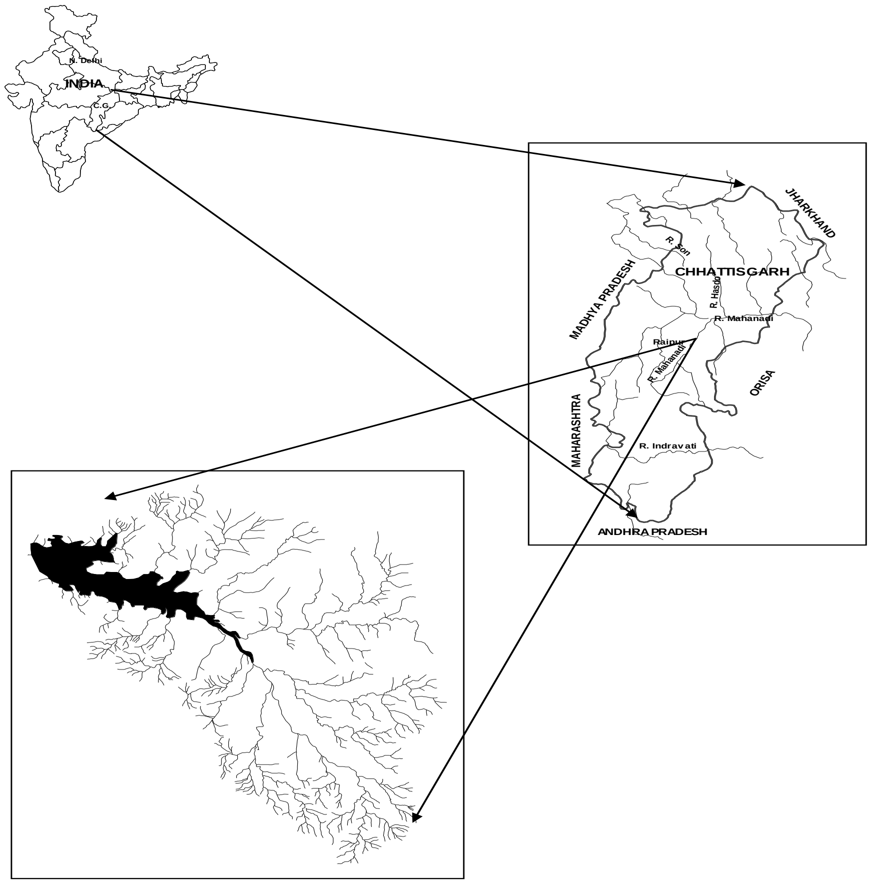



Figure 4.57: Base map of Kodar reservoir

### 4.11.3 Objectives

The Kodar reservoir which is constructed on river Kodar, a tributary of river Mahanadi has been selected for the systematic and scientific study of reservoir sedimentation prioritization of catchment for soil conservation measures, sediment modeling in the inflowing rivers and impact assessment analysis on sedimentation with the following objectives:

- Assessment of present status of reservoir storage by estimating revised capacity using remote sensing approach.
- Sediment modeling.
- Assessment of soil loss from catchment area.
- Prioritization of catchment area based on geomorphological characteristics, sediment yield and risk of erosion and soil loss from sub-catchments.
- Impact assessment analysis

- Development of management plan for catchment area with area specific soil conservation measures for minimizing sedimentation in reservoir.

## 4.11.4 Methodology

### 4.11.4.1 Creation of Data Base in GIS and Data Collection

For development of GIS data base, various thematic maps including catchment and command areas, river network, road network, geology, geomorphology, soil, contour, digital elevation model (DEM),village maps have been prepared in Integrated Land and Water Information System (ILWIS 3.0 & 3.6) and Arc GIS 9.3. The long-term meteorological data of Raipur has been collected from 1981 to 2012 and analyzed for preparation of weather generator in SWAT model. A gauging site on river Kodar near Koma village has been maintained for collection of discharge data and sediment samples from 2010 to 2012. Multi-date LISS III and LISS IV data of IRS 1D/P6 have been purchased from NRSC Hyderabad for revised capacity estimation and land use detection.

### 4.11.4.2 Revised Capacity using Remote Sensing and GIS

The basic principle of revised capacity estimation using remote sensing and GIS is that when the sedimentation occurred in a reservoir its water spread reduced with respect to its original area before impoundment and the revised water spreads at different levels can be computed with the help of image analysis technique of GIS software. The normalized difference water index (*NDWI*), normalized difference vegetation index (*NDVI*), band ratio, NIR (*Band III*) and false color composite (*FCC*) have been used to identify the water pixels in the images. The slicing operation of the *NDWI*, *NDVI*, *Band IV* or *BR* images has been carried out to extract the water pixels from the rest. The revised cumulative capacities have been obtained by adding the revised volumes between consecutive intervals.

### 4.11.4.3 Soil Investigation for soil erosion and sediment modelling

The detachment, entrainment and transportation which are the primary processes in soil erosion and sediment modeling may vary with the soil characteristics require detail soil analysis and their spatial distribution in the catchment. In the present study, infiltration tests using double ring infiltrometer, saturated hydraulic conductivity using Guelph permeameter, particle size analysis using coarse sieve and pipette analysis, sp. gravity using density bottle and dry density using core cutter method have been estimated on eleven sites covering all types of soils in the study area.

### 4.11.4.4 Prioritization of Sub-Watersheds using Saaty's AHP

The Saaty's AHP constructs a matrix of pair –wise comparisons (ratios) between the factors affecting the decision. In the present study, nine different factors may be termed as erosion hazards parameters (EHPs) including soil loss (*SL*), sediment production rate (*SPR*), sediment yield (*SY*), sediment production index (*SPI*), slope (*SLP*), drainage density ($D_d$), channel frequency ($C_f$), form factor ($R_f$) and circulatory ratio ($R_c$) covering topographical, land use, management, geology and geomorphological characteristics of catchment. The relative importance between two factors can be scaled between 1 and 9. The normalized principal Eigen vector which is called priority vector can be used to assign the weights for different EHPs. The Principal Eigen value ($\lambda_{max}$) of priority vector may be computed by the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix. The consistency of judgment can be checked by estimating consistency ratio. If the consistency ratio is less than 10%, the decision may be considered as consistent. On the basis of final priority, all sub-watersheds of Kodar catchment has been grouped in five classes of priority namely very high, high, moderate, low and very low on the basis of priority ranking.

#### 4.11.4.5 Development of Catchment Area Treatment (CAT) Plan

The CAT plan pertains to preparation of a management plan for treatment of erosion prone area of the catchment through mechanical, agronomic and biological measures. The CAT plans were prepared by overlaying the various thematic and base maps using ILWIS GIS software. The land use map obtained from digital image analysis of RS data, soil, hydro-geomorphology, slope and sub-watershed themes were built as raster features, whereas streams and roads were built as line features. The slope, land use and soil map have been crossed and an attribute table can be created to define various agronomic measures considering soil and slope for agriculture land. This attribute table has been used to generate a map showing the suitable areas for various agronomic measures. The biological measures have been suggested in barren and open forest for generation of source of income for rural population.

### 4.11.5 Application of SWAT Model

In the study, the SWAT model has been applied on Koma G/D site where gauging of runoff and sediment have been carried out and after calibration and validation the model has been applied on Kodar reservoir catchment for impact assessment analysis. The calibration of SWAT model has been conducted on Koma G/D site where discharge and sediment data for the year 2010, while the validation has been carried out using independent data of year 2011and 2012 collected by WRD Raipur. The Nash-Suctliff efficiency ( $\eta$ ), root mean square error (*RMSE*), integral squared error (*ISE*), relative error in peak (*REP*) and graphical representation etc. have been used to judge the model performance during calibration and validation.

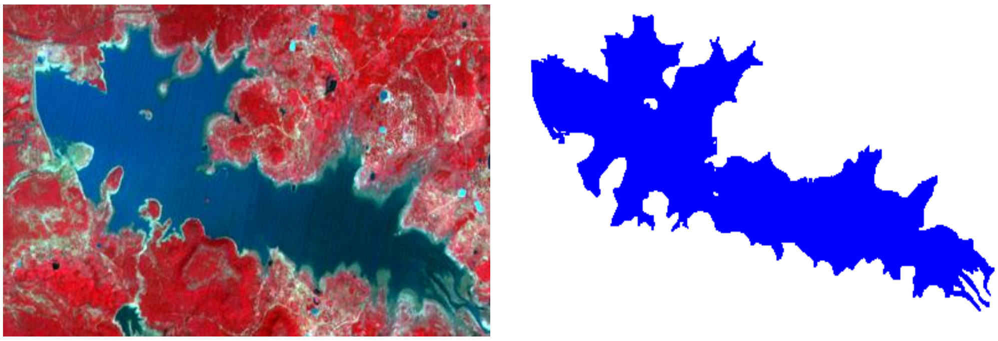
#### 4.11.5.1 Impact Assessment Analysis

The best management practices (BMP) refer to a variety of agronomic, biological and mechanical conservation measures to minimize the production and transport of sediments. Before carrying out impact assessment analysis, considering the present status of watershed, a simulation run with base line data for the watershed can be made and the resultant runoff, sediment and water quality can be saved as baseline data for comparison. The targeted areas in the watershed may be the areas of high erosion, excessive slope, environmentally stressed areas with concentrated development activities. After changing the necessary parameters in their respective files, these files are rewritten and simulate the run again and save it as another scenario. The comparison of runoff, sediment or water quality parameters with base line results can be made to see the impact of implementation of BMPs using SWAT model.

