INTEGRATED WATER RESOURCES MANAGEMENT IN CANAL COMMAND AREA IN TERAI REGION OF NEPAL

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this Dissertation entitled "INTEGRATED WATER RESOURCES MANAGEMENT IN CANAL COMMAND AREA IN TERAI REGION OF NEPAL" in the partial fulfillment and requirement for the award of degree of **Master of Technology** in **Water resources Development** and submit in the Water Resources Development and Management of Indian Institute of Technology, Roorkee is a record of my own work carried out during a period from July 2012 to June 2013 under the excellent supervision of **Dr. Deepak Khare,** Professor & Head in the Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, INDIA.

The matter embodied in this *Dissertation* has not been submitted by me for the award of any other degree.

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ABSTRACT

The study area lies within the command area of proposed Sikta irrigation System. 90% of the study area is rainfed, therefore, has severe threat of stress to the crops. Remaining land has received irrigation facility from groundwater. An irrigation system is ongoing to convey irrigation water for rest of the land from Rapti river. This study has focused on the availability of surface water and groundwater in the area and their integrated management. Quasi three dimensional ground water flow simulation modeling was, therefore, performed by using Visual MODFLOW 4.2 to assess the change in hydraulic head due to transient pumping and application of irrigation water from ongoing irrigation system. The interpreted model was calibrated and validated satisfactorily. Sensitivity analysis of the model parameter reveals that the ground water recharge is the most sensitive parameter followed by aquifer hydraulic conductivity at almost all site of the study area whereas the specific storage and specific yield are less sensible.

In existing boundary and stress condition of the groundwater system, around 64% of the area is in waterlogged situation in monsoon season whereas 6 percent of area has water table within 2 m depth from ground surface in non monsoon season. After three years continuous application of irrigation water, entire area would be water logged in monsoon season and about 85 percent of the area would be in waterlogged condition in non monsoon season.

In the month of June, there would be scarcity of water for irrigation for proposed cropping pattern which would reach upto 52 MCM. Available groundwater was found in unconfined aquifer is 27.22 MCM which is not sufficient for irrigation in the driest month. A study of semi and deep aquifer exploration is essential. Hence a comprehensive optimal land and integrated water resources development plan sustainable development water resources and agriculture activity of the study area is necessary.

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ACI	Agrifood Consulting International
ADPJ	Agriculture Development Project
ADB/N	Agriculture Development Bank of Nepal
BHIWA	Basin Wide Holistic Integrated Water Assessment
CBS	Central Beauro of Statistics
DEM	Degital Elevation Model
DHM/N	Department of Hydrology and Meteorology of Nepal
DOI	Department of Irrigation
DSS	Decision Support System
EU	European Union
FSSIPR	Feasibility Study of Sikta irrigation Project Report
GDP	Gross Domestic product
GLCF	Global Land Cover Facility
GWRDB	Ground Water Research and Development Board
GWP	Global Water Partnership
ICID	International Commission on Irrigation and Drainage
IWRM	Integrated Water Resources Management
MDG	Millennium Development Goal
RMSE	Root Mean Square Error
SEE	Standard Error of Estimation
SRTM	Shuttle Radar Topographic Mission
UN	United Nations
UNCED	United Nations Conference in Environment and Development
WWC	World Water Council
WSSD	World Summit in Sustainable Development
WFD	Water Framework Directive

CHAPTER - 1: INTRODUCTION

1.1 General

Nepali is a land locked country situated between People's Republic of China to the north and south, east and west is surrounded by India (Fig. 1-1). It is renowned as the country of highest peak of the world. The highest peak, the Mount Everest (8848), lies in this country. The country has elongated east to west with 885 km and north south average width is 193 km. It has total area of 147,181 sq km. The country is in between 84^0 04' and 88^0 12' east and 26^0 22' and 30^0 27'north. North part of the country has high terrain with southern slope having minimum mean sea level of 60 m (CBS, 2002:1). Nepal has huge variation in climate with altitude from arctic to humid sub tropic. Available different climates provide the perspective of varieties of crop production. The geographical area of Nepal is presented in Figure 1.2.

Source: Worldatlas

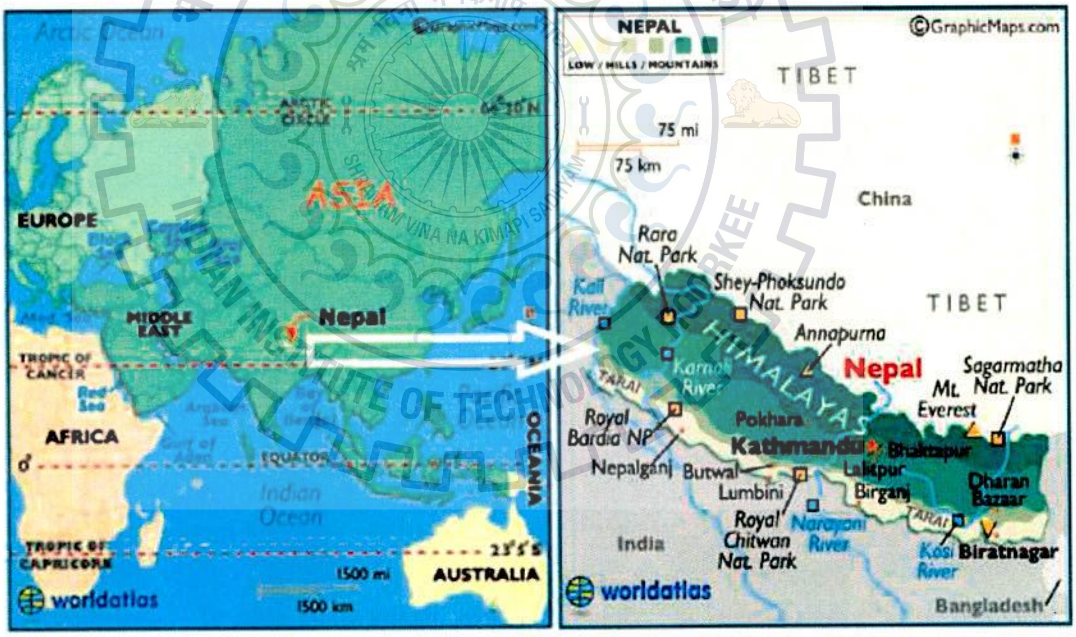


Fig. 1-1: Nepal in the World Map

Nepal is an under developed country. The population growth rate of the country is as high as 1.4% (*CBS, Nepal*). Population is growing and on the other hand agriculture land remains constant. To cope with the scarcity of food, production of food should increase. Since the limited crop land cannot be increased, the best way to increase food production is to increase yield of crops. Year round irrigation facility is only the way of increasing crop yields. In Nepal, only 2.641 million hectare area is arable and 1.766 million hectare land is irrigable out of the total 14.718 million hectare area of the country, and Terai region occupies 76% of potential irrigable area of it (DOI, Nepal).

Fig. 1-2 : Geographical Region of Nepal

Major portion of gross domestic production occupies by the agricultural activities. About 82 % of total population has engaged in agriculture. Agriculture production constitutes 35 % of national GDP which has major influence in national economy. For sustainable economic growth, development and adaption of modern technology of irrigation and other agricultural program is essential. Agriculture activities also generate the employment in rural area. About 66 % of employment has been generated in the form of agriculture skilled and semi-skilled labours in Nepal (*ACI,* 2012). Agricultural development is impossible without managing available water resources. Therefore water resource is the key amenity for agricultural development.

1.2 Necessity of Water Resources Management

Global population goes on rising rapidly (Fig. 1-3). The rate of population growth is higher in developing country than in developed country. In 1992, world's population was 5.7 billion and in 2012 it reached upto 7 billion (*UN water report. 2012*). UN has projected the world's population will reach around 10 billion in 2050. This rapid growth of population is due to high birth rate in third world.

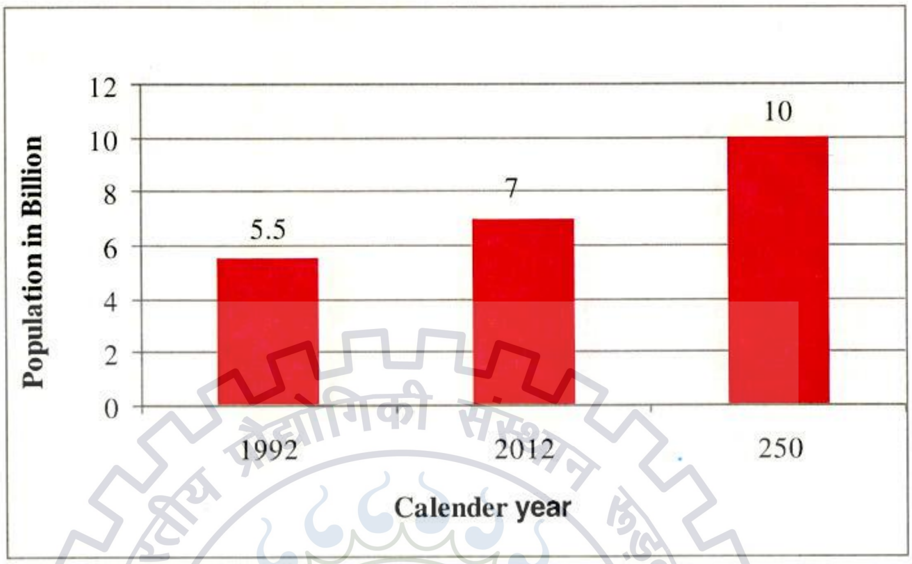


Fig. 1-3 : Global Population Growth

This increasing population and higher living standard has increased per capita demand of water. Growing population needs more food and forces to increase in crop yield which needs adequate and timely application of water. Some high yield varieties of crop need more irrigation water. Environmental provision set by national and international laws will require more water for aquatic life, wild life refuges, recreation and scenic value and riparian habitats. Beside above mentioned facts, environmental, social, economic and political landscapes change has further put more thrust on water resources.

The stress on management of water resource, the precious amenity of world, will increase with the elapse of time due increase in population and other economical and social activities. However ample water is available on the planet, sea water which is unfit to most human uses occupies 97% of the earth's water. 87% out of remaining 3% is unapproachable, either captured in polar icecaps or in deep underground aquifers. Hence, usable and accessible water for human beings is only 0.4% of all of the water on earth.

About 70 % of world accessible fresh water is used in agriculture. The gross per capita income of developing and under developed countries are dependent on agriculture production and generates 40 % of world employment. It has been projected that world's population will be increase by about 3 billion by 2050 (*UN Water Report 2012*). If we were unable to manage availability, supply and demand, agriculture generated employment would reduce and there would be severe starvation and unmanageable thrust on water resource. Increasing water requirement can be predicted but the when and where environment changes and its impacts on human and other ecosystems is locally unpredictable. Therefore the water resource management plan should be flexible to cope with changes in availability and demands for water (*Mc Clurg 1998*).It is a difficult task and cannot handle by an organisation. Therefore it is extremely necessary to prepare an efficient and flexible integrated water resource management plan based on national water policy considering all pertinent factors.

Similar situation might exist in Nepal as well. However the available water resources either in the form of surface or groundwater can be managed to fulfill all demand within the basin and aquifer level. Hence a study has been conducted in command area of ongoing Sikta irrigation system to suggest the proper management of available water resources within the aquifer.

1.3 Objectives

The study area lies within proposed Sikta irrigation system which had been conceptualized from the 1976 AD. Many debates in national and international arena arose regarding the feasibility of the system. Some pundits put forward their view regarding the scarcity of water that would divert from the river. They said that available water for whole command area taken for irrigation is insufficient. Some experts expressed their opinion in favour of the project. They argued that integrate use of available water within the command area is enough for year round irrigation. Within this stigma the project delayed and started recently.

At present the most of the study area is rainfed. Due to irregularity in rainfall and for winter crop irrigation, peasants irrigate their land by extracting ground water. There is no other resource of drinking water. Groundwater is only the reliable drinking water sources within the study area. Extractions of water more than replenish causing mining in the region.

In many area of India (e.g. Punjab), the ground water rises after introducing irrigation water. This rise of water table, if reached within the root zone, causes water logging.

Salinity increases in water logged area and yield of crop reduced drastically. Recovery of such land is time consuming and expensive. The study area is going to receive irrigation facility after some period. It is necessary to study such scenario in order to take preventive measure to reduce unwanted effect of water logging if it would occur due to irrigation. In the above context, the objectives of the study confined to:

i. To review of contemporary literatures on integrated irrigation water management in canal command area
ii. To develop a transient – state model and calculate the water balance of the area
iii. To study the availability of surface water and demand for irrigating the command area,
iv. To study the ground water scenario and its availability and possible strategies for improvement.

