INTEGRATED MANAGEMENT OF WATER RESOURCES IN CANAL COMMAND IN A PART OF INDO-GANGATIC PLAINS OF UTTAR PRADESH

A Thesis Submitted to

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By

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Certificate of the Supervisor

This is to certify that the thesis, entitled "Integrated management of water resources in canal command in a part of Indogangatic plain of Uttar Pradesh" submitted by Pradeep Kumar Srvastava for the award of Degree of Doctor Philosophy by Babu Banarasi Das University, Lucknow is a record of authentic work carried out by him under my supervision. To the best of my knowledge, the matter embodied in this thesis is the original work of the candidate and has not been submitted elsewhere for the award of any other degree or diploma.

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Declaration by the Candidate

I, hereby, declare that the work presented in this thesis, entitled "Integrated management of water resources in canal command in a part of Indogangatic plain of Uttar Pradesh" in fulfilment of the requirements for the award of Degree of Doctor of Philosophy of Babu Banarasi Das University, Lucknow is an authentic record of my own research work carried out under the supervision of Dr Raj Mohan Singh, Associate Professor, Department of Civil Engineering, M. N. National Institute of Technology, Allahabad.

I also declare that the work embodied in the present thesis is my original work and has not been submitted by me for any other Degree or Diploma of any university or institution.

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Place: Lucknow   Pradeep Kumar Srivastava

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Pradeep Kumar Srivastava

Preface

The requirement of proper water management and development plan for irrigation has been felt more acutely in tropical regions with monsoonal climate where the pattern of rainfall does not correspond to crops evapotranspiration water requirement pattern. In Uttar Pradesh, in certain regions dry weather irrigation canals which were constructed a few centuries ago to support livelihood and provide supplemental irrigation are still in use. Later on these canals were converted into all season canals by making permanent barrages. These canals were largely constructed to provide protection to crops from famines and droughts. The concepts in irrigated agriculture have changed since then to meet the food/fiber production needs of the ever-increasing population and from sustenance to intensive agriculture. This heavy dependence on groundwater resource for intensive cultivation, together with increased use of chemical fertilizers and pesticides has lead to its overexploitation and consequent water table decline at an alarming rate. Response of high yielding varieties is better with chemical fertilizers requiring more and frequent water application.

Moreover, water use for agriculture cannot be considered in isolation of other uses. This requires an integrated approach for sustainable water resources planning, management and operation under a river basin framework. Due to competition from increasing demands for agriculture, domestic, power, industrial, environmental and other uses, allocation of water to different stakeholders in appropriate quantity and quality has become increasingly difficult. Freely spatial availability, of ground water has increased its use very rapidly. Further it is more easily available on as and when required basis, without requiring any distribution system just like canal network. There is a real need to manage ground water reservoir in the region more effectively to ensure a sustainable dynamic balance between its annual replenishment and draft to sustain agriculture, and other demands for today and future.

Uttar Pradesh is having a geographical area of 242 lac ha and cultivable area of 165.88 lac ha. Through the constructed canal network a potential of 84.48 lac ha has been created in a canal command area of about 110.11 lac ha, but utilized potential is only 43.53 lac ha. In this created potential also, water-logging and consequent soil salinity-sodicity has increased in head and middle reaches of canal command areas due to unauthorized and excessive use of cheap and easily available canal water vice versa groundwater depletion is occurring in tail reach areas, resulting in reduced productivity both ways. Adoption of paddy and other high water guzzling crops has further increased gap between potential created and potential utilized through canal irrigation.

The dynamic ground water resource assessment report says that stage of ground water development has reached to 73.65% at the present cropping intensity of 160% and out of 820 blocks in Uttar Pradesh 111blocks has already reached to overexploited category, where ground water development is more than 100% and pre monsoon /post monsoon ground water levels are in declining trend. Further 150 more blocks has reached to semi critical or critical stages.

The large dependence on ground water resource in the overall development of water related plans & programmes of the State of U.P., particularly during the last 2 decades, has witnessed alarming depletion of this resource for which there is a strong need to lay down a proper scientific methodology for a sustainable and integrated water resource management at field level. This prompts to need of conjunctive irrigation management policy to be adopted for effective water management. The conjunctive management requires simulation of complex interaction between surface and ground waters, and management rules.

The work introduces GIS based integrated modeling framework integrating soil moisture accounting and irrigation water requirement module, rainfall-runoff module, system loss module and groundwater flow system module. Developed model was employed to evaluate different water management scenarios such as change in rainfall sequence (wet, normal and dry season), change in canal water supply, impact of canal lining and impact of land use changes including their socio-economic implications in canal commands.

The main developed canal command, ICROP model is calibrated from Visual MODFLOW by giving recharge from ICROP and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model, integrated water quantity and quality simulation model (IQQM) through which generated runoff values are checked from observed runoff values. The application of model is illustrated with real application in a part of Indo-Gangetic plain of Uttar Pradesh, India.

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LIST OF SYMBOLS AND ABBRIVATIONS

CCA	Cultivable Command Area
CGWB	Central Ground Water Board
FC	Field capacity
GEC-97	Groundwater estimation committee 97
GIS	Geographic Information System
HU	Homogeneous Unit
K	Hydraulic Conductivity
Kc	Crop factor
mbgl	meter below ground level
M.I.S.	Management Information System
MSB	Micro Sub-basin
NIC	National Information Centre
PRM	Pre monsoon
PTM	Post monsoon
SB	Sub-Basin
SIU	Sub-Irrigation Unit
SGWD	State Ground Water Department
SWP	State Water Policy
SRTM	Shuttle Radar Topographic Mission
T	Transmissivity
UNCED	United Nations Conference on Environment and Development

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water was primarily regarded as a natural resource necessarily free for human settlement. Society was least aware about its unsustainable exploitation issues. With the manifold increase in population and to meet its food and changed livelihood requirements, increased water (surface and ground water) use has led to overexploitation. That area of land can be said overexploited where annual water use is more than annual availability, resulting in depletion of ground water levels and a consequent non maintainability of minimum flow requirements in rivers for human and livestock livelihood activities. It is only very recently, particularly during the second half of the twentieth century, the community attitude towards water has changed and has led to the recognition that water is tending to become a "scarce resource" because of "overexploited." Today some visionaries even say that, water management will be the most critical resource management in the twenty-first century.

In the beginning of the 1980s, this debate led to the introduction of the concept of sustainable development in any natural resource development program. Brundtland Commission defined sustainable development that meets the consumptive needs of the present generation without compromising the needs for future generations. It was during the preparatory meeting for the UN Conference on Environment and Development (UNCED) in Rio de Janeiro, that the concepts of sustainable and integrated water resources management were widely discussed and adopted by the international community. At this meeting, the Dublin, principles of 1992 on water management were established.

1.2 The Dublin principles

Principle No. 1 -Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2 - talks of participatory approach.

Principle No. 3- talks of women participation in water resource management at all levels.

Principle No. 4 -Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price.

It is clear from the conceived Dublin principles that water management requires a holistic approach and therefore integrated and economic planning including protection of social development and ecology.

1.3 State Water Policy

Sustainable and integrated environmental water management is a key for maintaining overall sustainability of water resources in the state so as to keep water resources under harmony or in safe situations on spatial basis. State Water policy 1999 has a provision of conjunctive water management for effective and sustainable water development. The Government of UP adopted a State Water Policy (SWP) in May 1999 with the following objectives:

1. Ensure preservation of the scarce water resources and to optimize the utilization of the available resources.

2. Bring about qualitative improvement in water resource management which should include user's participation and decentralization of authority.

3. Maintain water quality, both surface and underground, to established norms and standards.

4. Promote formulation of projects as far as and whenever possible on the concept of basin or sub-basin, treating both surface and the ground water as a unitary

resource, ensuring multipurpose use of the water resource. This would inter alia consist of the following main uses:

i. Provide adequate water for drinking and domestic use.
ii. Providing water for irrigation.
iii. Maximize hydro power generation within the constraints imposed by other users.
iv. Provide water for industries including Agro industries.
v. Provide water for navigation, recreation, health and for other uses.

5. Ensure ecological and environmental balance while developing water resources.
6. Promote equity and social justice among individuals and groups of users in water resource allocation and management.
7. Ensure self-sustainability in water resource development.
8. Ensure Flood Management and drainage as integral part of water resource development.
9. Provide a substantive legal framework for management.
10. Provide a Management Information System (M.I.S.) for effective monitoring of policy implementation.
11. Promote research and training facilities in the water resource sector.
12. Provide mechanism for the resolution of conflicts between various users.

So the state water policy clearly emphasis that the sustainable and integrated water resource management treating water as single unitary resource in a holistic manner, ensuring multipurpose use of the water resource and maintaining ecological & environmental flows under river basin frame work is the only sustainable solution.

1.4 Integrated Management of Water Resources

In holistic and integrated approach water is treated as single unitary resource irrespective of source or place of occurrence. Integrated approach requires conjunctive management of surface water and ground water including optimization along with fulfilling the ecological and environmental flow requirements for present and future. Sustainable management adds a certain normative constraint on use, whereas integrated management may not pre-include a certain constraint statement about the main objective of development.

Water resources management refers to a whole range of different activities: resource assessment, demand management, modeling, design of measures and strategies, resource development, operation and maintenance, implementation of policy, monitoring, and evaluation. It also covers supportive activities such as institutional reform. Institutional reforms mean capacity building of institutions for understanding the issues built in within, developing and implementing integrated water resource management plans.

Water resource availability can be defined as natural annually regularly, replenishable resource, whose availability is limited to the performance of hydrological cycle and level of infrastructure development. There has never been one worldwideapplied recipe for how to manage water. Climate conditions and cultural practices have always varied to such a great extent that one cannot expect that such a recipe will ever be developed. Water management problems of the world are neither homogenous, nor constant or consistent over time. They often vary very significantly from one region to another, even within a single country, from one season to another, and also from one year to another.

Single largest use of water is for agriculture since time immemorial. The requirement of proper water management and development plan for irrigation has been felt more acutely in tropical regions with monsoonal climate where the pattern of rainfall does not correspond to crops evapotranspiration water requirement pattern. In Uttar Pradesh, in certain regions dry weather irrigation canals which were constructed a few centuries ago to support livelihood and provide supplemental irrigation are still in use. Later on these canals were converted into all season canals by making permanent barrages. These canals were largely constructed to provide protection to crops from famines and droughts. The concepts in irrigated agriculture have changed since then to meet the food/fiber production needs of the ever-increasing population and from sustenance to intensive agriculture. This heavy dependence on groundwater resource for intensive cultivation, together with increased use of chemical fertilizers and pesticides has lead to its overexploitation and consequent water table decline at an alarming rate. Response of high yielding varieties is better with chemical fertilizers requiring more and frequent water application.

Due to competition from increasing demands for agriculture, domestic, power, industrial, environmental and other uses, allocation of water to different stakeholders in appropriate quantity and quality has become increasingly difficult. Freely spatial availability, of ground water has increased its use very rapidly. Further it is more easily available on as and when required basis, without requiring any distribution system just like canal network. There is a real need to manage ground water reservoir in the region more effectively to ensure a sustainable dynamic balance between its annual replenishment and draft to sustain agriculture, and other demands for today and future.

1.5 Outline of the Thesis

Thesis is organized into nine chapters structured as follows:

After the introductory Chapter (Chapter 1), Chapter 2 presents the state of the art in the research areas of integrated management of water resources in canal command. After the literature review, Chapter 2 also presents the literature gaps and motivation for this work. Prime objectives as well as specific objectives are discussed in this Chapter. Chapter 3 presents the hydrogeology of the indogangatic plain of Uttar Pradesh. Aquifers of Indogangatic plain and that of Gomti basin are also discussed in the Chapter. For the modeling area districts of Ramganj distributaury and Daulatpur distributaury commands, borelogs, fence diagrams, yield, transmissivity and hydraulic conductivity parameters are also discussed. Chapter 4 presents the availability and utilization of water in Gomti basin. Topography, canal network, ground water behavior analysis based on Arc GIS, land use, climate and rainfall trend has also been discussed. Chapter 5 presents

Spatio temporal mapping of the study area using Arc GIS for ground water behavior in canal command and non command areas. Chapter 6 presents the ground water simulation model for the canal command area. Model calibration, simulation and different management scenarios and its impact has been discussed. Chapter 7 presents integrated model at distributaury level using soil moisture, rainfall runoff, system loss and ground water module on GIS platform. Management options for different type of land use, gross profit and ground water behavior has been discussed. Chapter 8 presents integrated model at Kulawa command upto field level using soil moisture, rainfall runoff, system loss and ground water modules on GIS platform. Different management scenarios for water regulation for land use based on field survey, NIC statistics and remote sensing has been discussed. Impact of rainfall sequence, canal water supply roster and lining on water use efficiency and ground water levels has been discussed. Dual roster for surface water and ground water use at Kulawa level has been developed for effective implementation of integrated water resource management through Water Users Associations. Chapter 9 presents the conclusions and scope for future work

CHAPTER 2

LITERATURE REVIEW

2.1-Introduction

Agriculture is a foundation in Indian Economy (Kumbhar and Singh, 2013). In India, large canal irrigation projects account for over 35 million hectares (m ha) of irrigated area. Of this, about 30mha were created after 1951, during successive Five Year plans. Groundwater was the main source of irrigation in these areas prior to the introduction of canal irrigation. It continues to be so in several areas even after the introduction of canal irrigation even though this factor was not considered explicitly in the design of canal irrigation systems.

Irrigation systems have been under pressure to produce more with lower supplies of water (Levidow et al., 2014). Various innovative practices can gain an economic advantage while also reducing environmental bur-dens such as water abstraction, energy use, pollutants, etc. (Faurèsand Svendsen, 2007). In recent years there has been considerable emphasis on integrated management of surface and groundwater resources in irrigation project areas to augment the canal supplies and to increase agricultural productivities. Integrated framework also controls ground water depletion, water logging, and soil salinity (Rosegrant and Svendsen, 1993; Water Technology Centre, 1998).

Agriculture has undergone several fundamental changes during the past century. Soil, water, labour resources, climatic scenarios and crop management practices are important components of sustainable agriculture (Ready and Rao, 1995). With the involvement of such biological, chemical and physical processes the agriculture production and processing systems have become more complex (Heinemann, 2010).

Ground water development is being done without adequate understanding of the balance between its occurrence (in space and time), replenishment (through recharge) and its impact on the environment, depletion of water levels in aquifers and decline in design yield of water wells. (Shah et al., 2000; Kendy et al., 2003; Pandey et al.,2011). Concerns for sustainable utilization of groundwater resources are growing in recent years (Douglas James et al., 1991; Duke U. Ophori et al., 1991; Shah et al., 2000; Hiscock et al., 2002; James McGhee al., 2004; Kretsinger and Narasimhan, 2005; Yueqing Xu et al.2005).

Groundwater sustainability may refer to the development and use of the resource in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999). The sustainability represents an optimal state; however, this is neither fixed nor constant but rather time and space dependent (De Carvalho et al., 2009).

Composite indicators representing the state of sustainable development (i.e. environment, economy and society), has been identified as a useful tool for policymaking and public communication on conveying information on groundwater situation and different sustainability index are developed by different researchers(Singh et al., 2009; Pandey et al., 2011). Groundwater infrastructures sustainability index developed by Pandey et al., 2011 considers five components viz groundwater monitoring, knowledge generation and dissemination, regulatory interventions, public participation and institutional responsibility which disaggregate into 16 indicators. The index is illustrated with Kathmandu Valley in Nepal as a case study.

2.1-Developed Models

A digital simulation model for groundwater basin of Mahi Right Bank Canal Project in Gujarat, is developed by S. K. Sondhi' et al (1989) in which the distribution of groundwater potential is determined by the use of specific empirical constants for estimating groundwater recharge from the surface water conveyance and distribution system. Only the annual assessment of ground water potential and its spatial distribution in study area after the construction of the canal has been done.

A lumped simulation model for Conjunctive Use of Surface and Ground Water Resources for Bagmati River Basin in Nepal has been developed by Pushpa Raj Onta et al.1991; to evaluate the alternative plans and policies, considering a number of mutually related synthetic sequences of stream flow and rainfall. Alternative plan are developed for indicating the system design (pumping and diversion canal) capacities and water allocation policies. Important policy and management implications are drawn from sensitivity analyses with respect to unit pumping cost, irrigation system efficiency, and recharge coefficient.

Linear programming-based optimization model has been used by many researchers to investigate a variety of water allocation problems. Linear programming is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. Latif et al. (1991) presented a linear programming-based conjunctive use model, applied for the Indus basin in Pakistan to maximize the net income of irrigators through cycles of wet and dry years over the long period. The model determines the optimal groundwater extraction for supplementing canal water to avoid adverse effects of high (water logging and salinity) or low (depletion and high pumping cost) groundwater level.

Conjunctive Water Use model developed to Control Water logging and Stalinization Salt distribution and transport in crop root zone are modeled by Douglas James et al., (1991), using the physical soil properties and mass balance. The main objective of this conjunctive-use study was to find the optimal ground-water extraction for stabilizing the water table at specific depths below land surface, while at the same time supplementing the surface irrigation supply. Salt distribution in the crop root zone is modeled and its effect on crop yield is also taken into account in the model. A daily crop water stress index is used to quantify crop yield reduction due to water stress over the growing season of a crop. Yield reduction due to salinity is calculated from the weighted average salinities (electrical conductivity) of applied waters.

In the conceptual model developed by P.K.Manumdar et al., 1991; for Ghataprabha sub in Krishna River basin for steady state condition and validated for both steady state and transient condition through USGS, 3D-Finite difference code, MODFLOW, various application were tried out on the calibrated model, like river-drain Influencing the aquifer, reasons for water logging and drying out of wells and well design strategies. Spatial aspect of water requirement and availability not considered.

Male et al. (1992) presented a dual-objective linear programming-based conjunctive use model, for the fixation of groundwater withdrawal permits, considering the use of groundwater without depletion of stream. Stream aquifer interaction was modelled using a linear lumped model, which uses stream depletion factor to represent basin characteristics. Peralta et al. (1995) developed a linear programming-based simulation cum optimization model to obtain the sustainable groundwater extractions over a period of five decades, under a conjunctive water use scenario. Running the model for five decades, considering potential increase in the water demand ensured sustainability of the groundwater, satisfying upper and lower bounds on the water levels in the aquifer.

In the MODSIM DSS developed by John W. Labadie et al.(1998) for a portion of the Lower South Platte River Basin, Colorado, MODRSP, a three-dimensional finite-difference ground water model is used for simulating spatially varied and time-lagged return depletion flows from stream-aquifer interactions. Results of the case study indicate significant differences between using ground water response coefficients developed from pre assigned stream depletion factor values, being used in the basin, and those generated using a finite-difference ground water model.

A groundwater balance model has been developed by Sethi et al.(2002) and applied to a portion of coastal river basin in Orissa State, considering mass balance approach. The groundwater balance of a basin was studied considering recharge from rainfall, irrigated rice fields, irrigated non-rice fields, base flow from rivers and seepage flow from drains and drafts through different groundwater structures like government deep tube wells, private shallow and medium deep tube wells. The linear programming model formulated for maximization of annual net return with optimal water and cropping pattern allocation considering the saline and non-saline soil type, rainfed and irrigated agriculture and the monsoon and winter seasons and the crops is found to be an effective tool for land and water resources allocation. All the assessments done are at basin level, spatial aspect within basin is not considered.

Barlow et al. (2003) presented a linear programming-based conjunctive management model to evaluate the tradeoffs between groundwater withdrawal and stream flow depletion for alluvial-valley stream aquifer systems representative of the north-eastern United States. Groundwater flow was simulated using the finite difference based program MODFLOW has been used (In a finite difference based program the assumption is that each directional velocity component varies linearly within a grid cell in its own coordinate direction. This assumption allows an analytical expression to be obtained describing the flow path within a grid cell. Given the initial position of a particle anywhere in a cell, the coordinates of any other point along its path line within the cell, and the time of travel between them, can be computed directly. While in the finite element method, a numerical technique is applied for finding approximate solutions of partial differential equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the partial differential equation into an approximating system of ordinary differential equations, which are then numerically integrated).Groundwater stream interactions were simulated using a stream routing package along with the MODFLOW. The objective function maximizes the sustained yield from the aquifer in a specified month for the given standard of stream depletion.

Yueqing Xu et al.(2005) developed a water balance model for the Hebei Plain in China, in conjunction with regression techniques (In regression technique a statistical procedure is used to find relationships among a set of variables. There is a dependent variable, and one or more independent variables that are related to it.) to estimate the groundwater recharge coefficient, specific yield, the groundwater withdrawn by different water use sectors and the corresponding drop in the water table. He determined the factors resulting in groundwater level decline and analyzes the impact of different land uses on groundwater table drawdown in order to develop a more practical plan to realize sustainable groundwater use in this region. Economic analysis on water economy benefit of crops is also performed and some alternatives to adjust cropping pattern to reach sustainable groundwater resources use are provided. Spatial water availability and requirement aspect not considered.

A three-dimensional transient groundwater flow model is used by Jaceb Scibek et al., (2007)to simulate three climate time periods (1960–1999, 2010–2039, 2040–2069) for estimating future impacts of climate change on groundwater–surface water interactions and groundwater levels within the unconfined Grand Forks aquifer in south-central British Columbia, Canada. The high-resolution (spatialand temporal) model is intended to capture not only the transient responses to river discharge and direct groundwater recharge from precipitation under the various climate change scenarios, but also the complex geometry of theaquifer and rivers. In addition, pumping wells and irrigation return flows during the peak demand period in the summer months are also considered.

A canal simulation model Icrop for Jaunpur branch sub basin a part of ghagra gomti basin of Uttar Pradesh has been developed by M/S SMEC International pty limited Australia in 2010,at micro sub basin level. Each micro sub basin is further subdivided in to four sub irrigation units depending upon the ground water levels. The developed I crop model is calibrated from Visual MODFLOW by giving recharge from Icrop and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model IQQM and generated runoff values are checked from observed runoff values. After calibration and validation various management scenarios has been developed for different land use, rainfall, canal supplies and ground water levels at micro sub basin level to solve the water distribution issues along with change in gross margin levels. Here ground water model has been used only for calibration purposes. Actual three dimensional movement of ground water has not been considered for sustainability aspect at micro sub basin level.

Groundwater recharge and evapotranspiration through the vadose zone are of great importance for sustainable groundwater use and control of salinity and water-logging in arid and semi-arid regions with shallow water tables (Lerner et al.,1990; Arnold et al., 1993).However, the recharge and evapotranspiration are observed to vary with topography, soil type, land use, and water management practices (Xu *et al., 2012);*. Some reports have centered on improving irrigation efficiency to reduce ground-water pumping and suggested that it is imperative to practice economical irrigation, utilize water resources efficiently and develop water-saving agriculture (Zhao et al., 1995; Jin et al., 1999; Zhang et al., 1999, 2003; Wang et al., 2001; Yang et al., 2001).

Geographic information systems (GIS) have emerged as powerful tools for handling spatial data and decision-making in several areas including engineering and environmental fields (Stafford 1991, Goodchild 1993).Thus for sustainable agriculture management modern frontier technologies such as geographical information system (GIS) and process simulation models needs to be integrated. Decision makers may employ an integrated and interactive framework to solve unstructured problems.

2.3. Literature gap and motivation

Synchronization of seasonal water availability with demands is a water resources management challenge in many agricultural river basins (e.g. Camnasio and Becciu 2011; Pavelic et al.2012). Excess wet season river flow causes flooding, while low flows are often inadequate for dry season water supply. This results in conflicts between upstream and downstream users in transboundary rivers (e.g. Uitto and Duda 2002; UNDP 2006). Under a changing climate, seasonal extremes (Kundzewicz et al. 2010) and supply–demand imbalance (Immerzeel et al.2010) are likely to increase. One approach to managing water resources in such basins is upstream storage of excess wet-season river flow for use during dry season. This requires conjunctive-use management strategies (Coe 1990). Effective conjunctive use of surface water and groundwater results in a total annual system yield that exceeds the sum of the yields of the separate components (Bredehoeft and Young 1983).

Conjunctive use of groundwater and surface water already occurs in many UP canal irrigation areas, but not to full potential, largely due to lack of management (Garduño and Foster 2010). In these areas, unmanaged water use and the greater cost of groundwater compared to surface water creates interlinked management issues. Surface water is used preferentially in canal head areas where it is readily available,forcing farmers in canal tail areas to pump groundwater when surface water becomes scarce (World Bank 2010). The result is a reduction in crop yield due to rising water tables and soil waterlogging in canal head areas (Singh et al. 2012), whereas in canal tail areas, groundwater use is unsustainable and water tables decline over time (Gandhi and Bhamoriya 2011) resulting in increasing pumping costs.

The strategies require re-engineering of the river and canal systems, and significant changes in irrigation practices throughout the basin.The actual efficacy of the conjunctive-use management schemes considered would vary in the basin depending on local aquifer geology, the local nature of riverbed and surficial sediments, river stage, river geometry, topography, and other hydrologic, geologic, and anthropogenic factors. Implementation would require testing in pilot projects within limited areas. Observations made in such projects can provide direct information for improving design, perhaps by narrowing the possible range of hydrogeologic parameters and conditions for each local area and by improving the modeling analysis to provide more locally descriptive predictions of system response.

Groundwater serves as the main source of irrigation and is preferred over surface water irrigation for a number of reasons: groundwater is easily assessable and pumped due to shallow depth; pumping and operational costs are low; the Government has provided sympathetic treatment to farmers in the form of free tubewell installations in early 60'sand, later, a subsidized electricity policy. All these benefits have fuelled and stimulated groundwater irrigation.

Based on reports of CGWB and that of SGWD, Groundwater is a major source of water for agricultural and domestic requirements in western Uttar Pradesh. Due to increasing agricultural requirements the abstraction of groundwater has increased manifold in the last two-to-three decades. Although the area hosts potential aquifers these have been adversely affected by poor management. For effective groundwater management of a basin it is essential that a careful water balance study should be carried out.

Keeping this in mind groundwater flow modelling was attempted to simulate the behaviour of the flow system and evaluate the water balance. The alluvial areas of Uttar Pradesh have provided the most productive soils and aquifers in this district.The expansion of the irrigation network has brought about a spectacular increase in agriculture production in these areas over the last few decades.

In the western part of Uttar Pradesh, this has led to declining groundwater levels with detrimental impacts to groundwater resources and agricultural, domestic and industrial users. Long term groundwater level trends show an average decline of 0.88m/year (Umar 2008).

Previous hydrogeological investigations in the area were mainly carried out by Central Ground Water Board (CGWB) and Groundwater Department of Uttar Pradesh (U.P.) government. Khan (1992) and Kumar (1994) carried out systematic hydrogeological investigations in Muzaffarnagar district and studied the first group of aquifer.They identified a number of blocks that were under- and over-exploited. A water balance study using water table fluctuation and tritium method was carried out in parts of Yamuna–Krishni interstream area by Ahmed and Umar (2008). The result of this water balance study showed a negative balance and place the area in an ‘overexploited ‘category.

Aquifer modelling studies have been carried out in Krishni–Hindon interstream region (Guptaet al 1979) and Daha region (Gupta et al 1985). They have assessed the stream aquifer interaction as well as conjunctive use of surface water and groundwater in Daha region. Ala Eldin et al (2000) quantified the river–aquifer interaction in Ganga–Mahaba sub-basin. The study also supported a new canal system to be introduced to check declining groundwater level. No modelling studies were carried out in the study area.

In alluvium plains of Uttar Pradesh average annual rainfall is 900-1000mm and the excepted average ground water recharge is about 25%,that comes out to be only 225-250mm.After base flow from ground water reservoir, left water can hardy meet out two furrow irrigation requirements for prevailing agricultural practices in Uttar Pradesh. The rates of recharge and evapotranspiration are the most difficult and uncertain components to estimate in groundwater budget, and they often vary spatially and temporally. Alone annually replenishible ground water from rainfall can never meet out irrigation requirements for all the three seasons and other drinking and industrial requirements. It will always reach in overexploited category and ground water will start depleting and energy cost in lifting ground water will go on increasing and this will create extra overburden on small land holding farmers, thereby decreasing their gross margin for livelihood. Spatial sustainability of annually replenishible ground water resources is manageable only at field level by considering the actual land cover and using canal water in conjunction with ground water reservoir.

An integrated approach considering surface water and ground water is imperative at field level incorporating modeling output. Application of conjunctive use of surface and groundwater employed through Water Users Associations (WUAs) and Kulaba Samities by adopting Osrabandi and Dual Roaster can increase canal water use efficiency and arrest excessive depletion of ground water levels in tail canal commands.

2.4. Objective

The prime objective is development of integrated water resources management framework for canal command in a part of Indo-gangatic plains of Uttar Pradesh.

Specific objective of the Thesis are:

1. To investigate hydrogeology of Indo-gangatic plains of Uttar Pradesh in vis a vis study area.
2. Water availability and utilization in gomti basin.
3. Spatio-Temporal mapping of ground water for the study area using Arc GIS
4. Development of ground water simulation model for the canal command area.
5. Development of Integrated Model at distributaury level using soil moisture, rainfall runoff, system loss and ground water modules on GIS plateform

6. Development of Integrated Model at Kulawa command upto field level using soil moisture, rainfall runoff, system loss and ground water modules on GIS plateform

CHAPTER 3

HYDROGEOLOGY OF THE STUDY AREA

3.1.Hydrogeology of the Indogangatic plain of Uttar Pradesh

Indo–Gangetic plain is the largest alluvial plain of the World, which has been formed by deposition of terigenous clastic sediments through streams of Indus, Ganga and Bramhaputra River Systems. The alluvial plains shows highly differentiated alluvial geomorphic features; many of them formed above to changing climatic conditions.

The Gangetic plain occupies the central position in the indo-Gangetic plain and extends from Delhi ridge in the West to Rajmahal hills in the East; Siwalik hills in the North and Bundelkhand–Vindhayan high land in the South. It is a foreland basis formed in response to the Himalaya tectonics (Figure 3.1).

Figure 3.1: Sketch map of Gangetic plain showing position of major basement structures below the alluvium. I. Delhi ridge, II. Faizabad Ridge, III. Monghyr-Saharsa Ridge. 1. Moradabad fault, 2. Bareilly fault, 3. Lucknow fault, 4. Patna fault, 5. Malda fault. Based on data of Sastri et. al. (1971), and Rao (1973).

3.2. Subsurface Basement Structure of the Indogangatic plain of Uttar Pradesh

The Quarternary alluvium of Gangetic plain including Siwalik sediments rests on a basement which is sometimes made up of late Proterozoic sediments or metamorphic Pre-cambrian rocks. The basement rocks show some major structures which have controlled the thickness of alluvium. The interpretation of basement structure is based on the aeromagnetic studies. There are three major basement highs referred to as ridges below the Gangetic plain near the western margin of Gangetic plain the rocks of Delhi – Aravalli tectonic trend continue towards North to North-East below the alluvium. The thickness of alluvium over this Delhi ridge is much reduced, and also termed as Delhi-Haridwar Ridge or Delhi –Muzaffarnagar ridge. In middle part of Gangetic plain, a basement ridge structure exists as Bundelkhand massif. This basement high is known as Faizabad ridge. This ridge also reduced thickness of alluvium. In the Eastern part of the Gangetic plain, a continuation of Satpura Bundelkhand massif. This basement trend extends below the alluvium in the form of ridge, Monghyr–Saharsa ridge (Figure 3.2).

