

Decision Support System (Planning) for Integrated Water Resources Development and Management

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INTRODUCTION

The Decision Support System Planning project has been implemented by the National Institute of Hydrology (NIH), Roorkee and the DHI Consultants, Denmark under the Hydrology Project Phase-II. The project started in December 2008 and completed in August, 2013. The project objective was to develop a decision support system, the DSS (P) software, for integrated water resources development and management, customized to meet the requirements of the implementing agencies, particularly the nine participating states (Table 1). The planning elements considered in the project were surface water planning, integrated operation of reservoirs, conjunctive surface water and ground water planning, drought monitoring and management and water quality. Within each state, one or more basins were chosen to illustrate the capabilities of the DSS (P) and were used in training technical staff in developing its functionality. Six central agencies were also participated in the DSS (P) development (Table 2) and NIH, Roorkee was the nodal agency for the development of DSS (P).

Table 1. List of participating states and case study areas (Figure 1)

S.No.	States	Case Study Area
1	Andhra Pradesh	Godavari/SRSP
2	Chhattisgarh	Seonath Basin
3	Gujarat	Mahi Basin
4	Karnataka	Palar Basin and Tungabhadra Command Area
5	Kerala	Bharathapuzha Basin
6	Madhya Pradesh	Wainganga Basin
7	Maharashtra	Upper Bhima Basin
8	Odisha	Lower Mahanadi Basin
9	Tamil Nadu	Vaippar, Agnyar and Tambiraparani Basins

A decision is a reasoned choice among alternatives and the decision support system can be defined as a computer based model together with their interactive interfaces. An alternate definition can be the computer-based systems with integrated tools and databases that assist a decision-maker in making informed decisions and analyse the consequences. There is a general misconception that DSS takes decisions by its own. Using a DSS, a project manager is able to make rational use of resources without an in-depth knowledge of modeling techniques that provides timely information and communicates results to a larger audience. A DSS can help to generate different scenarios of analyses and these scenarios can be compared and viewed in graphical as well as tabular form to take decisions. A typical schematic of decision support system is shown in Figure 2.

Key Functionalities of DSS Planning Software

- Import, manage, analyse, and display time series and GIS data.
- Import and apply models for short-term and long-term planning.
- Perform additional analyses using the incorporated spreadsheet.
- Additional tools can be developed through scripting.
- Publish water resources information on the Web through Dashboards.
- Development of drought and water quality Indicators.

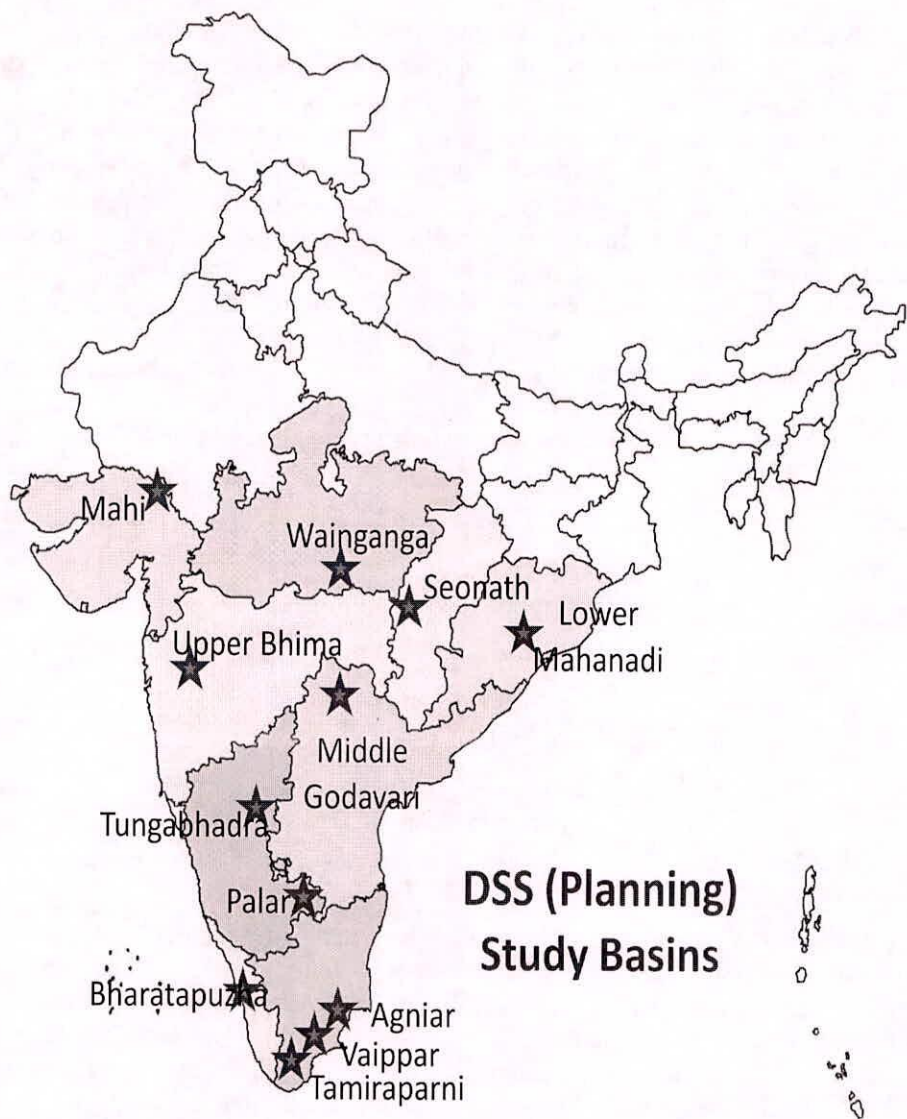
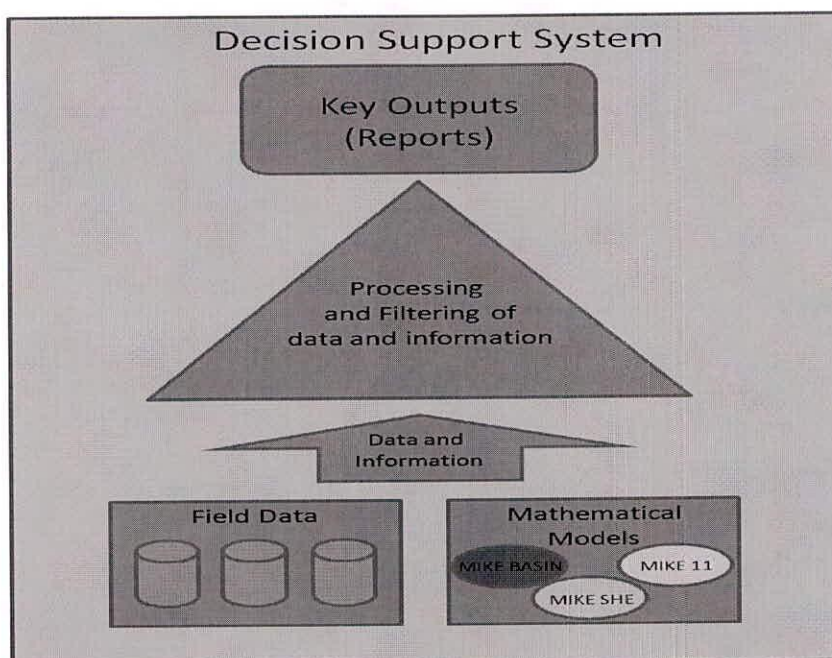