1.4 Organisation of Dissertation

Based on the above discussed background, my study mainly focused on the following chapters. These chapters are sincerely chosen to reflect the detail discussion of aforementioned objectives of the study. Therefore, these chapters reveal the glimpse of my study and overall view of my dissertation.

Chapter I: Introduction

This chapter has been focused on the need of the water resources management and its importance in development of social, economic and environmental aspects. Overall objectives of the study have enlisted there.

Chapter 2: Literature Review

This chapter has summarized the contemporary literature regarding integrated water resources management and the tools that are prevailing in assessing and managing the water resources in integrated manner. It also has explained in detail the need, principle methods of integrated water resources management.

Chapter 3: Study Area.

A brief discussion of Study area has been included in this chapter. The reasons of choosing this site have also been focused.

Chapter 4: Methodology/ Philosophy

It contains the methodology used in the study and the principles of tools used to obtain required data in order to achieve objectives. It explains brief theory of Visual MODFLOW 4.2 and use of Arc GIS 10. Data required and the sources of acquiring and methods of input in ground water modeling to interpret the actual ground water system of study area in the numerical model.

Chapter 5: Ground Water Modeling

It has discussed about the method of calibration and validation of ground water model, model performance evaluating parameters and the criteria of evaluation.

Chapter 6: Result and Discussion

It summarizes the outputs of model. It has also contained the scenario analysis of groundwater fluctuation after application of stresses different from the existing one.

Chapter 7: Conclusion and Recommendation

It suggests some management measures for better utilisation of water resources.

CHAPTER - 2: LITERATURE REVIEW

2.1 General

Different doctrines have been practiced to develop the existing water resources. Available quantity which is available in time and space with spatial population distribution is not sufficient for fulfillment of human demand. Therefore several tangible and intangible efforts had made to enhance the source of water resource for equitable distribution of it. Several improvements has been made in adapted principle in different decades based on demand, availability and prevailing management practices along with their pros and cons. At the beginning, sectoral development has been practiced. Multipurpose projects took the place in 1920 decades. Watershed wise management had practiced in the United State of America in 1960s. Second world Water Forum (2003) became able put integrated water resources management (IWRM) concept approving the positive principles and rectifying the negative approaches of practiced principles in previous decades onto the political agenda (M.Rahaman et al. 2005). Hence IWRM became popular in national and international arena to solve the basin level debate and judicious allocation of water resources within it. It has been successfully implemented all over the world.

2.2 Concept of Integrated Water Resource Management (IWRM)

N.S. Grig (2004) wrote that the concept of integrated planning had introduced in United State in the form of Water Resources Planning act (1965). He has presented a evolution of integrated water resource management from 1920. The concept of Integrated Water Resources Management (IWRM) emerged out from a word "Multipurpose" which was popular at that time.

Integrated water resources management was the recommended practice to include the various competing uses of water resources at the United Nations Conference on Water in the Mar del Plata (1977). Water related issues were disappeared from political arena in the 1980s. In the 1990s, strenuous efforts of several conferences and international organizations dragged the attention of whole world in water related concerns. Efforts such as the International Conference on Water and Environment (1992), Second World Water Forum (2000), International Conference on Freshwater (2001), World Summit on Sustainable Development (2002) and Third World Water Forum (2003) became able to set IWRM onto the political agenda (M.Rahaman et al. 2005). In this period of evolution of IWRM, many writers and organisation put forward the definition of this popular concept. Grigg (2008) wrote the definition of IWRM as *"Integrated water resources management is a framework for planning, organizing and operating water systems to unify and balance the relevant views and goals of stake holders"*. This definition accepted water resource management as a project because it explained the components of implementing a normal project. The Technical Committee of the Global Water Partnership (GWP) has been defined Integrated Water Resources Management (IWRM) holistically as *"a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."* This definition basically supports the three outcomes of IWRM; 1) economic, 2) Equity and 3) Sustainability (J. Clausen.2004).

2.3 Need of IWRM

Prevailing and past practices of water resources management (WRM) have failed to cope with the global water challenges. There are some reasons due to which the present approaches are unsuitable. These reasons arose by Mei Xie (2006) are similar to all the developing countries where sectoral development of water resources are still exists due to the poor development policies to integrate all governmental and nongovernmental organisations working in water resources sectors. These reasons are as follow.

2.3.1 Sectoral Management Approaches

Different sectors use water resources (agriculture, domestic use, industry, aquatic protection) which have managed independently without or limited coordination among sectors. This practice leads to fragmental and uncoordinated development of water resources. As water is a scarce amenity, it is extremely difficult to deal with water resources management discarding the interdependencies among stake holders (jurisdiction, sectors and graphical area)

2.3.2 Top Down Approaches

Traditionally the available water was allocated to different sectors judiciously. Government has encroached the jurisdiction of locals for water resources development due to increase in population and other development activities. Therefore top down approach suppressed the traditional approach to water resources development by introducing water services and regulation of water uses. Top down practice always focuses on supply augmentation rather than demand management and fixes the priority of uses. This decision is taken by the government agencies where local agencies, private agencies and user's participation is nil. This process leads to an ineffective and unsustainable development of water resources.

2.3.3 Supply Management Rather Than Demand Management

Prevailing water management based on supply management. To increase supply with demand requires other sources that may not be near the site. Conveying it from distance requires high cost consequently becomes unsustainable due to cost, ecological and social consequences. The main reasons of project failure in developing countries are financial sustainability, inefficient operation and low quality of service. These negative externalities dissatisfy users and deny paying tariffs which decline the water service quality and infrastructure maintenance.

Present debate is more focused on governance than scarcities. Inefficient and unregulated pollution of scarce sources results weak water quality and unsuccessful service provider, therefore, fails to serve public. IT could not address the social and environmental concern. Hence it is extremely necessary to shift the existing thought of water resource management otherwise present water scarcity will further increased. Given the above externalities with conventional WRM practices, Integrated Water Resources Management (IWRM) has evolved as a tool of dealing with the global water scarcity and working toward a sustainable future for water resources management.

2.4 Principles of IWRM

Integrated water resource management should ensure equal access to all people in quantity and quality required for living of human being. It also includes the need of recreation and other economic benefits generated by water resource. Economic efficiency means to get optimum benefit for greatest number of people with the available financial and water resources. Benefits includes out going price and improved living standard of people. Sustainability of aquatic life and flora and fauna for the future generation is another condition of integrated water resource management. The basic principles that the Dublin Conference was expected to set up sustainable water policies and an action program to be considered by UNCED. The conference reports formulated the recommendations for action at the local, national, and international levels, based on the following four guiding principles (ICWE, 1992):

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Women play a central part in the provision, management and safeguarding of water,
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels,
- Water has an economic value in all its competing uses and should be recognize as an economic good.

Water resources experts from developing countries criticized the fourth principle which raised debate in international arena. They argued that without considering equity and poverty eradication, water resources development could not be sustainable merely considering the water as economic goods (Rahama et al., 2005)

Agenda 21 declared that water should be utilized considering the requirement of aquatic life and ensuring the perenniality of water resources to meet and reconcile needs for water in human activities. It also focused on integrated water resources management which is the integration of land- and water-related aspects, should be performed at the level of the whole basin or sub-basin. Identified four basic principles of integrated water resource management are as follows:

2.4.1 Stake Holder's Participation

No plan could be materialized without involvement of stake holder. Involvement of public including women, indigenous people, youth and local communities to design, implement and evaluate project and programmes that are economically efficient and socially appropriate within clearly demarcated strategies is necessary for water management policy-making and decision-making.

2.4.2 Multisectoral Management

A dynamic, flexible, interactive and multisectoral approach including identification and protection of potential sources of fresh water supply for water resources management is necessary to integrate socio-economic, environmental, technological and human health considerations. Figure 2-1 shows a clear picture of sectors of water resources.

Source:GWP 2000

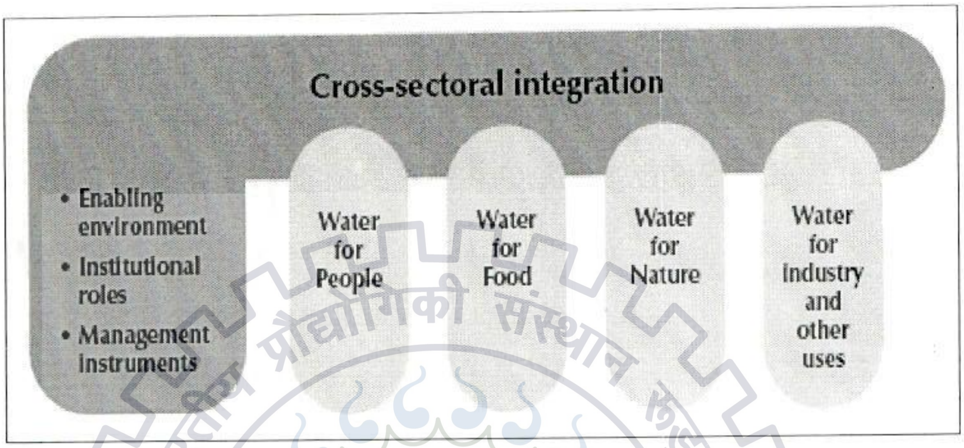


Fig. 2-1: IWRM and its Relation to Sub sectors

2.4.3 Sustainability

A plan formulated based on community needs and priorities within the framework of national economic development policy is essential for the sustainable and reasonable utilization, conservation, protection and management of water resources.

2.4.4 Institutional Development

Development and strengthen of appropriate Institutional, financial and legal mechanisms are necessary to ensure water policy and its implementation for sustainable social progress and economic growth of developing countries.

2.5 Issues and Challenges of IWRM

2.5.1 Strategic Issues

IWRM is a widely accepted popular conceptual frame work in which multi displinary agents works together. The basic principles laid by UN are very enthusiastic and will be the means to achieve millennium development goal (MDG). But the cross sectoral i.e. human sector and nature sector, management is critical (J. Clausen. 2004). At a first

glance, it seems to be attractive. A deep analysis reveals many problems from planning to implement stages of IWRM. It is also extremely difficult to implement the concept in field level.

Many questions rose after the Agenda 21 set the principles of IWRM. Different challenges and issues emerged from different forum and organisations regarding the principles and strategy set to achieve the benefit targeted by IWRM. A.K. Biswas (2004), in his critical analysis of a well known and many authors referred definition presented by Global Water Partnership, wrote that challenge of integrated water resource management is in practical ground. He raised questions of the present state of knowledge, identifying measurable criteria that reveal whether the achievement is integrated or unintegrated and the vague definition of Water Resources management. Another important question he raised is that it is not possible to use a single concept of integrated water resource management for all countries where many disparities exist in term of resources, technical, social, economical, cultural and educational development.

The Ministerial Declaration (WWC, 2000) pointed out the challenges related to implementation as commented by A.K. Biswas (2004). These challenges to be addressed for implementing IWRM are (WWC,2000):

- institution
- technological innovations
- financial innovations
- collaboration and partnership at all levels
- meaningful participation of all stakeholders
- establishment of targets and strategies
- transparent water governance and
- cooperation with international organizations and the UN system.

The challenges of implementing the integrated water resource management plan is different for developed and developing countries. Developed countries have already developed their water resources constructing dam, levees, and canals. Their problem is to manage the non structural investment. They should divert the investment toward the issues previously neglected non structural components viz. watershed management, land use planning and information system management. Developing countries have faced three major challenges: 1) many countries have much smaller infrastructures of climatically similar countries, 2) they have to invest in both structural and non structural elements and 3) there may be large gap between human demand and natural hydrological pattern (P. Gourbesville, 2008).

Bonn Recommendations for Action addressed issues such as poverty, gender equity, corruption mitigation, and water management at the lowest appropriate level. It searched a set of activities necessary to mobilize financial resources: improving economic efficiency, strengthening public financial abilities, and raising official support to developing countries. It prioritized the need for education and training regarding research, water wisdom, efficient water organization, modern technologies, and knowledge sharing in the field of capacity building. The Conference also recommended that World Summit in Sustainable Development (WSSD) would tune water issues with overall sustainable development objectives and correlate water into national poverty reduction strategies (WSSD, 2002).

2.5.2 Technical Issues

All above discussed issues and challenges are related to management and strategy. Besides these, technical challenges are also pronounced. These technical challenges that should be focused in integrated water resources management have been elaborated below.