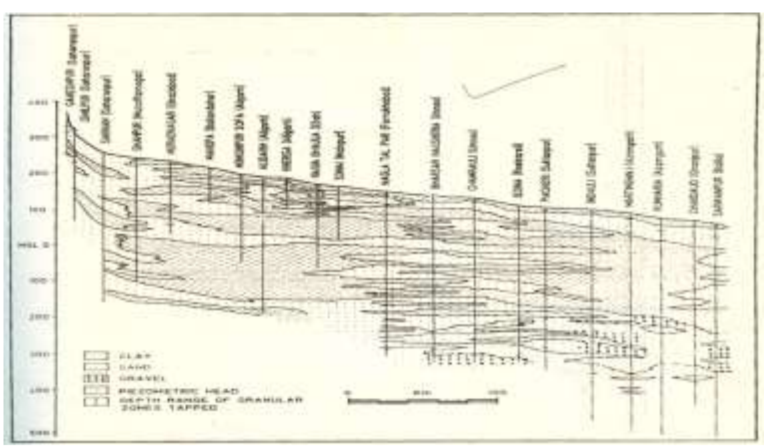


Figure 3.2: Lithological correlation chart of the Ganga basin from Saharanpur to Ballia districts, U.P., showing major aquifers and interbedded clay horizons.

Besides these three major basements ridges, there are a number of faults identified in the basement. These faults are: Moradabad fault, Bareilly fault, Lucknow fault, Patna fault and Malda Fault .Though basement highs have controlled the thickness of alluvium, there seem to be no surface and sub-surface expression of these faults in the alluvium .It appears that these faults are inactive faults in the basement.

3.3. Geomorphology of the Indogangatic plain of Uttar Pradesh

In classical literature, essentially two types of deposits and geomorphic regional features in Gangetic plain are identified namely older alluvium or Bhangar and the newer alluvium and / or khaddar. The older alluvium makes the regional high surface, while the newer alluvium refers to the river valley deposits and present flood plain deposits.

3.3.1. Based on geomorphic character and drainage patterns, Gangetic plain can be classified Western, Median and Eastern plains.(Singh,1989).

3.3.1.1. Western Gangetic plain

It stands from Yamuna River near Delhi-Aravalli ridge (elevation 225m) upto Allahabad (following 100m contour line).

3.3.1.2. Median Gangetic Plain

It is located between Allahabad and Manghyr-Saharsa, between 100-50 m. contour lines.

3.3.1.3. Eastern Gangetic Plain

Located between Manghyre-Saharsa in West and Rajmahal mills in the East, between 50-30 m. contour lines.

3.3.2. Based on geomorphology and Hydro geological features, the Gangetic plain is classified into four distinct areas from North to South (Pathak, 1982).

3.3.2.1. Bhabar Belt

It is located along the Himalayas foot hill, has southerly slopes of 10-20 m. /km. The rivers are gravel bearing, shallow braided streams. Ground water level is deep and water bearing strata are more potential.

3.3.2.2. Tarai Belt

It is located South of Bhabar belt with very high gentle slopes 20-30 cm. /km. It is flat, more waterlogged areas with ponds, swamps and many small sandy streams. The ground water level is very shallow varying from 0 to 6 mbgl.

3.3.2.3. Central Alluvial Plain

It makes the wide zone showing prominent higher surface with gentle South-easterly slope. The rivers flowing South-Eastern and Eastern directions, showing wide river valleys or Khadar.

3.3.2.4. Marginal Alluvial Plain

It is located south of axial river showing extensive higher plateau surfaces, narrow entrenched river valleys. It occupies the area south of Yamuna River in U.P. and South of Ganga River in eastern U.P. The rivers are mostly North and North-Easterly flowing gravel-coarse sand carrying streams.Bhabar and Tarai belts correspond to the northern domain, central alluvial plain to central domain and marginal alluvial plain to the southern domain of the Gangetic plain foreland basin.

3.4. Geomorphic Features

There are number of regionally significant geomorphic surfaces identified in Gangetic plain, along with a number of specific geomorphic features, based on reports of remote sensing data.

3.4.1. Upland Terrace Surface

It is most important regional planer surface, making gentle sloping higher areas. In the central alluvial plain it shows in 1/km. slopes in eastern and South-Eastern direction. It is probably the oldest geomorphic surface. It is made up of essentially silt sediments, with mud and sand horizons, and shows extensive development of calcrete bands. Often abandoned channel belts of highly sinuous streams are present. The surface is gentle undulating and shows a number of distinctive geomorphic features, namely ponds, lakes, abandoned channels, zones of alkaline soils, zones of extensive gulley. All the active rivers of Gangetic plain are entrenched in this surface. This surface makes the highest terraces for the active streams and is designated as T-2 surface. In the marginal alluvial plain, south of Yamuna River in Western part and South of Ganga River in eastern part, extensive high, plateau surface is developed showing prominent calcrete formation.

3.4.2. Large Relict Alluvial Fan Surface

The northern part of Gangetic plain shows a prominent southward sloping surface, which was formed by coalescence of large alluvial fans (F), which were about 100 km. wide. It starts from Siwalik Hills and extends deep into the Central Alluvial plain. In the areas of Ghaghra and Gandak Rivers a number of evidences for the presence of large alluvial fan surfaces are seen, namely abandoned diverging channels, linear lakes etc. but it is difficult to identify the boundary of these large relict fans. This fan surface shows evidence of gradual shrinkage towards Himalayas, due to decreased sediment supply and at present is confined to a narrow zone close to the Himalaya (Figure 3.3).

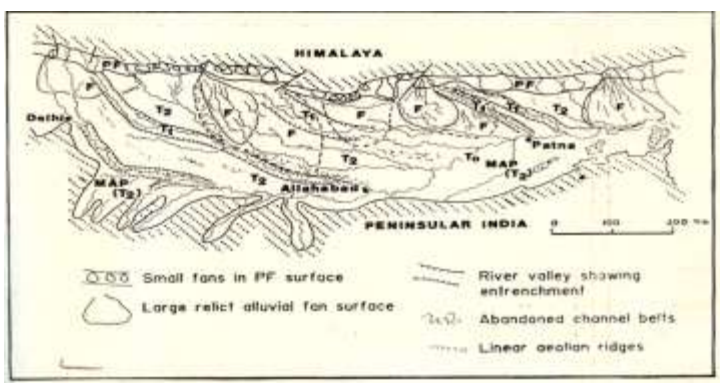


Figure 3.3: Schematic geomorphic map of Gangetic plain showing major geomorphic features. T2-Upland terrace surface, MAP (T2)-Upland terrace surface of Marginal alluvial plain, F-Large relict alluvial fan surface, PF-Piedmont fan surface, T_1-River valley terrace surface, T_0-Active flood plain.

3.4.3. Piedmont Fan Surface

The northern part of Gangetic plain near the Himalayan orogen shows a prominent narrow zone made up of coalescing, discrete alluvial fans (PF). These zones are about 10-20 km. wide and often correspond to the Bhabar zone. It is much younger than the large relict fan surface and is sometimes superimposed on the later. There is evidence of gradual decrease in the size of fans of this piedmont fan surface in the last few thousand years. On this surface, gravely sediments are present below few tens of meter thick sandy-muddy sediments.

3.4.4. River Valley terrace Surface

All the major rivers of Gangetic plain shows rather broad valleys in which a narrow present-day active flood plain is located. These broad river valleys are entrenched within the upland terrace surface (T2). It is newer alluvium which also included the present day active flood plain (T0). This surface is designated as T-1 surface, forming gentle sloping terrace surface, a few meter above the active flood plain.

3.4.5. Active Flood Plain

All the major rivers of Gangetic plain are subjected to annual flooding and make prominent flood plain predominantly make upto sandy sediments. In large rivers, it can be several km. wide, while in the smaller rivers; it is few hundred meters wide. This surface is designated as to surface, made up of active channel, braid bars, point bars, sandy flats and muddy flood plains.

3.5-Characteristic of the drainage

The Gangetic plain shows a wide variety of streams with respect to origin, direction of flow, dimensions, channel characteristics and hydraulic parameters. Based on their source, these rivers are classed into three broad categories: Himalayan Source Rivers, ground water fed rivers and Peninsular Source Rivers.

The Ganga is the trunk or axial river to which all the rivers join in a distinct pattern. The major rivers originating in Himalaya and within alluvium run parallel to each other for considerable distance, before joining the larger streams. Similarly, streams from Peninsular India also run parallel to each other before meeting the Yamuna or Ganga Rivers. Further, Central Alluvial plain shows a number of abandoned channel belts showing highly sinuous, free-meandering streams. The channel patterns of Gangetic plain are anatomizing, braided and meandering.

All the major rivers, originating in the Himalaya, e.g. Yamuna, Ganga, Ramganga, Ghaghra, Gandak show distinct braiding characters in the northern part of the Gangetic plain, slightly sinuous nature in the Central Alluvial plain. The central alluvial plain shows NW-SE oriented sub-parallel drainage system made up of Himalayan Rivers as well as ground water fed Rivers. The active channels are rather stable and show moderate to deep entrenchment and do not show evidences of river avulsion time scale of 10^2-10^3 years. The groundwater fed channels are meandering streams with narrow flood plains. The upland terrace surface shows many abandoned meanders, cut off meanders, etc often arranged in distinct channel belts.

3.6. Nature of Alluvial Fill

The sub- surface information on the nature of alluvium is essential based on the bore hole data of CGWB. It is about 2000 m in the northern part and gradually decreases to 10 m in the southern part. The Central Ganga Plain is very wide and shows much variability in sub-surface lithology in terms of sand: clay ratio and grain size characteristics. Information is usually available for top about 400m .The succession is made up of mainly clay and clay with kankar intercalated with few meter thick mostly fine sand horizons.

Few gravel horizons are recorded in deeper parts, which are mainly reworked carbonate-cemented sand and calcrete. The proportion of sand is high in the north-western part, but drops drastically in South-Eastern part of U.P. Topmost about 15 m of the alluvium is essentially made up of clay with thin lenses of very fine sand, often containing dispersed kankar.

The alluvial plain between Ganga and Yamuna River shows marked thinning of the alluvium. The thickness mostly varies from about 500m in the northern part to about 250 m in the southern part, resting on basement rocks. The sediments immediately above the basement are reddish coloured, arkosic sand and gravel derived from the peninsular source, locally known as Moorang. The arkosic sediments are followed by a succession of clay with kankar along with thin horizon of fine to medium grained sand. These are micaceous grey sand, derived from the Himalaya. The topmost 100 m lithology is essentially clay with kankar and thin lenses of very fine sand.

A significant aspect of the alluvial stratigraphy in Gangetic Plain is the presence of fining upward, about 5-10 m thick, clay dominant thickness at top, throughout the Gangetic Plain. The sub–surface lithology shows a number of fining upward or coarsening upward successions which must have been formed due to changing Climatic and tectonic conditions during late Quaternary.

The area between Ganga and Yamuna rivers is very important in understanding the southward shift of the foreland basin margin, just above the basement; southern derived arkosic sediments were deposited by Peninsular Rivers. Later Himalayan rivers pushed the peninsular rivers further south and depositing Himalayan derived micaceous lithic sand and mud over the arkosic sediment. (Singh, Bajpai 1989). Presence of clay-dominant sequence at the top of the alluvium throughout the Gangetic Plain suggests that at least, during Holocene, there has been strong alleviation of the Gangetic Plain by fluvial processes.

3.7.Physiography

The soil exhibits a wide variance; sandy on the elevated locations, clayey in the topographical lows and loamy on the flat surfaces. According to Singh (1992), the Gangetic alluvial plain has a gentle consistent regional slope and a narrow range of grain sizes but the channel shows a variety of forms namely braided, slightly sinuous, highly sinuous, anastomosing, ox-bow lakes, etc.

3.8. Aquifers in Indogangatic plains of Uttar Pradesh

Through the geophysical studies done by CGWB in 1992 using electric logs, four groups of aquifers namely 1, 2, 3 and 4 are recognized in order of increasing depth (Figure 3.4). Group 1 aquifers extend from the water table to a depth of 50 m to 110 m. Group 2 aquifers underlies group 1 at a depth of 70 m to 260 m, followed by Group 3 aquifers at a depth of 90 m to 375 m. The Group 4 aquifers have an upper boundary at a depth of 280 m to 400 m, while the lower limit remains largely unexplored. The aquifer material is generally fine to medium grained sand, which is micaceous in nature.

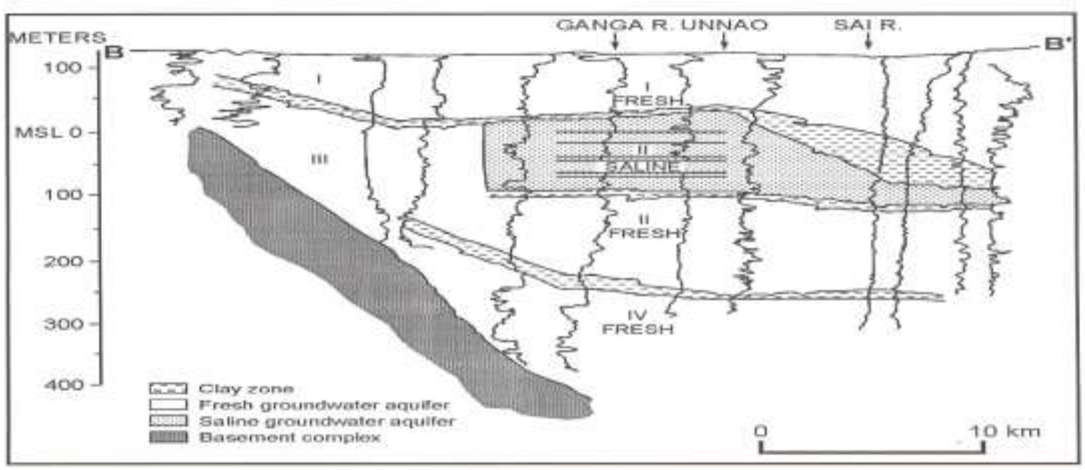


Figure 3.4 Group of 4 aquifers as reported by CGWB (1992)

Generally, flow of ground water in the unconfined zone follows the surface topography. It moves S to SE in foothills of Himalayas, then to the E-SE and then to the E in eastern most districts i.e. in Ghazipur and Ballia. Near the Gomti, Sai, Pilli and other rivers, flow direction is mostly towards river banks indicating that all the streams and rivers are being fed by ground water. Except for the Ghaghra River, which originates from the

Himalayas, all other rivers of this Basin originate from ground water springs, tanks and ponds. Ground water seeps into the Tarai zone of Pilibhit district and forms the Gomti River. The Sai River originates through a group of springs in Sitapur district at Namisarnya and other streams of Hardoi district contribute to its base flow downstream.

3.9.Regional analysis based on fence diagram in each of the Agro-Climatic zones from Central Ground Water Board and that of State Ground Water department

In the Bhabar zone sub-surface lithology is dominated by coarse sands and morum mixed with cobbles, pebbles, gravels with thin intercalation of clay lenses. The Tarai zone is also dominated by coarse sands and medium sands with thin inter-bedded clay layers. At some places sandy layers are very thin or absent up to the depth range of 60 to 100 m and farmers face problems for construction of tube wells due to unavailability of potential aquifers.

In North West plains the sub-surface lithology is dominant with medium to coarse sands inter layered with clay layers. The aquifers are wide extensive and highly potential for construction of both shallow and deep tube wells.

The lithology of Central plain is variable from place to place, but in general the proportion of sand-clay ratio is more or less the same up to the depth range of 50 m. In some areas the upper most sub-surface lithology is dominance with clays more suited for cavity tube wells up to 40 m depth and in other areas, sand layers are dominant inter layered with clays feasible for both cavity and screened tube wells.

The sub-surface lithology of North-East plain is widely variable from place to place; in general the upper most layer is dominant with medium to coarse sands and suitable for shallow tube wells. The under lying strata is dominance with clays, commonly intercalated with medium to fine sands. At many places the underlying clay layers are thick and extensive so that shallow and deep tube wells are not feasible.

Sub-surface lithology of Eastern plain is widely variable from place to place because of being fluvial deposit. In some areas clay lithology is dominant and in other areas sand layers are dominant with thin intercalation of clay layers. From place to place, there are also small kankars of in-situ origin. In most parts of the eastern plain, shallow tube wells are feasible with fresh ground water.

3.10. Aquifers in Gomti basin

The ground water aquifers in the area occur under unconfined, semi-confined and confined conditions. In the unconfined state the ground water occurs in the zone of saturation in the pore spaces of granular beds. The top granular zone which consists of sand, silt and Kankar, forms a phreatic aquifer and acts as a major source of water to open wells, hand pumps and shallow tube wells. The aquifer drawdown ranges up to 70 mbgl in locations where it is under severe stress due to the impact of human activities. In the semi-confined and confined condition, the ground water occurs below a confining layer. The middle and lower aquifers have alternate bands of clay and sand of pinching and variable thickness, starting from 70 mbgl to 200 mbgl. As an example, the semi-confined and confined aquifers in Sai–Gomti interfluve area are classified and given in Table 3.1

Table 3.1 Semi-confined and confined aquifers in Gomti basin

Aquifer	Lithology	Depth range (mbgl)	Quality of Ground water
I	Sand, silt and clay in various proportions	50-160	Fresh
II	Predominantly clayey silt with occasional thin beds of sand and clay	160-250	Brackish to saline
III	Fairly extensive sand beds and clay	Below 250	Fresh

(CGWB, 1995)

The hydraulic gradient of the aquifer is very high in the upper reaches of the Basin in Pilibhit district, with flows in south and south–east direction, whereas in central Ghaghra Gomti plain, hydraulic gradient is gentle and flows are in an almost west to east in direction. Hydraulic gradient varies with the influence of topography, and the presence or absence of water bodies. Hydraulic gradients in both river sub-basins do not show much variation. The gradient observed in the area is about 0.52 m/km in Sai basin and while hydraulic gradient varies between 0.44 m/km and 1.08 m/km in Gomti Sub-basin (CGWB, 1999). In the Jaunpur Branch Sub-basin, in the district of Jaunpur, hydraulic gradient varies from 0.155 m/km near Murladeeh to 0.624 m/km near Nanora in Suitha Kalan block in the north of the Gomti Sub-basin. In the Gomti sub-basin it varies from 0.155 m/km near Gujartal in Shahganj block to 3.12 m/km south of Kairadih in Khutahan block. It is recorded to be 2.81 m/km in Mahrajgunj block, north of the Sai

River to 1.66 m/km in eastern part of Sujanganj block, south of the Sai River. Similar conditions persist with different values of hydraulic gradient in almost all districts.

3.11. Fence Diagrams

The detail report based on fence diagrams from CGWB and SBWB, U.P is illustrated below.

3.11.1. Barabanki

In Barabanki, aquifers upto depth ranges 50 m are unconfined, and occur in alternation with clay layers. In wide extensive area upto depth range 50 m sand:clay ratio is 40:60, but the proportion of sandy strata is higher in Northern zones, and lower in Southern areas. In the North –East areas, the upper clay layer is thick, varying from 5 m to 40m, so the depth of potential aquifer is deeper. In South-Eastern areas, especially at Dariyabad, potential aquifers are at a depth of 50-70 m. Partially confined aquifers are interbedded in the clay layer (Figure 3.5).

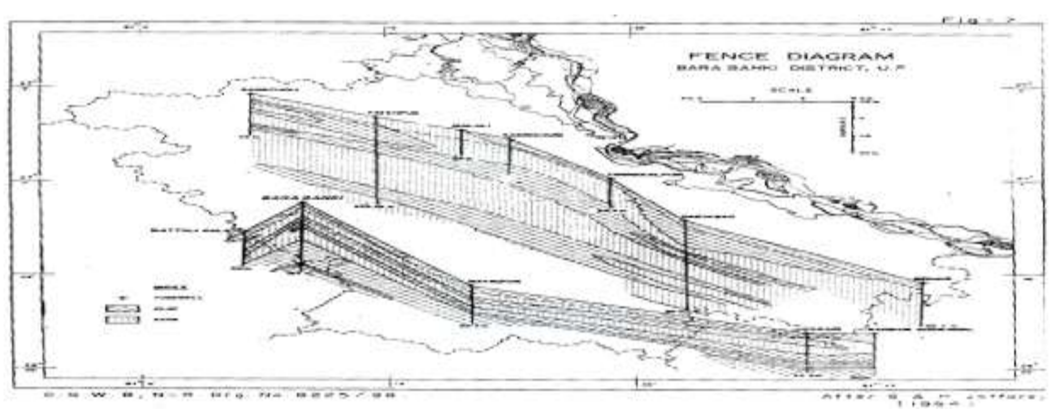


Figure 3.5: Fence Diagram for Barabanki

3.11.2. Jaunpur

The sub –surface geology of Jaunpur is more clay dominated. The thickness of the upper clay layer varies from 5 m to 30 m at Atardiha, Gairwa in north extremity. In north-zone, aquifers are of limited thickness, inter-layered with thick clay zones. They are partially confined and have saline ground water. In the southern part of the district, in Sikrara block, sand:clay ratio upto 50m depth is 45:55. The aquifer occurs at medium depth, is extensive laterally, with high potential for shallow tube wells. Deeper aquifers are partially confined, with thick clay layers. Groundwater quality is moderate to saline (Figure 3.6).

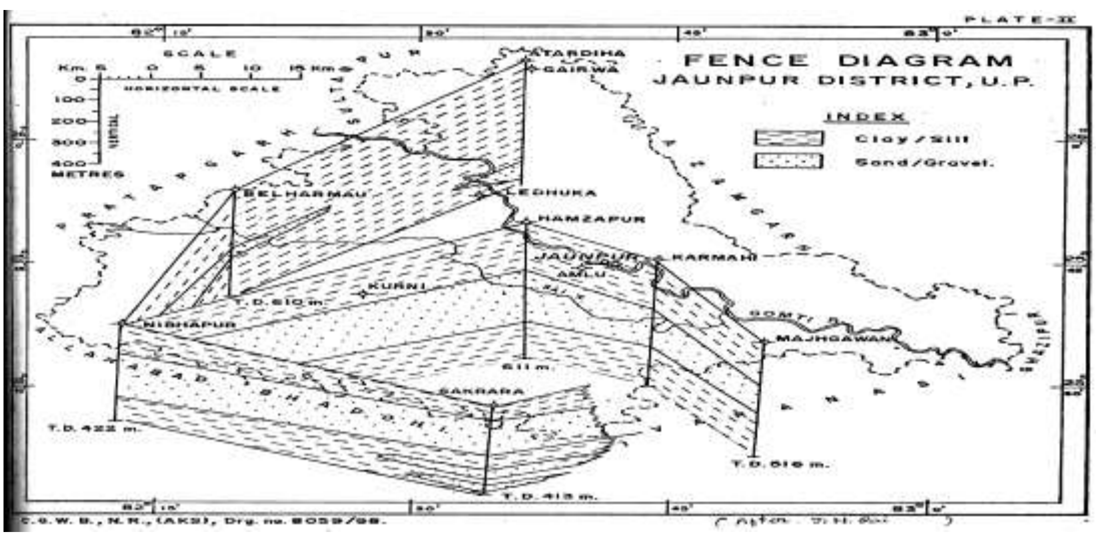


Figure 3.6: Fence Diagram for Jaunpur

3.11.3.Pratapgarh

The sub-surface geology of north-west areas, especially at Kandhari, shows the overlying clay layer being thick, with thin intercalation of sandy layers beyond the depth of 60 m. The thin aquifers are partially confined and the quality of groundwater is moderately saline. In North and Eastern areas, sand and clay strata occur in alternations and aquifers are of limited thickness, with moderate potential for shallow tube wells. Deep aquifers are partially confined, and have moderately saline ground water (Figure 3.7).

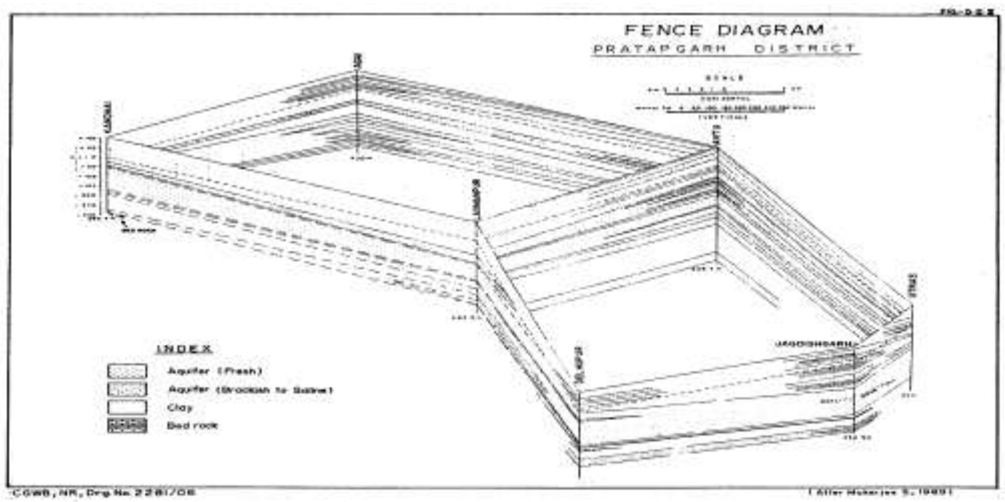


Figure 3.7: Fence Diagram for Pratapgarh

3.11.4-Raebareli

Sub-surface geology of Raebareli is more or less similar to Barabanki , having in general upto 50 m sand:clay ratio is 40: 60 . in North areas the sand layers upto 60-70percent in thickness. In South- Eastern areas the proportion of clay is comparatively high, causing deeper tube wells. The quality of groundwater is good for irrigation use (Figure 3.8).

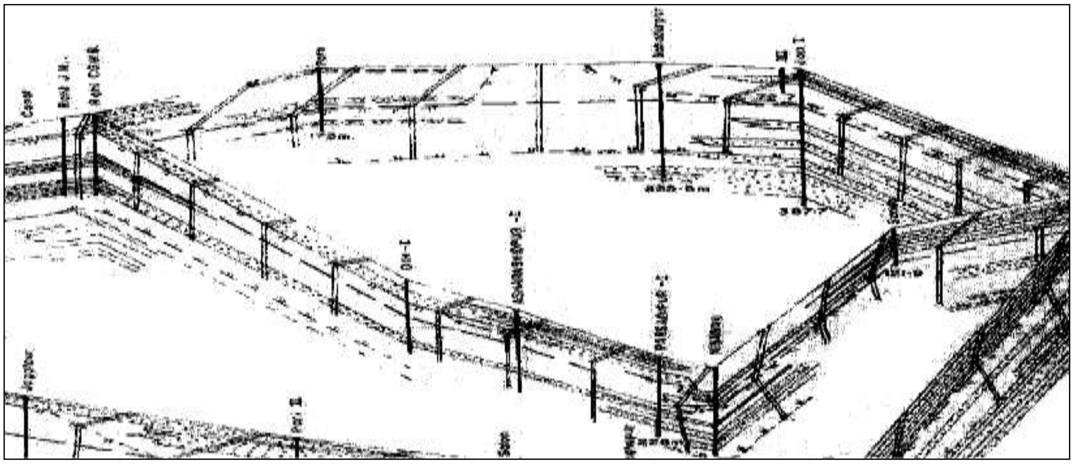


Figure 3.8: Fence Diagram for Raebareli

3.11.5.Sultanpur

The sub–surface geology is more or less similar to Jaunpur, dominated by clay lithology. In Southern and Western areas, a wide extensive thick clay layer occurs, varying in thickness from 5 m to 50 m , with thin intercalation of sandy zones (Bhadar). In general, the shallow aquifers are unconfined having good ground water. Deep aquifers beyond the depth of 70 m are partially confined. The thin semi-confined aquifers have moderately saline ground water (Figure 3.9).

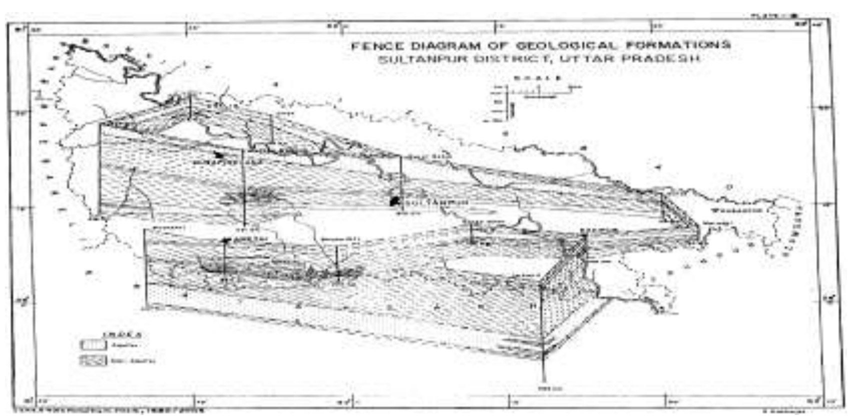


Figure 3.9: Fence Diagram for Sultanpur

3.12. Aquifer Parameters from Pumping Tests

The locations of the three pumping tests conducted by CGWB were at Amethi area in Sultanpur district, Indian Telephone Industries in Raebareli and Jagdishgarh in Pratapgarh district. The variation in lithology in these pumping tests for the top 50 m of depth are given in Table 3.2 to3.4.

Table 3.2: Koiripur, Bhadur and Amethi Areas - Dist Sultanpur

S. N	Depth Range in meters	Thickness	Lithology
1	0.00 - 16.27	16.27	Clay earthy mixed with varying amount of Kankar
2	16.27 - 19.27	6.88	Gravel and kankar (2 to 3mm) mixed with earthy sticky clay
3	19.277 - 26.15	6.88	Clay earthy mixed with varying amount of Kankar
4	26.15 - 44.30	18.15	Kankar (3 to 6 mm) mixed with earthy sticky clay (50%)
5	44.30 - 332.59	288.29	Clay earthy to yellowish brown, sticky mixed with sub-ordinate amount of kankar and medium to fine sand

Table 3.3: Indian Telephone Industries - II Dist – Raebareli

S. No	Depth Range in meters	Thickness	Lithology
1	00.00 - 20.65	20.65	Surface Soil - Silty clay
2	20.65 - 32.81	12.16	Kankar mixed with sand indurated greyish
3	32.81 - 44.81	12.00	Sand medium to fine grained greyish mixed with ferromagnesian minerals
4	44.81 - 54.04	9.15	Sand medium greyish mixed with kankar
5	54.04 - 76.96	22.92	Clay sticky and yellowish mixed with kankar

Table 3.4: Jagdishgarh Exploratory Dist – Pratapgarh

S. N	Depth Range in meters	Thickness	Lithology
1	0.00 - 3.00	3.00	Surface soil and clay yellowish
2	3.00 - 19.00	16.00	Clay sandy greyish fine grained
3	19.00 - 34.00	15.00	Sand fine grained
4	34.00 - 36.00	2.00	Clay plastic mixed with fine sand
5	36.00 - 41.00	5.00	Sand fine grained
6	41.00 - 45.00	4.00	Clay yellow sticky
7	45.00-52.00	7.00	Sand indurated greyish mixed with equal amount of clay
8	52.00 - 58.00	6.00	Sand indurated grayish
9	58.00 - 64.00	6.00	Clay silty
10	64.00 - 70.00	6.00	Clay yellowish

From the analysis of the Shallow aquifer in the aquifer test carried by Central Ground Water Board at Sultanpur area, it appears that silty–clay is the dominant lithology in this area, with the percentage of sand varying from 21%-50%. The aquifer is unconfined and the aquifer material varies from fine to medium sand with intervening clay beds and occasionally admixed with kanker.

