Report No. _______

DEVELOPMENT OF DSS FOR BINA RIVER BASIN IN BUNDELKAND REGION IN M.P. USING WEAP MODEL

(PILOT BASIN STUDIES: IWRM IN BINA RIVER BASIN IN BUNDELKHAND REGION OF MADHYA PRADESH)

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PREFACE

The basic concept of Integrated Water Resources Management (IWRM) is to integrate not only the stakeholders but also put together all aspects of natural resources for efficient use of available water in a river basin. It is essential to exercise the entire sources of supply and demands in a river basin for planning and prioritization of the water allocation for different uses, viz. domestic, industrial and agricultural purposes. The WEAP is a simple tool for prioritizing the supply sources, the surface water as well as ground water and also allocation for different demands. All the links and nodes can be assigned the priority in terms of numbers, viz. for highest priority, it is 1. The WEAP tool also gives answers for "What if?" type questions, like what if the rate of population growth increases or decreases, what if crop rotation changes, what if additional water harvesting structures or dams are constructed. The input for these types of situations is assigned in the form of scenario generation. The input may be in the form of maps, tables or formula. In other words, WEAP can simulate the dynamics of watershed characteristics and future changes in the basin, which affect the water supply and demand. This helps in planning and allocation of available water.

In the present study an attempt has been made to make an account of the present available water resources in Bina river sub-basin, a tributary of Betwa river in Bundelkhand region of Madhya Pradesh. The total water demands, supplies and the unmet water demands for the reference year, i.e. 2011 have been computed on the basis of population, climatic conditions, cropping pattern and watershed characteristics for the year 2011. Also, the changes in unmet water demands under three types of scenarios, viz. High Population Growth, Increase in Ground Water Recharge and Construction of proposed Madia Dam. I hope the study will be useful to the stakeholders of water resources in the Bina river basin, especially for planning of developmental activities.

Dr. Tejram Nayak, Scientist 'E' and team of Central India Hydrology Regional Centre, Bhopal have carried out the study under the Pilot Basin Studies: IWRM in Bina river basin in Bundelkhand Region in Madhya Pradesh during the year 2015-17. The State Water Data Centre, Water Resources Department, Bhopal and Central Ground Water Board, Bhopal deserves our special thanks for supplying hydrologic data for this study.

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ABSTRACT

Study and analysis of water allocation between user and ecosystem is useful when it is addressed at the basin level. In the cases of limited water resources, environmental quality and policies for sustainable water use, where conventional supply oriented simulation models are not adequate, WEAP is modern, straight forward and easy-to-use modelling tool. In the present study, WEAP has been applied to manage domestic and agricultural systems to govern a range of issues like: water allocation priorities, water conservation, groundwater and stream flow simulations, and water storage structure. The main purpose of the study is to simulate water demand and supply, recharge and draft using WEAP.

The study area is Bina River watershed falling in the Sagar, Vidisha and Raisen districts of Madhya Pradesh which falls in the Bundelkhand region of India. A major portion of the basin covers rural areas and so the main demand sites in the river basin include agricultural areas and domestic consumption only. The supply sources however are quite a few available in various forms of rivers, reservoirs, groundwater etc.

WEAP is a tool which heavily depends on the data available, but at the same time is flexible to the data type i.e., daily, weekly, monthly or annually. A huge set of data is required to feed into the model including water consumption rate, Head flow of streams, precipitation, average temperature, groundwater recharge etc. The basic methodology includes conversion of all the data into a WEAP supported format, feeding it into the model and obtaining the results. As a forecasting tool, the model has been used to generate a trend of future demand and supply of water for the next 15 years. Three types of scenarios have been generated including High Population growth; Groundwater Recharge and Water Storage Structure scenarios to obtain the future trends.

From the analysis, the levels of satisfaction of demands and the quantity of water deficit today and in future were obtained. The Unmet water demands in all Administrative Blocks, Catchments and Industries in the year 2011-2025 have been calibrated which comes to be 31.881 million cubic meters in 2011 and 33.318 million cubic meters in 2025. WEAP demonstrated that 10% annual increase in groundwater recharge would fulfill the entire unmet water demands by the year 2025 and it clearly indicated that the construction of water storage structure also fulfill the supply requirements in the connected areas.

1.0 INTRODUCTION

Essential to all, water is the basis of life. It is the most common source, covering about 71% of the Earth's surface. Although there is much available, it is sometimes a scarce resource. Water has its own domain of phenomenal significance. It gives life to everyone but also death to some. It is a vital source of agriculture, production and countless other human activities and yet it is one of the most poorly managed resources on earth. The big difference in the accessibility of water in different parts of the world makes its significance even more remarkable. Water supply on earth can't be changed but can be managed as per the needs. The impacts and spreading occurrence of water problems can be reduced by managing the resources in two ways: by decreasing the waste & unnecessary uses and increasing the usable supply. However this resource management is not as easy as it looks like. It includes innumerable parameters that need to be considered like climate factors (temperature, humidity, radiations, precipitation), economic factors, population variance, consumption, settlements and a lot more. Watershed boundaries provide the natural limits for considering and managing these parameters within.

Watershed is defined as a hydro-geological unit of area from which the rainwater drains through a single outlet. From the hydrological point of view, the different phases of hydrological cycle in a watershed depend on the various natural properties and human activities. Watershed is not only the hydrological unit but also a socio-political-ecological entity which plays important role in determining social, economical and food security and provides life support services to rural people (Wani et al., 2008). It restricts both surface and groundwater supplies, along with related terrestrial and community resources. Much of its water comes from rainfall and storm-water runoff. All the alterations to the land-mining, agriculture, roadways, urban development, and the activities of people within a watershed affect the quality and quantity of storm-water. And so these are responsible for most of the water quality use impairments throughout. This is a complex typical problem and difficult to manage that is why there is a requirement of better understanding of the interactions between the environmental components.

Watersheds are the physical features found everywhere across the landscape serving as the geographic foundation for political states. They supply drinking water, provide recreation and respite and sustain life in many other ways. Therefore watersheds planning and management is highly desirable. Watershed management implies to integrate planning for land and water; taking into account both ground and surface water flow, it recognizes and plans for the interaction of water, animals, plants and human land use found within the physical boundaries of the watershed. It also provides a framework to assess the nature and status of the watershed define and re-evaluate short and long-term objectives, actions and goals; identify watershed issues; assess benefits and costs; and implement and evaluate actions through integrated decision- making process. Integrated Watershed Management thus provides ridge to valley watershed planning for water, natural resources and environment. It is a holistic problem solving strategy used to protect and restore the physical, chemical and biological integrity of aquatic ecosystems, human health, and provides for sustainable economic growth (National Research Council, 1999).

Managing the supply and demand with an assurance of good quality water is a great deal now-a-days. There could be multiple factors within the boundary of a watershed that greatly alter the storage and availability of water by demanding more or less water than the usual expectations. Unusually increasing and decreasing demands of water can broadly affect future water supply unless there is some planning to manage the behaviour.

A research and development study on 'Integrating hydrology and IWRM with livelihood issues: Development of methodology and a DSS for water-scarce Bundelkhand region in India' has been completed by National Institute of Hydrology (NIH), Roorkee. It was the TIFAC (Department of Science and Technology, Government of India) sponsored project under India-IIASA program. The basic purpose of the project was to develop a proper water management plan for the study area, viz. Ur river sub-basin in Tikamgarh district of Bundelkhand region. The data base for this region has been analysed for the supply-demand management of available water using WEAP model.

1.1 Overview of WEAP Tool

Water Evaluation And Planning (WEAP) is a microcomputer tool for integrated water resources planning. It provides a flexible, comprehensive and user-friendly framework for policy analysis. WEAP is found to be useful by a growing number of water professionals, addition to their toolbox of models, databases, spreadsheets and other software. This overview summarizes purpose, approach and structure of WEAP. WEAP tutorial contents are also introduced; a series of modules that takes you through all aspects of WEAP modelling capabilities constructs the tutorial. Although the tutorial itself is built on very simple examples, it covers most aspects of WEAP. WEAP under the name "Bina River Basin" includes a more complex model presenting those aspects in the context of a real situation.

1.1.1 Background

Many regions are facing intense freshwater management challenges all over the world. Allotment of limited water resources, environmental quality, and policies for sustainable water use are concerning issues. Conventional supply-oriented simulation models are not always enough. An integrated approach to water development has emerged over places water supply projects over the last decade in the context of demand-side issues, water quality and ecosystem preservation. WEAP focuses to include these values into a practical tool for water resources planning. It is differentiated by its integrated approach towards simulating water systems and by its policy orientation. WEAP places the demand side of the equation - water use patterns, allocation, equipment efficiency, re-use, and prices on an equal footing with the supply side - streamflow, reservoirs, groundwater, and water transfers. WEAP is a laboratory for examining alternative water management strategies and water development.

WEAP is comprehensive, straightforward, and easy-to-use, and does not substitute but attempts to assist the skilled planner. A system for maintaining water demand and supply information is provided by WEAP as a database. WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge as a forecasting tool. WEAP assess a full range of water development and management options, and takes account of multiple and competing applications of water systems as a policy analysis tool.

1.1.2 WEAP Development

The Stockholm Environment Institute provided basic support for the development of WEAP. The Hydrologic Engineering Centre of the US Army Corps of Engineers funded significant enhancements. A number of agencies, including the World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in over one hundred countries.

1.1.3 WEAP Capabilities

- Water balance database: WEAP provides a system for maintaining supply information and water demand.
- Scenario generation tool: WEAP simulates water storage, runoff, demand, supply, streamflows, instream water quality, pollution generation, treatment and discharge.
- Policy analysis tool: WEAP takes account of multiple and competing uses of water systems and assess a full range of water development and management options.

1.2 Objectives

The Bundelkhand region, often called as the heartland of India, is a semi-dry area. For most part of the year, it experiences an acute scarcity of water for agricultural, industrial and domestic use.

Water sources are varied and often seasonal. Most of the agriculture is rain fed, so farmers are highly dependent on the monsoon rains.

As per a report by Development Alternatives, the region receives a fairly decent amount of average rainfall ranging 880-1000 mm but as the 90 percent of annual rainfall is received in the Monsoon season, the climate pattern is quite uncertain and erratic. It sometimes causes droughts and also floods in the monsoon. Thus, keeping in view the erratic rainfall pattern for most of years in Bundelkhand region, which caused acute scarcity for the different demands of the area, this study was aimed to manage the available water resources of Bina river watershed through different possible future scenarios.

In particular, the objectives of the study have been framed as:

1. To develop the Water Evaluation And Planning (WEAP) applications for the watershed management in Bina river sub-basin for Reference year.
2. Formulation and evaluation of the following scenarios:
   - Population growth
   - Groundwater recharge
   - Incorporating Water Storage Structure (Dam) in the study area

2.0 LITERATURE REVIEW

The WEAP tool has been used for planning water management in current scenario as well as future changes in demand and supply due to population growth, developmental activities in the watershed, cropping pattern and climate change.

Strzepek K. M., Major D. C. (1999) reported new methods of linking climate change scenarios with agricultural, hydrologic and water planning models to study future water availability for agriculture, an essential element of sustainability. They studied the integration of models for water supply and demand, and of crop growth and irrigation management. Rosenzweig C., Strzepek K. M. (2004) examined the implications of water availability for the reliability of irrigation and changes in crop water demand, taking into account changes in competing industrial and municipal demands, and explores the effectiveness of adaptation options in maintaining reliability. They reported on methods of linking climate change scenarios with hydrologic, agricultural, and planning models to study water availability for agriculture under changing climate conditions, to evaluate adaptation strategies for the water resources and agriculture sectors and to estimate changes in ecosystem services.

Jenkins M. W., Marques G. F. (2005) presents a study of the Water Evaluation and Planning System (WEAP) as a decision support tool (DST) in addressing shared water issues in the River Njoro watershed for local stakeholders and communities. The watershed includes a large shallow saline lake designated a RAMSAR wetlands site of international importance, an important downstream habitat at Lake Nakuru, and a broad mix of water uses and users located in the semi-arid Rift Valley of Kenya. Purkey et. al. (2008) looked at the impact of climate change on agricultural water management and the potential for adaptation in the Sacramento River Basin of California. In terms of improving irrigation efficiency and shifts in cropping patterns during dry periods, climate time series were used to simulate agricultural water management with and without adaptation. They found WEAP more robust than any other tool in evaluating future climate scenarios and also the water demand associated with high temperatures and low rainfall.

Bharati et al. (2008) used the model to evaluate the water availability as against water demand in the link from Godavari River (at Polavaram) to Krishna River (at Vijayawada). This study helped in examining whether the planned water transfers (Polavaram reservoir and link canal) would satisfy the growing agricultural water demands in the Polavaram link command area. Young C., Joyce B. (2008) worked with WEAP, which is simulation modelling software that includes a robust and flexible representation of water demands from all sectors and flexible, programmable operating rules for infrastructure elements such as reservoirs, canals, and hydropower projects. Additionally, it allows all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes with its watershed rainfall-runoff modelling capabilities. WEAP also allows for linking with other models to provide feedback mechanisms whereby the management regime can be altered to respond to changing water supply conditions.

Mugatsia (2010) adopted Decision Supportive System (DSS) to evaluate the current water management scenario and the effect of proposed water development projects in future in the Perkerra catchment of Kenya. To create spatial database and the impact of various water infrastructural developments, policy and regulation assessed under various scenarios, the data was geo-referenced in ArcView GIS software. Mounir Z.M. et. al. (2011) used WEAP as a forecasting tool of future water balance. They investigated the scenarios for future water resource development in the Niger River basin in Niger Republic for three main purposes: for human needs (domestic), for irrigation (agriculture) and for industrial purpose in the Niamey and Tillabery cities. Results for satisfied and unsatisfied (unmet) water demands were obtained by running and comparing the scenarios.

Page M., Berjamy B. et. al. (2012) Decision Support System has been set up as the result of a fruitful cooperation between several public and research institutions in the framework of a large cooperation program. The DSS aims to compare spatially and temporally sectorial water demands of the Haouz-Mejjate plain (Morocco) in regard to available surface and groundwater resources. A dynamic linkage between MODFLOW and WEAP transfers the results of one model as input data to the other. The model restitutes both spatial and temporal variations in head charges and allows the calculation of the ground water balance. Mehta V. K.; Purkey, et. al. (2013) studied on WEAP that includes a dynamically integrated watershed hydrology module that is forced by input climate time series. This software allows direct simulation of water management response to climate and land use change. They represented a WEAP application for the Yuba, Bear and American River (ABY) watersheds of the Sierra Nevada.

Fayad A., Alameddine I. (2014) investigated over the Upper Litani River Basin. The framework encompassed the ability to export back model simulation results and as time series records, incorporate them within the Hydrologic Information System HIS. Since then, the developed HIS system was adopted as a data repository for other water related projects in Lebanon and has helped identify key gaps in existing data and set monitoring priorities. Usha B., Mudgal B. V. (2014) studied that the effect of climate variability/climate change on runoff is limited in humid tropical regions. Climate change has effects on agriculture and fisheries other than the water resources sector. Their study provides information on climate variability/changes and its impacts on runoff in the Kosasthaliyar sub-basin. Rahimi et. al. (2014) investigated near Masouleh River in Guilan province of Iran for economic valuation of water resources.

Sampath D. S. and Weerakoon S. B. (2014) developed a model for water management in development area of LB canal and for the assessment of diversion requirement from the DeduruOya reservoir through the LB Canal to supplement LB irrigation demand. They used Hydrological Engineering Center-Hydrological Modeling System (HEC-HMS) for runoff estimations and CROPWAT model to estimate crop water requirements. For water balance simulations in Deduru Oya LB canal development area and to calculate water requirements from LB canal for the period of recent 10years, Water Evaluation and Planning (WEAP) model was used. Suryawanshi R. A. and Shirke A. J. (2014) worked with the software Water Evaluation And Planning System (WEAP 21) which operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of water demands, supply withdrawals and ecosystem requirements. The recent application of the WEAP model forms part of on-going research work in Subarnarekha River Basin, to develop, test and promote management practices and decision-support tools for effective management of water and land resources.

Malla M. A., et. al. (2014) used WEAP (water evaluation and planning model) developed by Stockholm Environment Institute to study the global climatic concerns, which began to cast their shadows on the climate of Jammu and Kashmir as well. This model is a tool for integrated water resource management and planning like, forecasting water use, supply, demand, inflows, outflows, reuse, water quality, priority areas and Hydropower generation, etc,. Asl-Rousta B., Araghinejad S. (2015) considered three different objectives namely Supply-demand Equilibrium, Drought Mitigation and Economic Efficiency for the analysis. The developed tool benefits from the ability of spatial weighting through which physical, economic and socio-environmental aspects are considered in a weighting process.

Bhatti G.H., et. al. (2015) discussed that there are limited resources of fresh water supply, while there is competing demand for water amongst agricultural, industrial and domestic users. In arid and semi arid regions, with limited availability of irrigation water, it has become necessary to optimize efficiency of water usage and maximize crop yields under deficit irrigation conditions. During the growth period of crops, water shortage has an impact on its ultimate yields. Thus to have more effective and optimal use of limited supplies of water, there is need to adopt irrigation scheduling techniques. Regulated deficit irrigation can provide a means of reducing water consumption while minimizing adverse effects on yield. Ortega C. V., et. al. (2016) considered WEAP as a policy making tool. By doing economic valuation of water resources and managing them in economized and executable manner, it helps the stakeholders and policy makers to take decision. They applied WEAP21 to manage the water resources of Guadiana river basin of Portugal through stakeholder participation for vulnerability and adaptation.