## 4.11.6 Results and Analysis

### 4.11.6.1 Estimation of Revised Capacity

For estimation of revised capacities at different levels of Kodar reservoir, eight different IRS LISS III images to cover whole range of live storage have been identified and purchased from NRSC, Hyderabad. The *NDWI*, *NDVI* and band ratio (*BR*) followed by slicing methods of image classification have been used to differentiate the water pixels from other land uses. The False Color Composite (FCC) and masked out water spread areas of one date has been presented in Fig. 11.2. The original and revised capacity curves for Kodar reservoir has been depicted in Fig. 11.3. The sedimentation analysis of Kodar reservoir indicated that 24.94 Mm$^3$ of gross storages and 4.89 Mm$^3$ of dead storage have been lost in 32 years (1976-77 to 2008-09).



(a) FCC (b) Extracted water spread

Figure 4.58: FCC and extracted water spread on Oct 24, 2009 (Res. Level: 291.69 m)

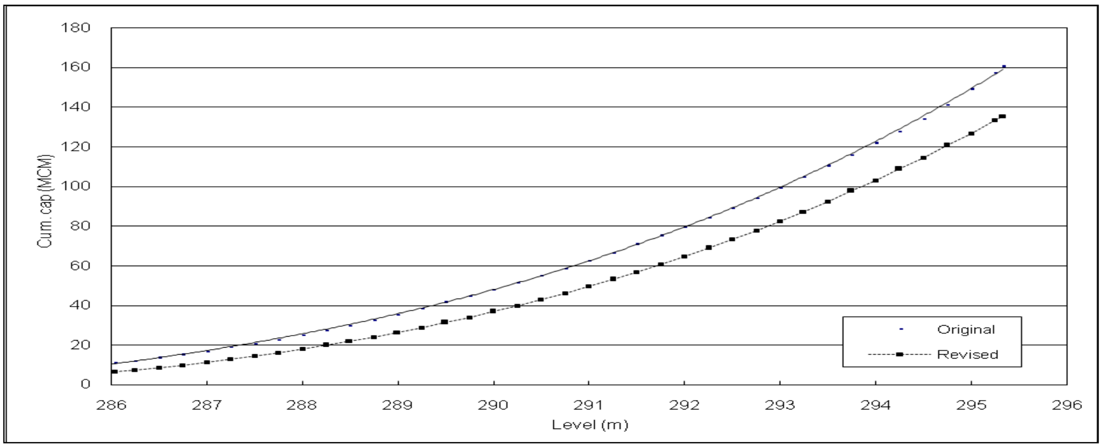



Figure 4.59: Original and revised capacity curves of Kodar reservoir

### 4.11.6.2 Soil Investigation

In the present study, considering the spatial distribution of various soils in the study area, detail soil investigation consisting of in-situ soil tests including infiltration test using double ring infiltrometer, saturated hydraulic conductivity test using Guelph permeater, bulk density and dry density using core cutter method and laboratory tests consisting of textural analysis using sieve and pipette analysis and sp. gravity using density bottle have been conducted on eleven sites in Kodar reservoir catchment. The results of infiltration tests indicated that modified Kostikov's model has been found best fitted infiltration model for Kherwar, Patewa, Thumsa, Gaboud, Khalari, Koma, Paterapali and Churki site. The Kostikov's model can be fitted well with the observed data of infiltration tests on Gaboud, Nawapara, Saraipali and Nawadih sites. It has been observed that the field saturated hydraulic conductivity in the study area varies between 0.10 cm/hr to 88.95 cm/hr. The soils in the study area are mainly silt loamy and sandy loam which is prone to erosion and conservation measures are necessary to reduce displacement of soils.

### 4.11.6.3 Watershed Prioritization

For prioritization purposes, the whole Kodar catchment has been divided into sixty seven sub-watersheds with area ranging from 0.05 sq. km. to 13.05 sq. km. In the present study, spatial distribution of all selected EHPs including soil loss using USLE/RUSLE model (*SL*), sediment production rate (*SPR*), sediment yield (*SY*), sediment transport index or sediment transport index (*STI*), slope (*SLP*), drainage density ($D_d$), channel frequency ($C_f$), form factor ($R_f$) and circulatory ratio ($R_c$) for all 67 sub-watersheds in Kodar reservoir catchment have been computed and converted to its normalized value. Considering the relative importance of each parameter on others, the priority matrix and subsequently the weights for each parameters using Saaty's AHP have been computed. The soil loss being the most important parameter got weight of 0.33 while circulatory ratio given minimum weight of 0.02 in Satty's AHP decision tool. The final priority for each watershed has been determined as a product of multiplication of priority weights and normalized values of all parameters. The sub-watersheds in Kodar catchment has been categorized in various groups including very high, high, moderate, low and very low priority groups. The priority map of Kodar catchment has been given in Fi[illegible]

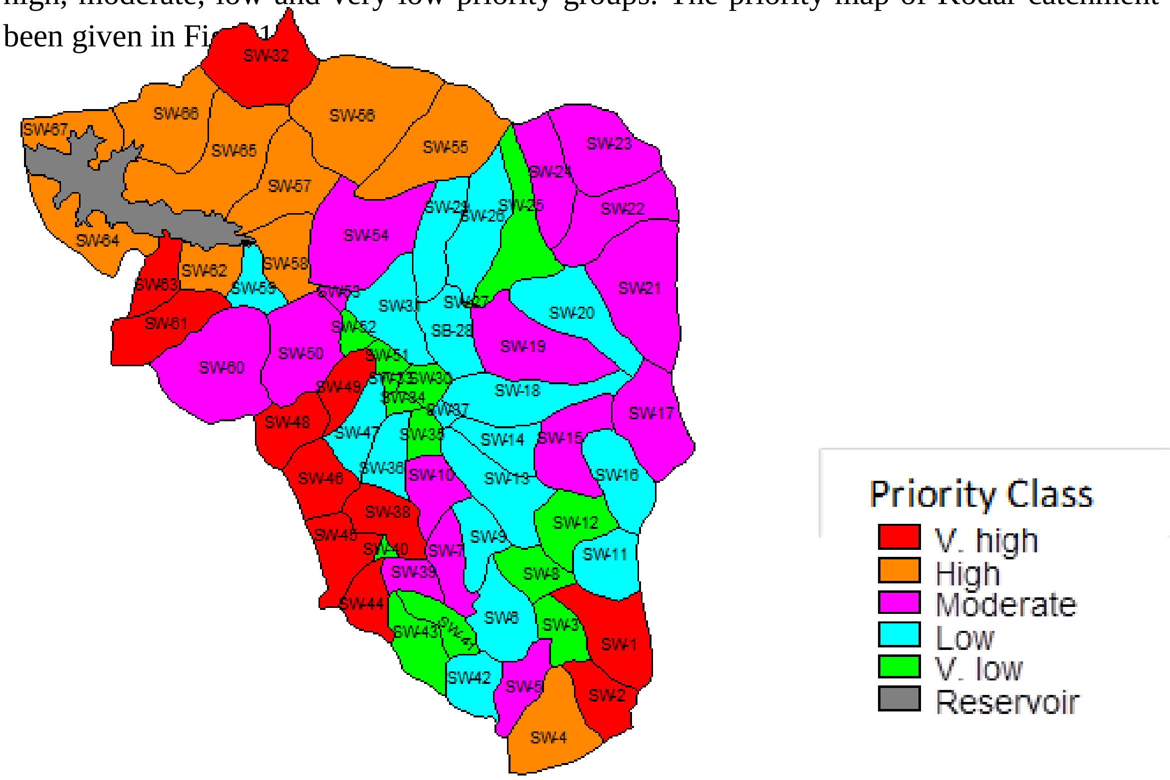



Figure 4.60: Priority sub-watersheds in Kodar catchment

### 4.11.6.4 CAT Plan

The cat plan for the Kodar catchment has been designed by crossing of landuse, soil, slope and geomorphology maps. Standard guidelines have been used for demarcation of areas suitable for agronomic and biological measure. An attribute table in ILWIS has been prepared for crossed map to determine suitable areas under different gram panchayats in the study area. Mechanical measures in the catchment have also been suggested including check dams, gully plug, nala plugs and boulder bunds. The map showing CAT plan of the study area consisting of suitable areas for agronomic and biological soil conservation measures and location of mechanical measures have been given in Fig. 11.5. The CAT plan suggests 101.61 ha land for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land with 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams in Kodar catchment. The agronomic measures should be used in all agriculture fields.