At Raebareli, the shallow aquifer is under unconfined conditions and the aquifer material is pre-dominantly silty-sand, with occasional occurrence of kanker. About 27% of sand was found up to the depth of 76 m. The transmissivity and hydraulic conductivity calculated for this area for the 126 m thick shallow aquifer is 1656.2 m2/day and 13 m/day respectively.

In Pratapgarh, the sand percentage was higher than Raebareli and was found to be about 35% of the total sediment column up to the depth of 70 m. The other aquifer characteristics and parameters were found to be consistent with the above two districts.

The data from the ten pumping tests carried out by Ground Water Investigation Organization, U.P. in the Sultanpur and Raebareli districts further support the above findings. From the analysis of four pumping tests in Amethi, Teri, Ghoraha and Kadipur villages of Sultanpur districts, it appears that the lithology in this area varies from clay/silt to fine sand (Table 3.5, 3.6 & 3.7). The lithology of the shallow aquifer up to the depth of 60 m shows that dominant grain size is clay/sand with few sandy (fine sand) horizons. The lithological variations in the grain size for these villages are as follows:

Table 3.5: Village: Ghoraha, Block: Bhader - Dist Sultanpur

S.No	Depth Range (mbgl)	Thickness (m)	Lithology
1	0.00 - 4.00	4.00	Not recorded
2	4.00 - 6.50	2.50	Hard Clay
3	6.50 - 9.00	2.50	Clay
4	9.00 - 12.50	3.50	Clay & Kankar
5	12.50 - 13.50	1.00	Clay
6	13.50 - 17.00	3.50	Clay & Kankar
7	17.00 - 19.50	2.50	Clay
8	19.50 - 20.50	1.00	Clay & Kankar
9	20.50 - 22.50	2.00	Clay
10	22.50 - 26.50	4.00	Clay & Kankar
11	26.50 - 27.50	1.00	Clay
12	27.50 - 30.00	2.50	Clay & Kankar
13	30.00 - 31.50	1.50	Clay
14	31.50 - 37.50	6.00	Clay
15	37.50 - 40.00	2.50	Clay
16	40.00 - 47.00	7.00	Clay & Kankar
17	47.00 - 50.00	3.00	Clay
18	50.00 - 52.50	3.50	Sandy clay / medium sand clay
19	52.00 - 57.50	5.00	Medium sand
20	57.00 - 60.00	2.50	Clay

Table 3.6: Village: Amethi, Block: Amethi - Dist Sultanpur

S.No	Depth Range (mbgl)	Thickness (m)	Lithology
1	0.00 - 3.00	3.00	Not recorded
2	3.00 - 6.00	3.00	Surface clay
3	6.00 - 10.00	4.00	Sandy clay
4	10.00 - 12.00	2.00	Clay
5	12.00 - 16.50	4.50	Clay & kankar
6	16.50 - 19.00	2.50	Clay
7	19.00 - 23.00	4.00	Fine sand
8	23.00 - 28.00	5.00	Clay
9	28.00 - 36.00	8.00	Fine sand
10	36.00 - 38.50	2.50	Clay
11	38.50 - 43.50	5.00	Clay kankar
12	43.50 - 45.00	1.50	Clay
13	45.00 - 50.50	5.50	Clay & kankar
14	50.50 - 54.50	4.00	Clay

Table 3.7: Village: Teri - Dist Sultanpur

S.No	Depth Range (mbgl)	Thickness (m)	Lithology
1	0.00 - 3.04	3.04	Clay Sandy Brown
2	3.04 - 12.19	9.15	Clay Sandy
3	12.019 - 24.38	12.19	Sand, fine with clay blackish
4	24.38 - 39.57	15.19	Clay with sand yellow
5	39.57 - 42.67	3.1	Sand, fine, brown
6	60.96 - 88.29	27.33	Kankar with clay yellow

At Ghoraha village, the geophysical survey (electrical logs) conducted by GWIO, U.P. suggests that in the whole well section, the occurrence of sandy aquifer was very poor and if we consider the well section up to the depth interval to 60 m bgl then the main aquifer was only recorded between the depth interval of 52 m to 57.5 m bgl. On the whole, the section is dominated by clay with occasional patches of kanker.

In Amethi village the conditions are quite different. Here the main sandy aquifer occurs between the depth ranges of 19 m to 23 m and 28 m to 36 m bgl. However, here also whole section is dominated by clay and/with kanker.

In Teri village, the main aquifer in the shallow zone (up to 60 m bgl) ranges between 39 m to 60 m bgl. The section is dominated by silt/sandy clay. The average coefficient of transmissivity of the pumping test was found to be 1234 m2/day.

The infiltration test at Kadipur village, district Sultanpur suggests that the hydraulic conductivity in this area should be 3.43 cm/hr (0.8 m/d) and specific yield is about 9.0 %.

The lithological variations in the grain size for the six villages of Raebareli district are as follows (Table 3.8 to 3.12). (Source: Groundwater Investigation Organization, U.P.):

Table 3.8: Village: Jais Town; Block: Jais; Dist: Raebareli

S. No	Depth Range (mbgl)	Thickness (m)	Lithology
1	0.00 - 2.50	2.50	Sand Clay
2	2.50 - 7.50	5.00	Hard Clay
3	7.50 - 10.00	2.50	Clay
4	10.00 - 15.00	5.00	Silt to fine sand
5	15.00 - 20.00	5.00	Clay
6	20.00 - 30.00	10.00	Fine clay
7	30.00 - 37.50	7.50	Silty or fine sand with kankar
8	37.50 - 40.00	2.50	Clay
9	40.00 - 42.00	2.00	Silty or fine sand with clay
10	42.00 - 45.00	3.00	Silty to fine sand
11	45.00 - 50.50	5.50	Silty or fine sand with clay
12	50.50 - 53.00	2.50	Clay
13	53.00 - 60.50	7.50	Clay with Kankar

Table 3.9: Village: Dlawarpur; Block Deeh - Dist Raebareli

S. No	Depth Range (mbgl)	Thickness (m)	Lithology
1	2.00 - 8.00	6.00	Fine Sand
2	8.00 - 9.00	1.00	Clay
3	9.00 - 12.50	3.50	Sand Clay
4	12.50 - 15.00	2.50	Clay
5	15.00 - 17.50	2.50	Sand Clay
6	17.50 - 18.50	1.00	Clay
7	18.50 - 22.50	4.00	Fine Sand
8	22.50 - 26.50	4.00	Sand Clay
9	26.50 - 31.50	5.00	Fine Sand
10	31.50 - 34.50	3.00	Clay
11	34.50 - 39-50	5.50	Sand Clay
12	39.50 - 42.50	3.00	Clay
13	42.50 - 49.50	6.50	Fine Sand
14	49.00 - 51.00	2.00	Sand Clay
15	51.00 - 53.00	2.00	Fine Sand
16	53.00 - 58.00	5.00	Clay

Table 3.10: Village: Sarai Baheria Khera; Block Sareni - Dist Raebareli

S. No	Depth Range (mbgl)	Thickness (m)	Lithology
1	3.00 - 5.00	2.00	Hard Clay
2	5.00 - 13.00	8.00	Clay
3	13.00 - 15.00	2.00	Fine Clay
4	15.00 - 20.00	5.00	Silty Sand
5	20.00 - 23.00	3.00	Fine Clay
6	23.00 - 25.00	2.00	Silty fine Sand
7	25.00 - 29.00	4.00	Fine to Silty Sand
8	29.00 - 31.00	2.00	Clay
9	31.00 - 36.00	5.00	Clay with kanker
10	36.00 - 40.50	4.50	Clay
11	40.50 - 44.50	4.00	Kankar or fine sand with clay
12	44.50 - 54.50	10.00	Fine sand
13	54.50 - 66.50	12.00	Clay

Table 3.11: Village: Mohiddinpur; Block: Salon; Dist- Raebareli

S.No	Depth Range (mbgl)	Thickness (m)	Lithology
1	3.00 - 9.50	6.50	Fine to medium sand
2	9.50 - 13.00	3.50	Clay
3	13.00 - 17.00	4.00	Fine sand and kankar
4	17.00 - 18.00	1.00	Clay
5	18.00 - 24.50	6.50	Fine sand and kankar
6	24.50 - 26.50	2.00	Clay
7	26.50 - 32.00	5.50	Clay and kankar
8	32.00 - 34.50	2.50	Clay
9	34.50 - 44.50	10.00	Kankar and clay
10	44.50 - 47.00	2.50	Clay
11	47.00 - 50.50	3.50	Clay and kankar

Table 3.12: Village: Kaurapur Gaura; Block: Dih; Dist- Raebareli

S. No	Depth Range (mbgl)	Thickness (m)	Lithology
1	0.0 - 4.0	4.00	Surface clay
2	4.0 - 12.5	8.50	Sand Clay / fine sand with clay
3	12.5 - 15.5	3.00	Fine sand
4	15.50 - 23.0	7.50	Clay
5	23.0 - 28.0	5.00	Fine sand
6	28.0 - 30.5	2.50	Sand Clay
7	30.5 - 35.5	5.00	Fine sand with clay
8	36.5 - 37.5	2.00	Clay
9	37.5 - 39.0	1.50	Silt or sand clay
10	39.0 - 43.0	4.00	Clay
11	43.0 - 47.5	4.50	Fine to Med Sand
12	47.5 - 49.0	1.50	Sandy Clay
13	49.0 - 50.0	1.00	Pure Clay
14	50.0 - 53.00	3.00	Fine to Med Sand
15	53.0 - 56.0	3.00	Sand Clay

The pumping test analysis for the Jais Town suggests that the aquifer material is sand, kanker, clay and their admixtures. In the shallow aquifer (up to 60 m); clay was found to be the dominant grain size fraction. However, the major zone of granular composition occurs at the depth range of 20-37.5 m. This zone could be considered as a good groundwater bearing horizon and construction of shallow tube wells were recommended in the 20-30 m depth zone. At Dlawarpur village, the lithology was found to be sand, kanker, clay and their admixtures. The occurrence of sand starts right from the surface and continues up to the depth of 53 m bgl with interference of clay layers in between. The aquifers are occurring in the depth range from 18.5 m to 22.5 m, 26.5 m to 31.5 m and 42.5 m to 48.5 m. The pumping test at Sarai Baheria Khera suggests that the aquifer material in this village is dominantly silt, clay and fine sand with occasional occurrence of kanker. The Strata Chart prepared on the basis of log interpretation by the Groundwater Investigation Organization suggests that the major shallow aquifers occur at the depth range of 13- 29 m and 44.5-54.5 m bgl.

The electrical log interpretation of Mohiddinpur village suggests that the dominant grain size in this area is fine sand and clay with occasional occurrence of kanker in the clay layers. Clay is dominant in the top 50 m lithology. In Kaurapur Gaura village, the lithology mainly shows the dominance of fine sand, clay and their mixtures. Since the sand formations are mostly fine grained and are comparatively thinner, so it seems to comprise a poor aquifer. It is being also suggested by the Groundwater Investigation Organization that there is lack of potential water bearing zones suitable for large scale exploitation, up to their depth of investigation. However, the fine to medium sand zones are present at the depth range of 43-47.5 m bgl and 50-53 m bgl. Tahal1 located two measurements of aquifer parameters in the shallow aquifer system in Sultanpur District. At Sultanpur Tehesil, Kurebhar Block, the transmissivity is

68.5 m2/day, Hydraulic Conductivity is 5.48 m/day and at Dhanpatganj transmissivity is 1,012 m2/day, Hydraulic Conductivity 14.6 m/day.

3.13-Hydraulic Conductivity:

With reference to the various available reports and strata charts from State Tube well drilling logs, the aquifer material was found to be more or less fine sand and thus a value of 15 m/day has been found to be appropriate to the conditions, the estimated recharge and prevailing water levels. The value was varied to 10, 20 and 30m/d for modelling purposes and is in conformance with the Central Ground Water Board (CGWB) norms.

3.14-Specific Yield:

The average value of 0.15 has been adopted as per recommendation of CGWB for various grains sized alluvial material in the Ground water estimation committee 1997 norms.

In the sensitivity testing of the developed Model, the testing was carried out for 0.10 and 0.20 to cover the range of grain size most commonly observed in the State Tube well logs.

3.15-Thickness of Aquifer:

From the CGWB report of 1996, the upper aquifer in Jaunpur, Sultanpur and Pratapgarh districts of the study area was stated to average 50 metres thickness. Review of State Tubewell logs and hydrogeological reports for each district showed that it is very difficult to define the unconfined (or phreatic) aquifer. This is because the alluvium consists of multiple inter-fingering layers of sand, silt and clay that are semi-continuous in the study area. However there does appear to be a consistent layer of clay about 20 m to 30 m thick.

In this groundwater modeling, we have focused on the interaction between the shallow phreatic aquifer and surface water (rivers, drains, soil moisture and recharge). Therefore, the model output of concern is the depth to groundwater level and the water balance between surface water and shallow groundwater. Deeper aquifers are of little consequence in this analysis as they do not significantly interchange with the unconfined aquifer in the study area.

CHAPTER 4

WATER AVAILAILITY AND UTILISATION IN GOMTI BASIN

4.1. Introduction

The part of Indo-Gangatic plain considered in this work is Gomti Basin.Area of Gomti Basin, lies between latitudes 25^0 25′ 00″ and 28^0 45′ 00″, and longitudes 80^0 03′ 00″ and 83^0 10′ 00″. The Gomti, an alluvial river of the Ganga Plain, originates near Mainkot, form a lake-Fulhar Jheel in Madhotanda about 30 km east of the Pilibhit town in Uttar Pradesh, at an elevation of 191 m. After flowing southwards through the districts of Sitapur, Lucknow, Barabanki, Sultanpur and Jaunpur, it confluences with River Ganga in Kaithi, Ghazipur bordering Varanasi (at an elevation of 56 m) after traversing 893 km. The total drainage area of Gomti basin is 30,934 sq. km. The total drainage network of Gomti basin consists of 42 drains and is having a total length of 2635 km. Kathna, Saraian, Kalyani, Behta, Reth and Pili nadi are the major tributaries. Sai River is its major tributary having drainage area of 12,900 sq. km, approximately 43% of the total catchment area of Gomti basin. The Sai River, originates in Hardoi district and it separates the district of Lucknow and Unnao.

4.2. Topography of Gomti Basin

Except Lucknow, 15 districts are partially covered in the catchment of Gomti River. Starting from Pilibhit, Lakhimpur, Shajahanpur, Hardoi, Sitapur, Lucknow, Unnao, Raiberelli, Barabanki, Sultanpur, Pratapgarh, Jaunpur, Faizabad, Gazipur, Varanasi and Allahabad are the districts falling in Gomti catchment. 169 blocks of these districts completely or partially, fall in the catchment of Gomti Basin. Surface elevation in Gomti Basin varies from 224 m to 58 m, based on Shuttle Radar Topographic Mission 90m resolution data, as shown in Figure 4.1.The area of Gomti basin lies between latitudes 25^0 25′ 00″ and 28^0 45′ 00″, and longitudes 80^0 03′ 00″ and 83^0 10′ 00″.

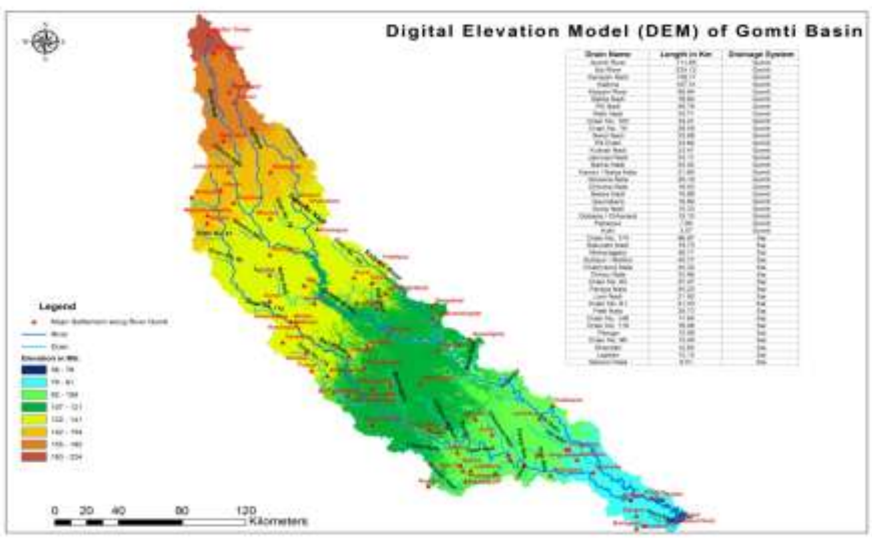


Figure 4.1 Digital Elevation Model of Gomti Basin, based on SRTM90

4.3. Canal Network in Gomti Basin

The basin is covered through a canal network of about 25000 km. From origin to Lucknow it is covered with Sharda canal network. Area lying between Hardoi and Khiri branches brings water from Banbasa barrage on river sharda in district pilibhit. Downstream Lucknow, additional water after diversion from Ghagra River at Sharda barrage, water is transferred in gomti basin through Sharda Sahayak feeder. Area lying between its Allahabad branch and Sultanpur branch falls under gomti basin.

4.3.1.Sarda System

The Sarda Canal is one of the largest and oldest systems in Uttar Pradesh. It was commissioned in 1928 to provide irrigation to a command area of 2.55 million ha in the area bounded by Ghaghra and Ganga Rivers. The main Sarda Canal takes off from the river Sarda at Banbassa. Originally the head discharge was 269 cumecs, but this was increased to 326 cumecs later to cater for increased water requirement, due to the introduction of high yielding varieties of crops.

The main Sarda Canal has a length of 45 km. The most important offtaking canals from the Sarda canal are Hardoi Branch (length 252 km, original capacity 125 cumecs, modified capacity 187 cumecs), Kheri Branch (length 200 km, capacity 79 cumecs) and Deoha Baigul Feeder System (capacity 68 cumecs). The total length of the Sarda canal system is about 9677 km. The existing CCA of the Sarda system is 1.61 million ha. Total proposed irrigation area is 804,000 ha (50% of CCA), of which 417,000 ha (26%) is the Kharif area and 385,000 ha (24%) is the Rabi area.

4.3.2. Sarda Sahayak System

Water is transferred from Girija Barrage constructed on Ghaghra River near Katarnia Ghat to Sarda River through a 28.7 km Link Channel of 480 cumecs capacity. The Link Channel transfers water to the Sarda River upstream of the Lower Sarda Barrage. 258.8 km long Feeder Channel (650 cumecs) from lower sharda barrage crossing Gomti and Sai Rivers through aqueducts providing irrigation water to CCA of 16.74 lakh ha at annual irrigation intensity of 115%.

1378 km long main canals and 14,684 km long distributaries and minors were constructed. The major branches offtaking from the Feeder Canal are Dariyabad Branch of length 153 km and 239 cumecs discharge capacity, Barabanki Branch of length 30 km and 35 cumecs discharge capacity, Haidergarh Branch of length 30.3 km and 141 cumecs discharge capacity, Allahabad Branch of length 59 km and 147 cumecs discharge capacity and Pratapgarh Branch of length 16 km and 32 cumecs discharge capacity.The details of canal and drainage network along with districts covered is shown in Figure 4.2

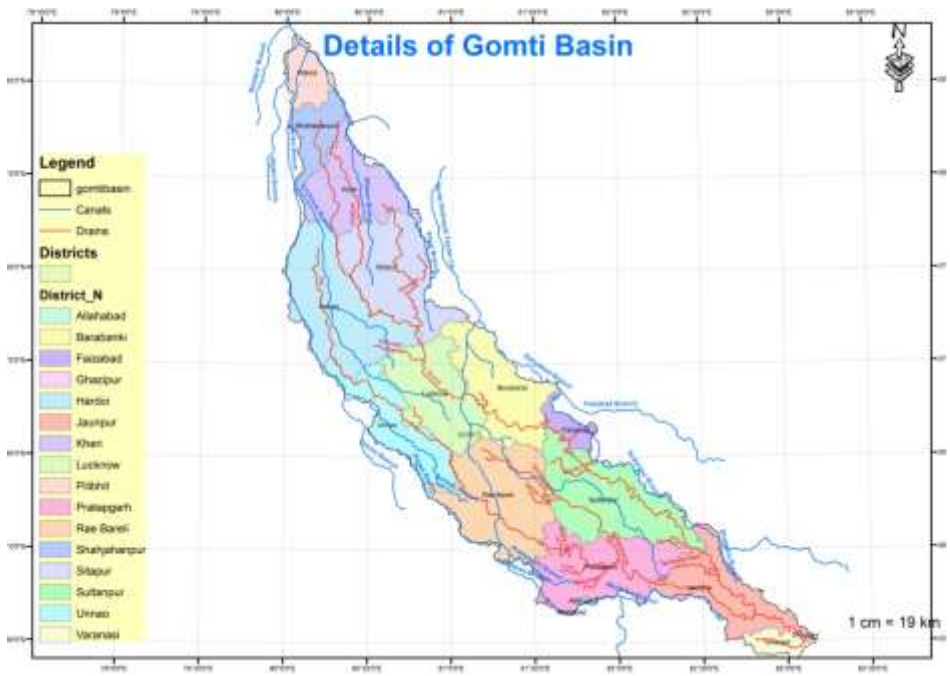


Figure 4.2-Canal network in Gomti Basin

4.4. Ground Water

Gomti basin, a part of indogangatic plains of Uttar Pradesh, where groundwater is easily assessable and widely available due to favorable aquifer pattern. It is significant to mention that ground water besides being the main source for irrigation, 80-90 % of drinking water supplies and more than 50% of the industrial needs of the state are ground water based. This growing dependence and excessive use of ground water has eventually put an adverse impact on the resource domain in the form of unsustainable over-extraction and subsequent lowering of ground water levels. As a result, the situation of ground water in many rural and urban segments of the study area has now reached to a critical stage. Large numbers of blocks are over stressed due to indiscriminate ground water extraction, while major cities are also experiencing water level decline at a much faster pace.

4.5. Ground Water Regime monitoring

The water level monitoring at hydrograph stations of Central Ground Water Board (more than 1200 wells) and State Ground Water Department, UP, spread throughout all the blocks of the state is carried out four and six times respectively in a year.

The current status report of State ground water board. U.P predicts that water levels in the state show a wide variation from less than 1 to more than 35 mbgl (meter below ground level). In Bhabar areas, the depth to water level varies from 8 to more than 35 mbgl, while in Terai area it ranges from less than 1 to 10 mbgl. The central and eastern parts of the state show a wider range of water levels varying from less than 1 mbgl (Canal Command area) to more than 30 mbgl along the natural levees formed on either side of river Ganga. Major part in the western Uttar Pradesh is characterized by deeper water levels. The water levels have shown significant declining trends over the last two decades in some parts of the state due to over-exploitation of the ground water resource. The deepest water levels of around 40 mbgl are encountered in the ravenous tracts along the Yamuna and Betwa rivers.

Ground water levels data are analyzed. During Pre-monsoon period there is a declining trend in water levels as observed at 82% of the monitoring stations distributed throughout the state, over the last 10 years period. Decline of 0 – 20 cm/yr is most extensive covering 430 (43%) wells followed by 20 – 40 cm/yr in 205 (20%) wells, 40 – 60 cm/yr at 88 (9%) stations and >60 cm/yr at 97 (10%) wells. Higher rate of decline occurs along the western and southern boundaries. There is a rise in trend in 18% of the monitoring wells over the same period.

During Post-monsoon period there is a declining trend observed at 79% of the monitoring wells over last 10 years period. Decline of 0 – 20 cm/yr is most extensive covering 381 (37%) wells followed by 20 – 40 cm/yr seen at 183 (23%) wells, 40 – 60 cm/yr decline is observed at 114 (11%) stations and more than 60 cm/yr at 132 (13%) stations. Higher decline occurs along the western, north western and southern boundaries and along Yamuna river. There is a rise in trend in 21% of the monitoring wells over last 10 years period.

The main factors contributing to the depletion of ground water are its over-exploitation to meet the demands of various sectors. This declining trend is causing an alarming situation thus adversely affecting water supply, increase in electricity consumption, agriculture production and economy of the State.

4.6. Ground water level trend analysis in Gomti basin using Arc GIS

Based on the availability of pre monsoon and post monsoon data for thirty years period from the State ground water department U.P, 479 monitoring wells from Gomti Basin were geo referenced for analysis on GIS plate form.

Pre monsoon data for the year 1984, was analysed on GIS plate form for Gomti Basin having a catchment of 30934 sq km in 16 districts starting from Pilibhit, Lakhimpur, Shajahanpur, Hardoi, Sitapur, Lucknow, Unnao, Raiberelli, Barabanki, Sultanpur, Pratapgarh, Jaunpur, Faizabad, Gazipur, Varanasi and Allahabad districts. It predicts that in pre monsoon of 1984, the ground water levels in 5.73% area was between 0 to 3m below ground levels and in 52.26 % it was between 3 to 5 m below ground levels as shown in Figure 4.3.While in 38.12 % area it was between 5 to 8 m and only in 3.89% area it was below 8m.We can further say that in 57.99 % area ground water was available within 5m from ground levels and in 42.01% areas it was below 5 m up to a maximum depth of 16.5m.

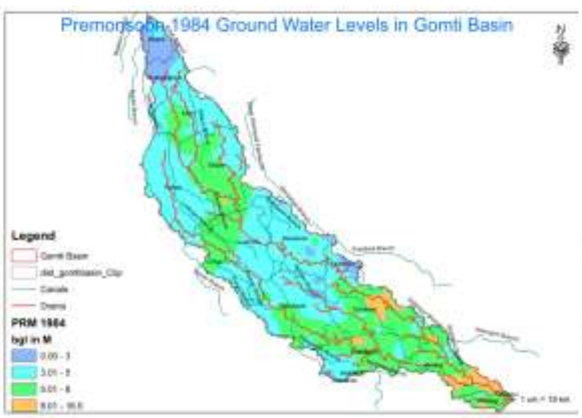


Figure 4.3 Pre monsoon 1984 Ground water levels

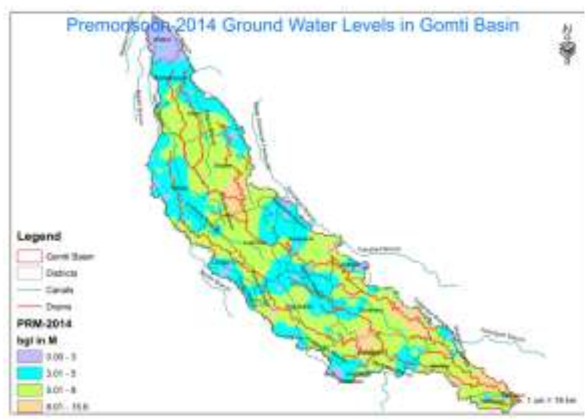


Figure 4.4 Pre monsoon 2014 Ground water levels

Pre monsoon data for the year 2014 was further analyzed on GIS plate form. It predicts that in pre monsoon of 2014, the ground water levels in 5.23% area was between 0 to 3m below ground levels and in 34.03 % it was between 3 to 5 m below ground levels as shown in Figure 4.4.While in 52.82 % area it was between 5 to 8 m and only in 7.97% area it was below 8m.We can further say that in 39.26 % area ground water was available within 5m from ground levels and in 60.74% areas it was below 5 m up to a maximum depth of 16.5m.

It clearly predicts that during a period of 30 years in pre monsoon periods the area where the ground water is available up to 5m below ground has reduced to 39.26% as against to 57.99 % and the areas where ground water is available below 5m has increased from 42.01% to 60.75 %.

Similarly for the post monsoon period of 1984, the ground water levels in 45.35% area was between 0 to 3m below ground levels and in 45.45 % it was between 3 to 5 m below ground levels as shown in Figure 4.5,While in 8.92 % area it was between 5 to 8 m and only in 0.28% area it was below 8m.We can further say that in 90.80 % area ground water was available within 5m from ground levels and in 9.20% areas it was below 5 m up to a maximum depth of 11.1m.

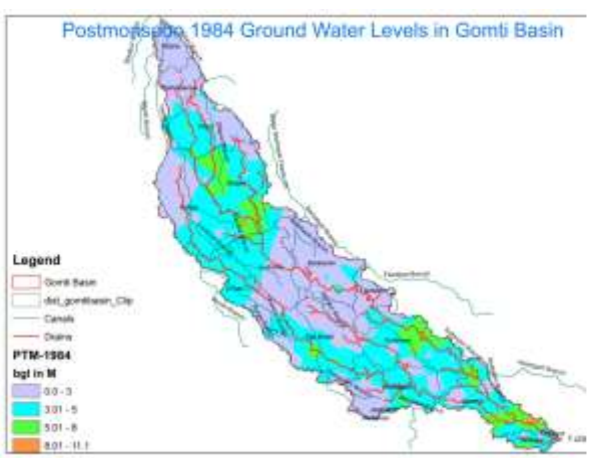


Figure 4.5 Post- monsoon 1984 Ground water levels

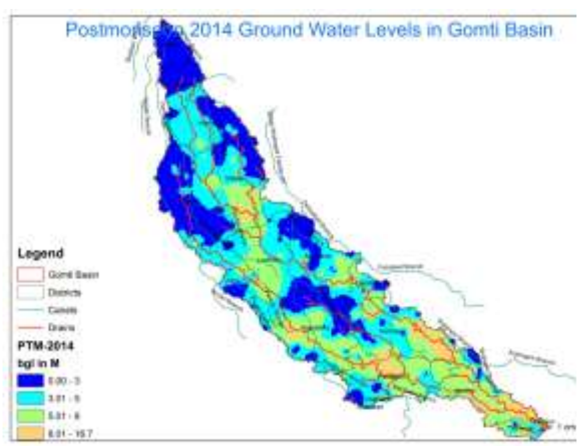


Figure 4.6 Post- monsoon 2014 Ground water levels

Post monsoon data for the year 2014 was further analyzed on GIS plate form. It predicts that in post monsoon of 2014, the ground water levels in 29.79% area was between 0 to 3m below ground levels and in 35.52 % it was between 3 to 5 m below ground levels as shown in Figure 4.6,While in 28.92 % area it was between 5 to 8 m and only in 5.77% area it was below 8m.We can further say that in 65.31 % area ground water was available within 5m from ground levels and in 34.69% areas it was below 5 m up to a maximum depth of 16.7m.

