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IRRIGATION PLANNING AND MANAGEMENT IN THE COMMAND OF HARSI RESERVOIR PROJECT IN MADHYA PRADESH

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PREFACE

Irrigation has been identified as one of the most critical input for agriculture development in India due to monsoon climate which limits rainfall to three or four months in a year and lot of spatial variability. To increase the crop production, the surface irrigation schemes are to be considered the most feasible way where extra water is accumulated by constructing dam across the rivers and transfer this water to the field by a network of canal and distributaries during lean periods. The surface irrigation has significant importance in Indian agriculture for its quest of self dependence in meeting the countries food requirement. The growing population creates more pressure on agriculture production therefore efficient irrigation systems and water management practices can help to increase farm profitability in an era of limited and high-cost water supplies.

The study titled "Irrigation Planning and Management in the Command of Harsi Reservoir Project in Madhya Pradesh" has been taken as three years joint research project of NIH RC Bhopal and State Water Data Centre, Govt. of M.P., Bhopal (2013-14 to 2014-15) primarily for water resources management in the command of Harsi reservoir project for irrigation management, conjunctive use and reservoir operation. The final report consists of development of GIS data base, estimation of revised capacities of Harsi reservoir, crop & gross water assessment, analysis of sources of supplies and demands, development of MIKE basin model for irrigation planning and scenarios based demand-supply analysis with conjunctive use in Harsi command. The study is being carried out jointly by Regional Centre, National Institute of Hydrology, Bhopal and State Water Data Centre, Govt. of M.P., Bhopal. The final report prepared by Sri R. K. Jaiswal, Sc-B, as P.I., with Co-P.I. as Sri T. Thomas, Sc-D, Sri R. V. Galkate, Sc-D, Dr. T. R. Nayak, Sc-D & Head from RC Bhopal, NIH and Dr. Jitendra Jain, S.E. as P.I., Dr. Brijendra Baghel, Scientific Officer as Co-P.I. from State Water Data Centre, Bhopal under the guidance of Dr. N. C. Ghosh, Coordinator & Sc-G is an outcome of two years work.

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ABSTRACT

Indian economy is primarily based on agriculture and more than 75% population depends on agriculture and agro related jobs. Despite high priority, massive investment and phenomenal growth in the irrigation sector since independence, the performance of irrigation systems, both in economic terms of crop yields, farm incomes and cost recovery as well as in water distribution terms of adequacy, equity, timeliness of water supplies has not been found encouraging. Because of lack of scientific inputs in water distribution/application and awareness of farmers, excess water is used in the head reach of the command area in the belief that more water will give more yields whereas the tail end of command is deprived of irrigation water. An efficient irrigation system and water management practices can help to maintain farm profitability in an era of limited, higher-cost water supplies. It is therefore necessary to develop and manage command areas and operate reservoir in such a manner so that available water can be used efficiently based on scientific knowledge of climate, soils, crops and irrigation practices in the region.

The Harsi reservoir project situated on river Parvati in Gwalior district of Madhya Pradesh was selected for systematic irrigation management through reservoir sediment assessment, rainfall analysis, assessment of crop water requirement, development of model for irrigation planning and assessment of impact of modernization works in command for sustainable development and increase crop production. The meteorological data, field surveys and auxiliary information on soil, geology, drainage etc. collected from multiple sources were used to develop GIS data base which can further be used for efficient management and irrigation planning. The seven multi-temporal LISS 3 remote sensing scenes were analyzed in GIS environment to determine revised water spreads which in turn provide revised capacities at various reservoir levels. From the analysis, it may be concluded that 47.44 Mm^3 volumes which is about 25% of gross storages capacity of Harsi reservoir has been lost in last 78 year (1935-2013).

For efficient management of water resource in Harsi command, scenarios based assessment of demand-supply analysis has been carried out to ascertain the competence of Harsi reservoir with supplies from other sources to manage Harsi command under variable climate, rainfall and efficiency conditions. The analysis of rainfall data confirmed that the rainfall in the study area is concentrated in the months of June to September only and irrigation from reservoirs and groundwater are the sources of supply in the remaining period. The 75% dependable rainfall in June, July, August and September months was computed as 10.5 mm, 129.8 mm, 158.0 mm and 59.4 mm respectively. The standard method suggested by FAO using CROPWAT software were used to compute crop and gross water requirements for six different scenarios separately for designed (DCP-1 to DCP-6) and present (PCP-1 to PCP-6) cropping pattern under variable climatic and efficiencies criterions for distributary committees and WUAs. The assessment of irrigation water on 10-Daily basis for different WUAs will be helpful to allot requisite quantity of water under real climatic and water availability situation.

The design cropping pattern in Harsi command may require 432.5 Mm^3 irrigation water in wet year (DCP-1) to 474.7 Mm^3 in dry years (DCP-5) under present condition (77% conveyance and 71% application efficiency). The improved conditions (86% conveyance and 76% application efficiency) may curtail the demand by 69.3 Mm^3 and 77.6 Mm^3 in wet and dry rainfall years respectively. The demand of present cropping pattern under variable conditions may vary from 408.9 Mm^3 (PCP-1) to 476.3 Mm^3 (PCP-5) that can be met properly if improvement in water management and conjunctive use of surface and groundwater are made. The supply analysis to Harsi reservoir confirmed an average availability of 427.2 Mm^3 water in the system and improved water management and operation can fulfill all the demands of design cropping pattern in all situation while more area can be brought under irrigation if present cropping pattern persists.

The crop water requirements assessed from CROPWAT does not account water availability status, reservoir and canal capacity, operation rules, spatial distribution of crops and groundwater application in the command. Therefore, in order to plan irrigation water in more efficient manner, a MIKE BASIN model for Harsi reservoir and its command was developed considering variability of climate, soils, cropping patterns, efficiency criterions and conjunctive use of surface and groundwater and sixteen different scenarios were generated separately for design and present cropping pattern. The simulation runs were made to assess irrigation demand, supply to command, demand deficit, reservoir level and capacity at different period of year. The simulation results confirmed the demand of design cropping pattern may vary from 313.6 Mm^3 (MB-DCP-1 & 2) in wet rainfall years to 372.4 Mm^3 (MB-DCP-9 & 10) in dry or drought years. The demand deficit of 41.2 Mm^3 water under existing 77% conveyance and 71% application efficiencies without using groundwater in wet years can be reduced to 2 Mm^3 by improving conditions of canals (81% conveyance and 76% application efficiencies), conjunctive use (10% demand from groundwater if possible) and operation of reservoir as suggested by model. Different MIKE BASIN simulation runs for present cropping pattern indicated little deficit of demand which can be met through improved water management in the command. The sedimentation study of Harsi reservoir showed the loss of nearly 25% gross storage and the effect of reduced capacity of reservoir were analyzed by changing characteristic curve and elevation-area-capacity table in the model. The simulation runs with reduced capacities indicated adverse impact for design cropping pattern in dry years while no effect observed in present cropping pattern. The developed irrigation model can be used for operation of reservoir and irrigation management in the command using real time data.

The Harsi command has good network of 5 distributary committees and 26 WUAs which are working in close cooperation with official of Water Resources Department for management of water in the command. It is recommended that these WUAS should be involved more in decision making, revenue collection, operation and maintenance of canals/outlets with scientific inputs from installing appropriate network of soil moisture measurement, soil testing, capacity building, application improved quality seeds and mechanization of agro related works.

CHAPTER -1: INTRODUCTION

1.1 General

Water is an essential element for the survival of living body and a natural resource having ecological and economical value for sustaining life, health and integrity of ecosystem. It is not only essential for life of mankind and environment but also necessary for economic development of country. Irrigation accounts for more than 70% of total water withdrawals and for more than 90% of total consumptive water use (Doll, 2009; FAO, 2010; Shiklomanov et al., 2000) therefore optimal use of water for irrigation is critical to social and economic sustainability of a country. The spatial and temporal distribution of water is extremely uneven and there is an urgent need to use available water resource management in efficient manner (Raheja and Taneja, 2000). Due to monsoon climate which limits rainfall to five months (June to October) in a year in India, irrigation becomes prerequisite for growing subsequent crops and surface irrigation schemes are to be considered the most feasible way in which the extra water is stored by constructing dam across the rivers and transfer this water to the field by a network of canal and distributaries during lean periods. Considering the importance of irrigation for increased crop production, large scale modern irrigation projects were implemented in India after independence and considered vital for crop production and overall economic and social development.

The crop water requirements fulfilled from irrigation or precipitation may be defined as the depth of water consumptively used by a crop plus unavoidable irrigation application losses. It also includes other aspects of beneficial use of water i.e. the water required for land preparation, leaching of salts, toxic substances and temperature control. The crops need water in certain quantities at specific intervals depend on several factors like type of crop, soil, meteorological conditions, rainfall, land grading and leveling, water conveyance and distribution, time of supply, method of water application, adequate inputs and agronomic technique, drainage etc. The improper scheduling, over irrigation and improper drainage often lead to reduction in crop yields, water logging and salt imbalance in soils and in some cases vast portion of agricultural land have been rendered unproductive due to these problems. Therefore the knowledge of soils, climate, cropping pattern and distribution methods are important and an integrated approach considering all aspects of demands and supplies should be used for economizing irrigation water use for optimum crop production.

The estimate of the magnitude and duration of water deficit/surplus are of vital importance for planning crop and water management practices in order to promote crop production both in irrigated and rain-fed areas. The knowledge of rainfall pattern and potential evapotranspiration (PET) is very useful to estimate the water deficit / surplus, water harvesting practices and assessing the drought proneness of the area. The expected rainfall amount at various probability level for different time periods, monthly, weekly etc. play an important role in estimating the water deficit/surplus at different periods. The increasing demand and scarcity of water makes it important to use available water in the most economical way. The management practices for conservation of water are increasingly emphasizes because of sparse natural precipitation, high evapotranspiration and excessive depletion of limited ground water resources.

Many irrigation projects in India are running on low efficiencies due to significant losses of water during conveyance and application, poor condition of canals and outlets, disparity in distribution and inefficient reservoir operations etc. An efficient management plan which consists of assessment of crop water requirement, soil moisture availability and scenarios based plan for reservoir operation and irrigation releases may solve the problem of less availability of water up to a reasonable extent. Other reason of getting less water from reservoir is the reduction of reservoir capacities due to soil erosion, movement and deposition and consolidation of sediment in the dead storage zone and water spread of reservoir. The rate of sedimentation in reservoirs and lakes is accelerated due to environmental degradation, lack of conservation measures in catchment, change in land use, deforestation, urbanization and industrialization. It is generally assumed that land use & land cover changes have caused accelerated soil erosion and increased sediment yield (Morris, 1997). Efficient utilization of the water resources requires that the reservoirs must be operated in the most judicious and scientific manner. Efficient regulation of the reservoirs can lead to increased benefits from the reservoir as well as significant reduction in damage due to floods. Periodic capacity surveys of the reservoir can help to assess the rate of sedimentation and reduction in storage capacity which may be useful for further reservoir operation and irrigation planning.

The primary objective of an irrigation project is to increase productivity in the command area that ultimately improve livelihood of the people. This objective can be achieved if canal system is properly designed and maintained to deliver an optimum quantity of water to every field at predetermined schedule. Normally, the delivery of water up to outlet head was the responsibility of the Water Resources Department which some time does not deliver satisfactory results due to lack of maintenance of canal and outlets, ignorance of local conditions, distribution problems and inefficient reservoir operation and irrigation management. From the past experiences in irrigation and command area management, it has been observed that the gap between the potential created and potential utilized was expected to be abridged by involving farmers at all stages of water management and distribution so as to motivate them to use their local knowledge to solve the problems and have ownership feeling of the distribution system to minimize the maintenance cost. For efficient management of irrigation project, the managers or project authorities should take whole system in totality and estimation of revised capacities, crop water assessment, efficient reservoir operation and irrigation management in command are prerequisite for getting maximum production and overall development of society.

The security of water supplies from reservoir promotes farmers to take water intensive cropping in the command and any failure in delivery may cause huge loss of income to the farmers, revenue to the government and overall economic development of society. Therefore, all development and restoration works in command should be monitored and evaluated with regard to water management and agricultural productivity so that the returns of investment can be evaluated. Satellite remote sensing technique provides objective primary data of cropping pattern, crop acreage, crop productivity, irrigation area utilization, water logging, and salinity/alkalinity on the spatial and temporal scales, thus helping comparative performances, evaluation and identifying problem areas within the command for corrective management measures and impact of command management on cropping pattern. For systematic study for command area management and irrigation planning, the Harsi command in Gwalior district of Madhya Pradesh has been selected.

1.2 Objectives

The Harsi reservoir project situated on river Parvati in Gwalior district commissioned in the year 1933 is selected for systematic study of reservoir sedimentation, assessment of crop water requirement, reservoir operation and irrigation planning, assessment of irrigation potential created and actually utilized due to modernization and command development works. The Harsi reservoir project is serving to the growth of the nation for more than 75 years and several restructuring and renovation works have been taken place in the past to enhance the irrigation potential of the project including lining of canals, public participation and proposed new canals in the command areas. The National Institute of Hydrology, Regional Centre Bhopal and State Water Data Centre, Water Resource Department, Govt. of Madhya Pradesh, Bhopal has taken up this study with the following objectives.

- Preparation of GIS based database for the study area
- Estimation of revised capacities using remote sensing and GIS approach
- Rainfall Analysis and computation of irrigation water requirement in the command area
- Scenario based assessment of demand and supply of water for irrigation planning
- Development of MIKE BASIN or NIH_ReSyP based model for irrigation management
- Irrigation management for the command.
- Impact assessment of modernization on irrigation potential

CHAPTER- 2: REVIEW OF LITERATURE

The present study deals with the preparation of GIS data base, collection and analysis of meteorological data, sedimentation study of Harsi reservoir, assessment of crop water requirements for different WUAs, demand supply analysis, application of model for irrigation water management in Harsi command, impact assessment of modernization activities in the command. A detailed review on all these aspects have been carried out and outlined here.

2.1 Reservoir Sedimentation

The releases from reservoir for different designated uses depends on availability of water in the live storage which get reduced with passes of time due to deposition of silt and sediment brought down by flowing water. Reservoir sedimentation process is a universal phenomenon, which has been considered as a most critical environmental hazard of modern time (Jain and Kothyari, 2000). The range of problems caused by reservoir sedimentation is varied and wide. Apart from loss of capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance lead to increase in their associated cost (Kothyari et al., 2002). A broad estimate of soil erosion in India showed that about 5334 million tones of soil is being lost every year, which means, soil erosion is taking place at the rate of 16.35 tones/hectare/year (Narayana and Ram Babu, 1983), which is more than the permissible soil loss tolerance value of 4.5 - 11.2 tones/hectare/year (Singh et al, 1981). As a result, it is widely viewed that, nearly 20 % of the live storage capacity of our major and medium sized reservoirs have been silted up by the end of the year 2000, which means a loss of irrigation potential of about 60,000 hectare every year due to silting. An analysis of sedimentation survey in respect of 43 major, medium and minor reservoirs in India indicated the variation of sedimentation rate between 0.003 – 0.28 M. cum/100 sq km/year for major reservoirs, 0.002 – 0.11 M. cum/100 sq km/year for medium and 0.01 – 0.02 M. cum/100 sq km/year for minor reservoirs (Shangle, 1991).

The reservoir sediment or loss in capacities of a reservoir can be determined with the help of conventional methods such as hydrographic survey and inflow-outflow method or advance technique of digital image classification of remote sensing data. Conventional method of reservoir sedimentation survey has been in practice for quite long time in India and elsewhere. The conventional methods of reservoir sedimentation are time consuming, costly, cumbersome and require lot off manpower, therefore cannot be used frequently. But using the synoptic and repetitive viewing capacity of remote sensing sensors and the ability of image processing with Geographic Information System (GIS) makes this method economical, less time consuming and easy. The data obtained from the remote sensing platforms by virtue of their repetitive and synoptic coverage and computer aided analysis make significant contributions in understanding and monitoring the environmental processes (Balakrishnan, 1986). Basically, multi-date satellite remote sensing data provide information on elevation contour areas directly in the form of water-spread areas. Any reduction in reservoir water-spread area at a specified elevation estimated from the satellite data is indicative of sediment deposition.

The ability to map and estimate water spread from satellite data is well understood and different techniques such as visual interpretation of satellite imagery, density slicing, and digital classification of water bodies have been employed for the delineation of water bodies (Work and Gilmer, 1976; Thiruvengadachari et. al., 1980; Thiruvengadachari and Manavalan, 1983, Jain & Goel, 1993; Goel & Jain, 1996, Jaiswal et al, 2010). Hanumantha Rao et. al. (1985) adopted visual interpretation of enlarged MSS images to estimate the water spread at eight different levels of the Sriramsagar reservoir. Suvit et. al. (1988) used digital techniques in which density slicing of Landsat MSS near-IR (0.8- 1.1 μm) data were used to extract the water spreads of the Ubolratana Reservoir of five different dates. White (1978) examined a variety of measuring techniques for determining reservoir surface areas extracted from Landsat MSS near-IR imageries of different scales and compared their accuracy with field data. Mangond et.al. (1985) employed digital classification techniques to estimate the water spread of the Malaprabha reservoir on March 02, 1973 using Landsat MSS data and reported a discrepancy of 8.29 % from the actual water spread. This discrepancy was attributed to the probable misclassification of boundary pixels.

2.2 Crop Water Assessment

The accurate estimation of irrigation water demand is essential for developing a rational policy for sustainable water resources. The rainfall is a basic input for fulfilling the crop water requirement in any region. For planning of irrigation and efficient operation of water resources projects, water requirement of crops under different rainfall scenarios and probability analysis of rainfall are essential in arid and drought affected region. The irrigation water requirements are usually determined to avoid crop stress implicitly assuming that maximum yield is desired and improvements in irrigation management are urgently needed in regions where water resources for irrigation are being depleted. Prasad *et al.* (1996) presented a study in Mahendragarh distributary canal in Haryana State to estimate net irrigation water requirement of crops under 17 minors for kharif and rabi seasons of 1992–93 period using IRS-1B satellite geo-coded FCC images. Manoli et al (2001) presented a prototype spatial decision support system for the evaluation of water demand and supply management schemes.

Santos *et al*. (2008) used a water balance model with satellite-based remote-sensing to estimate evapotranspiration to provide accurate irrigation scheduling guidelines for individual fields. Delavar et *al*. (2009) introduced a real-time modeling approach for optimal water allocation during drought. Raut et al (2010) used FAO model CROPWAT with the help of agro-meteorological and remote sensing data (1986–1998 and 2008) to calculate irrigation water requirements of wheat and mustard crops grown in Western Yamuna canal command. These water requirements, when analyzed with canal and tube well water supplies for crops, show large scale deficiencies in the irrigation command area. Due to changes of hydro-meteorological conditions and shifting goals of water requirements from one region to the others, the reservoirs have different operation rules. Therefore, without careful consideration of these conditions the reservoir operation will be inefficient. For optimal allocation of irrigation water, number of models have been developed based on stochastic dynamic programming (SDP) for a single crop situation by Dudley *et al.*, 1971; Dudley & Burt, 1973; Bras & Cordova, 1981etc. and for a multi crop situation by Rao *et al.*, 1990; Vedula & Mujumdar, 1992; Vedula & Nagesh Kumar, 1996 etc.

2.3 Reservoir Operation

Reservoir operation involves many decision variables, multiple objectives as well as risk and uncertainty lead to significant challenges for water resource managers to make operational decisions. Traditionally, fixed reservoir rule curves are used for guiding and managing the reservoir operation. These curves specify reservoir releases according to different controls such as current reservoir level, hydrological conditions, water demands and time of a year are often not very efficient for balancing the demands of different users (Oliveira & Loucks 1997; Ngo et al. 2006; Chang et al. 2005; Paderson et al. 2007). Rao *et al.* (1990) developed a model for optimal weekly irrigation scheduling policy for two crops, considering both seasonal and intra-seasonal competition for water. Optimization is a powerful technique that helps analyze complex water resource system for obtaining the most economical/viable solution. In many situations, decision makers would be interested in examining a number of scenarios rather than just looking at one single solution that is optimal (Jaiswal et al. 2013). Thus, there is a potential for improvement of reservoir operating policy with the help of optimization or development and examination of scenarios.

Arumugam *et al.* (1997) conducted a study on an integrated decision support system (DSS) that aids the operation of a tank (small-scale reservoir) irrigation system in south India. Prajamwong *et al.* (1997) developed a software package called Command Area Decision Support Model (CADSM) to estimate aggregate crop-water requirements and management options for irrigated areas. The water requirements for individual fields are aggregated to estimate the potential command area water requirement, and then totaled to determine the potential irrigation system demand. A queuing system was used to allocate available water to command areas and fields. Svendsen and Meinzen-Dick (1997) analyzed current dissatisfaction with past irrigation improvement approaches and examined reasons for widespread dissatisfaction. Raghuwanshi and

Wallender (1999) presented forecasting and optimizing furrow irrigation management decision variables. Furrow irrigation can be better managed if the management decision variables (irrigation time and amount; inflow rate and cutoff) can be determined ahead of time.

Bhadra et al. (2009**)** developed an integrated reservoir-based canal irrigation model (IRCIM) and successfully simulated the operation of the test reservoir after calibration and determined better delivery schedules than that actually practiced. Delavar et al. (2009) introduced a real-time modeling approach for optimal water allocation for drought period and showed that traditional operating procedures produced 42% loss that can be reduced to 12% by adopting the approach suggested by them. Various operating models and decision support system (DSS) have been developed and applied by researchers to address the issues of water supply from reservoirs for irrigation planning, flood management, power generation, multi objectives operation, enhancement of efficiencies (Martin et al. 1984; Koch and Allen 1986; Arumugam et al. 1997; Majumdar and Ramesh 1997; Prajamwong et al. 1997; Panigrahi and Mujumdar 2000; Manoli et al. 2001; Cancelliere et al. 2002; Reddy and Nagesh 2006; Reddy and Nagesh 2007; El-Mesiry et al. 2007; Kim et al. 2008; Canon et al. 2009; Li et al. 2012; Hosseini et al. 2013; Nikoo et al. 2013; Wang and Liu 2013; Daariane and Sarani 2013; Moghaddasi et al. 2013; Ahmadi et al. 2014 etc.).

Veerakcuddy and Nandalal (2005) developed a DSS for reservoir water management conflict resolution (RWM-CRSS) for a multipurpose single reservoir system. The system consists of a communication, database management, and a model-base management system. Goel et al. (2007) presented the utility of remote sensing and geographic information system (GIS) environment for determining realistic irrigation demands and reservoir operation of Samrat Ashok Sagar Reservoir in India. Using simulation analysis of 29 years inflow data, rule curves have been derived for operation of reservoir to meet demands in water deficit area (if any) in advance to avoid severe crop failure .