Fig. 1 Participating states and their case study basins

Table 2. List of participating central agencies in DSS (P)

S.N.	Central Agency
1	Central Water Commission (CWC)
2	Central Ground Water Board (CGWB)
3	Central Water and Power Research Station (CWPRS)
4	National Institute of Hydrology (NIH)
5	India Meteorological Department (IMD)
6	Central Pollution Control Board (CPCB)

**Fig. 2 Schematic of a Decision Support System**

DSS (P) and Supporting Software

The DSS Interface provides easy access to explorers, tools, maps and database. DSS Planning is a software package which builds upon Microsoft .Net Framework 3.5 SP1 and thus depends on it being installed for the correct functionality. DSS Planning uses PostgreSQL 9 as the database server and PostGIS 2.0.0 as the GIS extension to PostgreSQL. The PostgreSQL database server can either be installed on the same machine as the application in a “Professional” deployment or it can be installed on a CentOS machine located on the network on a “Corporate” deployment. Furthermore, the DHI modelling tools MIKE HYDRO BASIN and/or MIKE 11 need to be installed to run simulations. All of the above software packages must be installed before the installation of the DSS Planning.

The DSS (P) has been developed to assist the nine states in developing water management plans given current and future pressures and drivers affecting water quantity and quality within basins. The software includes a range of tools to process and analyse time series

and GIS information designed to a greater awareness of current conditions in order to better understand and quantify current water management issues (Figure 3).

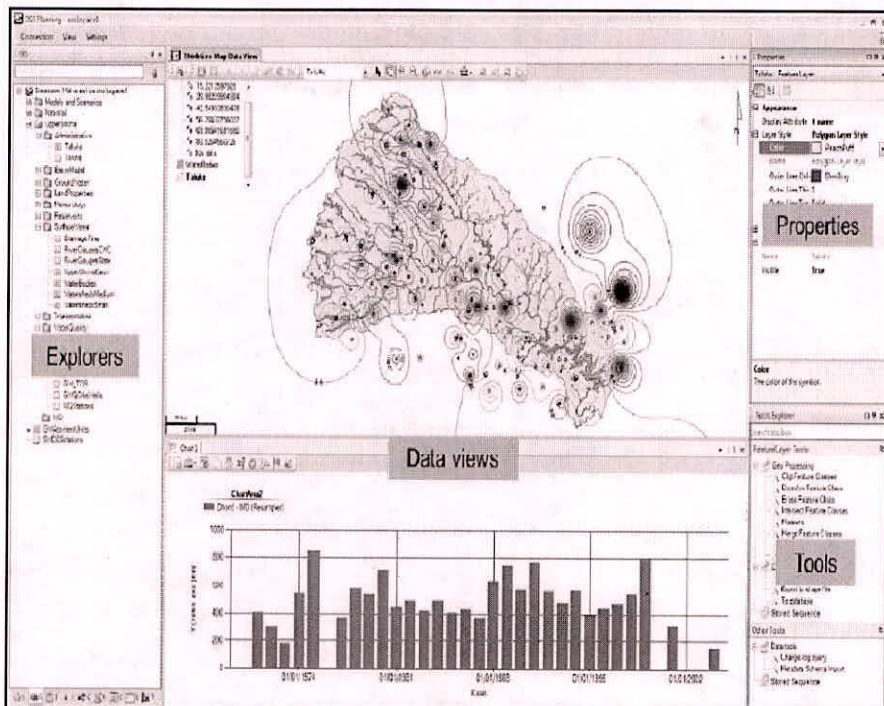


Fig. 3 Various views of the DSS (P) software

Before entering into the DSS (P) software, it requires login information as shown in Figure 4.

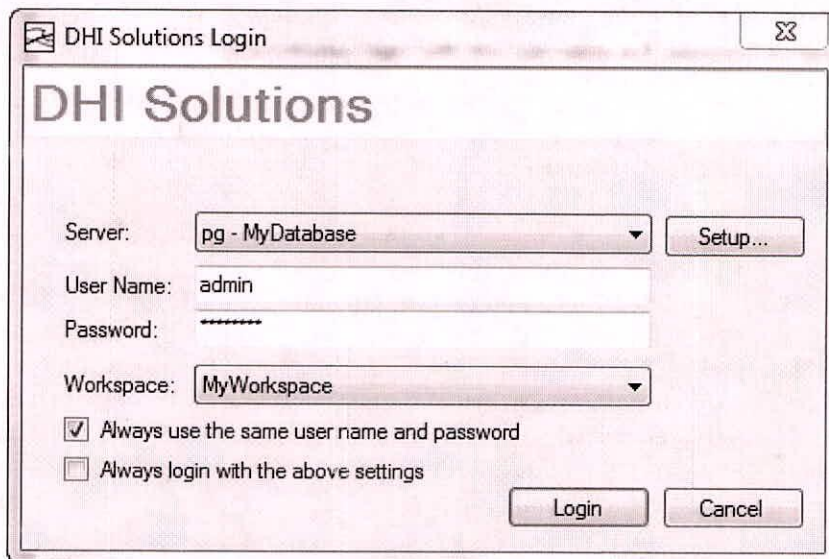


Fig. 4 Login window of the DSS (P) software

It requires database information, server details, workspace, login and password. After providing the desired login information, DSS software is opened and a window as shown in Figure 5.