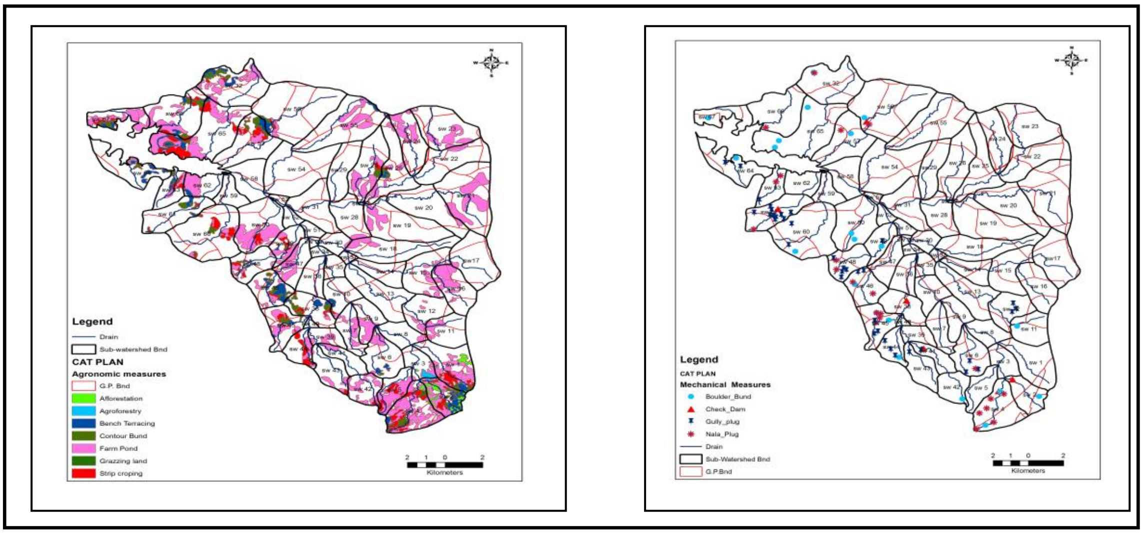



Figure 4.61: CAT plan for Kodar reservoir catchment

### 4.11.7 SWAT Model

The Arc-GIS based SWAT model has been set up at Koma G/D site of river Kodar and full Kodar basin using soil, DEM, land use map along with meteorological data (Fig. 11.6). The sensitivity analysis has been performed using observed data of runoff and sediment data of year 2010 and 2011. From the analysis of sensitivity simulation, it has been observed that the threshold depth of water in shallow aquifer required for return flow to occur (GWQMN) is very important for runoff, while Manning's N for main channel (CH_N2) is the most important from sediment concentration point of view. The output of the results consisting computed runoff and sediment load were compared with observed runoff and sediment load using standard performance indicators. The validation of SWAT model has been carried out using independent data of rainfall, climate, runoff and sediment load for the year 2011 & 2012 separately and all statistical goodness of fit have been computed. From the analysis of goodness of fit measures in calibration, validation and graphical representation of observed and computed values (Fig. 11.7), it has been observed that SWAT model work reasonably satisfactorily in validation and hence it can be used for modeling for other years with calibrated parameters.

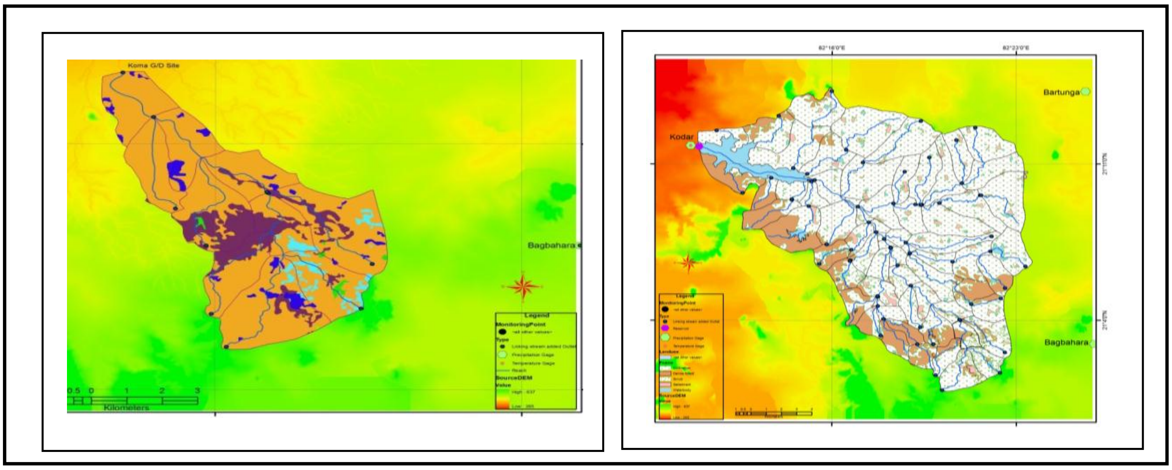
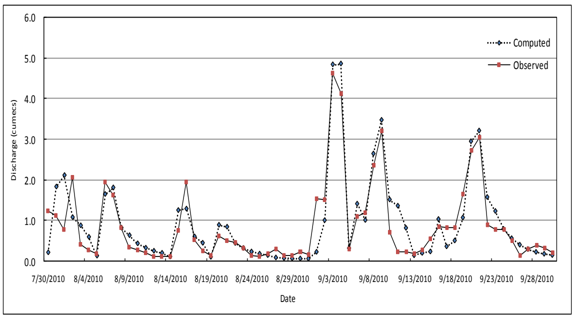
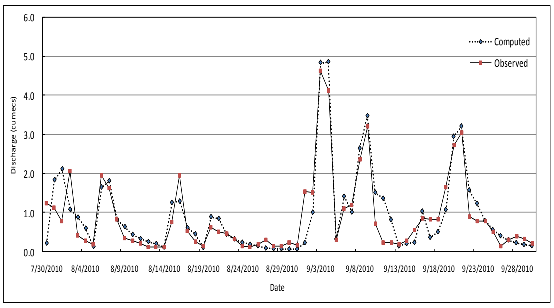


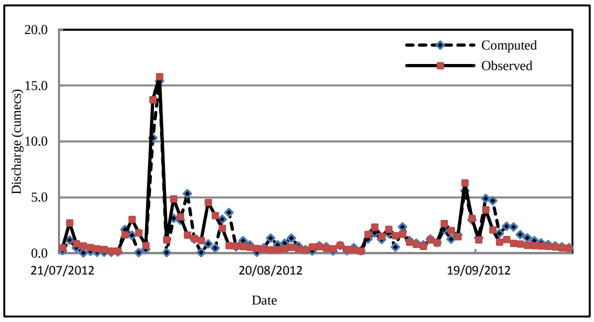

Figure 4.62: SWAT Model setup for Koma G/D site & Kodar reservoir catchment



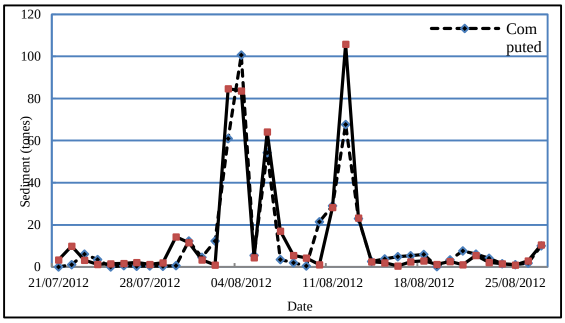

Runoff (calibration, 2010)




Sediment load (calibration, 2010)




Runoff (validation, 2012)




Sediment load (validation, 2012)

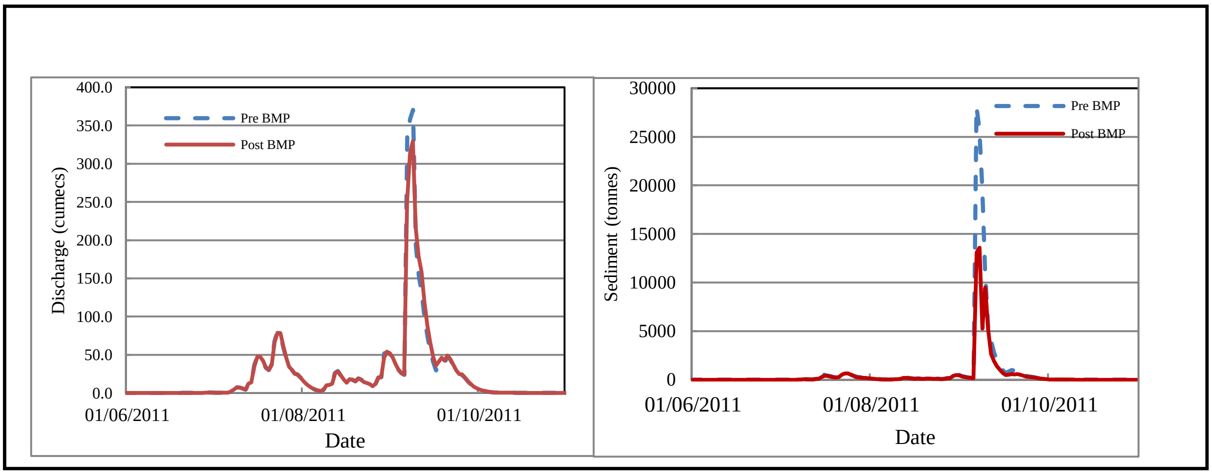
Figure 4.63: Comparison of observed and computed runoff and sediment load during calibration and validation of SWAT model