3.0 METHODOLOGY

Water Evaluation And Planning (WEAP) model has been used to analyse the water supply and demands in the Bina river basin. WEAP relies heavily on two-fold methodologies: generation of necessary datasets required to simulate future scenarios; and feeding these datasets into the model to obtain the results.

3.1 The WEAP Approach

WEAP is applicable to municipal and agricultural systems, single catchments or complex transboundary river systems as it operates on the basic principle of a water balance. Moreover, WEAP can define a wide range of issues, e.g., water conservation, water rights and allocation priorities, hydropower generation, sectorial demand analyses, groundwater and streamflow simulations, vulnerability assessments, reservoir operations, pollution tracking, ecosystem requirements, and project benefit-cost analyses. The analyst represents the system in terms of its various supply sources (e.g., rivers, creeks, groundwater, reservoirs, and desalination plants); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

The WEAP applications generally include several components:

- Project definition: The time frame, spatial boundaries, system components, and configuration of the problem are established.
- Current accounts: A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.
- Scenarios: A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored. (Possible scenario opportunities are presented in the next section.)
- Evaluation: The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

3.2 Program Structure

WEAP consists of five main views: Schematic, Data, Results, Scenario Explorer and Notes. These five views are presented below.

3.2.1 Schematic: This view contains GIS-based tools for easy configuration of your system. Objects (e.g., demand nodes, reservoirs) can be created and positioned within the system by dragging and dropping items from a menu. ArcView or other standard GIS vector or raster files can be added as background layers. You can quickly access data and results for any node by clicking on the object of interest.

The entire Bina River basin has been considered for the study. The watershed boundary, block boundaries, major streams, sources of supply, consumption nodes, return flows, etc. have been marked through nodes and transmission links and the Schematic has been developed for the Bina River basin (Fig.3.1).

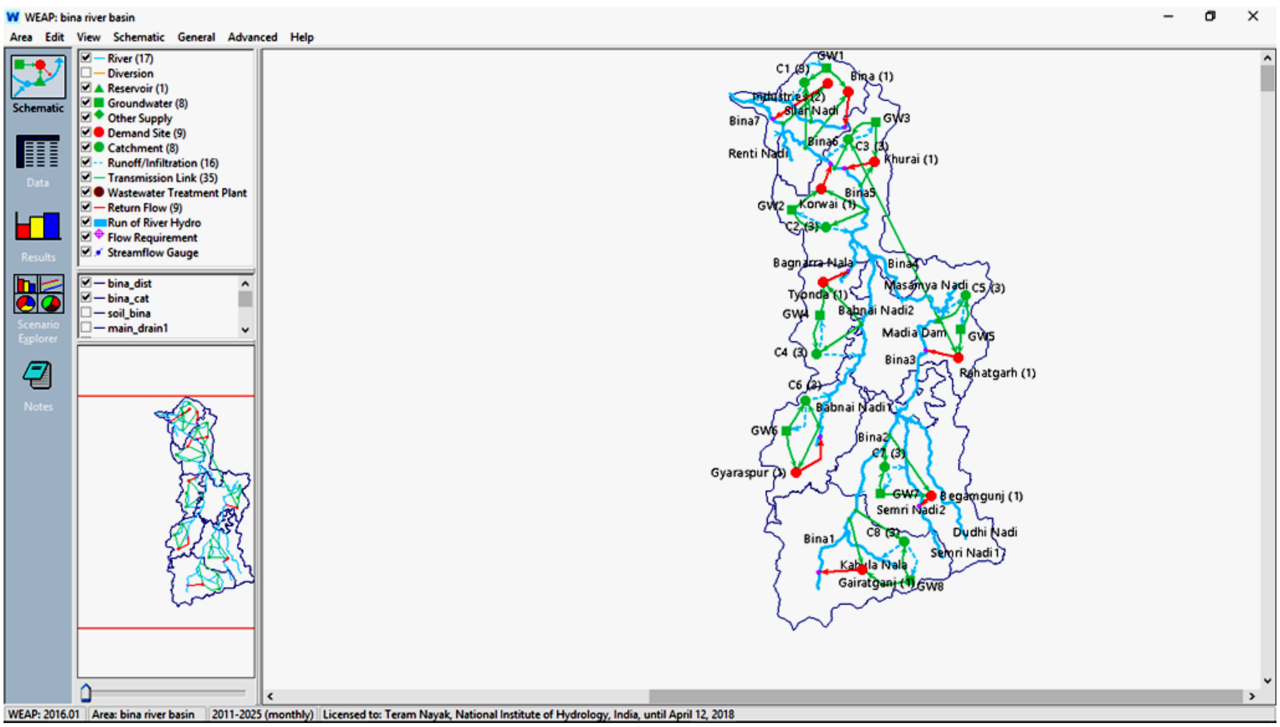

Fig. 3.1 Schematic view of WEAP

3.2.2 Data: The Data view allows you to create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel. Any modification of input data is possible at any stage of analysis. A sample data view of 'Water Use' is shown at Fig.3.2.

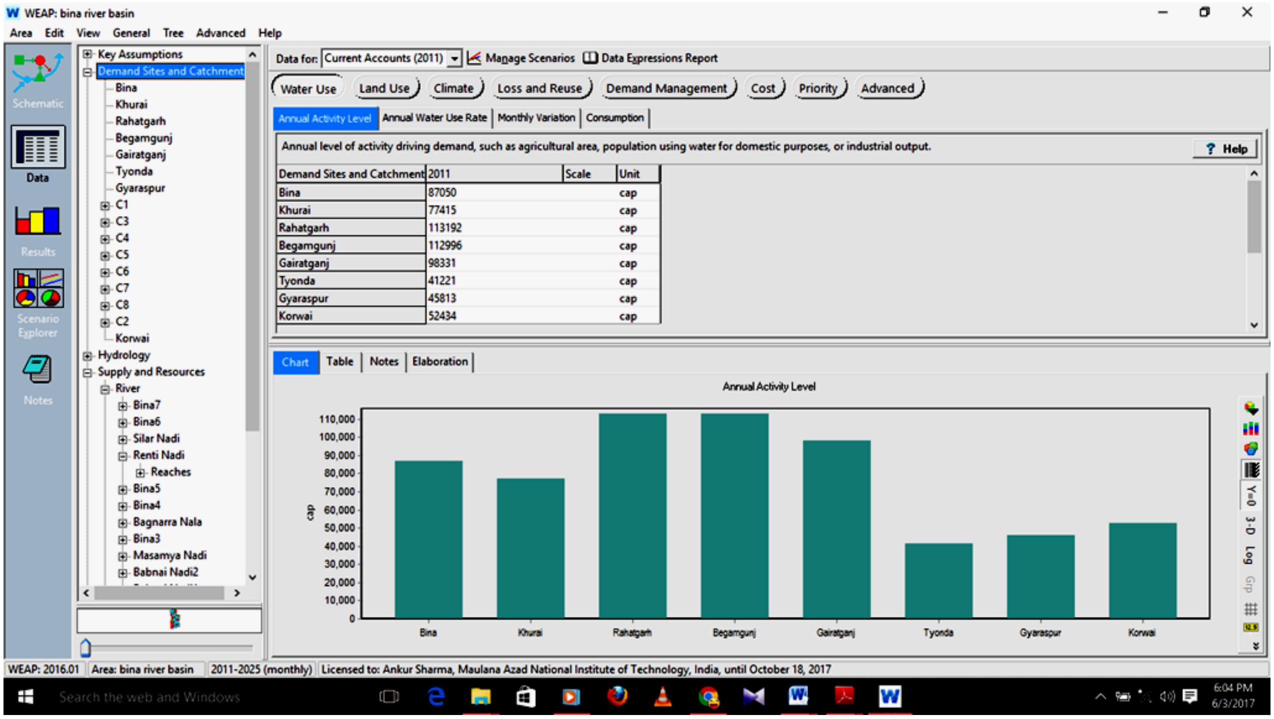

Fig. 3.2 Data view of Water Use in towns

3.2.3 Results: The Results view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic. Fig.3.3 shows bar chart of results.

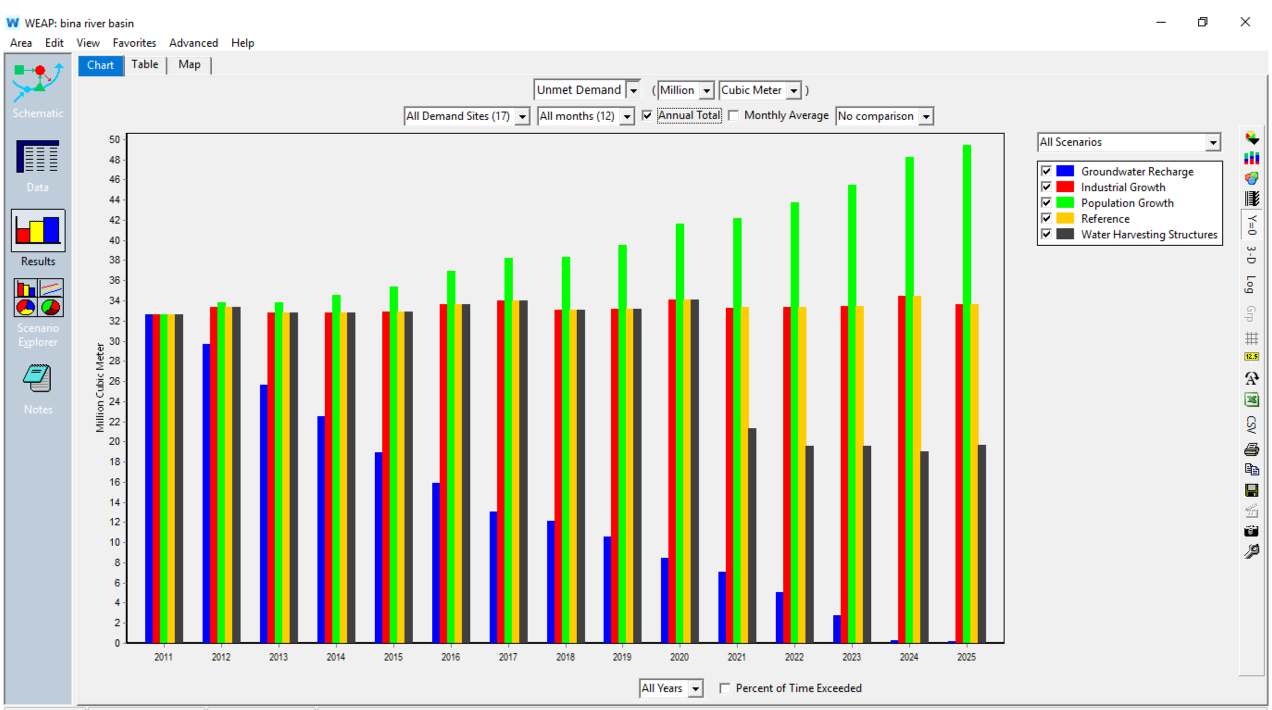

Fig. 3.3 Result view of WEAP

3.2.4 Scenario Explorer: You can highlight key data and results in your system for quick viewing. Bar charts of different scenarios is shown at Fig.3.4.

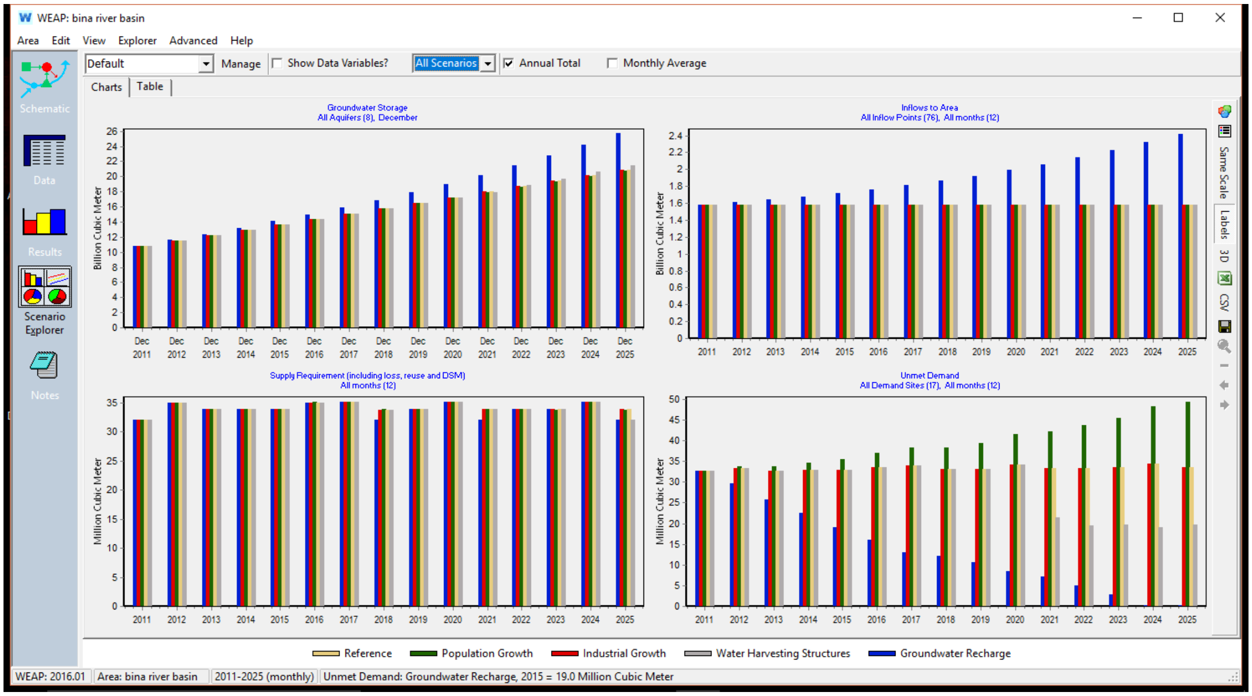

Fig. 3.4 Scenario explorer view of WEAP

3.3 The WEAP Steps:

To achieve the objectives for this study, the following steps were performed:

1. Data collection to define the current situation of the watershed: The watershed in the WEAP model is represented by its drainage pattern, and the demand and supply sites that happen to exchange water. They require huge varied datasets to define the current status of water in terms of availability, accessibility, and use. The variety of data collected from different sources is given in Table 3.1.
2. Displaying the watershed in schematic view: The drainage pattern of Bina River watershed was directed into schematic view. Demand sites, transmission links, runoff links, catchments, ground water and rivers were all located by using the default symbols.
3. Feeding the data into WEAP model: WEAP offers an easy way to import data from excel sheet into the model. The climatic data, precipitation, crop distribution, groundwater draft and recharge etc. as per requirement was fed into the model and saved.
4. Obtaining the results: The model was run to obtain the results for the current year 2011.
5. Generating the future scenarios: This study aimed to simulate the demand and supply of water for the Bina River watershed and managing the same in 'what if' scenarios for the next 14 years. Keeping in mind the physical, demographic and economic characteristics of the watershed, following three scenarios were generated:

- High Population growth: This scenario was generated to see the growing trend of water demands for next 14 years if there is an increase in the rate of population growth.
- Incorporation of the Madia Dam after the year 2020: The trend of changing water demands in future by changing the priority of water supply for domestic and irrigation use from reservoirs to harvested water; was obtained by running the model in this scenario.
- Increase in Groundwater Development and Rainwater Recharge: This scenario gave information about the effect of increase in groundwater recharge and draft.

6. The model was finally run to obtain results in these scenarios.

Table 3.1: Different sources for Data collection

S. No.	Type of data	Parameters	Source
1	Population	• Human Population • Livestock Population	Census of Madhya Pradesh
2	Climate data	• Average humidity • Min. and max. temperature • Precipitation • Reference ET • Wind speed • Sun hours • Radiations	CLIMWAT 2.0 for CROPWAT
3	Water demand data	Domestic consumption	M.P. Government
4	Land use data	• LULC Map • Total land area	RS Data and Agriculture Deptt.
5	Reservoir data	Proposed Dam and Storage capacity	W.R.D., Govt. of M.P., Bhopal
6	Ground Water Data	• Initial Storage • GW withdrawal • GW recharge	Regional Director, CGWB, Bhopal
7	Soil	• Soil Map	NBSS&LUP, Nagpur
8	Other Maps	• District Block Map • Drainage Map • Topographical Map • Watershed Boundary	SOI toposheet

The overall methodology can be summed up and shown in Fig. 3.5.