Yang *et al.* (2009) developed the multi-objective genetic algorithm (MOGA), constrained differential dynamic programming (CDDP) and the groundwater simulation model ISOQUAD for multi-objective planning for conjunctive use of surface and subsurface water using genetic algorithm and dynamics programming. Safavi *et al*. (2010) focused on the simulation-optimization for conjunctive use of surface water and groundwater on a basin-wide scale for Najafabad plain in west central Iran. The results of the proposed model demonstrated the importance of the conjunctive use approach for planning the management of water resources in semiarid regions. Hassaballah *et al*. (2012) developed a methodology based on coupled simulation-optimization approach for determining filling rules for the proposed Mandaya Reservoir in Ethiopia with minimum impact on hydropower generation downstream at Roseires Reservoir in Sudan, and ensuring power generation from the reservoir.

2.4 Application of MIKE BASIN Model

The MIKE BASIN model developed by DHI, Denmark to address complex issues water sharing, water allocation, reservoir operation, water quality and conjunctive use of surface and groundwater on basin scale in simple and intuitive yet in-depth insight for water resources planning and management (DHI, 2009). Typical areas of the MIKE Basin applications are (Srinivas, 2007):

- Water availability analysis: conjunctive surface and groundwater use, optimization thereof.
- Infrastructure planning: irrigation potential, reservoir performance, water supply capacity, waste water treatment requirements.
- Analysis of multi-sectoral demands: domestic, industry, agriculture, hydropower, navigation, recreation, ecological, finding equitable trade-offs.
- Ecosystem studies: water quality, minimum discharge requirements, sustainable yield, effects of global change. Regulation: water rights, priorities, water quality compliance.

Talagala (2003) presented a study for optimum utilization of water resources of Walawe Ganga, to assess the water availability at the Uda Walawe reservoir with regulation at Samanalawcwa using MIKE BASIN. The basic input to the model was consists of time series data of catchment runoff for each branch of the river network. The rainfall data during 1991- 2000 were used for the analysis and as the time of resolution for rainfall was 24 hours the objective functions of NAM calibration were limited to overall water balance error and overall root mean square error. Jha and Gupta (2003) developed MIKE BASIN model for Mun river basin in Thailand that provide a basis for optimal allocation of water resources. DHI, Inc. (2006) developed a surface water budget model for the Lemhi river basin (LRMBM), Idaho used to quantify and collectively represent source and uses of stream flow throughout the entire main stem of the Lemhi river. Lerson *et al*. (2006) presented a study proposes the coupling of a strategic scale water resources management simulation model (MIKE- BASIN) and a finite difference groundwater model (ASM), as a tool to support decision making in data scarce environments. DHI, Inc. (2008) developed model for river Mckenzie and its tributaries. The MRMBM (Mckenzie River MIKE BASIN Model) includes a series of rainfall-runoff models constructed using DHI’s NAM model in order to provide catchment inflows to the model. Jaiswal et 2013 and Guru et al 2014 applied MIKE BASIN model for irrigation management and reservoir operation for reservoir having sharing agreement among different stake holders.

2.5 Assessment of Changes Using Remote Sensing and GIS

The remote sensing data due to their synoptic viewing, availability of archive imageries and capability of capturing changes in plant growth, chlorophyll content or structural changes have tremendous potential for routine monitoring irrigation. The digital nature of satellite data also makes it relatively easy to integrate into a Geographic Information System (GIS) for synthesis or comparison with other data sources. (Ozdogan et al 2010). The supervised as well as unsupervised classification of multi date remote sensing data are commonly used to identify different classes of land uses including crop types their growth etc. The supervised classification is the process of using training samples of known identity to classify pixels of unknown identity. On the other hand, unsupervised classification uses some well known indices which are the algebraic manipulation of spectral bands. The vegetation indices are the most predominant method for identification of vegetative areas and change detection studies without bias (Deering & Hass, 1980) uses reflectance of multi band remote sensing data and converted to single value correlating to physical vegetation parameters (such as biomass, productivity, leaf area index, or percent vegetation ground cover) (Tucker, 1979; Hartfield et al, 2008). The normalized difference vegetative index (NDVI) is the most commonly used and widely accepted method requires two wavelengths to identify plant characteristics (Henik, 2012). The NDVI is also used to evaluate plant nitrogen status, chlorophyll content, green leaf biomass and grain yield (Ma et al., 1996; Shanahan et al., 2001; Shanahan et al., 2003; Solari et al., 2008). Gitelson et al, 2005 described and used green index which is the ratio between reflectance of infra red and green to distinguish chlorophyll contents.

CHAPTER- 3: STUDY AREA AND DATA USED

3.1 Location

The Harsi irrigation project is situated in Gwalior district of the Madhya Pradesh (India) at 25°45’ N latitude and 77°58’ E longitude. The Harsi dam is situated on river Harsi at about 100 km from the Gwalior and 55 km from Dabra Town. The location map of Harsi irrigation project in Madhya Pradesh has been given in Fig. 3.1.

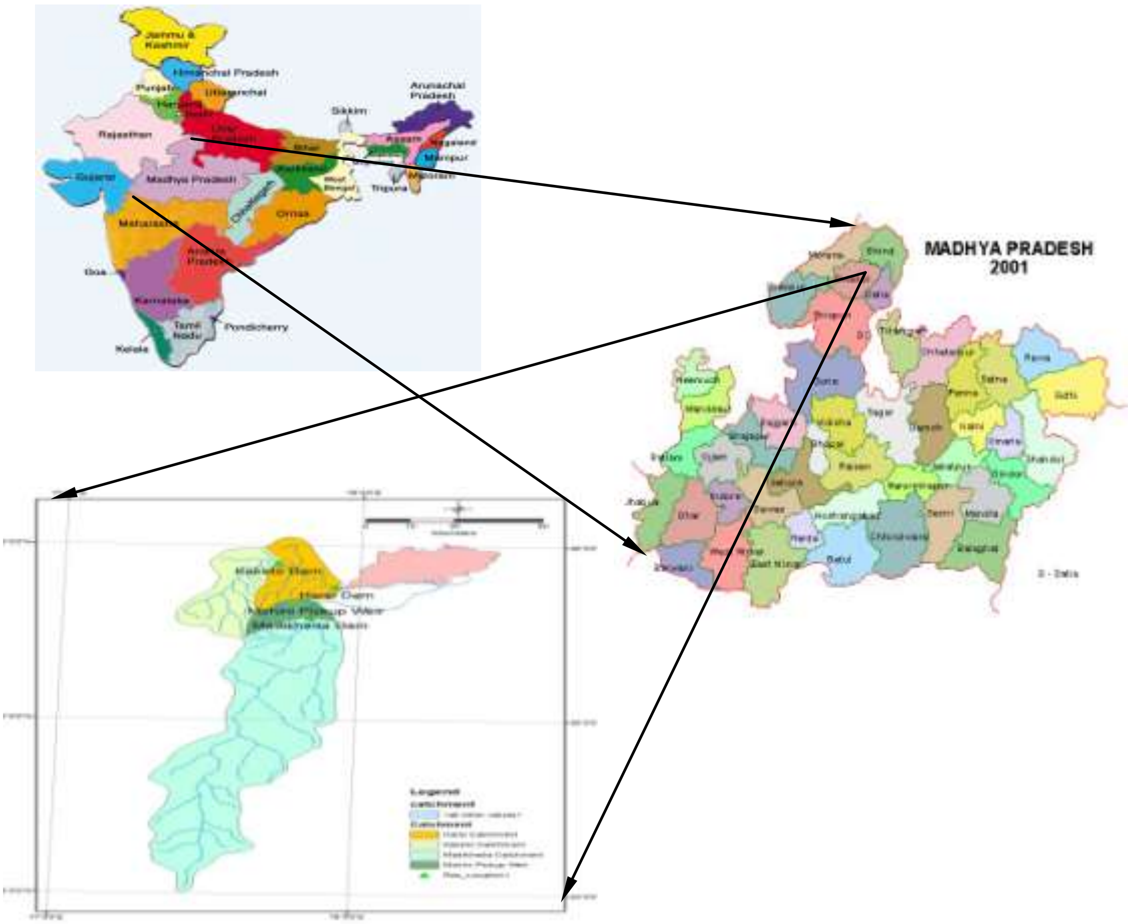


Fig. 3.1 Location map of Harsi reservoir in Gwalior district (M.P.)

3.1.1 Harsi dam

Harsi dam was constructed before independence (during 1928-1935) by Gwalior State. It was originally designed to irrigate 7085 hectares of Kharif and 20243 hectares of Rabi and 3036 hectares of Sugarcane. The dam is situated on Parvati River which is a tributary of river Sindh of Yamuna river system. The Google map of the study area has been presented in Fig. 3.2. The Harsi project was envisaged to provide irrigation facilities in 62675 ha culturable command area (CCA) with 91057 ha gross command area (GCA) in Gwalior district. The dam site and command area of the project falls in survey of India toposheet 54G. Due to increasing demand of irrigation water in the command, shortage of water is experienced every year in this project and WRD, Govt. of M.P. explored the new possibilities by diverting Sindh river water through Mohini pick up weir in first phase and through Madikheda dam in second stage. After implementation of both the phases of Sindh project, the Harsi command is able to get 137.07 Mm^3 water from Madikheda dam through Mohini Pick up weir. Rehabilitation and modernization of Harsi canal system was also done to reduce losses of 75 year old canal system. The salient features of Harsi project are presented in Table 3.1.

Fig. 3.2 Google image of the study area (Source: www.google.com)

3.2 Data Used

The meteorological data including monthly average of minimum temperature, maximum temperature, average wind speed, average relative humidity and sunshine hour of Datia district (M.P.) from 1999 to 2008 with some gapes have been used for computation of crop water requirement and setting up MIKE BASIN model. The rainfall data of Dabra block from 1984 to 2011 have been used for probability analysis. The proposed cropping patterns in the design of the projects and average existing cropping pattern have been used for computation of crop water requirement. The area-elevation-capacity table/curve for reservoir and spillway, reservoir characteristics, cropping pattern, soil details and canal characteristics were used in modeling. The Reservoir levels at different time periods were used to select LISS III remote sensing data of IRS satellites for sedimentation study. The changes in irrigating areas were determined using LISS IV scenes of different periods (2009 and 2013). The details regarding data used in the study are presented in Table 3.2.

CHAPTER- 4: METHODOLOGY

The methodology for irrigation management in Harsi command consists of collection and analysis of meteorological data, GIS data base generation, reservoir sedimentation study, rainfall analysis, assessment of crop and irrigation water requirement, scenarios based demand supply analysis, development of MIKE BASIN model for irrigation management and reservoir operation. In the study, an attempt has also been made to demonstrate the impact of modernization works and command development works in the command using multi-temporal remote sensing data.

4.1 Generation of GIS Data Base

For the study, a GIS data base has been generated with the help of raster maps, information and toposheets collected from diverse sources. The Arc GIS software was used for generation of catchment, command, committee's/WUAs jurisdiction, soil, geology, drainage etc which were further employed in MIKE BASIN application and impact analysis whereas, ILWIS 3.0/3.7 was used for image analysis of remote sensing data for reservoir sedimentation study.

4.1.1 Arc GIS

The Arc GIS is a versatile software consists of a suite of integrated applications that allow to perform GIS tasks including mapping, geographic analysis, data editing and compilation, data management, visualization and geo-processing. The important applications of ARC GIS software are as follows:

- Mapping and visualization with Arc Map
- Data management with Arc Catalog
- Editing and data compilation
- Table and attribute information
- Geoprocessing
- 3D visualization with Arc Globe and Arc Scene
- The geo database
- GIS Servers and services

The Arc GIS provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. The Arc GIS is an integrated family of GIS software products for building a complete GIS. The Arc GIS Desktop is the primary seat used by GIS professionals to compile, author, and use geographic information and knowledge. It is available at three functional levels as Arc View, Arc Editor, and Arc Info. Arc GIS Desktop includes an integrated suite of comprehensive desktop applications—Arc Map, Arc Catalog, Arc Toolbox and Arc Globe. Each application has a rich set of GIS tools and operators. The Arc GIS Desktop is a comprehensive set of professional GIS applications used to solve problems, to meet a mission, to increase efficiency, to make better decisions, to communicate, visualize and understand an idea, a plan, a conflict, a problem, or the status of a situation. In the present study/project, a GIS base data base has been created for Harsi command that will be useful for future planning and scientific management of water resources. For development of GIS data base, various thematic maps including catchment and command areas, river network, road network, geology, soil, village maps, and jurisdiction of committees have been prepared/ generated.

4.2 Reservoir Sediment Study

The construction of barrier in the form of dam for storage of water causes siltation of reservoir due to reduction of speed of flowing water . The periodical assessment of capacity of reservoirs is necessary for determination of extent of degradation in the catchment areas, allocation of existing water for different purposes, determination of useful life of reservoir and rate of siltation etc. 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. The digital images of different dates are required to cover the whole range of live storage. After importing, all the images may be geo-referenced with the help of topo-sheets/maps so that they can be overlaid and linked with the latitude and longitude and the geographical area also can be determined. After geo-referencing, all the images have been cut down to small sizes to cover the water spread area of the reservoir and its surroundings.

The remote sensing provides land resource data in the form of digital magnetic types and in different bands of the electromagnetic spectrum. For any given material, the amount of solar radiation that it reflects, absorbs, transmits, or emits varies with wavelength. This important property of matter makes it possible to identify different substances or classes and to separate them by their individual spectral signatures. In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorption and reflectance are low. The reflectance of water in the visible region scarcely rises above 5%. The absorption of water rises rapidly in the near-infrared (NIR) band where both, the reflectance and transmittance are low. The reflectance of various objects present on the earth is different than water and this reflectance recorded in digital format by the sensors mounted on satellite. The digital data obtained from the sensors can be used to extract water spreads at different levels. The normalized difference water index (NDWI), band ratio and slicing has been used to identify the water pixels in the images. The *NDWI* and band ratio (B*R*) for identification of water pixels can be written as:

$$NDWI = \left[\frac{GREEN - NIR}{GREEN + NIR}\right] \tag{4.1}$$

where, GREEN = Band-I data of IRS 1D/P6 satellite, NIR = Band III data of IRS 1D/P6 satellite.

$$BR = \frac{NIR}{GREEN} \tag{4.2}$$

The slicing operation of the NDWI and band ratio images has been carried out to extract the water pixels from the rest of image. A graph was then plotted between reservoir elevations and revised water spread areas to estimate the revised areas at regular intervals of whole range of live storage. The revised areas obtained from this operation may be used to estimate the revised volume between two consecutive short elevations with the help of cone formula. In the cone formula, the volume of water (V) between two consecutive spread A_1 and A_2 can be expressed as:

$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right) \tag{4.3}$$

where, h = height between two elevations. The revised cumulative capacities have been obtained by adding the revised volumes between consecutive intervals.

4.3 Computation of Crop Water Requirement (CWR)

The appropriate design and management of irrigation system and the judicious application of water in the field require reliable information on consumptive use of various crops grown in the command area. The water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place. The water applied in the field during irrigation acts as a carrier for nutrients for plants and a major part of applied water lost through transpiration with little uses by plants for building tissues. The crop water requirement includes evapotranspiration, application losses and special needs. Application losses include the loss of water during water application. The special needs include water required for land preparation, transplantation and leaching etc. In the present study, CROPWAT 8.0 software has been used for computation of irrigation requirement and is being described here.

4.3.1 CROPWAT 8.0

The CROPWAT 8.0 for Windows is a computer program for the calculation of crop water and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. The CROPWAT 8.0 can also be used to evaluate farmer's irrigation practices and to estimate crop performance under both rain fed and irrigated conditions. All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of Irrigation and Drainage Series, namely, "No. 56: Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements" and "No. 33: Yield Response to Water".

In case where local data are not available, CROPWAT 8.0 includes standard crops and soils data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5,000 stations worldwide from Climwat, the associated climatic database. The development of irrigation schedules in CROPWAT 8.0 is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. The scheme water supply is calculated according to cropping pattern defined by the user, which can include up to 20 crops. The CROPWAT 8.0 for Windows includes a host of updated and new features, including:

- Monthly, decade and daily input of climatic data for calculation of reference evapotranspiration (ET_o).
- Backward compatibility to allow use of data from Climate database.
- Possibility to estimate climatic data in the absence of measured values.
- Decade and daily calculation of crop water requirements based on updated calculation algorithms including adjustment of crop-coefficient values.
- Calculation of crop water requirements and irrigation scheduling for paddy & upland rice, using a newly developed procedure to calculate water requirements including the land preparation period.
- Interactive user adjustable irrigation schedules.
- Daily soil water balance output tables.
- Easy saving and retrieval of sessions and of user-defined irrigation schedules.
- Graphical presentations of input data, crop water requirements and irrigation schedules.
- Easy import/export of data and graphics through clipboard or ASCII text files.
- Extensive printing routines, supporting all windows-based printers.
- Context-sensitive help system.
- Multilingual interface and help system: English, Spanish, French and Russian.

The CROPWAT uses FAO approved Penman-Monteith formula for computation of evapotranspiration for reference crop. The reference crop may be defined as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an Albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered. The method overcomes shortcomings of previous FAO Penman method and provides values more consistent with actual crop water use data worldwide. The FAO Penman- Monteith method to estimate ET_o is expressed as:

$$ET_o = \frac{0.048\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{4.4}$$

where, ET_o is the reference evapotranspiration [mm/day], R_n is the net radiation at the crop surface [MJ m^{-2}/day], G is the soil heat flux density [MJ m^{-2}/day], T is the mean daily air temperature at 2 m height [°C], μ_2 is the wind speed at 2 m height [m/s], e_s is the saturation vapor pressure [kPa], e_a is the actual vapour pressure [kPa], e_s-e_a is the saturation vapour pressure deficit [kPa], Δ is the slope vapour pressure curve [kPa/°C], y is the psychometric constant [kPa/°C]. The screen shot of CROPWAT8.0 is shown in Fig. 4.1. In the present study, the crop water requirement has been estimated for dry, normal and wet rainfall years which can be used to plan irrigation according to variable climate and inflows conditions. The procedure of rainfall data processing for computation of rainfall distribution in dry, average and wet years are being presented below.

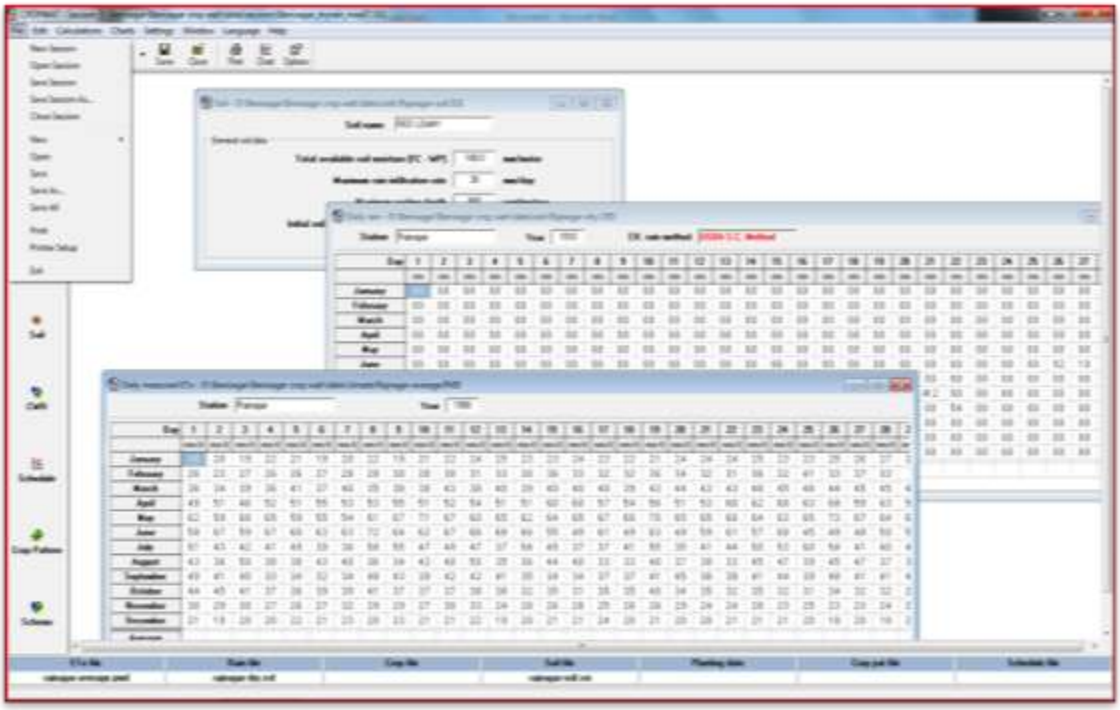


Fig. 4.1 Data entry and analysis in CROPWAT 8.0 (screen shot)

4.3.2 Rainfall data processing

For determination of rainfall data for dry, average and wet years, the yearly/seasonal rainfall data are arranged in descending order and given a rank from 1, 2, 3, 4, ….m. The weibull formula is used to determine plotting position. A graph is plotted on semi-log paper with rainfall on ordinate and plotting position on abscissa with log scale. A regression line is plotted to estimate dependable yearly rainfall at 20%, 50% and 80% probability. The rainfall at 20%, 50% and 80% probability of exceedance are called annual rainfall for wet, average and dry year respectively. The daily, decadal or monthly rainfall values for average, dry and wet years can be computed using the following formulas:

For dry years

$$p_{i(dry)} = \frac{p_{i(av)} * P_{dry}}{P_{av}} \tag{4.5}$$

where, $p_{i(dry)}$ is the rainfall for i^{th} period of dry year, P_{dry} is the annual rainfall at 80% probability of exceedance and P_{av} is the average annual rainfall. Similarly, rainfall for wet and average years can be computed replacing P_{dry} to P_{wet} or P_{av}.

4.3.3 Crop & soil data

To determine the irrigation requirements in a command, an assessment of the different crops grown under irrigation and their crop characteristics such as length of the growth cycle, crop factors, rooting depth etc. are required. The CROPWAT 8.0 has crop data for several common crops taken from selected FAO publications. However, the most reliable crop data remain the data obtained from local agricultural research stations. The Crop module requires crop data over the different development stages, defined as follow:

- **Initial stage**: It starts from planting date to approximately 10% ground cover.
- **Development stage**: It runs from 10% ground cover to effective full cover. The effective full cover for many crops occurs at the initiation of flowering.
- **Mid-season stage**: It runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the ET_o.
- **Late season stage**: It runs from the start of maturity to harvest or full senescence.