#### 4.11.7.1 Impact Assessment Analysis

In the study, SWAT model for Kodar reservoir catchment has been set up to analyze the impact of proposed CAT plan on sediment load in the reservoir by considering two scenarios. In the first scenario, the base line data with no or minimum conservation practices have been considered (Pre-BMP). In the second scenario (Post-BMP), the effect of various mechanical, biological and agronomic measures such as gully plug, terraces, stream bank stabilization, conservation structures, afforestation etc applied in different sub-watersheds have been assessed by changing parameters in different files of SWAT model. The graphical representation of runoff and sediment concentration for the year 2011 for Kodar catchment has been presented in Fig. 11.8. The results indicated that maximum monthly sediment load was computed as 2.97 t/ha in the month of Sept 2011 can be reduced to 1.63 t/ha, if suitable soil conservation measures and BMP applied in the catchment under same rainfall condition. The analysis suggested that there will be small reduction in runoff and availability of water for irrigation will not be affected if conservation measures are adopted in the catchment.

### 4.11.7.2 Recommendations and Applications

The soil erosion and sediment transport is spatial phenomena varies with space and time require inputs that vary with space, therefore, a GIS database of study area has been developed which will be useful for further monitoring and implementation of conservation measures. The conventional techniques of reservoir sedimentation such as sounding and inflow-outflow technique should be applied to know the exact status and position of sediment deposits after interval of 10 to 15 years. The recent technique of digital image analysis technique of remote sensing should be applied after the interval of 5 years so that loss of capacities in live storages can be determined and reservoir operation plan can be modified accordingly.




Runoff Sediment load

Figure 4.64: Impact assessment of BMPs on runoff and sediment production in Kodar catchment

Each reservoir project should be developed with sound and scientific catchment area treatment plan so that the incoming sediment in the reservoir can be reduced up to considerable extent. The awareness regarding agronomic and biological measures should be developed among the farmers by local level awareness program. The participation of local governance and rural department organizations and local population should be ensured in development and implementation of CAT plan. The sediment model developed in the PDS can be used for determination of runoff and sediment load and impact assessment in other projects of the region. The proposed methodology can be used as state of art technology for development of CAT plan and soil conservation measures during design of water resources projects in the region.

### 4.11.8 Conclusions

The important conclusions drawn from this study are given below:

- The sedimentation analysis of Kodar reservoir indicated that 24.94 $Mm^3$ of gross storages and 4.89 $Mm^3$ of dead storage have been lost in 32 years (1976-77 to 2008-09).
- The land use analysis using supervised classification of LISS IV data concluded that the Kodar reservoir catchment is an agriculture watershed covering 80% area under agriculture.
- The soils in the study area are mainly silt loamy and sandy loams which are prone to erosion and conservation measures are necessary to reduce displacement of soils. The sp. gravity of soils in the region ranges from 2.21 to 2.59.
- The whole Kodar catchment has been divided into sixty seven sub-watersheds with area ranging from 0.05 sq. km. to 13.05 sq. km. The soil loss (*SL*) has maximum weight as 0.33, while circulatory ratio ($R_c$) with weight of 0.02 exhibits the least importance in prioritization decision.
- The AHP analysis suggested that more than 21 sub-watersheds covering 117 sq. km area of Kodar reservoir catchment fall under very high and high priority.
- The CAT plan suggests 101.61 ha land can be used for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land which will be beneficial for rural population for their additional income and environmental health of the watershed.
- It may be concluded that nearly 41 sq. km area in Kodar catchment is suitable for farm ponds. The mechanical measure under the CAT Plan of Kodar reservoir catchment includes 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams.
- The Nash-Suctliff efficiency ($\eta$) and root mean square error (*RMSE*) have been found as 80.46 % and 0.055 for runoff while the same have been computed as 91.16 % and 0.407 for sediment during calibration. In the validation, efficiency of model was found as 83.65% for runoff and 70.04 % for sediment with independent data of 2011 indicative of reasonably appropriate match.
- The simulation run has been made for 2010 to 2012 data with base line scenario (Pre BMP) and improved scenario (Post BMP) in impact assessment analysis. From the analysis of results of impact assessment analysis, it may be concluded that the maximum sediment load under Pre-BMP scenario in the month of Sept 2011 which was 2.97 t/ha can be reduced to 1.63 t/ha under same rainfall condition, if suitable measures applied in Kodar catchment.

## Photos and Images

Pictorial view of Kodar reservoir

Discussion of officials for activities under PDS

Soil testing

# 5 CAPACITY BUILDING AND TRAININGS

Training programs on the specialized topics were conducted for dissemination and knowledge sharing among the participating States and Central agencies. Total Trainings and Workshops organized under HP-II are given in Table 5.1. The year wise details of these trainings workshops are provided in Table 5.2 to Table 5.9 .

The Scientists of the Institute also received foreign trainings during HP-II. The details of these trainings workshops are provided in Table 5.2 to Table 5.9 .

Table 5.1: Total Trainings Workshops and Workshops organized under HP-II

| S. No. | Year of the Training Course | No. of Training Course | Total Number of Participants |
|---|---|---|---|
| 1. | 2006-2007 | 5 | 219 |
| 2. | 2007-2008 | 6 | 163 |
| 3. | 2008-2009 | 10 | 282 |
| 4. | 2009-2010 | 19 | 588 |
| 5. | 2010-2011 | 17 | 483 |
| 6. | 2011-2012 | 17 | 487 |
| 7. | 2012-2013 | 13 | 327 |
| 8. | 2013-2014 | 13 | 280 |
| **Total** | | **100** | **2829** |

Table 5.2: Training Programs/ Workshops Organized During the Year 2006-07

| S.No. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1 | Workshop on "Preparedness Review for DSS (Planning)" | July 12-13, 2006 | Roorkee | 65 |
| 2 | Application of Surface Water Data Processing Software with Special Emphasis on SWDES | Aug. 28-30, 2006 | Roorkee | 9 |
| 3 | Training Course on Applications of Modern Techniques in Practicing Hydrology | Oct. 9-13 2006 | Roorkee | 47 |
| 4 | Interactive Workshop for Prioritization of Structure, Inputs and Outputs of DSS (Planning) | Nov. 22-24 2006 | Roorkee | 62 |
| 5 | Training course on Hydrological Modelling | March 07-09, 2007 | NWA, Pune | 36 |
| **Total Number of Participants** | | | | **219** |

Table 5.3: Training Programs/ Workshops Organized During the Year 2007-08

| S.N. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1 | Training Program/ Workshop on, "SWDES and/or HYMOS" | May, 14-19, 2007 | Shimla | 29 |
| 2 | Training Program/ Workshop on, "Integrated Water Resources Development and Management (IWRDM)" | May, 28-June 1, 2007 | Roorkee | 24 |
| 3 | Training Program/ Workshop on, "SWDES and/or HYMOS" | July,9-20, 2007 | Chennai | 31 |
| 4 | Training Program/ Workshop on, "Application of RS and GIS in Water Resources Management" | October, 2007 (first week) | Roorkee | 23 |
| 5 | Organised Training course on Data Processing and Validation using SWDES and HYMOS, | November 12-16, 2007 (5 days) | Thiruvana nthapuram | 29 |
| 6 | Training Workshop on, "Project Hydrology" | February 25-29, 2008 | Roorkee | 27 |
| **Total Number of Participants** | | | | **163** |