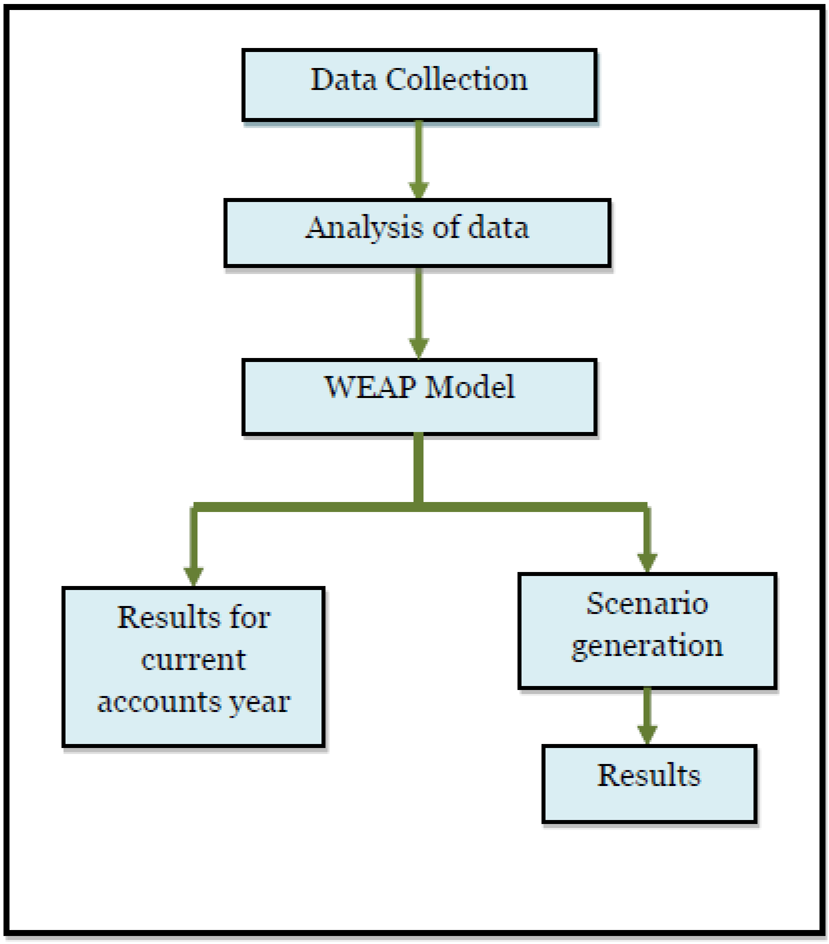

Fig. 3.5: Flow chart of methodology

4.0 STUDY AREA

4.1 Bina River Basin

The area selected for present study is Bina River basin of Madhya Pradesh, India. Bina River is a tributary of Betwa River in Bundelkhand region of Madhya Pradesh. Study area is bounded by Latitude 23’18’’N to 24’15’’ N and Longitudes 78’03’’E to 78’32’’E. Bina River originates from Begamganj Block of Raisen District and enters Sagar district at Rahatgarh block and it transverses Kurwai block of Vidisha district and Bina Tehsil before confluence with river Betwa near Basoda town in Vidisha. Presently, domestic water supplies to Rahatgarh, Khurai and Bina town. The upper part of the study area is highly undulating and covered by forests, barren lands and localized rain-fed agriculture. The drainage density is more in the upper catchment as compared to the lower part of the Bina river basin, later is mostly gently sloping to plain topography largely covered with agricultural fields. The streams are dry after the monsoon months despite enough rainfall; the average annual rainfall in recent years over the basin is 1049 mm and during monsoon months, i.e. June to October the rainfall is 980.35 mm. Therefore groundwater is exploited for domestic and agricultural uses during Rabi season causing depletion of the water table in most of the area.

4.1.1 Base Map

The study area is located in the part of Sagar, Vidisha and Raisen districts of Madhya Pradesh. The base map was created from SOI toposheet No. 55I/2, 3, 6, 7 and 11 on 1:50,000 scale showing the watershed boundary, road, railway and drainage network and major settlements.The base map is given at Fig.4.1. The drainage area and the length of stream are the important parameters for a watershed. The geographical area of the Bina river watershed delineated in GIS platform has been computed to be 2808.08 Km^2. The study area covers part of eight blocks in Raisen, Vidisha and Sagar districts. The demographic details are given at Table 4.1.

Table 4.1: demographic details of the Bina river basin

S. No.	Block Name	District	Area in Sq.km.	Population	Live Stock
1	Begumganj	Raisen	563.17	69459	43537
2	Gairatganj		518.82	60239	38092
3	Gyaraspur	Vidisha	265.66	37555	8258
4	Kurwai		251.93	44631	7803
5	Tyonda		200.49	32538	8683
6	Bina	Sagar	263.76	75493	11557
7	Khurai		235.04	59200	18215
8	Rahatgarh		509.21	77430	35762
	Total		**2808.08**	**456545**	**171906**

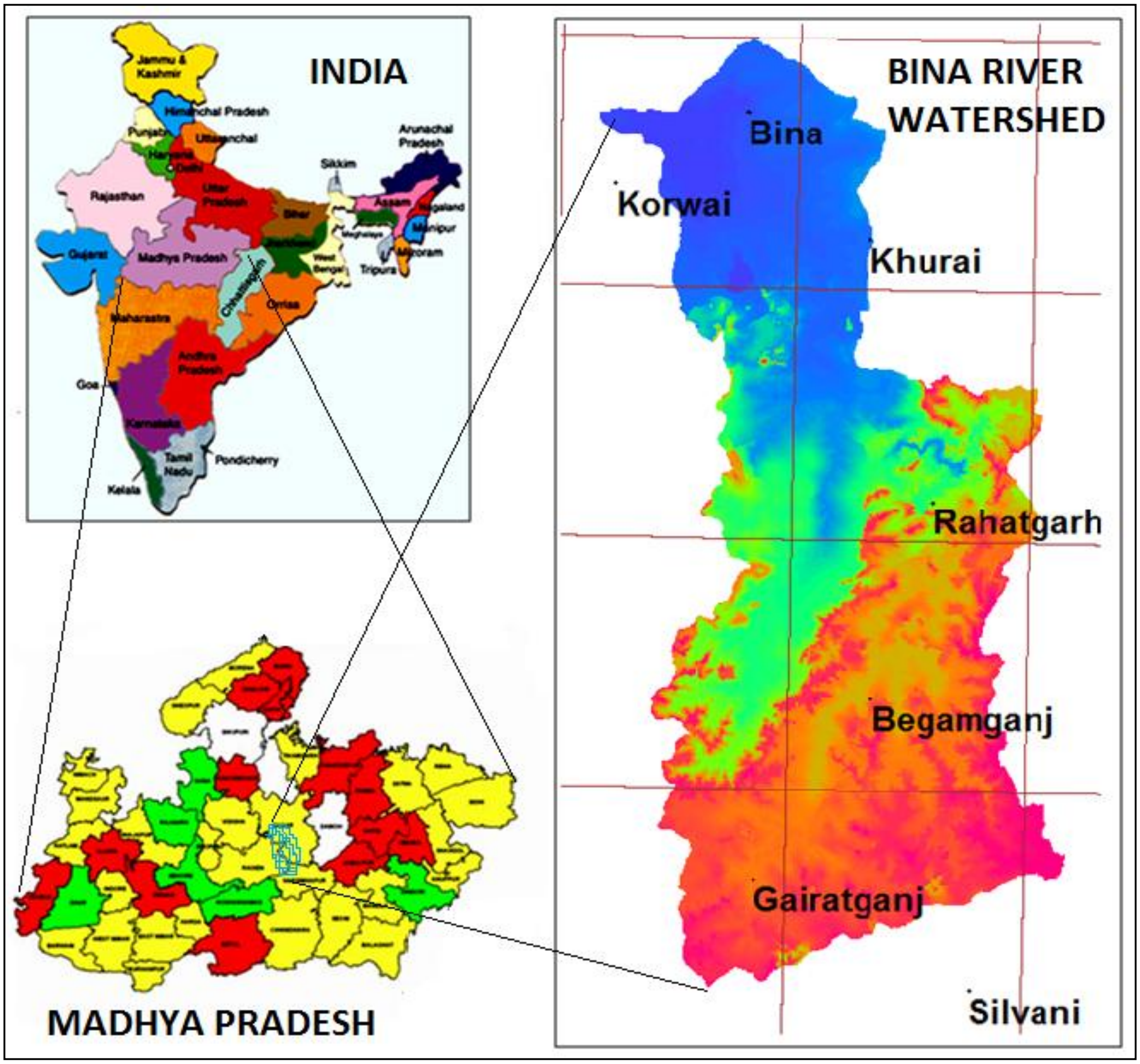

Fig. 4.1: Index map showing location of Bina river watershed

4.1.2 Drainage Network

Bina takes its course up to several Kilometres and enters its nearest village Mahura. After flowing through Rahatgarh block, the rivers take a north easterly course and form the boundary with Vidisha district. The height of water fall near Rahatgarh town is about 15m. It joins the Betwa River at about 16 km west of Bina town. The drainage pattern is of dendritic type as shown in Fig.4.2. Only major streams have been considered to be the sources of surface water for domestic and irrigation water supply having sufficient flow till winter/Rabi season.

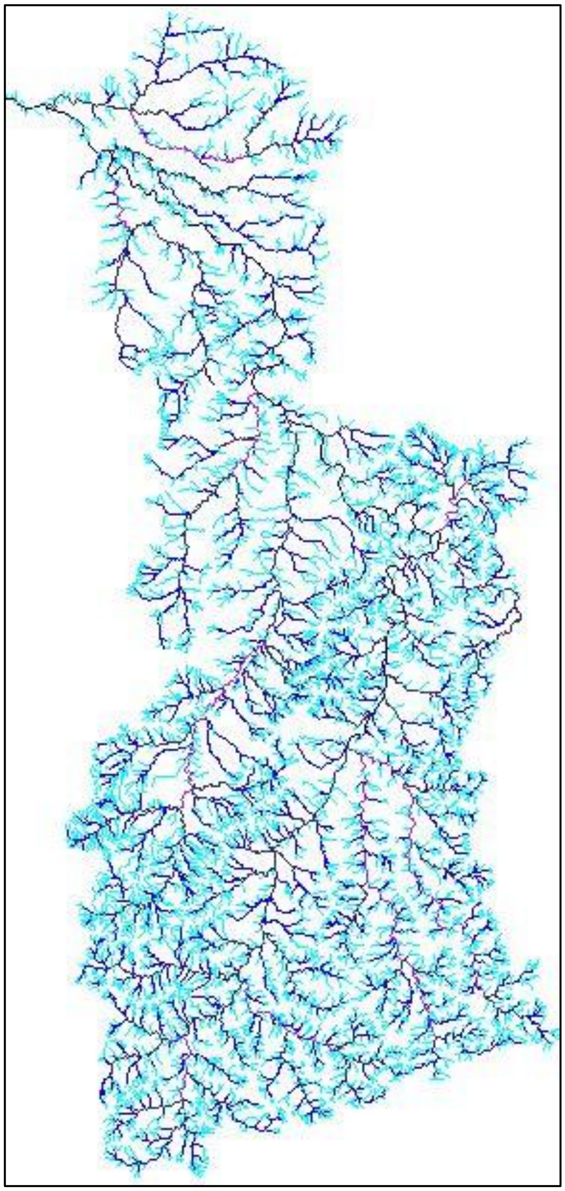

Fig 4.2: Drainage Map of Bina River basin

4.2 Climate

It has semi-arid to sub-tropical climate. There are three distinct season i.e. summer (March to May), monsoon (mid-June to mid of October) and winter (mid of November to end February). Nearly 90% of the annual rainfall takes place during southwest monsoon period i.e. June to October, only 5.5% of annual rainfall takes place during winter and about 4.5% of rainfall occurs during the summer season. The maximum monthly rainfall occurs during the month of July followed by. Average annual rainfall recorded at long term rain gauge station in the project region is 1049 mm with small variation between stations. The average, maximum and minimum values observed at Sagar station are 1192 mm, 1645mm and 779 mm respectively.

4.2.1 Temperature

The long term average (normal) of maximum temperature varies from about 25˚ C in January to 41˚C in May. During winter season the January is the coldest month with the average minimum temperature of 11.5˚C whereas the hottest month is May with average maximum temperature up to 40.9˚C. The wind speed ranges from 170 Km/day in December to 288 Km/day in June. Agro-climatically, the area is part of Sagar Division, Zone V called the Vindhyan Plateau. Reference Evapotranspiration (ET0) Varies from a 3.2 mm/day in January to a high of 8.8 mm/day in the month of May. The summer is extremely dry especially in the afternoons, when relative humidity is less than 20 percent are common. During the monsoon season the moisture content of air is high. The humidity again falls to the values well below 60 percent with the withdrawal of the monsoon by the end of the September. The maximum humidity is in the months of July and August. The humidity in these months varies from 91 to 93% in the morning. The humidity is to be decreased up to 11 to 13% in the months of April and May.

4.2.2 Rainfall

Due to unpredictable nature of precipitation and other climatic variables, and manmade change in land and water use in the catchment, the water availability at any site on a river is constantly under change. The normal annual rainfall in study area is 1049 mm; nearly 85% of the rainfall is recorded during the south-west monsoon. Rainfall distribution is an important factor in delineating ground water potential zones due to its direct influence on groundwater recharge. The higher precipitation on a relatively flat terrain having good permeability conditions is considered as s GWPZ due to higher infiltration rates and lower surface runoff. The maximum rainfall recorded in this period is 1645 mm in the year 1991 and minimum rainfall was recorded 779 mm in the year 1980. The average annual rainfall observed in Bina river basin is given at Table 4.2.

Total seven raingauge stations, namely Bina, Kurwai, Khurai, Rahatgarh, Begamganj, Gairatganj and Silvani fall in and around Bina River basin. The annual rainfall observed at these stations available for last fifteen years were collected from State Water Data Centre, Water Resources Department, Bhopal (M.P.). Most of the rainfalls occur during the monsoon period, and the rainfall intensity is also very low therefore soil erosion during monsoon months is less. Further, the runoff during non-monsoon period in the Bina River is very low (mostly due to the base flow).

Table 4.2: Rainfall distribution in Bina River basin

Rain Gauge Station	Bina	Kurwai	Khurai	Rahatgarh	Begamganj	Gairatganj	Silvani
Average Annual Rainfall (mm)	1064.1	1002.5	1193.3	1166.9	1209.2	1183.8	1067.3

4.3 Surface Water

Bina River is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh. The Bina river watershed experience very heavy rainfall during monsoon but due to lack of water conservation and management practices the river goes dry by the end of November or mid-December, depending on the departure of monsoon in this region. Another, major issue for depletion of stream flow is land use change; farmers intend to grow more water required crops, like wheat as the availability of electricity supply is improved and advancement in technology for deep bore-wells. This practice has also resulted into depletion of groundwater in some pockets of the region. The depletion of groundwater has intensified the scarcity of drinking water in rural areas and also led to rapid reduction in vegetation cover (forest cover). Three medium cities, namely Rahatgarh, Khurai and Bina, and about 150 villages fall in the jurisdiction of Bina River basin. The lower part of the basin has good fertile lands which produce the best quality wheat. The crops grown are irrigated mostly by groundwater pumping is absence of dam and canal water supply.

4.4 Soil

Soils in the study region are predominantly black Cotton type, having clay and clayey loam texture and low to very low infiltration capacity. The depth of soil varies from mostly very deep to deep with very limited area comprising hills coming under shallow category. Available water holding capacity (up to 90cm deep) is more than 12 cm for soils in most parts of the area. Soils on hills and hill ridges are generally fine loamy to coarse in texture. The area around Bina river basin is mostly fertile black cotton soil and some area under red soil. The area around Bina river basin is mostly fertile black cotton soil and some area under red soil as shown in Fig.4.3.

The soil maps published by NBSS & LUP, Nagpur, Maharashtra was digitized and stored in vector format. Various categories of soils are found in the study area, namely loamy sand, sandy clay loam, coarse sandy loam, heavy clay, clay and silty clay etc. In the Indian soil classification of these soils are put under Pellusterts, Chromusterts and Ustochrepts i.e., medium and shallow black soils categories.

4.5 Land Use

Land use activity is a linkage between human and environment. Human activity of development is a primary driving force global environmental change of environment in return affect land use types. The land use map of the Bina watershed was prepared from IRS satellite LISS-III imagery data. Digital Image Processing (DIP) technique using the Maximum Likelihood Classifier

(MLC) was applied to prepare the land use map of the Bina basin using remote sensing data. Total nine land use classes could be identified in the Bina basin through Digital Image Processing module available in ILWIS. Based on the ground truth survey and discussions held with the Joint Director, Department of Agriculture (Govt. of M.P.), Sagar. The cropland was classified as good crop and poor crop. In the good crop, the crops are healthy and applied more irrigation. The current fallow is the agricultural land without crops for that particular season. The forest areas were also classified into two categories, i.e. open forest and dense forest. Four other land use classes include settlements, water body and land with or without scrubs. The land use map thus classified from satellite imagery has been stored in raster format. The spatial distribution of land use in Bina basin is shown in the Fig.4.4.