2.5.2.1 Global Population and Water Supply

Global population growth rate reveals that the population of will increase by three billion by 2050 (UN, Water report). Present trend of economic development and social development shows there will be huge migration of people from village to urban area. Urban population needs more renewable water. More population produce more sewerage. For western and industrialised countries, necessary

replenishing water supply is at least 2000 m^3 per person per year. The country is said to be in water stressed if only 1000-2000 m^3 per capita per annum is available. It is said that below 500 m^3 per capita per annum is water scarce. The global replenishing water supply is about 7000 m^3 per capita per annum. Therefore this is enough water for the three fold of present population (Bouwer,2000) The shortage seen in the world is due to imbalanced between population and precipitation distribution. It is a profound challenge to management this imbalance distribution of population with precipitation.

2.5.2.2 Groundwater Recharge

Due to climate change some parts of the world receive access precipitation and some parts draught. Also small changes in precipitation can cause significant changes in natural recharge of groundwater in relatively dry climates. At present around 10% of world's agriculture food production depends on exploiting ground water (P Gourbesville, 2008). Mining of ground water is faster than it is recharge. This increased use of ground water has led to the over exploitation of ground water in some arid and semi arid zone where water table falling at frightening rate of 1-3 m per year. More storage of water is needed to save water supplies against these externalities and changes including long-term storage (years to decades) to build water stores during times of water excess for use in times of water scarcity. Water cannot be stored over the ground for long times. Dams have been constructed all over the world but several dams already breached. Some of them are in the stage of breach. Construction dam is not easy especially in third world due to high investment and ecological and environmental problems. The easy way is to store water in underground aquifer. Aquifer has been stored about 98 % of world fresh water. It has enough space to store fresh water for long period. It can store water in excess rainfall and can release at the time of draught. Evaporation loss in aquifer storage is nil whereas evaporation in surface storage ranges from 0.5 m per year in humid climate to 2.5 m per year in hot dry climate (Bouwer, 2000). Storing in aquifer has no any environmental effects.

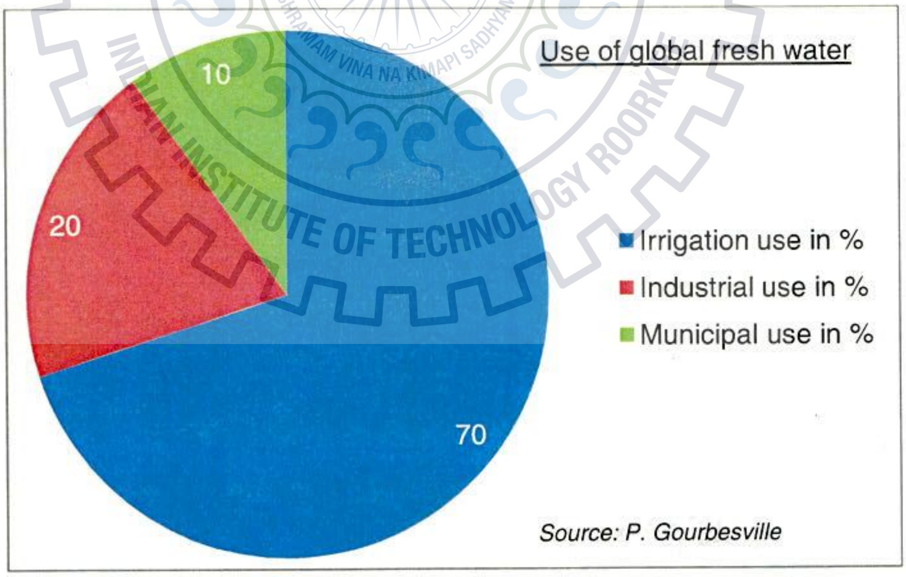
Therefore another challenge of IWRM is to store ground water. Focus should be on ground water recharging technique for long term water.

2.5.2.3 Irrigation and Drainage

Major portion of world's available fresh water is utilised in irrigation. 70 % of global water extraction used for irrigation, 20 % for industries and 10 % f or municipal use (Fig. 2-2). Around 18 % of world's arable land has been irrigated and produces 40% of the world food. Asia has about 65 % of world irrigated land (P.Gourbesville). Compare to other uses of water, irrigation water is of more volume, less quality and low cost use. Due to this large volume of water used, development of irrigation has major implication on other uses of water.

Global scenario of increasing irrigation land is about 1.4 %. Irrigation of land from ground water has been increased exceptionally due assure resource and subsidy in electricity and increase in technology.

Drainage of waterlogged area in irrigated land due to over irrigation causes serious environmental problem of salinity. Water logging problem is caused by improper design of drainage system or not providing effective drainage network. Therefore appropriate use of water and drainage is necessary for sustainable water resources management.



Source: P. Gourbesville

Fig. 2-2: Global Fresh Water Use

2.5.2.4 Use of Treated Waste Water

Reuse of municipal treated effluent is becoming important for water resource management. The stringent rule and regulation for treatment of effluent to protect the quality of receiving surface water for protecting aquatic life, downstream users and recreation is becoming extremely difficult and expensive. The cost of treatment of effluent to discharge into the surface water following the stringent norms is so high that it would be financially unattractive to municipalities. Therefore local reuse of such effluent is preferred to other purpose rather than discharging into the river.

The other reason is that in municipalities, where water scarcity prevails, municipal waste water would be significant water resources that can be utilized in number of purposes. The most reasonable reuse is for non potable purpose like urban irrigation, agricultural irrigation, industrial uses, fire fighting, environment enhancement(wetlands, wildlife refuges, urban lakes and riparian habitats), dust control toilet flush etc. The treatment of effluent to reuse in the area enlisted above is less stringent and cost effective which fulfills the quality requirement of the area of reuse (H.Bouwer, 2000).

2.5.2.5 Conjunctive Use of Water

Groundwater is more reliable sources of water which is less affected by the vagaries of climate than surface water. Generally surface water is preferred by the farmers as it is often cost effective than ground water where subsidy has not been provided to the government for the fuel and electricity used to extract groundwater. When there is less surface water available, groundwater and surface water are used conjunctively. Surface water is used when available and ground water is used for fulfil the requirement when stream and lakes are dry or has less water. When the increased water requirement is fulfilled by extracting ground water, all the unwanted effects such as salt intrusion, land subsidence, aquifer depletion and increase in cost of pumping would occur. The solution of eradicating such externalities is either to build dams in rivers or increasing round water storage by artificial recharge. Increase in groundwater storage is called water banking an is available for decades.(Mc Clurg, 2001).

2.5.2.6 Virtual Water

Virtual water is the water required to produce commodity (Allan, 1998). Water scarce country can by food from the country which has more water. The water to be used in food production can be used for other purposes. For example, for one kilogram of wheat imported, the country also gets about 1 m^3 of virtual water at much less cost than the price or value of local water resources, if available, in the country itself (Bower, H, 2000). Beside above mentioned challenges, environmental change, power production, ecological and biological need are other challenges to be addressed by Integrated Water Resource Management.

2.6 Implementation Process of IWRM

Public pressure caused by lack of water for their livelihood, transboundary conflict and crisis and international agreement on water all open opportunities and provide incentives for governments (J. Clause.2004) Clausen concluded that target can be achieved after providing proper attention to the national issues like flood management, fulfilling irrigation demand and conflicts on water right etc. In this context, management of available water resources with best management practice with proper policy was essential. UN accepted the concept of IWRM and set three implementing processes of it: 1) enabling environment, 2) institutional framework, 3) management Instrument, 4) infrastructure development and 5) monitoring and evaluation of progress (UN et al.,2005).

2.6.1 Enabling Environment

Existing policies and laws related to water may not be sufficient for achieving targeted national goals. Therefore revision and amendment of policies and laws is necessary based on the national and international water issues. Accepting water as a economic goods it should be mainstreamed into national development policies, strategies, plans. For implementation appropriate and sustainable funding in national budgets is necessary.

2.6.2 Institutional Framework

Integrated water resources management is a multi-sectoral and interdisciplinary in nature. A cross-sectoral co-ordination frameworks establishment is essential. Present mandates of delegated to ministries and department may not match with IWRM process. These mandate modification or change is necessary. Formal involvement of stakeholders making a institution at basin or sub basin level will a best solution for conflict management. IWRM process and targeted out puts of the basin information to grass root level is necessary. Launching of awareness programs and mobilization campaigns is the suitable methods to inform public. Top down planning is not the basic principle of IWRM, a bottom up planning provides a sustainable development. Proper power delegation to lower authority for taking necessary decision is mandatory. Integrated water resources management process is a complex phenomenon. To understand it and to deliver service, program should organize to upgrade capacity of government staffs and stakeholder groups.

2.6.3 Management Instruments

A comprehensive, road map based on policies of nation, water resources issues arising in basin sub basin and command area level assessment should prepare along with milestones. Many rainfall runoff models are available to assess surface water and ground water. These tools provide total water available in nature. Based on the availability and issues, demand management, users behaviour, water use efficiency issues for water management should solve. Public behaviour change is a difficult task. Continuous public awareness, mobilisation and conflict mediation, economic incentives can change the inbuilt behaviour of public. This behaviour change should make sustainable enforcing by regulations. The success of IWRM program can be evaluated from rich information from whole basin. Therefore an improved information management is essential.

2.6.4 Infrastructure Development

Infrastructure development is the implementation plan of Integrated Water Resources Management out comes. After full consensus of stake holder, agreed water resource allocation water diversion, distribution and other augmenting infrastructures along with water management efficiency plan are constructed. It manages the demand and efficient use of water in a sustainable manner without raising conflicts.

2.6.5 Monitoring and Evaluation of Progress

Success and failure of IWRM is based on the relevant data collection of progress. Data can be collected through information management channel. Evaluation of data reveals whether the progress is in the way of integrated approach or not. If not what are the necessary actions to be taken that brings the project in track.

2.7 Integrated Water Resources Management Focused on Sustainable Irrigation.

Increased global population requires more food commodities. For more food production needs intensive irrigation management and increase in irrigation land which forced us to manage its consequences. Some major issues of Integrated Water Resource Concept related to sustainable irrigation, on which most of the researchers have worked, have been discussed here.

2.7.1 Pollution Control

Irrigation sector consumes more fresh water and the management of irrigation water is crucial. It also produces more return flow producing off site pollution. Water logging is another in irrigated land. Water logging in irrigation land is due to over irrigation. In a study of Bardenas I Irrigation scheme, Ebro river basin, Spain, the offsite pollution caused by irrigation water mainly depends on: 1) soil characteristic, 2) irrigation management and irrigation system, and 3) crop requirement (J.Causepe et al.,2004). Therefore ,the critical recommendation for improving the quality of irrigation are 1) change to pressurized system in shallow and highly permeable soil, 2) increase the efficiency of flood irrigation and 3) reuse of return flow within and beyond the command area.

2.7.2 Sustainable Watershed Management

For attaining sustainable natural resources use an integrated approach is necessary. Rural development and poverty alleviation may be combined with sustainable watershed management. Watershed management is a holistic approach to bringing about development of integrated forming system on watershed basis. This approach aims at optimizing use of vegetation and land water in an area to eradicate drought, prevent soil erosion, moderate floods, increase fuel and improve water availability, folder and agricultural production on sustainable basis. In a watershed a chain of sustainability occurs containing economics, resources and institutions (Visnudas et al.,2005).

2.7.3 Water Management, Regulation and Pricing

Water management directly affects by pricing of irrigation water. Subsidize irrigation water managed by government leads to use of uncontrolled water. Result of that is the head reach farmers will use more water and tail reach farmers will have to stay without water even the available water in the canal is more. The legal framework in the European Union (EU) has developed a new Water Framework Directive (WFD) that sets up new criteria for regulation, water management and pricing. Bazzani *et al.* (2004) studied the problem of water regulation in agriculture connecting with the WFD. This is done by setting up and testing a simulation model based on the integration of a mathematical programming model at farm level and an optimal regulation model at the level of irrigation boards. The model allows optimal regulation from the policy maker's point of view and quantifying water demand. When implementing both the polluter pays principle and full cost recovery, the results show likely major impacts of water pricing on employment and farm income. The optimal policy is a combination of pricing instruments related at the same time to crop mix, pollution and water consumption. Altogether social,, economic and environmental issues have to be carefully considered to design suitable water policies.