Table 5.4: Training Programs/ Workshops Organized During the Year 2008-09

| S.N. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1. | Training Course on Applications of Remote Sensing and GIS in Water Resources Management | May 06-08, 2008 | Roorkee | 22 |
| 2. | Training Course on Data Processing and Validation using SWDES | June 09-13, 2008 | Shimla | 32 |
| 3. | Training Course on Data Processing and Validation using SWDES and HYMOS | July 21-25, 2008 | Chennai | 29 |
| 4. | Training Course on Applications of RS and GIS in Water Resources Management | October 20 – 24, 2008 | Roorkee | 21 |
| 5. | Training Course on Data Processing and Validation using SWDES and HYMOS | November 17-21, 2008 | Goa | 34 |
| 6. | Training Course on Emerging Trends in Groundwater with special reference to coastal aquifers | December 15-19, 2008 | Kakinada | 22 |
| 7. | Training Course on Basic Surface Water Data Processing (HYMOS4) | January 12 – 16, 2009 | Gandhinag ar | 28 |
| 8. | Training Course on Water Quality Assessment and Management | February 2 - 6, 2009 | Belgaum | 23 |
| 9. | Inception Workshop on DSS (Planning) for Integrated Water | Feb 9-10, 2009 | New Delhi | 47 |

| | | | | |
|---|---|---|---|---|
| | Resources Development and Management | | | |
| 10. | Training Course on Project Hydrology | Feb 23-27, 2009 | Anand | 24 |
| **Total Number of Participants** | | | | **282** |

Table 5.5: Training Programs/ Workshops Organized During the Year 2009-10

| S.N. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1. | DSS Needs Assessment Workshop | August 05 - 06, 2009 | New Delhi | 60 |
| 2. | Hydrological Modelling | September 14-18, 2009 | NIH, Roorkee | 22 |
| 3. | Project Hydrology | Sept. 21-23, 2009 | RC Kakinada | 26 |
| 4. | Training Course on SWDES/HYMOS Software | Sept. 24-Oct. 1, 2009 | Goa | 35 |
| 5. | Rainfall Runoff and River Basin Modelling | Oct., 19-23, 2009 | NIH, Roorkee | 25 |
| 6. | Hydrological Studies for Major & Medium Irrigation Projects | Oct. 26-Nov. 6, 2009 | NIH, Roorkee | 16 |
| 7. | Rainfall Runoff and River Basin Modelling for Five States & Central Agencies | Oct. 26, Nov. 6, 2009 | NIH, Roorkee | 24 |
| 8. | Water Quality & its Assessment | Nov. 9-13, 2009 | CSMRS, New Delhi | 17 |
| 9. | Rainfall Runoff and River Basin Modelling for Four States & Central Agencies | Nov. 9-20, 2009 | NIH, Roorkee | 25 |
| 10. | DSS(P) for Decision Makers | Nov 11, 2009 | New Delhi | 71 |
| 11. | Ground Water Assessment, Modelling and Management | Nov. 16-20, 2009 | HRRC, NIH, Belgaum | 30 |
| 12. | Training Course on Data Processing and Validation using SWDES & HYMOS Software | Nov. 30-Dec. 4, 2009 | Nasik | 18 |
| 13. | Workshop on DSS(P) Model Conceptualization | January 7, 2010 | New Delhi | 72 |
| 14. | Flood Management | Jan. 18-22, 2010 | WALMI, Anand | 31 |
| 15. | Rainfall Runoff and River Basin Modelling | Jan 25 - Feb 5, 2010 | NWA, Pune | 24 |
| 16. | Training Workshop on SWDES and/or HYMOS | Feb 3-6, 2010 | WALMI, Anand | 24 |
| 17. | Rainfall Runoff and River Basin | Feb 08 - 19, | NIH, | 24 |

| | | | | |
|---|---|---|---|---|
| | Modelling | 2010 | Roorkee | |
| 18. | Training Workshop on SWDES and/or HYMOS | Feb 09-12, 2010 | Shimla | 28 |
| 19. | Application of Remote Sensing and GIS in Water Resources | March 8-12, 2010 | Roorkee | 16 |
| **Total Number of Participants** | | | | **588** |

Table 5.6: Training Programs/ Workshops Organized During the Year 2010-11

| S.N. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1 | Workshop on "Groundwater Modelling and Planning Issues for DSS(P)" | June 10, 2010,(1day) | New Delhi | 49 |
| 2 | Workshop on "DSS(P) Database Development" | June 11, 2010,(1day ) | New Delhi | 68 |
| 3 | Training Course on "Water Quality Monitoring Analysis and Management" | June 29-July 1, 2010 (3 days) | Shimla | 26 |
| 4 | Training Course on "Predictions in Ungauged Basins" | July 26-30, 2010,(5 days) | Roorkee | 22 |
| 5 | Workshop on "Demo Presentation of DSS(P) Software" | July 30, 2010 (1 day) | New Delhi | 54 |
| 6 | Training Course on "Ground Water Modelling" | Sept. 20-24, 2010,(5 days) | Roorkee | 23 |
| 7 | Training Course on "Urban Hydrology" | 04-06 Oct., 2010 (3 days) | Chennai | 21 |
| 8 | Training Course on "Soil erosion modelling and reservoir sedimentation" | Oct. 11-13, 2010 (3 days) | BBMB Chandigarh | 23 |
| 9 | Training Course on "Coastal Groundwater Modelling & Management" | Nov. 22-26, 2010 (5 days) | Anand | 26 |
| 10 | Training Course on "Data Entry and Processing Using SWDES" | Nov. 30-Dec 02, 2010 (3 days) | Thiruvananth apuram, Kerala | 21 |
| 11 | Training Course on "Hydrologic Extremes – Prediction, Management & Mitigation" | Dec, 06-10, 2010 (5 days) | Belgaum, Karnataka | 10 |
| 12 | Workshop on "Generic DSS(P) Development" | Jan 9, 2011(1 day) | New Delhi | 52 |
| 13 | Training Course on "DSS Introduction and Case Study Support" | Jan.10-21, 2011 (2 Weeks) | Roorkee | 16 |
| 14 | Training Course on "Dash Board Manager for DSS(P)" | Jan. 24-28, 2011 (5 days) | Roorkee | 10 |
| 15 | Training Course on "DSS Introduction and Case Study Support" | Feb. 7-18, 2011 (2 Weeks) | Roorkee | 20 |
| 16 | Applications of remote sensing and GIS in water resources management | Feb. 21-25, 2011 (5 days) | Roorkee | 16 |

| | | | | |
|---|---|---|---|---|
| 17. | Training course on Application of Modern Techniques in Hydrological Modelling | March 3-5, 2011 | WALMI, Anand | 26 |
| **Total Number of Participants** | | | | **483** |

Table 5.7: Training Programs/ Workshops Organized During the Year 2011-12

| S.N. | Topic | Period | Venue | No. of Participants |
|---|---|---|---|---|
| 1 | Groundwater modeling | 27 June – 1 July (5 days) | NWA, Pune | 22 |
| 2 | Hydrological Processes in an Ungauged Catchment | July 25-29, 2011(5 days) | NIH, Roorkee | 18 |
| 3 | DSS Customization Workshop-I | August 5, 2011 (One day) | New Delhi | 53 |
| 4 | Water Quality and Its Management | Sept 12-14, 2011 | Shimla | 20 |
| 5 | Project Hydrology | Sept. 12-16, 2011(5 days) | Belgaum | 34 |
| 6 | Storm Water Management in Urban areas | Sept. 21-23, 2011 (3 days) | Kakinada | 21 |
| 7 | Drought Monitoring and Management | Oct.31 - Nov.04, 2011 (5 days) | Roorkee | 20 |
| 8 | DSS Customization Workshop-II | Nov. 25, 2011 (One day) | New Delhi | 30 |
| 9 | Surface Water Data Entry and Processing using SWDES | Nov. 16-19, 2011 (4 days) | Goa | 36 |
| 10 | DSS(P) Workshop on DSS customization for Orrisa, Madhya Pradesh and Karnataka | November 25, 2011 | New Delhi | 40 |
| 11 | DSS(P) workshop | January 9-13, 2012 | Roorkee | 18 |
| 12 | DSS(P) workshop | January 16-20, 2012 | Pune | 24 |
| 13 | Data Processing and validation Using SWDES and HYMOS | January 30 – February 3, 2012 | Bhopal | 20 |
| 14 | Climate Change and its Impact on Water Resources | February 06-10, 2012 (5 days) | HRRC, NIH Belgaum | 30 |
| 15 | Basic Hydrology | February 14-16, 2012 | WALMI Anand | 35 |
| 16 | DSS Planning Workshop on DSS Customization for Andhra Pradesh, Kerala and Tamil Nadu | March 2, 2012 | New Delhi | 39 |

| | | | | |
|---|---|---|---|---|
| 17 | Remote Sensing, GIS and GPS for Engineers of Water Resources Department, Karnataka | 19-22 March, 2012 | ATI, Mysore | 27 |
| **Total Number of Participants** | | | | **487** |