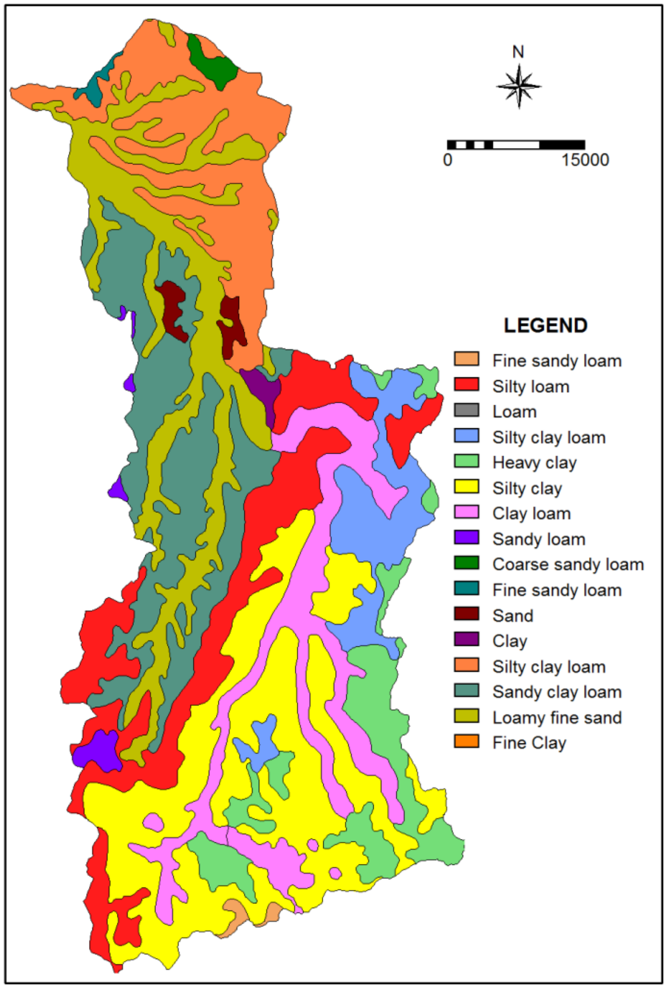

Fig.4.3: Soil map of Bina river basin

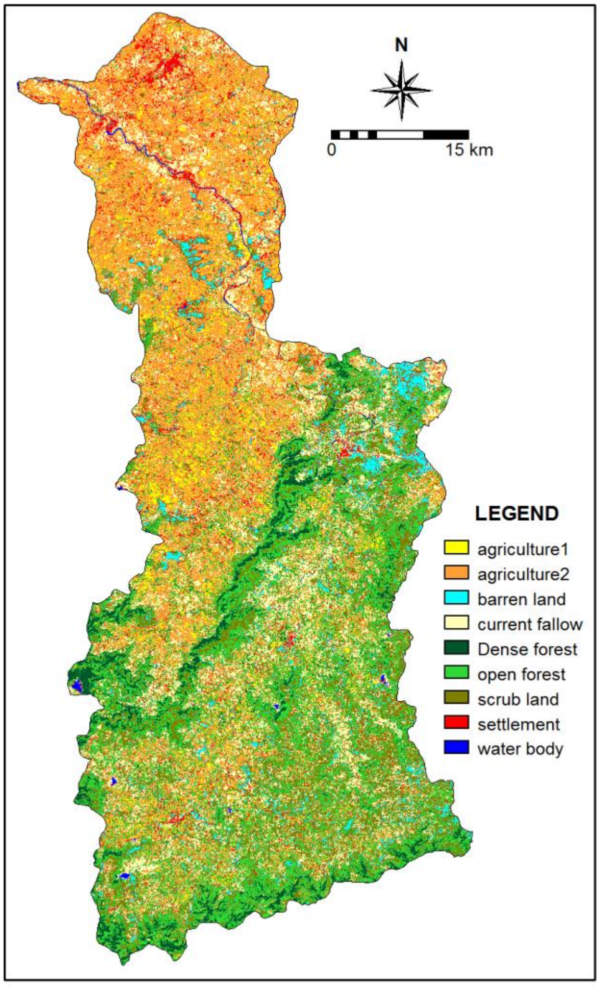

Fig.4.4: Classified Landuse map

4.5.1 Crops

The irrigation demand mainly depends on crop type, showing period, climatic condition and soils of the agricultural area. Block wise landuse data has been extracted from the Statistical handbook and from the Agriculture Department, Govt. of M.P., which is given at Table 4.3.

Table 4.3: Block wise Distribution of Crops in Bina River Basin

Tehsil	Rahatgarh	Bina	Khurai	Kurwai	Tyonda	Gyaraspur	Begamgunj	Gairatganj
Distt.	Sagar	Sagar	Sagar	Vidisha	Vidisha	Vidisha	Raisen	Raisen
catchment	C7	C8	C1	C3	C5	C6	C2	C4
Wheat	10962.3	8292.1	14995.8	20253.7	4538.7	11197.9	14465.7	14565.5
Rice/Grain	44.5	61.0	224.0	42.4	14.3	158.1	114.2	194.0
Sorghum	18.8	48.8	32.4	10.8	7.3	2.7	86.5	24.8
Maize	65.6	129.5	147.2	106.4	24.4	77.7	281.0	195.1
Chickpeas	5034.8	5419.1	15478.7	8584.4	2104.2	4256.7	10486.9	13939.7
Pigeonpeas	168.1	6.3	81.1	12.2	16.9	11.0	18.5	64.8
Blackgram	566.5	3566.7	3957.7	6819.5	1454.8	1371.9	7073.8	4399.2
Sugarcane	1.0	0.0	4.4	1.0	0.5	0.0	1.0	3.0
Sesame	4.2	7.8	1.2	2.8	0.8	1.8	5.6	1.1
Linseed	47.6	0.0	0.0	0.0	0.0	3.4	0.0	0.0
Groundnut	16.1	0.0	7.5	10.4	0.3	6.1	0.0	6.8
Musturd	33.8	25.0	38.7	26.4	3.7	9.4	48.2	35.0
Soyabean	16267.7	9599.7	18894.8	20313.0	4924.3	13715.3	19478.2	17059.5
TOTAL	**33231.1**	**27156.2**	**53863.5**	**56182.9**	**13090.2**	**30812.0**	**52059.5**	**50488.5**

As per the demographic information collected for villages in catchment area, around 40% of area in Rabi season is under wheat cultivation. The area under wheat cultivation varies from 36% in Dehra to 47% in Dhasan village. Gram is grown in around 38% of area cultivated in Rabi. The area covered under gram cultivation in the villages is in the range of 35-45%. Less than 20% area in Rabi season is under lintel cultivation. Lintel is grown more in Madia village which is around 25% of the total Rabi crop. The Kharif crops are mostly rain fed and there is no canal irrigation facility. The farmers make their own arrangements to irrigate the crops by pumping groundwater or surface water bodies, in order to save the crops during the dry spell period in Kharif season. The main crops grown in Kharif season are Soyabeen, Urad and Paddy and main crops grown in Rabi season are Wheat, Red Gram. Other staple crops like linseed, chickpeas, sorghum, oilseeds are also grown in the study area. Mostly wheat crops grown in the Rabi season are irrigated through the groundwater pumping, as there are limited surface water storage structures, like check dams, tanks, ponds, weirs etc.

4.6 Groundwater

The groundwater in the basin is exploited for irrigation to the largest sowing area of wheat crops in Rabi season, because there is no reservoir and canal water supply in the area. The surface water in the Bina River is generally available for the beginning of the Rabi season only till the end of December and farmers are dependent on the groundwater pumping from the private dug wells or tube wells. Few number of minor irrigation tanks are available is this basin to supply irrigation water in the Rabi season. During the summer months, almost all villages depend on the groundwater for their drinking and domestic purposes; however pond water is used for live stocks also. The groundwater table is about 5m to 25m below ground level and more than 50% area is under decline trend, the rainwater recharge in the basin reclaims the declining water table during the Rabi season. More water conservation measures are required to maintain the sustainable groundwater levels in the sub-basin (CGWB, 2013).

4.6.1 Ground Water Recharge

Downward movement of water into earth through a saturated zone by force of gravity or in any direction determined by hydraulic conditions is known as recharge. Groundwater recharge occurs naturally due to precipitation over the catchment and from the Bina River. Estimating groundwater recharge rate is a basic prerequisite of efficient groundwater resource management and it is vital in semi-arid regions where such resources are often the key to economic development.

Ground water recharge from monsoon and non-monsoon rainfall has been computed for non-command areas, since canal command does not exist in Bina river basin. For computations of recharge from monsoon rainfall both methods i.e., water level fluctuation method and rainfall infiltration factor method have been used. For comparison of figures obtained from these two methods, percent deviation is calculated and figures of recharge have been accepted as recommended in this methodology.

For computation of non-monsoon rainfall recharge, rainfall infiltration factor method is adopted when ratio of normal non-monsoon rainfall to normal annual rainfall is more than 10% as suggested in the methodology. CGWB, Bhopal has computed the Block wise total recharge into the groundwater for Madhya Pradesh. Area proportionate groundwater recharge for the Blocks falling in the study area has been computed based on the CGWB Report. The total groundwater recharge in Bina river basin is given at Table 4.4.

Table 4.4: Assessment of Dynamic Ground Water Resources of Bina Basin (Groundwater Recharge as on March, 2011)

S. No.	Assessment Unit District	Recharge from rainfall during monsoon season (ham)	Recharge from rainfall during non-monsoon season (ham)	Recharge from other sources during monsoon season (ham)	Recharge from other sources during non-monsoon season (ham)	Total Annual Groundwater Recharge (4+5+6+7) (ham)
1	Raisen District					
	Begumganj	6756	0	151	528	7435
	Gairatganj	4854	0	156	479	5489
2	Vidisha District					
	Gyaraspur	2884	0	79	313	3277
	Kurwai	4683	0	140	471	5294
	Tyonda	3555	0	88	334	3977
3	Sagar District					
	Bina	3478	0	90	426	3994
	Khurai	8559	0	267	991	9816
	Rahatgarh	4005	0	103	435	4543
	Total	30216	0	1074	3976	43825

4.6.2 Ground Water Draft

Block wise ground water draft for irrigation has been calculated based on the number of ground water structures and the unit draft of different types of structures. Number of ground water structures data was obtained from State Land Records, for the year 2006, 2007, 2008, 2009 and 2010 (Table 4.5). The unit draft of different ground water abstraction structures in each assessment unit for irrigation was determined in the field abstraction structures in each assessment unit for irrigation was determined in the field considering discharge of the well, pumping hours, number of running hours, days during monsoon and non monsoon seasons in command and non command area separately.

The unit draft is also validated with the delta factor of crop water requirement and irrigated area Dug wells and bore wells/tube wells are main structures, which requirement for irrigation in the State.

Table 4.5: Assessment of Dynamic Ground Water Resources of Bina Basin (Groundwater Draft as on March, 2011)

S. No	District/ Assessment Unit	Net Annual Groundwater Availability (ham)	Existing Gross Groundwater Draft for Irrigation (ham)	Existing Gross Groundwater Draft for Domestic & Industrial water Supply (ham)	Existing Gross Groundwater Draft for All uses (11+12) (ham)
1	Raisen				
	Begumganj	7063	2688	164	2852
	Gairatganj	5214	2208	151	2360
2	Vidisha				
	Gyaraspur	3113	1581	87	1668
	Kurwai	5030	2965	170	3135
	Tyonda	3778	1767	262	2030
3	Sagar				
	Bina	3795	2282	62	2344
	Khurai	9326	5575	144	5718
	Rahatgarh	4315	2448	105	2553
	Total	41634	21515	1146	22661

5.0 DATA USED AND ANALYSIS

5.1 Demand Sites and Catchments

Demand analysis in WEAP is a disaggregated, end-use based approach for modelling the requirements for water consumption in an Area. Using WEAP you can apply economic, demographic and water-use information to construct alternative scenarios that examine how total and disaggregated consumption of water evolve over time in all sectors of the economy. Demand analysis in WEAP is also the starting point for conducting integrated water planning analysis, since all Supply and Resource calculations in WEAP are driven by the levels of final demand calculated in the demand analysis.

WEAP provides a lot of flexibility in how you structure your data. These can range from highly disaggregated end-use oriented structures to highly aggregate analyses. Typically a structure would consist of sectors including households, industry and agriculture, each of which might be broken down into different subsectors end-uses and water-using devices. You can adapt the structure of the data to your purposes, based on the availability of data, the types of analyses you want to conduct, and your unit preferences. Note also that you can create different levels of disaggregation in each demand site and sector.

In each case, demand calculations are based on a disaggregated accounting for various measures of social and economic activity (number of households, hectares of irrigated agriculture, industrial and commercial value added, etc.). In the simplest cases, these activity levels are multiplied by the water use rates of each activity (water use per unit of activity). Each activity level and water use rate can be individually projected into the future using a variety of techniques, ranging from applying simple exponential growth rates and interpolation functions, to using sophisticated modelling techniques that take advantage of WEAP's powerful built-in modelling capabilities. More advanced approaches can incorporate hydrologic processes to determine demand (e.g. crop evapotranspiration calculations to determine irrigation requirements).

5.1.1 Population Demand

The collected census data from the MP Government Districts Statistical Handbook for human and Livestock were for the complete districts. But Since in Bina River Basin only some proportions of the districts fall, the population of each block has been considered same as the ratio of the geographical area. The WEAP consider water demand for the human population only. Therefore, the water demands for the livestock has been converted into equivalent population in order to include the water demand for cattles. Hence we derived the human population and cattle population accordingly (Fig. 5.1).

Total Population = human population + (70/25.55) * Livestock

Where,

Annual water use rate for Domestic Purposes = 25.55 m^3/Capita

Annual water use rate for Livestock = 70 m^3/Livestock

Table 5.1: Administrative Blocks wise population and live stock

S.No.	Block Name	District	Population	Live Stock	Equivalent Total Population
1	Bina	Sagar	75493	11557	107156
2	Khurai		59200	18215	109104
3	Rahatgarh		77430	35762	175408
4	Tyonda	Vidisha	32538	8683	56327
5	Kurwai		44631	7803	66009
6	Gyaraspur		37555	8258	60180
7	Begumganj	Raisen	69459	43537	188738
8	Gairatganj		60239	38092	164601

Also according to the World Population Prospects – 2010 Revision we have the following table:

Table 5.2: Medium Variant Population Growth Rate (%) for India

Period	2005-2010	2010-2015	2015-2020	2020-2025
Growth Rate (% per annum)	1.40	1.27	1.10	0.92

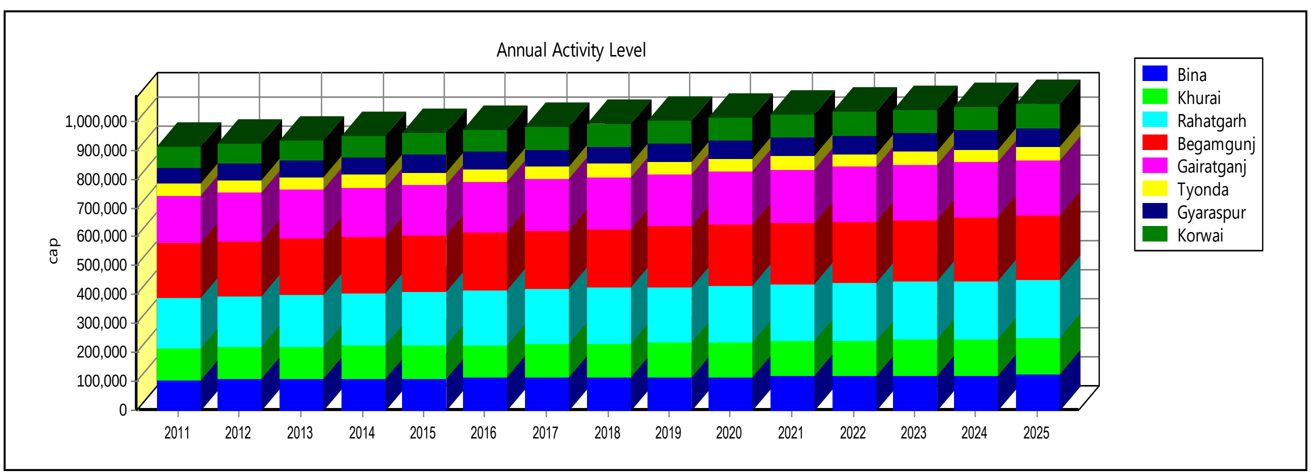

Fig 5.1: Population growth from 2011 to 2025 in all blocks

5.1.2 Crop Water Requirement

There is a choice among five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff and (2) Irrigation Demands Only versions of the Simplified Coefficient Approach, (3) the Soil Moisture Method, (4) the MABIA Method, and (5) the Plant Growth Method or PGM. You can click on the "Advanced" button at the top of the Data Entry window for a particular catchment to select among these options. The choice of method should depend on the level of complexity desired for representing the catchment processes and data availability.

For Irrigational Crop water requirement here we have used MABIA method in WEAP model. The MABIA Method is a per day simulation of transpiration, irrigation requirements, evaporation, crop growth and yields, and scheduling and includes modules for estimating soil water capacity and reference evapotranspiration. It was derived from the MABIA suite of software tools, developed at the Institute National Agronomies de Tunisia by Dr. Ali Sahli and Mohamed Jabloun. The algorithms and descriptions contained here are for the combined MABIA-WEAP calculation procedure.

The MABIA Method uses the 'dual' K_c method, as described in FAO Irrigation and Drainage Paper No. 56 (Spanish version of FAO 56), whereby the K_c value is divided into a 'basal' crop coefficient, K_{cb}, and a separate component, K_e, representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration. In this way, MABIA is an improvement over CROPWAT, which use a single Kc method, and hence, does not separate evaporation and transpiration. This method can be used to model both agricultural crops as wells as non-agricultural land classes, such as forests and grasslands.

Although the time step for MABIA is daily, the time step for the rest of your WEAP analysis does not need to be daily (although it can be daily). For each WEAP time step (e.g., monthly), MABIA would run for every day in that time step and aggregate its results (evaporation, transpiration, irrigation requirements, runoff, and infiltration) to that time step. For example, in January, MABIA would run from January 1 to 31, and sum up its results as January totals, including most importantly, the supply requirement for irrigation. WEAP would then solve its supply allocations, using this monthly irrigation requirement from the MABIA catchments. In the case where the supply delivered to the catchments was less than the requirement, MABIA would rerun its daily simulation, this time using only the reduced amount of irrigation to determine actual evaporation, transpiration, irrigation requirements, runoff, and infiltration.