The data required differ in case of non-rice or a rice crop. In case of non-rice crop, the following information is necessary:

- Crop name and planting date
- Crop coefficient (K_c)
- Stages length
- Rooting depth
- Critical depletion fraction (p)
- Yield response factor (K_y)

If available, maximum crop height should be provided. The rice crop module requires the following additional information in comparison to non-rice crops:

- Planting date in case of direct sowing, or transplanting date in case of sowing in a nursery
- Duration of nursery and land preparation (including puddling) stages
- Dry and Wet Crop coefficients (Kc)
- Puddling depth

The Soil module is essential data input for crop water estimation and requires total Available Water (TAW), maximum infiltration rate, maximum rooting depth and initial soil moisture depletion in case of non-rice and additionally drainable porosity, critical depletion for puddle cracking, water availability at planting and maximum water depth for rice crop.

4.3.4 Gross water requirement

When water is supplied from any source to irrigation field, it undergoes some losses during conveyance and application to the field. Hence, water required from source is much more than the crop water requirement. Also, the crop water requirement depends on climatic and rainfall conditions. During dry or drought years, the requirement of water for irrigation is more because of higher temperature and low effective rainfall. The conveyance and application losses play important role in computation of gross irrigation water requirement for a command. A reconnaissance survey of the command has been carried out to assess the present condition of canals and field applications and it has been found that the canals are partly lined and partly left unlined intentionally to recharge groundwater as per the govt. policies. Few photographs showing canal conditions in Harsi command have been presented in **Fig. 4.2**.

Lined Canals

Unlined Canals

Figure 4.2 Condition of canals in Harsi command

A report of Water Resources Deptt., Govt. of M.P. titled "Scheme Modernization Plan of Harsi Project, District: Gwalior (Scheme Project No.: P073370)" explained present main canal and distributary efficiency as 86%, field channel efficiency as 90%, field application efficiency as 75% and operational efficiency as 95%. By grouping main canal and field channel efficiencies under the head conveyance efficiency (77%) and application and operational efficiencies under the head application efficiencies (71%) were used for computation of gross water requirement (Govt. of M.P., 2005-06). A major restructuring program is being taken by State Govt. for Harsi project, an improved conditions using conveyance efficiency as 86% and application efficiency as 76% were considered to compute gross water requirement were determined to know the effect of modernization works.

The analysis of seasonal rainfall of Dabra rain gauge station confirmed variation from 476 mm to 1199 mm with mean of 730 mm. This large variation in rainfall and extreme weather conditions in the area led a challenge for water resources managers to use proper irrigation management. After the development of Harsi command, it was observed that Harsi dam could not fulfill the entire demand of its command and its renovation plan was implemented with transfer of water from Kaketo reservoir, Madikheda dam and Mohini pickup weir and modernization of canal system. For formulation of scenarios, variation of climate, rainfall, reservoir inflows and cropping pattern, losses during conveyance and application have been considered as key factors and six different scenarios for design and present cropping patterns were formulated for computation of gross water requirements. The irrigation water requirements computed for different WUAs will be helpful to water resources managers for efficient irrigation planning and more crop production under variable climatic and inflow conditions.

4.4 Irrigation Management using MIKE BASIN Model

The MIKE BASIN is a versatile, GIS based decision support tool for integrated water resources management and planning. It can be used for addressing water allocation, conjunctive use, reservoir operation, or water quality issues and couples the power of Arc GIS with comprehensive hydrological modeling to provide basin scale solutions (Fig 4.3). The MIKE BASIN philosophy is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. For hydrological simulations, MIKE BASIN builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. For carrying out demand-supply analysis from reservoir, irrigation release and optimization in MIKE BASIN software, the following information related to reservoir and commands are required.

- Inflows from catchment of the reservoir

- The storage capacity of the reservoir
- The level-area-volume characteristics of the reservoir
- The reservoir operating rules and other characteristics such as reservoir losses and gains, minimum and maximum releases and minimum and maximum operating levels
- Soil properties, cropping pattern, crop calendar, cropping areas
- Climatological data, crop coefficients for computation of crop evapotranspiration
- Canal and application losses etc.

The reservoir operation and irrigation planning in MIKE BASIN operates on the basis of a digitized river network generated directly on the computer screen in the map view. All the information regarding configuration of the river branch network, location of water users, channels for intakes and outlets to and from water users, reservoirs are also defined by on-screen editing or using DEM. After digitizing the river network, reservoirs can be inserted and diversion channels and irrigation nodes can be digitized. An irrigation node represents an irrigation area comprising one or more irrigation fields which are drawing water from same source(s). In the model, based on calculated demand, water is extracted from one or more sources, e.g., river nodes and/or reservoir nodes according to specific allocation rules. An irrigation node can extract groundwater and excess water may be returned to river system through surface water channel. In the present study, scenarios based irrigation planning and demand-supply analysis in the commands has been carried out; therefore, setting up of model depicting rivers reaches, reservoir, irrigation nodes, channels and transfer of water through from other sources (as per project) need to be specified. The setting up of reservoirs, irrigation model and channels are being described here.

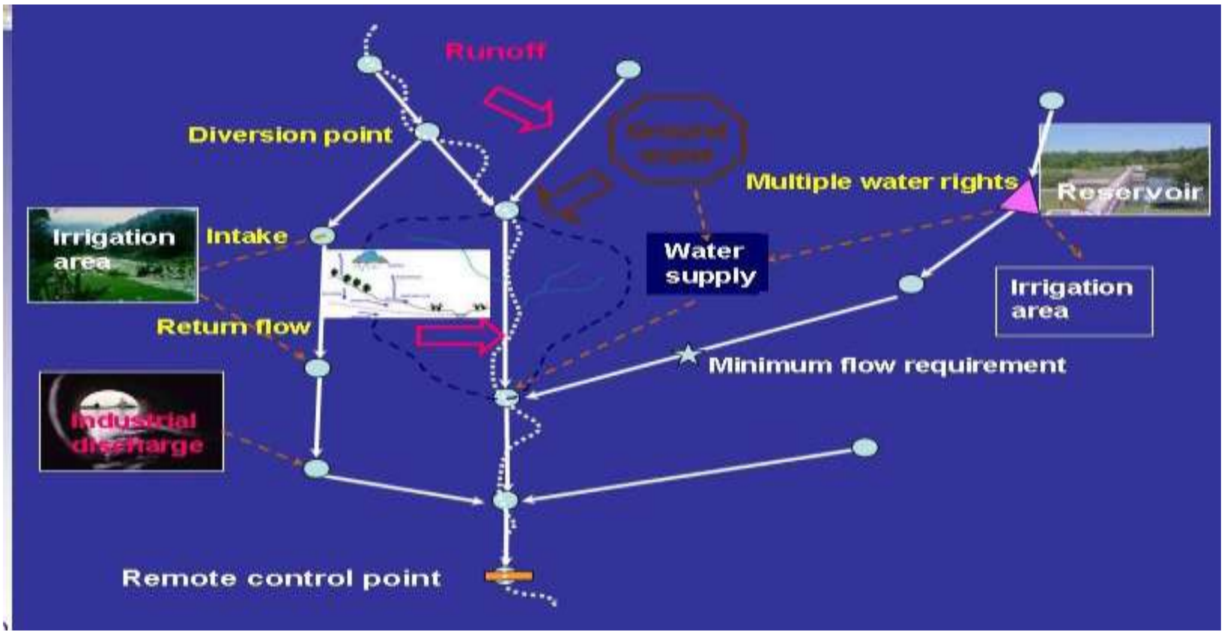


Figure 4.3 Working of MIKE BASIN through nodes and channel (Reproduce from MIKE BASIN Manual)

4.4.1 Reservoir

The MIKE BASIN can accommodate multiple multi-purpose reservoir system and individual reservoirs can simulate performance of specified operating policies using associated operating rule curves. These policies and curves define the desired storage volumes, water levels and releases at anytime as a function of current water level, the time of the year, demand for water, losses and gains. Reservoirs can be inserted anywhere on the river branches except on river bifurcation nodes or the most upstream nodes. In MIKE BASIN, three types of storages reservoirs can be modeled either as rule curve reservoir, allocation pool reservoir or lake. The rule curve reservoir has a single physical storage and all users can draw water from the same storage. The operating rules for each user apply to that same storage and users compete with each other to fulfill their water extraction rights. The allocation pool reservoir has a physical storage but the individual user has allocated certain storage right within a zone of water levels. An accounting procedure keeps track of the actual water storage in one pool for downstream minimum flow releases (water quality pool) and in individual pool allocated for water supply users. The Lakes are specific reservoirs where no operation rules apply. The outflow from a lake can be restricted by a spillway relationship. For operating the reservoir in MIKE BASIN, its general, operation, spillway and water quality (optional) properties need to be specified. The brief description of various time series data required to define these properties is presented below.

4.4.2 General reservoir properties

The reservoir characteristics, operating rules and upstream and downstream connections to users and control nodes are all specified in the reservoir property dialog box. The height-volume-area (HVA) table is used to compute reservoir volume at any level in reservoir. During the simulation, linear interpolation between the user-specified neighboring data triplets in the table is performed to arrive at piece-wise linear HVA function. The characteristic levels time series requires bottom level, top of dead storage, dam crest level and losses/gain time series (optional).

4.4.3 Reservoir operation properties

The operation tab gives access to specify reservoir operation rules. Operating rules are defined to include not only storage target levels (e.g. the flood control level in case spillways information is not specified), but also various storage allocation zones, release and spill requirement and constraints respectively. These can vary in time as described by rule curve time series. With the help of priority tab, reservoirs can directly be connected to multiple downstream water user nodes, hydropower nodes or reservoir or nodes. The rule field will automatically be filled when downstream nodes are connected to the reservoir. Remote flow rule are logical relations between nodes far away from each other- not neighboring nodes. Lastly, the storage demand rule is a way of operating two reservoirs in series or in parallel, if two reservoirs are located on the same river branch in series it is often an advantage to keep as much water as possible in the upstream reservoir. The storage demand option will ensure that water is released from the upstream reservoir for the downstream reservoir only to maintain a certain critical water level in the downstream reservoir.

4.4.4 Spillway

The releases during flood control operations from reservoir can be controlled by two spillways: a (top) spillway defined by hydraulic capacity, spill capacity table and its bottom level while a second spillway defined by the bottom outlet capacity time series often assumed located at the base of the dam. The spill capacity table, spillway bottom level and bottom outlet capacity time series are required to define the operation of spillway. All these time series are optional and if these time series are not specified, all excess water above HFL will go to downstream.

4.4.5 Irrigation Modeling

In order to define heterogeneity of soils, crops, irrigation methods and climate, various sub-models including Climate, Reference ET, Soil water, Runoff, Irrigation method, Crop, Yield and Crop sequence sub-models are needed to be defined for irrigation planning. The climate sub-model accepts a number of commonly available climate inputs and convert them to the input required for Reference ET sub-model and Precipitation. Presently two types of model are available which include rainfall only and FAO 56 climate model. In rainfall only model, the rainfall is used as an input in the form of time series while FAO 56 model requires air temperature (min and max), wind speed, sunshine hour, relative humidity and rainfall series. The reference ET sub-model provides reference evapotranspiration to crop sub-model at each time step of simulation. The evapotranspiration rate may either be computed based on climate sub-model or provided directly as time series.

The main task of the soil water model is to keep track the amount of soil water available for soil evaporation and crop evapotranspiration at any time during the simulation. The soil water content may also be used by Irrigation sub-model to determine the irrigation demand. Presently, FAO56 Soil Water Model which is a simple water balance model is available in MIKE BASIN software. It keeps track of the soil moisture content in a surface storage from where soil evaporation takes place that provides water for transpiration. The depth of the surface storage is specified as the “Depth of evaporable layer” and the depth of the root zone equals the root depth at any time during the simulation. It is assumed that the evaporable layer drains to the root zone when field capacity is reached. The wetting fraction (equals 1.0 for rain and is user specified for irrigation) is taken into account when the exchange between evaporable layer and root zone is calculated for wetting fractions less than 1, water may be exchanged for average water contents in the evaporable less than field capacity. The Runoff sub-model is an optional model and if no model is selected in the field the runoff is assumed to be zero. The task of the runoff model is to calculate the fraction of the precipitation that will leave the field as surface runoff and hence never enter the root zone. If the irrigation node is connected to the river network, surface runoff will enter the connection channel. Specification of a runoff model is optional where surface runoff is calculated by assuming a linear relationship between rainfall intensity and the amount of surface runoff.

The irrigation sub-model is used to specify how and specify how and when a given field is irrigated. Presently, the FAO 56 irrigation model is available in MIKE BASIN. The irrigation model requires a wetting fraction that determines the fraction of the field surface that is being wetted during irrigation e.g. sprinkler irrigation will be close to 1 whereas for drip irrigation it may be as low as 0.1. The wetting fraction is also an important factor determine how much irrigation is required before the surface soil storage is filled and hence when the root zone starts to fill. The specification of a spray loss is required which is the fraction of the irrigation water that is evaporated before the water reaches the soil surface For sprinkler irrigation this fraction may be relatively high, whereas it is relatively low for drip irrigation. In the MIKE BASIN following three trigger options are available to determine when the irrigation will start.

1. Fraction of Total Available Water (TAW): Irrigation starts when the soil moisture content reaches the specified fraction of TAW. TAW is defined as the volume of water contained in the root zone when at field capacity.
2. Fraction of Readily Available Water (RAW): Irrigation starts when the soil moisture content reaches the specified fraction of RAW. RAW is defined as the volume of water that can be transpired by the crop without exposing the crop to soil water stress and can be calculate using the following equation:

   $$RAW = (1 - p) * TAW \qquad (4.6)$$

   where, p is a factor based on sensitivity of crop with soil moisture stress, or more specifically the fraction of the totally available water (TAW) at which soil moisture stress will start to reduce crop transpiration.
3. Specified depletion depth: Irrigation will start when the soil moisture content reaches the specified depletion.

When the irrigation has started as per the trigger option, the application depth is calculated according to available following three application option:

- Fraction of Total Available Water (TAW): Irrigation stops when the soil moisture content reaches the specified of TAW.
- Fraction of Readily Available Water (RAW): Irrigation stops when the soil moisture content reaches the specified fraction of RAW.
- Fixed depth. The specified depth of water is applied to the field.

The crop sub-model is used in MIKE BASIN to compute crop evapotranspiration and soil evaporation for crops using soil moisture content and reference evapotranspiration. The FAO 56 method is currently available in the model uses dual crop coefficient method. The dual crop coefficient method calculates transpiration and soil evaporation separately and thus allows more accurate quantification of different irrigation technologies. The FAO56 defines the crop stages into an initial, development middle and late crop stage. For each stage, the length of stage and a Basal crop coefficient (K_{cb}) is assigned. The Basal crop coefficient is defined as the ratio of crop evapotranspiration over the reference evapotranspiration (ET_c/ET_0) when the soil surface is dry but transpiration is occurring at potential rate. The K_{cb} is assumed constant in the initial and middle stages and assumed to follow a linear variation between the stages. The root zone depth determines the maximum depth from which the crop can extract water and the minimum and maximum depth has to be specified. It is assumed that the maximum depth is obtained at the beginning of the middle stage and that the variation between the initial depth and the maximum depth is determined by the following relationship.

$$R = \frac{(K_{cb} - K_{cb,ini})}{(K_{cb,mid} - K_{cb,ini})}(R_{max} - R_{min}) + R_{min} \quad (4.7)$$

Where, $K_{cb,ini}$ is the initial Basal coefficient, $K_{cb,mid}$ is the Basal coefficient in middle stage, R_{max} is the maximum root depth and R_{min} is the minimum root depth. The influence of the surface roughness on the evapotranspiration is taken into account through a climatic factor applied to the basal crop coefficient. The vegetation height (H) is assumed to scale with the Basal coefficient and is calculated as:

$$H = \frac{(K_{cb} - K_{cb,ini})}{(K_{cb,mid} - K_{cb,ini})} H_{max} \quad (4.8)$$

The yield option attached to crop sub-model makes it possible to convert a soil water stress in to the corresponding yield loss, and hence to quantify the costs of a soil moisture deficit. The FAO 33 yield model is currently available is based on potential yield (Y_p) which is the crop yield under optimal conditions (no soil moisture stress). The sensitivity of a crop to soil moisture stress depends on the growth stage. A crop will usually be more sensitive to soil moisture stress in an early stage than in a late growth stage and taken into account with a yield Response Factor (K_y)

which is to be specified for each of four growth stages. The length of each stage is to be assigned but does not have to be the same as the growth stages in the cop model. The crop yield is calculates using the following equation:

$$\frac{Y_a}{y_P} = \prod_{i=1}^{i=G}\left[1 - K_{yi}\ \left(1 - \frac{Et_a}{Et_p}\right)\right] \tag{4.9}$$

Where Ya is the actual yield, Yp is potential yield, Eta is the actual transpiration and EtP is the potential transpiration, index i is the ith growth stage in a growing season with a total of G growth periods.

A crop sequence is really not a sub-model but it is just a convenient way of specifying how a field is managed. However, since the same crop sequence may be used in several fields, it makes sense to keep the crop sequence dialogs with sub-models. A crop sequence consists of a sequence in crop shifts can be characterized by a starting data (sowing data), a crop and optionally a reference and irrigation sub-model that will be used to irrigate the crop. A crop shift lasts until the end of the last growth stage of the crop in the field. If a crop harvested before the next crop is planted the model assumes that there are no crop at this field in the time between crops and hence that the irrigation demand is zero. When the next crop is sowed, the water content in the root zone will be reset to the initial water content as specified in the soil water model.

4.4.6 Channels

The channels are the segments that connect water users and hydropower nodes to a river or a reservoir. The flow losses and flow capacity times series are the optional time series required to define loss or gain of water due to seepage and loss of water due to evaporation. Both seepage and evaporation can be specified as a friction of actual flow (dimensionless) or as flux (volume per unit time). The flow capacity time series of river/channel is used to determine the maximum capacity that never be exceeded at any case. Similarly, river hydraulics tab is used to define four different routing options in channel. No routing, linear routing, Muskingum routing and wave translation routing are available in MIKE BASIN software.

4.4.7 Simulation

After setting up all sub models, reservoirs and channel details and priority setting, the model can be run for simulation. The most general output items at irrigation node is written to the MIKE BASIN output files and imported into Arc GIS just like the output from the remaining MIKE BASIN model building blocks. The output files contain evapotranspiration, total irrigation demand, net flow, demand deficit, stored volume and water levels in reservoirs, channel flows etc at given time span assigned during simulation.

4.5 Impact Assessment of Modernization Works

To assess the impact of restoration, repair and rejuvenation (RRR) works in command and canals, digital image analysis technique of remote sensing data were used to determine cropped areas in the command. For this, two different LISS 4 scenes before/during modernization (2009) and after modernization (2013) were selected, acquired and analyzed in ERDAS IMAGINE, GIS software. The normalized difference vegetation index (NDVI) was used to identify crop areas from rest of the land uses. The NDVI image from remote sensing data can be computed using following equation in Raster application of any GIS software

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4.10}$$

Theoritically, the values of NDVI can be ranged between -1 to 1. The negative values of NDVI indicated water as it has higher reflectance in red band and values close to zero in NIR band. The positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). The NDVI values for different objects are given below.

Object type	Reflectance* in the red spectrum	Reflectance in the near-infrared spectrum	NDVI
Dense vegetation	0.1	0.5	0.7
Scarce vegetation	0.1	0.3	0.5
Bare soil	0.25	0.3	0.025
Clouds	0.25	0.25	0
Snow and ice	0.375	0.35	-0.05
Water	0.02	0.01	-0.25
Artificial materials (concrete, asphalt)	0.3	0. 1	-0.5

** Indicates the portion of light reflected by the object. Scale range from 0 to 1.*

CHAPTER- 5: ANALYSIS OF RESULTS

Various analysis & works carried out for efficient management of irrigation water include GIS data base generation, estimation of revised capacity, rainfall analysis, computation of crop and gross water requirement for WUAs, MIKE BASIN based irrigation management, scenarios based assessment of demand-supply analysis and impact of modernization works on crop production in Harsi command.

5.1 Generation of GIS Data Base

Various thematic maps have been generated in GIS environment. The ARC GIS has been used to generate different thematic maps including jurisdiction of water user associations, drainage, canals, soils, geology and water transfer system in Harsi project.

5.1.1 Water transfer & water user association (WUA)

The Harsi reservoir alone cannot fulfill the complete demand of crops in the command and hence water is transferred from Kaketo reservoir, Madikheda dam and Mohini pickup weir. The different structures and water transfer in Harsi project is presented in the **Fig. 5.1**. To improve water conveyance efficiency and water management in the command, Command Area Development & Water Management (CADWM) Program works are being taken up and WUAs have been formed for close interaction between farmers and govt. official /water resources managers under participatory irrigation management (PIM). There are 26 WUAs works under 5 Distributaries Committees (under the administration of sub-division) within the command of Harsi canal system (Table 5.1, Fig. 5.2 (a) and Fig. 5.2 (b)).

5.1.2 Rivers & drainage system

The command area of Harsi Project is situated in a natural drainage system of Parvati River in the initial reach followed by Sindh River a Tributary of the Yamuna. The tail command is on the boundary of Chhachhond, a small tributary of Sindh river, whereas the Noon river passes across the command to drain excess water from most of the area, which is intercepted by Salwai Pick up weir (PUW) to divert water through Salwai Channel to the tail reach of D15A (Dabra Branch) of Harsi canal system (Fig. 5.3).