Table 5.8: Training Programs/ Workshops Organized During the Year 2012-13

| S. N. | Topic | Period | Course Coordinator | Sponsoring Agency/ Project | No. of Participants |
|---|---|---|---|---|---|
| 1. | Hydrology Online | May 18-19, 2012 NIH, Roorkee | Dr. A.K. Lohani, Scientist E2 | HP-II (Institutional Strengthening) | 32 |
| 2. | Using the Dashboard Manager for making scripts in the DSS | 04-08, June 2012 (5 days) | Sh. D. S. Rathore, Scientist E2, NIH & DHI Consultants | HP-II DSS(P) | 30 |
| 3. | Hydrological Investigation Techniques for Water Resources Development and Management | 27-30 August, 2012 (5 days) | Dr. M. S. Rao, Scientist E1 | HP-II (PDS) | 25 |
| 4. | DSS(P) Sustainability-Issues and Future Plan | August 29, 2012 | Dr. Rakesh Kumar Scientist F & Dr. A.K. Lohani, Scientist E2 | HP-II | 20 |
| 5. | Application of Remote Sensing and GIS in Hydrology | 11-13, Sept 2012 (3 days) | Dr. Chandra Mohan T. Scientist E1 | HP-II | 23 |
| 6. | Storm water modeling in urban areas | 27-28, Sept. 2012 (2 days) | Dr. Y. R. Satyaji Rao, Scientist F | HP-II (PDS ) | 24 |
| 7. | DSS(P) Applications | 4 October, 2012 | Dr. Rakesh Kumar Scientist F & Dr. A.K. Lohani, Scientist E2 & DSS(P) Consultants | HP-II | 29 |
| 8. | Regionalization of Watershed Response in Ungauged Basins: Special Reference to Flood Estimation | Oct. 15-19, 2012 Roorkee | Dr. Pradeep Kumar Bhunya, Scientist E1 | HP-II (PDS) | 26 |
| 9. | Environmental Hydrology with special referance to surface and ground water quality | 29-31, January 2013 Belgaum | Dr. B. K. Purandara Scientist `E1' | HP-II | 22 |
| 10. | GIS in Water Resources Sector" | 18-22 Feb., 2013,WALMI, Anand | Dr S.K. Jain Scientist F & Dr J.V. Tyagi, Sc F | HP-II | 30 |
| 11. | Surface Water Data Processing and its validation Using HYMOS Software | February 25-March 1, 2013. WALMI, Anand | Dr A.K. Lohani, Scientist F | HP-II | 18 |

| | | | | | |
|---|---|---|---|---|---|
| 12. | Rainfall-Runoff Modelling | March 11-15, 2013 | Dr A.K. Lohani, Scientist F | HP-II | 30 |
| 13. | Training Course on Groundwater Investigat ions and Management in Hard Rock Area | March 18-22 2013 | Dr Sudheer Sudhir Kumar, Scientist F | HP-II | 18 |
| **Total Number of Participants** | | | | | **327** |

Table 5.9: Training Programs/ Workshops Organized During the Year 2013-14

| S. N. | Topic | Period | Course Coordinator | Sponsoring Agency/Project | No. of Participants |
|---|---|---|---|---|---|
| 1 | Climate Change and Its Impact on Water Resources | 27-29 August, 2013 | Dr. B. Venkatesh Scientist E | HP-II | 22 |
| 2 | Role of Isotopes in Groundwater Management in India | 12-14 November, 2013 | Dr. Sudhir Kumar Sc. F | HP-II | 11 |
| 3 | Long lead-time Ensemble River and flood forecasting | 18-23 November, 2013 | Dr. Rakesh Kumar, Sc. F | HP-II | 26 |
| 4 | Ground Water Resources Management | 11- 13 December, 2013 | Dr. M.K. Jose, Sc. D | HP-II | 19 |
| 5 | User Interaction Workshop on 'Storm Water Management in coastal urban areas' | 17-19, December 2013 | Dr. Y R Satyaji Rao Scientist F | Chennai (PDS under HP-II) | 20 |
| 6 | Scripting and Dashboard in Decision Support System for Water Resource Planning | 20-24 January, 2014 | Sh. D.S. Rathore Sc. F | HP-II | 17 |
| 7 | Hydrological Analysis using statistical and Stochastic Techniques | 24-28 February, 2014 | Dr. P K Bhunya, Scientist D | HP-II | 12 |
| 8 | Mike Hydro | 3-7 February, 2014 | Dr. A.K. Lohani Sc. F | HP-II | 28 |
| 9 | Coastal Groundwater Development, Modeling and Management | 3-7 March, 2014 | Dr. Anupma Sharma Sc. D | HP-II | 24 |
| 10 | One day workshop on PDS at BBMB Nangal | 10 March, 2014 | Dr. Sanjay Kumar Jain Scientist F | Roorkee PDS (HP-II) | 52 |
| 11 | Application of Remote Sensing in Water | 13-15 March, 2014 | Dr. B.K. Purandara, Scientist D | HP-II | 22 |

| | | | | | |
|---|---|---|---|---|---|
| | Quality Assessment | | | | |
| 12 | Drought Monitoring and Mitigation | 24-25 March, 2014 | Dr. R.P. Pandey Sc. F | Tamil nadu HP-II | 10 |
| 13 | Surface water data entry and processing using SWDES | 18-20 March, 2014 | Dr. Manmohan Kumar Goel Scientist F | Jammu (HP-II) | 17 |
| **Total Number of Participants** | | | | | **280** |

Table 5.10: Foreign Trainings received by NIH Scientists under DSS (P)

| S.No. | Training Name | Name of Scientist | Duration | Venue |
|---|---|---|---|---|
| 1. | Development of Decision Support System | Dr. A.K. Lohani<br>Sc. E1, NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 2. | Development of Decision Support System | Dr. Sanjay Kumar<br>Sc. C, NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 3. | Development of Decision Support System | Sh. D.S. Rathore<br>Sc. E2<br>NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 4. | Development of Decision Support System | Dr. M.K. Goel, Sc. E2<br>NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 5. | Development of Decision Support System | Dr. Vijay Kumar<br>Sc. E1,<br>NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 6. | Development of Decision Support System | Dr. R.P. Pandey<br>Sc. E1,<br>NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 7. | Development of Decision Support System | Dr. Surjeet Singh<br>Sc. C,<br>NIH, Roorkee | 25 Oct. to 12 Nov., 2010 | DHI,Denmark |
| 8. | Use of DSS in Water Resources Management and Application of the Developed DSS Software | Dr. B. Venkatesh<br>RC, Belgaum | 19 Sep. to 7 Oct., 2011 | DHI,Denmark |
| 9. | Use of DSS in Water Resources Management and Application of the Developed DSS Software | Dr. P.C. Nayak<br>RC, Kakinada | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |
| 10. | Use of DSS in Water Resources Management and Application of the Developed DSS Software | Mr. Ravi Galkate<br>RC Sagar | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |
| 11. | Use of DSS in Water Resources Management and Application of the Developed DSS Software | Dr. Anupama Sharma<br>NIH, Roorkee | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |

Table 5.11: Foreign Trainings received by NIH Scientists under HP-II

| S.No. | Training Name | Name of Scientist | Duration | Venue |
|---|---|---|---|---|
| 1. | Water Quality Assessment | Dr. M.K. Sharma<br>NIH, Roorkee | 7 to 25 Feb. 2011 | UNESCO, IHE,<br>The Netherlands |
| 2. | Introduction to River Flood Modelling | Dr. P.K. Bhunya<br>NIH, Roorkee | 26 April to 13 May, 2011 | UNESCO, IHE,<br>The Netherlands |
| 3. | Managing Water Organisations | Dr. Rakesh Kumar<br>NIH, Roorkee | 14 June to 01 July, 2011 | UNESCO, IHE,<br>The Netherlands |
| 4. | Flood risk Management | Dr. Jaiveer Tyagi<br>NIH, Roorkee | 14 June to 01 July, 2011 | UNESCO, IHE,<br>The Netherlands |
| 5. | Applied Groundwater Modelling | Dr. M.S. Rao<br>NIH, Roorkee | 14 June to 01 July, 2011 | UNESCO, IHE,<br>The Netherlands |
| 6. | Climate Change: Earth System, Future Scenarios and Threats | Sh. L.N. Thakural<br>NIH, Roorkee | 13-18 Nov. 2011 | Univ. of New Castle, U.K. |

Table 5.12: Study Tour under taken by NIH Scientist under DSS (P)

| S.No. | Study Tour | Name of Scientist | Duration | Venue |
|---|---|---|---|---|
| 1. | Development of Decision Support System (Planning) | Dr. Rakesh Kumar<br>Sc. F & Nodal Officer,<br>NIH, Roorkee | 8 to 12 Nov., 2010 | South Africa and Denmark |

Table 5.13: International Trainings on Decision Support System DSS (P) Under HP-II

| S.No. | Training Name | Name of Scientist | Duration | Venue |
|---|---|---|---|---|
| 1. | Use of Decision Support System in Water Resources Management and Application of the Developed DSS Software | Sh. H.S. Sengar<br>SJC, MoWR<br>New Delhi | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |
| 2. | Use of Decision Support System in Water Resources Management and Application of the Developed DSS Software | Sh. Ramjeet Verma<br>Dy. Director<br>CWC, N.Delhi | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |
| 3. | Use of Decision Support System in Water Resources Management and Application of the Developed DSS Software | Dr. C Ramesh<br>CWPRS, Pune | 19 Sep. to 7 Oct., 2011 | DHI,Denmark |

| | | | | |
|---|---|---|---|---|
| 4. | Use of Decision Support System in Water Resources Management and Application of the Developed DSS Software | Sh. Shiva Kumar<br>Sc. C<br>CGWB,Chennai | 19 Sept. to 7 Oct., 2011 | DHI,Denmark |