The steps in the MABIA calculations are as follows:

- Reference Evapotranspiration (ET_{ref})
- Basal Crop Coefficient (K_{cb})
- Evaporation Coefficient (K_e)
- Potential and Actual Crop Evapotranspiration (ET_c)
- Soil Water Capacity
- Water Balance of the Root Zone
- Irrigation
- Yield

5.1.3 Agricultural Land Cover

The Block wise area under major crops grown in Bina river basin have been collected from the district H.Q. for the eight blocks falling in the study area and for each and every block agricultural areas have been assigned in the WEAP model along with Crops and the percentage of land area covered by each and every crop.

The block wise area under major crops sown during the Kharif and Rabi season is given in the Table 5.3.

Table 5.3: Distribution of Crops in Bina River Basin

District	**Sagar**			**Vidisha**			**Raisen**	
Tehsil	**Rahatgarh**	**Bina**	**Khurai**	**Kurwai**	**Tyonda**	**Gyaraspur**	**Begamgunj**	**Gairatganj**
Wheat	10962.3	8292.1	14995.8	20253.7	4538.7	11197.9	14465.7	14565.5
Rice/Grain	44.5	61.0	224.0	42.4	14.3	158.1	114.2	194.0
Sorghum	18.8	48.8	32.4	10.8	7.3	2.7	86.5	24.8
Maize	65.6	129.5	147.2	106.4	24.4	77.7	281.0	195.1
Chickpeas	5034.8	5419.1	15478.7	8584.4	2104.2	4256.7	10486.9	13939.7
Pigeonpeas	168.1	6.3	81.1	12.2	16.9	11.0	18.5	64.8
Blackgram	566.5	3566.7	3957.7	6819.5	1454.8	1371.9	7073.8	4399.2
Sugarcane	0.4	0.0	4.4	0.9	0.3	0.0	0.6	2.8
Sesame	4.2	7.8	1.2	2.8	0.8	1.8	5.6	1.1
Linseed	47.6	0.0	0.0	0.0	0.0	3.4	0.0	0.0
Groundnut	16.1	0.0	7.5	10.4	0.3	6.1	0.0	6.8
Musturd	33.8	25.0	38.7	26.4	3.7	9.4	48.2	35.0
Soyabean	16267.7	9599.7	18894.8	20313.0	4924.3	13715.3	19478.2	17059.5
TOTAL	**33230.5**	**27156.2**	**53863.5**	**56182.9**	**13090.0**	**30812.0**	**52059.1**	**50488.3**

5.1.4 Monthly Rainfall Data:

Eff. rain method: USDA Soil Conservation Service formula:

$P_{eff} = P_{mon} * (125 - 0.2 * P_{mon}) / 125$ for $P_{mon} <= 250$ mm

$P_{eff} = 125 + 0.1 * P_{mon}$ for $P_{mon} > 250$ mm

Table 5.4: Monthly Rainfall and Eff. Rainfall

Month	Rainfall (mm)	Eff. Rainfall (mm)
January	21.0	20.3
February	15.0	14.6
March	10	9.8
April	2.0	2.0
May	7.0	6.9
June	136.0	106.4
July	334.0	158.4
August	447.0	169.7
September	174.0	125.6
October	38.0	35.7
November	19.0	18.4
December	15.0	14.6
Total	1218.0	682.5

5.1.5 Climate Data

CLIMWAT 2.0 offers observed agroclimatic data of over 5000 worldwide stations distributed as shown below.

CLIMWAT provides long-term monthly mean values of seven climatic parameters, namely:

• Mean daily maximum temperature in °C

• Mean daily minimum temperature in °C

• Mean relative humidity in %

• Mean wind speed in km/day

• Mean sunshine hours per day

• Mean solar radiation in $MJ/m^2/day$

• Monthly rainfall in mm/month

• Monthly effective rainfall in mm/month

• Reference evapotranspiration calculated with the Penman-Monteith method in mm/day.

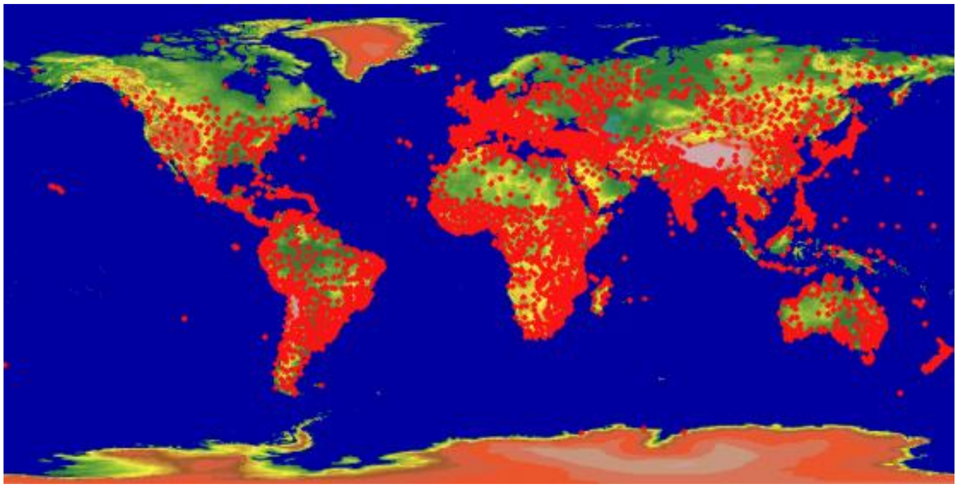

Fig. 5.2: Location of stations included in CLIMWAT 2.0.

(http://www.fao.org/landandwater/aglw/climwat.stm)

Table 5.5: Derived Climatic data from CLIMWAT 2.0 (extracted in XPS doc format)

Country: Location 141 Station: SAGAR
Altitude: 551 m. Latitude: 23.85 °N Longitude: 78.75 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	11.2	24.5	41	147	7.5	15.0	3.36
February	13.0	26.7	37	147	8.6	18.2	4.04
March	18.3	32.2	27	147	8.8	20.8	5.29
April	23.3	37.8	21	147	9.3	23.3	6.55
May	26.3	40.6	19	164	9.5	24.2	7.62
June	25.4	37.2	44	190	7.2	20.8	6.82
July	23.2	30.2	77	190	4.5	16.7	4.23
August	22.5	28.6	85	164	4.3	15.9	3.50
September	22.1	30.4	69	147	6.2	17.5	4.19
October	20.2	31.6	50	121	8.3	18.4	4.41
November	16.0	28.7	43	121	8.4	16.4	3.74
December	12.5	25.1	46	121	7.8	14.6	3.05
Average	19.5	31.1	46	151	7.5	18.5	4.73

Note: Monthly ETo has been derived from Penman-Monteith method

5.1.6 Industrial Demand

There are two industries in the Bina River Basin, considering both utilises an amount of almost 50,000 Litres of water per day.

- Bina Oil Refinery
- Bina Railway station

5.2 Supply and Resources

Given the monthly supply requirement established from the definitions of the system demand, and the definitions of Hydrology, the Supply and Resources section determines the amounts, availability and allocation of supplies, simulates monthly river flows, including surface/groundwater interactions and instream flow requirements, hydropower generation, and tracks reservoir and groundwater storage.

Supply and Resources include the following subsections:

- **Transmission Links**: transmission links carry water from local and river supplies to demand sites, subject to losses and physical capacity, contractual and other constraints.
- **Rivers and Diversions**: surface inflows to rivers, properties and operation of reservoirs and run-of-river hydropower facilities, instream flow requirements, surface water-groundwater interaction, and streamflow gauges.
- **Groundwater**: aquifer properties, storage and natural recharge..
- **Local Reservoirs**: reservoirs not on a river.
- **Other Supplies**: e.g., surface sources that are not modelled in your WEAP application, such as inter-basin transfers or desalination.
- **Return Flows**: wastewater from demand sites can be routed to one or more wastewater treatment plants, rivers, groundwater nodes or other supply sources; treated effluent from wastewater treatment plants can be routed to one or more rivers, groundwater nodes or other supply sources.

5.2.1 River and Tributaries

An important aspect of modelling a water system understands how it operates under a variety of hydrologic conditions. Natural variations in hydrology -- month to month and year to year -- can have major effects on the results of your scenarios.

WEAP has four methods for projecting the surface water hydrology over the study period: Water Year Method, Expressions, Catchments Runoff and Infiltration and Read from File Method. These methods may be used to project the inflow to every surface and groundwater inflow point in the system for every month in the study period. This includes river and tributary head flows, surface water inflows to river reaches, groundwater, local reservoir another supply inflow.

Table 5.6: Headflow of drainages (Year 2011)

Rivers	Area (Sq.Km)	Jul	Aug	Sep	Oct	Nov	Dec
Bina_1	350.85	5.287	14.493	3.612	4.657	2.977	1.298
Kahula Nala	167.96	10.27	28.15	10.016	9.046	5.476	2.388
Bina_2	145.2	6.332	17.356	6.326	5.577	3.566	1.555
Semri Nadi	198.74	5.083	13.932	3.472	4.477	2.862	1.248
Dudhi Nadi	184.25	2.236	6.13	2.528	1.97	1.259	0.549
Bina_3	75.38	9.724	26.653	6.643	8.565	5.476	2.388
Bina_4	213.42	5.332	14.614	3.642	4.696	3.002	1.309
Babnai_1	327.74	4.308	11.808	4.943	3.794	2.426	1.058
Babnai_2	179.7	10.41	28.532	10.11	9.168	5.862	2.556
Bagnarra	171.32	4.983	13.659	3.404	4.389	2.806	1.224
Masamya	77.58	5.897	16.162	4.028	5.194	3.32	1.448
Bina_5	346.15	5.467	14.984	3.734	4.815	3.078	1.342
Silar	178.21	4.366	9.966	4.382	3.844	2.459	1.072
Bina_6	122	79.695	216.439	66.84	70.192	44.569	19.435
Bina_7	33.98	5.287	14.493	3.612	4.657	2.977	1.298
Renti Nadi	35.59	10.27	28.15	10.016	9.046	5.476	2.388
Total	2808.07	6.332	17.356	6.326	5.577	3.566	1.555

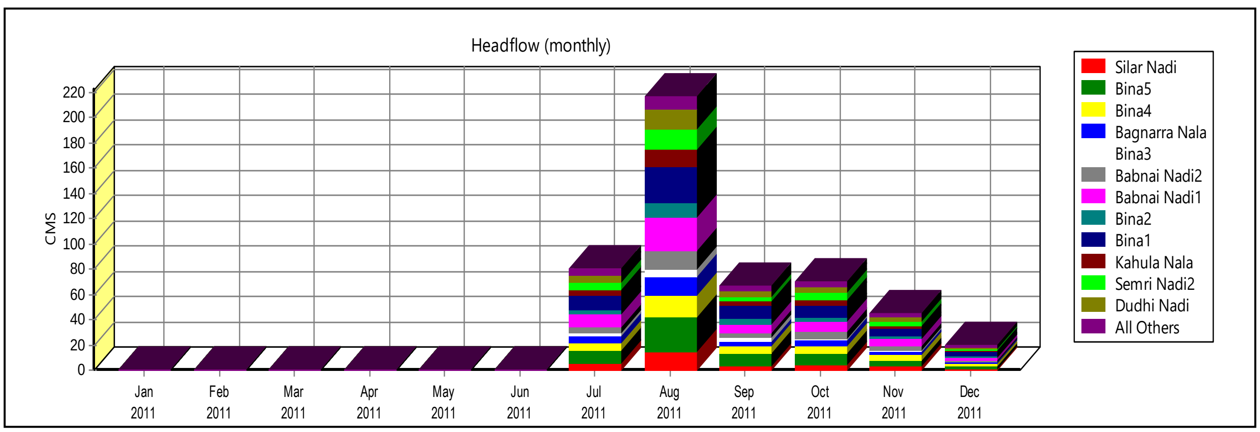

Fig. 5.3: Headflow of Each River (Blockwise)

5.2.2 Ground Water Storage Capacity

The Storage Capacity represents the maximum theoretically accessible capacity of the aquifer, while the Initial Storage is the amount of water initially stored there at the beginning of the first month of the Current Accounts Year. Among other factors, these data will depend on pump depths. The Storage Capacity was left blank to model unlimited capacity. WEAP maintains a mass balance of monthly inflows and outflows in order to track the monthly groundwater storage volume. WEAP does not allow the storage volume to exceed the storage capacity (any excess will overflow, and be lost from the system).

Table 5.7: Natural Recharge (monthly) (Million m^3)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
GW1	0.85	0.85	0.85	0.00	0.00	6.37	9.46	10.16	7.52	2.14	0.85	0.85
GW2	0.61	0.61	0.61	0.00	0.00	5.55	8.26	8.85	6.55	1.86	0.61	0.61
GW3	0.80	0.80	0.80	0.00	0.00	6.34	9.43	10.11	7.48	2.13	0.80	0.80
GW4	0.39	0.39	0.39	0.00	0.00	3.80	5.65	6.06	4.48	1.27	0.39	0.39
GW5	1.41	1.41	1.41	0.00	0.00	9.88	14.71	15.76	11.66	3.32	1.41	1.41
GW6	0.63	0.63	0.63	0.00	0.00	5.29	7.88	8.44	6.25	1.78	0.63	0.63
GW7	1.06	1.06	1.06	0.00	0.00	1.23	1.84	1.97	1.46	0.41	1.06	1.06
GW8	1.16	1.16	1.16	0.00	0.00	8.95	13.32	14.27	10.56	3.00	1.16	1.16
Sum	6.91	6.91	6.91	0.00	0.00	47.41	70.55	75.62	55.96	15.91	6.91	6.91

(Source: CGWB, 2013)

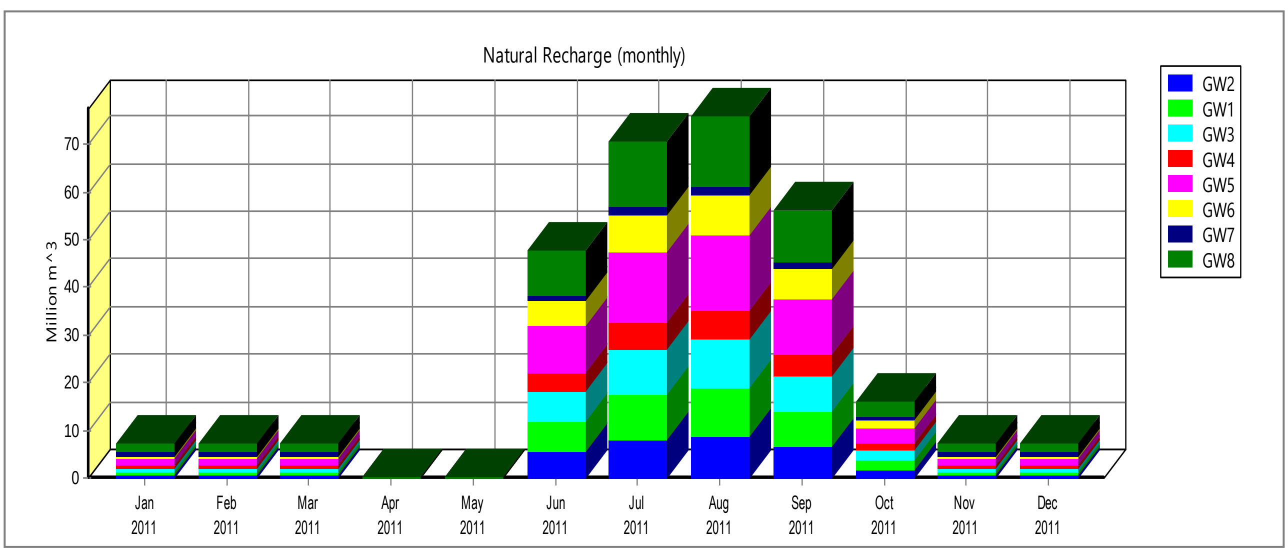

Fig. 5.4: Natural Recharge (monthly) (MCM)

Table 5.8: Maximum Withdrawal (monthly) (Million m^3)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GW1	4.62	4.62	2.33	2.33	0.05	0.05	0.05	0.05	0.05	2.33	2.33	4.62
GW2	3.91	3.91	2.00	2.00	0.09	0.09	0.09	0.09	0.09	2.00	2.00	3.91
GW3	4.53	4.53	2.29	0.05	0.05	0.05	0.05	0.05	0.05	2.29	2.29	4.53
GW4	2.19	2.19	1.16	1.16	0.13	0.13	0.13	0.13	0.13	1.16	1.16	2.19
GW5	6.71	6.71	3.42	3.42	0.12	0.12	0.12	0.12	0.12	3.42	3.42	6.71
GW6	3.23	3.23	1.65	1.65	0.07	0.07	0.07	0.07	0.07	1.65	1.65	3.23
GW7	5.51	5.51	2.82	2.82	0.14	0.14	0.14	0.14	0.14	2.82	2.82	5.51
GW8	4.54	4.54	2.33	2.33	0.13	0.13	0.13	0.13	0.13	2.33	2.33	4.54
Sum	35.24	35.24	18.00	15.76	0.78	0.78	0.78	0.78	0.78	18.00	18.00	35.24

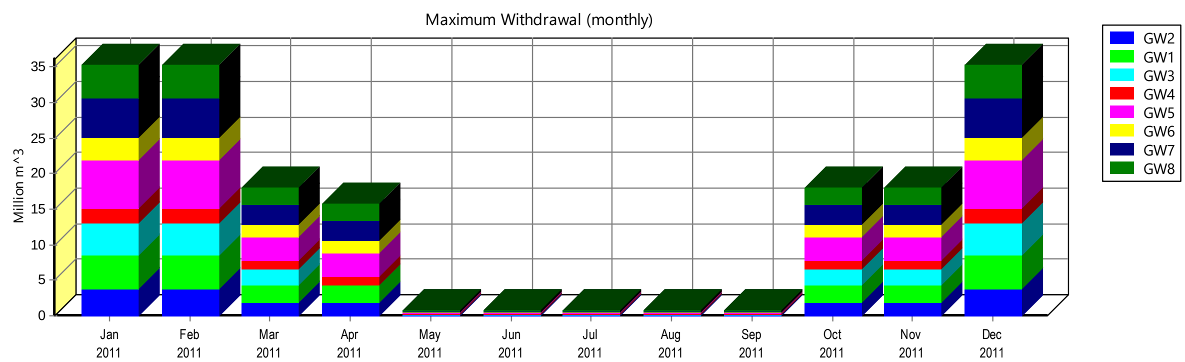

Fig. 5.5: Maximum Withdrawal (monthly) (MCM)

5.2.3 Local Reservoirs Storage Capacity

Similar to the Ground Water Storage Capacity, the Local Reservoir Storage Capacity also represents the maximum theoretically accessible capacity of the reservoirs, the Storage Capacity was left blank in the model for the current scenario because it is introduced later as the water demand comes to be higher.