It clearly predicts that during a period of 30 years in post monsoon periods the area where the ground water is available up to 5m below ground has reduced to 65.31% as against to 90.80 % and the areas where ground water is available below 5m has increased from 9.20% to 34.69 %.

4.7. Land use of Gomti Basin:

Gomti basin with a geographical area of 30.93 lac ha is having net sown area of 20.24 lac ha and canal commands of 14.84 lac ha. Landuse in Gomti basin based on NIC statistics of 2012 is summarized and tabulated below in Table 4.1

Table 4.1. Landuse of Gomti Basin

Basin Name	Basin area in ha	Net Area Sown in ha	Net Area Sown %	Forest area%	Gross Cropped Area	Cropping intensity	Area Sown in Different Season %of gross cropped				
							Kharif	Rabi	Zaid	Area left for sugarcane	Total
GOMTI	3093409	2024502	65.66	3.62	3197007	157.92	45.95	48.5	5.44	0.12	100

4.8. Irrigation Status in Gomti basin

The details of irrigated area from different sources based on NIC statistics of 2012, is given below in Table 4.2.

Tale 4.2-Irrigation from different sources in Gomti Basin

Basin area in lac ha	Canal irrigation in lac ha	Government T.W irrigation in lac ha	Private TW irrigation in lac ha	Irrigation by other means in lac ha	% rain fed
30.93	6.50 (20.52%)	0.62 (1.97%)	20.00 (63.25%	0.48 (1.53%)	(12.74%)

4.9. Climate

The climate of Gomti Basin is sub-tropical, monsoonal. Winters (October to February) are cool and dry with occasional fogs and light showers, summers (March to early June) are hot and dry, and the monsoon season (middle June to September) is warm and humid, with frequent heavy rainfall.

4.9.1.Rainfall data analysis of districts in Gomti basin

Rainfall data of Indian Meteorological department Pune, data available on India water Portal and that of tehsil head quarters available with Irrigation department U.P and has been collected and used in the model for different rainfall sequences of normal, dry and wet sequences along with different dependability of 50%.60%.75%,90% on yearly and monthly basis.

Monthly rainfall data analysis of District Pilibhit for the last 43 years staring from 1971-72 to 2012-13 was analyzed. It predicts that an annual rainfall figure varies between 448 mm to 1734 mm with a decreasing trend from 1150 mm per year to 810 mm per year during the last forty three years. While the monsoon rainfall figures vary between 347.8 mm to 1621mm per year with a decreasing trend from 1040 mm to 720 mm. Non monsoon period rainfall during the last forty years period varies between 172 mm to 3.0mm only with a more or less constant trend of 100 mm per year as shown in Figure 4.7.

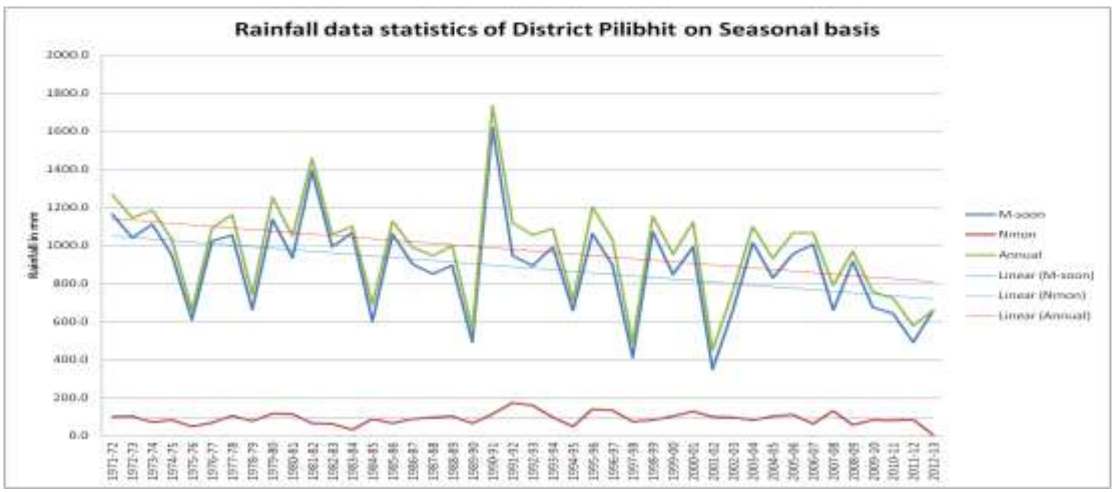


Figure 4.7-Rainfall data analysis of District Pilibhit on seasonal basis

Monthly rainfall figures with maximum rainfall in a month varies from 182mm to 584 mm with an average of 343 mm .However it also shows a decline trend from 400 mm to 295 mm during the last forty three years. Mean monthly rainfall varies from 37 mm to 145 mm with an average of 82mm; however it also shows a declining trend from 100 mm per year to 80 mm per year, as shown in Figure 4.8.

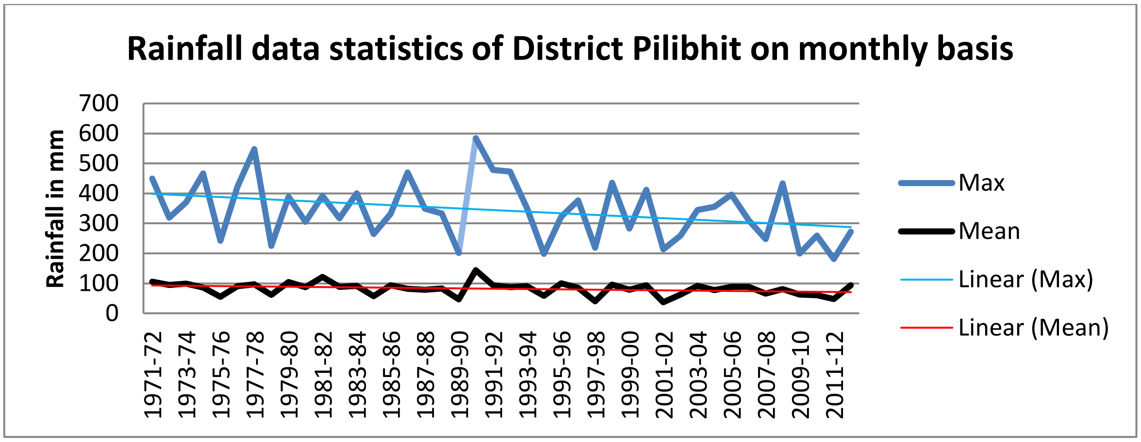
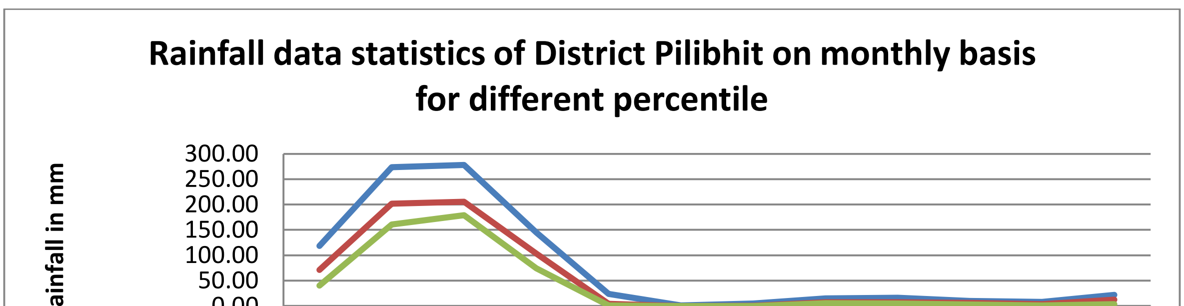


Figure 4.8-Rainfall data analysis of District Pilibhit on monthly basis

Monthly rainfall data analysis at different percentile of 50%.,75% and 90%,shows an yearly rainfall of 914 mm per year on 50% percentile,623 mm per year on 75% percentile and 423 mm per year on 90% percentile. Monthly availability at different percentiles is shown in Figure 4.9.



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
50% Percentile	118.36	273.45	277.74	144.63	23.41	1.06	4.98	14.57	15.92	9.93	8.12	21.70
75% percentile	71.12	201.76	205.55	103.20	4.42	0.00	0.35	7.25	7.37	5.72	3.55	12.23
90% percentile	39.91	160.85	179.00	74.07	0.83	0.00	0.00	5.42	4.47	2.96	0.94	3.35

Figure 4.9-Rainfall data analysis of District Pilibhit on monthly basis for different percentile

It clearly predicts that monthly rainfall behavior plays a major role in meeting the crop water requirement to be supplemented either from surface water through canal irrigation or through ground water irrigation through shallow or deep borings.

Yearly rainfall of districts falling in Gomti basin, namely Pilibhit, Khiri, Shahajahanpur, Hardoi, Sitapur, Unnao, Lucknow, Raiberelli, Barabanki, Faizabad, Pratapgarh, Sultanpur, Jaunpur, Allahabad and Varanasi for the last 43 years from 1971-72 to 2012-13 was analyzed. It was found that average rainfall in the basin has declined to about 800 mm in the year 2012-13, as against 1050 mm in the year 1971-72 as shown in Figure 4.10.

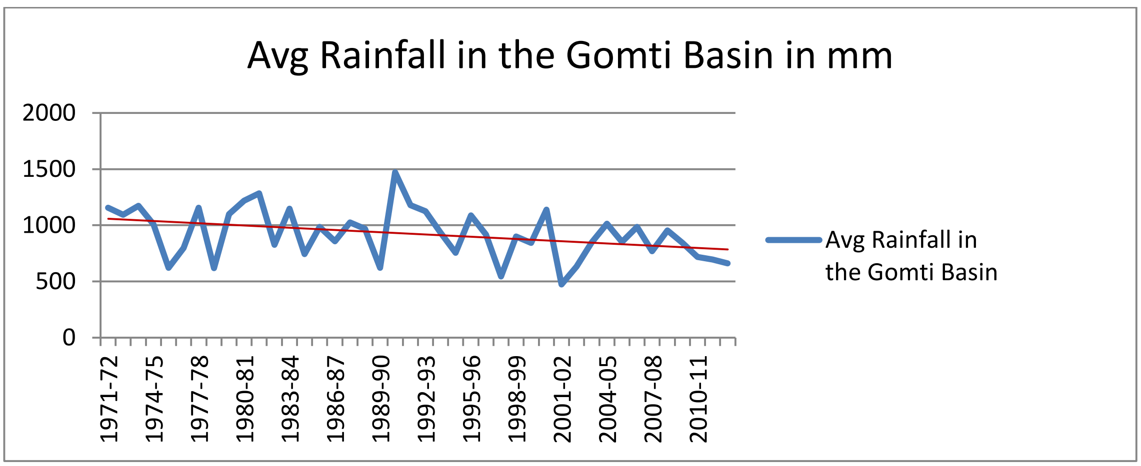
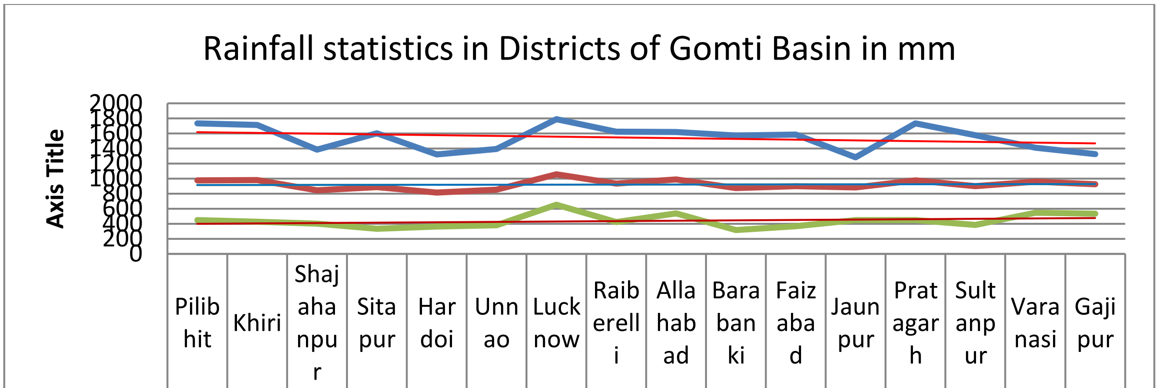


Figure 4.10-Rainfall data analysis in Gomti basin on yearly basis

However, if we take maximum, average and minimum rainfall figures for all the stations of Gomti basin for the same 43 years starting from 1971-71 to 2012-2013, it predicts that maximum rainfall figures in the basin has declined from 1600 mm to 1470 mm, while the average rainfall figures in the gomti basin for the concern districts is more or less constant that is about 920 mm per year and the minimum rainfall figures for the concerned districts has even increased from 400 mm per year to 450 mm per year, as shown in Figure 4.11.



	Pilibhit	Khiri	Shajahanpur	Sitapur	Hardoi	Unnao	Lucknow	Raibereli	Allahabad	Barabanki	Faizabad	Jaunpur	Pratagarh	Sultanpur	Varanasi	Gajipur
max	1734	1712	1386	1601	1323	1394	1790	1624	1621	1575	1584	1281	1734	1576	1411	1325
avg	976	982	842	889	813	854	1058	933	990	876	899	884	976	899	958	927
min	448	427	402	334	361	379	652	424	538	315	368	450	448	384	546	535

Figure 4.11-Rainfall data analysis of Districts falling in Gomti basin on yearly basis

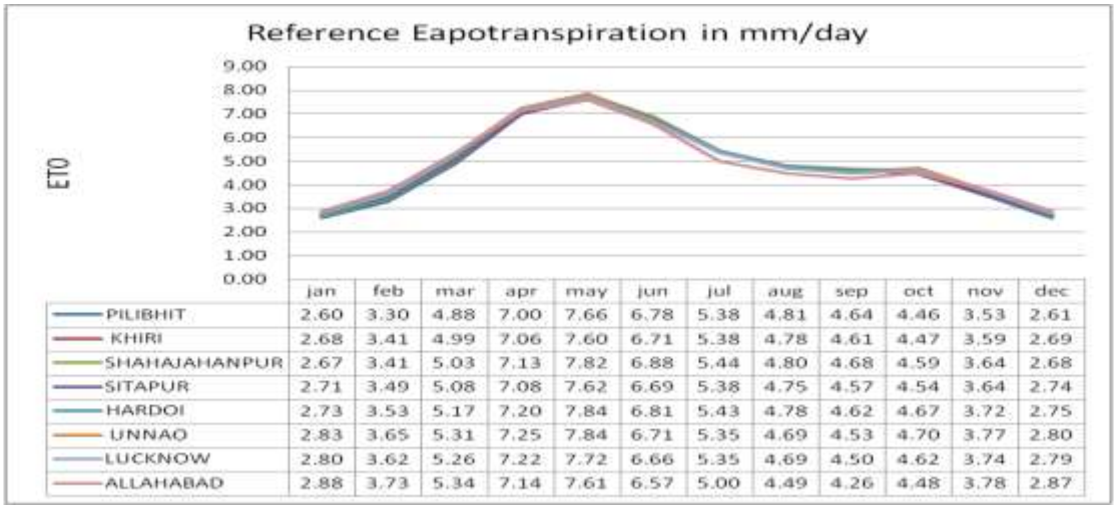
It clearly predicts that, as a whole for Gomti basin the yearly rainfall has declined to 800 mm as against 1050 mm during a period of 43 years, however if we analyze at district level, it predicts that average rainfall figures in the basin are more or less constant to about 920 mm .

4.9.2. Evapotranspiration data analysis of districts in Gomti basin

Evapotranspiration is said to equal potential evapotranspiration when there is ample water. Potential evapotranspiration is expressed in terms of a depth of water, Potential evapotranspiration is usually measured indirectly, from other climatic factors, but also depends on the surface type, such free water (for lakes and oceans), the soil type for bare soil, and the vegetation. Often a value for the potential evapotranspiration is calculated at a nearby climate station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration, and can be converted to a potential evapotranspiration by multiplying with a surface coefficient. In agriculture, this is called a crop coefficient. The difference between potential evapotranspiration and precipitation is used in irrigation scheduling.

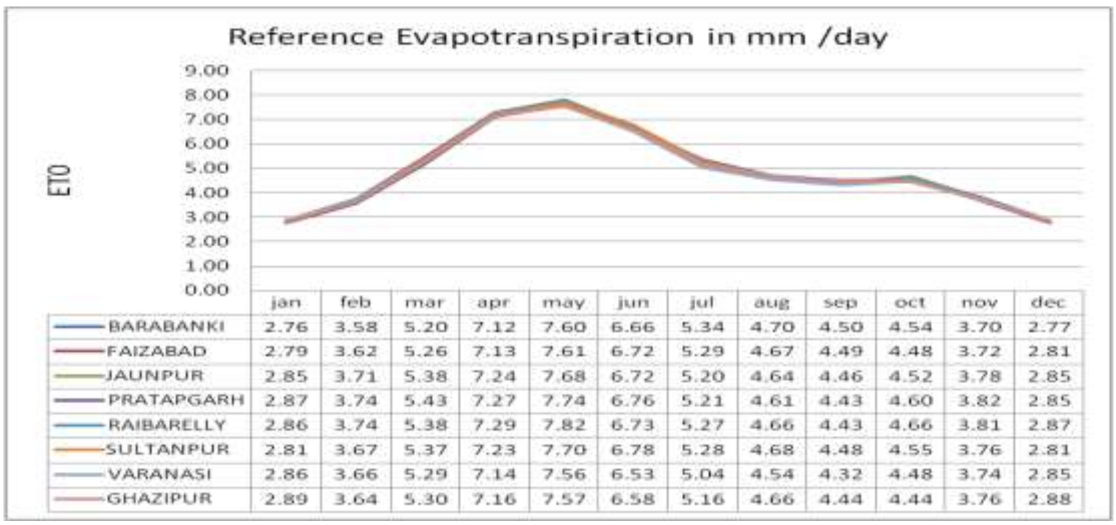
The evapotranspiration process is composed of soil evaporation (E) and transpiration (T). Transpiration is the water transpired or lost to the atmosphere from small openings on the leaf surfaces. Evaporation is the water evaporated or lost from the wet soil and plant surfaces. Significant evaporation can take place only when the soil's top layer (1-2 inches) or plant canopy is wet. Once the soil surface is dry, evaporation decreases sharply.

Reference evapotranspiration figures variation depends upon temperature, humidity, air velocity and other climatic parameters. It varies between 7.84 mm per day during summer period to as low as about 2.60 mm per day during cool period, as shown in Figure 4.12 & Figure 4.13.



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
PILIBHIT	2.60	3.30	4.88	7.00	7.66	6.78	5.38	4.81	4.64	4.46	3.53	2.61
KHIRI	2.68	3.41	4.99	7.06	7.60	6.71	5.38	4.78	4.61	4.47	3.59	2.69
SHAHAJAHANPUR	2.67	3.41	5.03	7.13	7.82	6.88	5.44	4.80	4.68	4.59	3.64	2.68
SITAPUR	2.71	3.49	5.08	7.08	7.62	6.69	5.38	4.75	4.57	4.54	3.64	2.74
HARDOI	2.73	3.53	5.17	7.20	7.84	6.81	5.43	4.78	4.62	4.67	3.72	2.75
UNNAO	2.83	3.65	5.31	7.25	7.84	6.71	5.35	4.69	4.53	4.70	3.77	2.80
LUCKNOW	2.80	3.62	5.26	7.22	7.72	6.66	5.35	4.69	4.50	4.62	3.74	2.79
ALLAHABAD	2.88	3.73	5.34	7.14	7.61	6.57	5.00	4.49	4.26	4.48	3.78	2.87

Figure 4.12 monthly reference evapotranspiration for the districts falling in Gomti basin



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
BARABANKI	2.76	3.58	5.20	7.12	7.60	6.66	5.34	4.70	4.50	4.54	3.70	2.77
FAIZABAD	2.79	3.62	5.26	7.13	7.61	6.72	5.29	4.67	4.49	4.48	3.72	2.81
JAUNPUR	2.85	3.71	5.38	7.24	7.68	6.72	5.20	4.64	4.46	4.52	3.78	2.85
PRATAPGARH	2.87	3.74	5.43	7.27	7.74	6.76	5.21	4.61	4.43	4.60	3.82	2.85
RAIBARELLY	2.86	3.74	5.38	7.29	7.82	6.73	5.27	4.66	4.43	4.66	3.81	2.87
SULTANPUR	2.81	3.67	5.37	7.23	7.70	6.78	5.28	4.68	4.48	4.55	3.76	2.81
VARANASI	2.86	3.66	5.29	7.14	7.56	6.53	5.04	4.54	4.32	4.48	3.74	2.85
GHAZIPUR	2.89	3.64	5.30	7.16	7.57	6.58	5.16	4.66	4.44	4.44	3.76	2.88

Figure 4.13 monthly reference evapotranspiration for the districts falling in Gomti basin

4.10. Summary and Conclusions

Gomti basin with a geographical area of 30.93 lac ha ,covered through a canal network of 25000 km, is having net sown area of 20.24 lac ha and canal commands of 14.84 lac ha.Net sown area in Gomti Basin is 65.66%, with a cropping intensity of

157.92.Only 20.52% area is supported from canal irrigation, 1.97 % area is supported from deep tube wells and major area of 63.25% is supported from private shallow borings. Monthly reference evapotranspiration in the basin varies from 2.60 mm per day to 7.84 mm per day.

The average rainfall in the Gomti basin,consisting a whole or part of districts namely,pilibhit,khiri,shahajahanpur,hardoi,sitapur,unnao,lucknow,raiberelli,barabanki,faizabad,pratapgarh,sultanpur,jaunpur,allahabad and Varanasi of Uttar Pradesh, has declined to about 800 mm in the year 2012-13, as against 1050 mm in the year 1971-72,during a period of 43 years. However if we analyze at district level, it predicts that average rainfall figures in the basin are more or less constant to about 920 mm.

In Gomti basin having an area of 30,934 sq. km, during a period of 30 years (1984 to 2014) the area in pre monsoon periods, where the ground water is available up to 5m below ground has reduced to 39.26% as against to 57.99 % and the areas where ground water is available below 5m has increased from 42.01% to 60.75 %.Similarly for the post monsoon periods the area where the ground water is available up to 5m below ground has reduced to 65.31% as against to 90.80 % and the areas where ground water is available below 5m has increased from 9.20% to 34.69 %.

CHAPTER 5

SPATIO-TEMPORAL MAPPING OF GROUNDWATER FOR THE STUDY AREA USING Arc GIS

5.1.0. Introduction

Detailed field level studies are carried out for Gomti Balrampur drain doab and Ramganj distributaury command, which is a part of Gomti basin. Gomti balrampur drain doab with a geographical area of 66939 ha is located between N 25^0 50′ 50″ and 26^0 13′ 35″, and E 82^0 01′ 53″ and 82^0 35′ 43″, while Ramganj distriutaury command area of 39860 ha is also located between N 25^0 50′ 50″ and 26^0 13′ 35″, and E 82^0 01′ 53″ and 82^0 35′ 43″,

Digital automatic ground water level monitoring data available for the study area for 56 wells from the department was analyzed on GIS platform for the pre monsoon and post monsoon periods of 2009 and 2010 for 15th june and 15th oct, for the Gomti ,balrampur drain doab.

5.2. Spatio - temporal mapping of Gomti -Balrampur drain doab

Pre monsoon data analysis of 2009 predicts that, the ground water levels in 3.10 % area was between 0 to 3m below ground levels and in 9.81 % it was between 3 to 5 m below ground levels, While in 30.01 % area it was between 5 to 8 m and in 57.09% area it was below 8m.We can further say that in 12.90 % area ground water was available within 5m from ground levels and in 87.10 % areas it was below 5 m up to a maximum depth of 15.8m,as shown in Figure 5.1.

Similarly Pre monsoon data analysis of 2010 predicts that , the ground water levels in 2.34 % area was between 0 to 3m below ground levels and in 10.37 % it was between 3 to 5 m below ground levels, While in 35.81 % area it was between 5 to 8 m and in 51.49% area it was below 8m.We can further say that in 12.70 % area ground water was available within 5m from ground levels and in 87.30 % areas it was below 5 m up to a maximum depth of 12.8m. ,as shown in Figure 5.2.

It clearly predicts that during a period of one year in pre monsoon periods the area where the ground water is available up to 5m below ground has reduced to 12.70 % as against to 12.90 % and the areas where ground water is available below 5m has increased from 87.10% to 87.30 %.

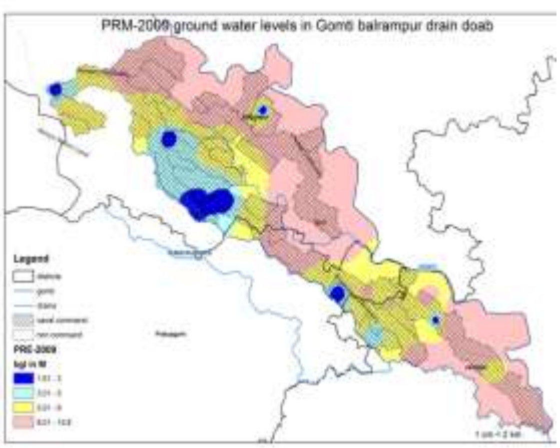


Figure 5.1 Pre monsoon 2009 Ground water levels

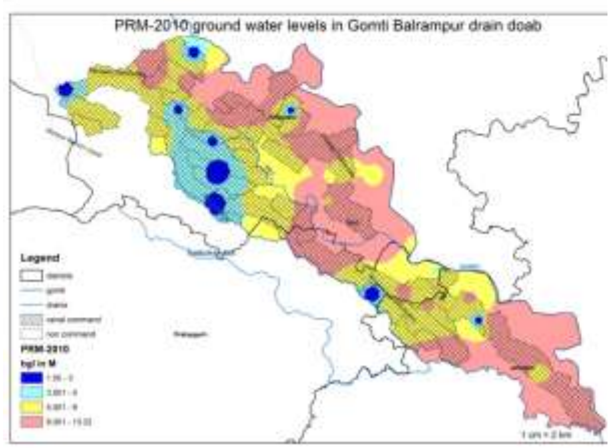


Figure 5..2 Pre monsoon 2010 Ground water levels

Similarly Post monsoon data analysis of 2009 predicts that, the ground water levels in 3.57 % area was between 0 to 3m below ground levels and in 8.75 % it was between 3 to 5 m below ground levels, While in 29.50 % area it was between 5 to 8 m and in 58.17 % area it was below 8m.We can further say that in 12.32 % area ground water was available within 5m from ground levels and in 87.68 % areas it was below 5 m up to a maximum depth of 15.8m, as shown in Figure 5.3.

And the Post monsoon data analysis of 2010 predicts that , the ground water levels in 2.48 % area was between 0 to 3m below ground levels and in 8.76 % it was between 3 to 5 m below ground levels, While in 36.81 % area it was between 5 to 8 m and in 51.95% area it was below 8m.We can further say that in 12.70 % area ground water was available within 5m from ground levels and in 87.30 % areas it was below 5 m up to a maximum depth of 12.8m. ,as shown in Figure 5.4.

It clearly predicts that during a period of one year in post monsoon periods the area where the ground water is available up to 5m below ground has reduced to 11.24 % as against to 12.32 % and the areas where ground water is available below 5m has increased from 87.68% to 88.76 %.

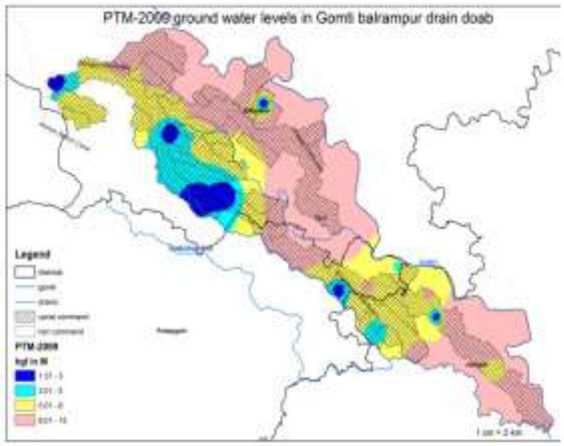


Figure 5.3 Post monsoon 2009 Ground water levels

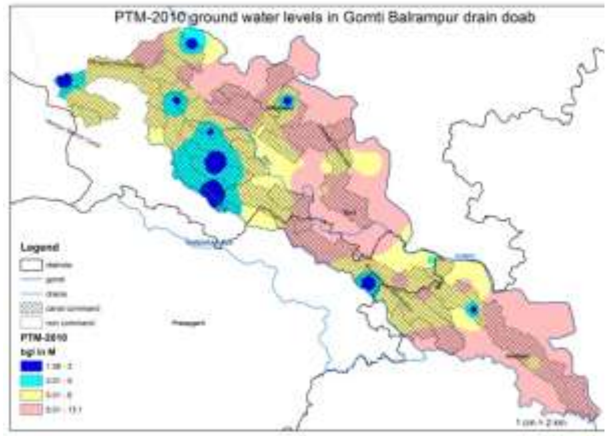


Figure 5.4 Post monsoon 2010 Ground water levels

5.3. Spatio - temporal mapping of Ramganj distributaury command lying between Gomti -Balrampur drain doab

Similarly digital automatic ground water level monitoring data available for the study area for 46 wells from the department was analyzed on GIS platform for the pre monsoon and post monsoon periods of 2009 and 2010 for 15th june and 15th oct, for the Ramganj distributaury command lying between Gomti ,balrampur drain doab.

Pre monsoon data analysis of 2009 predicts that, the ground water levels in 5.18 % area was between 0 to 3m below ground levels and in 15.01 % it was between 3 to 5 m below ground levels, While in 36.20 % area it was between 5 to 8 m and in 43.61% area it was below 8m.We can further say that in 20.19 % area ground water was available within 5m from ground levels and in 79.81 % areas it was below 5 m up to a maximum depth of 15.8m,as shown in Figure 5.5.

Similarly Pre monsoon data analysis of 2010 predicts that , the ground water levels in 3.79 % area was between 0 to 3m below ground levels and in 16.20 % it was between 3 to 5 m below ground levels, While in 42.84 % area it was between 5 to 8 m and in 37.17 % area it was below 8m.We can further say that in 19.90 % area ground water was available within 5m from ground levels and in 80.01 % areas it was below 5 m up to a maximum depth of 12.8m. ,as shown in Figure 5.6.

It clearly predicts that during a period of one year in pre monsoon periods the area where the ground water is available up to 5m below ground has reduced to 19.99 % as against to 20.19 % and the areas where ground water is available below 5m has increased from 79.81% to 80.01 %.