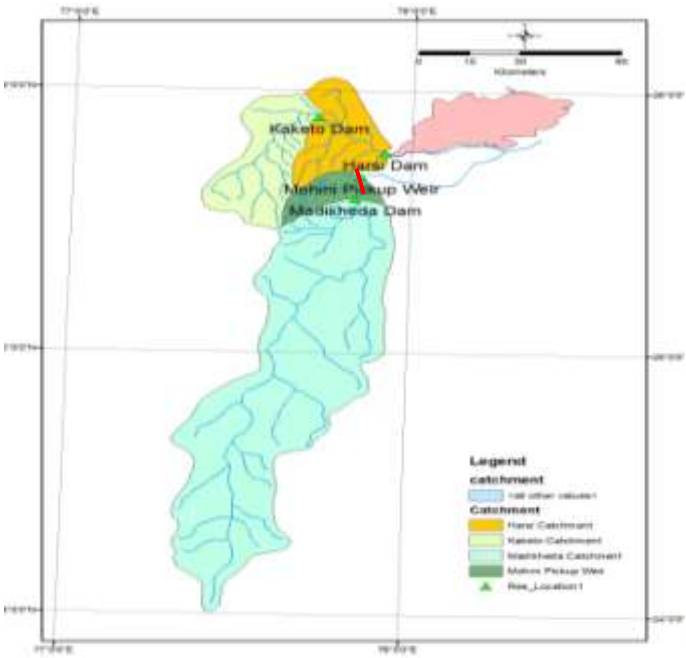


Fig. 5.1 Water transfer system in Harsi project

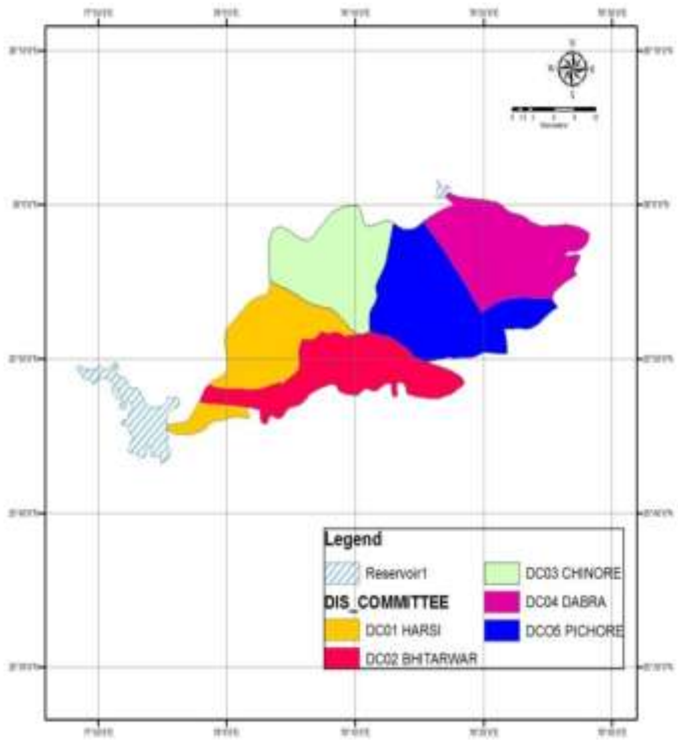


Fig. 5.2 (a) Areas under different commitees

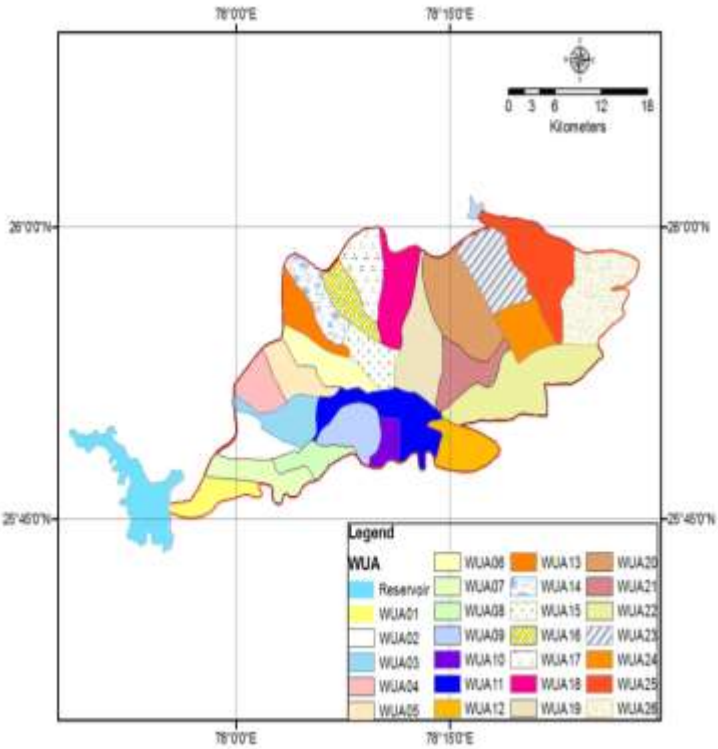
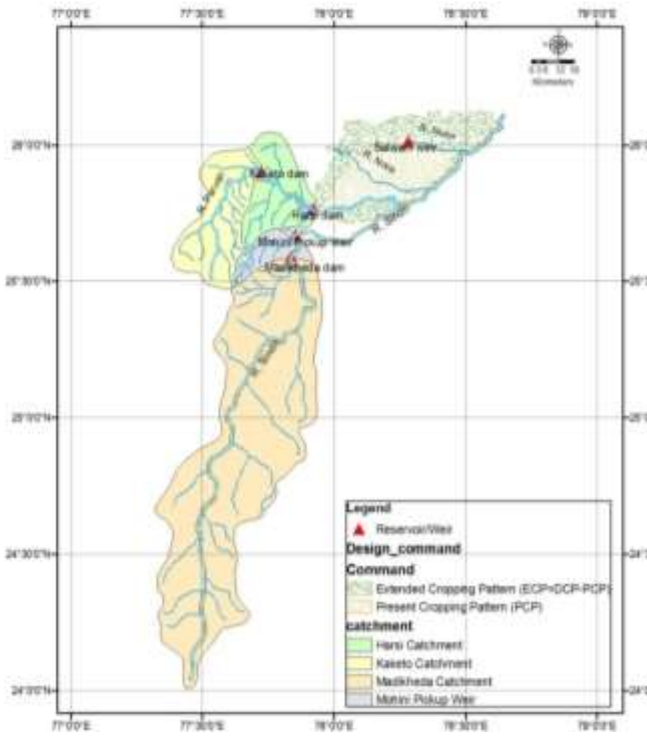


Fig. 5.2 (b) Water users associations

5.1.3 Topography & Soil

General topography of command area is plain having gentle slopes. The soils in the Harsi Command area fall under the broad group of alluvial soils. Alluvium deposited is an old one as the soil profiles do show horizon differentiation. The soil appears to be mixed with alluvium as the area is in a depression. The soil taxonomy map of the study area was prepared with the help of map from National Bureau of Soil Survey and Landuse Planning (NBSSLUP, Nagpur). The soil map of the command is shown in Fig. 5.4 and the detail description of soils in study area is given in the Table 5.2. The soils found in the command are mainly deep moderately well drained, clayey soils on very gently or moderately sloping undulating plain and mounds with moderate erosion.



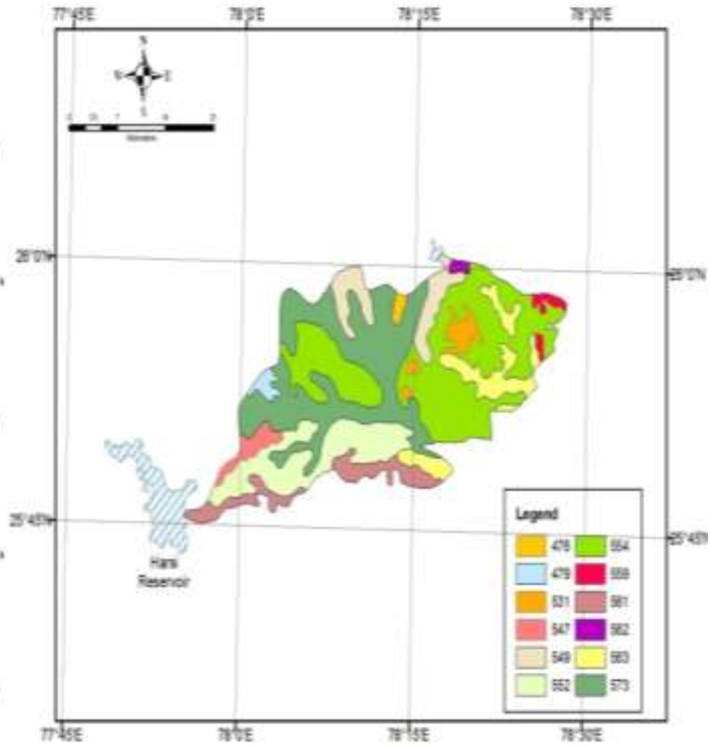


Fig. 5.3 Drainage system in catchment and command

Fig. 5.4 Soil map of Harsi Command

5.1.4 Geology

The geology map of Harsi command was derived from district resource map obtained from Geological Survey of India, Bhopal (M.P.). The geology map of the study area shows that Harsi command covers mainly by alluvium with granite near the dam only. The map showing geological distribution in the Harsi command is presented in Fig. 5.5.

5.1.5 Canals and villages

The Harsi command has only one main canal in the system which is a contour canal to irrigate right side portion only. With the implementation of Sindh Project Phase-1, the head discharge of Main Canal is redesigned to carry discharge of 37.10 m^3/sec and irrigate an area of

53, 158 ha in Dabra and Bhitarwar black of Gwalior District. The main canal and distributaries in Harsi command have been depicted in Fig. 5.6. The area under Harsi command having dense population and number of villages. The village map showing location of important villages in and around the Harsi command is depicted in Fig. 5.7. Dabra, Harsi, Bhitarwar, Pichore, Chinnor are some of the important villages in the area.

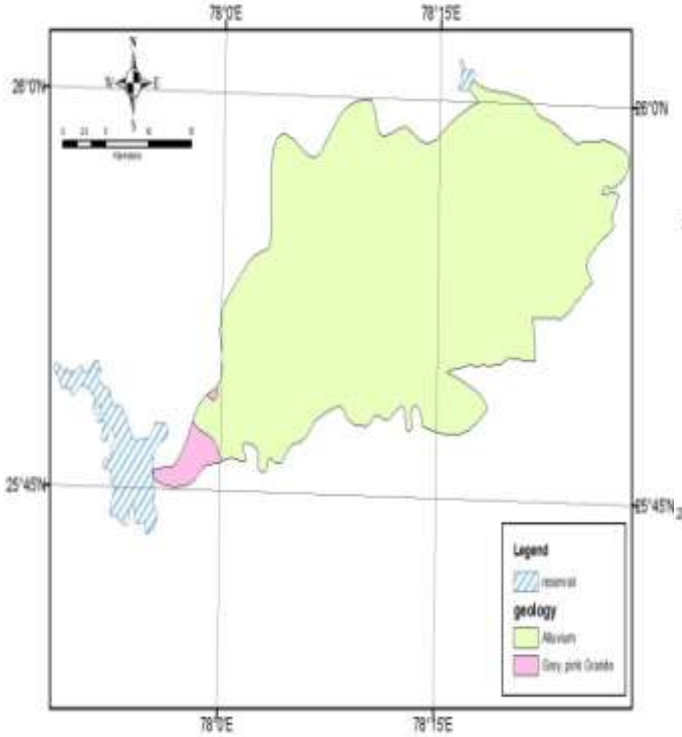


Fig. 5.5 Geological distribution in Harsi command

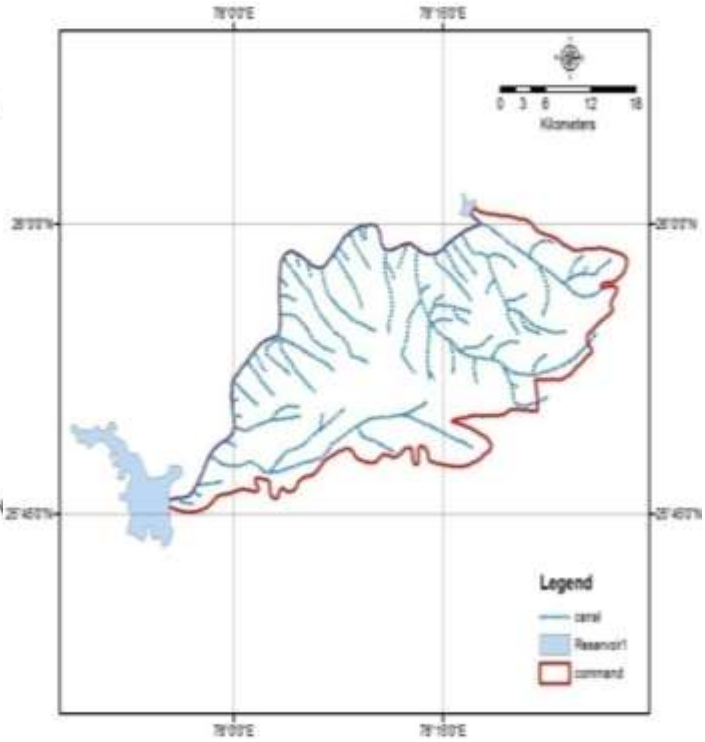


Fig. **5.6** Canals in Harsi command

5.1.6 Crops and cropping pattern

The main crops of Harsi command in kharif season are soybean, urad and paddy while wheat, gram and mustard are grown in rabi season. Other crops like sugarcane are also grown on large scale in command area. The present cropping pattern (PCP) of Harsi command consists of total irrigable area of 53518 ha with 23482 ha paddy in kharif, 25223 ha wheat in rabi and 4453 ha sugarcane as annual crop. After proposal of modification and construction of high level canals, the designed cropping pattern (DCP) increases to 62675 ha. The present gross command and extended gross command (Design gross command-Present gross command) after modification and construction of high level canals is presented in Fig. 5.8. The designed and present cropping patterns and crop duration in Harsi command are given in Table 5.3(a) and Table 5.3(b) and crop calendar for present and design cropping pattern are given in Fig. 5.9 (a) and Fig. 5.9 (b) respectively.

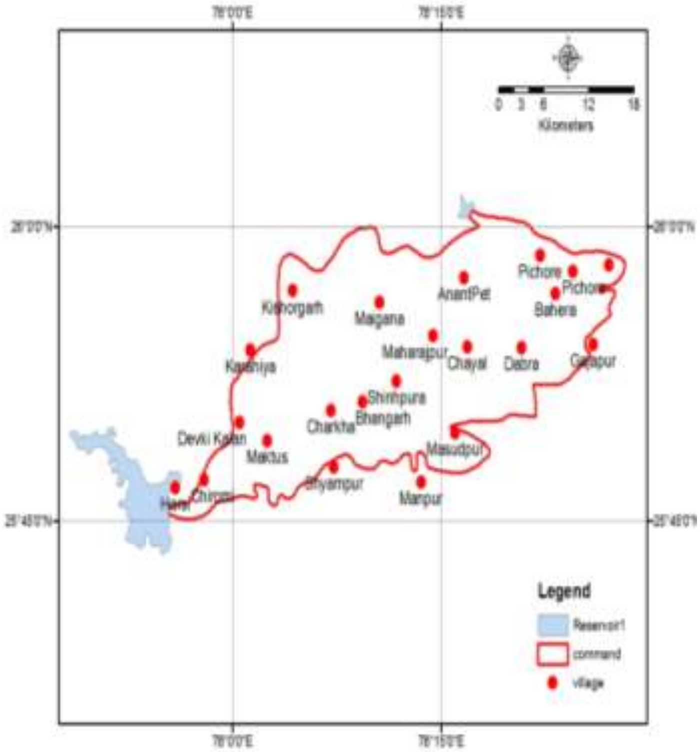


Fig. 5.7 Villages map of Harsi command

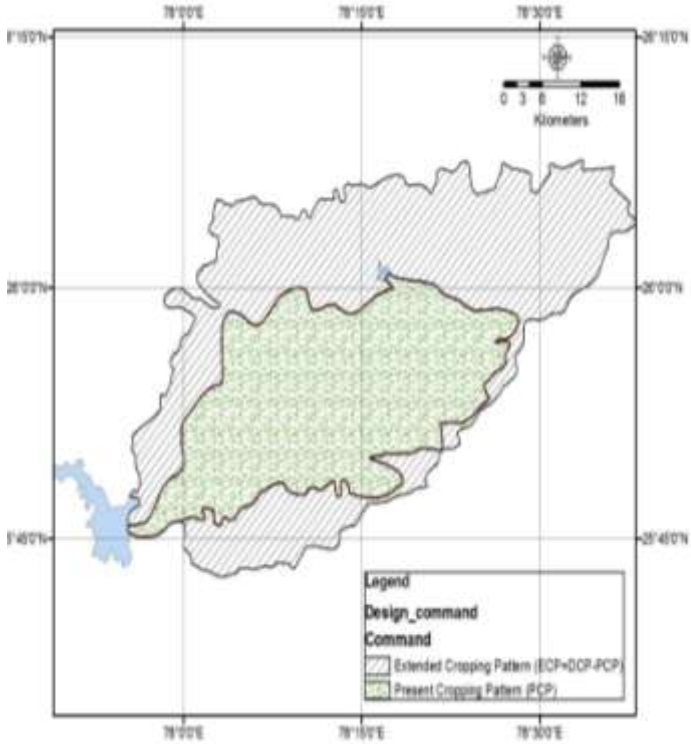


Fig. 5.8 Present and extended cropping patterns

5.2 Climate

The rainfall in the study area concentrated mainly from July to October with average annual rainfall is 770 mm. The Dabra rain gauge station lies in the centre of command and rainfall data of this station suggested that the maximum annual rainfall observed was 1211 mm in the year 1996 while minimum rainfall was observed as 508 in the year 1989 during last 28 year (from the year 1984 to 2011). The climate in winter season from November to February remains dry cold and temperature goes to freezing point while the regions experiences hot and dry summer from March to June when temperature goes up to 48^0C. The direction of the prevailing wind is generally south-west during period of April to July and north – west during September to November with maximum speed during the summer season. The weather is generally dry except during monsoon when it remains sub humid.

5.3 Estimation of Revised Capacity

In the present study, digital image classification of remote sensing data was carried out to determine revised water spreads which in turn used for estimation of revised capacities and losses at various levels of reservoir. For determination of revised water spreads at regular intervals, seven remote sensing LISS 3 scenes were purchased from NRSC, Hydearbad, imported and geo-referenced with the index map/topo-sheets in ILWIS 3.0, GIS software. The digital image analysis has been performed to estimate the revised water spread. The normalized deviation water index

Name of Crops	Area (ha)	January			February			March			April			May			June			July			August			September			October			November			December		
		D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3
Paddy 1	11741																			P												H					
Paddy 2	11741																				P												H				
Sugar cane	4453				P																																
				H																																	
Wheat 1	12611.5																															P					
						H																															
Wheat 2	12611.5																																P				
							H																														

Fig. 5.9 (a) Crop calendar for present cropping pattern (P-planting, H-harvesting)

Name of Crops	Area (ha)	January			February			March			April			May			June			July			August			September			October			November			December		
		D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3
Paddy 1	7780																			P												H					
Paddy 2	7780																				P												H				
Urad	648																				P											H					
Soya bean	1081																				P								H								
Wheat HYV 1	10806																															P					
						H																															
Wheat HYV 2	10806																																P				
							H																														
Wheat dwarf 1	7564																															P					
						H																															
Wheat dwarf 2	7564																																P				
							H																														
Gram	2161																													P							
			H																																		
Mustard	2161																													P							
								H																													
Sugar cane	4322				P																																
				H																																	

Fig. 5.9 (b) Crop calendar for design cropping pattern (P = Planting, H= Harvest)

(NDWI), image rationing and slicing methods of image classification have been used to differentiate water pixels from other land uses. The false color composite (FCC) and masked out water spread area of some selected dates have been presented in Fig. 5.10. The satellite data at dead storage level (DSL) i.e. 252.06 m and full supply level (FSL) i.e. 264.93 m were not available because of mismatch of satellite passes and levels of reservoir. To determine revised capacities on these levels, a scatter graph was plotted between reservoir elevation and revised water spread area and best-fit curves was fitted to evaluate revised water spreads on these levels. The revised water spread area at different elevations is presented in Table 5.4. The best-fit curve for revised water spread suggested 251.35 m is the revised bed level of Harsi reservoir in 2013. Using revised water spread areas, the revised cumulative capacity and percentage loss in cumulative storages at different levels have been estimated. The original, revised capacities and percentage loss between the levels of Harsi reservoir is presented in Table 5.5. The graphical representation of the elevation v/s original capacities in the year 1935 and revised cumulative capacities in the year 2013 for Harsi reservoir have been presented in Fig. 5.11. The result of remote sensing analysis confirmed that 47.44 Mm^3 of gross storage has been lost due to deposit of sediment in 78 years (1935 to 2013) and if the uniform rate is considered, the sedimentation in this reservoir comes out to be 0.61 Mm^3/ year. It can also be confirmed that nearly 82% dead storage and 23% gross storage has been lost in 78 years of reservoir operation.

5.4 Assessment of Demand on Harsi Reservoir

The only demand on Harsi reservoir is variable irrigation demands of Harsi command depend on climatic factors such as maximum, minimum temperature, humidity, rainfall, wind speed, sunshine hour, rainfall etc. The crop type and soil properties also affect the requirement of water for healthy growth of crops. The scenarios based assessment of water demands consist of identification of dry, average and wet rainfall years & corresponding climatic data for computation of cop water requirements for design and present pattern which then amplified using conveyance and application efficiencies for determination of gross water requirement. In the study, crop water requirements in different 10-daily periods have been computed for six different scenarios each for designed cropping (DCP-1 to DCP-6) and present cropping pattern (PCP-1 to PCP-6) whose details are presented in Table 5.6.