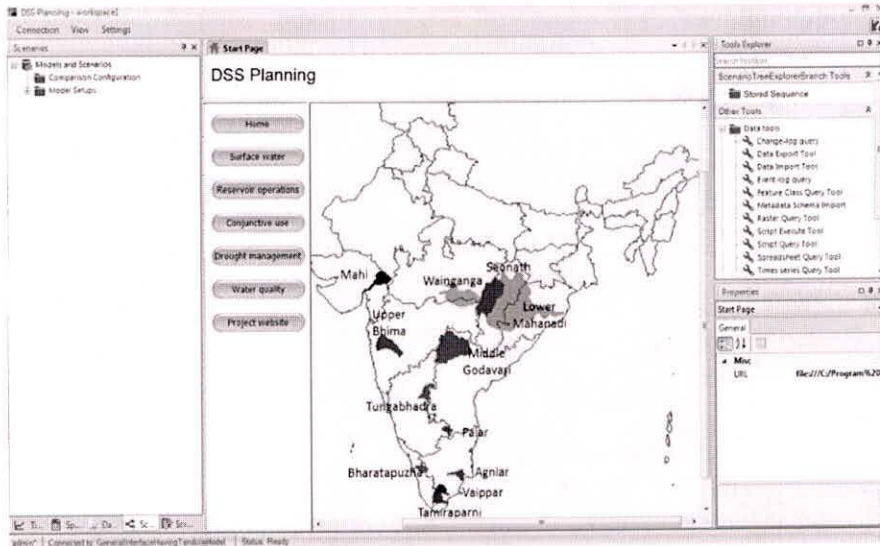


Fig. 5 Front-end of the DSS (P) software

Once the DSS (P) front end window is opened, then the desired analysis manager can be opened as shown in Figure 6.

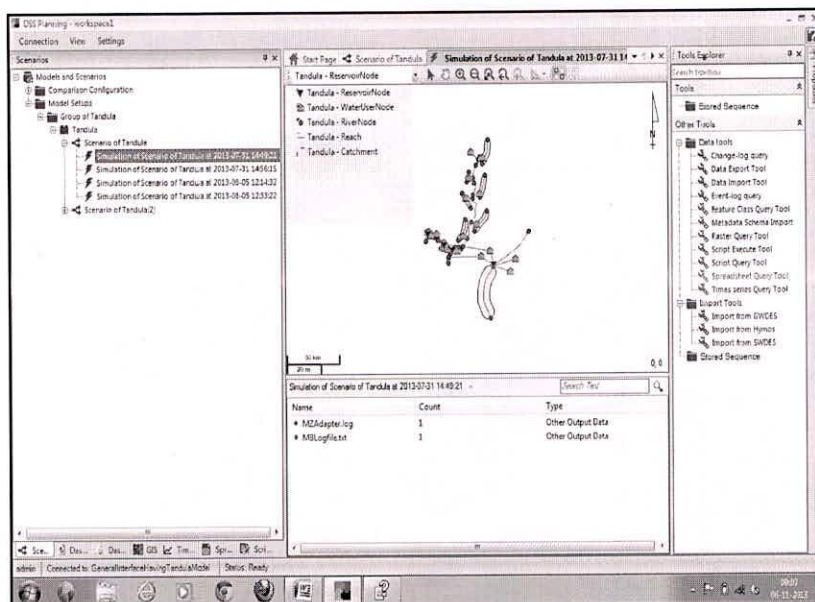


Fig. 6 Visualization options of scenarios in the DSS (P) software

The Decision Support System (DSS) provides easy access to data and information and enables analysis of water management options. The main components 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.
- Modelling tools to analyse water management options and extract key results for decision makers.
- Web tools to easily upload data and information on the water resources situation, water management plans, etc. to external stakeholders.

The DSS (P) software comprises of various managers that are used for various kinds of analysis. These managers are:

- GIS Manager
- Time Series Manager
- Spreadsheet Manager
- Scripts Manager
- Dashboard Manager
- Dashboard Objects Manager
- Indicator Manager
- Metadata Manager
- System Manager
- Scenarios Manager

Components of DSS (P)

The DSS front-end is shown above in Figure 5. It includes Explorers for the different components, such as the GIS data, model scenarios, time series data, etc., a central data view, where maps, tables and charts are displayed, and a window showing the properties of the currently selected item. The windows can be moved and docked to suit the user. DSS tool provides functionalities within a GIS environment for many kinds of investigations. DSS (P) has a number of components that are used in water management as given in Figure.7

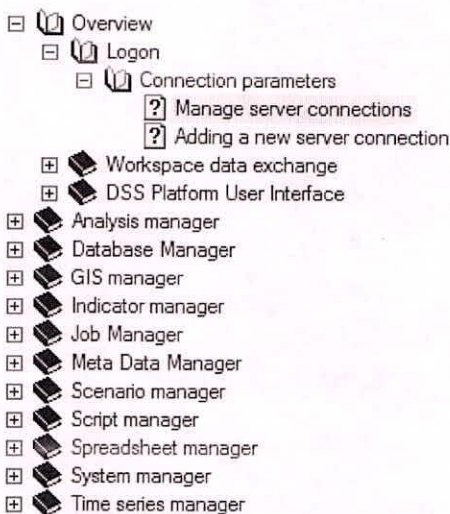


Fig.7 DSS (P) components

GIS Manager

The GIS manager provides the ability to work with GIS maps within the DSS. It offers a number of visualization options as well as tools for various kinds of spatial processing as given in Figure. 8:









