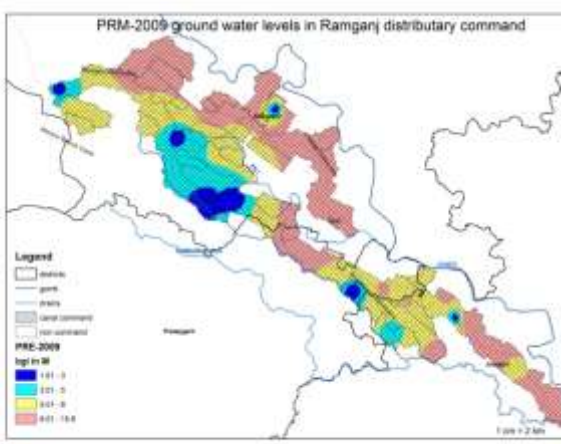


Figure 5.5 Pre monsoon 2009 Ground water levels

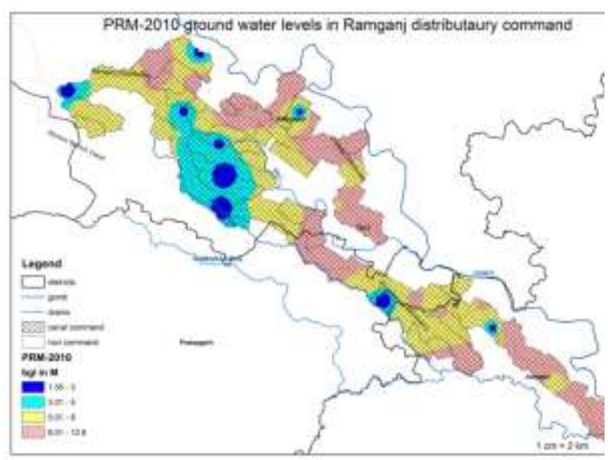


Figure 5.6 Pre monsoon 2010 Ground water levels

Similarly Post monsoon data analysis of 2009 predicts that, the ground water levels in 5.91 % area was between 0 to 3m below ground levels and in 13.13 % it was between 3 to 5 m below ground levels, While in 36.19 % area it was between 5 to 8 m and in 44.77 % area it was below 8m.We can further say that in 19.04 % area ground water was available within 5m from ground levels and in 80.96 % areas it was below 5 m up to a maximum depth of 15.8m,as shown in Figure 5.7.

And the Post monsoon data analysis of 2010 predicts that , the ground water levels in 4.03 % area was between 0 to 3m below ground levels and in 13.93 % it was between 3 to 5 m below ground levels, While in 44.09 % area it was between 5 to 8 m and in 37.96% area it was below 8m.We can further say that in 17.96 % area ground water was available within 5m from ground levels and in 82.04 % areas it was below 5 m up to a maximum depth of 12.8m. , as shown in Figure 5.8.

It predicts that during a period of one year in post monsoon periods the area where the ground water is available up to 5m below ground has increased to 19.04 % as against to 17.96 % and the areas where ground water is available below 5m has increased from 80.96% to 82.04 %.

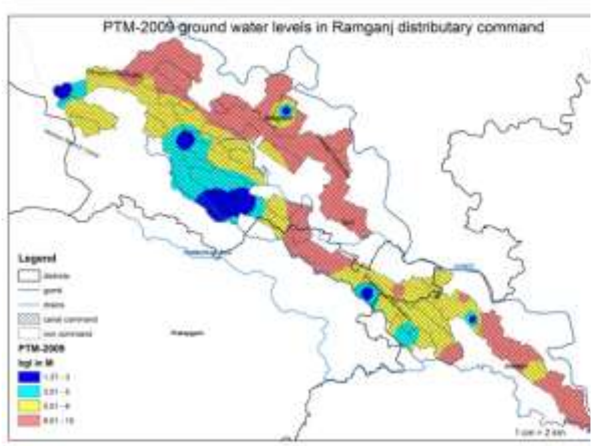


Figure 5.7 Post monsoon 2009 Ground water levels

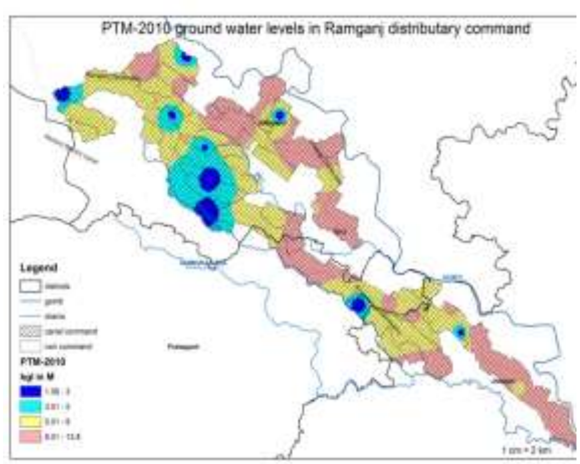


Figure 5.8 Post monsoon 2010 Ground water levels

5.4-Behaviour of ground water levels in Canal command and doab areas (including non command areas)

Ground water behaviour analysis on GIS platform predicts in canal command area of 39861 ha 20.19 % area was lying between 0-5 m below ground levels in the pre monsoon period of 2009, while as a whole for doab area of 66939 ha; only 12.90 % area was lying between 0-5 m below ground levels. Similarly for post monsoon period’s area lying between 0-5 m was 19.99 % in canal command, while it is only 12.70 %at doab level as shown in table 5.1.

Table 5.1- Behaviour of ground water levels

Ground water level behaviour in Gomti Balrampur drain doab(area 66939 ha)				
Ground water levels in bgl	Premonsoon 2009	Premonsoon 2010	Post monsoon 2009	11.24
0-5 M	12.90	12.70	12.32	88.76
> 5M	87.10	87.30	87.68	**100.00**
	100.00	**100.00**	**100.00**	
Ground water level behaviour in Ramganj distribtaury command lying between Gomti Balrampur drain doab (area 39861 ha)				
0-5 M	20.19	19.99	19.04	17.96
> 5M	79.81	80.01	80.96	82.04
	100.00	**100.00**	**100.00**	**100.00**

5.5. Summary and Conclusions

In Gomti Balrampur drain doab area of 66939 ha, during a period of one year in pre monsoon periods the area where the ground water is available up to 5m below ground has reduced by 0.2%, that is in an additional area of 134 ha ground water levels area depleted below 5m.Similarly for post monsoon area this depletion is only .08%, that is an additional area of 54 ha.

While in canal command area of 39861 ha, during a period of one year in pre monsoon periods the area where the ground water is available up to 5m below ground has also reduced by 0.2%, that is in an additional area of 80 ha ground water levels area depleted below 5m.Similarly for post monsoon area there is a rise of 1.08%, that is an additional area of 430 ha.

It predicts that there is depletion in ground water levels; however this deletion is arrested after post monsoon periods depending upon the rainfall behavior in that area.

In canal command ground water table area lying between 0-5 m is about 20 %(7972 ha), while it is in about 12% (8032 ha) at doab level. It predicts that only an area of (8032-7972) 60 ha lies in non canal command zone where the ground water level remains between 0-5 m in pre monsoon periods.

It clearly predicts that canal water supply provides a good source of recharge in maintaining ground water levels in addition to providing irrigation facilities.

CHAPTER 6

GROUND WATER SIMULATION MODEL FOR THE CANAL COMMAND AREA

6.1. Introduction

Ground water simulation model was developed for the study area. Ground flow equation needs proper boundary conditions, aquifer parameters to simulate real study area. Observed ground water levels at different locations are used to calibrate and validate the model.

6.2-Ground water simulation using ,Visual mudflow

A groundwater model, Visual MODFLOW is used to predict the effects of hydrological changes (like groundwater abstraction or irrigation developments) on the behaviour of ground water table that simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method (McDonald and Harbaug).
Ground water flow equation

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \qquad 6.1$$

Where

Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

W is a volumetric flux per unit volume representing sources and/or sinks of water, with W<0.0 for flow out of the ground-water system, and W>0.0 for flow in (T-1);

Ss is the specific storage of the porous material (L-1); and

t is time (T).

Equation 6.1, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

The Ground-Water Flow Process solves equation 6.1 using the finite-difference method in which the groundwater flow system is divided into a grid of cells .For each cell, there is a single point, called a node, at which head is calculated.

The finite difference form of the partial differential in a discredited aquifer domain (represented using rows, columns and layers) is:

$$CR_{i,j-\frac{1}{2},k}\left(h^m_{i,j-1,k} - h^m_{i,j,k}\right) + CR_{i,j+\frac{1}{2},k}\left(h^m_{i,j+1,k} - h^m_{i,j,k}\right) +$$
$$CC_{i-\frac{1}{2},j,k}\left(h^m_{i-1,j,k} - h^m_{i,j,k}\right) + CC_{i+\frac{1}{2},j,k}\left(h^m_{i+1,j,k} - h^m_{i,j,k}\right) +$$
$$CV_{i,j,k-\frac{1}{2}}\left(h^m_{i,j,k-1} - h^m_{i,j,k}\right) + CV_{i,j,k+\frac{1}{2}}\left(h^m_{i,j,k+1} - h^m_{i,j,k}\right) +$$

Where $P_{i,j,k}\, h^m_{i,j,k} + Q_{i,j,k} = SS_{i,j,k}\left(\Delta r_j \Delta c_i \Delta v_k\right)\dfrac{h^m_{i,j,k} - h^{m-1}_{i,j,k}}{t^m - t^{m-1}}$

$h^{m}_{i,j,k}$ is the hydraulic head at cell i,j,k at time step m

CV, CR and CC are the hydraulic conductance, or branch conductance between node i,j,k and a neighboring node

$P_{i,j,k}$ is the sum of coefficients of head from source and sink terms

$Q_{i,j,k}$ is the sum of constants from source and sink terms, where $Q_{i,j,k} < 0.0$ is flow out of the groundwater system (such as pumping) and $Q_{i,j,k} > 0.0$ is flow in (such as injection)

$SS_{i,j,k}$ is the specific storage

$\Delta r_j \Delta c_i \Delta v_k$ are the dimensions of cell i,j,k, which, when multiplied, represent the volume of the cell; and

t^{m} is the time at time step m

6.3. Model Inputs: The inputs to the model are:

6.3.1. Hydrological inputs:

The hydrological inputs consist of hydrological data like rainfall, evapotranspiration and surface runoff, which determine the recharge. These inputs may vary in both time and space.

6.3.2. Operational inputs:

The operational inputs concern human interferences with the water management like irrigation, drainage, pumping from wells, water table control and the operation of retention or infiltration basins, which are often of a hydrological nature. These inputs may also vary in time and space.

6.3.3. Boundary and initial conditions:

Boundary conditions can be related to levels of the water table, artesian pressures, and hydraulic head along the boundaries of the model on the one hand (the head conditions), or to groundwater inflows and outflows along the boundaries of the model on the other hand (the flow conditions). They may also include quality aspects of the water like salinity.

In MODFLOW's River package the Conductance for the River boundary condition in each grid cell is calculated using the following formula:

$$\$COND = \frac{\$RCHLNG \cdot \$WIDTH \cdot \$K \cdot \$UCTOCOND}{\$RBTHICK}$$

Where

$COND = Riverbed Conductance [L2/T]

$RCHLNG = Reach length of the river in each grid cell [L]

$RBWIDTH = Riverbed width in each grid cell [L]

$RBTHICK = Riverbed thickness in each grid cell [L]

$K = Riverbed vertical hydraulic conductivity [L/T]

$UCTOCOND = Unit conversion factor

The reach length ($RCHLNG) of the river in each grid cell is determined from the line used to digitize the river location in the model. The riverbed width ($RBWIDTH), riverbed thickness ($RBTHICK), and riverbed hydraulic conductivity ($K) are user-defined parameters. The unit conversion factor ($UCTOCOND) is used to convert the hydraulic conductivity value from conductivity units to conductance units.

In MODFLOW's Drain Package is designed to simulate the effects of features such as agricultural drains, which remove water from the aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or elevation. The Drain package assumes the drain has no effect if the head in the aquifer falls below the fixed head of the drain. The drain package is also used for the study area to simulate its impact .The Conductance value per unit length/area of the Drain grid cells is as follows

$COND = $RCHLNG · $LCOND

Where

$COND: is the Conductance

$RCHLNG: is the reach length of the drain in each grid cell

$LCOND: is the Conductance per unit length of the drain in each grid cell

The initial conditions refer to initial values of elements that may increase or decrease in the course of the time inside the model domain and they cover largely the same phenomena as the boundary conditions do. The initial head and boundary conditions may vary from place to place. The boundary conditions may be kept either constant or be made variable in time.

6.3.4. Parameters:

The parameters usually concern the geometry of and distances in the domain to be modelled and those physical properties of the aquifer that are more or less constant with time but that may be variable in space. Important parameters are the topography, thicknesses of soil / rock layers and their horizontal/vertical hydraulic conductivity (permeability for water), aquifer transmissivity and resistance, aquifer porosity and storage coefficient, as well as the capillarity of the unsaturated zone.

6.4. Model development:

The groundwater model presented in this report relates to the upper, unconfined aquifer only, as it is considered separate from deeper aquifers. The X axis of the developed modeling frame work in MODFLOW lies between latitude 602950m to 660139 m while Y axis of lies between longitude of 2859775 m and 2901713 m. The modeling framework area is 239839 ha or 2398.39 sq km (57.189 km*41.938 km) as shown in Figure 6.1. The model area of 57.189km*41.938 km has been divided in 400 columns and 300 rows that are in the grid size of 143 m *140 m.

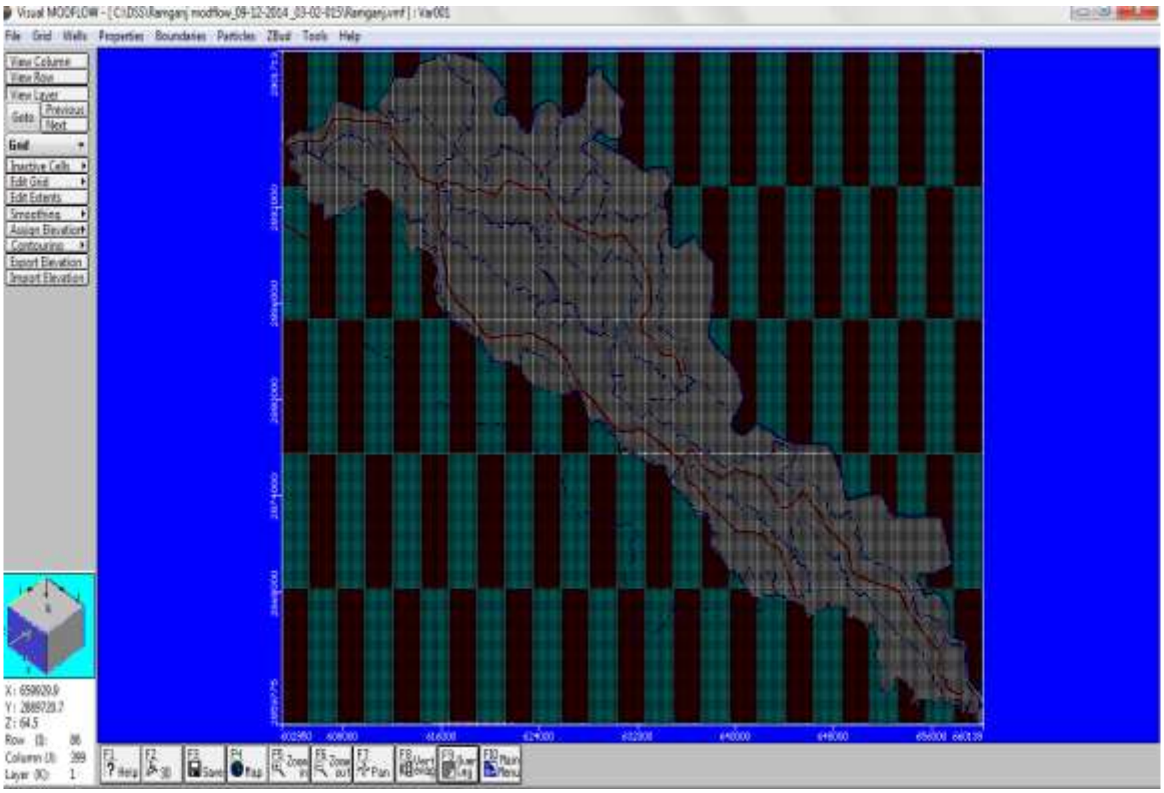


Figure 6.1.Developed Model for Study Area

The parameters usually concern the geometry of and distances in the domain to be modelled and those physical properties of the aquifer that are more or less constant with time but that may be variable in space. Important parameters are the topography, thicknesses of soil / rock layers and their horizontal/vertical hydraulic conductivity (permeability for water), aquifer transmissivity and resistance, aquifer porosity and storage coefficient, as well as the capillarity of the unsaturated zone

6.4.1. Topography:

The topography of the model area based on SRTM (Shuttle Radar Topographic Mission)90 M resolution data predicts that the levels in the model area varies from 68 to 110 m in the decreasing order from west to east as well as from north to south.

6.4.2. Layers

A single layer model is developed to represent the unconfined aquifer which extends in the Sub-Basin area, at an average depth of 50 m. The aquifer is comprised of an alternating litho logy of silty, very fine to fine sand and clay which are non-continuous over the scale of the sub-basin. The aquifer is underlain by a clay layer of the order of 20 to 40 m in thickness.

6.4.3. Hydraulic Conductivity

With reference to the various available reports and strata charts from State Tube well drilling logs, the aquifer material was found to be more or less fine sand and thus a value of 15 m/day has been found to be appropriate to the conditions, the estimated recharge and prevailing water levels. The value was varied to 10, 20 and 30m/d and is in conformance with the Central Ground Water Board (CGWB) norms.

6.4.4. Specific Yield

The average value of 0.15 has been adopted as per recommendation of CGWB for various grains sized alluvial material in the Groundwater estimation committee norms-97.In the sensitivity testing, testing was carried out for 0.10 and 0.20 to cover the range of grain size most commonly observed in the State Tube well logs.

6.4.5. Aquifer Thickness

From the CGWB (Central Groundwater Board) report of 1996, the upper aquifer in Jaunpur, Sultanpur and Pratapgarh districts of the study area was stated to an average thickness of 50 metres. Review of State Tubewell logs and hydrogeological reports for each district showed that it is very difficult to define the unconfined (or phreatic) aquifer. This is because the alluvium consists of multiple inter-fingering layers of sand, silt and clay that are semi-continuous in the study area. However there does appear to be a consistent layer of clay about 20 m to 30 m thick. In this groundwater modelling, we have focused on the interaction between the shallow phreatic aquifer and surface water (rivers, drains, soil moisture and recharge). Therefore, the model output of concern is the depth to groundwater level and the water balance between surface water and shallow groundwater. Deeper aquifers are of little consequence in this analysis as they do not significantly interchange with the unconfined aquifer in the study area.

6.4.6. Timeframes

The model has been run using seasonal inputs for the monsoon and non monsoon periods. The model used a three year time frame that is from 15th June 2011 to 14 th June 2014, to compare predicted groundwater levels with the observed water levels.

6.4.7. Boundary Conditions

Consideration of the boundary conditions of a groundwater model is one of the most important aspects in conceptualizing the model. Using a correct judgement means that the boundaries have no undue effect on the predicted water levels and flows. Sub Basin has external "no-flow" boundary conditions on the general assumption that the sub-basin surface water catchment is coincident with the groundwater sub-basin. On the northern side of the Gomti River and the southern side of Balrampur River, the catchment divides are taken at the sub-basin boundaries with "no-flow" conditions. These two boundaries meet on the south-eastern corner at the confluence of the two rivers.

The two rivers are represented in the model using the river package. The landmark bed elevations were used to define the bed of the river through linear interpolation. Figure 6.2. shows the river boundary conditions. The stages of the rivers were averaged to be constant at an average depth of 4 metres for monsoon period of 153 days starting from 15th June to 15th Oct and 2 m for non monsoon period from 16th Oct to 14th June for Gomti River and similarly for Balrampur river on the other side an average depth of 3 metres for monsoon period of 153 days from 15th June to 15th Oct and 1.5 m for non monsoon period from 16th Oct to 14th June. The bed layer was assumed as 0.5 m thick (M) and with a vertical hydraulic conductivity (K) of 1.5 m/day. Hydraulic conductance (C) was calculated within the model as follows:

(C = $\frac{KxLxW}{M}$), where L = length of the river in each cell (m).

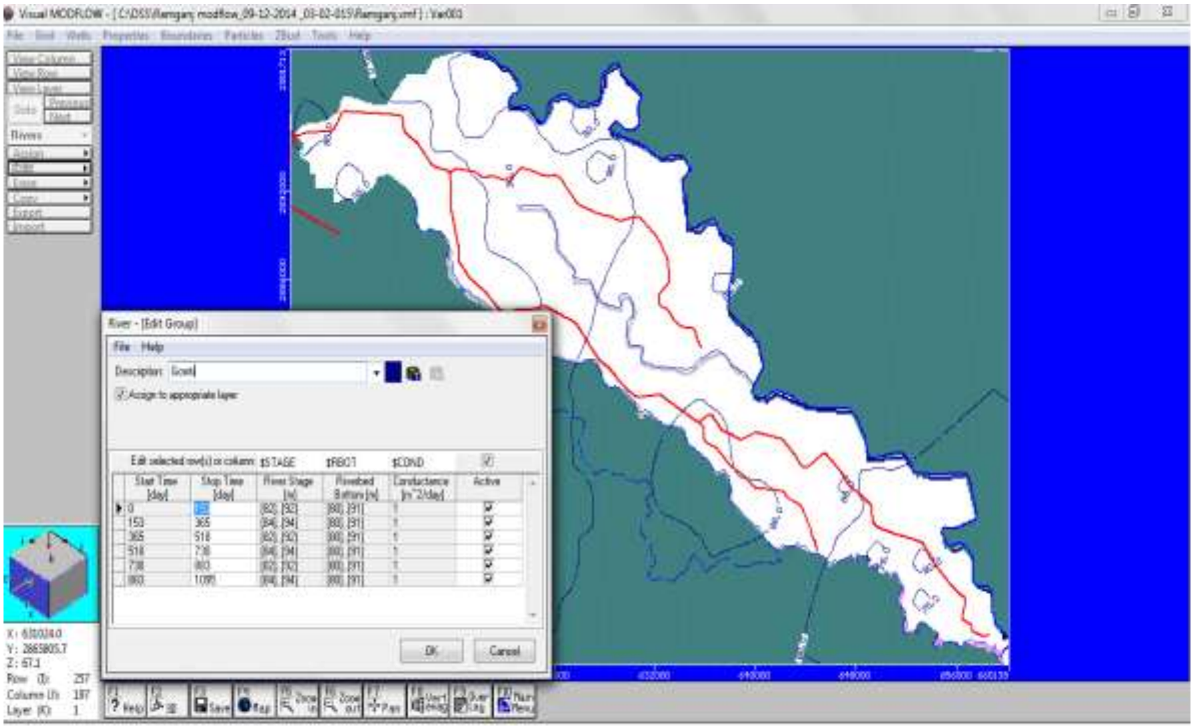


Figure 6.2.River boundary condition

6.4.8. Drains

Pili drain lying between Gomti and Balrampur rivers is also being used for the surplus run off in the of distributaries command. Since the flow data for different periods of the drain is not available, hence an average depth of flow for the entire periods has been assumed depending on field enquiry, as shown in Figure 6.3.

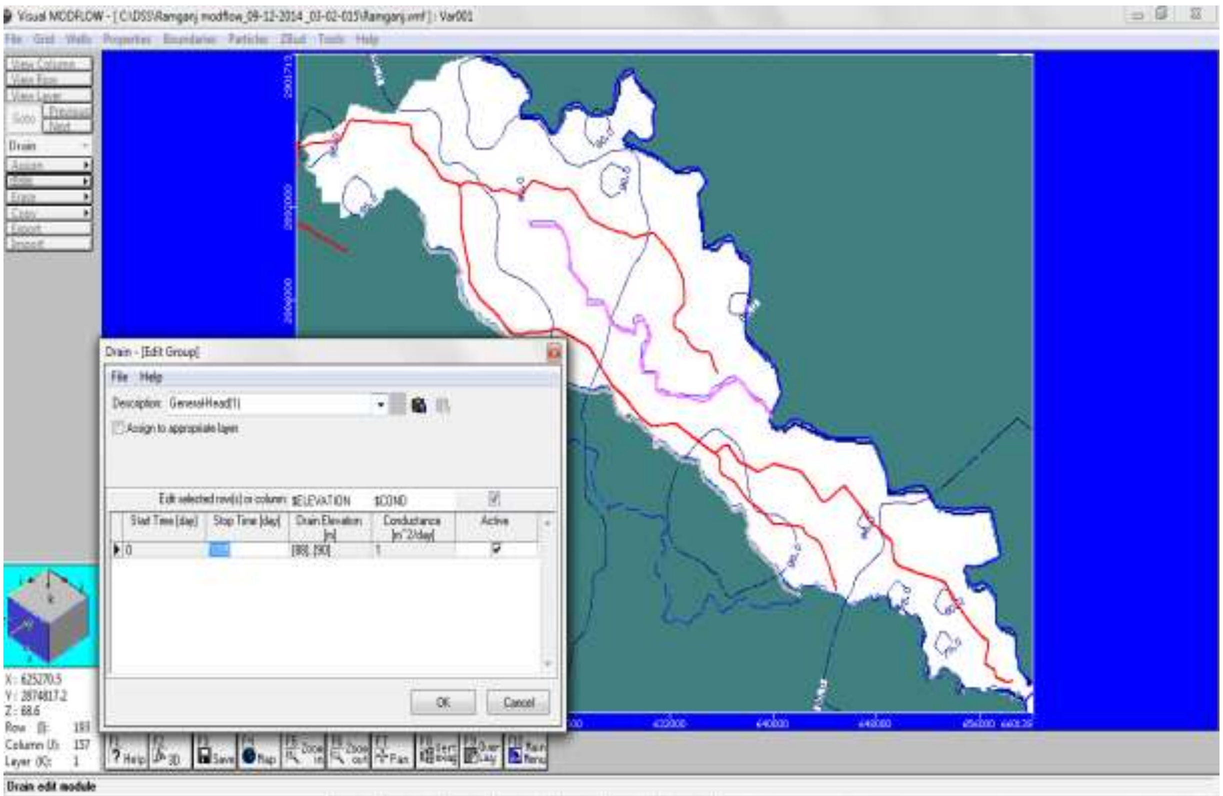
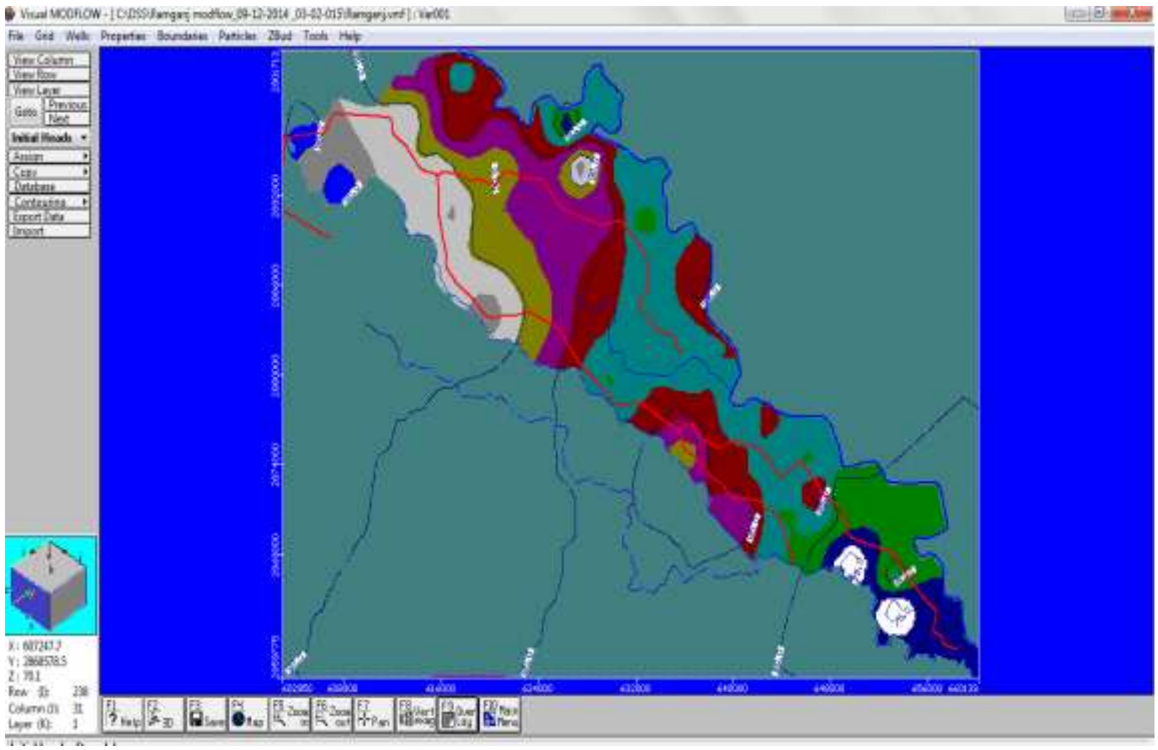


Figure 6.3.Status of drains in the Model area:

6.4.9. Initial Groundwater Levels

Initial groundwater levels of 60 monitoring wells of the study area, were collected for pre-monsoon date of 15th June 2011 from automatic groundwater level recorders. The initial water level contours generated from available data of imported file of 60 observatory well levels at GIS platform is shown in Figure 6.4.



I.

Figure 6.4. Initial groundwater levels

6.4.10. Recharge zones

Net recharge values for the model area has been calculated at block level, based on Groundwater estimation committee report 1997 for monsoon and non monsoon periods separately. Groundwater extraction from private borings has been calculated separately based on available borings and average running hours for each Rabi and Kharif periods as shown in Figure 6.5.

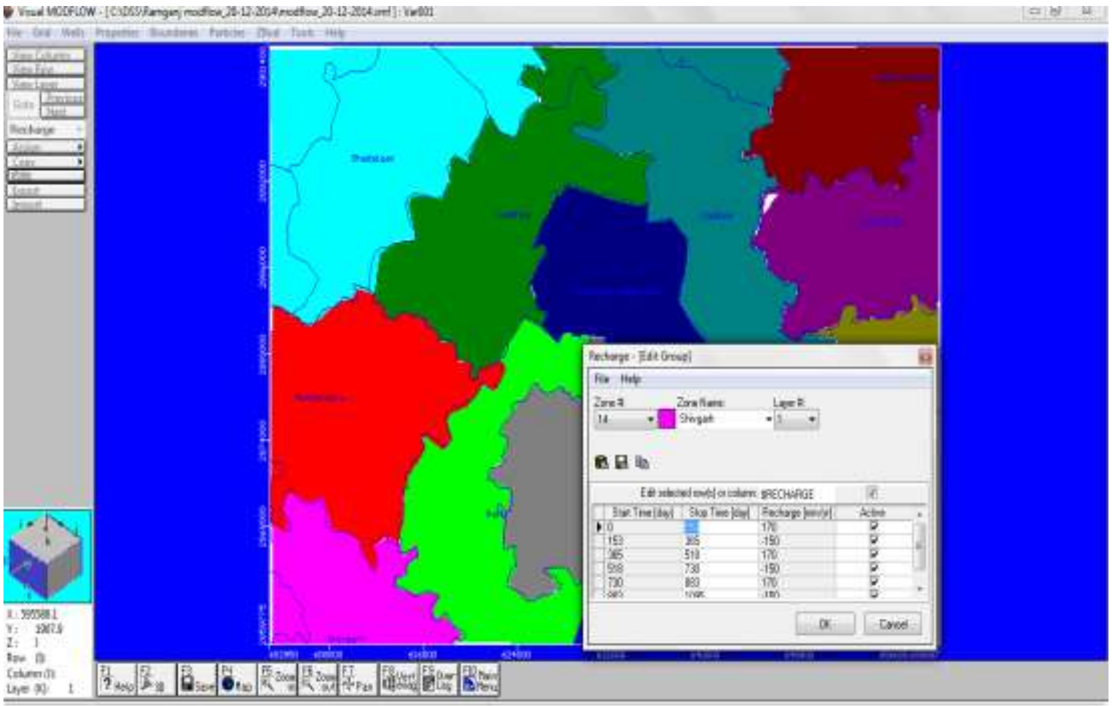


Figure 6.5. Recharge zones at Block level in groundwater model

6.4.11. Observatory wells

Groundwater levels for 11 monitoring wells, for which data for the complete three years was available, has been used for comparison with the model run results as shown in Figure 6.6.