2.7.4 Multi-sectoral Integration.

Population, urbanization, economic development, tourism, industrialization and inefficient agricultural activities are the dominant water users. Multi-sectoral integration is necessary for better management of water resources,. Harmancioglu *et al.* (2008) studied the case of the semiarid Gediz River Basin in Turkey within the scope of two EU projects, where water scarcity is a major problem like in most river basins of the Eastern and Southern Mediterranean. Their approach is based on a multi-sectoral integration of qualitative and quantitative analysis, combining advanced tools of quantitative systems engineering, based on numerical simulation models, with methods of environmental, policy impact assessment, socioeconomic, using rule-based expert systems technology and interactive decision support methods. The paper presented the results of the analysis of current situation and of scenarios of possible future changes for the study region. policy impact assessment, using rule-based expert systems technology and interactive decision support methods.

2.7.5 Efficiency Management

Efficiency of our irrigation system is very low. It is around 37 %. This efficiency can be increased by applying innovative technology which performs high overall efficiency. Some methods prevailing in irrigation system are:

2.7.5.1 Efficient Irrigation Water Application

Efficient application and distribution, minimum soil erosion, minimum surface and deep percolation should be the requirement of the irrigation. Same method is not applicable for all type of topography, soil and crops grown. Therefore different methods are used to obtain optimum use of irrigation water. The system of application may be as follows:

- Irrigation System, Drip or Trickle : A low pressure application of water through conduit directly to the root of the crops with all necessary facility is drip irrigation.
- Irrigation System, Sprinkler : A irrigation system planning with necessary accessories for efficient application of water by means of nozzles or perforated pipes operated under pressure.
- Irrigation Land Levelling: Undulation and grade of land to be irrigated is reshaped and levelled to reduce the loss of water through deep percolation.

2.7.5.2 Efficient Irrigation Water Transport

Irrigation water transportation from source to irrigation field can be a major source of water loss and causes both ground water and surface water degradation. Seepage along the perimeter and length of transmission and evaporation during transmission are the losses during conveyance of water. It can be lessen by taking the measure of ;

- Lining of irrigation water conveyance; ditch and canal;

- Use of pipeline for irrigation water conveyance and
- Construction of water control structure

2.7.6 Awareness

Water resources planning in basin level always seeks an achievement of other objectives of IWRM. Considering the socio- economic, educational and technical constraints increase in awareness of farmers in planning, implementation and environmental impacts should be consider in research activities particularly in developing countries. One of the approaches may be the sustainable watershed management combined with water resources management which helps to reduce the poverty and rural development (M Billib et al.,2009).

Aforementioned discussion reveals that integrated water resources management is a holistic model which requires not only supply and demand but also the availability, quality, public health, sustainability, augmentation, regional approach, conjunctive use of surface and irrigation water, ecological and environmental demand and flexibility. Involvement of all stake holders within the basin and probable inter basin transfer and trans-boundary issues should also include in integrated water resource management. Popular model in water resource management includes following sectors:

i. Assessment of water resources
ii. Demand
iii. Optimisation
iv. Management

Basin wise assessment of water resources is necessary for planning purpose of whole basin demand and management. Without the knowledge of available resources, allocation of resources will not be possible. Different models are used to assess the present and future availability of water resources. Among them BHIWA(Basin wide Holistic Integrated Water Assessment) and EU Water Framework Directive along with Decision support system are popular.

2.8 Basin Wide Water Resources Assessment

2.8.1 The Basin Wide Holistic Integrated Water Assessment (BHIWA)

The Basin wide Holistic Integrated Water Assessment (BHIWA) model uses a water cycle simulation and environmental approach. It was developed by ICID in 2004

(ICID, 2004; China Institute of Water Resources and Hydropower Research 2004). The original BHIWA model is a Microsoft Excel interface and a semi-lumped. It is able to incorporate the whole hydrologic cycle of land phase, including the consideration of hydrologic changes due to changes in agriculture use and the land use. The model is able to depict surface and groundwater balances separately and impacts of storage and depletion through withdrawals and allowing interaction between them as well. Khan et al. (2005) have provided a summary of system approaches in water resources management. Under the VenSim environment, a system dynamics version of the BHIWA model was developed latter on which allows users to conceptualize, simulate, analyze, and optimize models for the complex systems.

The BHIWA is the model which forecasts the upcoming scenario of water for rural development and food, environmental need and public need to obtain sustainable water resources development. It is flexible and simple to use and is calibrated for present situation and the simulated model is used to forecast the future scenario of water flux at monthly intervals.

The detailed water assessment of two rivers in India, a water abundant basin in the east coast, Brahmani river basin and a water scarce basin in the west coast, the Sabarmati river basin were chosen. A Basin-wide Holistic Integrated Water Assessment (BHIWA) model evolved by ICID has been applied to these two basins. In China, Qiantang river basin, is a part of tributary of Yangtse River Basin has also been applied to assess the present and future water resources along with demand (Khan et al., 2005)

2.8.2 European Union Water Framework Directive (WFD)

Today the legal structure in the European Union (EU) should pass through with the new Water Framework Directive (WFD) which arranges new criteria for regulation, water management, and pricing in basin level along with Decision Support System (DSS). WFD has effectively implemented in European Union although it has certain mismatch with the IWRM process accepted by United Nations.

The aim of this Directive is to set up a framework for the protection of, transitional waters, inland surface waters coastal waters and groundwater which:

- promotes sustainable water use based on a long-term protection of available water resources;

- prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;
- ensures the progressive reduction of pollution of groundwater and prevents its further pollution, and
- aims at enhanced protection and improvement of the aquatic environment, inter alia, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;
- contributes to mitigating the effects of floods and droughts

After the implementation of the legal frame work it has been expected that it contributes to:

- the provision of the sufficient supply of good quality surface water and groundwater as needed for sustainable, balanced and equitable water use,
- a significant reduction in pollution of groundwater,
- the protection of territorial and marine waters

WFD mainly focused on the quantity and quality of water and not accepted as commercial good as other commodities. Therefore it ensures equitable distribution but it ignores wide participation of users. More effort has been provided for large stock holders. There is no any provision of women's participation and poverty reduction schemes. Therefore this concept of water resource management is not suitable for developing countries whose major stake holders are farmers. It also emphasized on pricing of water which is not applicable in developing countries where major part of surface water is being used in agriculture and the cost of their products frequently decides by the market irrespective of their cost of production without their involvement.

2.8.3 Soil and Water Assessment Tool (SWAT)

Quantification of the major effective components of the hydrologic balance including return flow, surface runoff is essential for basin-scale water resources development and management plans. (Arnold, J.G.,1993), impoundment storage, plant uptake, consumptive use and depletion of ground water. Arnold et al. (1993) developed a surface ground water model and tested in the area lies within the Grand Prairie Physiographic Province of Texas having catchment area of 2.6 million hactres.

SWAT (Soil and Water Assessment Tool) is a partly physically-based, continuous and partly lumped, large-watershed model that functions on a daily time-step. The watershed can be subdivided into sub basins, each sub basin is treated as a single lumped unit. Numerous peer review papers have been published regarding SWAT. Improvement in SWAT model is continuing. Many researchers have been performed of different basin analysis using SWAT and have provided a good match with observed and calculated basin response. It provides availability water resources at present and future. Hence this tool can be used to assess water resources for IWRM process and other decision making process of water resources.

As far as the ground water modeling component of the SWAT is concerned, it is not able enough to incorporate accurately the distributed parameters and variable pumping groundwater level as it is a lumped system. On the other hand MODFLOW has good interaction with stream aquifer system. Both SWAT and MODFLOW, which are in public domain, represent field conditions adequately, well established, flexible and provide a wide range of modeling options, incorporate robust numerical schemes, are GIS-capable, and have a long history of successful use in the field. Therefore for better basin wide water resources assessment, Sophocleousa et al.(1999) combined two SWAT and MODFLOW by certain modification and named SWATMOD for the combined model. Sophocleousa et al.(1999) applied this model in the Rattlesnake Creek basin of Kansas in central United States which provided good match with the observed ground water level and stream flow.

2.9 Ground Water Management

Integrated water resources management in basin level is a vast process, It takes time and lots of human and monetary resources. Canal command area is relatively small area within which both surface and ground water are available. The area, where intense agricultural activities and surface water is insufficient and high population exists, extraction of the groundwater is high to fulfill the need resulting over exploitation of groundwater. In the area where surface water availability is insufficient farmers use ground water for irrigation purpose by extracting water from aquifer.

Groundwater is conveniently available to large number of individuals at cheap cost. Individual can extract groundwater in low investment and is not dependent in mega water project. It can be developed by private individual with short recovery period. The quality of groundwater is high when not exploited by human intervention. (Calow et al. 1997, 242).

For efficient management of surface and ground water, understanding of interaction between surface and ground water is necessary. Ground water management needs to increase the social and economic welfare to raise the living standard of farmers. However management process has faced mainly the following three dominate ground water problems:

- *depletion of groundwater* due to overdraft;
- waterlogging and salinization due to improper drainage and conjunctive use
- *pollution* due to industrial, agricultural and other human activities.

Due to readily and economically available to needy people, overdraft of ground water is common in most of the aquifer of the World. The most common symptom of over exploitation is secular decline in water tables. In Henan province of North China, around 2 million hectares, 52 percent of irrigated lands are irrigated by tube wells. During 1975–87, declination of groundwater table was found to be 0.75–3.68 meters. About 8 to 50 meters declination in groundwater table occurred during the year 1967–2000 in the Fuyang river basin of North China (Shah et al.2000).

Groundwater problems in West and South Asia are same or even worse than in China. In western, northwestern and peninsular India and Pakistan, vast number of irrigation wells has increased each year, groundwater extraction exceeds annual replenish. In Nepal, after establishment of Ground Water Research and Development Board, many shallow and deep tube wells have been installed for irrigation. Number of tube wells are increasing overwhelmingly causing overdraft of ground water consequently ground water table is lowering at alarming rate. The shallow tube wells which had sufficient discharge have dried and becoming functionless.

Another problem encountered in ground water is salinity and water logging. Water logging became serious problem in major irrigation system canal command area of India and Pakistan. It is a serious problem because in one hand it reduces the yield of crops and the other hand the cost of recovery of the land is very high. This situation arises due to over irrigation and improper drainage system management in irrigation field. In 1970s, around 6 million hectares of land was found to be waterlogged as reported by an Irrigation commission established by government of India. 2 million hectares of land out of 11 million hectares of irrigated land in twelve irrigation projects is in under water logged condition and another million hectares was salinized (Mudrakartha 1999). In Pakistan, waterlogging and increase in groundwater salinity are among the most important issues in the Indus basin (Shah et al.2000).

Beside these two reasons, another one is ground water pollution. Over usage of pesticides, effluent discharged from chemical and other industrial product are main causes of ground water pollution. Leaching of effluent down to the ground water level deteriorates the quality of stored water within unconfined aquifer. In the west Indian State of Gujarat, textile processing and increasing chemical industries have polluted groundwater in such an extent that the State's High Court had to ordered an entire industrial estate—housing over 1,200 manufacturing units, 70 percent of them chemical to close in 1998 because they withheld the establishment of a wastewater treatment and disposal system.

Under developed countries are striving to reduce their growing percentage of poverty. The national economy of under developed countries as Nepal depends on agriculture. Rural poverty of such countries can be reduced by introducing some innovative technology of irrigation using ground water. If ground water of such area deplete or contaminated, farmers depending on agriculture may displace increasing rural poverty which the nation never expect. The stringent rule helps to control and reduce the impact of over-exploitation of the aquifer. However reduction in water use might cause reduction in many jobs in agriculture and small industries. The two most important lessons learned are (K.Kennedy et.al,2009):

1. Good water management needs to consider the whole hydrological cycle: surface and underground waters cannot be managed separately or independently of the ecosystems on which they depend.

2. Good water management requires sustaining a balance between pumping of groundwater and recharging the aquifer. Aquifer management needs

Considering above facts, it is utmost necessary to develop and manage ground water resources for sustainable development of agriculture sector and other use of ground water. A major barrier that prevents transition from the groundwater *development* to *management* mode is lack of information. The first hand facts needed for water resources development is the information regarding water resources. In case of ground water, its availability, distribution, present use and water table level are utmost important. Most of the development countries do not have up to date data. The available data may not have in required level of accuracy. Therefore development to management process must have following steps (Shah et al.2000).

1. Information Systems and Resource Planning:

It is important steps of water resources planning. Based on it, many researches regarding concerned aquifer and system will be performed. Therefore it must be:

- Appropriate and reliable method of data collection
- Regular monitoring of water table
- Regular monitoring of contaminants

2. Demand-Side Management:

It may include:

- registering of users through a permit or license system
- creating appropriate laws and regulatory mechanisms
- a system of pricing that aligns the incentives for groundwater use with the goal of sustainability
- promoting conjunctive use
- promoting "precision" irrigation and water-saving crop production technologies and approaches

3. Supply-Side Management:

The third aspect of managing groundwater is augmenting groundwater recharge through:

- mass-based rainwater-harvesting and groundwater-recharge programs and activities

- maximizing surface water use for recharge
- improving incentives for water conservation and artificial recharge
- Groundwater Management in the River Basin Context:

This adapts the principle of integrated water resources management recommended by United Nations for efficient management of entire water resources within basin.In tis study only aquifer scale ground water study has been done. Hence ground water study tools have been explain later headings.