- [-]  GIS manager
 - [?]  Overview
 - [?]  Terminology
 - [+]  Organizing GIS data
 - [+]  Create and Import Spatial Data
 - [-]  Working with the Map data view
 - [?]  Adding data to a Map data view
 - [?]  Map navigation and properties
 - [?]  Map Layout options (vector data)
 - [?]  Map Layout options (raster data)
 - [?]  Adding Charts to a map
 - [?]  Selecting Features
 - [?]  Selecting features using spatial query tools
 - [?]  Selecting features by querying by Attributes
 - [?]  Saving Selected features in a new feature class
 - [?]  Saving raster data
 - [?]  Zonal statistics tool strip
 - [-]  Editing GIS data
 - [?]  Editing feature geometry
 - [?]  Adding features to a feature class
 - [?]  Editing feature attribute values
 - [?]  Edit feature class attribute fields
 - [?]  Clip features
 - [?]  Erase features
 - [?]  Split features
 - [?]  Merge features
 - [?]  Catchment Delineation
 - [+]  Projections
 - [-]  GIS Tools for vector data processing
 - [+]  Import Tools
 - [+]  Export and Output Tools
 - [+]  Geo processing tools (vector data)
 - [+]  Raster Interpolation
 - [+]  Vector Conversion
 - [-]  GIS Tools for raster data processing
 - [+]  Import Tools
 - [+]  Output Tools
 - [+]  Geo processing tools (raster data)
 - [-]  Soil Erosion Tools
 - [+]  RUSLE

Fig.8 GIS Manager Tools

Similar to any other DSS manager, the GIS manager is organized around four different components:

- The GIS explorer that provides functionality for organizing GIS data (e.g. feature classes).
- Map data view for visualizing spatial data.
- A property dialogue that holds properties on the selected spatial object.
- Tools explorer that contains a list of available tools for spatial processing based on the selected spatial object.

Indicator Manager

The Indicator Manager offers the user opportunity to define and organize *Indicators*. An Indicator ties together 3 things:

- A script as defined in Script Manager. Only scripts returning a number are eligible as indicator scripts.
- Definition of inputs to be supplied as arguments to the script. These can be simple types like numbers, strings, and Booleans, IDs (type guide) of entities in the database or objects (entities in the database).
- The indicator values ~ the result of the script evaluation. This has to be a number, i.e. an integer, a float or a double.

As with (most of) the other managers, the indicators can be organized in a group/folder structure similar to folders of files on the disk.

Scenario Manager

The purpose of the Scenario Manager is to create and compare model simulations, called *Scenarios*. The Scenario Manager is designed as an explorer, in which scenarios are organized in folders (groups) in an intuitively and convenient way that you design. When opening the Scenario Manager for the first time, it comes with a default folder structure containing only two folders called Comparison Configuration and Model setups respectively. Under the Model Setups folder you organize the models and scenarios you are simulating, and under the *Comparison Configuration* you compare the scenarios.

Scenario manager allows us to setup MB models, and on them create scenarios and also gives us a means to compare the results from these scenarios. The following are the parts of the basic procedure to use the scenario manager:

- Creating and managing groups
- Registration of the model/models
- Creation of the required scenarios and their management
- Populating the scenarios with input/output time series to be changed/compared from the basic registered models
- Editing time series

Various tools of the scenario manager are given in Figure. 9:
















- [-]  Scenario manager
 - [?] Overview
 - [+]  Organizing models and scenarios
 - [+]  Registering models
 - [+]  Working with models
 - [-]  Working with Scenarios
 - [?] Create a new scenario
 - [?] Copy an existing scenario
 - [?] Open a scenario
 - [?] Populate a scenario
 - [?] Edit model object variables
 - [?] Analyze model object variables
 - [-]  Working with Simulations
 - [?] Run a simulation
 - [?] View a simulation
 - [?] Analyze simulation input and output variables
 - [-]  Retrieving existing models
 - [?] Quick Search
 - [?] Assisted search
 - [?] Get all models
 - [?] Get models with specific names
 - [?] Get models in specific groups
 - [?] Combine search criteria
 - [?] Using Recent searches
 - [?] Using saved search strings
 - [?] Copy a model setup
 - [?] Search for model object variables
 - [?] Copy an existing scenario
 - [-]  Scenario comparison
 - [?] Create new comparison template
 - [?] Make a comparison
 - [?] Compare scenarios across models
 - [+]  Calculating Indicators
 - [+]  Optimization
 - [-]  Adapters
 - [+]  The modeling concept
 - [?] How to prepare a setup
 - [+]  MIKE 11 Adapter
 - [+]  MIKE BASIN Adapter
 - [+]  MIKE SHE Adapter

Fig. 9 Scenario Manager Tools

Creating comparisons

The simulation results of two or more scenarios of a model or multiple models can be compared. Scenario manager has a provision of creating these comparisons.

Running the comparisons

Before running the comparison, the time series in the comparison can be analysed individually using the time series tool in the tools explorer.

Script Manager

The *Script Manager* offers the possibility for users to write their own scripts and thereby create customized functionality using DSS Application Interfaces to other Managers and Tools. With scripting it is possible to create customized workflow processes, tailored to specific needs. Scripts can be organized in a logical folder structure, and when opening the Script Manager for the first time it will show only the root node. From this it is possible to create a folder structure, similar to folders on disk into which the scripts are placed.

The scripting language in the DSS is Iron Python – Microsoft .NET Framework implementation of the Python scripting language.

Scripts are conveniently arranged in groups (and subgroups if desired) and storages. Storage is a physical collection of script functions similar to a file, and the scripts within the storage may call each other (allowing common functionality to be shared among scripts in the same storage). Groups and subgroups can be created and renamed, and subgroups can be moved between groups, similar to the way files and folders are managed on disk. A group (or sub-Group) can contain a number of scripts and these scripts may come from different storages. Similarly the scripts in storage may be organized in different groups.