6.0 RESULTS

As per the suggested methodology, the required data was fed into data view of the model and results for the 'Current accounts year (2011)' were calculated. The values for annual water use rate, population, and supply capacity of the sources were input; and WEAP thus gave the results for Total Water Demand, Available Supply and Unmet Demand of the watershed. Water Demand here is the total amount of water that is required in the region for use of various domestic and industrial purposes. The Bina sub-basin has a major agricultural area and the irrigation demands are complex, therefore these demands have been computed separately. Unmet Demands are the unsatisfied water demands that require great concern and alternatives to cope up with them. The database available on human population, live stocks, agricultural area under different crops, irrigation supply from surface water and groundwater, etc. for the study pertains to the year 2011, therefore this year has been chosen as the base year or 'Current accounts year' to compare the future years with different scenarios with interventions, such as population growth, decrease or increase in rainfall/runoff, etc.

Fig. 6.1 Detailed view of WEAP area including administrative blocks and demand fields

The table 6.1 describes the information on demands and supply represented by the links and nodes given in the Fig. 6.1.

Table 6.1: Demand Sites And Their Supply Sources

S.no	Demand Sites	Supply Preference	Supply Source
1	Bina	1 2 3	Bina6 GW1 Madia Reservoir
2	Khurai	1 2	Bina5 GW3 Madia Reservoir
3	Rahatgarh	1 2 3	Bina3 GW5 Madia Reservoir
4	Tyonda	1 2	Babanai, Nadi2 GW4
5	Kurwai	1 2	Bina5, GW2, Madia Reservoir
6	Gyaraspur	1 2	Babanai, Nadi1 GW6
7	Begumganj	1 2	Bina2 GW7
8	Gairatganj	1 2	Bina1 GW8
9	C1	1 2 3	Bina6 GW1 Madia Reservoir
10	C2	1 2	Bina5 GW2
11	C3	1 2	Bina5, GW3 Madia Reservoir
12	C4	1 2	Babnai, Nadi2 GW4
13	C5	1 2 3	Bina3 GW5 Madia Reservoir
14	C6	1 2	Babnai, Nadi1 GW6
15	C7	1 2	Bina2 GW7
16	C8	1 2	Bina1 GW8

6.1 Results as Per the Reference Scenario

The WEAP setup has been run for the results after assigning supply and demands through links and nodes for each blocks falling in the study area. After inserting the data to the WEAP model, the RESULT View of the model shows the output information both in graphs and Tables. The output obtained from the WEAP model have been shown at the following graphs from Fig. 6.2 to Fig. 6.6 and the results are also given at Table 6.2 to Table 6.6 respectively.

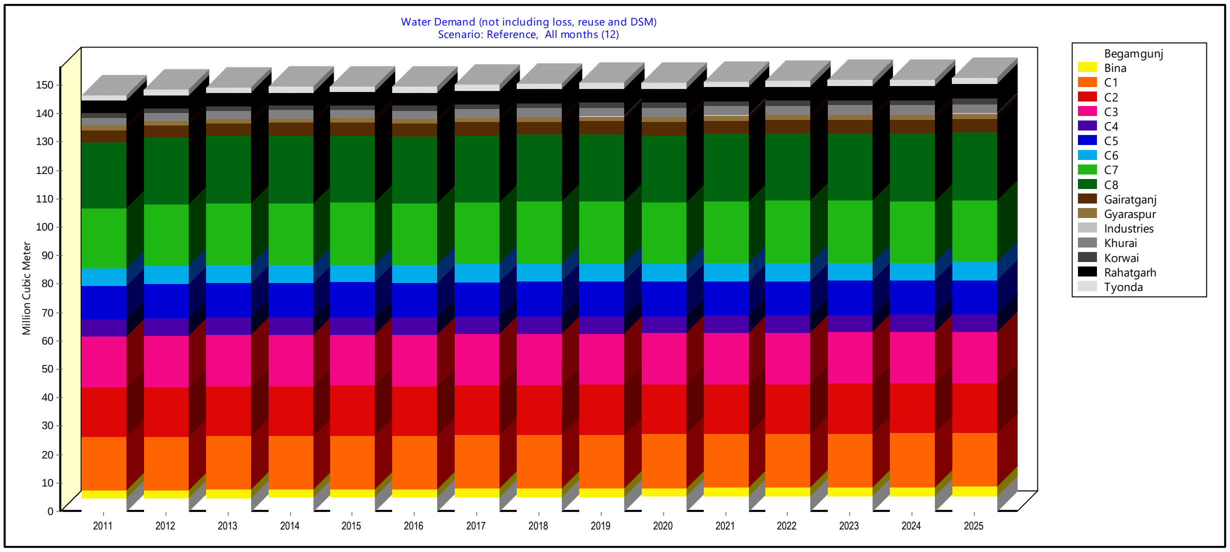

Fig.6.2: Water demands (Excluding losses and reuse) in all Administrative Blocks, Catchments and Industries in the year 2011

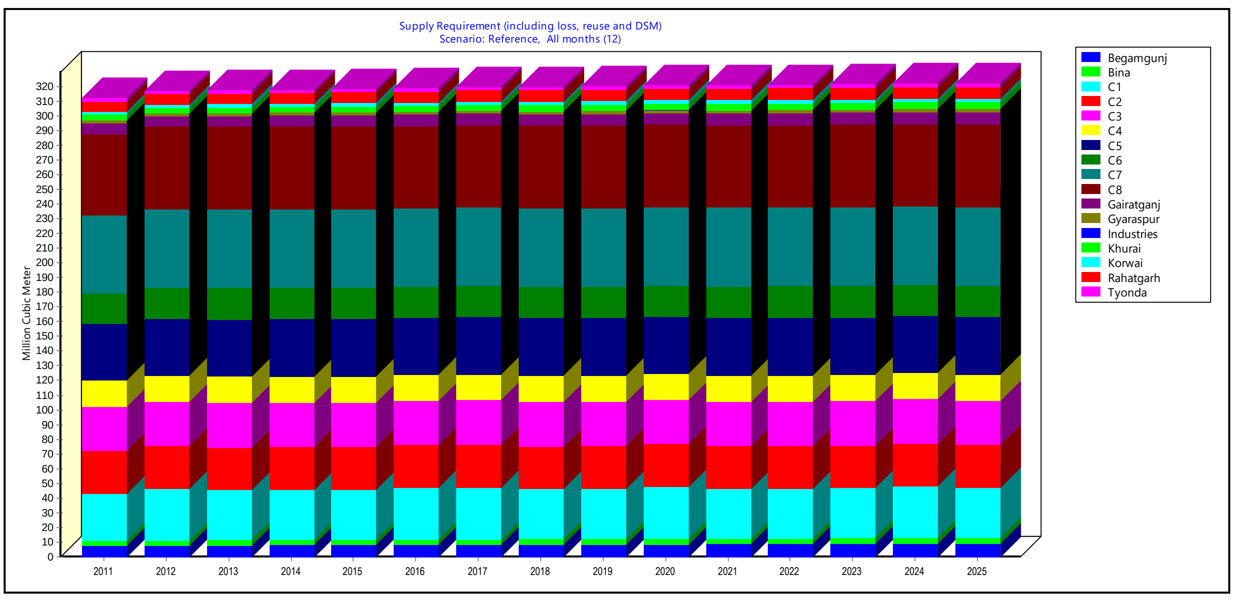

Fig. 6.3: Supply Requirement (including losses and reuse) in all Administrative Blocks, Catchments and Industries in the year 2011

Table 6.2: Water Demands (Excluding losses and reuse) in MCM

Demand sites	2011	2015	2020	2025
Begamgunj	4.823	5.038	5.322	5.621
Bina	2.738	2.860	3.021	3.191
Gairatganj	4.206	4.394	4.641	4.902
Gyaraspur	1.537	1.606	1.697	1.792
Khurai	2.787	2.912	3.075	3.248
Korwai	1.686	1.762	1.861	1.965
Rahatgarh	4.481	4.682	4.945	5.223
Tyonda	1.439	1.504	1.588	1.678
C1	19.185	20.295	21.071	20.303
C2	17.425	17.474	17.469	17.474
C3	17.842	18.063	18.068	18.063
C4	13.890	13.945	13.849	13.945
C5	30.852	31.077	30.908	31.075
C6	16.935	17.224	17.124	17.225
C7	38.825	39.121	38.874	39.120
C8	40.110	40.540	40.341	40.538
Sum	**218.760**	**222.496**	**223.853**	**225.361**

Table 6.3: Supply Requirement (including losses and reuse) in MCM

Demand sites	2011	2015	2020	2025
Begamgunj	4.823	5.038	5.322	5.621
Bina	2.738	2.860	3.021	3.191
Gairatganj	4.206	4.394	4.641	4.902
Gyaraspur	1.537	1.606	1.697	1.792
Industries	0.018	0.032	0.051	0.069
Khurai	2.787	2.912	3.075	3.248
Korwai	1.686	1.762	1.861	1.965
Rahatgarh	4.481	4.682	4.945	5.223
Tyonda	1.439	1.504	1.588	1.678
C1	31.975	33.825	35.119	33.838
C2	29.042	29.123	29.115	29.123
C3	29.736	30.105	30.113	30.106
C4	17.893	17.984	17.867	17.984
C5	38.716	39.092	38.910	39.087
C6	20.923	21.405	21.296	21.406
C7	52.874	53.367	53.050	53.365
C8	55.531	56.248	56.005	56.245
Sum	**300.405**	**305.938**	**307.675**	**308.843**

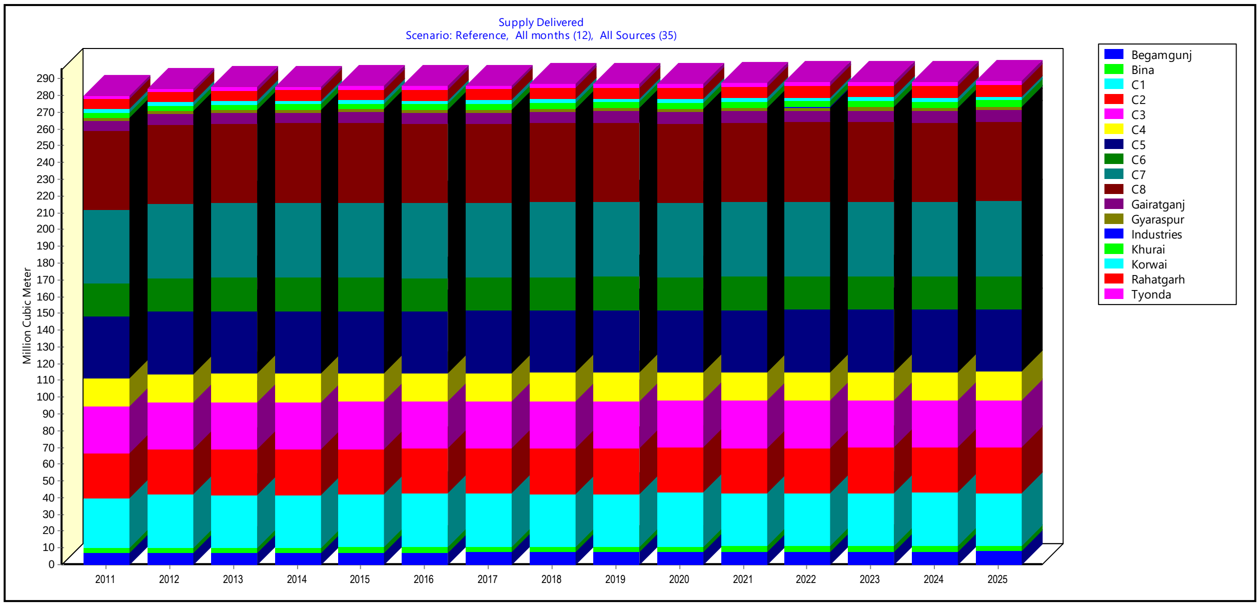

Fig. 6.4: Supply Delivered in all Administrative Blocks, Catchments and Industries in the year 2011

Table 6.4: Supply Delivered (in MCM)

	2011	2015	2020	2025
Begamgunj	7.011	7.358	7.753	8.102
Bina	2.942	3.083	3.242	3.410
Gairatganj	6.125	6.429	6.776	7.081
Gyaraspur	1.722	1.804	1.897	1.979
Industries	0.018	0.032	0.046	0.061
Khurai	3.216	3.376	3.558	3.719
Korwai	2.018	2.110	2.214	2.306
Rahatgarh	6.031	6.331	6.672	6.972
Tyonda	1.439	1.514	1.597	1.661
C1	29.824	31.681	32.366	31.640
C2	27.041	27.110	26.775	27.085
C3	27.970	28.298	28.026	28.280
C4	16.865	16.942	16.664	16.922
C5	36.853	37.183	37.143	37.072
C6	19.511	19.983	19.674	19.967
C7	44.423	44.898	44.777	44.856
C8	46.604	47.301	47.265	47.255
Sum	**279.616**	**285.432**	**286.444**	**288.369**

In Table 6.2, the Annual Variation of Water demands (Excluding losses and reuse) in all Administrative Blocks, Catchments and Industries is calibrated which shows that there is slight increase in the water demand from the year 2011 to 2025 which is from 218.760 MCM to 225.361 MCM. So if the conditions remain normal and the climatic conditions are similar for all the future year the increase in the water demand will be 6.601 MCM due to normal population growth in 14 years ignoring all the losses and reuse. Table 6.3 shows the Annual variations of the Water Demands including losses and reuse.

Table 6.4 shows the Annual Variation in Supply Delivered in all Administrative Blocks, Catchments and Industries in the year 2011, 2015, 2020 & 2025, in which supply from the Bina River and its tributaries play a major role along with the Ground water storage. Since all the conditions and sources are kept similar for all the years from 2011 to 2025, only slight changes is observed due to increase in the ground water storage. The supply delivered increases from 279.616 MCM in the year 2011 to 288.369 MCM in the year 2025.

The unmet water demand may be taken as difference between the Supply Requirement (including losses and reuse) of all sites and the supply delivered. The annual unmet water demands for all administrative blocks and catchment sites have been worked out through WEAP modelling under the Reference Scenarios from the year 2011 to 2015. The Annual Variation in Unmet Demands for the year 2011, 2015, 2020 and 2025 for all administrative Blocks and for the Catchments have been shown in Fig.6.5 and Fig.6.6 respectively.