2.10 Ground Water Study Tool

2.10.1 Background

Ground water is the science of occurrence, distribution and movement of water below the surface of the earth. Ground water development started from ancient times. Huge number of qanates which are still in existence in Iran is the evidence of ground water management even though no systematic study of ground water was absent. Many theories had been given by the philosopher regarding ground water at that time. Some prevailing philosophies were funny and some were near realities. In recent century, fundamentals in geology were established which were the basis of understanding of occurrence, movement and distribution of ground water. Henry Darcy (1803-1858) studied the movement of water in porous media and established a relation. This relation is known as Darcy's theory. Mathematically he symbolized it as:

$$v = ki$$

Where,

v= velocity of fluid

k= Darcy's coefficient (Permeability)

i= Head causing flow

This is the first ground water model used to systematic study of ground water in one dimension flow. This provided an important milestone in ground water study. On the basis of this theory, significant contribution had made by J. Boussinesq, G.A Daubree, J Dupuit, P Forchheimer and A Thiem(Todd D.2007). Charles Vernon Theis was the first person who provided the analytical solution of transient ground water flow. Analytical method of ground water modeling inherently incorporate the errors in modeling of ground water as there are many assumptions to make the model simple. Therefore a new powerful model was necessary to interpret the aquifer system.

To overcome the complexity in analytical model, the application of computer techniques were used to many ground water simulation tools for ground water study and management. Among them, useful tool to study and development of ground water in proper management strategies are numerical ground water simulation. Physical-based numerical flow models have been used to simulate and analysis of ground water system since last several decades. Initially they had merely used for research purpose. With the proliferation of user's friendly software, they became the basic tools for professional and consulting firm.

Numerical models embody the principles of mass balance and momentum theory. It is flexible modular nature allows selective use of packages for specific simulation tasks. Coppola et al. 2003 noted that the numerical model can captured the high variability in aquifer properties in space and time and stress and boundary conditions that are inherent in natural hydrological system. This capacity of the numerical model makes the model data intensive. To achieve acceptable simulation and prediction performance, interpretation of natural system of groundwater must be represented accurately in numerical model. However certain discrepancies would be always there between simulated and observed values to be compared, which are known as prediction errors. These types of errors occur because no physical based numerical model can accurately interpret the actual field condition of the study area and the data available are of limited space and time which do not represent the actual ground water system as the properties of the aquifer differ in space and boundary conditions are invariably different in space and time domain of model.

2.10.2 MODFLOW Groundwater Management Tool

Groundwater is a reliable resource compared to flashy surface water because of time lag response of ground water level and yield of wells after recharge to the system (Carter and Howsam 1994). Therefore a systematic study of groundwater regarding its sustainability is essential. MODFLOW is one of the popular tools used to assess and manage the groundwater. Many researchers have applied it in different aquifers for their research works because it is well established and practically tested numerical model aand provides reliable results if the aquifer is properly conceptualize. Brief discussions regarding the research for groundwater management conducted by different researchers using MODFLOW have been presented below.

Mao et al. 2005 found that the declination of groundwater levels caused by irrigation is the main problem for agricultural development in piedmont of Mt. Tiahang, Northern China. The behavior of ground water table in response of boundary conditions and stress had been studied with the help of Visual MODFLOW. The groundwater deficiency was 40 million m3 per annum on average, resulting in a groundwater decline of 0.57 m per year.

In this study Mao et al. concluded as "based on the simulated results, the groundwater table could decrease at a much slower rate if irrigation became less. A reduction of 100 mm in irrigation would almost keep the groundwater table steady at present. But if the irrigation increased 100 mm, the groundwater table would additionally decline 0.65 m in June and 0.45 m in December." Therefore water-saving agriculture is the first strategy for agriculturally and economically sustainable development in this area.

In an another study in Northern China conducted by Xu et al., 2011, application of water saving practices at both farm and district levels are required for sustainable agriculture development due to severe scarcity of water in Jiefangzha Irrigation System in Hetao Irrigation district. They applied Visual MODFLOW model with Geological information system (GIS) to study the impact on ground water dynamics of the area due to human activities because the ground water flow models are appropriate tools for assessing the effects of human activities in ground water dynamics (Mao et al. 2005). However, Xu et al. sincerely aware about the quality of data required for physical and hydrogeological setting of model. They identified that the physical one are topography,land use, soils,canals and drainage ditches, climate and crop demand for water. Hydrological settings include the aquifer system,and boundary condition, main hydraulic parameter characterization of each aquifer layer and the dynamics of ground water layers.

Ground water dynamic study of Jiefanzha Irrigation system of Hetao, Yellow River basin, Xu et al. modified the code of MODFLOW to simulate the evaporation appropriately because the inbuilt MODFLOW code is not suitable to simulate ground water evaporation in wet lands and low land where the ground water level is above the ground level (Xu et al. 2005). An integrated methodology based on loose coupling of modified version of MODFLOW and GIS is applied, which includes the changes in the evaporation algorithm, for assessing the impact of various irrigation water saving practices and ground water abstraction in the River basin.

In this study Xu et al. had foreseen the effects of water saving practices for the year of 2020. The results of the study revealed that the water saving practices with the 60 % of canal lining and upgrading hydraulic structures and improved farm irrigation technology in 50% of the area constitute a reasonable solution. Their implementation would lead to reduce groundwater evaporation by 43 mm and total diversion from the Yellow River by 208 mm. In spacialized results, they showed " the application of water-saving practices and the increase of groundwater abstractions will result in the decline of the groundwater table. In some areas this decline could be excessive since it leads to a large decrease of the groundwater contribution to the vegetation consumptive water use. In other areas with a shallow groundwater depth, the foreseen changes are expected to provide for improved cropping conditions and the control of salinity. Overall, relatively important decreases in diversions of water from Yellow River are expected (Xu Xu et al. 2005)

Rahul et al. 2011 carried out a simulation of Hirakunda canal command areaof eastern India using VisualMODFLOW which is under severe threat to imbalance between irrigation water availablability and demand. Canal supply of irrigation water meets 54% of demand at 90% probability of exceedance of that command area. They identified ground water is as the supplementary sources of irrigation. Rahul et al. developed a numerical quasi three dimensional ground water simulation model was developed using Visual MODFLOW in order to interpret the ground water investigation and hydrologic consequences.

Rahul et al evaluated the results by means of observed and simulated ground water levels and statistical parameters as standard error of estimate (SEE) and root mean square error (RMSE). SEE and RMSE of calibrated model is found to be varied from 0.036 to 0.256 and 0.253 to 1.131 respectively and for validation model varied from 0.024 to 0.197 and 0.437 to 3.097 respectively.

Most sensitive parameters that Rahul et al. found were groundwater recharge and aquifer conductivities in that study area. In the study, enhance pumping scenarios showed the possibility of increasing ground water withdrawal by 50 times existing level of pumping without causing any adverse effect to the aquifer as the ground water table remains within 2 meters below the ground level in 90 % of the command area in monsoon and 2 to 4 meters below ground surface in non monsoon period.

Abdulla et al.2006 carried out simulation of ground water of Mujib aquifer of Jorden where annual precipitation is less than 200mm and water supply significantly dependent on ground water. The study was performed using MODFLOW computer code for predicting, with reasonable accuracy, the response of Mujib aquifer to different scenarios of future abstractions. Transient state calibration also has been shown good agreement and it was verified by using drawdown data for the period 1996 to 2002. Agreement of the validation period was less than the calibration period but it gives also good and acceptable agreement for most observation wells (www.ias.ac.in).

In the study of ground water in Mujib aquifer, future scenarios of different stresses have been predicted for the year 2010, 2020 and 2030 under following different condition:

No reduction of current withdrawal rate
50% reduction of the withdrawal rate
50% increased of current withdrawal rate
50% reduction of recharge rate

Using Visual MODFLOW, Rejani et al. 2008 analyse Balasore coastal groundwater basin in Orissa, India which is under treat of seawater intrusion and groundwater depletion due to overdraft of groundwater. The simulation model was calibrated and validated satisfactorily. Using the validated model, the groundwater response to five pumping scenarios under existing cropping conditions was simulated. The results of the sensitivity analysis indicated that the Balasore aquifer system is more sensible to the river seepage, recharge from rainfall and interflow than the horizontal and vertical hydraulic conductivities and specific storage (R. Rehani et al. 2008)

In Pintung plain of Tiwan, Ting et al. 1998 developed a conceptual and numerical model using MODFLOW. Ting et al. developed a groundwater management model and applied the model for managing scarcity of irrigation and drinking water, disputes on water right and contamination of ground water. For calibration of model trial and error method had been applied. They found that the discrepancy between observed and simulated ground water level were within 2 meters but the wells near foothill showed the discrepancy more than 2 meters. After calibration, the global mean error was -0.102m and global mean absolute error was 0.579 m. The global root mean square error is 0.465 while the global relative error is less than 2 percent.

Many fertile alluvial plains with high agricultural productivity have unsustainable groundwater management practices. There is a strong trend to overexploitation of groundwater for agricultural activities and domestic and industrial water supply. These human activities have resulted the quality deterioration and water table level declination which reduce the quantity of ground water. Hollander et al. 2008 had studied the catchment of Balasore district in the Indian state of Orissa. Along term groundwater simulation had been carried out using MODFLOW to determine the effect of infiltration and withdrawal of groundwater and the maximum volume of water which could be stored in the underlined aquifer. The aim of the study was to develop a managed aquifer recharge (MAR) using ASR- wells (Aquifer Storage and Recovery).

In turkey, a study had carried out by Sakiyan et al. 2004 of Kucuk Menderes River basin This study was conceived on the basis of a desire to establish a management policy for the sustainable development and management of the basin. They used MODFLOW to simulate the aquifer system of the basin and calibraton of model had done in study state and transient state condition. Results of the study of groundwater management scenarios showed that the present annual groundwater pumpage rate (213 hm3/year) is about 68–103 hm3/year and 33 hm3/ year greater than the sustainable yield (110–145 hm3/ year) and traditionally defined safe yield (180 hm3/year), respectively. Thus, the continuation of the present annual pumping rates even with no increase in the planning period would produce an annual average draft of 55 hm3/ year in groundwater reserves with a consequent average decline of 17 m in groundwater levels at the end of the planning period. The study revealed that the sustainable yield of the aquifer (110–145 hm3/year) is unable to meet the current water demands, therefore it is of utmost importance to adopt the efficient management policy and plan for sustainability of ground water of the basin

Carma San Juan and Kenneth E. Kolm (1996) studied Jackson Hole aquifer system to develop the state of the art data base. Different boundary conditions and proper size of grid cell(500x500m) had been assign to the Jacson Hole valley study area. An iterative MODFLOW package had been used to simulate the ground water scenario. Jaun et al. found there the simulated head obtained i.e. calculated head is differed from observed one by an average value of 0.5m with standard deviation of 7.1m. MODFLOW mass balance volumes were within an order of magnitude of hand-calculated estimates of recharge and evapotranspiration; river flux was within an order of magnitude of measured gage data, and constant head nodes were gaining or losing according to the conceptual model. They found that the ground water management was not possible only with the help of MODFLOW package. Some other data regarding application and availability of other sources of water and agricultural data are required.

CHAPTER - 3: STUDY AREA

3.1 General

As already mentioned in introduction chapter, agriculture is the major component of national economy of Nepal as it creates employment and takes major parts in national economic growth. Most of the irrigable land of Nepal is in Terai region. All season irrigation facility in this region increases the yield which reduces the ever growing scarcity of food. Therefore Government of Nepal has provided high priority to initiate and implement big irrigation projects to provide year round irrigation facility to these irrigable lands. Among such systems Sikta Irrigation System is one which would provide irrigation to most of the cropping land of Banke district of Nepal by diverting water from West Rapti river at Aghaiya. The main aim of the Sikta system is to add assistance to the National Development Objectives of nation which would increase the living standard of the people in Banke District. This objective would be achieved if irrigation facilities together with modern agricultural support programme are implemented together. This would improve the productive capacity of farmers so that agricultural production and thus incomes would be increased. This system is under construction.