Spreadsheet Manager

The *Spreadsheet Manager* offers Excel compatible functionality within the DSS. It is possible to organize spreadsheet workbooks consisting of several spreadsheets into a logical folders structure with the database and import and export spreadsheets from/to Excel files. The spreadsheet is compatible with Excel with respect to built-in functions and charting functionality and each sheet can contain data and graphics as well as link to data in the DSS database such as time series. When opening the Spreadsheet Manager for the first time it will show only a root node. From this it is possible to create a folder structure, similar to folders on disk into which the spreadsheet workbooks are placed. Various tools of the Spreadsheet manager and their uses are given in Figure.10:

Time Series Manager

The time series describes any data that consists of pairs of time and value. The DSS uses the same conventions for describing these times and values as other DHI software products. These conventions include definitions of how to interpret the time indication, what physical entity the value represents and in which units. The time axis interpretation is defined by its so-called “value type”. The available value types are:







- [-]  Spreadsheet manager
 - [?] Overview
- [-]  Organizing spreadsheets
 - [?] Create a new spreadsheet group
 - [?] Rename a group
- [-]  Create and import spreadsheets
 - [?] Create a new spreadsheet
 - [?] Import a spreadsheet
 - [?] Rename a spreadsheet
 - [?] Copy a spreadsheet
 - [?] Move a spreadsheet
 - [?] Delete a spreadsheet
- [-]  Working with spreadsheets
 - [?] Opening a spreadsheet
 - [?] DSS spreadsheet menu and toolbar
- [-]  SpreadsheetGear menus
 - [?] Cell or Range
 - [?] Chart
- [-]  DSS functions
 - [?] GetCellValueByRC
 - [?] GetCellValueByRef
 - [?] GetRangeValueByRC
 - [?] GetRangeValueByRef
 - [?] GetTimeseries
 - [?] GetTimeseriesQuantile
 - [?] MovingAverageTimeseries
 - [?] TimeseriesMaximumValue
 - [?] TimeseriesMinimumValue
 - [?] TimeseriesAnnualMaximum
 - [?] TimeseriesAnnualMinimum
 - [?] TimeseriesExceedence
 - [?] TimeWeighedAverageValue
- [?] DSS scripts
- [?] Saving spreadsheets
- [?] Exporting a spreadsheet

Fig. 10 Spreadsheet Manager Tools

Instantaneous (I): the value represents something that was measured and representative of exactly that moment in time which the time step indicates. This is typically the right value type for such variables as temperature, wind speed, stage height and groundwater level.

Accumulated (A): the value represents how much of an entity has accumulated at the point of time indicated by the time stamp since the beginning of the entire time series (the first time stamp). This type is not often used in measurements but can be a result of processing, where for example rainfall and discharge can be accumulated over time for comparison and analysis needs.

Step Accumulated (SA): the value represents how much of an entity has accumulated since the previous time step. This is widely used for entities that can be collected such as rainfall, where a typical rain gauge is checked once a day and the amount found represents the accumulated rain that has fallen since the last time the gauge was checked.

Mean Step Accumulated (MSA): the value represents a rate that was true since the previous time step and until the current time step. This is very similar to step accumulated except that the accumulated entity is divided with the period of time of accumulation. So for example the same rainfall that can be represented in mm accumulated since last day can be represented in mm/day. Another classical example of mean step accumulated is the inflow to a reservoir when it is calculated based on changes in storage since yesterday.

Reverse Mean Step Accumulated (RMSA): the value represents a rate that is true from the current time step until the next time step. It is basically the same as the MSA except that it points to the future. For example a planned release rate from a reservoir should be followed from the date t is specified for until the next date where a new rate is specified.

The values are defined by pre-programmed variable types, each having a set of allowed units. For example any river flow measurements can be specified as variable type discharge and the assigned units such as m^3/s , ft^3/day or $l/minute$. Various tools of the Time Series manager and their uses are shown above.

Various functionalities of the time series manager and their uses are given in figure. 11.

DSS (P) also contains various time series tools used for database management and hydrological analysis. A brief listing of these tools is given in figure. 12.

Dashboard Manager (DBM)

The DBM provides a fast and flexible way of creating web user interfaces. It is highly modular and has an open well documented architecture which allows new components to be built and included seamlessly. The Dashboard Manager includes over 50 generic objects including presentation of time series, hydraulic profiles, gauges, alarm statuses, labels, images, reporting, EXCEL and many others. The data used to populate the controls in the web pages can come from different sources.

The Dashboard Manager supports native access to the DHI products DIMS and Temporal Analyst and provides support for connections to most database systems via ADO. The DBM has a wide range of potential applications, examples are:

- Interface for Water Information Management Systems displaying historical data.
- Interface for On-line data and analysis display with query capabilities.



































- [-]  Time series manager
 - [?]  Overview
 - [+]  Charts
 - [+]  Chart favorites
 - [-]  Create time series
 - [?]  Create a new time series (D23)
 - [-]  Export time series
 - [?]  Export to file (D24)
 - [-]  GIS and time series
 - [?]  Associating time series with GIS features (D25)
 - [?]  Removing associations (D26)
 - [?]  Find associated features (D27)
 - [?]  Find associated time series (D28)
 - [-]  Import time series
 - [?]  Import time series (D29)
 - [?]  Batch import of time series (D30)
 - [-]  Managing time series
 - [?]  Create a group (D32)
 - [?]  Rename a group (D33)
 - [?]  Copy groups (D34)
 - [?]  Move groups (D35)
 - [?]  Copy time series (D36)
 - [?]  Move time series (D37)
 - [-]  Time series properties
 - [?]  View and edit time series properties (D38)
 - [-]  Time series tables
 - [?]  Add time series to table (D39)
 - [?]  Editing time series (D40)
 - [?]  Auto-commit changes (D41)
 - [-]  Quality flags
 - [?]  Define quality flags (D42)
 - [?]  Assign a flag to a time step (D43)
 - [?]  Filter time series tables by flag ((D44)
 - [+]  Time series tools

Fig. 11 Time series Manager Tools


- ☐  Time series tools
 - ? Annual maximum series (D200)
 - ? Append (D202)
 - ? Average (D203)
 - ? Check time series (D204)
 - ? Count (D205)
 - ? Count per year (average) (D206)
 - ? Create time series (D207)
 - ? Data quantile (D208)
 - ? Import from Dfs0 (D228)
 - ? Differences (D224)
 - ? Distribution (D209)
 - ? Duration curve (D210)
 - ? Ensemble statistics (D229)
 - ? Extract period (D211)
 - ? L-moments (D212)
 - ? Mann-Kendall test (D213)
 - ? Mann-Whitney test (D214)
 - ? Maximum (D215)
 - ? Minimum (D216)
 - ? Mode (D217)
 - ? Ordinary moments (D218)
 - ? Resample (D219)
 - ? Standard deviation (D220)
 - ? Synchronize (D221)
 - ? Flag outliers (D222)
 - ? Moving average (D223)
 - ? Quality flag filter (D224)
 - ? Replace values tool (D225)
 - ? Run test (D226)
 - ? To file (D227)
 - ? Weather shuffler (D230)

Fig. 12 Time series Tools

The DBM provides fast, efficient and effective means of presenting and visualizing many types of data. Customization and tailoring to specific project needs are easily implemented and encouraged.