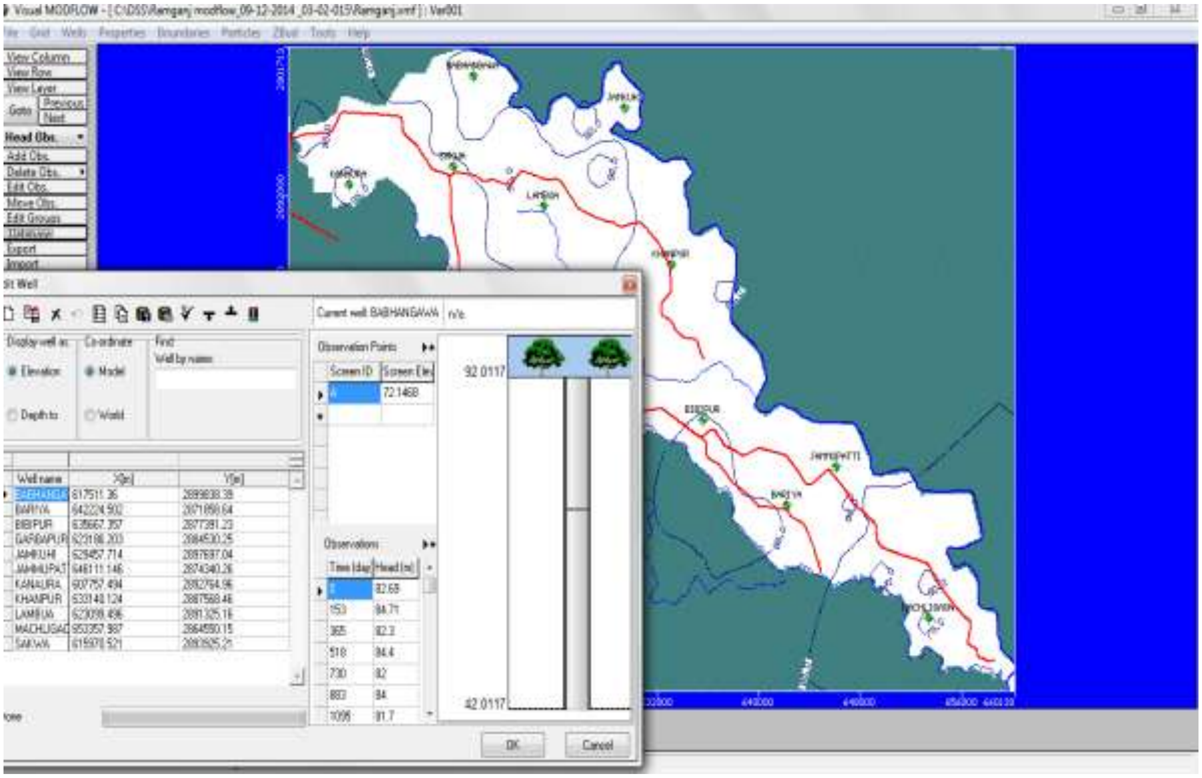


Figure 6.6. Monitoring wells used for water level calibration

6.5. Ground water simulation runs

6.5.1. Groundwater Simulation Model Calibration

Developed model was run for a period of three years staring from 15th of June 2011.The thickness of the upper unconfined layer is taken as 50 m (meter) for the modelling purposes based on bore logs, as groundwater extraction is mainly limited to upper strata being used by shallow borings for irrigation purposes. The values aquifer parameters such as specific yield=0.15%, hydraulic conductivity =15m per day in X and Y directions and 1.5 m per day in the Z direction are taken based on bore logs and pump test results. The net recharge applied at block level was calculated outside the model domain based on Groundwater estimation committee report 1997 norms. Following observations may be made from the model runs:

(i) For the net recharge values calculated at block level as per Groundwater Estimation Committee norm 1997, with the current cropping intensity of 163.1% and prevailing irrigation practises, the model run output shows a correlation coefficient of 0.94 to 0.92 between the observed and predicted groundwater levels at the different stages of running period of three year.

(ii) Spatial variation in groundwater levels for the study area shown in figure 6.7. predicts that with the current irrigation practices for the present cropping intensity of 163.1% as per Table 6.1, the groundwater levels depletion in the wells selected in non command and tail canal command areas is between 0.5m to 1.0m per year and in the head canal commands, where the canal density is good, it is showing a rise in groundwater levels between 0.5 m to 1.0 m per year. Field visit confirms that the areas adjacent to canals, where canal water is easily accessible, are experiencing the problem of water logging whereas non command and tail of canal command areas are facing the problem of depletion in groundwater levels, thereby increasing the energy cost through diesel driven private borings.

Table 6.1 -Showing details of Present Cropping pattern in Ramganj distributaury command area of 39861 ha   as per National Informatics Centre Statistics 2011-12

Kharif	RICE_K	12585.2409	32	47%
	MAIZE_K	3456.41149	9	
	Other_Kharif	2830.84537	7	
	Kharif_Fallow	14200.5515	36	36%
Rabi	WHEAT	16953.6919	43	58%
	GRAM	2891.16975	7	
	Other_Rabi	3143.94433	8	
	Rabi-Fallow	10084.2433	25	25%
Jaid	URD_J	11.8542679	0	1%
	Other-Jaayad	212.879281	1	
	Jaayad_Fallow	32848.3157	82	
Perrinial	SUGARCANE	91.445525	0	
	Vegitation	1357.62809	3	16%
	Wasteland	5338.74949	13	
Net sown area				65%
Cropping Intensity in % of polygon area				106%
Cropping Intensity in % of Net sown area				163.1%

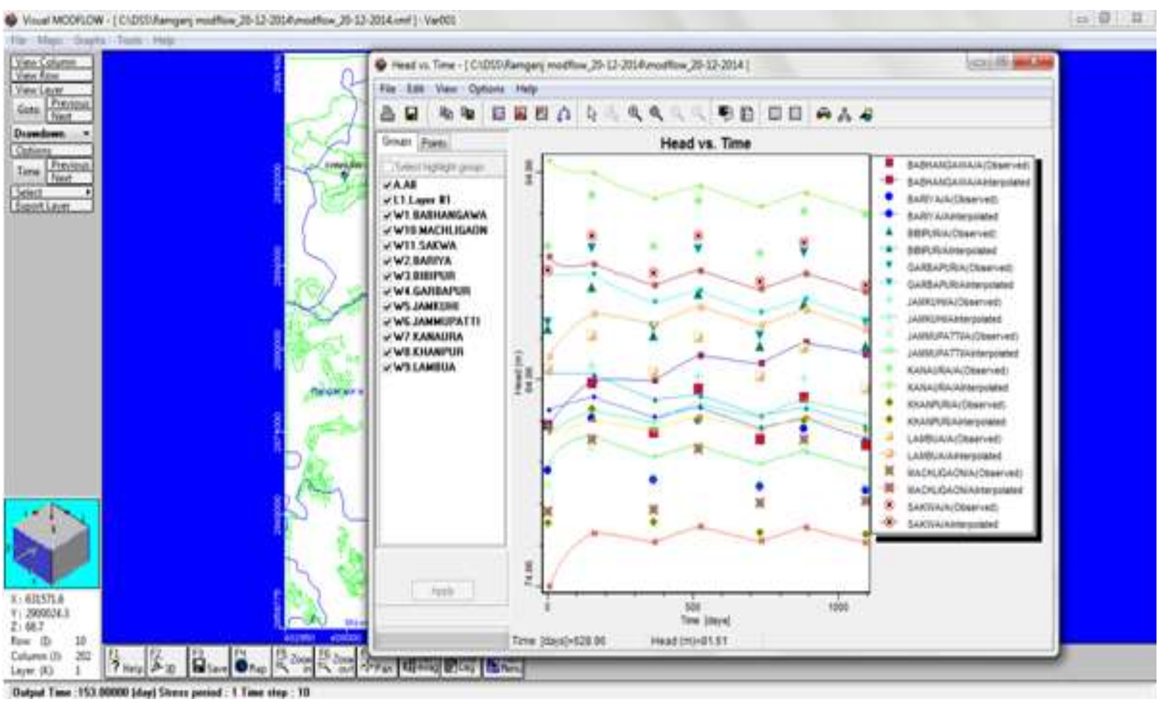


Figure 6.7.Model calibration run showing the calibrated water levels and actual water levels

6.5.2. Sensitivity Analysis

The sensitivity of the model calibration and prediction was initially assessed by varying model parameters over the potential range of values for the key parameters of hydraulic conductivity, specific yield and river leakage. Following points may be noted:

(i) The value of hydraulic conductivity is not a sensitive factor in the calculation of groundwater levels or flows as it is constrained by being in a relatively small range for fine sands. So for the whole model a single value of 15 m per day for hydraulic conductivity was adopted.

(ii) The Specific Yield varied between 0.10 and 0.20 in the short-term. Specific Yield affects the amplitude of fluctuations in groundwater levels between pre- and post-monsoon conditions. When applied over long time periods (decades), variations in Specific Yield have an impact on the size of long-term trends (rising or falling).

(iii) The model uses thickness for calculating transmissivity (T = kb) and thus doubling the thickness has the same resultant as doubling the hydraulic conductivity, which was effectively carried out in sensitivity runs of that parameter. Therefore, the depth of aquifer has little impact on predicted depth to groundwater.

(iv) It was found that the model predictions of depth to groundwater are sensitive to recharge. For a net increase in recharge per year the predicted groundwater levels shows an increasing trend at all the observatory well locations, while for a net decrease in recharge per year the predicted groundwater levels showed an decreasing trend at all the observatory well locations.

6.5.3 Model Predictions on Conjunctive Use Implementation

For the future predictions in the model area, the cropped area and its crop water requirement has been calculated outside the model domain for the different cropping intensities and uniform net recharge values required are calculated, to see the impact of model run on groundwater levels if conjunctive use is implied. Groundwater assessment done for districts of the study area under Groundwater estimation committee 97(GEC-97) norms is tabulated in Table 6.2. .It shows an annual recharge of 340 mm per year from all the sources, while present annual draft is only 250 mm per year for the current cropping intensity.

Table 6.2.Status of Districtwise Ground Water Resource Potential (2004, 2008 & 2012) as per GEC-97 Norms

S.	Assessment Unit (District)	Net annual Ground water Recharge/ potential (m)			Existing Gross Ground water draft for all uses (m)			Stage of Ground water development (%)		
		2004	2008	2012	2004	2008	2012	2004	2008	2012
1	Jaunpur	0.41	0.36	0.32	0.24	0.28	0.27	58.26	77.36	82.77
2	Pratapgarh	0.24	0.21	0.35	0.08	0.13	0.24	33.53	60.56	69.86
3	Sultanpur	0.41	0.38	0.35	0.19	0.28	0.24	46.09	72.77	69.94
	Average	0.35	0.32	0.34	0.17	0.23	0.25	45.96	70.23	74.19

The present cropping intensity is 106% (47% Kharif (K), 58% Rabi (R) and 1% Jaid (J)) of polygon area or 163.1% (72.3% K, 89.2% R, 1.6% Jaid) of net sown area. The Net sown area is 65% only [SMEC, 2010].Following scenarios are investigated:

(i) If conjunctive use is applied for the current cropping intensity of 106% (47% Kharif (K), 58% Rabi (R) and 1% Jaid (J)) of polygon area or 163.1% (72.3% K, 89.2% R, 1.6% Jaid) of net sown area with annual recharge 340 mm per year and ground water drafts of 250 mm per year, it will show a rising trend in ground water levels as predicted in model run, shown in Figure 6.8.

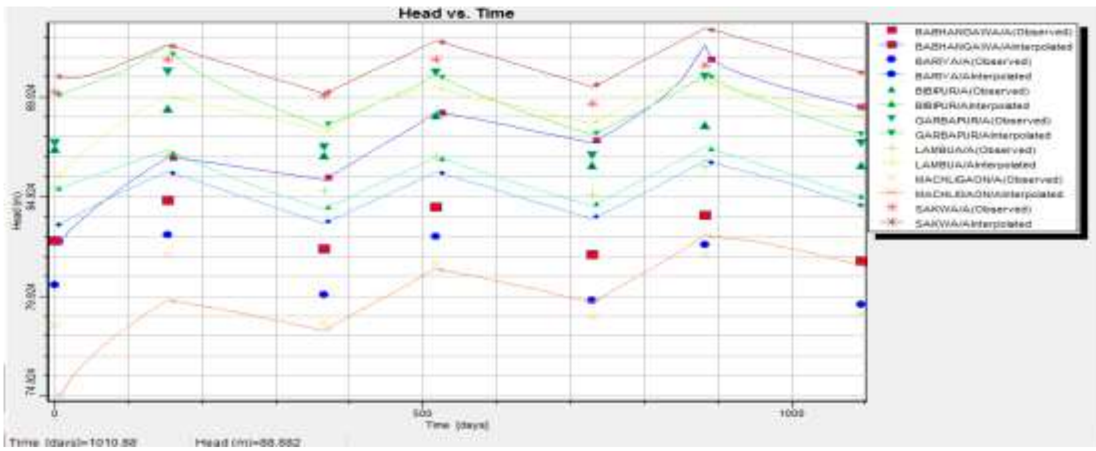


Figure 6.8. Ground water levels with current cropping intensity of 163.1%, if conjunctive use is applied

(ii) If Conjunctive use is implemented, for the proposed cropping intensity of 222% of net sown area (=163.1*34/25) by keeping net recharge value equal to zero, simulation results show that, groundwater levels will always remain sustainable, as shown in Figure 6.9.

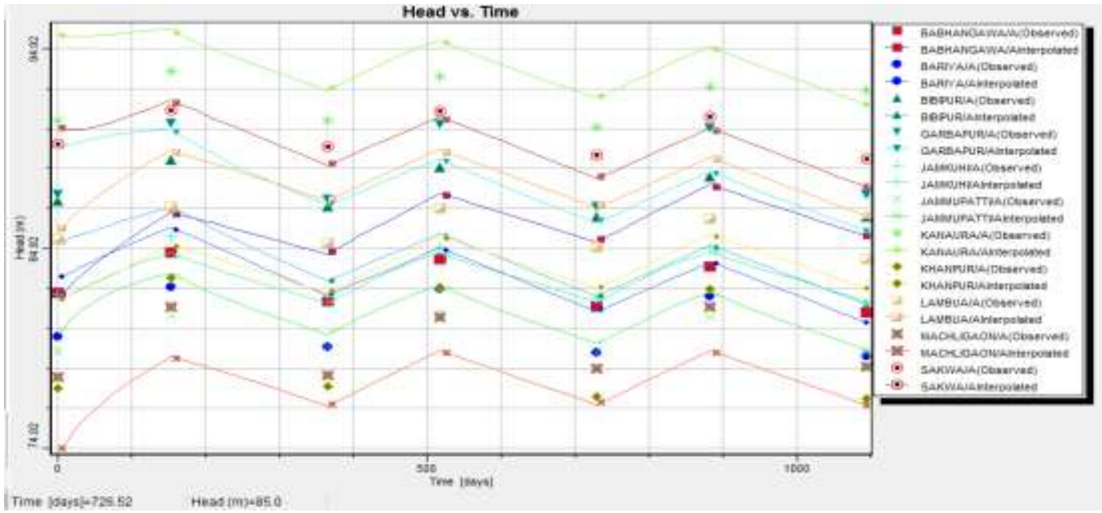
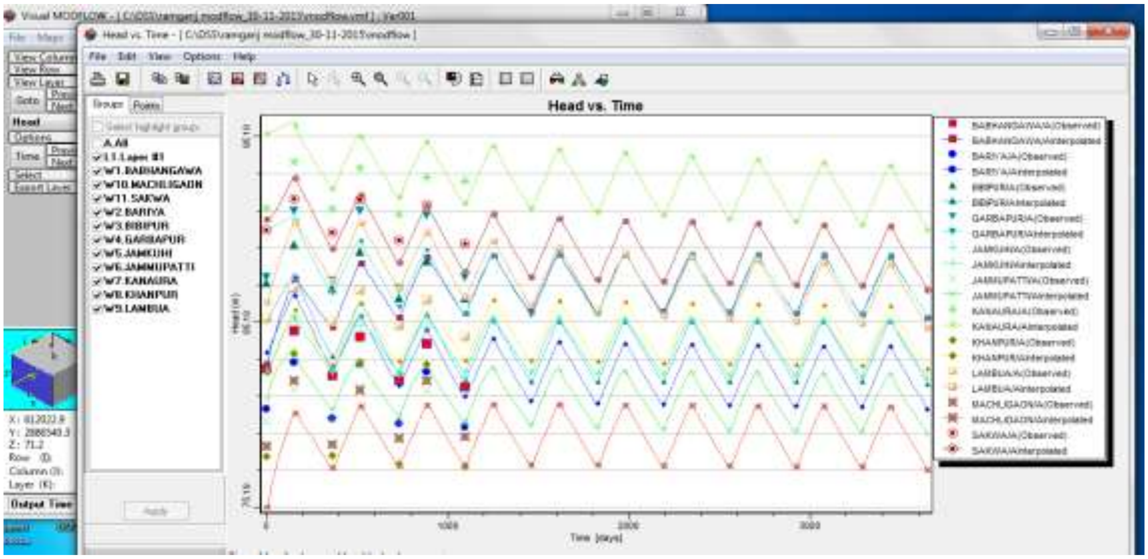


Figure 6.9. Ground water levels for proposed cropping intensity of 222%, if conjunctive use is applied

(iii) Groundwater simulation model is run with conjunctive use implementation for a period of ten years from June 2011 to June 2020.For the net recharge of 340 mm per year mainly in rainy seasons from 15th June to 15th Oct and ground water draft of 340 mm per year from 16th Oct to 14th June, shows that the ground water levels in pre monsoon and post monsoon periods will remain more or less sustainable at 222% cropping intensity as shown in Figure 6.10.



6.10- Ground water behaviour under proposed cropping intensity of 222% for a period of 10 years, if Conjunctive use is applied

(iv) Groundwater simulation model is run for conjunctive use implementation for a period of three years. The groundwater sustainable area will increase to 92% for the present cropping intensity of 163.1 % of net sown area as against the sustainable area of only 65% under current irrigation practices. Further, the groundwater depletion area will reduce from 30% to 7%, having yearly depletion of more than 0.34 m and the waterlogged area will reduce from 5% to 1%, where the rise in groundwater levels is more than 0.34 m per year as shown in Figure 6.11. and 6.12.

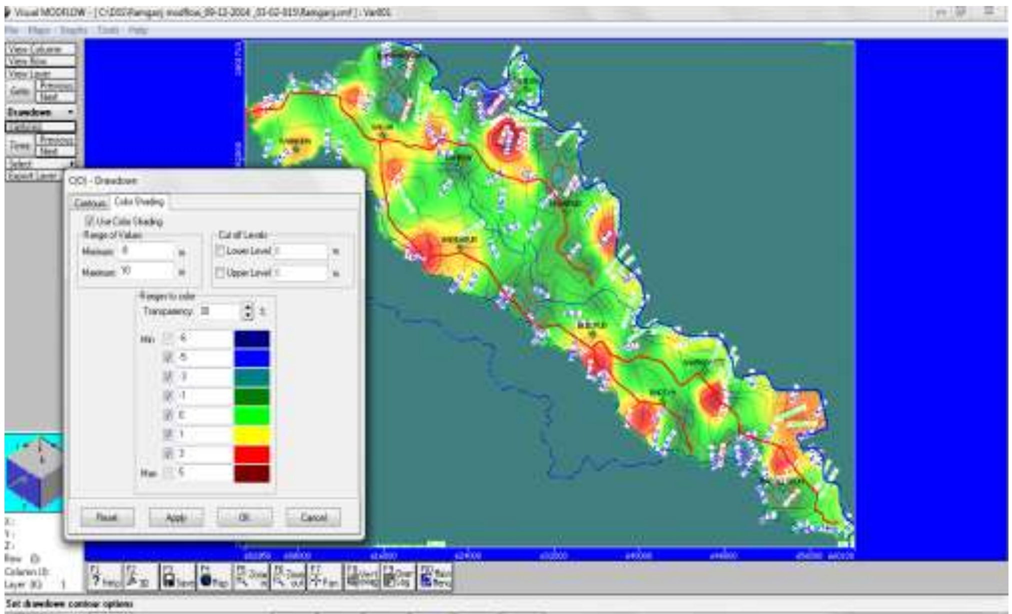


Figure 6.11. Draw down in Ground water levels during a period of 3 years under current irrigation practices for the existing cropping intensity of 163.1%

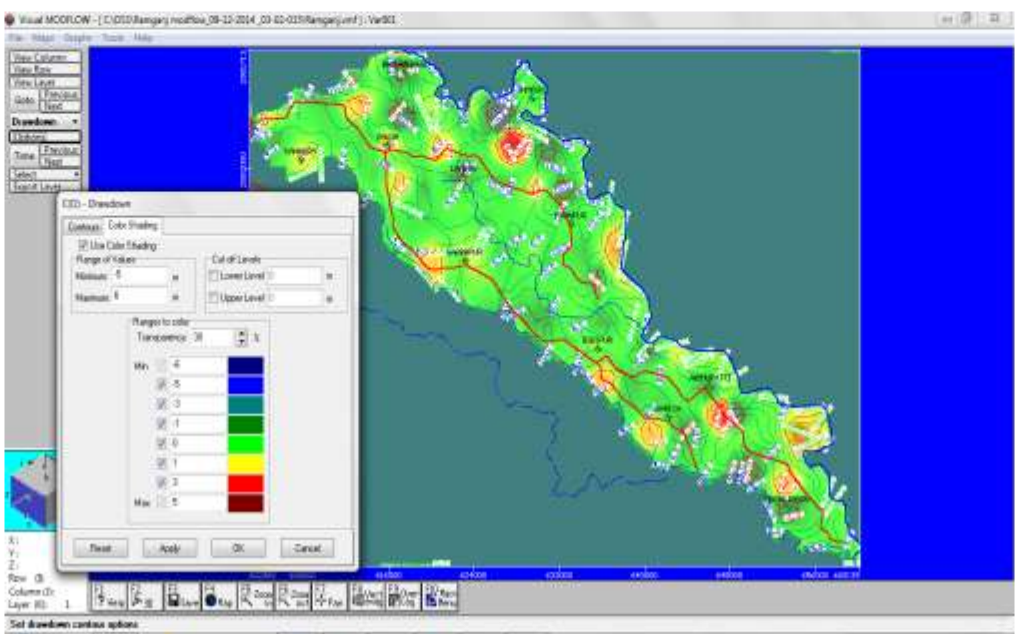


Figure 6.12. Draw down in Ground water levels under proposed cropping intensity of 222% during a period of 3 years, if Conjunctive use is implied

6.6. Summary and Conclusions

Groundwater modeling framework has been developed through Visual Modflow for Ramganj distributaries command able area, a part of Indo-Gangatic alluvial plains of Uttar Pradesh in northern India. The simulated model predicts that if conjunctive use is opted the cropping intensity may be increased to 222 percent from the existing intensity of only 163.1 percent. It also shows an overall increase in ground water sustainable area and decrease in groundwater depletion area. The sustainable area may increase to 92 percent at percent cropping intensity of 163.1, with implementation of conjunctive use, against the sustainable area of only 65 percent with existing irrigation practices. Water logged area will also reduce to 1 percent as against to present 5 percent. Groundwater withdrawal may add additional cost for lifting groundwater through electric/diesel driven private borings. However, there is saving in terms of overall additional gain in terms of bringing prevailing waterlogged and barren areas crops under cultivation, thereby increasing gross margin to farmers. At the same time simulation of model for a period of ten year from june 2011 to june 2020 shows that the ground water levels in pre monsoon and post monsoon periods will remain sustainable.

CHAPTER 7

INTIGRATED MODEL AT DISTRIBUTAURY LEVEL, USING SOIL MOISTURE, RAINFALL RUNOFF, SYSTEM LOSS AND GROUND WATER MODULES ON GIS PLATEFORM

7.1. Introduction

A GIS based generic decision support system developed by M/S SMEC Pvt. limited; Australia for management of water resources in canal commands of Ghagra Gomti Basin in Uttar Pradesh, India for Irrigation department has been used (SMEC, 2010). The main developed canal command, ICROP model is calibrated from Visual MODFLOW by giving recharge from ICROP and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model, integrated water quantity and quality simulation model (IQQM) through which generated runoff values are checked from observed runoff values.

7.2. ICROP Model

The iCROP model uses four levels of spatial units: Homogeneous Unit (HU), Sub-Irrigation Unit (SIU), Micro Sub-basin (MSB) and Sub-Basin (SB). The Sub-basin is the largest spatial unit within the iCROP model. This may be the gross command area of a Branch or a Main Canal. MSB is the gross command area of a canal, which may be either a Distributary or a Branch canal. A Sub-basin may consist of several MSBs. Micro Sub Basin (MSB) is the largest calculation unit for the model.

Sub-Irrigation Unit consists of one or more HUs. A HU in a SIU has the same potential to be waterlogged, soil characteristics, access to irrigation and depth to groundwater levels. They differ from each other in land use or crop grown. As the command area of a MSB is usually a large area having different water management practice at the canal head, middle and tail. Each MSB is further divided into different SIUs or Sub-Irrigation Units. SIUs can also be classified based on command and non-command area, distance from canals, susceptibility to be waterlogged, soil drainage and so on. A HU is the smallest calculation unit in the model. The classification is based mainly on land use.

Further each homogeneous unit is performed by a series of interlinked modules on daily basis:

(i) Soil moisture accounting and irrigation water requirement module

(ii) Rainfall-runoff module

(iii) System loss module

(iv) Groundwater system module.

7.2.1. Soil moisture accounting and irrigation water requirement module:

Irrigation demand module is similar to the procedure included in the IQQM software. The irrigation demands are computed differently for ponded crops (i.e. rice) and non-ponded crops (all other crops eg wheat, sugarcane etc). For all crops other than rice, crop water demand is computed using the potential evapotranspiration for a reference crop (ETo) and crop factors (FAO 56). Potential evapotranspiration for the reference crop is intended to be estimated using the Penman-Montieth procedure.

For rice crops, the irrigation requirement (Ireq) is computed as:

If Pdesirable ≤ Pactual ≤ Pmax then $I_{req} = 0$ (7.1)

If Pactual < Pdesirable then Ireq = (Pdesirable – Pactual)*Ahu*10 (7.2)

where

Ireq	= Crop irrigation water requirement (m3)
Pdesirable	= Desirable ponded depth (mm)
Pmax	= Max permissible ponding depth (mm)
Pactual	= Actual depth of ponding (mm)

For all other crops the irrigation requirement is computed as follows:

During the irrigation season, the estimate is based on the actual amount of soil water (SW) and the target level of soil water (TWL) for daily average irrigation requirement over all farms. Within a homogeneous unit the estimated requirement is:

If $SW \geq TWL$; then $I_{req} = 0$ (7.3)

If $SW < TWL$; then $I_{req} = (TWL - SW) * A_{hu} * 10$ (7.4)

The soil moisture on any given day is computed as:

For all crops (except rice during ponded days)

$$SW_t = SW_{t-1} + R_e + I_{sup} / (Ahu * 10) \quad (7.5)$$

$$SW_t = Max(WP, SW_t - \frac{K_C * ET_o}{K_e}) \quad (7.6)$$

$$SW_t = Max(FC, SW_t - S_L) \quad (7.7)$$

Where: SWt = Projected soil moisture at end of time step (mm)

SWt-1 = Actual soil moisture at beginning of time step (mm)

SWmax = Maximum available soil water (mm)

ETo = Reference crop potential evapotranspiration (mm)

Re = Effective rainfall less runoff

Kc = Crop factors

Ke = If method such as evaporation pans, Priestly-Taylor equation, Morton equation etc are used then this factor can be used to adjust this estimate to the Penman-Montieth ETo.

FC = Field capacity (mm) computed as

FC (in mm) = FC (%) * Root depth (mm) * Soil density/Water density

SL = Actual seepage from soil water store (mm)

$$SL = S_{L\max} * \frac{SW_{t-l}}{SW_{\max}} \quad (7.8)$$

For rice during ponded days

$$SW_t = SW_{\max}$$

$$SL = S_{L\max} \quad (7.9)$$

Where: SLmax = Maximum seepage from soil water store (mm)

The soil moisture is updated based on actual water supply through surface or groundwater sources, once irrigation requirements are computed. The calculations for soil moisture updating and irrigation requirements are carried out on a daily basis and results presented as a cumulative total for a week, season and simulation period as a whole.

7.2.2. Rainfall-runoff module:

Runoff from all land uses except ponded crops is estimated using the USDA SCS Curve Number method corrected for soil moisture (Sharpely and Williams, 1990). The approach adopted is similar to the one used in a number of widely used models such as SWAT, EPIC, PERFECT etc. The curve number varies non-linearly with the moisture content of the soil. The curve number decreases as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The SCS Curve Number

approach has limitations but is one of the commonly used methods for the study areas with extremely limited or no data availability.

The SCS curve number equation is (SCS, 1972):

$$Qsurf = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (7.10)$$

Where

Qsurf = Runoff (mm),

Rday I = Rainfall for the day (mm),

Ia = Initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm), and

S = Retention parameter (mm) that varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content.

The initial abstraction values for Indian conditions are taken from the recommended Handbook of Hydrology, 1972.

Runoff will only occur when Rday > Ia. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. The Curve number for moisture condition II to the current soil moisture condition and slope of the catchment, are modified as that used in the SWAT model (Neitsch et al, 2002).

The recommended Curve Numbers have been grouped under four hydrologic soil groups based on infiltration characteristics of the soils under similar storm and cover conditions. The four soil groups are:

A: The soils have a high infiltration rate (i.e. low runoff potential) even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D: (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Runoff computed using the above steps is modified to take in to account the bunding around the farms built by farmers to capture runoff on the farm itself. The depth of bunding is an input parameter and runoff equal to bunding depth is retained on the farm to increase the infiltration and meet crop water requirements. However, if soil is saturated then this retention of some runoff on the farm is not done.

For ponded crops runoff is estimated as:

If Pactual(t) > Pmax then Qsurf = Pmax - Pactual(t) else Qsurf = 0. (5)

7.2.3. System Loss

The seepage losses from canal are calculated based on discharge Vs Wetted area relationships. The seepage from fields is calculated on daily basis. These values have been mostly taken from standard textbooks and FAO manuals.