The aim will be fulfilled when available amount of irrigation water is enough. Water availability can be studied in two parts. One is surface water sources and the other is ground water sources. Although the west Rapti river is rainfed, significant flow is available. Therefore the Rapti is only the perennial one among the stream available in Banke district of Nepal.

Land use in upper part of the catchment of the river is changing. Deforestation and encrochment of forest is continuing. Rainfall pattern is also changing due to these changes. Praganna Irrigation system has been completed recently commanding 4000 ha of land. Another Badkapath irrigation system is in pipeline to irrigate 5000 ha of land in dang district on the left bank of West Rapti River. Therefore availability of water in the river would go on reducing which may affect in irrigation of this area.

At present around 10% of world's agriculture food production depends on mined ground water (P Gourbesville, 2008). In Nepal, about 7,26,000 ha. land has good potential for shallow aquifer development and in addition, 3,05,000 ha. land of the Terai has marginal potential. Similarly, about 1,90,000 ha. land of the Terai can be irrigated exploiting deep aquifer. Until now, Department of Irrigation (DOI), Agriculture Development Project, Janakpur (ADPJ), Agriculture Development Bank of Nepal (ADB/N) and private wells have provided year round irrigation facility for about 2,53,242 ha. land of the Terai. Due to climate change some parts of the country receive access precipitation and some parts draught. Also, in relatively dry climates, significant effect will occurs in groundwater recharge in small variation of precipitation in relatively dry climate. People extract ground water for domestic, industrial and irrigation use. Mining of ground water is extraction of water more than it is replenished. This increased use of ground water has led to the over exploitation of ground water table falling at alarming rate.

To protect water supplies against these externalities and changes, more storage of water is needed, including long-term storage (years to decades) to build water reserves during times of water surplus for use in times of water shortage. Water cannot be stored over the ground for long time viz. years and decades. Dams have been constructed all over the world but several dams have already breached. Some of them are in the stage of breach. Construction dam is not easy especially in third world due to high investment and ecological and environmental problems. The efficient way of collecting for water future is to store in underground aquifer. Aquifer has been stored about 98 % of world fresh water. It has enough space to store fresh water for long period. It can store water in excess rainfall and can release at the time of draught. Evaporation loss in aquifer storage is nil whereas evaporation in surface storage ranges from 0.5 m per year in humid climate to 2.5 m per year in hot dry climate (Bouwer, 2000). Storing in aquifer has no any environmental effects. Focus should be on ground water recharging technique for long term water. This study area is also a good reservoir of ground water

A number of depressions are present within the command area. They occupies wide spread area with shallow depth. They might help in recharge process but has no significant contribution in irrigation despite some nearby area to grow vegetable for their daily use. Therefore, integrated study of the surface water availability and surface water availability together with the demand of water within these study area is necessary.

3.2 Study Area

3.2.1 Location

Banke district is the only Terai district in the mid-western development region having large potential for the agriculture development. The total area of the Banke district is 235,980 ha out of which 58,990 ha is arable, 167,190 ha is covered by forest and the remaining 9,800 ha is used for grazing or covered by urban areas and industries (Fig. 3-1) Government has been implementing Sikta Irrigation System covering most of the irrigable land of the district. The study area has been taken within the command area of the Sikta Irrigation System.

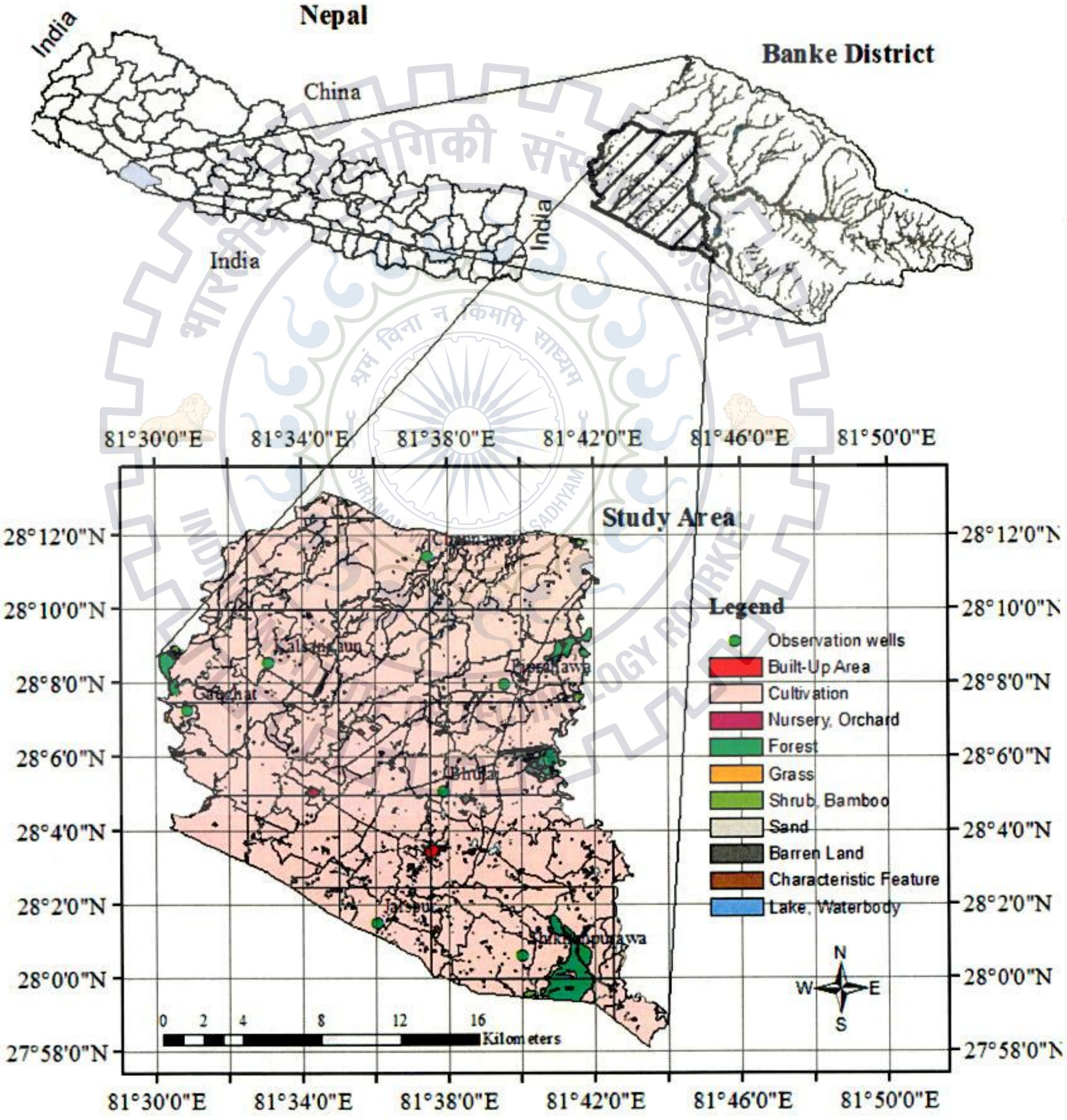


Fig. 3-1: Location Map of Study Area

Geographically the area comprises lands between 27^0 58' 07" and 28^0 13'12" N latitudes and 81^0 30'07" and 81^0 43'55" E longitudes. A location map of the project area is shown in Figure 3-1 whereas the google map of the same is given in Figure 3-2.

Out of total cultivable area of 58,990 ha in the District, the study area covers about 37,352 ha enclosed by the East-West Highway (Mahendra Rajmarg) to the North, the national boundary to the South, the Duruwa khola to the East and Man Khola to the West (Fig. 3-2).

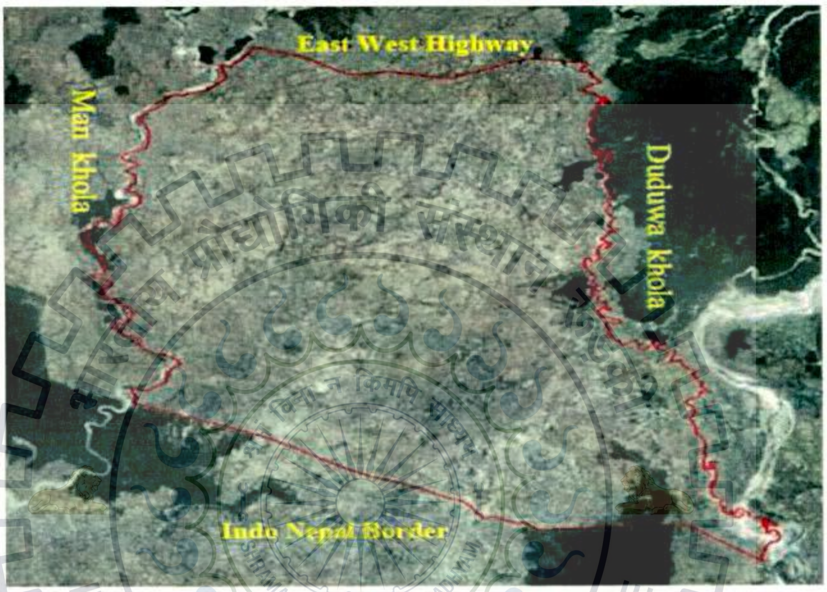


Fig. 3-2: Study Area in Google Map

3.2.2 Climate

Nepal has a large variation in climate due to vast range of altitude within short North West width of it. In Tarai region, prevailing climate is tropical and subtropical whereas outside of Tarai completely different climate exists. East-west-presence of Himalayan range located to the north and the monsoonal change of wet and dry seasons also significantly add to local deviation in climate.

The Study area is situated in a sub-tropical monsoon type climatic zone. Around 80% of annual rainfall occurs in monsoon period (June to September). The annual average rainfall in the study area is about 1400 mm. Minimum temperature within the study area is about 5° C in the month of January and the maximum temperature reaches upto in the month of June. Humidity ranges from 60% in May to 85% in January.

3.2.3 Geomorphology

The Terai is underlain by a thick sequence of saturated detrital sediments of alluvial and colluvial origin which makes this area one of the most productive aquifers in the subcontinent. The Bhabar zone is formed by erosion of Siwalik Hills and the outwash fans of rivers. The sediments of this area are coarse and have very high permeability. This area is considered to be the main source of recharge for the Terai's ground water which makes the region very potential for groundwater resources. The study area is on the foot hill of Churia Hill (Siwalik Hill). The elevation of the area ranges from 134 to 174m. This variation has been shown in Figure 3-3.

The slope of the land is gentle toward south. The study area is an alluvial plain formed by material transported by several rivers which rise in the highlands to the north of the command area and flow southwards to the Indian border.

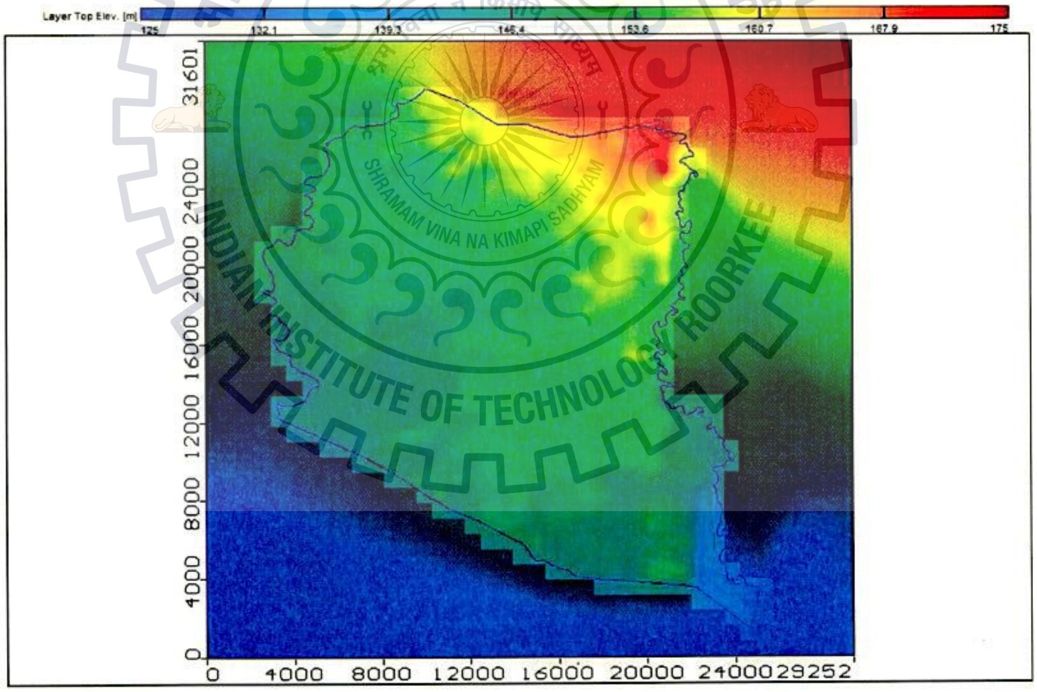


Fig. 3-3: Ground Surface Elevation

This area is the gangatic plane and formed in different ancient time period. The vertical formation of the area has different layers of varieties of soil type (Fig. 3-4). Perusal study of litho log of the area revealed that each layer has same type of soil. The top soil is composed of alluvial soil as previously mention. Other successive layers are aquifer and aquitard of fine to medium sand and clay mixed with silt and sand respectively (Fig. 3-4). For the study purpose only three layers have been considered for unconfined aquifer study.