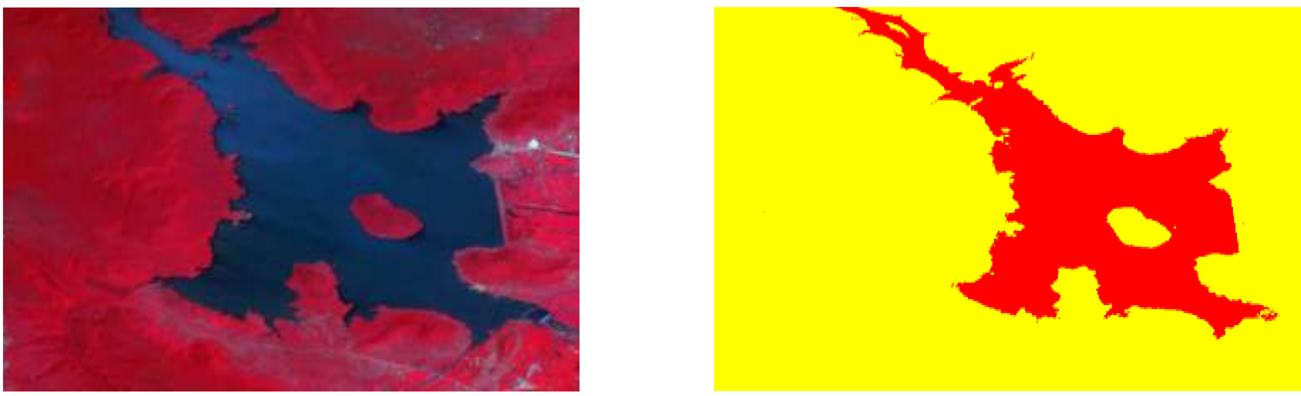
5.4.1 Computation of rainfall for dry, average and wet years

For the estimation of seasonal rainfall for dry, average and wet years, the probability analysis of seasonal rainfall has been carried out and presented in Fig. 5.12. The best-fit line plotted with this

Reservoir Level: 256.37 on dated 04-04-2011

Reservoir Level: 260.05 on dated 05-04-2013

Reservoir Level: 264.79 on dated 26-12-2013



Reservoir Level: 264.79 on dated 26-12-2013

Fig. 5.10 False Color Composite (FCC) and extracted revised water spreads of Harsi reservoir

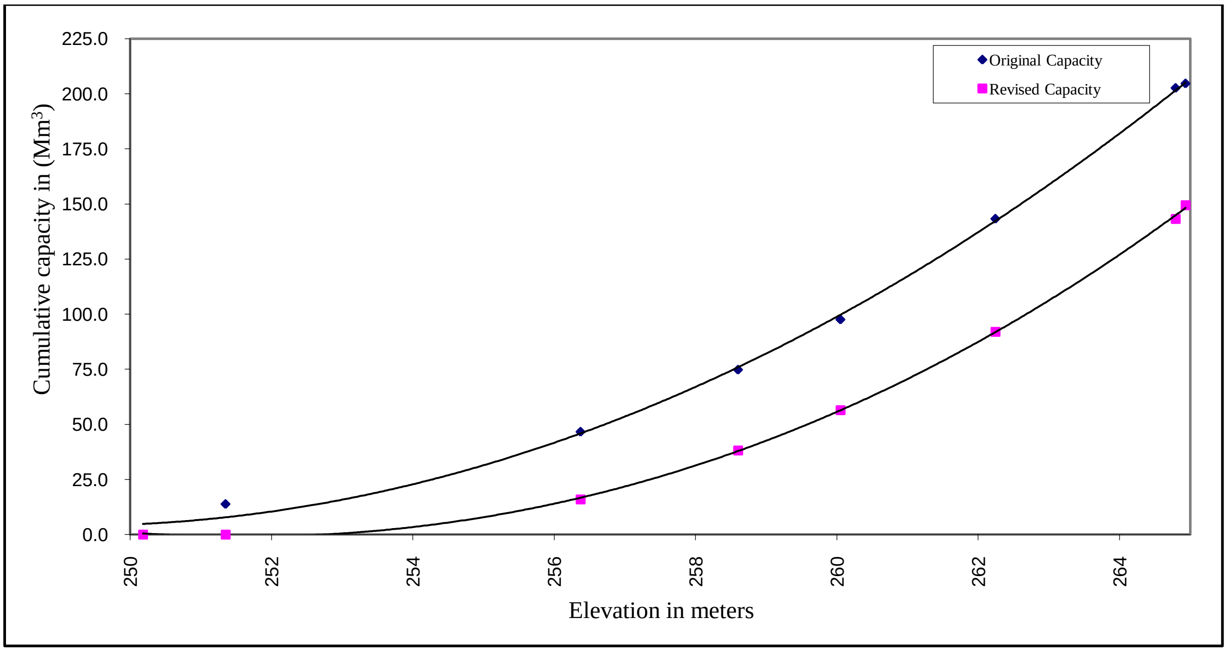


Fig. 5.11 Original and revised capacity curves for Harsi reservoir

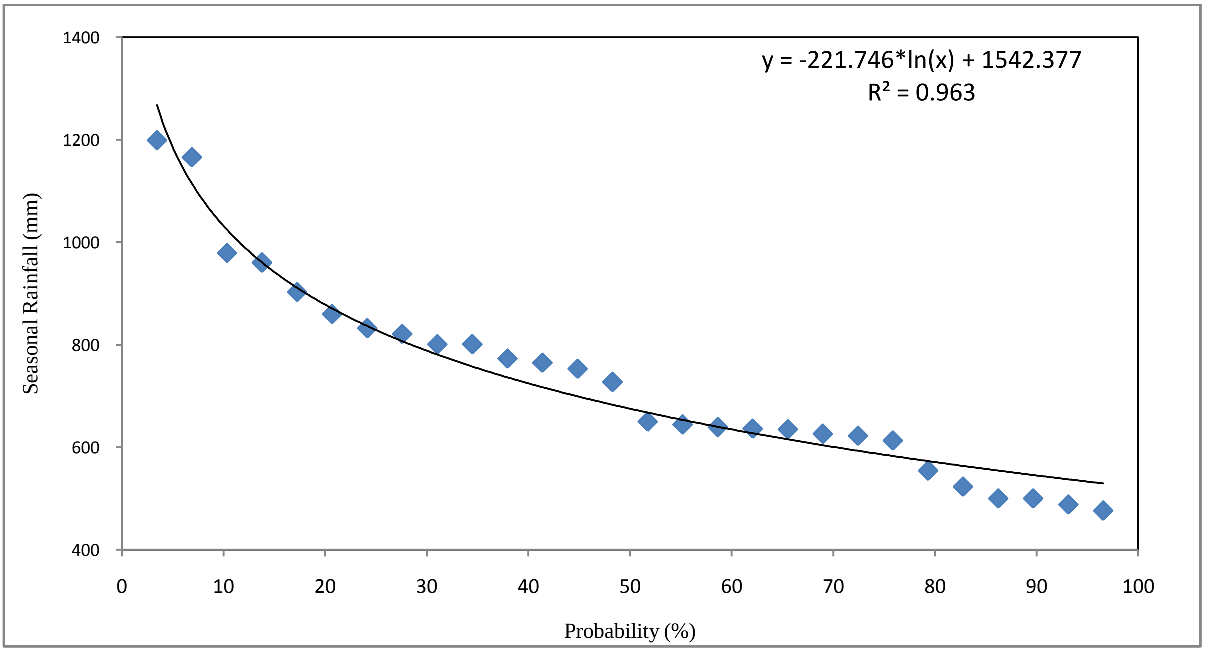


Fig. 5.12 Probability analysis of seasonal rainfall in Harsi command

graph has been used for estimation of seasonal rainfall at 20%, 50% and 80% probability. The equation obtained for computation of seasonal rainfall (P_p) at any probability of occurrence (p) is given below.

$$P_p = -221.7465 \times \ln(p) + 1542.3768 \qquad (5.1)$$

The seasonal rainfall in wet, average and dry years has been computed as 878.08 mm, 674.90 mm and 570.68 mm respectively. The rainfall data of 1974, 1993 and 2011 have been used as representative data for dry rainfall year, average rainfall year and wet rainfall year respectively. The irrigation water requirements under different scenarios for Harsi project are being described below.

5.4.2 Irrigation water requirement for design cropping pattern

The designed cropping pattern in Harsi project consists of 15561 ha paddy, 648 ha urad, and 1081 ha soybean in kharif season, 15128 ha wheat dwarf, 2161 ha gram, 2161 ha mustard and 21612 ha wheat HYV in rabi season and yearly crops as sugarcane in 4322 ha of command. As the cultivation does not start simultaneously in whole command areas, paddy, wheat HYV, and wheat dwarf have been divided in two parts on the basis of sowing dates as given in Fig 5.9 (a). The requirements of irrigation water have been computed for each sub-division and WUAs considering 77% efficiency during conveyance and 71% efficiency during field application and further improving to 86% and 76% during conveyance and field application respectively (DCP-1 to DCP-6). Sub-division and WUAs wise crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for designed cropping pattern in wet (DCP-1 and DCP-2), average (DCP-3 and DCP-4) and dry rainfall (DCP-5 and DCP-6) year have been presented in table 5.7 (a) and 5.7 (b) respectively. The gross water requirement with 77% conveyance efficiency and 71% field application efficiency may vary from 423.46 Mm^3 in wet rainfall years (DCP-1) to 474.67 Mm^3 in dry rainfall years (DCP-5). The gross water requirement can be reduced to 354.19 Mm^3 in wet rainfall years (DCP-2) and 397.03 Mm^3 in dry rainfall years (DCP-6) by improving conveyance efficiency to 86% and application efficiency to 76%. The results of analysis indicated that 8% and 12% more water is required during average and dry rainfall years respectively corresponding to wet rainfall years.

5.4.3 Irrigation water requirement for present cropping pattern

The present cropping pattern in Harsi command consists of 23482 ha paddy, 25223 ha wheat (HYV) and 4453 ha sugarcane. The sub-division and WUA wise crop water and gross water requirements for variable climatic and efficiencies conditions (PCP-1 to PCP-6) requirement of irrigation water have been depicted in Table 5.8 (a) and 5.8 (b) respectively. The gross water requirements for present cropping pattern with 77% conveyance efficiency and 71% application efficiencies may be 408.85 Mm^3 (PCP-1), 457.16 Mm^3 (PCP-3) and 476.28 Mm^3 (PCP-5) for wet, average and dry rainfall years respectively. By improving conveyance efficiency and application efficiency to 86% and 76% respectively, the gross water requirements for present cropping pattern may be reduced to 341.98 Mm^3 (PCP-2), 382.39 Mm^3 (PCP-4) and 398.38 Mm^3 (PCP-6) which indicate about 16% saving of water.

The scenarios based assessment of gross water requirements for different WUAs will be helpful for water resource managers to plan releases of water from Harsi reservoir. The storage capacity of Harsi reservoir (164.00) Mm^3 and water transfer from Kaketo reservoir (36.79 Mm^3), Madikheda dam (199.33 Mm^3) and Mohini pickup weir (107.07 Mm^3) make total availability of water is about 427.19 Mm^3. The gross water in average years and crop water requirements for different scenarios given below may vary from 341.98 Mm^3 to 474.78 Mm^3 (Table 5.9). Therefore, it is necessary to manage irrigation in efficient manner to make optimum use of water in dry years and brought more area under irrigation using conjunctive used of surface and groundwater in average and wet years. For efficient management of water resource and determination of optimum releases from reservoir, a MIKE BASIN based irrigation model for Harsi reservoir and command has been developed and described in next section.

5.5 Irrigation Management for Harsi Command using MIKE BASIN

Water resources projects run under variable conditions of demands and supplies. The various demands on project consist of irrigation, hydropower, domestic and industrial purposes, while supplies mainly contribute from water storage in reservoir and supplies from other sources. A systematic scheduling of irrigation water that matches with the periodic water requirement of crops can go a long way in increasing the agriculture productivity, farm income and employment of farm related labors. It is necessary that a requisite quantity of water must reach the field at appropriate time for which mechanization of releases, soil moisture measurement, proper operation & maintenance, community participation, conjunctive use and modeling based reservoir operation are necessary. The reservoir operation under variable crops, soils, climate and efficiencies may be the key to success for irrigation management where model run can be made in advance to take appropriate decisions regarding reservoir release or changing cropping pattern according to real time field situation.

For efficient irrigation management, the source of supplies for Harsi reservoir were analyzed and found that due to limited storage capacity, this reservoir is connected from different external sources from where water is transferred to the reservoir through channels. The Harsi reservoir receives water from Kaketo reservoir situated up-stream and Madikheda dam on river Sindh from where water is released to Mohini Pickup weir which is connected to a tributary of Parvati. These sources supply water to Harsi reservoir during rabi crop season. The data related to supplies of water were analyzed to determine firm supplies of water from different sources to the system. The MIKE Basin model developed for the study consists of catchment and reservoir node of Harsi dam, supply nodes from Kaketo reservoir, Mohini Pickup weir and Madikheda dam and Harsi command to receive water. The water resource system of Harsi reservoir depicting all sources of supplies and demand has been presented in Fig. 5.13 and average supplies from different sources in Table 5.10. For irrigation management and reservoir operation model for Harsi reservoir and its command in MIKE BASIN, the DEM of study area has been as input and automatic delineation of sub-watersheds have been performed using facility available in the software. A command in MIKE BASIN with name Harsi command has been described and joined through canals from the outlet of reservoir. The representation of MIKE BASIN model for Harsi reservoir, water transfer from Kaketo reservoir, Madikheda dam and Mohini Pickup Weir and supply of water to its command has been depicted in Fig. 5.14.

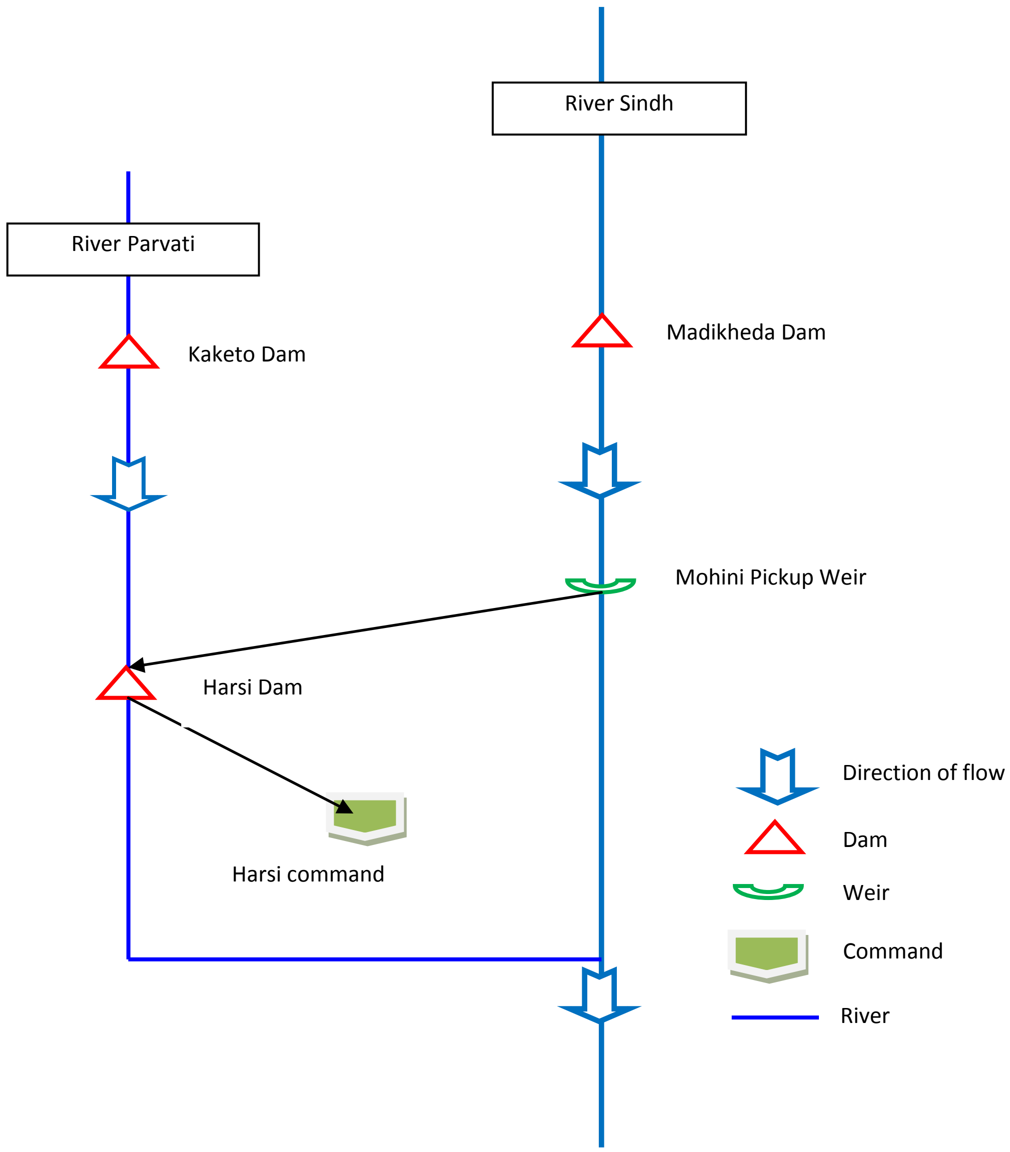


Fig.5.13 The water transfer system for Harsi reservoir

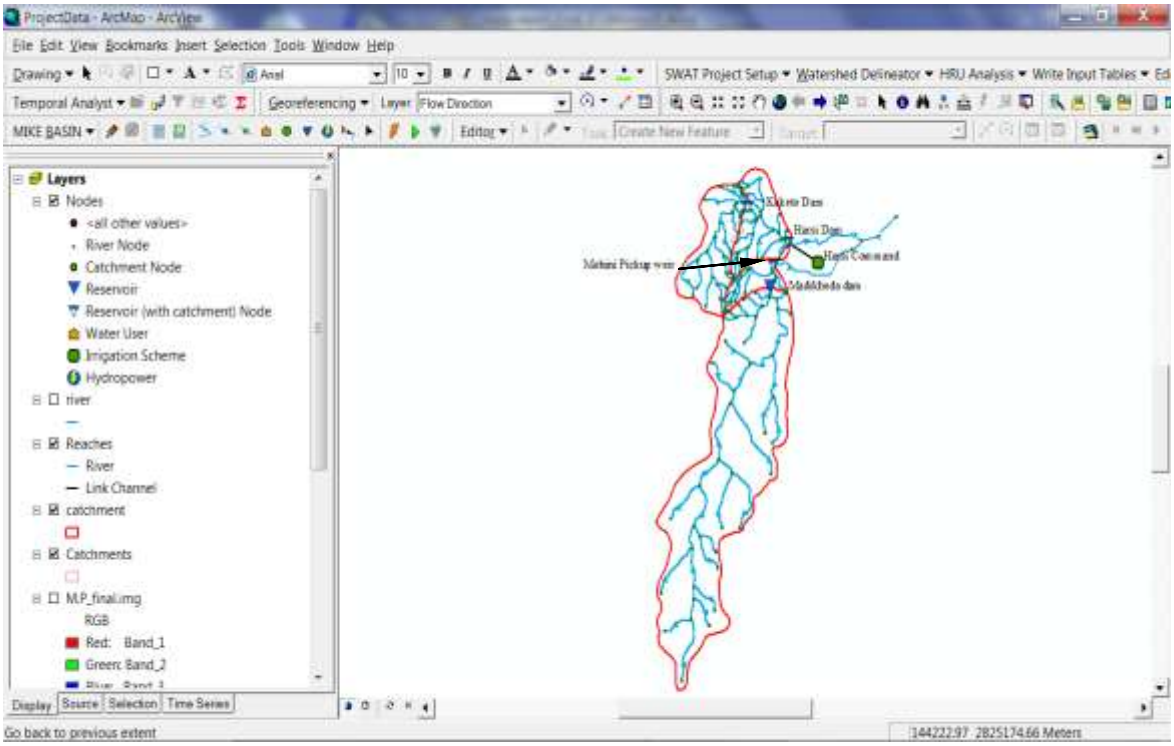


Fig. 5.14 Representation of MIKE BASIN model for Harsi reservoir and its command

The reservoir details including elevation-area-capacity table, full reservoir level, dead storage level, water supply priorities and reduction in supply have been defined in Reservoir Property tab (Table 5.11). The climatological data of Datia was used in climate sub-model for computation of reference evapotranspiration. Various sub models including climate, reference ET, soil, crop, irrigation were developed considering variability of climate, soils, crops, irrigation methods etc. All these sub-models were used to define cropping pattern under variable climatic condition in the command which ultimately connected with reservoir through connecting channel which incorporated application and conveyance losses.

For development of different scenarios, two separate MIKE BASIN model were prepared for design and present cropping patterns where suitable change have been made in time series to represent rainfall, climatic parameter, reservoir inflows, inflows from other sources, groundwater uses, conveyance and application losses. The results of probability analysis of rainfall were used and 2011, 1993, 1974 and 2002 have been selected as representative wet, average, dry and 75% rainfall years respectively. The rainfall and climatic data of these years and inflows computed from monthly equations adopted for Harsi reservoir were used as inputs in the model. The average monthly supplies from other sources were given as input to the system and change were made in seepage loss time series in reach properties of connecting canal. The conjunctive use of surface and ground water has been incorporated by using time series of friction of total demand (10%) used from groundwater storages. The irrigation demand, deficit and supply were evaluated for sixteen different scenarios of design and present cropping pattern representing variable climate, groundwater uses, conveyance and application losses (Table 5.12).

5.5.1 Simulation results for designed cropping pattern (DCP)

The MIKE BASIN model for irrigation management in Harsi command for design cropping pattern was developed and simulated for sixteen different scenarios (MB-DCP-1 to MB-DCP-16) covering a wide range of climatic variability, efficiencies condition and conjunctive use option in the field. The MIKE BASIN outputs of demand and deficit in different scenarios for the command can be seen in **Fig. 5.15 (a) and 5.15 (b**). From the analysis it has been observed that irrigation demands on Harsi reservoir may vary from 295.96 Mm^3 in wet years, 86% conveyance efficiency, 76% application efficiency and 10% groundwater use (MB-DCP-4) to 372.37 Mm^3 in dry year, 77% conveyance efficiency, 71% application efficiency and no groundwater use (MB-DCP-9), if reservoir is operated as per the releases suggested by the model. The irrigation demand, deficit, net flow and groundwater uses for different scenarios have been presented in Table 5.13. The demand deficit for design cropping pattern in 75% probable rainfall year may be 40.93 Mm^3 (MB-DCP-13) under present efficiency condition which can be reduced to 6.83 Mm^3 (MB-DCP-13) by improving efficiencies and further to 0.78 Mm^3, if surface and groundwater are used conjunctively in the command. In dry years, the demand deficit may reach to 86.77 Mm^3 and appropriate measures including change of cropping pattern, micro/sprinkler irrigation and other conservation measures are needed. The analysis suggested that the present supplies from different sources in Harsi reservoir may be able to irrigate command in most of the conditions, if proper irrigation management and timely supplies are made.

After 39 years of working, nearly 39.5 Mm^3 live storage of Harsi reservoir has been lost due to sedimentation, therefore, it is necessary to operate reservoir using presently available capacity. In the study, an attempt has been made to operate reservoir and plan irrigation for design as well as present cropping pattern with revised capacity of reservoir. The catchment characteristics and elevation-area-capacity tables were modified in the earlier developed models and separate simulation runs were made to determine irrigation demand, deficit, net flow and reservoir levels etc. The irrigation demand, groundwater use and demand deficit for different scenarios developed with original and revised storages in Harsi reservoir can be seen in **Fig. 5.16**. From the analysis, it has been observed that demand deficit with revised capacity may increase significantly during dry years due to limited availability of water in Harsi reservoir, other supply sources and groundwater storage. In wet, average and 75% probable supply year, the reduction of capacities may not have any significant impact on irrigation for design cropping pattern.