Table 5.14: Study Tour Under Decision Support System DSS (P)

| **S.No.** | **Training Name** | **Name of Scientist** | **Duration** | **Venue** |
|---|---|---|---|---|
| 1. | Development of Decision Support System | Dr. Rakesh Kumar<br>Sc. F & Nodal Officer, NIH, Roorkee | 8 to 12 Nov., 2010 | South Africa and Denmark |
| 2. | Development of Decision Support System | Sh. A.K. Bajaj<br>Chairman<br>CWC, New Delhi | 8 to 12 Nov., 2010 | South Africa and Denmark |
| 3. | Development of Decision Support System | Sh. Sushil Gupta<br>Member (SAM) CGWB, Faridabad | 8 to 12 Nov., 2010 | South Africa and Denmark |
| 4. | Development of Decision Support System | Sh. Ramesh Grover<br>SJC, PCS, New Delhi | 8 to 12 Nov., 2010 | South Africa and Denmark |
| 5. | Development of Decision Support System | Mrs. P. Latika<br>Chief Engineer<br>Water Resources Deptt., Kerala | 8 to 12 Nov., 2010 | South Africa and Denmark |

# 6 EXPENDITURE INCURRED UNDER HP II FROM 2006 TO MAY 2014

**Statement of Expenditure incurred under HP II from 2006 to May 2014**

| Category | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 | 2014-15 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| **Civil Work** | - | - | - | - | - | - | - | 43,71,829 | | **43,71,829** |
| **Goods** | 32,28,856 | 37,90,048 | 88,427 | 61,20,235 | 83,20,952 | 55,96,227 | 16,69,200 | - | | **2,88,13,945** |
| **Consultancy Service** | | - | 3,19,28,450 | 7,69,24,848 | 2,88,65,923 | 6,34,61,307 | 3,38,18,386 | 9,56,65,527 | | **33,06,64,441** |
| **Training** | 5,94,742 | 5,85,086 | 7,64,944 | 7,01,151 | 10,23,403 | 15,38,781 | 8,67,271 | 8,46,933 | 1,41,047 | **70,63,358** |
| **Operating Cost** | 26,89,873 | 45,24,772 | 63,49,303 | 1,09,44,058 | 1,47,96,213 | 1,73,65,220 | 1,93,61,279 | 1,79,59,006 | 33,13,682 | **9,73,03,406** |
| **Total** | **65,13,471** | **88,99,906** | **3,91,31,124** | **9,46,90,292** | **5,30,06,491** | **8,79,61,535** | **5,57,16,136** | **11,88,43,295** | **34,54,729** | **46,82,16,979** |

**Note:** Rs. 36,98,500 was paid for Civil Work in the F/Y 2010-11. However, the same was refunded in the F/Y 2012-13. Hence the expenditure is not included in the total expense of the F/Y 2010-11.

Rs. 80,000 paid for designing of buidling was transferred to Any other head/ operating cost since the building was not constructed and the amount of Rs. 36,98,500 which was given for construction of building was refunded later.

Total expenditure as per FMR is Rs. 472485280, whereas the total expenditure as per Financial statements is Rs. 468,216,979. The difference of Rs. 5,69,801 is on account of advances, which were refunded subsequently, but were shown as expenditure in FMR.

# 7 LESSONS LEARNT

a) Technology advancement, adaptation of the best practices and training and capacity building are essential for integrated water resources development and management.

b) DSS (P) provides a very useful and efficient tool for generating and analysing various scenarios for taking apt decisions.

c) Involvement of planning and design wings of the State Water Resources Departments along with the data centres may lead to larger applicability of the DSS (P) for IWRDM in future.

d) Engineers/ Officers involved in development and implementation of DSS (P) should be retained as their continuity is essential for sustainability of the DSS(P) sofware.

e) Data collection, processing, storage, retrieval and dissemination using the state-of-art knowledge in Information Technology should be encouraged.

# 8 DISSEMINATION OF DATA AND APPLICATION OF HIS/ ONLINE AND WEB APPLICATION OF DSS (P)

a) DSS (P) software has been made online in 11 agencies in 9 states by deploying the software on server.

b) Online application for prediction of post monsoon drinking water scarcity situations was implemented for Maharashtra state.

c) Online application for depicting current and historic reservoir water levels was developed for Maharashtra.

d) Dash Board functionality in the DSS (P) software may be used for dissemination of hydrological data and analysis of the results.

# 9 SUPPORT PROVIDED FOR DSS (P) UNDER WARRANTY PERIOD

| Sr.No | Issue | Action Taken | Action Date |
|---|---|---|---|
| 1 | APSW-HP2 - Renewal of Arc GIS license ( To be expired on 19-sep-2013) | Resolved on | 18-Sep-13 |
| 2 | Updation and training of DSS(P) software for the officers of CGWB | Installation completed in CGWB- Acknowledged by Dr. R.C. Jain | 18-Sep-13 |
| 3 | Asked for the Dashboard installation manual | Dashboard Manual send to Gujarat | 18-Sep-13 |
| 4 | Tamil Nadu - MIKE BASIN and MIKE SHE permanent license issue | Helped them in finding the correct dongle over the phone and forwarded them permanent license of two dongles acknowledged by Ms. Vidhya | 25-Sep-13 |
| 5 | Gujarat requested Reservoir Working Table interface in their format | Developed an interface of Reservoir working table and send it to Gujarat | 25-Sep-13 |

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| 6 | Tamil Nadu reported ArcGIS authorization problem | Send a document to Tamil Nadu describing steps of authorization | 26-Sep-13 |
| 7 | Admin boundaries like district, taluka and village needs to be displayed on scarcity map. | Completed and Demonstrated on Server as well as on Local Work Station. | 26-Sep-13 |
| 8 | According to DHI consultant direct import from GEMS cannot be made, but a tool to import from eGEMS is envisaged. In this regard DHI consultant agreed to help in identifying ways of facilitating the procedure of updating ground water levels. But no significant progress has been seen in this regard. | It's demonstrated that with two simple steps GEMS Data can export in GWDES and that can successfully import in DSS using GWDES Data retrieval utility. | 26-Sep-13 |
| 9 | Problems while accessing the data, and the map layers. | Dashboard has been made operational. It's already demonstrated by connecting Database and Web Server to two workstations using IP address. GSDA requires a static IP address with good internet connection. | 26-Sep-13 |
| 10 | Gujarat requested MIKE 11 license | MIKE 11 license send to Gujarat | 4-Oct-13 |
| 11 | CWC DSS(P) installation | Installed DSS (P) on three new systems acknowledge by MR. Ashish Banerjee, Dir (NWP) & I/C Dir. (RO) | 4-Oct-13 |
| 12 | 3 days MIKE SHE training | Arranged international expert of MIKE SHE | 16-Oct-2013 - 18-Oct-2013 |
| 13 | 2 days water quality training | Arranged international expert of water quality | 22-Oct-2013 - 23-Oct-2013 |
| 14 | Gujarat requested IT Security Audit for DSS (P) | Shared all the useful information with Gujarat and NIH | 7-Nov-13 |

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| 15 | Updation and installation of DSS (P) software in CPCB | Installation completed in CPCB- Acknowledged by Dr. R.M. Bhardwaj | 1-Nov-13 |
| 16 | NIH Mr. Rathore send a Spreadsheet Error | Send a patch for the spreadsheet problem | 6-Nov-13 |
| 17 | Andhra Pradesh - Arc GIS authorization issue | Solved by Remote acces | 26-Nov-13 |
| 18 | Gujarat - Requested for extra license for internal training on MIKE Basin between December 17 to December 21 2013 | Arranged 10 seat network license and dongle courier to Gujarat and also helped them in installation of network license. o DSS installation and queries about DSS statistic tools. | 15-Dec-13 |
| 19 | Gujarat queries about MIKE BASIN Simulations and DSS Tools | Explained them over the phone during their internal training | 17-Dec-2013 - 21-Dec-2013 |
| 20 | Gujarat - Requested for all interfaces in one database | Merged all interfaces and send to Gujarat acknowledge by Mr. Bipin Upadhyay | 6-Dec-13 |
| 21 | Kerala - Requested for extra license for internal training held on December 17 and 18, 2013 | Arranged 2 seat network license and also helped them in installation of network license | 17-Dec-13 |
| 22 | Gujarat - Extension of MIKE 11 license | Extended MIKE 11 License till March 31, 2013 on January 02, 2013 | 2-Jan-14 |
| 23 | NIH requested for extra licenses for Scripting and Dashboard training for all states and central agencies in NIH Roorkee between January 20 to 24, 2013 | Arranged 10 seat network license and also helped them in installation of DSS (P) and MIKE Basin on training machines over the phone | 19-Jan-14 |
| 24 | 5 days MIKE HYDRO -2014 training for all states and central agencies at NIH, Roorkee | Arranged international expert of MIKE HYDRO | 3-Feb-2013 - 7-Feb-2013 |
| 25 | Upgraded DSS (P) software and modelling software | Provided latest DSS (P)software and modelling software to all IA's and CA's with required license | 11-Mar-14 |
| 26 | Gujarat reported crash is spreadsheet manager | Tried to reproduced at our end and forward it to development team | 9-Apr-14 |