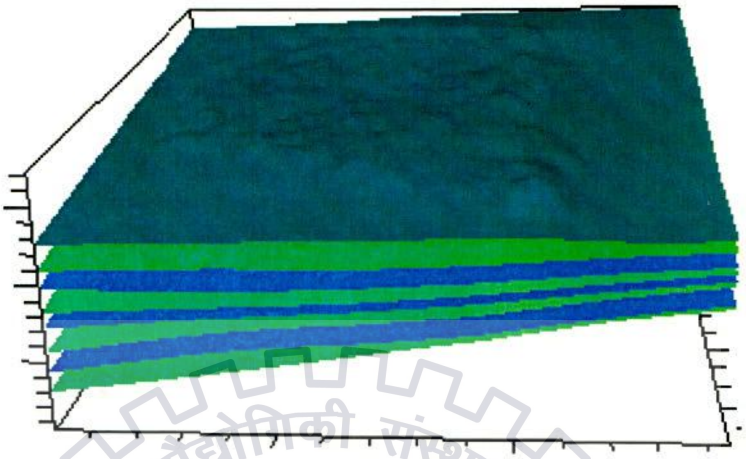


Fig. 3-4: Vertical Layers of Soil of Study Area

3.3 Land Use Pattern

The study area is very fertile land. It supplies food for most of the mountainous district of Mid western development region of Nepal. But it has to rely on irregular precipitation for cropping. About 10% of cultivated land has year round facility of irrigation using ground water and surface water. Surface water has scarcity in winter season because there are not any perennial surface sources of water within the study area. Yield of the crop in this area is uncertain due to irregularities in precipitation and lack of irrigation facilities.

The total coverage area within the study boundaries is 37,351.00 hactre. Nepalgunj municipality area is within the study area. Airport and a Kohalpur town planning are also within the study area therefore the built up area is about 1000 hactre. Although Banke district has more forest area, the study area has very less forest. About 150 hactre land has covered by forest. Some lands area fellow area which has occupied about 350 hactre .

Major portion of the study area has covered by agricultural land and is about 35,851 hactre. Due to inefficient and less irrigation facilities, the cropping intensity of the area is less. The overall cropping intensity in the proposed command area has been estimated at 168%, which is slightly higher than the Banke district average of 161%. Although cropping intensity is slightly higher in the command area than the district average, the level of cropping intensity in the command area can be considered still low. The low rate of overall cropping intensity (168%) in the area has to be seen in the context of very low irrigation coverage in the area. The existing cropping pattern is shown in Table 3-1.

Table 3-1: Existing Cropping Pattern of the Study Area

Sl.	Crop	Percentage of command area	
		Summer Crop	Winter Crop
1	Paddy	68	
2	Wheat		24
3	Maize	23	
4	Pulses +		27
5	Potato		3
6	Oilseeds Crops *		14
7	Summer Vegetables	6	
8	Winter Vegetables		3
	Sub Total	97	71
Total		168 %	
+ include : red gram (Cajanuscajan), gram, lentil, peas and latharus			
* include : mustard, linseed, sunflower, sesame			

Source: District Agriculture office, Banke, Government of Nepal (Personal communication)

CHAPTER - 4: METHODOLOGY/PHILOSOPHY

4.1 Background

To achieve the stated objectives, it is necessary to know the amount of water required for the crop and amount of water resource available (surface and ground water). Therefore the work has been divided into three parts: crop water requirement and surface water and ground water availability. A flow chart showing in Figure 4-1 gives an overview of methodology of study. Comparing crop water requirement with the surface water availability, the excess and scarcity of the irrigation water will be calculated so that whether the requirement of extra water can be managed from ground water. Availability of ground water can be found out by using numerical ground water modeling tools.

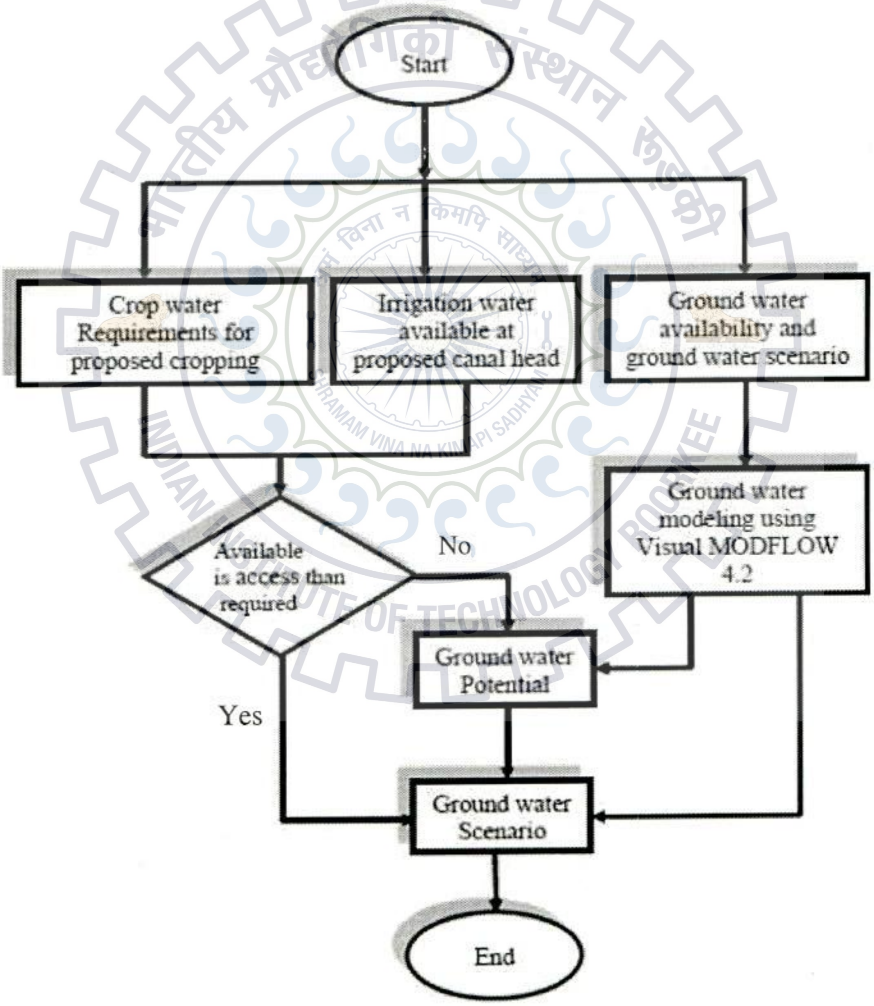


Fig. 4-1: Methodology Flow Chart

Although several software packages are available for ground water flow simulation, the Visual MODFLOW model has been selected as it has been widely used because of easy accessibility, user's friendly versatility (Kashaigili et al. 2003). The USGS Visual MODFLOW model was used to simulate groundwater flow in the study area. MODFLOW is an industry standard model that simulates 2/3-dimensional cell-to-cell groundwater flow in heterogeneous and anisotropic porous media using the finite difference method (Harbaugh et al., 2000; Harbaugh, 2005). It has applied the principle of mass balance and momentum theory. Its flexible modular nature allows selective use of packages for specific simulation tasks. Many researchers and professional have used this model for ground water scenario study and sustainable management of ground water within the study area. In this study, Visual MODFLOW has been used here to interpret the aquifer. The ground water scenario for different stress conditions have been analysed and presented in result and discussion chapter.

4.2 Overview of Visual MODFLOW

Ground water models are the computer programs of ground water flow system for the calculation of ground water flux and head. Because of the assumptions made for deriving the mathematical formula for simplicity, the models using these formulae do not match exactly the ground water environment. Yet they provide acceptable results for the analysis of ground water and help to decision making.

The first step of Groundwater modeling is to understand the conceptual understanding of the natural ground water system and the next is interpretation of the natural system into mathematical terms. The basic principles used by most models to solve the general form of non linear three-dimensional groundwater flow equation is a combination of the water balance equation and Darcy's law. MODFLOW also use the following equations to calculate the groundwater head and flux.

$$v = ki \qquad \text{........ 4-1}$$

Where,

v = velocity through porous media, k = hydraulic conductivity, i = head causing flow, and

$$\frac{\partial}{\partial x}\left[k_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial h}{\partial y}\right] + \frac{\partial}{\partial z}\left[k_z \frac{\partial h}{\partial z}\right] \pm W = S_s \frac{\partial h}{\partial t} \qquad \text{........ 4-2}$$

Where,

*K*x, *K*y, *K*z are hydraulic conductivity values along the x, y, z axes [LT-1],

h = hydraulic head [L], *W* = source/sink terms [T-1], *Ss*= specific storage coefficient [L-1], *t*is time [T].

The modular finite-difference groundwater flow model MODFLOW-2000 (Harbaugh et al. 2000) was selected to simulate the behaviour of groundwater flow in the study area because it is a well-documented and extensively tested model, which can be readily incorporated into future studies for optimal water resources management (Xu Xu et al. 2011). It simulates transient/steady groundwater flow in complex hydraulic conditions with various natural hydrological processes and/or artificial activities and, can be used for large areal extent and for multi-aquifer modelling. Hydrogeologic layers can be simulated as confined, unconfined or a combination of the two (R. Rejani et al. 2008). Boundary conditions include specific head, specific flux and head-dependent flux. The Visual MODFLOW (Waterloo Hydrogeologic Inc. 2006) version 4.2 was adopted to simulate three-dimension unsteady groundwater flow in this study.

Visual MODFLOW is an *Integrated Conceptual and Numerical Groundwater Modeling* and is the most complete and easy-to-use graphical modeling environment for professional 3-D groundwater flow and contaminant transport simulations. Visual MODFLOW Pro seamlessly combines the standard Visual MODFLOW package with WinPEST and the Visual MODFLOW 3D-Explorer to give the most complete and powerful graphical modeling environment available. This fully-integrated groundwater modeling environment allows to:

- Graphically design the model grid, properties and boundary conditions,
- Visualize the model input parameters in two or three dimensions,
- Run the groundwater flow, path line and contaminant transport simulations,

Visual MODFLOW stores all of the data in a set of files. Most of the input files are stored in ASCII text format. As a result, the input files can be manipulated using a text editor or even generated using a FORTRAN or Visual Basic program. Visual MODFLOW then translates these data files to the required format prior to running the models. By constructing the model, Visual MODFLOW creates the modules, basic pieces of the program code, needed by the numeric engine. ArcView GIS has been used to store analyze and display the spatial data on topography, recharge, and in making the base map for the visual MODFLOW.

ArcGIS 10.0 is GIS software that allows creating maps and adding information. Using ArcGIS 10.0 GIS visualization tools and records from existing databases can be accessed and showed on maps. These output files can be evaluated using ArcGIS 10.0 in which these files are compatible.

4.3 Conceptual Model of the Study Area

The conceptual model of the study area was developed based on the surface elevation, location of observation wells and litho logs of the area. The surface elevation of the study area was obtained from the SRTM DEM downloaded from GLCF web site (Fig. 4-2). The SRTM DEM with resolution of 90 m x 90 m which represent fairly accurate ground surface than other DEM (Frey et al. 2012). The Visual mudflow has facility to import the DEM directly to represent the ground surface of the area of concern. The DEM showed the study area has downward slope toward south.

An important tool to characterize the aquifer is hydrogeological profiles. Hydrogeological profile was conceptualized from the data obtained from litho logs. Unfortunately most of the litho logs were available in lower southern part. These litho log points have been shown in Appendix I. The geologic profiles obtained from litho logs of the area revealed that the basin is comprised mainly of several layers. Among them three layers were taken ground water study purpose. There are alternatives distinct confined/ semi-confined aquifers separated by clay layers of thickness ranging from 2 to 41 m. These three aquifers consist of fine and medium sand. First aquifer having thickness 3–51 m exists at height from mean sea level is 191–80 m. Level of the second aquifer from mean sea level ranges from 165 to 64 m, with a thickness of 3 to 80 m. Third aquifer having a thickness of 3–34 m exist at level of 137–43 m from mean sea level.