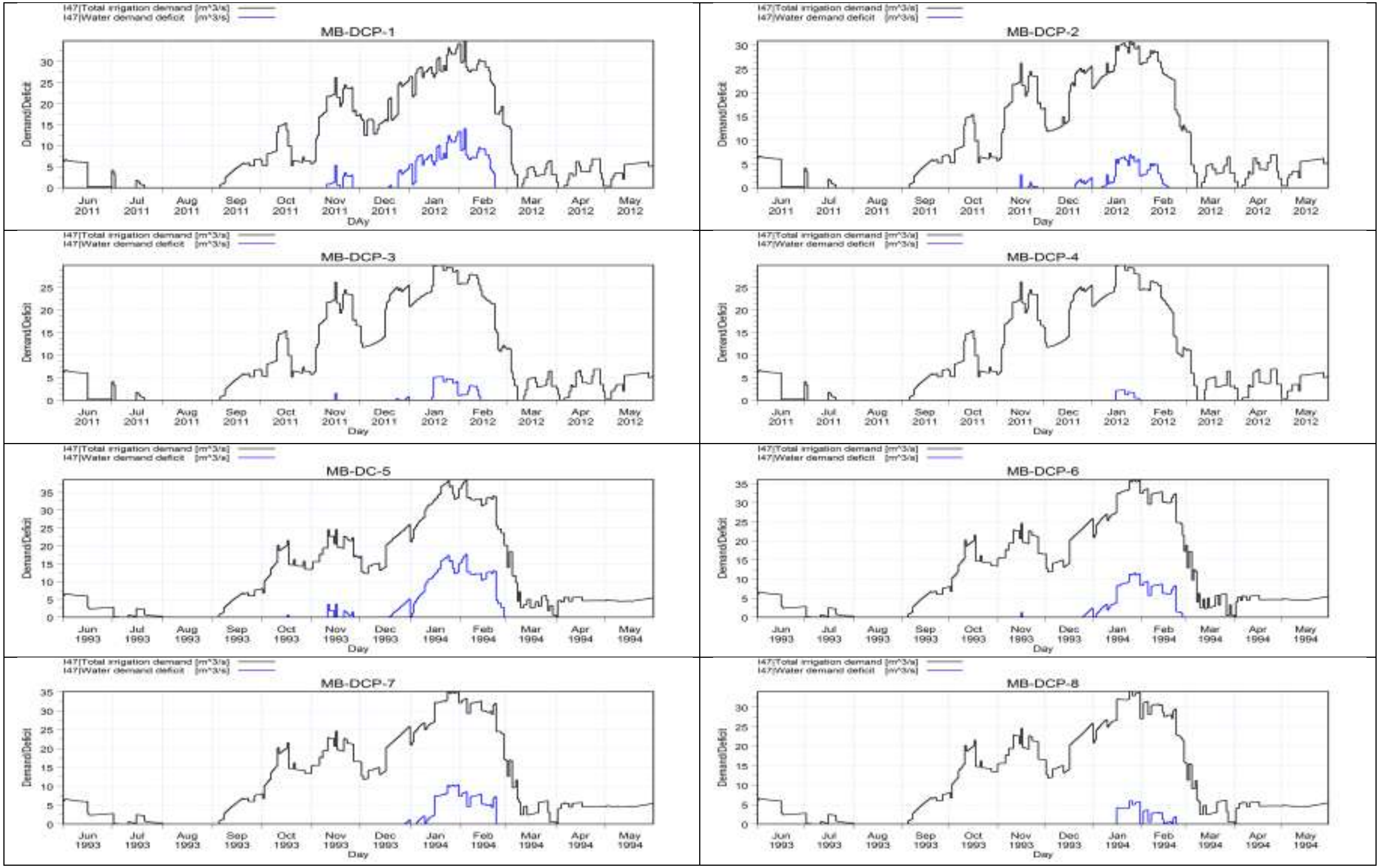


Fig. 5.15 (a) MIKE BASIN outputs of demand/deficit during different periods for Scenarios MB-DCP-1 to MB-DCP-8

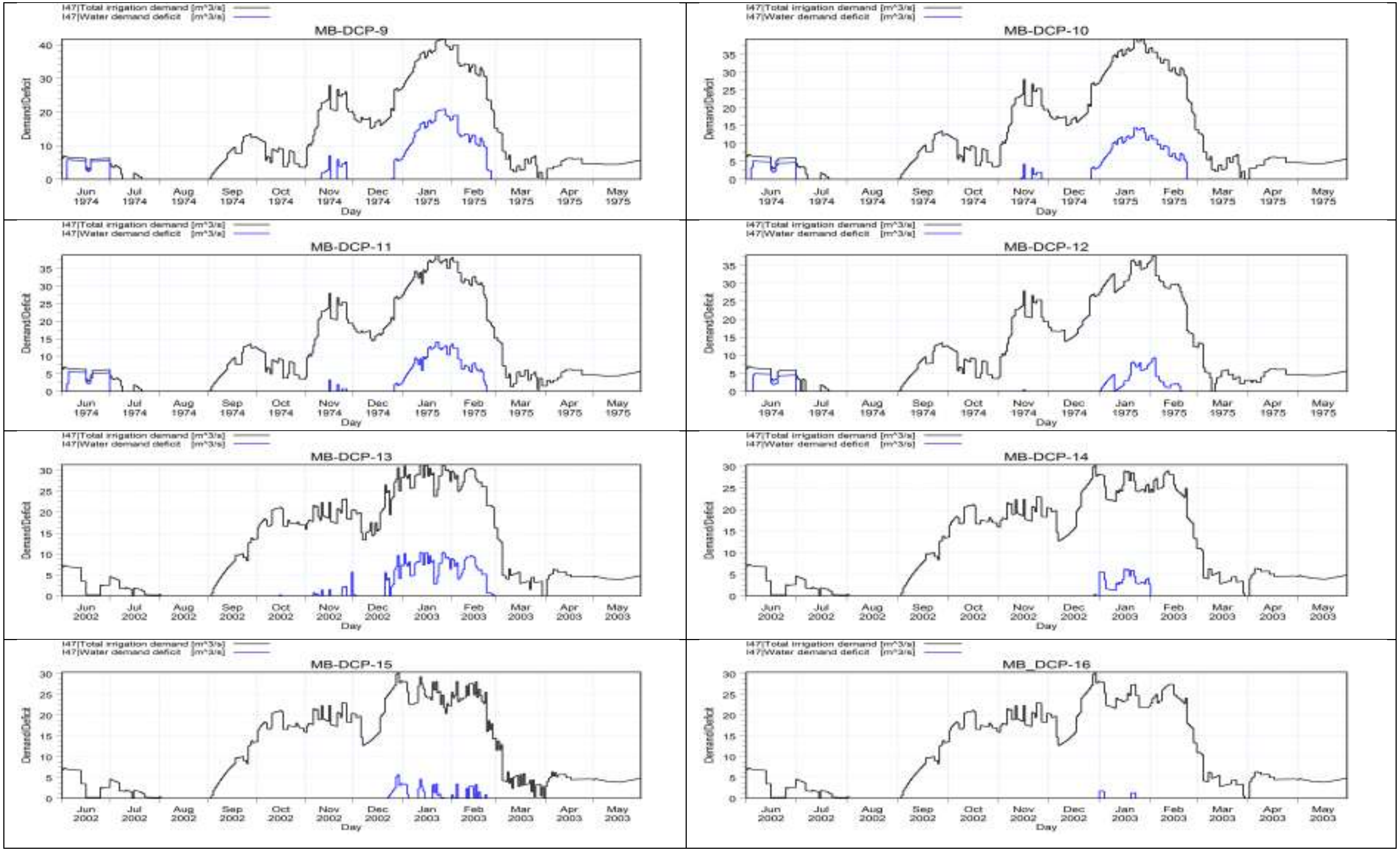
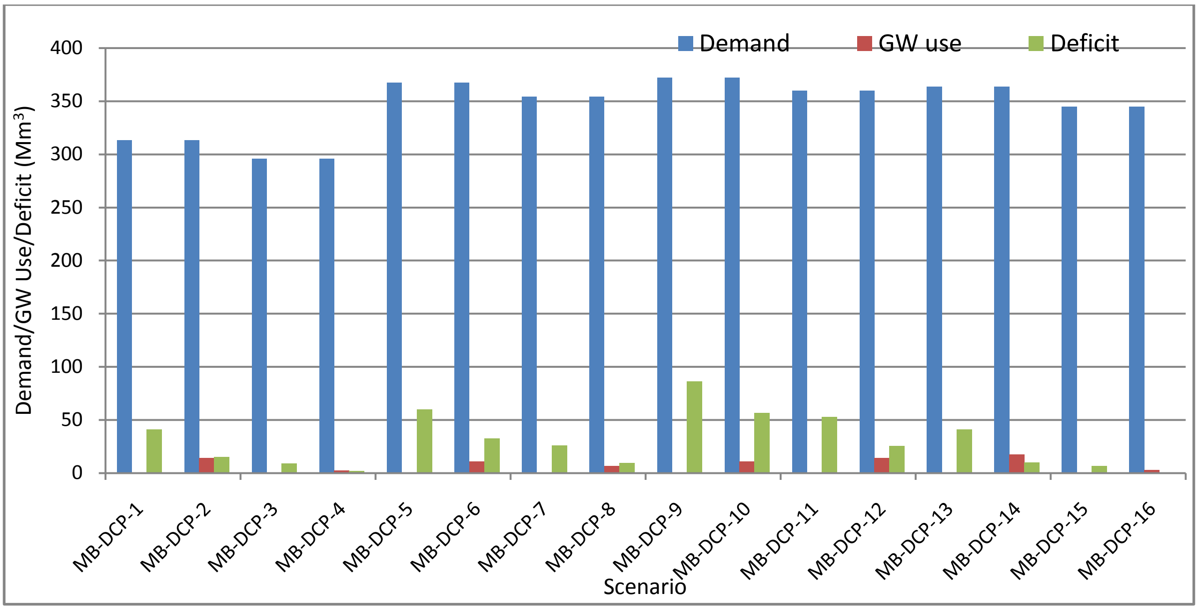
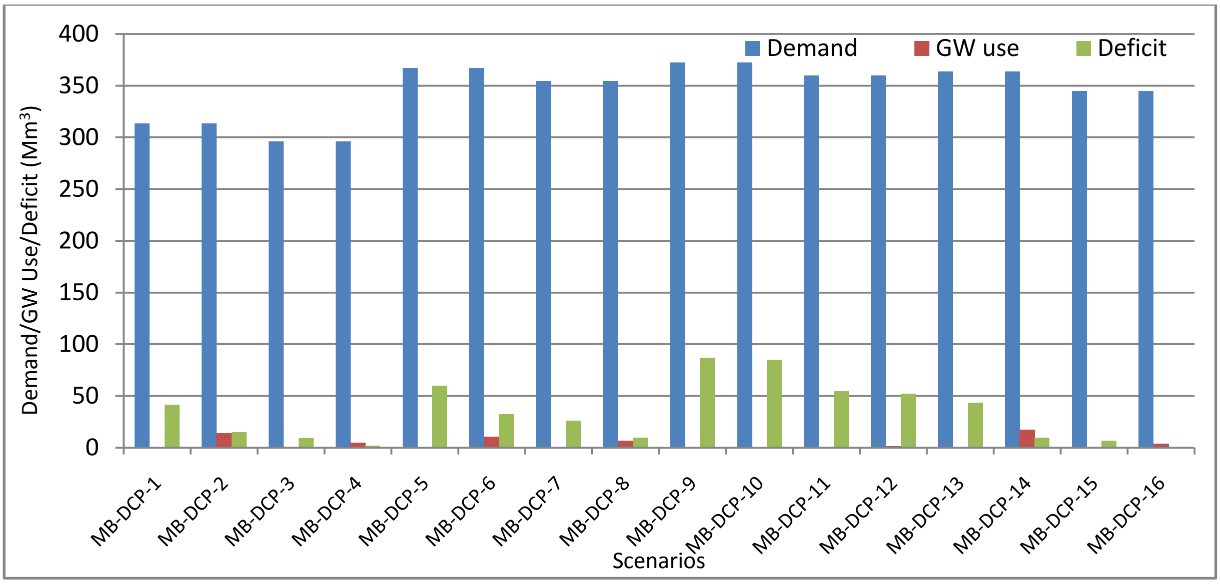


Fig. 5.15 (b) MIKE BASIN outputs of demand/deficit during different periods in Scenarios MB-DCP-9 to MB-DCP-16



Scenarios with original capacity



Scenarios with revised capacity

Fig. 5.16 Irrigation demand, groundwater use and demand deficit for DCP with original and revised capacity

5.5.2 Simulation results for Present cropping pattern (PCP)

The MIKE BASIN model for present cropping pattern was formulated where average cropping pattern in Harsi command was used as input to crop, crop sequence sub-models and command representation of the model. Sixteen different scenarios as used for design cropping pattern were developed for present cropping pattern also. The simulation runs were made to determine demand, demand deficit, net flow to node, reservoir volume and level etc. The MIKE BASIN outputs depicting irrigation demand and deficit in different scenarios for the command are presented in **Fig. 5.17 (a) and 5.17 (b**). The yearly demand, deficit, net flow to the command and groundwater uses for different scenarios can be seen in Table 5.14. From the analysis, it has been observed that the Harsi reservoir is able to fulfill most of the water requirements of present cropping pattern and shows meager deficit (0.21 Mm^3 to 2.65 Mm^3) mainly in the month of June and July because of non-availability of supplies from other sources during these periods. The efficient management and proper planning may be able to bring more area under irrigation and developed model can be used for real time reservoir operation and irrigation management in the command. The MIKE Basin simulation runs for present cropping pattern in all four scenarios confirmed no significant impact of reduced capacity on demand deficit.

5.6 Impact Assessment of Modernization

The impact of modernization works in the form of lining of canal, remolding of outlets, formation and empowerment of WUAs in decision making etc. has been taken after 2006 and completed in 2009. For impact assessment of modernization works in Harsi command, multi date remote sensing LISS IV data of 2009 and 2014 were analyzed using normalized deviation vegetation index (NDVI) which is widely used unsupervised techniques for identification vigor of vegetation/crop. As complete command did not cover in one scene, two scenes of LISS IV were integrated through mosaic operation in ARC GIS. The raster operation was used to compute NDVI images of both the years. The NDVI images has been used to detect changes in vegetation vigor by classify the image in 5 different classes less than 0.0 (Water/Cloud), 0.0 to 0.025 (Bare Soil), 0.025 to 0.25 (Grass), 0.025 to 0.50 (Scars Vegetation) and 0.50 to 0.70 (Scarce Vegetation). The false color composite (FCC) and NDVI images of 2009 and 2014 have been presented in **Fig. 5.18 (a) and 5.18 (b)** respectively. The areas under different classes based on NDVI is presented in Table 5.15 and found that scarce vegetation increased from 24259.51 ha (30.65 %) in 2009 to 47974.83 ha (60.60 %) in 2014. The dense vegetation increase from 150.62 ha to 14764.05 ha during the same period due to restoration, repair and renovation works in the command.

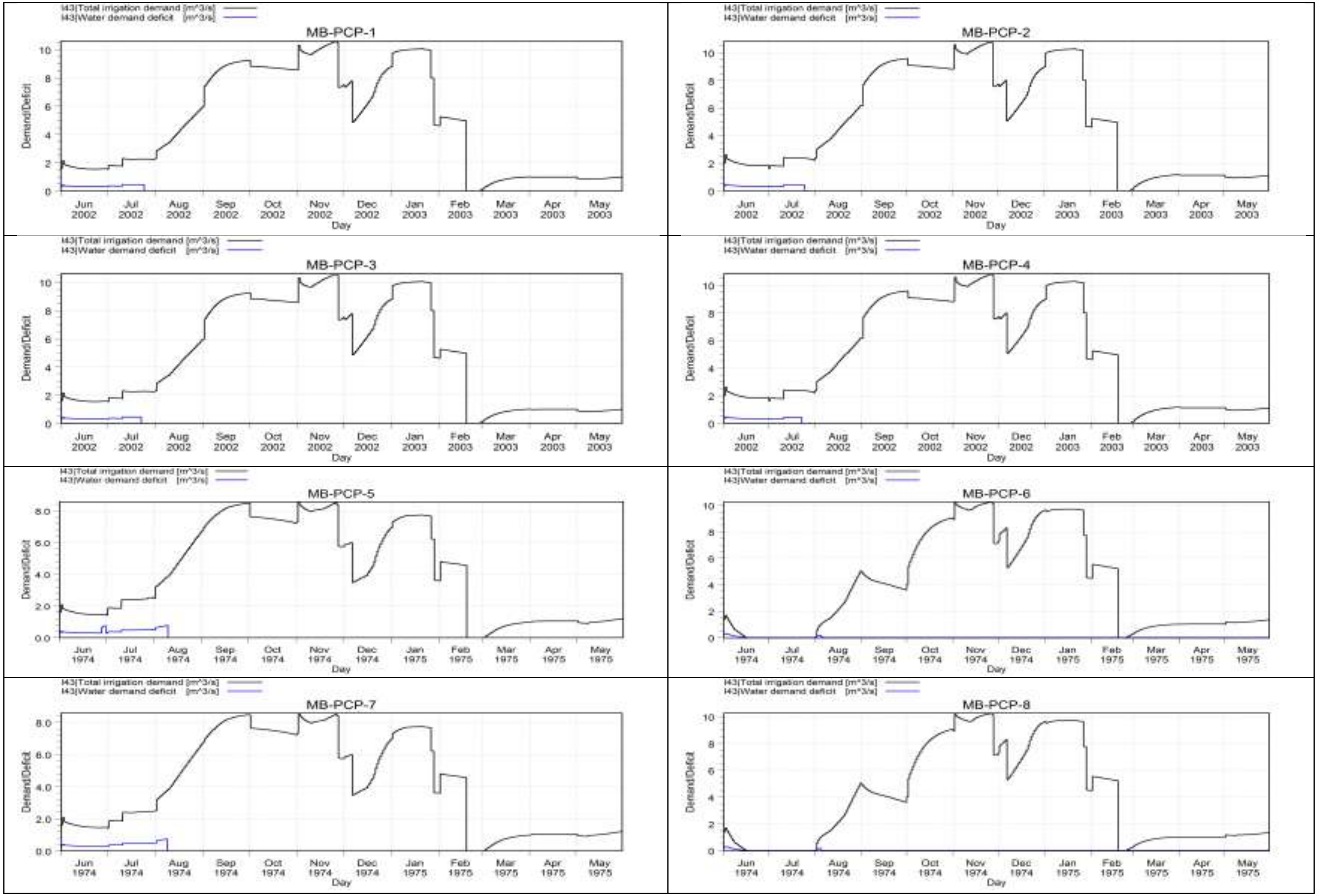


Fig. 5.17 (a) MIKE BASIN outputs of demand/deficit during different periods for Scenarios MB-PCP-1 to MB-PCP-8

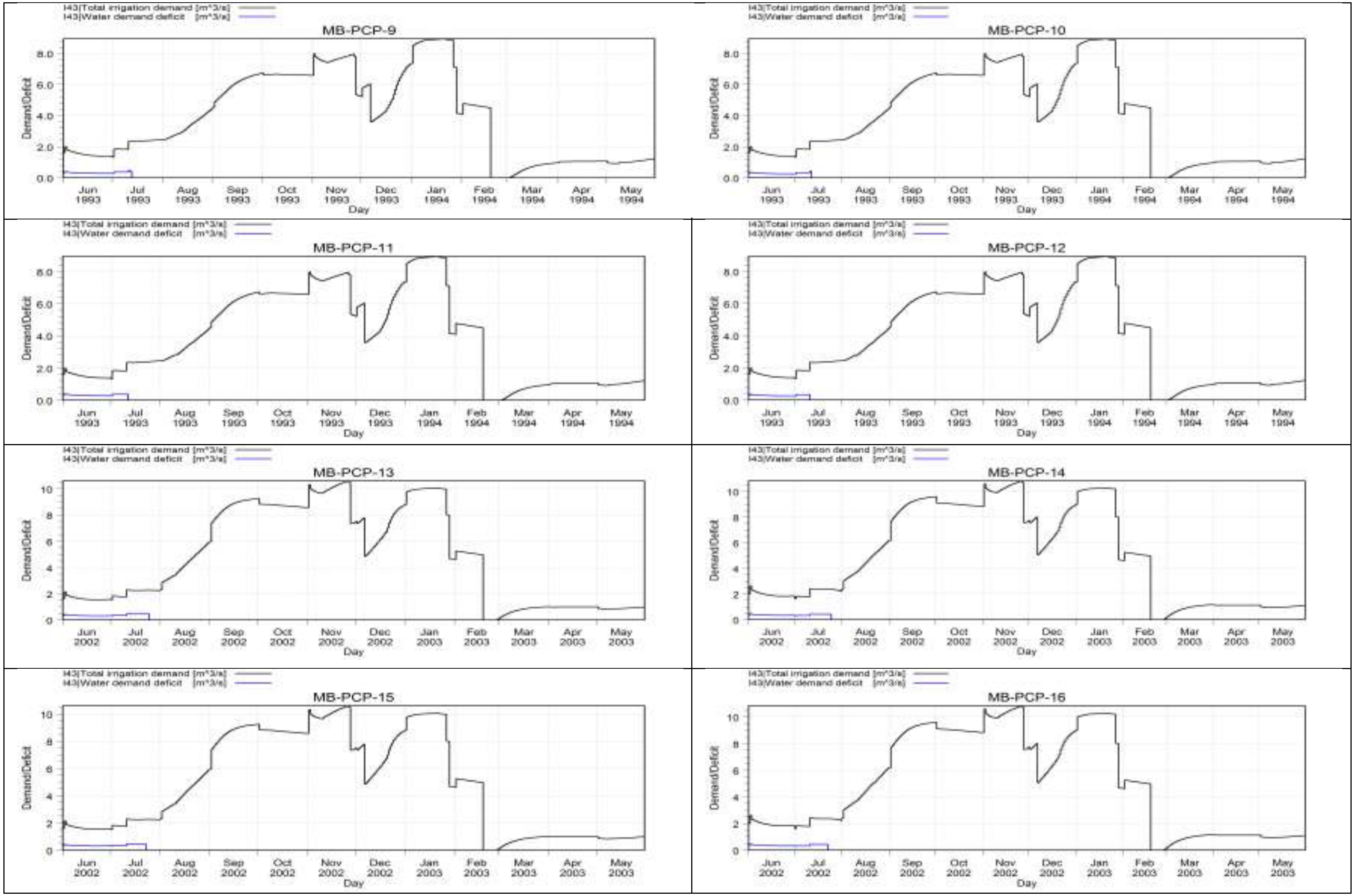


Fig. 5.17 (b) MIKE BASIN outputs of demand/deficit during different periods in Scenarios MB-PCP-9 to MB-PCP-16