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| 27 | Kerala was not able to download MIKE Zero software | Send a software CD to Kerala | 16-Apr-14 |
| 28 | Kerala asked for Support for a NAM problem | Our modeler solved this problem and explained to concern person | 20-May-2014 |
| 29 | Andhra asked for MIKE Hydro manual and requested to upload latest DSS on ftp | We send them MIKE Hydro manual with example database and uploaded DSS (P) on ftp | 27-May-2014 |
| 30 | NIH scientist Dr. Rathore reported problem in dashboard installation | Error resolved on remote access | 10-June-2014 |
| 31 | MP requested us for DSS installation on server | This is in progress on remote access. Not completed yet due to internet problem at their end. | Started 19-June-2014 (waiting for remote access) |
| 32 | Dr. Rathore facing problem in MIKE Hydro model registration | Successfully registered model by changing the projection | 30 –June-2014 |
| 33 | DSS planning 4.0 was not working in Kerala, raising some shell and NGPSQL error. | Installed DSS successfully in their system and explained them some basic functionality | 30 –June-2014 |
| 34 | There was some problem in installation of MIKE Zero 2014 on server and workstation in Kerala. | Installed MIKE Zero on server | 01 –July-2014 |
| 35 | ArcGIS license not working in Gujarat GW Deptt. | Successfully installed | 01 –July-2014 |
| 36 | Few states having problem in DSS 4.0 and MIKEbyDHI download | Dispatched software CD to various states involved in HP-2 | 01 –July-2014 |
| 37 | In Kerala DSS(P) and dashboard does not work on server | Installed DSS(P) and dashboard on server | 02 –July-2014 |

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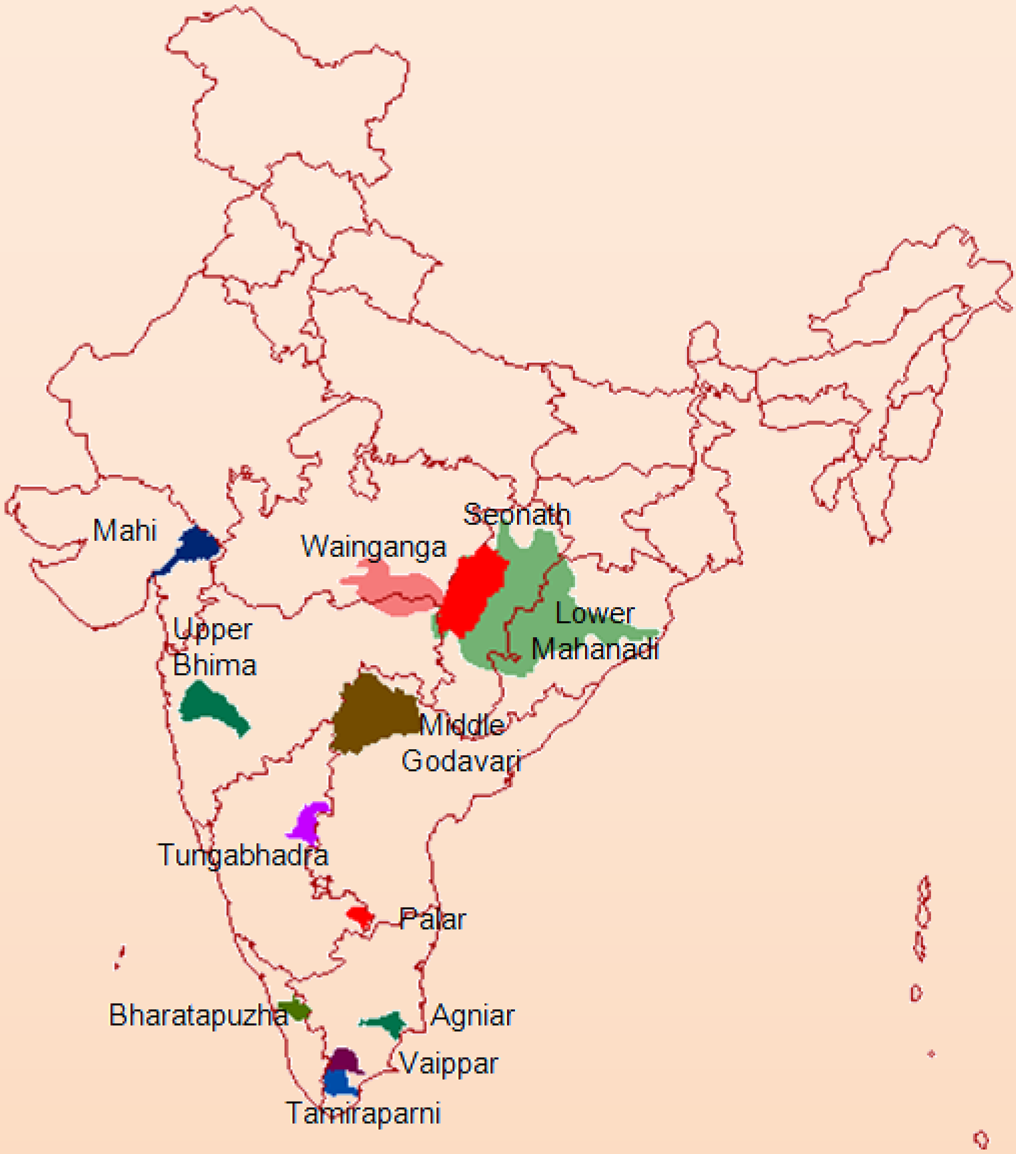
| 38 | DSS up gradation issue in Dr Anupama Sharma's laptop | Installed DSS(P) 4.0 and created Mahi basin model with interfaces. | 03 –July-2014 |
| 39 | Dashboard showing error in GSDA Maharashtra | Updated dashboard files | 03 –July-2014 |
| 40 | Kerala asked for 5 days support for MIKE Hydro and DSS (P) software over phone and remote desktop | We are providing support to Kerala for their issues on pre fixed dates by them | 09 - July – 2014 – On going |

# 10 FUTURE PLANS

- A proposal for AMC of the DSS (P) software for technical support, trainings and maintenance has been prepared by deliberations during the two meetings of the Committee constituted for AMC of the DSS (P) and the same has been forwarded to MoWR for its consideration.

- Trainings for states and central agencies on DSS (P) for sustainability of DSS (P) are proposed to be organized.

- Applications of DSS (P) in selected additional basins of the states are under progress.


Mahi
Wainganga
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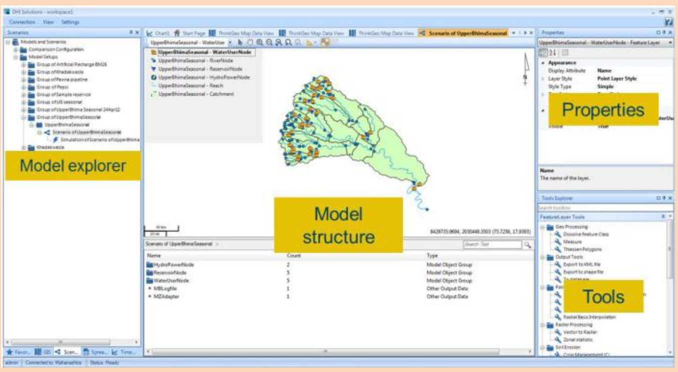
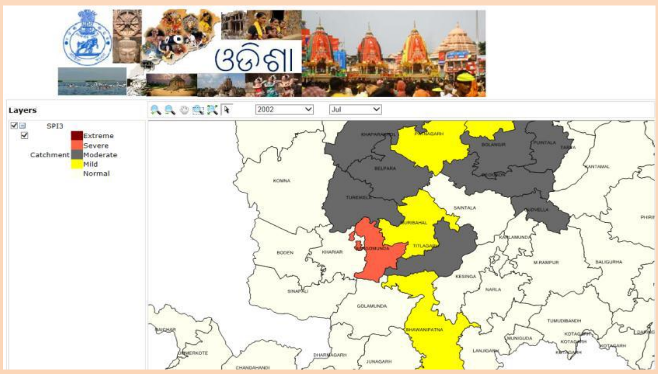

Model explorer
Model
structure
Properties
Tools


Layers
SPI3
Catchment
Extreme
Severe
Moderate
Mild
Normal