7.2.4. Groundwater system module

This module simulates changes in groundwater storage due to recharge and usage. The groundwater store is treated as a two-dimensional process i.e. vertical and horizontal. The horizontal process drives the base flow component and vertical one for shallow aquifer. The variation in groundwater storage/levels in the current model set up is computed according to:

GWi – GWi-1 = MSBrecharge -GWuse – Baseflow (7.11)

GLinc = (GWi – GWi-1)/(Ahu*10*Sy) (7.12) where:

GWi = Groundwater storage under each MSB for time step I (m3),

GLinc = Incremental change in groundwater level since previous time step (mm),

Sy = Specific yield of the aquifer (%) and

Baseflow = Baseflow to drainage system (m3)

7.2.5. Water Balance and Water Requirement Calculations

This is the main module of the model which manages calls to other modules and also aggregates water requirements of various MSBs, water required at the headworks, rostering decisions and supply of water among MSBs. The module operates in two modes i.e.:

Bottom up to cumulate orders of all MSBs including losses in the canal reaches linking MSBs subject to canal capacity constraints,

Top down starting from available water at headworks and then supplying water to various MSBs also taking into account losses in canal reaches linking MSBs.

7.2.6. Drinking Water and Industrial Water Requirement

Drinking water and industrial water requirement of each MSB are estimated outside this model and included as daily values. The model has an option to assign a priority to various demands to be applied during any period of shortage. For example, the model assigns the highest priority to drinking water, the next to industrial water and the third to irrigation use. The user can assign percentage water use from canal water as compared to ground water use.

7.2.7. Socio Economics

The effect of climatic parameters is incorporated using daily reference evapotranspiration. The effect on crop productivity of water availability and soil is simulated using water stress dependent production function and a multivariate regression analysis of actual productivity of crops and soil parameters such as calcareousness, sub-surface drainage, and soil slope, pH and texture.

An economic module using the crop production estimates from multiple regressions was developed as a post-processor to the water balance module. The module estimates gross margins for various crops, considering also cost of irrigation, groundwater or canal water. The effect of changing other inputs such as labour, agricultural equipment and fertilisers/pesticides is also modelled.

7.2.8. Model Inputs

The inputs to the model are:

7.2.8.1. Climatic

Daily rainfall,

Daily Pan Evaporation,

Reference Crop Evapotranspiration,

7.2.8.2. Flow data

Daily canal flow at headworks

Daily flows in drains

7.2.8.3. Infrastructure data

Canal capacities at various locations,

Cross-section information,

Lined versus unlined sections, and

Location and capacity of escape structures.

7.2.8.4. Cropping information

Crops planted and area under them during Kharif, Rabi and Jaayad,

Monthly crop factors for crops planted,

Irrigation efficiency including field channel losses,

Crop calendars showing planting and harvesting dates, and

Rice ponding requirements during its various stages of growth as desirable ponding depth and maximum permissible ponding depth, number of days before harvesting when irrigation is stopped.

7.2.8.5. Losses

Seepage losses from the canals built in different soil conditions under lined/unlined conditions,

Estimate of escape loss for typical field channels, and

Estimate of escape losses from Minors/Distributaries/Branch canal.

7.2.8.6. Water usage

Groundwater pumping capacity from aquifer, and

Drainage water use and locations.

7.2.8.7. Land use, soils and topography

Average slope in various homogeneous units of MSBs,

Land use in MSBs,

Soil types in MSBs,

Soil properties i.e. field capacity, wilting point, saturation moisture content, and

Specific yield of shallow and deep aquifers.

7.2.9. Model Interface

All the information related to Climate, Soil, Land use, Surface and Ground water infrastructure and water use details including crop information and Agro economic inputs with other modelling parameters required are to be filled in excel sheets at created MSB and polygon levels. The model interface has been shown in figure 7.1.

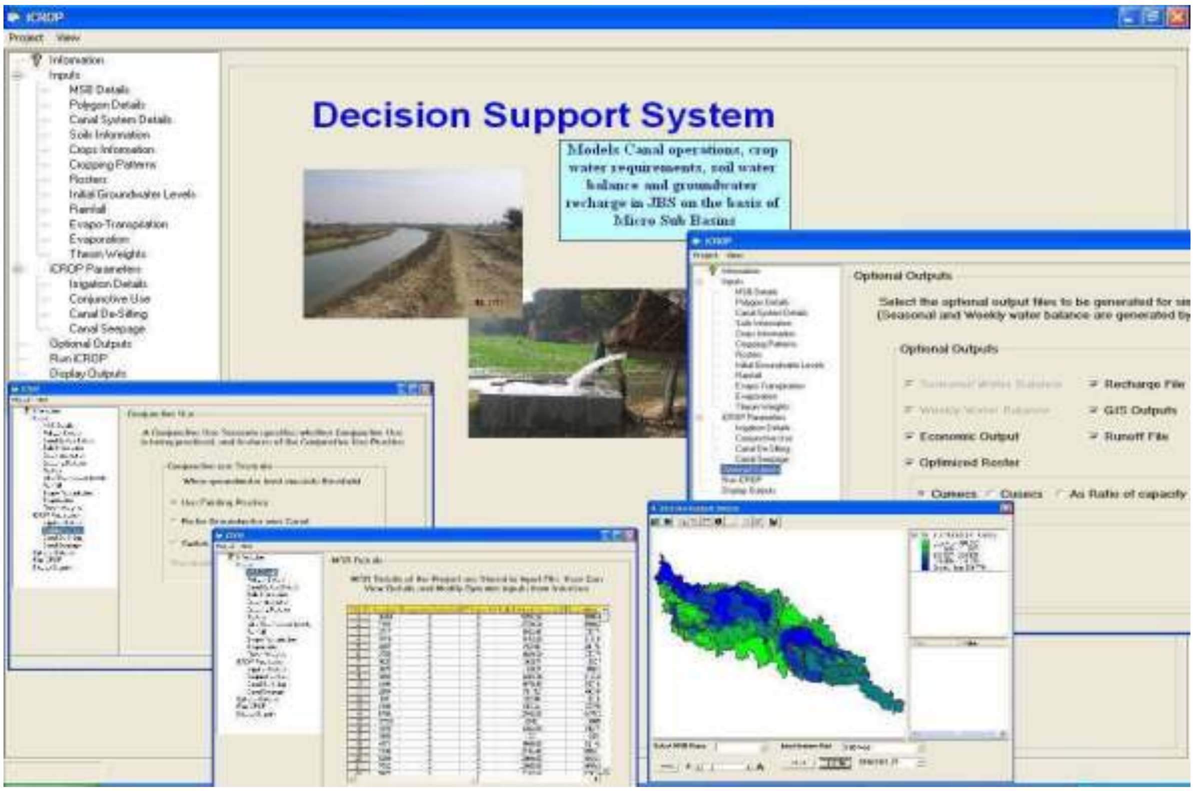


Figure 7.1-Interface of Decision support system, I CROP model

7.3. Model development for Ramganj distributaries command

Ramganj distributaury system having canal command area of 39861 ha provides canal supplies in the area through a canal network of 243 km through 35 number minors/distributaries for irrigating mainly rice and wheat cycle. The canal system lies between Gomti River and Balrampur drain doab having an area of 66939 ha, lying between 25^0 50′ 50″ to 26^0 13′ 35″ north latitude and 82^0 01′ 53″ to 82^0 25′ 43″ east longitude, in 9 blocks of Sutanpur, Pratapgarh and Jaunpur districts of Uttar Pradesh. The non canal command area lying between Gomti balrampur drain doab is irrigated by ground water irrigation.

Ramganj distributaury command is divided into 13 micro sub-basins (MSB) as shown in Figure 7.2. and further it has been divided in 34 Sub-Irrigation Units(SIU) as shown in Figure 7.3 on GIS platform depending upon the ground water levels below ground for modeling purposes. Each sub-Irrigation Unit consists of one or more homogenous unit (HU). A HU in a SIU has the same potential to be waterlogged, soil characteristics, access to irrigation and depth to groundwater levels. They differ from each other in land use or crop grown.

The area where ground water level lies between 0-3.0 m below has been marked as 1, the area where ground water level lies between 3.0-5.0 m below has been marked as 2, the area where ground water level lies between 5.0-8.0 m below has been marked as 3 and the area where ground water level is below 8 m has been marked as 4.

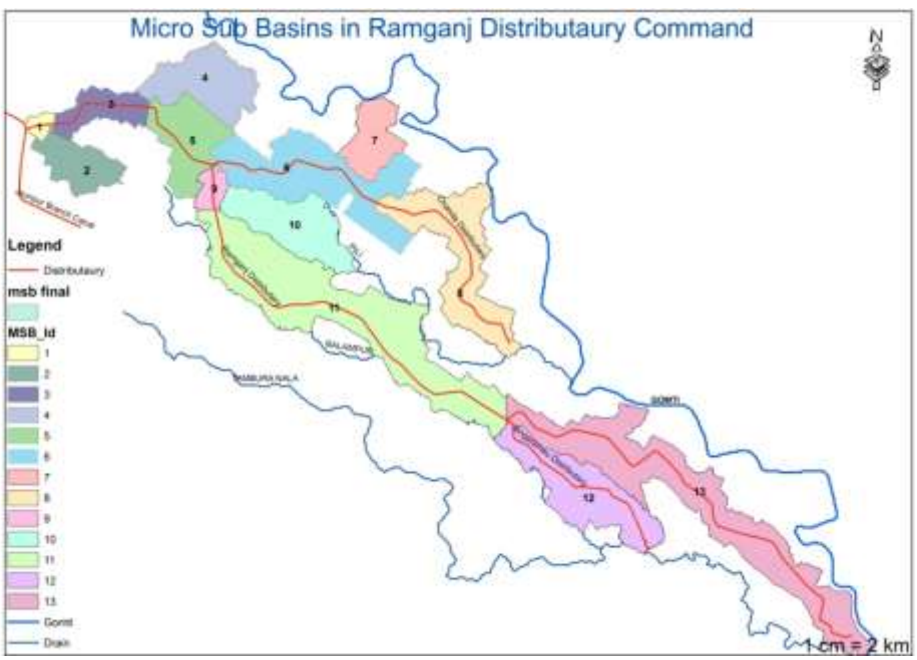


Figure 7.2. Micro sub-basins in Ramganj distributaury command

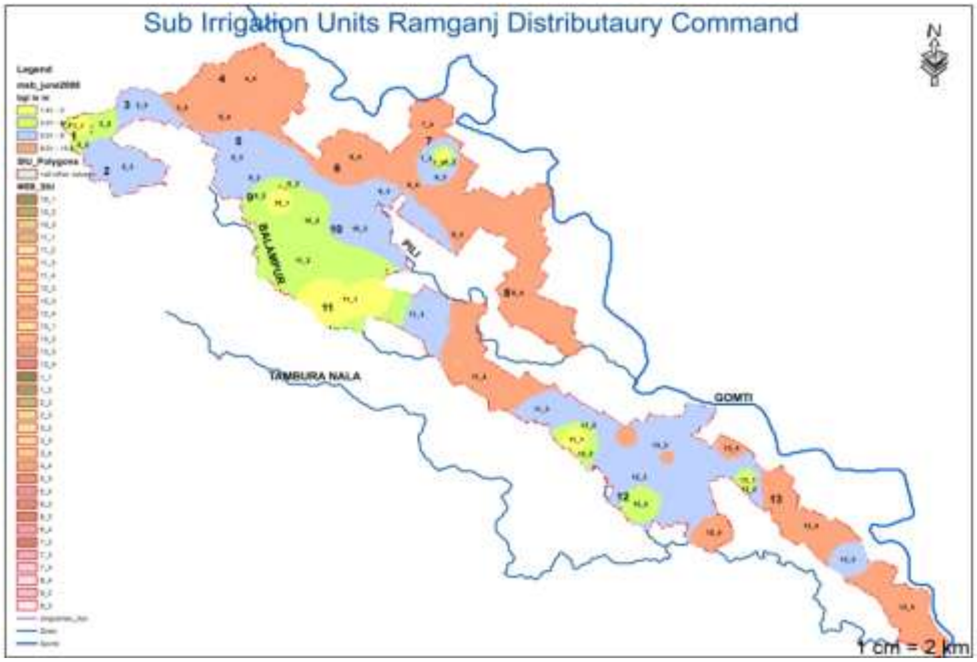


Figure 7.3. Sub Irrigation units in Ramganj distributaury command

The daily rainfall and evapotranspiration data collected has been used in the model run, through Thiesan weight percentage for the corresponding station, as shown in Table7.1.

Table 7.1.Thiesan weight percentage for the corresponding station

MSB ID	MSB Name	Station ID	Station Name	Percent Area
1	Ramganj Head - Beerpur	13	sultanpur	100
2	Beerpur Dy	13	sultanpur	100
3	Ramganj Beerpur - Ramganj Babhangawa	13	sultanpur	100
4	Babhangawa Dy	13	sultanpur	100
5	Ramganj Babhangawa- Chanda	13	sultanpur	100
6	Chanda Head - Karanpur	11	kadipur	78.38
6	Chanda Head - Karanpur	13	sultanpur	21.62
7	Karanpur Dy	11	kadipur	100
8	Chanda Dy	11	kadipur	100
9	Ramganj Chanda - Khandauli	13	sultanpur	100
10	Khandauli Dy	11	kadipur	82.13
10	Khandauli Dy	13	sultanpur	17.87
11	Ramganj Khandauli - Singramau	11	kadipur	33.52
11	Ramganj Khandauli - Singramau	5	patti	58.18
11	Ramganj Khandauli - Singramau	13	sultanpur	8.30
12	Singramau Dy	3	machlishahar	3.18
12	Singramau Dy	5	patti	96.82
13	Ramganj Singramau Tail	11	kadipur	35.37
13	Ramganj Singramau Tail	5	patti	11.98
13	Ramganj Singramau Tail	4	shahganj	36.22
13	Ramganj Singramau Tail	2	jaunpur	16.43

7.3.1 Model inputs

The data related to modeling inputs is placed as MSB details consisting of MSB ID, MSB name, Evaporation Station Number, Evapo-transpiration station number, daily domestic and industrial needs, as Polygon Details consisting of MSB ID, Index Class, Polygon area, maximum pumping rate, maximum pumping depth, specific yield and soil ID corresponding to each polygon.

The information related to Canal System Details consists of MSB ID, Reach ID, Name, Length of reaches, Actual and design capacity of canal system.

Soils Information sheet includes Soil ID, Soil name, Saturated hydraulic conductivity in mm/day, Field capacity in percentage, wilting point in percentage and Saturation moisture content in percentage while Crops Information sheet includes Crop Code, Crop name, Sowing date, crop period, season code and irrigation method corresponding to that crop.

For consideration of different land use options in the model, existing major eleven crops opted in the study area are considered. Normal yield values of different crops and the required inputs cost of materials and labour are taken for good irrigation practises. Selling price of produce is based on cost of crop fixed by the State Government for the year 2012-13.Crop yield reduction factors due to water logging, calcareousness, slope and soil texture are based on the analysis of crop cutting data of the corresponding area. Irrigation cost for ground water irrigation is based on current rates, while for surface water irrigation through canals; the seasonal rates for each crop fixed by the State Government are considered, as detailed in Table 7.2.

Table 7.2. Showing details of crop economics

Crop Code	Crop Name	Normal yield (Q/ha)	Waterlogged yield (Q/ha)	Yield Reduction Drainage	Yield Reduction Sub-Surf texture	Yield reduction Slope	Yield reduction Calcareous	Yield reduction factor (Water deficit)	Input Cost (Rs/ha)	Irrigation fee (canal) Rs/ha	Irrigation fee (Pumping) Rs/m3	Labour Input (Rs/ha)	Selling price (Rs/Q)	By Products selling price (Rs/ha)
1	Rice	50.00	45.02	-1.40	-10.49	-3.53	-2.96	1.2	23161	287	1	21200	1310	5000
2	Wheat	40.00	39.01	4.29	-2.46	-4.01	2.71	1	28400	287	1	17400	1400	18000
3	Sugarcane	580.00	565.63	0.00	0.00	0.00	0.00	1.2	40000	474	1	40000	280	0
4	Arhar	20.00	19.50	0.00	0.00	0.00	0.00	1.15	15800	212	1	15200	4300	1000
5	Maize	40.00	36.03	0.00	0.00	0.00	0.00	1.25	2500	173	1	10000	1310	3000
6	Pulses	15.00	14.64	0.00	0.00	0.00	0.00	1	6000	212	1	8000	4000	2500
7	Others_Rabi	20.00	19.50	0.00	0.00	0.00	0.00	0.7	14000	212	1	6000	3000	2000
8	Others_Jaayad	12.00	11.70	0.00	0.00	0.00	0.00	0.7	9000	212	1	6000	4000	1000
9	Others_Kharif	30.00	29.26	0.00	0.00	0.00	0.00	1.15	9000	173	1	9000	1500	4000
10	Mentha	1.50	1.46	0.00	0.00	0.00	0.00	1	25000	173	1	20000	100000	0
11	Barley	30.00	29.26	0.00	0.00	0.00	0.00	0.85	19500	287	1	14500	1100	8000

7.3.2-Model calibration: The developed canal command, ICROP model is calibrated from Visual MODFLOW by giving recharge from ICROP and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model, integrated water quantity and quality simulation model (IQQM) through which generated runoff values are checked from observed runoff values.

7.3.3. Management Options: The different management scenario options are considered.

7.3.3.1. Rainfall-Daily- rainfall sequence of different dependability's has been considered. For modeling purposes rainfall sequence with 10% dependability is considered as dry rainfall sequence, rainfall sequence with 50% dependability is considered as normal rainfall sequence and the rainfall sequence with 90% dependability is considered as wet rainfall sequence,

7.3.3.2. Canal supply options-Canal supply options with design canal capacity, silted canal capacity, with changed rosters, along with head priority and tail priority has been considered. Options are tried both for lined and unlined sections of canals also.

7.3.3.3.Changed land use options-Existing land use options based on NIC statistics, based on remote sensing land use shape files along with field survey has been considered. For future scenarios different cropping patterns are considered as tabulated below in Table 7.3.

Table 7.3. Details of existing and proposed cropping patterns

Existing Cropping Pattern			Proposed Cropping pattern1		Proposed Cropping pattern2		Proposed Cropping pattern3	
Polygon Area	39860.91 ha							
	area in ha	% area	area in ha	% area	area in ha	% area	area in ha	% area
RICE_K	12585.2	31.57	19685.5	49.39	26785.8	67.2	12585.2	31.57
MAZE_K	3456.41	8.67	3456.41	8.67	3456.41	8.67	3456.41	8.67
Other_Kharif	2830.85	7.1	2830.85	7.1	2830.85	7.1	17031.4	42.73
Kharif_Fallow	14200.6	35.63	7100.28	17.81	0	0	0	0
Total Kharif	18872.5	47.35	25972.8	65.16	33073.1	82.97	33073.1	82.97
WHEAT	16953.7	42.53	21995.8	55.18	27037.9	67.83	16953.7	42.53
GRAM	2891.17	7.25	2891.17	7.25	2891.17	7.25	2891.17	7.25
Other_Rabi	3143.94	7.89	3143.94	7.89	3143.94	7.89	13228.2	33.19
Rabi_Fallow	10084.2	25.3	5042.12	12.65	0	0	0	0
Total Rabi	22988.8	57.67	28030.9	70.32	33073.1	82.97	33073.1	82.97
URD_J	11.85	0.03	11.85	0.03	11.85	0.03	11.85	0.03
Other_Jaayad	212.88	0.53	212.88	0.53	212.88	0.53	33061.2	82.94
Jaayad_Fallow	32848.3	82.41	32848.3	82.41	32848.3	82.41	0	0
Total Jayad	224.73	0.56	224.73	0.56	224.73	0.56	33073.1	82.97
SUGARCANE	91.45	0.23	91.45	0.23	91.45	0.23	91.45	0.23
Vegitation	1357.63	3.41	1357.63	3.41	1357.63	3.41	1357.63	3.41
Wasteland	5338.75	13.39	5338.75	13.39	5338.75	13.39	5338.75	13.39
Total cropping % of gross polygon area	42177.5	105.81	54319.9	136.27	66462.3	166.74	99310.6	249.14

7.3.3.4. Conjunctive use options: Canal water preference, ground water preference up to prescribed depth below ground levels and conjunctive use options are considered.

7.3.4. Model runs results: Different scenarios are tried.

7.3.4.1. Model run output for existing cropping Pattern of 105.81% of polygon area, 75% dependable rainfall, design canal flows, and conjunctive use are tabulated in Table 7.4.

Table 7.4. Model run out put showing details at existing cropping pattern of 105.81%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	20.1	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.7	20.2	31.1	403.6	28.6
Drainage Reuse	0.0	0.0	2.8	1.2	0.0	0.0	2.8	0.2
Total	1118.0	100.0	230.8	100.0	64.9	100.0	1413.7	100.0
Outputs								
ET (Plants use)	337.3	34.1	264.1	65.8	79.3	67.9	680.6	45.1
Domestic & Industrial use	8.0	0.8	7.6	1.9	5.2	4.4	20.7	1.4
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	454.5	45.9	18.4	4.6	0.0	0.0	472.9	31.4
Escape flow (Net of reuse)	158.1	16.0	78.8	19.7	17.5	15.0	254.4	16.9
Base flow	31.5	3.2	31.7	7.9	14.7	12.6	77.9	5.2
Total	990.1	100.0	401.1	100.0	116.7	100.0	1507.8	100.0
Increase in subsurface storage	127.9		-170.3		-51.7		-94.1	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	201.8		181.6		20.2		403.6	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	158.1	78.4	76.0	41.8	17.5	86.5	251.6	62.3
Water supplied to farms	27.0	13.4	83.2	45.8	0.2	1.0	110.4	27.4
Total	201.8	100.0	181.6	100.0	20.2	100.0	403.6	100.0

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	7.3	22.0	37.5	2.4	97.8	40.4	14.5
Seepage from field	202.1	92.7	36.7	62.5	0.1	2.2	238.9	85.5
Total	218.1	100.0	58.7	100.0	2.5	100.0	279.3	100.0
Extractions								
For agriculture	0.0	0.0	144.7	78.6	0.0	0.0	144.7	59.5
For domestic and industrial use	8.0	20.2	7.6	4.1	5.2	26.1	20.7	8.5
Flow to drains/river	31.5	79.8	31.7	17.2	14.7	73.9	77.9	32.0
Total	39.5	100.0	184.0	100.0	19.9	100.0	243.4	100.0
Increase in subsurface storage	178.6		-125.3		-17.4		35.9	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403, 6 mm at existing Cropping Pattern of 105.81%, ground water recharge in kharif period is 178.6 mm, while 125.3 mm is used in rabi period and 17.4 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 35.9 mm is seen.

7.3.4.2. Model run output for proposed cropping Pattern of 136.27% of polygon area, 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.5.

Table 7.5. Model run output at proposed cropping Pattern of 136.27%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	24.3	44.8	24.1	1007.2	67.4
Canal supply	201.8	18.1	141.3	74.1	141.3	75.9	484.4	32.4
Drainage Reuse	0.0	0.0	3.0	1.6	0.0	0.0	3.0	0.2
Total	**1118.0**	**100.0**	**190.5**	**100.0**	**186.0**	**100.0**	**1494.6**	**100.0**
Outputs								
ET (Plants use)	419.5	40.7	254.5	70.6	102.1	47.6	776.1	48.3
Domestic & Industrial use	8.0	0.8	7.6	2.1	5.2	2.4	20.7	1.3
Canal net evaporation	0.7	0.1	0.3	0.1	0.6	0.3	1.7	0.1
Runoff	415.7	40.3	17.9	4.9	5.1	2.4	438.7	27.3
Escape flow (Net of reuse)	158.1	15.3	54.7	15.2	89.4	41.6	302.2	18.8
Base flow	29.9	2.9	25.7	7.1	12.1	5.6	67.8	4.2
Total	**1031.9**	**100.0**	**360.7**	**100.0**	**214.6**	**100.0**	**1607.2**	**100.0**
Increase in subsurface storage	**86.1**		**-170.1**		**-28.5**		**-112.6**	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	**201.8**		**141.3**		**141.3**		**484.4**	
Outputs								
Evaporation losses	0.7	0.3	0.3	0.2	0.6	0.5	1.7	0.3
Seepage losses	16.0	7.9	17.1	12.1	14.7	10.4	47.8	9.9
Escape flow	158.1	78.4	51.7	36.6	89.4	63.3	299.2	61.8
Water supplied to farms	27.0	13.4	72.1	51.0	36.6	25.9	135.6	28.0
Total	**201.8**	**100.0**	**141.3**	**100.0**	**141.3**	**100.0**	**484.4**	**100.0**

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	8.3	17.1	31.3	14.7	68.3	47.8	17.7
Seepage from field	177.5	91.7	37.5	68.7	6.8	31.7	221.9	82.3
Total	**193.5**	**100.0**	**54.7**	**100.0**	**21.5**	**100.0**	**269.7**	**100.0**
Extractions								
For agriculture	0.0	0.0	166.1	83.3	0.0	0.0	166.1	65.3
For domestic and industrial use	8.0	21.0	7.6	3.8	5.2	30.0	20.7	8.1
Flow to drains/river	29.9	79.0	25.7	12.9	12.1	70.0	67.8	26.6
Total	**37.9**	**100.0**	**199.4**	**100.0**	**17.3**	**100.0**	**254.6**	**100.0**
Increase in subsurface storage	**155.6**		**-144.8**		**4.2**		**15.1**	

With 75% dependable rainfall of 1007.2 mm, canal supply of 484.4 mm at existing Cropping Pattern of 136.27%, ground water recharge in kharif period is 155.6 mm, while 144.8 mm is used in rabi period and 4.2 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 15.1 mm is seen.

7.3.4.3. Model run output for proposed cropping pattern of 166.74% of polygon area , 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.6.

Table 7.6. Model run output showing details at proposed cropping pattern of 166.74%, 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	20.0	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.4	20.2	31.1	403.6	28.5
Drainage Reuse	0.0	0.0	3.7	1.6	0.0	0.0	3.7	0.3
Total	1118.0	100.0	231.6	100.0	64.9	100.0	1414.5	100.0
Outputs								
ET (Plants use)	396.2	40.2	292.5	68.6	87.5	71.4	776.1	50.6
Domestic & Industrial use	8.0	0.8	7.6	1.8	5.2	4.2	20.7	1.3
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	393.1	39.9	21.9	5.1	0.0	0.0	415.1	27.0
Escape flow (Net of reuse)	153.9	15.6	72.7	17.1	17.4	14.2	244.0	15.9
Base flow	33.7	3.4	31.3	7.3	12.4	10.1	77.4	5.0
Total	985.7	100.0	426.4	100.0	122.5	100.0	1534.6	100.0
Increase in subsurface storage	132.3		-194.8		-57.6		-120.1	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	201.8		181.6		20.2		403.6	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	153.9	76.3	69.1	38.0	17.4	86.2	240.4	59.6
Water supplied to farms	31.2	15.5	90.2	49.6	0.3	1.3	121.6	30.1
Total	201.8	100.0	181.6	100.0	20.2	100.0	403.6	100.0

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	6.7	22.0	32.4	2.4	97.3	40.4	13.1
Seepage from field	221.2	93.3	45.9	67.6	0.1	2.7	267.2	86.9
Total	237.2	100.0	67.9	100.0	2.5	100.0	307.6	100.0
Extractions								
For agriculture	0.0	0.0	199.6	83.7	0.0	0.0	199.6	67.0
For domestic and industrial use	8.0	19.1	7.6	3.2	5.2	29.5	20.7	7.0
Flow to drains/river	33.7	80.9	31.3	13.1	12.4	70.5	77.4	26.0
Total	41.7	100.0	238.5	100.0	17.5	100.0	297.7	100.0
Increase in subsurface storage	195.5		-170.6		-15.0		9.9	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403.6 mm at existing Cropping Pattern of 166.74%, ground water recharge in kharif period is 195.5 mm, while 170.6 mm is used in rabi period and 15.0 mm is used in jaayed period. If conjunctive use is applied an overall recharge of 9.9 mm is seen.

7.3.4.4. Model run output at proposed cropping Pattern of 249.14% of polygon area, 75% dependable rainfall, design canal flows and conjunctive use are tabulated in Table 7.7.

Table 7.7. . Model run output showing at proposed cropping pattern of 249.14**,** 75% dependable rainfall, design canal flows, and conjunctive use

System Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Rainfall	916.2	81.9	46.3	19.9	44.8	68.9	1007.2	71.2
Canal supply	201.8	18.1	181.6	78.2	20.2	31.1	403.6	28.5
Drainage Reuse	0.0	0.0	4.3	1.9	0.0	0.0	4.3	0.3
Total	**1118.0**	**100.0**	**232.2**	**100.0**	**64.9**	**100.0**	**1415.2**	**100.0**
Outputs								
ET (Plants use)	455.1	46.4	324.5	70.7	95.5	74.7	875.1	55.8
Domestic & Industrial use	8.0	0.8	7.6	1.6	5.2	4.1	20.7	1.3
Canal net evaporation	0.7	0.1	0.4	0.1	0.1	0.1	1.2	0.1
Runoff	331.1	33.7	25.3	5.5	0.1	0.0	356.4	22.7
Escape flow (Net of reuse)	150.8	15.4	70.9	15.4	17.3	13.5	239.0	15.2
Base flow	36.0	3.7	30.2	6.6	9.8	7.7	76.1	4.8
Total	**981.7**	**100.0**	**458.9**	**100.0**	**127.8**	**100.0**	**1568.4**	**100.0**
Increase in subsurface storage	**136.3**		**-226.7**		**-62.9**		**-153.2**	

Canal Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Canal supply	**201.8**		**181.6**		**20.2**		**403.6**	
Outputs								
Evaporation losses	0.7	0.3	0.4	0.2	0.1	0.4	1.2	0.3
Seepage losses	16.0	7.9	22.0	12.1	2.4	12.1	40.4	10.0
Escape flow	150.8	74.7	66.6	36.7	17.3	85.5	234.7	58.1
Water supplied to farms	34.3	17.0	92.6	51.0	0.4	2.0	127.3	31.5
Total	**201.8**	**100.0**	**181.6**	**100.0**	**20.2**	**100.0**	**403.6**	**100.0**

Ground Water Balance

All Units are in mm

Component	Kharif		Rabi		Jaayad		Total	
	Average	Percent	Average	Percent	Average	Percent	Average	Percent
Inputs								
Seepage from canals	16.0	6.2	22.0	28.4	2.4	96.2	40.4	12.0
Seepage from field	239.9	93.8	55.5	71.6	0.1	3.8	295.5	88.0
Total	**255.9**	**100.0**	**77.5**	**100.0**	**2.5**	**100.0**	**336.0**	**100.0**
Extractions								
For agriculture	0.0	0.0	262.4	87.4	0.0	0.0	262.4	73.1
For domestic and industrial use	8.0	18.1	7.6	2.5	5.2	34.6	20.7	5.8
Flow to drains/river	36.0	81.9	30.2	10.1	9.8	65.4	76.1	21.2
Total	**44.0**	**100.0**	**300.2**	**100.0**	**15.0**	**100.0**	**359.2**	**100.0**
Increase in subsurface storage	**211.9**		**-222.7**		**-12.4**		**-23.2**	

With 75% dependable rainfall of 1007.2 mm, canal supply of 403.6 mm at existing Cropping Pattern of 249.14%, ground water recharge in kharif period is 211.9 mm, while 222.7 mm is used in rabi period and 12.4mm is used in jaayed period. If conjunctive use is applied an overall depletion of 23.2 mm is seen.