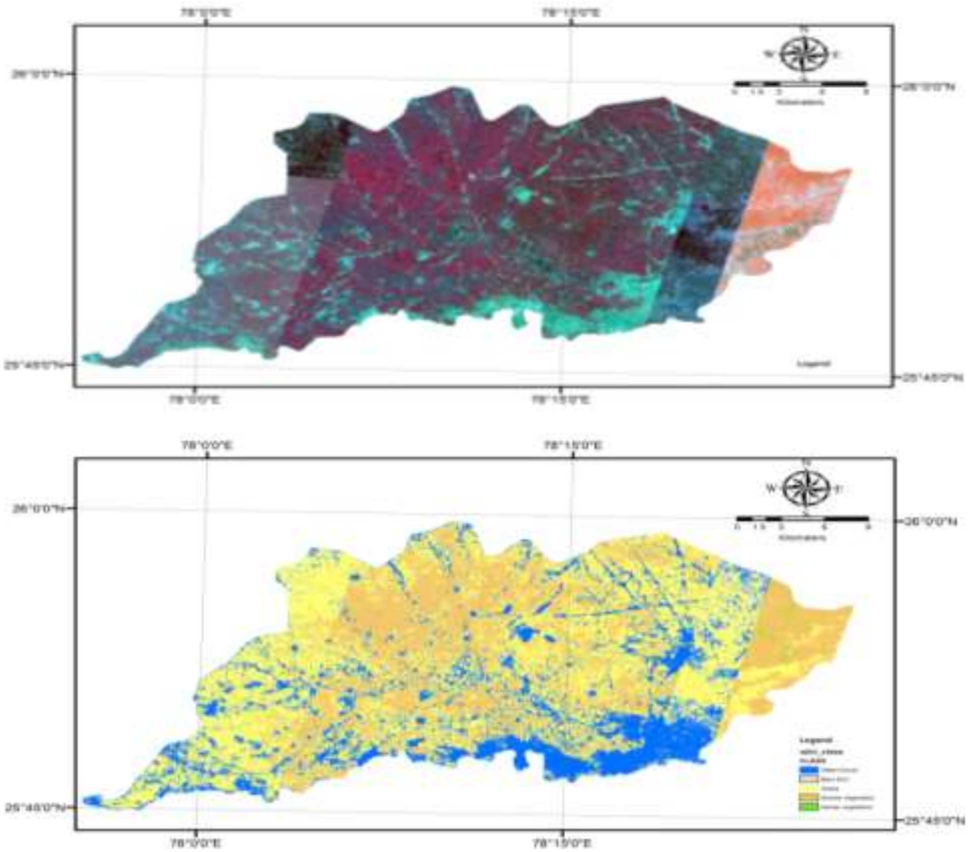


Fig 5.18 (a). FCC and classified images for the year 2009

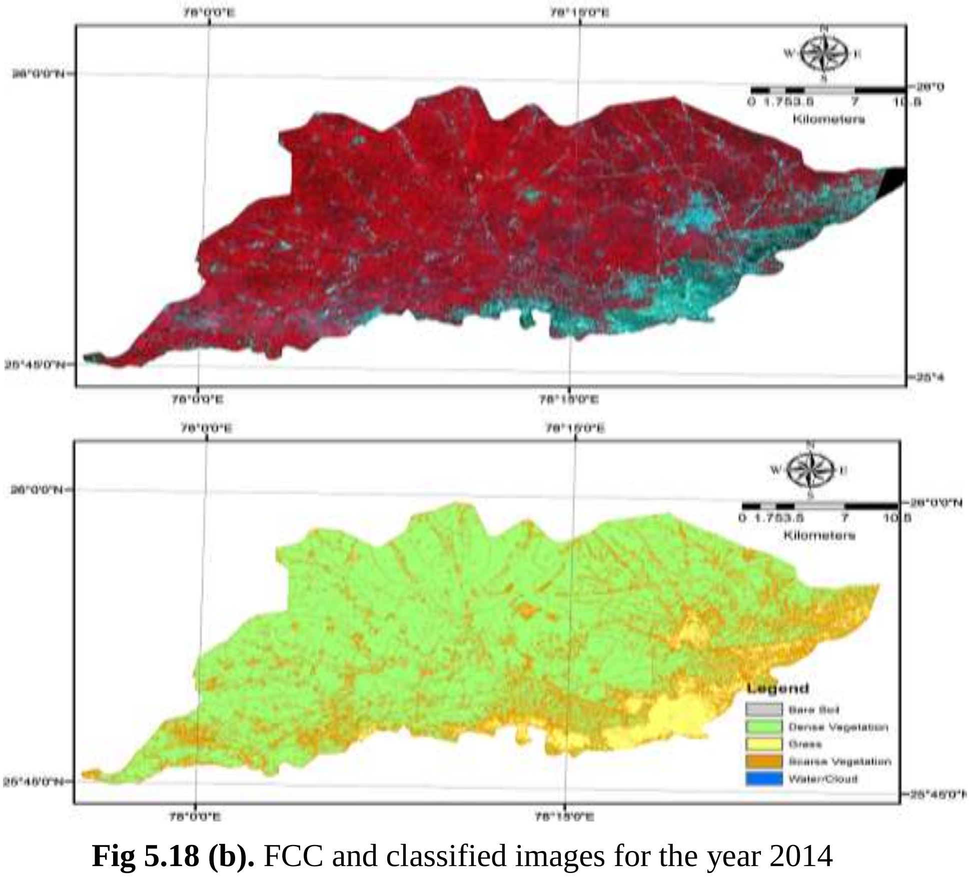


Fig 5.18 (b). FCC and classified images for the year 2014

CHAPTER- 6: CONCLUSIONS

A large number of irrigation projects in India are unable to utilize their designed potential due to various technical and social reasons right from storage of water in reservoir to distribution of water in the fields. The irrigation management in command area should be implemented in a holistic manner considering all aspects of water requirements of crops, efficient distribution, designing of irrigation scheduling, equitable distribution and participatory irrigation management for maximum utilization of irrigation potential and agriculture production. For maximization of project efficiencies, it is necessary to manage irrigation water in a command with participation of local farmers, use of technical inputs in decision making and capacity building of all stake holders. The NIH Regional Centre Bhopal and State Data Centre, Water Resources Department, Govt. of M.P., Bhopal have conducted this study jointly to scientifically assess all the aspects of water management in Harsi command area of Gwalior district including reservoir sedimentation study, assessment of irrigation water for crops, demand-supply analysis, development of MIKE BASIN model for irrigation water management, scenario based reservoir operation for irrigation management.

The GIS base data base prepared for the study area consists of catchment map, soil, drainage, geology, command boundary, jurisdiction of WUAs and Committees etc will be helpful for further studies and planning. The weather is generally dry except sub humid during monsoon season. The revised capacity of reservoir was estimated using digital image processing of multi-date remote sensing data in GIS as Harsi dam has started its operation in the year 1935 and concluded that 32.5 Mm^3 live storage has been lost in 78 years (1935-2013) which is about 17% of initial storage. It is therefore recommended that irrigation releases and reservoir operation should be revised considering present available capacity. The analysis of rainfall and water requirements of kharif crops in the command confirmed supplemental water requirement in the months of June and July for which adequate reserve storage should be kept in Harsi dam for protective irrigation. The probability analysis of rainfall have suggested that a year having seasonal rainfall more than 878 mm and more can be considered as wet year, 675 mm as average year and 570 mm and below as dry or drought year and it is recommended that irrigation planning should be made according to rainfall/availability of water in reservoir and motivate farmers to adopt less water demanding crops specially in dry years.

The requirement of gross water for designed and present cropping patterns for different divisions and water user associations have been computed using present overall efficiency of 55% and suggested improved efficiency of 65% for the system. The gross water requirements for design cropping pattern computed as 423.5 Mm^3, 458.6 Mm^3 and 474.7 Mm^3 in wet, average and dry years respectively at 55% efficiency can be reduced to 354.2 Mm^3, 384.6 Mm^3 and 397 Mm^3 by improving efficiencies through lining of canal, proper maintenance of outlets and release of water as computed to different WUAs for different 10-daily periods. The water requirement for present cropping pattern is more or less similar to design cropping pattern varies between 342 Mm^3 to 476.3 Mm^3. The scenarios based assessment of crop and gross water requirement for different WUAs may be helpful for management authority to plan efficient releases from Harsi reservoir. The average annual availability of water to the command from Harsi reservoir and other sources of supply is about 427.19 Mm3 demands more efficient use of available water and increase of efficiencies.

The demand-supply analysis carried out using CROPWAT did not take care of several complex aspects of irrigation management such as temporal variability of available water, reservoir rule curves and capacities, spatial distribution of crops, canal capacities and conjunctive use etc. Therefore, MIKE BASIN model was developed for Harsi reservoir and its command for efficient irrigation planning and reservoir operation. The model depicts the water transfer system of Harsi project connected to Harsi command node that includes distribution of crops, soil, irrigation method and climatic sub-models. The Harsi reservoir node connected through link channel from Mohini pickup weir and Madikheda dam and upstream Kaketo reservoir to get additional water. Suitable changes in reservoir and other inflows, climate sub-models and cropping pattern were made to simulate irrigation model for 16 different scenarios for design and present cropping pattern separately to induce different climatic (wet, average and dry years) and efficiencies conditions (55% and 65 % overall efficiencies) with conjunctive use of surface and groundwater (10% demand met by groundwater). From the analysis, it may be concluded that the irrigation demand may vary from 313.58 Mm^3 to 372.37 Mm^3 during variable climate prevailed in the region for design cropping pattern. The improved canal maintenance and operation can reduce this demand in the range of 295.96 to 359.95 Mm^3. The demand deficits for design cropping pattern depend on rainfall and irrigation efficiencies which is presently 60 Mm^3 for average rainfall years can be reduced to nearly 9.5 Mm^3 if canal regulation and application is improved and at the same time surface and groundwater are used conjunctively in the command. As most of the irrigation projects are designed for 75 % dependability, the MIKE BASIN model suggests very meager deficit nearly 0.8 Mm^3 under improved conditions. The present cropping does not have any significant deficit and more area can be brought under irrigation if suitable conservation and improved irrigation practices are adopted in the command. The MIKE BASIN model developed for irrigation management uses real time data can be used to determine releases on real time basis using inflows, crops and climatic data. The impact of repair, restoration and rejuvenation works carried out in Harsi command were analyzed with the help of digital classification of remote sensing data clearly indicated the improvement of vigor in the command due to modernization works.

From the field visits and analysis, it may be concluded that there is considerable scope of enhancement of efficiencies through application of sprinkler or modern techniques instead of flooding method presently used in the command. The operation and maintenance of canals and outlets are crucial and should be maintained properly for getting optimum benefits from available resources especially in dry rainfall years. The soil moisture measurement and its retention characteristics are vital to assess the amount of water required for irrigation and transportation of fertilizers and pesticides through soil media. It is therefore necessary to determine soil texture, soil water retention characteristic and setting of appropriate monitoring network for measurement of soil moisture to determine irrigation amount in the field. The nutrient analysis should be conducted and health-card of each field should be prepared to determine the need of essential nutrients for maximization of crop production.

The distributary committees and water user associations can play an important role in the management as the members of these committees and WUAs are direct beneficiaries of improved condition in the command. From the experience of participatory irrigation management (PIM) and constant monitoring and support of officials of Water Resources Department of Madhya Pradesh, the actual irrigation has been increased from 976000 ha in 2011 to 2435000 ha in the year 2015. In the line of development of agriculture in M.P. state, the Harsi command also witnessed sizable change in irrigated areas witnessed by unsupervised classification of remote sensing data. The Harsi command has good network of 26 WUAs under 5 distributary committees and it is recommended that these WUAs should be involved in decision making of water releases with scientific inputs from field observations and experiences. The participatory irrigation management (PIM) act passed by MP Govt in the year 1999 is a welcome step to empower association providing legal status, equity, administrative autonomy, women empowerment, freedom to raise resources and right to recall etc. The operation and maintenance grant for WUAs needs to be revised time to time and they should be involved in revenue collection from their areas. The capacity building of these WUAs can be developed through training on their field and visits of mechanized farms and automated irrigation fields.

CHAPTER- 7: REFERENCES

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Table 3.1 Salient features of Harsi project

S. N.	Description	Detail	
i.	District & Tahsil	Gwalior, Dabra	
ii.	River	Parvati river	
iii.	Location of Dam Site	Longitude 77°58' E, Latitude 25°58'N	
iv.	Annual rainfall (mm)	841 mm	
v.	Seasonal rainfall (mm)	757 mm (90% of annual)	
vi.	75% dependable yield from catchment	206 Mm^3	
vii.	Probable maximum flood	8192 m^3	
viii.	Standard project flood	6554 m^3	
ix.	Catchment area	777.5 km^2	
x.	75% dependable yield	206.02 Mm^3	
xi.	Gross storage capacity	206.30 Mm^3	
xii.	Dead storage capacity	13.64 Mm^3	
xiii.	Live storage capacity	192.66 Mm^3	
xiv.	Full supply level (F.S.L.)	R.L. 264.93 m	
xv.	Maximum water level (M.W.L)	R.L. 267.31 m	
xvi.	Top bund (T.B.)	R.L.270.36 m	
xvii.	Lowest sill level (L.S.L.)	R.L. 252.07 m	
xviii.	Water spread area at F.T.L.	25.05 Sq. Km^2	
xix.	Water spread area at M.W.L.	28.43 Sq. Km^2	
xx.	Length of dam (m)	2133.60 m	
xxi.	Maximum height of dam from lowest river bed level (m)	29.26 m	
xxii.	Earth	241.10 m	
xxiii.	Top width of dam (m)	7.32 m	
Command & distributaries		Existing (Km)	Proposed for improvement (km)
i.	Length of main /Distributaries/Minor	418.3	418.3
ii.	Length water course and field channel	1393	1737.6
iii.	Water course and field channel lining	Not existing	443.6
iv.	Structure (Numbers)	563	7344
v.	Head discharge	37.01m^3	
vi.	Duty adopted	928 ha/m^3	
vii.	At canal out let	683 ha/m^3	
viii.	Area commanded (Agriculture Statistical)		
ix.	Number of village to be served	200	
x.	Gross command area (GCA)	90878 ha	
xi.	Culture able command area (CCA)	62675 ha	
xii.	Design irrigation (existing)	53158 ha	
xiii.	Design irrigation (proposed)	62675 ha	

Table 3.2 Data used in the study

SN	Data used	Details	Period	
Climatic data				
1.	Rainfall	Dabra RG Station	1984 to 2011	
2.	Mean monthly maximum and minimum temperature, wind speed, relative humidity, sunshine hour	Datia	1999 to 2008	
Hydrological data				
1.	Reservoir levels	Harsi reservoir	1980 to 2014	
2.	Inflow information	Kaketo dam, Madikheda dam and Mohini Pickup weir		
Remote sensing data (Sedimentation Study)				
S.N.	Date of pass	Satellite	Path/Row	Scene
1.	31 May 2008	IRS 1D	97-53	LISS 3
2.	04 Apr 2011	IRSP6	97-53	LISS 3
3.	23 May 2013	ResourceSat-2	97-53	LISS 3
4.	05 April 2013	ResourceSat-2	97-53	LISS 3
5.	12 March 2013	ResourceSat-2	97-53	LISS 3
6.	25 Dec 2013	Resourcesat-2	97-53	LISS 3
7.	27 Aug 2013	ResourceSat-2	97-53	LISS 3
Remote sensing data (Impact assessment Study)				
S.N.	Date of pass	Sensor	Image description	
1.	06 Feb 2009	LISS 4	IRS, P6, LISSIVMX, 27551-1-2-32 (SHIFT 40%)	
2.	25 Feb 2009	LISS 4	IRS, P6, LISSIVMX, 27821-2-2-38	
3.	07 Mar 2014	LISS 4	Resourcesat-2, LISSIVFMX, 97-53-D	
4.	02 Nov 2014	LISS 4	Resourcesat-2, LISSIVFMX, 97-53-D	

Table 5.1 Area covered under different water user association (WUA)

S.N.	Name of WUA	Original area covered by WUA (ha)	Present area covered by WUA (ha)	Area covered by WUA (ha) under design cropping pattern
W R Sub Division Harsi				
1	Harsi	1482	1628	1920
2	Mastoora	1534	1805	2128
3	Singharan	1209	1494	1762
4	Karahiya	1395	1684	1986
5	Etma	1295	2073	2444
6	Virgawan	688	937	1105
W R Sub Division Bhitawar				
7	Silha	1987	1919	2262
8	Bhitawar	1192	1408	1660
9	Nayagaon	1459	1642	1936
10	Kariyawati	1874	1889	2227
11	Jhadoly	1847	2019	2380
12	Masoodpur	980	1602	1889
W R Sub Division Chinore				
13	Mehgaon	1575	2072	2443
14	Kishorgarh	1670	1760	2075
15	Sekra	2075	1947	2295
16	Chinor	2323	2539	2993
17	Bhori	1104	1187	1400
18	Badkisaray	1618	1695	1998
Sank Swarn Rekha Link Canal Sub Division No 1 Ghatigaon Hq. Dabra				
19	Fatehpur	2449	3426	4039
20	Beru	2719	3220	3796
21	Salwai	1418	2054	2422
22	Magrora	1252	2074	2445
W R Sub Division Dabra				
23	Samoodan	2872	3583	4225
24	Dabra	1682	2086	2459
25	Akbai	2740	3026	3568
26	Ajaygarh	1915	2390	2818
	Total	**44354**	**53158**	**62675**

Table 5.2 Detail description of soils in the study area

Unit	Description	Soil taxonomy	Area in ha (%)
476	Deep, well drained, loamy soils on moderately sloping plateau (slightly dissected) with moderate erosion, associated with: Rock out crops.	Fine-loamy, kaolinitic, hyper-thermic, Typic Ustochrepts	7050 (0.01)
479	Deep, moderately well drained, calcareous, clayey soils on very gently sloping pediments with moderate erosion, associated with: Deep, moderately well drained, clayey soils on moderately sloping with moderate erosion.	Fine, mixed, (Cal), hyper-thermic, Vertic Ustochrepts Fine, mixed, hyperthermic, Typic Ustochrepts	1820 (0.004)
531	Extremely shallow, excessively drained, loamy soils on moderately steep sloping residual hills with dykes with very severe erosion, associated with: Very shallow somewhat excessively drained, loamy soils on moderately steep sloping with very severe erosion.	Loamy, kaolinitic, hyper-thermic, Lithic Ustorthents. Loamy, kaolinitic, hyper-thermic, Typic Ustorthents	6430 (0.01)
547	Deep, moderately well drained, calcareous, clayey soils on moderately sloping undulating plain with mounds with moderate erosion, associated with: Slightly deep, well drained, calcareous, loamy soils on gently sloping with moderate erosion.	Fine, montmorillonitic, (Cal.), hyperthermic, Typic Haplusterts Fine-loamy, mixed, (Cal.) hyperthermic, Typic Ustochrepts	6290 (0.01)
549	Deep, moderately well drained, clayey soils on moderately sloping undulating plain with mounds with moderate erosion, associated with: Deep, moderately well drained, calcareous, clayey soils on gently sloping with moderate erosion.	Fine, mixed, hyper-thermic, Chromic Haplusterts Fine, mixed, (Cal), hyper-thermic, Typic Haplusterts	5112 (0.11)
552	Deep, moderately well drained, calcareous, clayey soils on gently sloping plain with hummocks with moderate erosion, associated with: Deep, moderately well drained, calcareous, clayey soils on gently sloping with moderate erosion.	Fine, mixed, (Cal), hyper-thermic, Typic Ustochrepts Fine, mixed, (Cal), hyper-thermic, Vertic Ustochrepts	1082 (0.02)
554	Deep, moderately well drained, calcareous, clayey soils on very gently sloping plain with hummocks with moderate erosion, associated with: Deep, moderately well drained, calcareous, loamy soils on very gently sloping with moderate erosion.	Fine, mixed, (Cal), hyper-thermic, Vertic Ustochrepts Fine-loamy, mixed, (Cal.) hyperthermic, Typic Ustochrepts	4164 (0.09)
559	Deep, moderately well drained, clayey soils on gently sloping undulating plain land with valleys with moderate erosion, associated with: Deep, moderately well drained, calcareous, clayey soils on very gently sloping with moderate erosion.	Fine, mixed, hyper-thermic, Chromic Haplusterts Fine, mixed, (Cal), hyper-thermic, Vertic Ustochrepts	749 (0.01)
561	Deep, moderately well drained, calcareous, loamy soils on moderately sloping flood plain with severe erosion, associated with: Deep, moderately well drained, clayey soils on moderately sloping with severe erosion.	Fine, mixed, (Cal), hyper-thermic, Fluventic Ustochrepts Fine, mixed, (Cal), hyper-thermic, Vertic Ustochrepts	137 (0.003)
562	Moderately deep, well drained, loamy soils on very gently sloping flood plain with moderate erosion, associated with: Deep, well drained, calcareous, loamy soils on very gently sloping with moderate erosion.	Fine, mixed, hyper-thermic, Udic Ustochrepts Fine, mixed, (Cal), hyper-thermic, Fluventic Ustochrepts	1281 (0.02)
563	Deep, well drained, calcareous, loamy soils on moderately sloping flood plain with severe erosion, associated with: Deep, moderately well drained, clayey soils on moderately sloping with severe erosion.	Fine, mixed, hyper-thermic, Typic Ustochrepts Fine-loamy, mixed, (Cal.) hyperthermic Fluventic Ustochrepts	2496 (0.05)
573	Deep, well drained, calcareous, loamy soils on moderately steep sloping ravenous land with very severe erosion, associated with: Deep, well drained, calcareous, loamy soils on moderately steep sloping with very severe erosion.	Fine, mixed, hyper-thermic, Vertic Ustochrepts Fine, mixed, hyper-thermic, Typic Ustochrepts	8815 (0.19)

Table 5.3(a) Designed cropping pattern and crop duration in Harsi command

S. N.	Name of Crop	Crop duration	Area sown (ha)
1.	**KHARIF**		
	Paddy 1	10July-Oct- 4month	7780
	Paddy 2	20July-Nov- 4month	7780
	Urad	15-June- 4 month	648
	Soyabeen	15 July-Oct 4- month	1081
	TOTAL		17290
2.	**RABI**		
	Wheat dwarf 1	10 Nov-March-5month	7564
	Wheat dwarf 2	20 Nov-Apr-5month	7564
	Gram	10 Oct-Feb-5month	2161
	Mustard	15 Oct-Feb-5 month	2161
	Wheat HYV 1	10 Nov-March-5month	10806
	Wheat HYV 2	20 Nov-Apr-5month	10806
	TOTAL		41063
3.	Sugarcane	01 Feb-Jan	4322
	G. TOTAL		62675