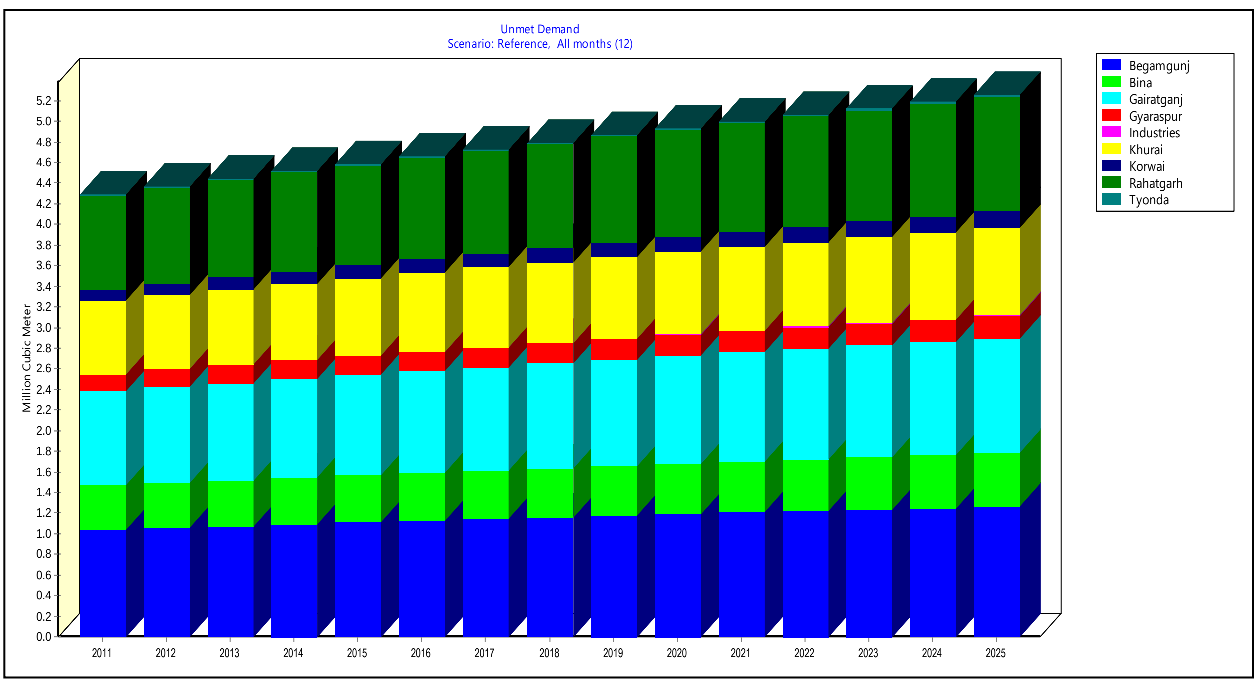

Fig. 6.5: Annual Variation of Unmet Water Demands in all Administrative Blocks

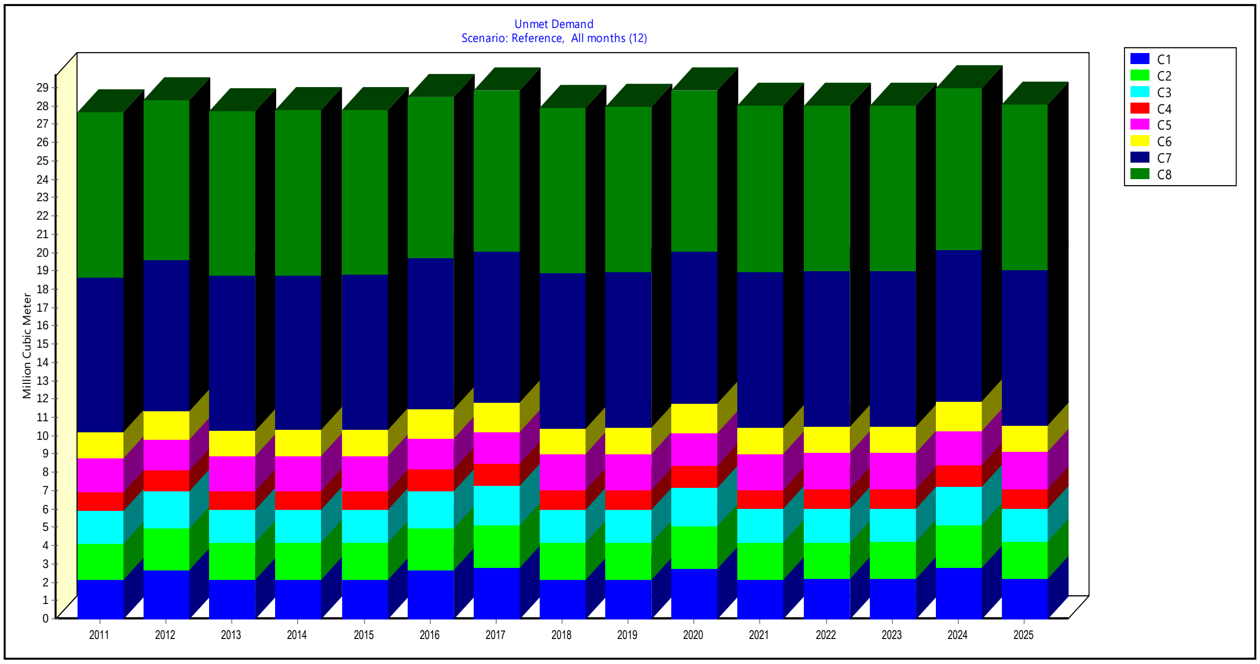

Fig. 6.6: Annual Variation Unmet Water Demands in all Catchments

Table 6.5: Unmet Water Demands (all Administrative Blocks)

Demand Site	2011	2015	2020	2025
Begamgunj	1.044	1.114	1.196	1.266
Bina	0.428	0.456	0.488	0.522
Gairatganj	0.915	0.976	1.045	1.106
Gyaraspur	0.168	0.184	0.203	0.220
Industries	0.000	0.000	0.004	0.008
Khurai	0.712	0.756	0.805	0.849
Korwai	0.105	0.123	0.144	0.163
Rahatgarh	0.914	0.973	1.043	1.104
Tyonda	0.000	0.000	0.002	0.013
Sum	**4.285**	**4.582**	**4.931**	**5.250**

Table 6.5 shows the unmet demand of all Administrative Blocks, including domestic and other demands of population and livestock. The Unmet Water Demands in all Administrative Blocks for the year 2011-2025 have been calibrated which comes to be 4.285 MCM in 2011 and 5.250 MCM in 2025. The increase in the unmet water demand from year 2011 to 2025 is due to increase in population. The difference between the water demand in the year 2025 and 2011 comes to be 965 Thousand Cubic Meters. The following Table 6.6 shows the Unmet Water Demands in all Catchments including crop water requirements. There is also a slight variation in unmet demands between the year 2011 and 2025.

Table 6.6: Unmet Water Demands (all Catchments)

Demand Site	2011	2015	2020	2025
C1	2.150	2.162	2.771	2.189
C2	2.001	2.012	2.340	2.037
C3	1.766	1.806	2.086	1.825
C4	1.028	1.041	1.203	1.061
C5	1.863	1.912	1.770	2.019
C6	1.412	1.420	1.621	1.438
C7	8.450	8.470	8.273	8.510
C8	8.927	8.947	8.741	8.990
Sum	27.596	27.771	28.805	28.068

6.2 Results as Per the Future Scenario

6.2.1 Results for Scenario I: High Population Growth

Since reference scenario is the scenario that is generated to calculate future possibilities by keeping every aspect of future similar to that of 'Current accounts year'. Here, population growth rate is kept as per the Medium Variant Population Growth Rate for every five year block periods for India, given at Table 5.2. If we consider the High Variant population growth rate of 1.50 % per annum for the future years, i.e. from 2011 to 2025, a significant variation in water demands have been observed (Table 6.7).

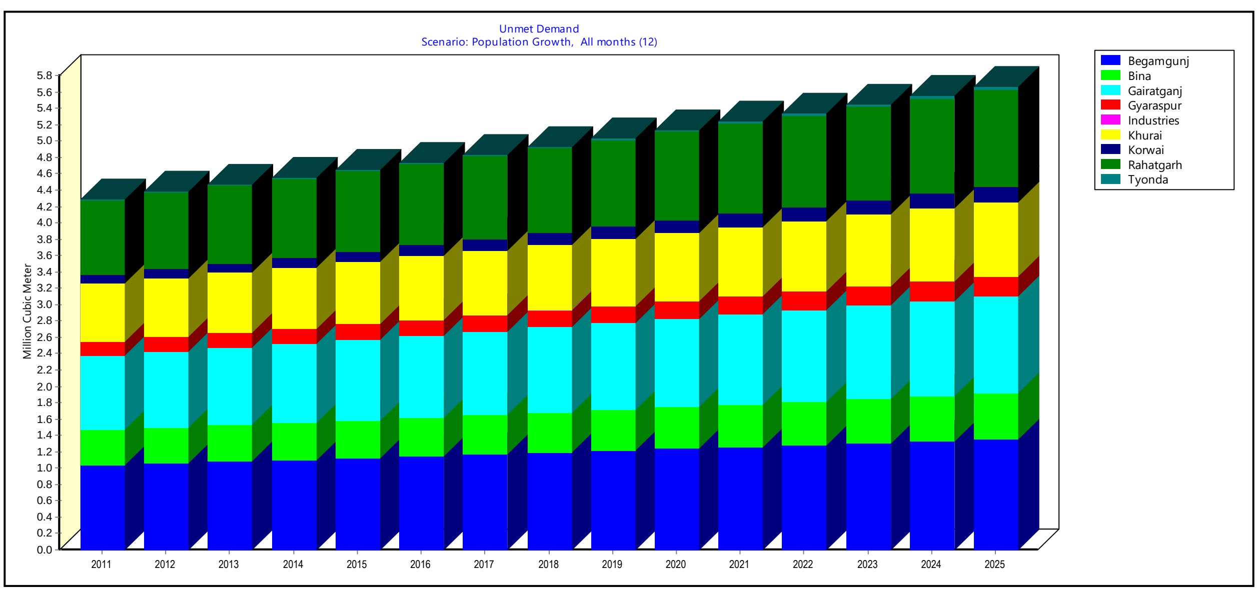

Fig. 6.7: Unmet water demands with High population growth rate (1.50%) scenario

Table 6.7: Unmet water demands with High population growth rate (1.50%) scenario

Demand Site	2011	2015	2020	2025
Begamgunj	1.044	1.127	1.240	1.359
Bina	0.428	0.463	0.509	0.559
Gairatganj	0.915	0.987	1.083	1.187
Gyaraspur	0.168	0.188	0.213	0.241
Industries	0.000	0.000	0.005	0.008
Khurai	0.712	0.764	0.833	0.907
Korwai	0.105	0.127	0.156	0.187
Rahatgarh	0.914	0.984	1.081	1.184
Tyonda	0.000	0.000	0.008	0.029
Sum	4.285	4.638	5.128	5.661

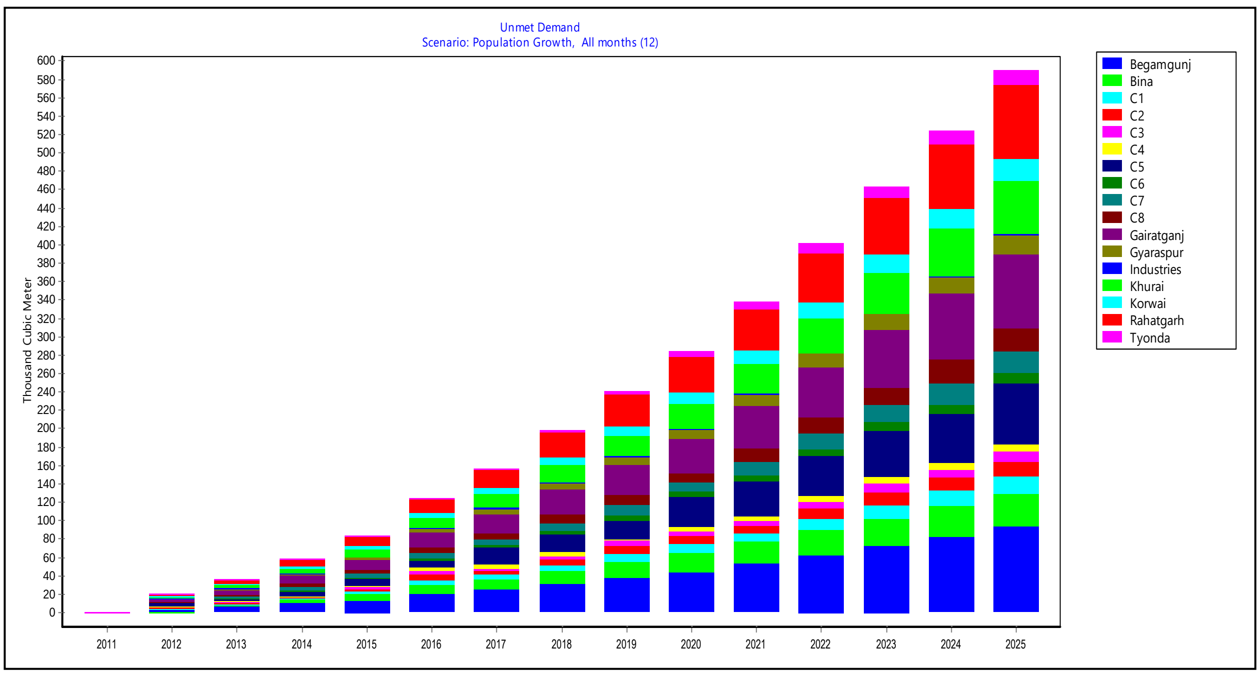

Fig. 6.8: Comparison between Unmet water demands, Annual variation (2011-2025) with Reference scenario and High population growth rate scenario

The unmet water demand in all administrative blocks and all catchments have been given at Table 6.7. The WEAP model suggested through the results that in High Population Growth Rate scenario, the total unmet demands are expected to increase up to 3.510 Million Cubic Meters in the year 2025 as compared to the reference scenario.

Table 6.8: Difference between Unmet Water Demands with Reference scenario and High Population Growth Rate scenario

Demand Site	**2011**	**2012**	**2015**	**2020**	**2025**
C1	0.000	0.003	0.010	0.018	0.111
C2	0.000	0.003	0.008	0.017	0.103
C3	0.000	0.002	0.006	0.011	0.070
C4	0.000	0.002	0.004	0.007	0.054
C5	0.000	0.008	0.033	0.067	0.370
C6	0.000	0.002	0.005	0.012	0.068
C7	0.000	0.004	0.010	0.023	0.149
C8	0.000	0.004	0.010	0.024	0.155
Begamgunj	0.000	0.013	0.044	0.093	0.548
Bina	0.000	0.006	0.021	0.037	0.234
Gairatganj	0.000	0.011	0.038	0.081	0.478
Gyaraspur	0.000	0.003	0.010	0.022	0.128
Industries	0.000	0.000	0.001	0.000	0.004
Khurai	0.000	0.008	0.027	0.058	0.341
Korwai	0.000	0.003	0.012	0.024	0.144
Rahatgarh	0.000	0.011	0.039	0.080	0.475
Tyonda	0.000	0.000	0.006	0.017	0.075
Sum	**0.000**	**0.082**	**0.283**	**0.589**	**3.510**

High Population Growth Rate: The population growth rate was increased to 1.50% per annum to see the change in unmet demands that would happen to the existing unmet demands in 2025. There has been an increase in the population growth rate of the watershed in 2011 than it was in 2001 (as per census 2011). A maximum of 5.661 million cubic meters is expected to be the unmet demand in 2025, which is 3.510 MCMs more than the unmet demand in Reference Scenario, as given at Table 6.8.

6.2 **Results for Scenario II:** Ground Water Recharge (Rain Water Harvesting)

It is the scenario, which considers 10% increase in the total volume of groundwater recharge by all means, i.e. rainwater harvesting structures in the watershed and check dams on the streams. The cumulative effect of increase in groundwater recharge will be rise in groundwater table and increase in the groundwater storage. In order to maintain the groundwater table at an acceptable level, we have to increase the groundwater draft, to maintain the equilibrium between the recharge and draft. Therefore, 10% increase in groundwater draft has been assumed. The WEAP suggest through the results that in this scenario, the unmet demands are expected to be almost NIL by the year 2025. In other words, all the water demands shall be met by 2025, if groundwater recharge and draft is increased by 10% every year.

Table 6.9 and Fig. 6.9 show the difference between the supply delivered with 10% annual increase in the groundwater recharge as well as in the groundwater draft and in the reference scenario. The difference is zero in the reference year, i.e. 2011 and +31.513 in the year 2025, which indicates the increase in groundwater supply.

Table 6.9: Supply Delivered: Comparison between Reference Scenario and Ground Water Recharge Scenario

Demand Site	2011	2015	2020	2025
C1	0.000	2.127	2.749	2.828
C2	0.000	1.988	2.337	2.034
C3	0.000	1.736	2.011	1.747
C4	0.000	1.039	1.193	1.051
C5	0.000	1.744	1.608	1.855
C6	0.000	1.374	1.582	1.427
C7	0.000	1.549	4.530	8.363
C8	0.000	1.643	4.801	8.851
Begamgunj	0.000	0.137	0.410	0.850
Bina	0.000	0.063	0.166	0.327
Gairatganj	0.000	0.122	0.356	0.733
Gyaraspur	0.000	0.069	0.199	0.220
Industries	0.000	-0.004	0.004	0.005
Khurai	0.000	0.060	0.174	0.359
Korwai	0.000	0.116	0.144	0.163
Rahatgarh	0.000	0.112	0.334	0.687
Tyonda	0.000	0.000	0.002	0.013
Sum	**0.000**	**13.874**	**22.600**	**31.513**

Table 6.10 and Fig. 6.10 show the comparison of Unmet Demands between the reference scenario and the ground water recharge scenario. The Unmet Demands are expected to reduces from 31.881 MCM in the year 2011 to 2.295 MCM in the year 2025.