DSS (P) APPLICATIONS

A number of DSS (P) applications are developed by the implementing agencies (IAs). Selected examples of DSS (P) applications made by the IAs are given below within the fields of surface water planning, integrated operation of reservoirs, conjunctive surface water and ground water planning, drought monitoring and management and water quality.

Integrated Reservoir Operation

Seasonal planning

A fraction of the water stored in a reservoir is normally reserved to ensure delivery up to the start of the next wet season, even if this is delayed. The minimum storage in a year is therefore often representing a considerable amount of water, which might have been utilized while taking a calculated risk. The DSS (P) can help assessing this potential through model tests of additional water allocation and evaluation of the associated benefits and risks. Each model includes decades of historical, daily inflow to the reservoirs in the model area as a basis for assessing the likely inflow in the future. Considering the reservoir levels of today and utilizing this historical inflow information, the DSS (P) provides answers to the following questions for given scenarios of planned water allocation:

- What is the risk of reaching critically low levels this dry season?
- What is the likelihood of filling the reservoir in the coming wet season?

This example shows the likely development of the total storage in four reservoirs supplying water to Pune City, industrial areas, and local irrigation schemes in Maharashtra. The storage may be expected to exceed the 50%-curve every second year in average and the 90%-curve in 9 years out of 10 (Figure 13). These curves may change over time depending on the actual water allocations and losses, so it is recommended to perform the analysis regularly. Reduction in water allocations was necessary up to the 2012 monsoon in this area, and the DSS (P) helped Maharashtra to decide on the timing and magnitude of the required reductions.

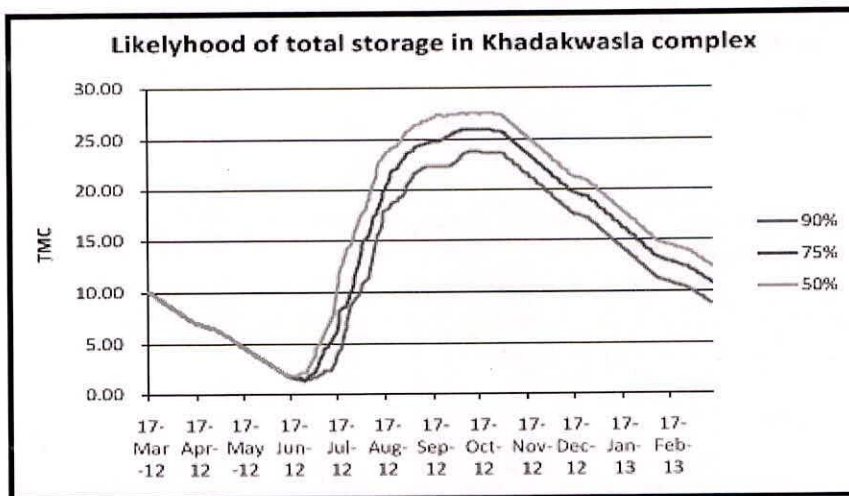


Fig.13 Likelihood of total storage in Khadakwasla reservoir complex

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 Sagar project in Andhra Pradesh as shown below in Figure 14.

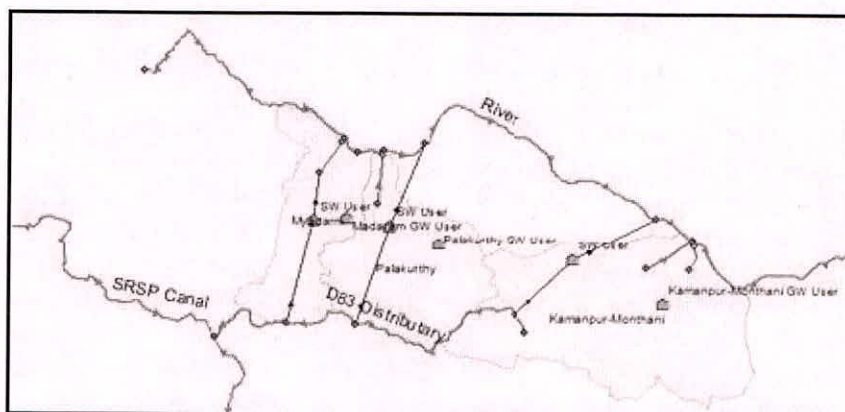


Fig.14 Distributary D83 and associated command area under Sri Ram Sagar project

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 whenever 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 surface 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.

Figure 15 shows the impact on the depth to groundwater in each area over a period of eight years.

The plots indicate that 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.

Artificial Recharge

The potential of increasing groundwater availability through a range of artificial infiltration structures has been tested for a selected watershed. In a scenario of increased water demands from groundwater, the depth to groundwater has been simulated over a 40 year period

to indicate the sustainability of this utilization with and without the proposed artificial recharge, as shown in Figure 16.