Table 5.3(b) Present cropping pattern and crop duration in Harsi command

S. N.	Crop	Crop duration	Area sown (ha)
1.	Paddy 1	10 July-Oct- 4month	11741
2.	Paddy 2	20 July-Nov- 4month	11741
3.	Sugar cane	1 Feb-Jan-12month	4453
4.	Wheat1(H.Y.V.)	10 Nov-March-5month	12611.5
5.	Wheat2(H.Y.V.)	25 Nov-Apr-5month	12611.5
	Total Area		53158

Table 5.4 Revised water spread areas at various elevations

Date of pass satellite	Reservoir level (m)	Revised water spread area (ha)
11-03-2011	254.20	865.87
04-04-2011	256.37	957.54
23-05-2013	258.60	1037.51
05-04-2013	260.05	1486.14
12-03-2013	262.24	1770.57
25-12-2013	264.79	2261.89
27-08-2013	265.12	2505.00

Table-5 .5 Original and revised capacity with Percentage loss in capacities

Date of Pass Satellite	Reservoir Elevation (m)	Original Capacity (Mm^3)		Revised Capacity (Mm^3)		Loss in Cum. Capacity (Mm^3)	% Loss in Cumulative Capacity
		Volume	Cumulative Capacity	Volume	Cumulative Capacity		
River Bed	250.18	0.000	0.000		0.000		-
Revised River bed	251.35	9.39	9.39	0.000	0.000	9.39	100.00
11-Mar-11	254.20	17.33	26.72	8.23	8.23	18.49	69.21
04-Apr-11	256.37	19.91	46.63	19.78	28.00	18.63	39.95
23-May-13	258.60	28.21	74.84	22.24	50.24	24.60	32.87
05-Apr-13	260.05	22.79	97.63	18.20	68.44	29.19	29.90
12-Mar-13	262.24	45.60	143.23	35.62	104.06	39.18	27.35
25-Dec-13	264.79	59.50	202.73	51.29	155.34	47.39	23.38
FSL *	264.93	3.22	205.95	3.17	158.51	47.44	23.04
27-08-2013	265.12	6.39	212.34	4.30	162.81	49.53	23.33

Table 5.6 Scenarios considered for computation of irrigation water requirement

S.N.	Cropping Pattern	Rain and climate	Conveyance efficiency		Application efficiency		Scenario
			Main & Dist. canal efficiency	Field channel efficiency	Field application efficiency	Operational efficiency	
1.	Design	Wet year	86%	90%	75%	95%	DCP-1
2.	Design	Wet year	90%	95%	80%	95%	DCP-2
3.	Design	Average year	86%	90%	75%	95%	DCP-3
4.	Design	Average year	90%	95%	80%	95%	DCP-4
5.	Design	Dry year	86%	90%	75%	95%	DCP-5
6.	Design	Dry year	90%	95%	80%	95%	DCP-6
7.	Present	Wet year	86%	90%	75%	95%	PCP-1
8.	Present	Wet year	90%	95%	80%	95%	PCP-2
9.	Present	Average year	86%	90%	75%	95%	PCP-3
10.	Present	Average year	90%	95%	80%	95%	PCP-4
11.	Present	Dry year	86%	90%	75%	95%	PCP-5
12.	Present	Dry year	90%	95%	80%	95%	PCP-6

Table 5.7 (a) Sub-division wise Crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for design cropping pattern

Sub-division	**DCP-1**		**DCP-2**		**DCP-3**		**DCP-4**		**DCP-5**		**DCP-6**	
	C.W.R.	**G.W.R.**	**C.W.R.**	**G.W.R.**	**C.W.R.**	**G.W.R.**	**C.W.R.**	**G.W.R.**	**C.W.R.**	**G.W.R.**	**C.W.R.**	**G.W.R.**
		77-71		**86-76**		**77-71**		**86-76**		**77-71**		**86-76**
W R Sub Division Harsi	41.90	76.65	41.90	64.11	45.38	83.01	45.38	69.43	46.97	85.92	46.97	71.86
W R Sub Division Bhitawar	45.63	83.46	45.63	69.81	49.42	90.40	49.42	75.61	51.15	93.56	51.15	78.26
W R Sub Division Chinore	48.77	89.21	48.77	74.62	52.82	96.62	52.82	80.81	54.67	100.00	54.67	83.64
Sank SwarnRekha Link Canal Sub Division No 1 GhatigaonHq. Dabra	46.92	85.82	46.92	71.79	50.81	92.94	50.81	77.74	52.59	96.20	52.59	80.46
W R Sub Division Dabra	48.28	88.31	48.28	73.87	52.28	95.63	52.28	79.99	54.12	98.99	54.12	82.80
Total	231.50	423.46	231.50	354.19	250.71	458.59	250.71	383.58	259.51	474.67	259.51	397.03

77-71: Conveyance efficiency-77%, Application efficiency-71%

86-76: Conveyance efficiency-86%, Application efficiency-76%

Table 5.7 (b) WUA wise Crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for design cropping pattern

WUA	DCP-1		DCP-2		DCP-3		DCP-4		DCP-5		DCP-6	
	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.
		77-71		86-76		77-71		86-76		77-71		86-76
Harsi	7.09	12.97	7.09	10.85	7.68	14.05	7.68	11.75	7.95	14.54	7.95	12.16
Mastoora	7.86	14.38	7.86	12.03	8.51	15.57	8.51	13.02	8.81	16.11	8.81	13.48
Singharan	6.51	11.91	6.51	9.96	7.05	12.90	7.05	10.79	7.3	13.35	7.3	11.17
Karahiya	7.34	13.43	7.34	11.23	7.94	14.52	7.94	12.15	8.22	15.04	8.22	12.58
Etma	9.03	16.52	9.03	13.82	9.78	17.89	9.78	14.96	10.12	18.51	10.12	15.48
Virgawan	4.08	7.46	4.08	6.24	4.42	8.08	4.42	6.76	4.58	8.38	4.58	7.01
Silha	8.35	15.27	8.35	12.78	9.05	16.55	9.05	13.85	9.37	17.14	9.37	14.34
Bhitawar	6.13	11.21	6.13	9.38	6.64	12.15	6.64	10.16	6.87	12.57	6.87	10.51
Nayagaon	7.15	13.08	7.15	10.94	7.74	14.16	7.74	11.84	8.02	14.67	8.02	12.27
Kariyawati	8.23	15.05	8.23	12.59	8.91	16.30	8.91	13.63	9.22	16.86	9.22	14.11
Jhadoly	8.79	16.08	8.79	13.45	9.52	17.41	9.52	14.57	9.85	18.02	9.85	15.07
Masoodpur	6.98	12.77	6.98	10.68	7.56	13.83	7.56	11.57	7.82	14.30	7.82	11.96
Mehgaon	9.02	16.50	9.02	13.80	9.77	17.87	9.77	14.95	10.12	18.51	10.12	15.48
Kishorgarh	7.66	14.01	7.66	11.72	8.3	15.18	8.3	12.70	8.59	15.71	8.59	13.14
Sekra	8.48	15.51	8.48	12.97	9.18	16.79	9.18	14.05	9.5	17.38	9.5	14.53
Chinor	11.05	20.21	11.05	16.91	11.97	21.90	11.97	18.31	12.39	22.66	12.39	18.96
Bhori	5.17	9.46	5.17	7.91	5.6	10.24	5.6	8.57	5.8	10.61	5.8	8.87
Badkisaray	7.38	13.50	7.38	11.29	7.99	14.61	7.99	12.22	8.27	15.13	8.27	12.65
Fatehpur	14.92	27.29	14.92	22.83	16.16	29.56	16.16	24.72	16.72	30.58	16.72	25.58
Beru	14.02	25.64	14.02	21.45	15.18	27.77	15.18	23.23	15.72	28.75	15.72	24.05
Salwai	8.95	16.37	8.95	13.69	9.69	17.72	9.69	14.83	10.03	18.35	10.03	15.35
Magrora	9.03	16.52	9.03	13.82	9.78	17.89	9.78	14.96	10.12	18.51	10.12	15.48
Samoodan	15.61	28.55	15.61	23.88	16.9	30.91	16.9	25.86	17.49	31.99	17.49	26.76
Dabra	9.08	16.61	9.08	13.89	9.84	18.00	9.84	15.06	10.18	18.62	10.18	15.58
Akbai	13.18	24.11	13.18	20.17	14.27	26.10	14.27	21.83	14.77	27.02	14.77	22.60
Ajaygarh	10.41	19.04	10.41	15.93	11.27	20.61	11.27	17.24	11.67	21.35	11.67	17.85
Total	231.5	423.45	231.5	354.19	250.71	458.57	250.71	383.57	259.51	474.67	259.51	397.03

77-71: Conveyance efficiency-77%, Application efficiency-71%

86-76: Conveyance efficiency-86%, Application efficiency-76%

Table 5.8 (a) Sub-division wise Crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for present cropping pattern

Sub-division	PCP-1		PCP-2		PCP-3		PCP-4		PCP-5		PCP-6	
	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.
		77-71		86-76		77-71		86-76		77-71		86-76
W R Sub Division Harsi	40.46	74.01	40.46	61.90	45.24	82.75	45.24	69.22	47.13	86.21	47.13	72.11
W R Sub Division Bhitawar	44.06	80.59	44.06	67.41	49.27	90.12	49.27	75.38	51.32	93.87	51.32	78.52
W R Sub Division Chinore	47.09	86.13	47.09	72.05	52.65	96.31	52.65	80.55	54.86	100.35	54.86	83.94
Sank SwarnRekha Link Canal Sub Division No 1 Ghatigaon Hq. Dabra	45.3	82.86	45.3	69.31	50.65	92.65	50.65	77.49	52.77	96.52	52.77	80.74
W R Sub Division Dabra	46.61	85.26	46.61	71.31	52.12	95.34	52.12	79.74	54.3	99.32	54.3	83.08
Total	223.51	408.85	223.51	341.98	249.93	457.16	249.93	382.39	260.38	476.28	260.38	398.38

77-71: Conveyance efficiency-77%, Application efficiency-71%

86-76: Conveyance efficiency-86%, Application efficiency-76%

Table 5.8 (b) WUAs wise irrigation water requirement for crops under present cropping pattern in Harsi command

WUA	PCP-1		PCP-2		PCP-3		PCP-4		PCP-5		PCP-6	
	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.	C.W.R.	G.W.R.
		77-71		86-76		77-71		86-76		77-71		86-76
Harsi	6.85	12.53	6.85	10.48	7.66	14.01	7.66	11.72	7.98	14.60	7.98	12.21
Mastoora	7.59	13.88	7.59	11.61	8.49	15.53	8.49	12.99	8.84	16.17	8.84	13.53
Singharan	6.28	11.49	6.28	9.61	7.03	12.86	7.03	10.76	7.32	13.39	7.32	11.20
Karahiya	7.08	12.95	7.08	10.83	7.92	14.49	7.92	12.12	8.25	15.09	8.25	12.62
Etma	8.72	15.95	8.72	13.34	9.75	17.83	9.75	14.92	10.15	18.57	10.15	15.53
Virgawan	3.94	7.21	3.94	6.03	4.41	8.07	4.41	6.75	4.59	8.40	4.59	7.02
Silha	8.07	14.76	8.07	12.35	9.02	16.50	9.02	13.80	9.4	17.19	9.4	14.38
Bhitawar	5.92	10.83	5.92	9.06	6.62	12.11	6.62	10.13	6.9	12.62	6.9	10.56
Nayagaon	6.9	12.62	6.9	10.56	7.72	14.12	7.72	11.81	8.04	14.71	8.04	12.30
Kariyawati	7.94	14.52	7.94	12.15	8.88	16.24	8.88	13.59	9.25	16.92	9.25	14.15
Jhadoly	8.49	15.53	8.49	12.99	9.49	17.36	9.49	14.52	9.89	18.09	9.89	15.13
Masoodpur	6.74	12.33	6.74	10.31	7.53	13.77	7.53	11.52	7.85	14.36	7.85	12.01
Mehgaon	8.71	15.93	8.71	13.33	9.74	17.82	9.74	14.90	10.15	18.57	10.15	15.53
Kishorgarh	7.4	13.54	7.4	11.32	8.27	15.13	8.27	12.65	8.62	15.77	8.62	13.19
Sekra	8.18	14.96	8.18	12.52	9.15	16.74	9.15	14.00	9.53	17.43	9.53	14.58
Chinor	10.67	19.52	10.67	16.32	11.94	21.84	11.94	18.27	12.43	22.74	12.43	19.02
Bhori	4.99	9.13	4.99	7.63	5.58	10.21	5.58	8.54	5.82	10.65	5.82	8.90
Badkisaray	7.13	13.04	7.13	10.91	7.97	14.58	7.97	12.19	8.3	15.18	8.3	12.70
Fatehpur	14.4	26.34	14.4	22.03	16.11	29.47	16.11	24.65	16.78	30.69	16.78	25.67
Beru	13.54	24.77	13.54	20.72	15.14	27.69	15.14	23.16	15.77	28.85	15.77	24.13
Salwai	8.64	15.80	8.64	13.22	9.66	17.67	9.66	14.78	10.06	18.40	10.06	15.39
Magrora	8.72	15.95	8.72	13.34	9.75	17.83	9.75	14.92	10.16	18.58	10.16	15.54
Samoodan	15.07	27.57	15.07	23.06	16.85	30.82	16.85	25.78	17.55	32.10	17.55	26.85
Dabra	8.77	16.04	8.77	13.42	9.81	17.94	9.81	15.01	10.22	18.69	10.22	15.64
Akbai	12.72	23.27	12.72	19.46	14.23	26.03	14.23	21.77	14.82	27.11	14.82	22.67
Ajaygarh	10.05	18.38	10.05	15.38	11.24	20.56	11.24	17.20	11.71	21.42	11.71	17.92
Total	223.51	408.83	223.51	341.97	249.93	457.22	249.93	382.44	260.38	476.28	260.38	398.38

77-71: Conveyance efficiency-77%, Application efficiency-71%

86-76: Conveyance efficiency-86%, Application efficiency-76%

Table 5.9 Total irrigation water requirement for Harsi Project (Mm^3)

Sr. No.	Cropping Pattern	Wet rainfall year		Average rainfall year		Dry rainfall year	
		77*-71**	**86*-76****	**77*-71****	**86*-76****	**77*-71****	**86*-76****
1	Designed cropping pattern	423.46 (DCP-1)	354.19 (DCP-2)	458.59 (DCP-3)	383.58 (DCP-4)	474.67 (DCP-5)	397.03 (DCP-6)
2	Present cropping pattern	408.85 (PCP-1)	341.98 (PCP-2)	457.16 (PCP-3)	382.39 (PCP-4)	476.28 (PCP-5)	398.38 (PCP-6)

* Conveyance efficiency, ** Application efficiency

Table 5.10 Annual replenishment of water in Harsi reservoir

S.N.	Source of water to the system	Quantity (Mm^3)
1.	75% Dependable yield of Harsi Reservoir (Live storage)	192.66
2.	Deduction for seepage and evaporation (15% approx)	28.66
3.	Remaining usable water	164.00
4.	From Kaketo feeder reservoir during summer	36.79
5.	From Mohini pick-up weir through feeder channel during Monsoon (average diversion)	107.07
6.	From Madikheda dam	199.33
7.	Replenished water (Approximately 75% of sum of 4, 5 and 6)	263.19
8.	Total water available for irrigation (8=3+7)	427.19

Table 5.11: Details of Harsi Reservoir and its commands used in MIKE BASIN model setup

S.N.	Description	Benisagar reservoir	
1.	Reservoir detail		
	Crest level	268.90 m	
	Flood Control Zone	264.93 m	
	Normal operation zone	258.0 m	
	Minimum operation level	252.07 m	
	Bottom Level	251.00 m	
	Reduction factor	0.80	
2.	Soil details	Soil 1 (Loamy)	Soil 2 (Clay)
	Field capacity	0.41	0.28
	Wilting point	0.27	0.15
	Initial water content	0.2	0.14
	Depth of evaporable layer	0.01 m	0.15 m
	Porosity	0.55	0.40
3.	Gross command area	Soil 1 (Loamy)	Soil 2 (Clay)
	Design cropping pattern	31651 ha	31024 ha

	Present cropping pattern	29715 ha	23443 ha
3.	Irrigation details		
	Irrigation method	Flooding	
	Wetting friction	0.95	
	Spray loss	0.05	
	Trigger option-	Friction of Readily available Water (RAW): 0.20	
	Application option	Friction of Readily available Water (RAW): 0.80	

Table 5.12 Scenarios for MIKE BASIN based irrigation management

S. N.	Cropping Pattern	Rain and climate	Conveyance efficiency		Application efficiency		Ground water contribution	Scenario
			Main & Dist. canal efficiency	Field channel efficiency	Field application efficiency	Operational efficiency		
1.	Design	Wet year	86%	90%	75%	95%	0 %	MB-DCP-1
2.	Design	Wet year	86%	90%	75%	95%	10 %	MB-DCP-2
3.	Design	Wet year	90%	95%	80%	95%	0 %	MB-DCP-3
4.	Design	Wet year	90%	95%	80%	95%	10 %	MB-DCP-4
5.	Design	Average year	86%	90%	75%	95%	0 %	MB-DCP-5
6.	Design	Average year	86%	90%	75%	95%	10 %	MB-DCP-6
7.	Design	Average year	90%	95%	80%	95%	0 %	MB-DCP-7
8.	Design	Average year	90%	95%	80%	95%	10 %	MB-DCP-8
9.	Design	Dry year	86%	90%	75%	95%	0 %	MB-DCP-9
10.	Design	Dry year	86%	90%	75%	95%	10 %	MB-DCP-10
11.	Design	Dry year	90%	95%	80%	95%	0 %	MB-DCP-11
12.	Design	Dry year	90%	95%	80%	95%	10 %	MB-DCP-12
13.	Design	75 % Rain	90%	95%	80%	95%	0 %	MB-DCP-13
14.	Design	75 % Rain	90%	95%	80%	95%	10 %	MB-DCP-14
15.	Design	75 % Rain	90%	95%	80%	95%	0 %	MB-DCP-15
16.	Design	75 % Rain	90%	95%	80%	95%	10 %	MB-DCP-16
17.	Present	Wet year	86%	90%	75%	95%	0 %	MB-PCP-1
18.	Present	Wet year	86%	90%	75%	95%	10 %	MB-PCP-2
19.	Present	Wet year	90%	95%	80%	95%	0 %	MB-PCP-3
20.	Present	Wet year	90%	95%	80%	95%	10 %	MB-PCP-4
21.	Present	Average year	86%	90%	75%	95%	0 %	MB-PCP-5
22.	Present	Average year	86%	90%	75%	95%	10 %	MB-PCP-6
23.	Present	Average year	90%	95%	80%	95%	0 %	MB-PCP-7
24.	Present	Average year	90%	95%	80%	95%	10 %	MB-PCP-8
25.	Present	Dry year	86%	90%	75%	95%	0 %	MB-PCP-9
26.	Present	Dry year	86%	90%	75%	95%	10 %	MB-PCP-10
27.	Present	Dry year	90%	95%	80%	95%	0 %	MB-PCP-11
28.	Present	Dry year	90%	95%	80%	95%	10 %	MB-PCP-12
29.	Present	75 % Rain	86%	90%	75%	95%	0 %	MB-PCP-13
30.	Present	75 % Rain	86%	90%	75%	95%	10 %	MB-PCP-14
31.	Present	75 % Rain	90%	95%	80%	95%	0 %	MB-PCP-15
32.	Present	75 % Rain	90%	95%	80%	95%	10 %	MB-PCP-16

Table 5.13 Demand, net flow, groundwater use and deficit for design cropping pattern in Harsi command

Scenarios	Demand (Mm^3)	Net Flow (Mm^3)	GW use (Mm^3)	Deficit (Mm^3)
MB-DCP-1	313.58	272.36	0	41.22
MB-DCP-2	313.58	284.36	14.14	15.08
MB-DCP-3	295.96	287.13	0	8.83
MB-DCP-4	295.96	291.44	2.45	2.07
MB-DCP-5	367.39	307.51	0	59.88
MB-DCP-6	367.39	324.37	10.73	32.29
MB-DCP-7	354.23	328.15	0	26.08
MB-DCP-8	354.23	337.96	6.78	9.49
MB-DCP-9	372.37	286.26	0	86.11
MB-DCP-10	372.37	304.78	10.84	56.75
MB-DCP-11	359.95	306.99	0	52.96
MB-DCP-12	359.95	320.43	13.93	25.59
MB-DCP-13	363.79	322.86	0	40.93
MB-DCP-14	363.79	336.71	17.33	9.75
MB-DCP-15	344.96	338.13	0	6.83
MB-DCP-16	344.96	341.29	2.89	0.78

Table 5.14 Demand, net flow, groundwater use and deficit for present cropping pattern in Harsi command

Scenarios	Demand (Mm^3)	Net Flow (Mm^3)	GW use (Mm^3)	Deficit (Mm^3)
MB-PCP-1	121.46	120.29	0	1.17
MB-PCP-2	121.46	120.4	0.04	1.02
MB-PCP-3	121.42	120.3	0	1.12
MB-PCP-4	121.42	120.43	0.01	0.98
MB-PCP-5	130.95	128.3	0	2.65
MB-PCP-6	130.95	124.54	6.2	0.21
MB-PCP-7	130.82	128.35	0	2.47
MB-PCP-8	130.82	124.55	6.06	0.21
MB-PCP-9	156.32	148.62	0.00	7.7
MB-PCP-10	156.32	146.12	5.88	4.32
MB-PCP-11	155.5	150.29	0	5.21
MB-PCP-12	155.5	148.02	5.11	2.37
MB-PCP-13	130.85	128.2	0	2.65
MB-PCP-14	130.85	124.76	5.88	0.21
MB-PCP-15	130.82	128.35	0	2.47
MB-PCP-16	130.82	124.55	6.06	0.21

Table 5.15 Comparison of areas under different classes in the year 2009 and 2014

S. N.	NDVI range	Class	Year 2009		Year 2014		Percent change from 2009
			Area (ha)	Percentage of total	Area (ha)	Percentage of total	
1.	Up to 0.0	Water/Cloud	16204.78	20.47	7.69	0.01	-99.95
2.	0.0 to 0.025	Bare soil	2394.43	3.02	6.07	0.01	-99.95
3.	0.025 to 0.25	Grass	36151.78	45.67	16408.48	20.73	-54.61
4.	0.25 to 0.50	Scarce vegetation	24259.51	30.65	47974.83	60.60	97.76
5.	0.50 to 0.70	Dense vegetation	150.624	0.19	14764.05	18.65	9701.92

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