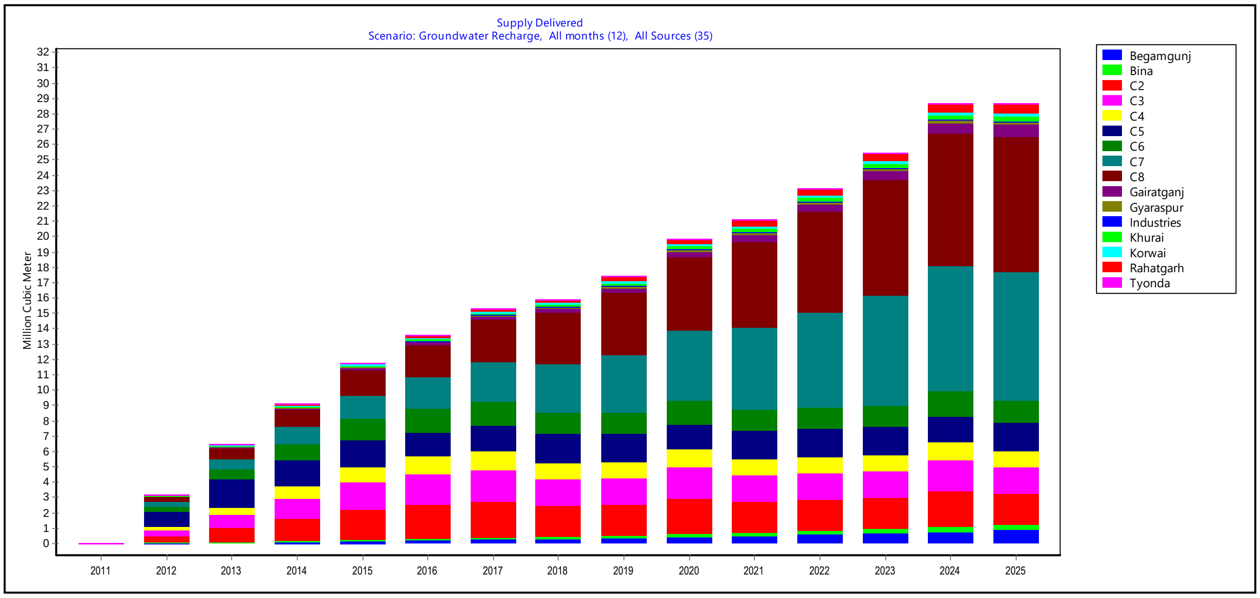

**Fig. 6.9: Supply Delivered, Annual Variation (2011-2025)
With 10% Growth Rate in Ground Water Recharge**

Table 6.10: Unmet Water Demands: With 10% Ground Water Recharge Rate Scenario

Demand Site	**2011**	**2015**	**2020**	**2025**
C1	2.150	0.046	0.035	0.032
C2	2.001	0.022	0.000	0.000
C3	1.766	0.060	0.059	0.060
C4	1.028	0.000	0.000	0.000
C5	1.863	0.076	0.070	0.076
C6	1.412	0.032	0.029	0.000
C7	8.450	6.920	3.740	0.130
C8	8.927	7.303	3.936	0.102
Begamgunj	1.044	0.977	0.786	0.416
Bina	0.428	0.393	0.322	0.195
Gairatganj	0.915	0.854	0.689	0.373
Gyaraspur	0.168	0.116	0.004	0.000
Industries	0.000	0.004	0.000	0.003
Khurai	0.712	0.696	0.631	0.490
Korwai	0.105	0.007	0.000	0.000
Rahatgarh	0.914	0.861	0.708	0.417
Tyonda	0.000	0.000	0.000	0.000
Sum	31.881	18.367	11.009	2.295

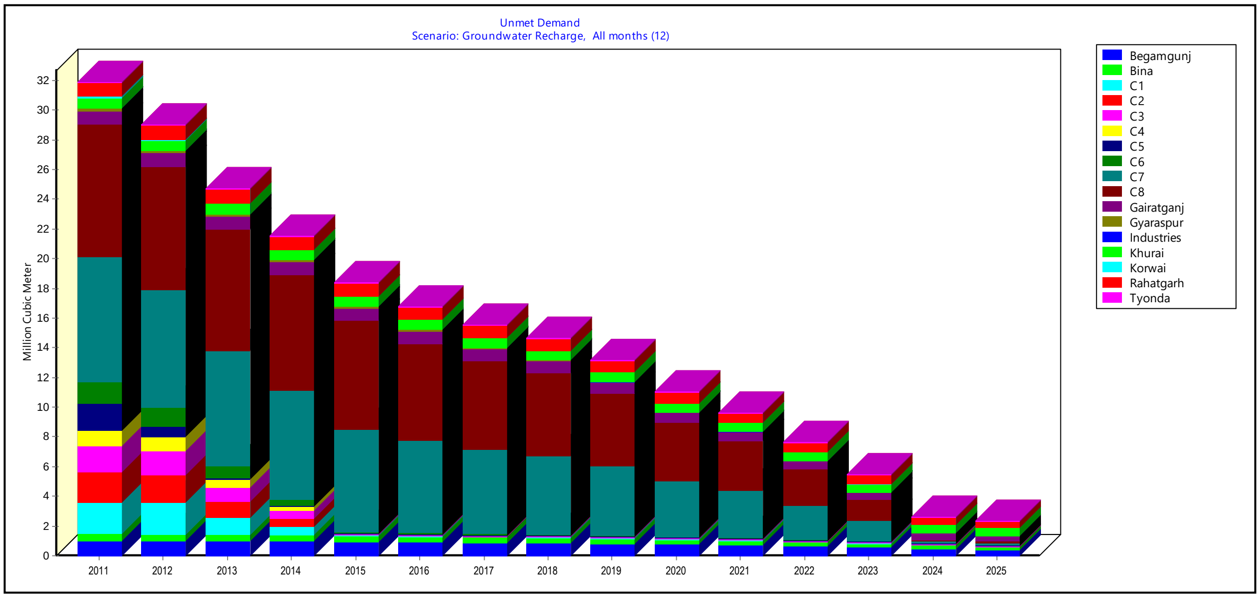

Fig. 6.10: Unmet Water Demands: With 10% Ground Water Recharge Rate Scenario

6.3 Results for Scenario III: Water Storage Structure (Madia Dam)

The proposed Madia dam on the Bina river near Rahatgarh has been placed over the Schematic of the WEAP model created for Bina River Basin (Fig. 6.1). The supply links have been placed from the reservoir to Rahatgarh, Khurai and Bina Blocks for both domestic and irrigation water supply. After the creation of the Madia reservoirs in 2020, the irrigation demands of C1, C3 and C5 catchments and domestic demands of Bina, Khurai and Rahatgarh are fully met, therefore unmet demands are zero at these nodes. The annual variation of Unmet Demands for all demand sites for the years 2011-2025 have been shown at Fig. 6.11 and Table 6.11.

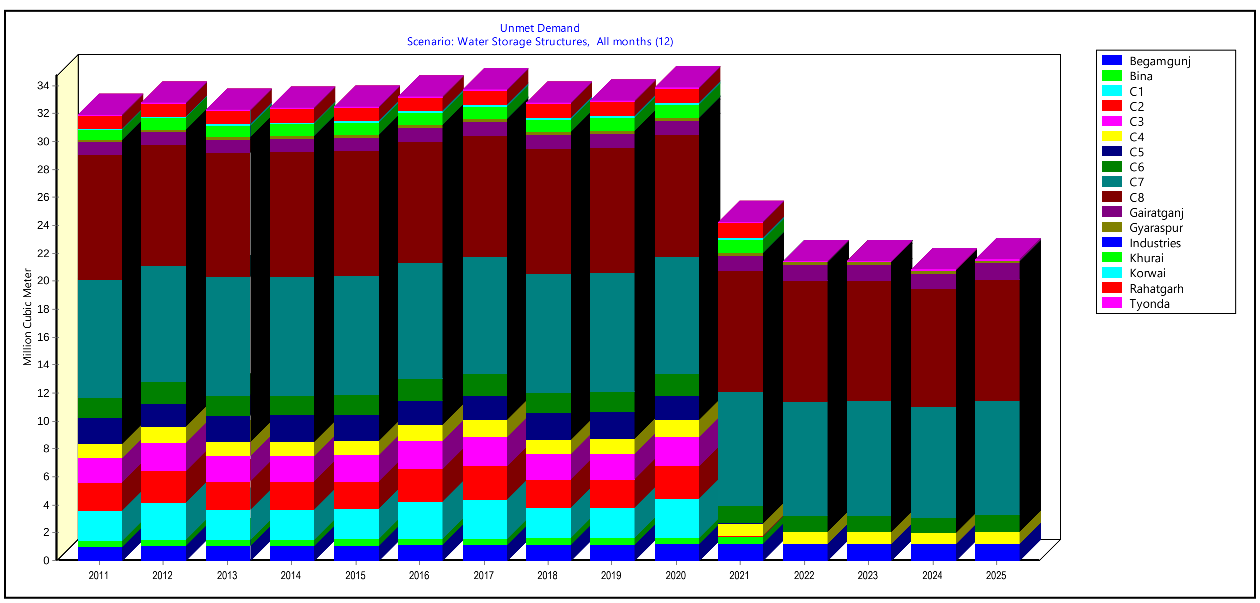

Fig. 6.11: Unmet Water Demands, Annual variation (2011-2025) with Water Storage Structures (Madia Dam) introduced

Table 6.11: Unmet Water Demands, Water Storage Structures (Madia Dam) introduced

Demand Site	2011	2020	2021	2022	2023	2024	2025
C1	2.150	2.771	0.049	0.000	0.000	0.000	0.000
C2	2.001	2.340	0.022	0.000	0.000	0.000	0.000
C3	1.766	2.093	0.064	0.000	0.000	0.000	0.000
C4	1.028	1.203	0.862	0.863	0.864	0.788	0.867
C5	1.863	1.770	0.076	0.000	0.000	0.000	0.000
C6	1.412	1.621	1.164	1.166	1.167	1.066	1.170
C7	8.450	8.273	8.193	8.199	8.206	7.992	8.217
C8	8.927	8.741	8.653	8.660	8.666	8.442	8.680
Begamgunj	1.044	1.196	1.210	1.221	1.235	1.249	1.263
Bina	0.428	0.488	0.495	0.000	0.000	0.000	0.000
Gairatganj	0.915	1.045	1.057	1.067	1.080	1.092	1.104
Gyaraspur	0.168	0.203	0.206	0.202	0.205	0.209	0.212
Industries	0.000	0.004	0.005	0.000	0.000	0.000	0.000
Khurai	0.712	0.927	0.937	0.000	0.000	0.000	0.000
Korwai	0.105	0.144	0.148	0.000	0.000	0.000	0.000
Rahatgarh	0.914	1.043	1.056	0.000	0.000	0.000	0.000
Tyonda	0.000	0.002	0.004	0.012	0.015	0.017	0.020
Sum	**31.881**	**33.865**	**24.200**	**21.390**	**21.438**	**20.856**	**21.533**

A sudden noticeable decline in the unmet demands can be seen in Fig. 6.11 from the year 2021, the year in which the Madia dam is pounded and is effectively supplying water to the demand sites. But as many of the demand sites can not draw water from the reservoir, the unmet demands remains in the basin.

The Unmet Demands for all four scenarios, viz. Reference, High Population Growth, Ground Water Recharge and Water Storage Structure have been shown at Fig. 6.12. This figure gives an overall outlook of the effect of different scenarios together. The figure also represent the relative effects of all scenarios, viz. unmet demands increases in case of High Population Growth Rate scenario and it decreases in case of Ground Water Recharge and Water Storage Structure scenarios. Thus the WEAP predicts the future demands under different scenarios.

Table 6.12: Annual Variation in Unmet Demand (MCM), All Demand Sites

Year	Scenarios			
	Reference	Population Growth	Groundwater Recharge	Water Storage Structures
2011	32.55	32.55	32.55	32.55
2012	33.32	33.83	29.64	33.34
2013	32.74	33.84	25.65	32.76
2014	32.81	34.55	22.45	32.83
2015	32.87	35.33	18.94	32.89
2016	33.58	36.83	15.91	33.60
2017	34.01	38.14	13.05	34.03
2018	33.08	38.17	12.11	33.10
2019	33.15	39.31	10.58	33.17
2020	34.09	41.45	8.43	34.11
2021	33.29	41.95	7.05	21.33
2022	33.36	43.48	5.02	19.58
2023	33.44	45.15	2.79	19.62
2024	34.40	47.88	0.31	19.02
2025	33.59	49.01	0.18	19.69

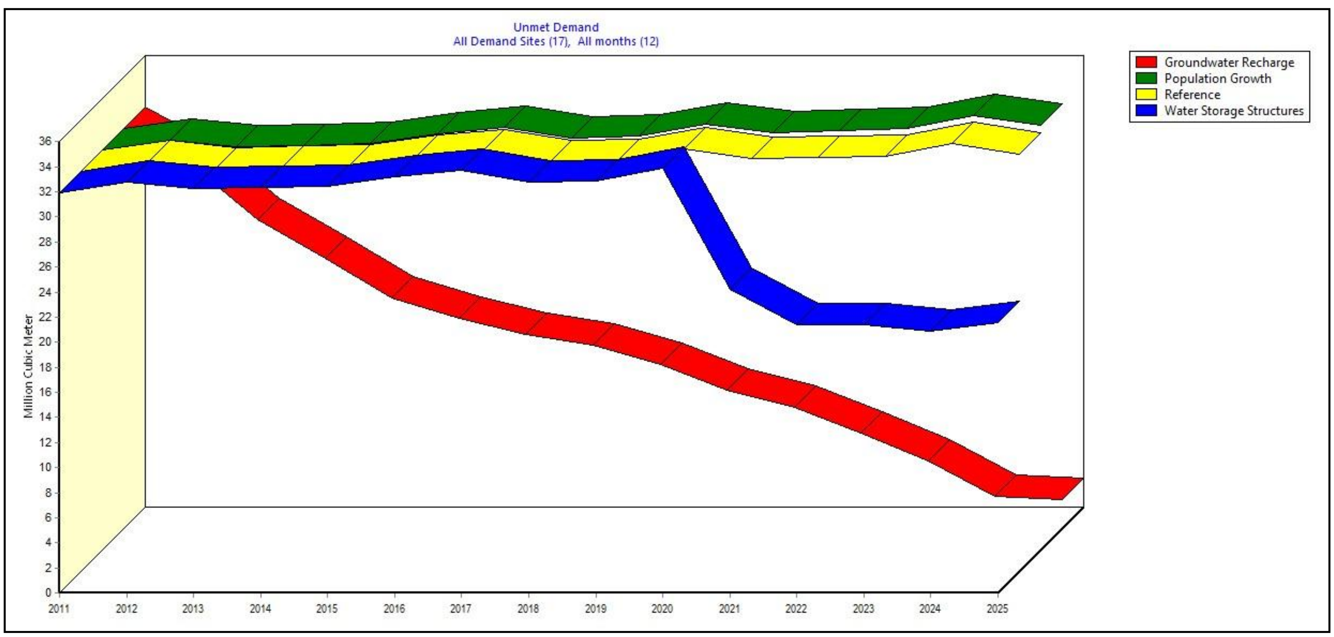

Fig. 6.12: Unmet Water Demands, Annual variation (2011-2025) with all Scenarios

7.0 CONCLUSIONS

This study was aimed at allocation and management of demand; supply and unmet water demand of Bina River watershed under various scenarios. Though WEAP is a flexible model with respect to the type of data available (monthly, daily, annually, etc.); but availability of the data is imperative. Absence of quantitative data made the present study slightly difficult to find broader results. Climate data was one such type in this study. The data was available to run the model but not enough to run scenarios on it. This is one limitation of the present study.

Another limitation of the study is time constraints that prevented us from carrying out more detailed approach in understanding the other aspects of the watershed like considering the agricultural demands under different crop cycle, or doing economic evaluation and simulating them in future scenarios (change in cropping pattern, modernization in irrigation techniques etc.). So these analyses may be studied in another similar project on Bina River. Following conclusion may be drawn from the present study:

- The levels of satisfaction of demands and the quantity of river water deficit today and in future were obtained. The Unmet water demands in all Administrative Blocks, Catchments and Industries in the year 2011-2025 have been calibrated which comes to be 32.55 million cubic meters in 2011 and 33.59 million cubic meters in 2025 for the reference scenario.

- WEAP has a unique characteristic of realizing the possibilities of future scenarios. In this study, we saw how water demands can be affected if there is a higher rate of population growth than present rate. The scenario is highly probable because population is rising day-by-day with an increasing rate, so the present scenario of the population growth rate (increased exponentially) getting changed in to 1.50% is not a difficult move. Realizing the possibilities and its consequences before the scenario actually becomes a reality is a strategy of sustainable development, and this is what we should know. The Unmet water demands tend to increase from 32.55 MCM for the year 2011 to 49.01 MCM for the year 2025.

- Similarly incorporating the improved groundwater recharge condition through watershed management program and rainwater harvesting structures, like contour bunds, percolation tanks, check dams or Gabion structures will help meeting the future demands by augmenting the supply sources. Once the harvesting structures are built, more recharge of ground water takes place and thus supply load on rivers decrease and gets transferred to the ground water bodies. Consequently, groundwater draft may be increased without affecting the sustainable groundwater level. Through WEAP, this has been demonstrated by increasing the groundwater recharge and draft both by 10%, the unmet demands reduces from 32.55 MCM for the year 2011 to merely, 0.18 MCM for the year 2025 for all demand sites.

- The impact of construction of proposed Madia dam on the Bina river near Rahatgarh town has also been modelled through WEAP and found that the all the demand sites getting supply from the Madia reservoir are satisfied, the unmet water demands are nil.

All these scenarios are important to understand and the consequences must be taken in consideration while planning developmental activities for an area. The WEAP model made it easier for us by predicting future probabilities and hence we now can plan accordingly in a more strategic way. The impact of Climate Change could not be incorporated in the present study, due to time limitation, which may be taken up immediately to make the outcome of the study even more useful.

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