7.3.4.5. Area of cultivation and gross margin to farmers

With the implementation of conjunctive use at 75% dependable rainfall and designed canal flows, the area of cultivation and gross margin to farmers can be increased even to double, as tabulated below in Table 7.8,as a result of model runs in different scenarios.

Tale 7.8, showing results of gross margin in different model run scenarios

S.N	Cropped area (% of polygon area of 39860.9 ha)				Cropping Intensity in %	Area under cultivation in Ha	Gross Profit in crore	Ground water depletion in mm
	Karif	Rabi	Jaid	Total				
1	2	3	4	5	6	7	8	9
1	47.3	57.7	0.6	105.8	162.77	42177.5	16.67	35.9
2	65.2	70.3	0.6	136.3	209.69	54319.9	20.86	15.1
3	83	83	0.6	166.7	256.46	66462.3	24.93	9.9
4	83	83	83	249.1	383.23	99310.6	34.6	-23.24

7.4. Summary and Conclusions

In Ramganj distributaury command at 75% dependable rainfall , if canal supplies are made at design discharge and conjunctive use is opted, an area of 166.74%(82.97% kharif,82.97 % rabi,0.56% jaayed and 0.23 % sugarcane) of polygon area or 256.52%

cropping intensity can be irrigated and ground water can be kept sustainable with an overall net recharge of 9.9mm per year. The gross margin to farmers and area of cultivation can even be doubled by bringing additional area under cultivation.

CHAPTER 8

INTEGRATED MODEL AT KULAWA COMMAND UPTO FIELD LEVEL, USING SOIL MOISTURE, RAINFALL RUNOFF, SYSTEM LOSS AND GROUND WATER MODULES ON GIS PLATEFORM

8.1. Introduction

A smaller canal command area of 3755 ha, of daulatpur disributaury system located between N 26^0 17′ 09″ and 26^0 23′ 57″, and E 81^0 23′ 14″ and 81^0 29′ 20″,has been considered with detailed data base after field survey to see the impact of different management scenarios with the consultation of Water Users Associations and its field application. Modeling procedure is discussed in subsequent section of Chater7.

8.2. Command area details

Study area (3755 Ha) falls in Tiloi block of Raiberreli district between Bhusela Tal and Moong Tal drains. Irrigation facilities are provided through a canal network of 57.40 km in Daulatpur distributaury system with a head discharge of 39.00 cusec. The detail of main distributaury and its off taking minors (i.e. Bhadsana, Fareedpur, Savitapur and Urwa minors) is shown in Fig. 8.1. Ground water is supplied for irrigation (through private boring in each kulawa command). The actual ground water use in each kulawa command has been calculated on the basis of number of actual borings in each kulawa command and its average run during each season.

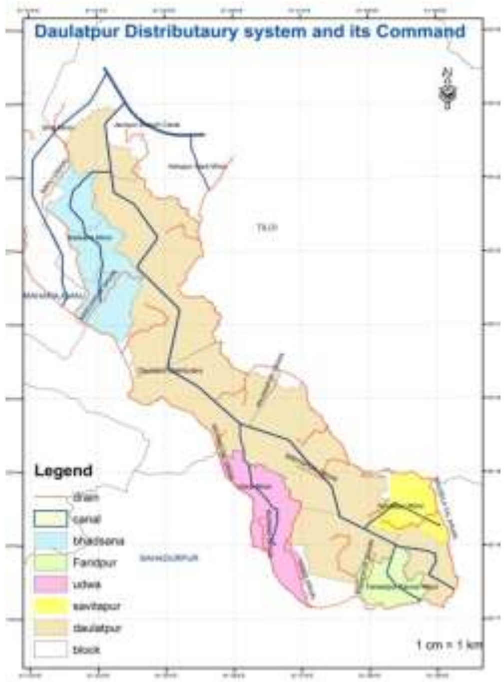


Figure 8.1-Details of Daulatpur distributaury system

The canal water is supplied through distributaury and different minors as per roaster. For the existing land use details based on imageries (Figure-8.2),with statistics in Table 8.1,It may be stated that in a canal command of 3755 ha, rabi sown area is 1912.08 ha (51.52%), Kharif sown area is 1848.67 ha (49.82%) while the Zaid is only 150.72 ha (4.06%). The total sown area is 3911.47 ha (105% of command area). While based on field survey existing cropping pattern of 130% (64% Kharif, 60 % Rabi and 6% Zaid of command area) and that based on NIC statistics existing cropping pattern of 109% (54% Kharif, 48 % Rabi and 7% Zaid of command area) has been considered. The duration for Kharif crop in study area is from June to November, for Rabi crop from November to March and that for Zaid crop is from April to September.

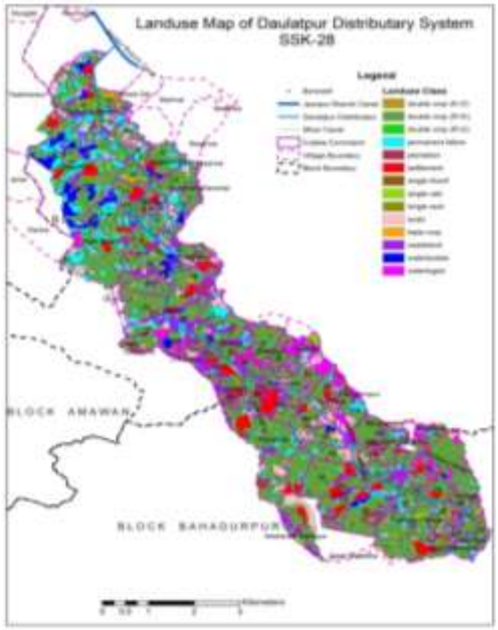


Figure 8.2-Land use map

Table 8.1-Landuse details pf Daulatpur distributaury system

land use details (Area in ha)	
single kharif	97.7
single rabi	126.67
single zaid	32.12
double crop (K+Z)	13.13
double crop (R+K)	1679.94
double crop (R+Z)	47.56
triple crop	57.9
permanent fallow	505.88
plantation	96.64
settlement	173.88
sodic	268.56
wasteland	224.9
waterbodies	128.28
waterloged	145.98
Rabi	1912.08
Kharif	1848.67
Zaid	150.72
Total Sown	3911.47

The 100 years rainfall data analysis for the study area at different rainfall depend abilities shows that average annual rainfall is 891.03 mm, while the 75% dependable rainfall is 669.67 mm. Daily rainfall data analysis shows that daily rainfall of more than 100 mm is exceptional. Daily Evaporation data used for study area shows that maximum evaporation per day is of the order of 10.27 mm/day, while the minimum evaporation is 0.76 mm/day, with an average of 4.00 mm /day. Ground water levels in the bore wells located at Udawa and Faridpur villages of the study area are in declining at the rate of more than 100 cm per year for the existing cropping pattern. The daily trend of ground water behaviour at Faridpur &Udawa villages, below ground is shown in Fig- 8.3.

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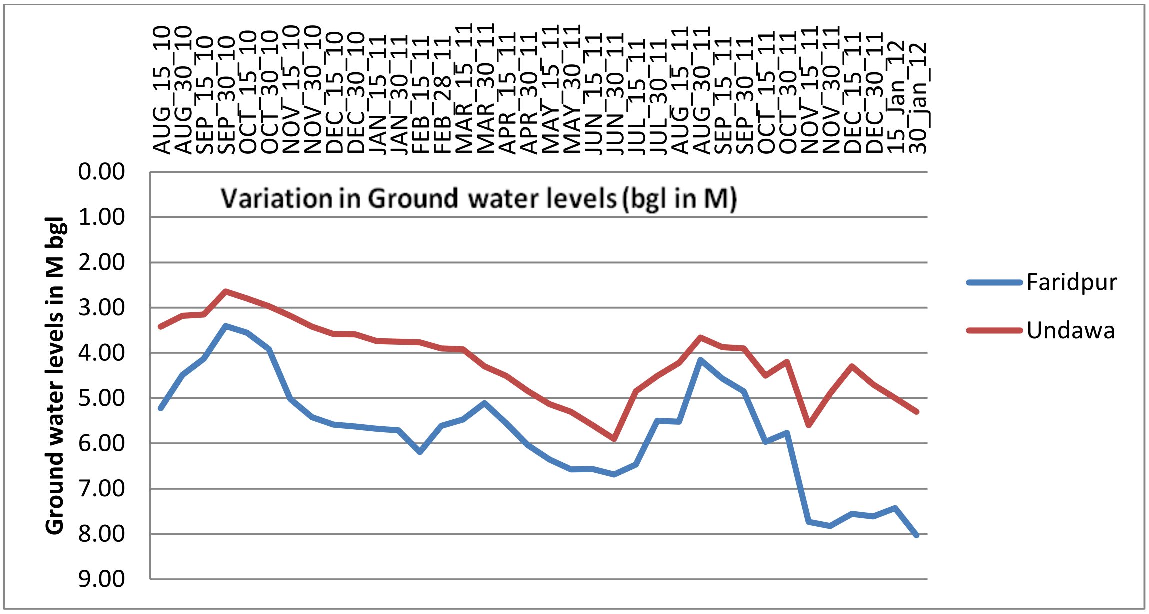

Fig. 8.3-Variation of ground water levels in bore well at Village Faridpur &Udawa

Different land use options in the model represents existing major eleven crops(Rice, Wheat, Sugarcane, Arhar, Maize, Pulses, Other Rabi, Other Zaid, Other Kharif, Mentha and Barley) opted in the study area. Normal yield values of different crops and the required inputs cost of materials and labour are considered for good irrigation practises. Selling price of produce is based on cost of crop fixed by the State Government for the year 2012-13. Crop yield reduction factors due to water logging, calcareousness, slope and soil texture are based on the analysis of crop cutting data of the corresponding area. Irrigation cost for ground water irrigation is based on current rates. The seasonal rate for each crop is fixed by the State Government for surface water irrigation through canals.

8.3. Models implementation scenarios

The study area has been divided into number of reaches and MSBs. GIS and other Input files for the study area are prepared to see the impact of following model run scenarios considered:

i. Rainfall occurrence at normal, wet and dry sequences.
ii. Water supply at canal head as per roaster, when canal efficiency is at 100% and at lower efficiency in silted condition.
iii. Canal section earthen or lined.
iv. Land use existing or as proposed with different alternatives of changing cropped areas along with priorities for ground water or surface water use.

8.4. Model run results for different scenarios

The different management scenarios tried, are detailed below.

8.4.1. Impact of change in rainfall sequences

Different rainfall sequences of wet, normal and dry seasons are simulated by different model runs. At daily rainfall series of 1023.3 mm with canal supply of 500.6 mm through roster, average water use efficiency of canal water is only 14.8% and the average depletion in ground water reservoir is 9.85 cm per year for the existing cropping pattern of 109% (of command area) based on statistics of national information centre as shown in model run output (Table 8..2). With decrease in rainfall i.e in normal rainfall sequence of 729.5 mm with the same canal supply of 500.6 mm through roster, average water use efficiency of canal water increases to 23.9% and the average depletion in ground water reservoir increases to 12.04 cm per year for the existing cropping pattern of 109%(of command area) as shown in model run output (Table 8.2).

Table 8.2-Impact of change in rainfall sequences for existing cropping pattern of 109% (of command area)

Model run for different	Rainfall in mm	Canal supply in mm	Canal water efficiency	Ground water depletion in mm
Wet rainfall sequence	1023.3	500.6	14.85%	9.85 cm/yr
Normal rainfall sequence	729.5	500.6	23.90%	12.04 cm/yr
Dry rainfall seqence	425.1	500.6	25.50%	39.59 cm/yr

With further decrease in rainfall i.e. in dry rainfall sequence of 425.1 mm with the same canal supply of 500.6 mm through roster, average water use efficiency of canal water further increases to 25.5 % and the average depletion in ground water reservoir increases to 39.59 cm per year for the existing cropping pattern of 109% (of command area) as shown in model run output (Table 8.2).It clearly indicates that with decrease in rainfall canal water use efficiency increases, while the ground water use or depletion in ground water reservoir is also increased. Decrease in groundwater level may be attributed for withdrawal of groundwater by private tube wells to augment the canal supply.

8.4.2. Impact of change in canal water supply

When the canal supplies are increased to 1675.8 mm per year and the rainfall of 555.1 mm per year is considered water use efficiency of canal water decreases to 8.1%

only. The increase in ground water depletion reduces to 3.85 cm per year as shown in Table 8.3. With the same rainfall sequence of 555.1 mm per year and decrease in canal water supply to 321.8 mm per year, the canal water use efficiency increases to 52.2% and the depletion in ground water reservoir increases to 16.56 cm per year as shown in Table 8.3.

Table 8.3-Impact of change in canal water supply

Model run for different canal supply sequence	Rainfall in mm	Canal supply in mm	Canal water efficiency	Ground water depletion in mm
Increased canal supply	555.1	1675.8	8.10%	3.85 cm/yr
Decreased canal supply	555.1	321.8	52.20%	16.56 cm/yr

Different model runs clearly indicates that at the same rainfall sequence with the increase in canal water supply, canal water use efficiency decreases. At the same time the ground water depletion also decreases vice versa. With the decrease in canal water supply canal water use efficiency increases but the ground water depletion also increases.

8.4.3. Impact of canal lining

For the normal rainfall sequence of 847.3 mm per year and canal supply of 314.4 mm per year (as per roster for unlined section) the canal water use efficiency was 37.3%, while the ground water decline was 18 cm per year for the existing cropping pattern of 109% (of command area) as shown in Table 8.4.With the option for lined section at the same rainfall sequence of 847.3 mm per year and canal supply of 314.4 mm per year, the canal water use efficiency increased to 40.7%, but the decline in ground water levels increased to 19 cm per year for the same cropping pattern, as shown in Table 8.4.

Table 8.4-Impact of canal lining for existing cropping pattern of 109% (of command area)

Model run for different canal sections	Rainfall in mm	Canal supply in mm	Canal water efficiency	Ground water depletion in mm
Unlined canal section	847.3	314.4	37.30%	18.01 cm/yr
Lined canal section	847.3	314.4	40.70%	19.01 cm/yr

It clearly indicates that with lining, canal water use efficiency increases, but ground water depletion also increases. It means, if conjunctive use is opted, lining is not beneficial.

8.4.4. Impact of land use changes with implementation of conjunctive use

At head reaches of canal command ground water table is high due to excessive use of canal water and in tail command there is more depletion in ground water levels. Model run indicates that for the normal rainfall sequence of 849.2 mm and existing cropping pattern of 130% (based on field survey 64% Kharif, 60 %Rabi and 6% Zaid of command area) and opting for conjunctive use (with preference of ground water pumping up to 2m), ground water decline is 9.88 cm per year while the canal water use efficiency is 44.1% as shown with output of model run in Table 8.5.

Table 8.5-Impact of land use changes with implementation of conjunctive use

Model run for different land uses	Rainfall in mm	Canal supply in mm	Canal water efficiency	Ground water depletion in mm
Existing cropping pattern of 130%(based on field survey 64% Kharif, 60 %Rabi and 6% Zaid of command area) , with opting conjunctive use	849.2	314.4	44.10%	9.88 cm/yr
Proposed cropping pattern of 159 % (77% Kharif, 76% Rabi and 6% Zaid of command area) with opting conjunctive use	849.2	314.4	48.80%	12.18 cm/yr
Proposed cropping pattern of 230 % (77% Kharif, 76% Rabi and 77% Zaid of command area) with opting conjunctive use	849.2	314.4	47.70%	13.75 cm/yr

Model run also indicate that with the proposed cropping pattern of 159% (77% Kharif, 76% Rabi and 6% Zaid of command area) and the normal rainfall sequence of 849.2 mm, the decline in ground water level will again reduce to 12.18 cm per year, while the canal water use efficiency will further increase to 48.8%, as shown with model output in Table 8.5.

With the proposed cropping intensity of 230 % (77% Kharif, 76% Rabi and 77% Zaid of command area) and the normal rainfall sequence of 849.2 mm, opting for conjunctive use model run simulate the decline in ground water level to be 13.75 cm per year , while the canal water use efficiency increase to 47.7% as shown with model output in Table 8.5.

The different management scenario runs of the Model, indicates that depletion in ground water levels is directly related to proposed cropping pattern /cropping intensity and it reduces with increase in rainfall or increase in canal water supply or with the proposal of less water requiring crops. However this depletion in ground water level can be maintained more effectively at constant level with implementation of conjunctive use at Kulawa command level to bring more area under cultivation and saving energy cost in tail commands.

Based on weekly availability of canal water supply and ground water requirements, dual roster can be developed from the model run outputs on weekly basis for the corresponding scenarios to be decided by the cultivators. The ground water weekly pumping requirement per boring is based on the number of private borings available in the said kulawa command. The developed roster for Kharif is shown in table 8.6.

Table 8.6-Developed Dual roster for Kharif

DUAL ROASTER DAULATPUR DISTRIBUTARY KHARIF 2012																								
	Component Name	Command Area in Ha	Design Canal discharge in cusec	Canal discharge allowed in cusec	No.of Existing Borings	Source	unit	15-06-2012	22-06-2012	29-06-2012	06-07-2012	13-07-2012	20-07-2012	27-07-2012	03-08-2012	10-08-2012	17-08-2012	24-08-2012	31-08-2012	07-09-2012	14-09-2012	21-09-2012	28-09-2012	05-10-2012
Reach	Head Daulatpu		43.00	43.00		SW	cusec	43.1	0.0	43.1	43.1	0.0	0.0	43.1	43.1	0.0	43.1	0.0	0.0	0.0	43.1	0.0	43.1	0.0
MSB	Daulatpur Head to Bhadsana Head	186	2.40	2.40	9	SW	cusec	2.4	0.0	2.4	2.4	0.0	0.0	2.4	2.4	0.0	2.4	0.0	0.0	0.0	2.4	0.0	2.4	0.0
						GW	running	10.3	2.6	32.2	11.5	0.0	0.0	0.0	0.0	0.0	0.0	20.6	0.0	0.0	0.0	1.7	0.0	0.0
MSB	Badsana Minor	470	5.19	5.19	56	SW	cusec	5.2	0.0	5.2	5.2	0.0	0.0	5.2	5.2	0.0	5.2	0.0	0.0	0.0	5.2	0.0	5.2	0.0
						GW	running	52.4	0.0	160.0	63.2	0.0	0.0	0.0	0.0	0.0	0.7	128.0	0.0	0.0	0.0	4.4	0.5	0.0
MSB	Bhadsana Head to Udwa Head	1301	15.01	15.01	131	SW	cusec	15.0	0.0	15.0	15.0	0.0	0.0	15.0	15.0	0.0	15.0	0.0	0.0	0.0	15.0	0.0	15.0	0.0
						GW	running	132.0	0.0	396.6	168.7	0.0	0.0	0.0	0.0	0.0	0.0	299.4	0.0	0.0	0.0	12.2	0.9	0.0
MSB	Udwa Minor	317	3.25	3.25	48	SW	cusec	3.2	0.0	3.2	3.2	0.0	0.0	3.2	3.2	0.0	3.2	0.0	0.0	0.0	3.2	0.0	3.2	0.0
						GW	running	23.2	0.2	132.3	48.9	0.0	0.0	0.0	0.0	0.0	1.1	106.5	0.0	0.0	0.0	3.0	0.4	0.0
MSB	Udwa Head to Savitapur Head	891	12.71	12.71	82	SW	cusec	12.7	0.0	12.7	12.7	0.0	0.0	12.7	12.7	0.0	12.7	0.0	0.0	0.0	12.7	0.0	12.7	0.0
						GW	running	153.2	118.6	312.0	143.7	98.7	0.0	0.0	0.0	0.0	103.3	250.8	103.3	0.0	0.0	0.4	11.1	0.0
MSB	Savitapur Minor	189	2.30	2.30	32	SW	cusec	2.3	0.0	2.3	2.3	0.0	0.0	2.3	2.3	0.0	2.3	0.0	0.0	0.0	2.3	0.0	2.3	0.0
						GW	running	19.1	0.0	75.2	20.8	0.0	0.0	0.0	0.0	0.0	0.0	68.3	0.0	0.0	0.0	1.8	0.2	0.0
MSB	Savitapur Head to Fareedpur Head	59	1.55	1.55	9	SW	cusec	1.6	0.0	1.6	1.6	0.0	0.0	1.6	1.6	0.0	1.6	0.0	0.0	0.0	1.6	0.0	1.6	0.0
						GW	running	5.3	0.0	21.9	5.9	0.0	0.0	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	0.5	1.3	0.2
MSB	Fareedpur Minor	168	1.91	1.91	32	SW	cusec	1.9	0.0	1.9	1.9	0.0	0.0	1.9	1.9	0.0	1.9	0.0	0.0	0.0	1.9	0.0	1.9	0.0
						GW	running	41.4	3.1	104.6	52.3	0.0	0.0	0.0	0.0	0.0	4.8	68.8	0.0	0.0	0.0	1.8	3.8	0.6
MSB	Fareedpur Head to Tail Daulatpur	174	2.19	2.19	32	SW	cusec	2.2	0.0	2.2	2.2	0.0	0.0	2.2	2.2	0.0	2.2	0.0	0.0	0.0	2.2	0.0	2.2	0.0
						GW	running	43.3	3.3	108.3	55.4	0.0	0.0	0.0	0.0	0.0	5.0	72.0	0.0	0.0	0.0	1.8	3.9	0.6
		3755		46.5	431																			

8.5. Socio economic benefits

Gross margin to the cultivators may be doubled and amounting to Rs 12.04 crore with a return of Rs 24030.48/ha by opting conjunctive use under current cropping intensity of 130% based on field survey (of command area) and the ground water depletion may be restricted to 9.88 cm per year in place of depletion of even more than 3.0 m during the year in selected areas for the normal rainfall sequence.

With the increase in cropping intensity of 159% (of command area) the gross margin may be increased to Rs 14.28 crore with the return of Rs 23432.73 per ha and the ground water depletion may be restricted to 12.18 cm ,against the increased depletion rate of even more than 3.0 m during year in selected areas for the normal rainfall sequence. With the further increase in cropping intensity to 230% (of command area) the gross margin may be further increased to Rs 24.10 crore with the return of Rs 27379.90 per ha and the ground water depletion may be restricted to 13.75cm, against the depletion rate of more than 3m during the year with the current irrigation practises, in the present scenario. Results are shown in Table 8.7.

Table 8.7-. Results of cropping intensity versus economic return

S.N	Cropping Intensity(% of command area)				Area under cultivation in Ha	Gross Profit in crore	Return per Ha (Rs /Ha)
	Karif	Rabi	Jaid	Total			
1	2	3	4	5	6	7	8
1	64	60	6	130	5010.84	12.04129	24030.48
2	77	76	6	159	6096.626	14.28606	23432.73
3	77	76	77	230	8802.212	24.10037	27379.9

The socio economic benefits could be increased to double by bringing more area under cultivation and by adopting conjunctive use with good irrigation practices.

8.6. Summary and Conclusions

The canal water use efficiency may increase with decrease in rainfall or canal water supply resulting in increased ground water use or depletion in ground water reservoir for the same cropping pattern and intensity. At the same time with the increase in rainfall or canal water supply, the canal water use efficiency may decreases but the ground water depletion is reduced. By opting conjunctive use of surface and groundwater in Daualatpur distributaries command, the water use efficiency of canal water may increase up to 58%. It clearly indicates that with lining, canal water use efficiency increases, but ground water depletion also increases that mean if conjunctive use is opted, lining is not beneficial. For the normal rainfall sequence of 847.3 mm per year and canal supply of 314.4 mm per year in Daulatpur distributaries system, canal water use efficiency increases to 40.7% against 37.3%, while the depletion in ground water level is increases to 19cm per year in place of 18cm per year in case of present cropping intensity of 130% (of command area).

It clearly indicates that depletion in ground water levels is directly related to proposed cropping pattern/cropping intensity and it reduces with increase in rainfall or increase in canal water supply or with the proposal of less water requiring crops. However this depletion in ground water level can be maintained more effectively at constant level with implementation of conjunctive use at Kulawa command level to bring more area under cultivation and saving energy cost in tail commands.

Gross margin to the cultivators may be increased to Rs 12.04 crore with a return of Rs 24030.48/ha by opting conjunctive use under current cropping intensity of 130% based on field survey (of command area) and the ground water depletion may be restricted to 9.88 cm during the year in place of depletion of even more than 3.0 m during the year in selected areas for the normal rainfall sequence.

With the increase in cropping intensity of 159%(of command area) the gross margin may be increased to Rs 14.28 crore with the return of Rs 23432.73 per ha and the ground water depletion may be restricted to 12.18 cm during the year against the increased depletion of even more than 3m during the year in selected areas for the normal rainfall sequence.

With the further increase in cropping intensity to 230%(of command area) the gross margin may be further increased to Rs 24.10 crore with the return of Rs 27379.90 per ha and the ground water depletion may be restricted to 13.75cm against the increased depletion of much more than 3m during the year in the case of present scenario.

CHAPTER 9

CONCLUSIONS AND SCOPE FOR FUTURE WORKS

9.1. Conclusions

(I) The average rainfall in the Gomti basin having an area of 30,934 sq. km, consisting a whole or part of districts namely, Pilibhit, Khiri, Shahajahanpur, Hardoi, Sitapur, Unnao, Lucknow, Raiberelli, Barabanki, Faizabad, Pratapgarh, Sultanpur, Jaunpur, Allahabad and Varanasi of Uttar Pradesh, has declined to about 800 mm in the year 2012-13, as against 1050 mm in the year 1971-72, during a period of 43 years. However if we analyze at district level, it predicts that average rainfall figures in the basin are more or less constant to about 920 mm.

(II) In Gomti basin having an area of 30,934 sq. km, during a period of 30 years (1984 to 2014) the area in pre monsoon periods, where the ground water is available up to 5m below ground has reduced to 39.26% as against to 57.99 % and the areas where ground water is available below 5m has increased from 42.01% to 60.75 %.Similarly for the post monsoon periods the area where the ground water is available up to 5m below ground has reduced to 65.31% as against to 90.80 % and the areas where ground water is available below 5m has increased from 9.20% to 34.69 %.

(III) In modeling area of Ramganj distributaries command, having a command able area of 66939 ha, and present canal command area of 39861 ha, in pre monsoon periods of 2013, the area where the ground water is available up to 5m is about 20% in canal command area and it is near about negligible in present non canal command areas. It predicts that the depletion of ground water levels in non canal command areas is at much faster rate and the canal network plays a major role in providing an additional recharge to ground water in canal commands.

(IV) Groundwater modeling framework has been developed through Visual Modflow for Ramganj distributaries command able area, a part of Indo-Gangatic alluvial plains of Uttar Pradesh in northern India. The simulated model predicts that if conjunctive use is opted the cropping intensity may be increased to 222 percent from the existing intensity of only 163.1 percent. It also shows an overall increase in ground water sustainable area and decrease in groundwater depletion area. The sustainable area may increase to 92 percent at percent cropping intensity of 163.1, with implementation of conjunctive use, against the sustainable area of only 65 percent with existing irrigation practices. Water logged area will also reduce to 1 percent as against to present 5 percent. Groundwater withdrawal may add additional cost for lifting groundwater through electric/diesel driven private borings. However, there is saving in terms of overall additional gain in terms of bringing prevailing waterlogged and barren areas crops under cultivation, thereby increasing gross margin to farmers. At the same time simulation of model for a period of ten year from june 2011 to june 2020 shows that the ground water levels in pre monsoon and post monsoon periods will remain sustainable.

(V) An integrated model developed using GIS based Icrop model for Ramganj distributaries command , predicts that with the implementation of conjunctive use at 75% dependable rainfall of 1007.2 mm, canal supply of 403.6 mm with existing Cropping Pattern of 105.81% of polygon area, an overall recharge of 35.9 mm will be seen. It further predicts that even for proposed cropped area of 166.74% (82.97% kharif, 82.97 % rabi, 0.56% zaid and 0.23 % sugarcane) of polygon area or 256.52% cropping intensity can be achieved at 75% dependable rainfall and designed canal supplies with an overall net recharge of 9.9mm per year. The cropped area and gross margin to farmers can even be doubled, by bringing additional area under cultivation.

(VI) An integrated model developed using GIS based Icrop model for daulatpur disributaury system, having a smaller area of 3755 ha, with field survey at kulawa level, was developed to see the impact of different management scenarios. The developed model runs predict that the canal water use efficiency will increase with decrease in rainfall or canal water supply, resulting in increased ground water use or depletion in ground water reservoir for the same cropping pattern and intensity. At the same time with the increase in rainfall or canal water supply, the canal water use efficiency will decrease but the ground water depletion will also be reduced. By opting conjunctive use of surface and groundwater in Daualatpur distributaries command, the water use efficiency of canal water may increase up to 58%.

Model run also predicts that with lining, canal water use efficiency increases, but at the same time, ground water depletion is also increased, that mean if conjunctive use is opted, lining is not beneficial.

Model runs clearly indicate that depletion in ground water levels is directly related to proposed cropping pattern/cropping intensity and it reduces with increase in rainfall or increase in canal water supply or with the proposal of less water requiring crops. However this depletion in ground water level can be reduced or maintained at constant levels more effectively at Kulawa command level with the support of water users association.

Gross margin to the cultivators may be increased to Rs 12.04 crore with a return of Rs 24030.48/ha by opting conjunctive use under current cropping intensity of 130% based on field survey (of command area) and the ground water depletion may be restricted to 9.88 cm during the year in place of depletion of even more than 3.0 m during the year in selected areas for the normal rainfall sequence.

With the increase in cropping intensity of 159%(of command area) the gross margin may be increased to Rs 14.28 crore with the return of Rs 23432.73 per ha and the ground water depletion may be restricted to 12.18 cm during the year against the increased depletion of even more than 3m during the year in selected areas for the normal rainfall sequence.

With the further increase in cropping intensity to 230%(of command area) the gross margin may be further increased to Rs 24.10 crore with the return of Rs 27379.90 per ha and the ground water depletion may be restricted to 13.75cm against the increased depletion of much more than 3m during the year in the case of present scenario.

Developed dual roster at kulawa command level on weekly basis for the scenario decided by Cultivators can keep ground water sustainable with optimization of land and water resources.

9.2. Limitations

More detailed site-specific investigation of input parameters such as specific yield, saturated infiltration, canal seepage, canal capacities etc is required for accurate estimation of parameters;

The model predictions can be made even more realistic by use of most up-to-date groundwater, rainfall and canal discharge dat.

9.3. Scope for future work

Real time linkage with daily climate data, canal roster, canal and drain flow along with field wise soil parameters and irrigation requirement depending upon crop, as required by Water Users Associations.

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