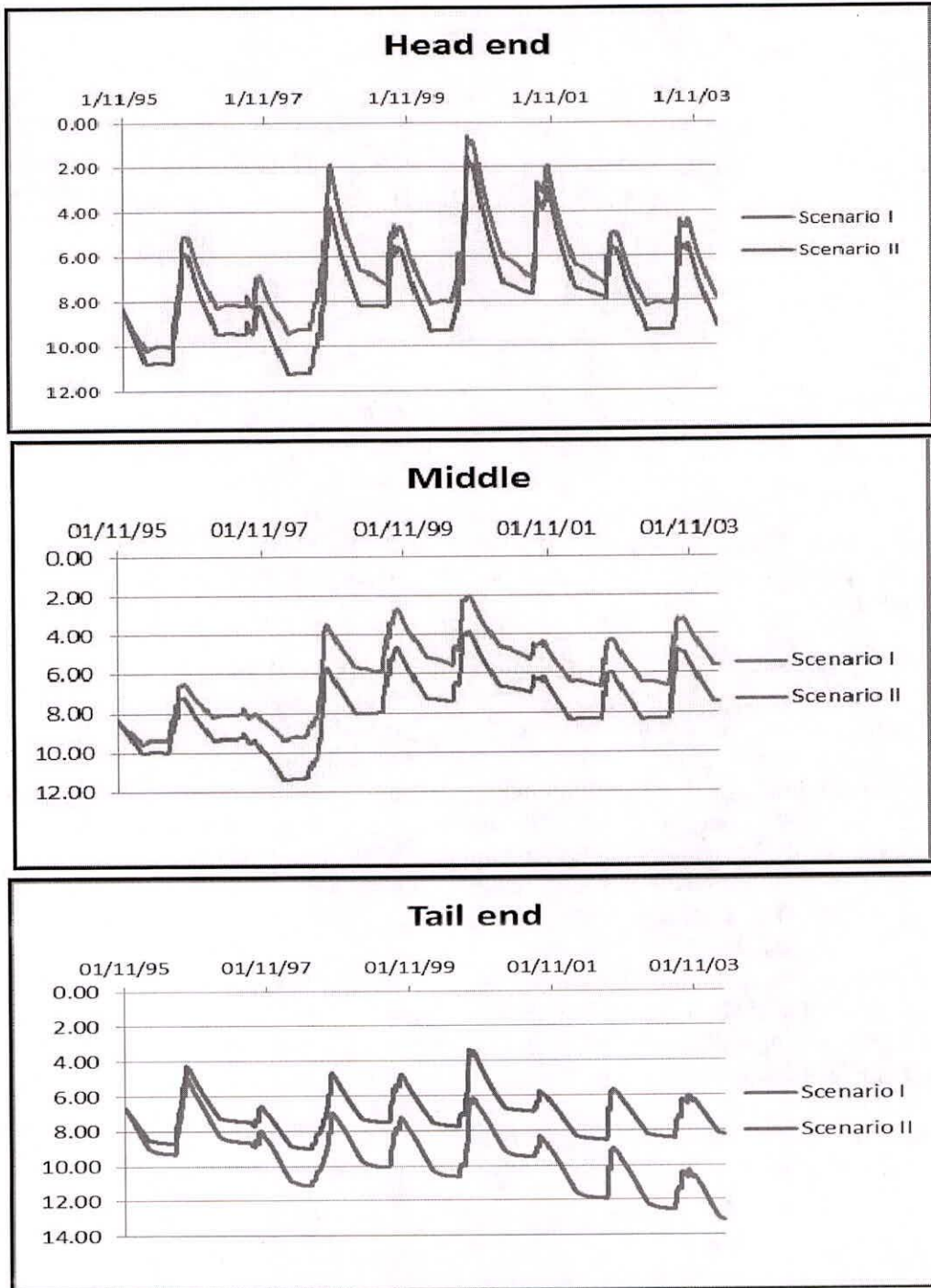


Fig. 15 Simulated depths to groundwater (metres) at head, middle and tail end of D83

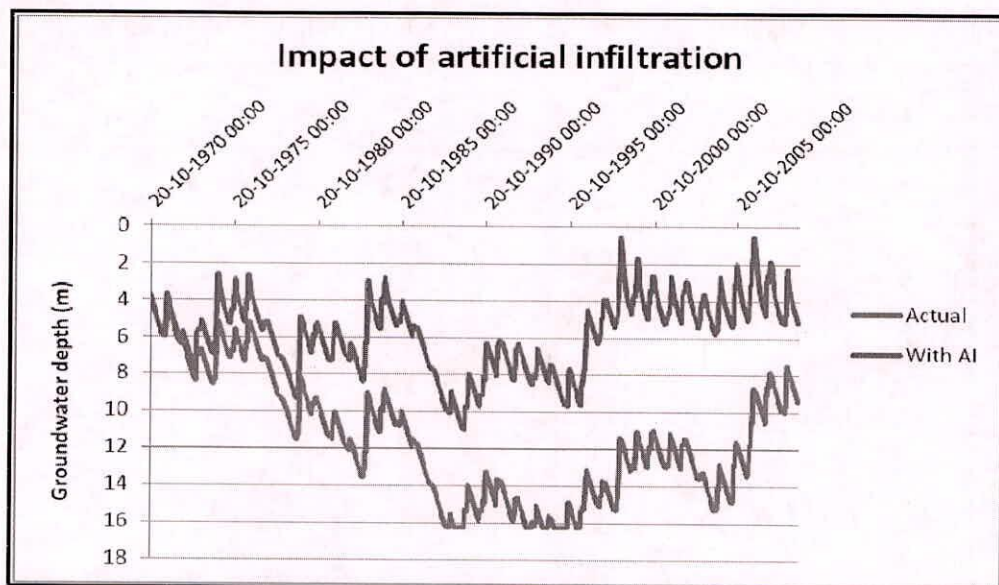


Fig. 16 Simulated groundwater depth with and without artificial infiltration

These simulations indicate that increased draft will only be sustainable with the artificial recharge in place. Note that an analysis based only on the recent, relatively wet years would have given the false impression that increased groundwater pumping would be possible also without the artificial recharge.

Drought Management

The management of drought is highly prioritised by the participating Indian states. Drought situations are often characterized by low post-monsoon storage in surface water reservoirs and falling groundwater levels, as the utilization of groundwater typically exceeds the recharge. This may be acceptable for a limited period of time provided the groundwater levels may be expected to return to normal levels during subsequent years with average or high rainfall. Different model applications have been made in various states to help determine the sustainable water abstraction in these situations.

Tools are also available to generate web-pages, which are linked to the DSS (P) database and built on-the-fly based on database information. These may be used e.g. to indicate the likely severity of future drought, based on recent measurements, and thereby the need for remedial measures in the coming months.

This is illustrated here, where drought conditions are monitored through indicators for each watershed, showing the severity of drought in colour, dark red indicating extreme conditions (Figure 17).

Water Quality

The possibility of utilizing groundwater is limited in many areas due to the high concentrations of e.g. nitrate or fluoride. The DSS (P) includes tools to provide an overview of

the water quality situation and illustrates the variation from year to year directly from the data. Figure 18 shows the fluoride concentration in groundwater in colour-code, generated directly from the measured data. Maps of this type are useful in the planning of groundwater utilization and mitigation measures.

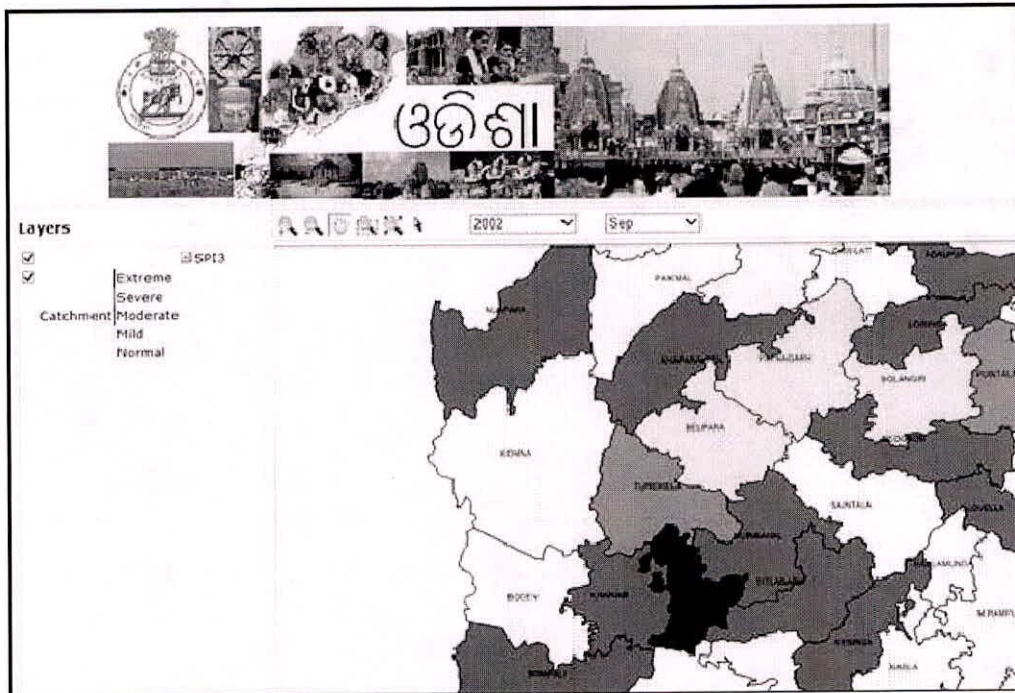


Fig.17 Dashboard for characterization drought conditions

The water quality of the Upper Bhima has been analyzed in a model prepared by Central Pollution Control Board (CPCB) and DHI with support from the Government of Maharashtra. MIKE BASIN was been applied as a screening tool to identify the relative impacts of the analysed scenarios. The model applications include an assessment of pollution loads from urban, industrial and agricultural sources and their impact on the river water quality. Based on the calibrated model, analyses were performed to identify the relative contribution from waste water treatment plants (WWTP) and diffuse sources, and scenarios of the impact of future population growth and climate change were analysed.

SUMMARY

The Decision Support System (Planning) software is developed for integrated water resources development and management and customized to meet the requirements of the implementing states. The planning elements considered in the project are surface water planning, integrated operation of reservoirs, conjunctive use of surface water and ground water, drought monitoring and management and water quality. A number of tools are available for various purposes to support water management decisions on the basin scale. The modelling tools MIKE HYDRO BASIN or MIKE SHE need to be installed to run the simulations. The DSS (P) software can effectively be used to manage the water resources of a basin for planning purposes.

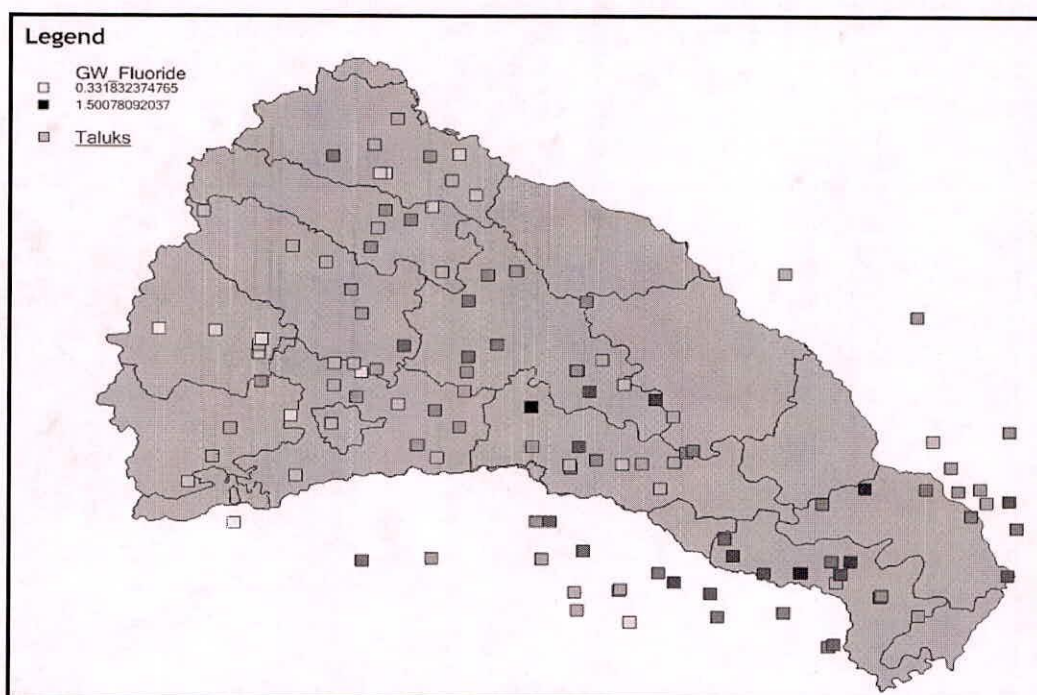


Fig.18 Fluoride concentration in groundwater in Upper Bhima basin

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- Development of Decision Support System (Planning) for integrated water resources development and management, Final Report (DSS Planning) under Hydrology Project Phase-II, National Institute of Hydrology (NIH), Ministry of Water Resources (MoWR), GoI, August, 2013.
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