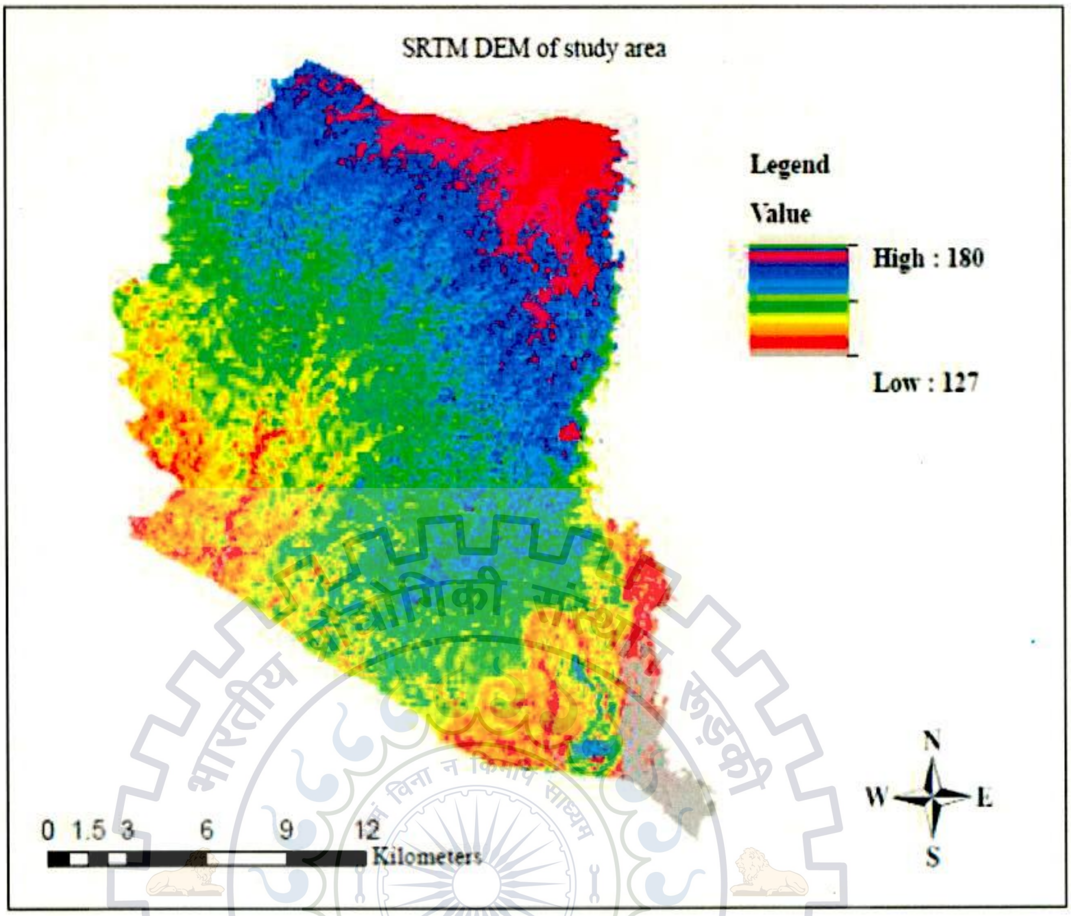


Fig. 4-2: SRTM DEM of Study Area

The first aquifer has exploited by extracting water using shallow tube wells of 610 of different village development committee. Location of these shallow tube wells has been shown in Figure no. 4-3. These tube wells have less discharging capacity and has utilized for irrigation purpose. For drinking water small hand pumps were installed almost all individual houses. Due to overexploitation of ground water from the first aquifer, the water table of southern part of the area has gradually decreasing. Some deep tube wells have been installed for irrigation and drinking purposes and some industrial institution.

For model simulation, some observed values of known points were necessary. Those observed values are compared with the simulated value to ascertain theoretical representation of actual natural system within prescribed computer code so that the

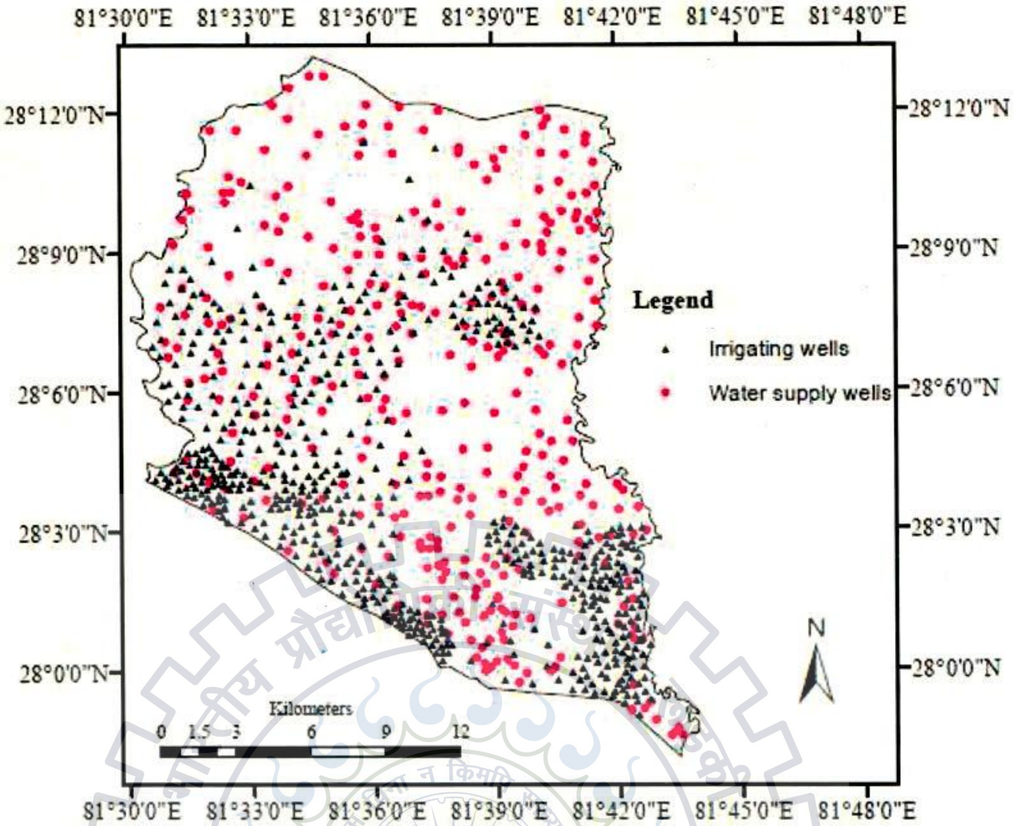


Fig. 4-3: Location of Shallow Tube Wells

predicted values are reliable. In ground water model, groundwater head is a threshold for comparing measured and calculated values. Historical data for groundwater level were available in seven observation points. Those points were scattered within the study area (Fig. 4-4).

4.4 Abstraction of Groundwater

The well package of MODFLOW is designed to simulate the inflow and outflow through recharge wells and pumping wells, respectively (R. Rejani et al. 2008). The withdrawal quantities in the unconfined aquifer were assigned to 610 wells. Average pumping from shallow tube wells that extract in the first aquifer ranges from 5 to 10 lps and that from deep tube wells which extract water from second and third aquifers ranges from 15 to 40 lps. No data are available to assess the actual withdrawal of groundwater from first and other semi confined aquifers. A thumb rule is prevailing in

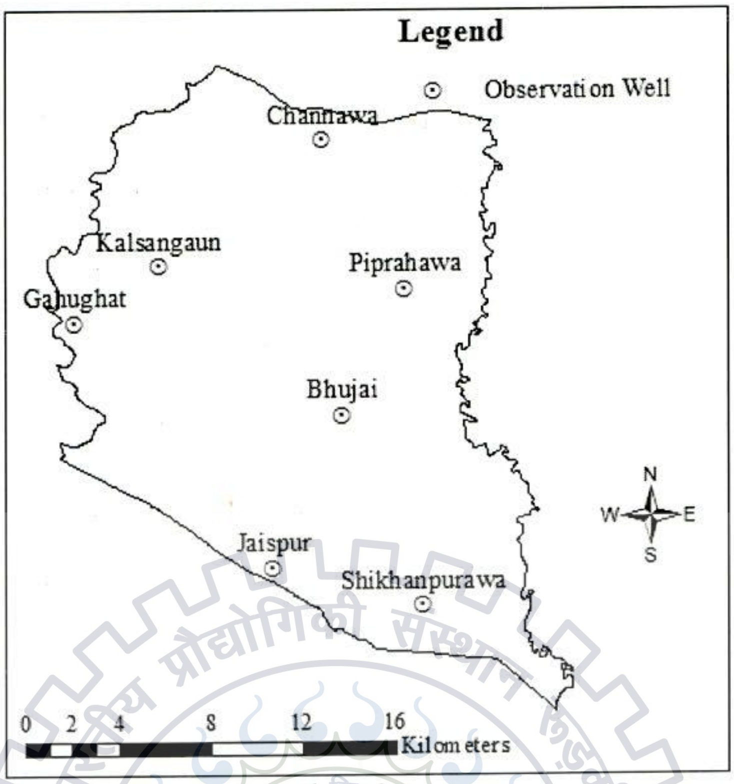


Fig. 4-4: Location of Observation Wells

Nepal that a shallow tube well would irrigate 2.5 hactres of land and that of a deep tube well would irrigates 40 hactres of land. Actual withdrawal of ground water had been assumed to be equal to the amount lesser of average of crop water required for existing cropping pattern or maximum discharge of the tube well during that very month. The average crop water requirement had been calculated by averaging the crop water requirement of crops prevailing in respective months. There are nine numbers of non irrigating wells in the study area. They supply the water for industries, municipal and rural water supply. The amount of groundwater extraction from these deep tube wells other than irrigation tube wells was taken as the amount of ground water extraction in 10 hours of their running in one day with the with their average discharging capacity. The average discharging capacity irrigating deep wells was taken as 25 lps and of water supply well was taken as 15 lps for this study purpose.

The total population of the study area is 0.227 million (CBS, 2012). According to the GIS shape file provided by Department of Survey of Nepal, there are 311 villages within the study area. On an average the number of population in each village except municipality is 731. There is no other source of drinking water other than ground water.

Almost all people extract groundwater for their daily use. In rural area, one person needs 45 litres of water per day. Therefore from one village average amount of water extracted for drinking and other purpose is 32.85 m^3 per day and one well in each village was assumed to abstract the stated amount of water from unconfined aquifer for drinking purpose. Groundwater extraction is summarized in the table 4-1 below.

Table 4-1: Extraction of Groundwater

S.N	Month of year	Extraction of ground water (m^3/day) per tube well			
		Irrigating Shallow tube well	Water supply Shallow tube well	Irrigating Deep tube well	Water supply Deep tube well
1	January	95.83	32.85	958.28	1296.00
2	February	128.75	32.85	1287.45	1296.00
3	March	181.66	32.85	2160.00	1296.00
4	April	205.41	32.85	2160.00	1296.00
5	May	332.93	32.85	2160.00	1296.00
6	June	319.65	32.85	2160.00	1296.00
7	July	99.54	32.85	995.37	1296.00
8	August	90.13	32.85	901.26	1296.00
9	September	150.88	32.85	2160.00	1296.00
10	October	371.01	32.85	2160.00	1296.00
11	November	151.69	32.85	2160.00	1296.00
12	December	58.98	32.85	589.77	1296.00

4.5 Discretization of of Study Area

The study area has been divided into number of finite difference cells having dimensions 500 mX 500m. Aquifer parameters and other physical properties of the natural ground water system were assigned to each cell. Visual MODFLOW calculates the hydraulic head and aquifer parameter at the center of the cells. The area was divided into 46 columns and 56 rows (Fig. 4-5). Hence, there is 2576 number of cells over the area in each layer. The cells outside the study area were inactivated so that model discards that cell during simulation of groundwater system. Available data for observation well was in monthly time step.

Therefore month was selected as the time step within which all hydrological stresses can be assumed to be constant. Visual MODFLOW is versatile in importing the data. It can import data from ASCII format of file or surfer.grd. So, the data on elevation of each layers, surface elevation and groundwater elevation were made in ASCII format and fed as input.

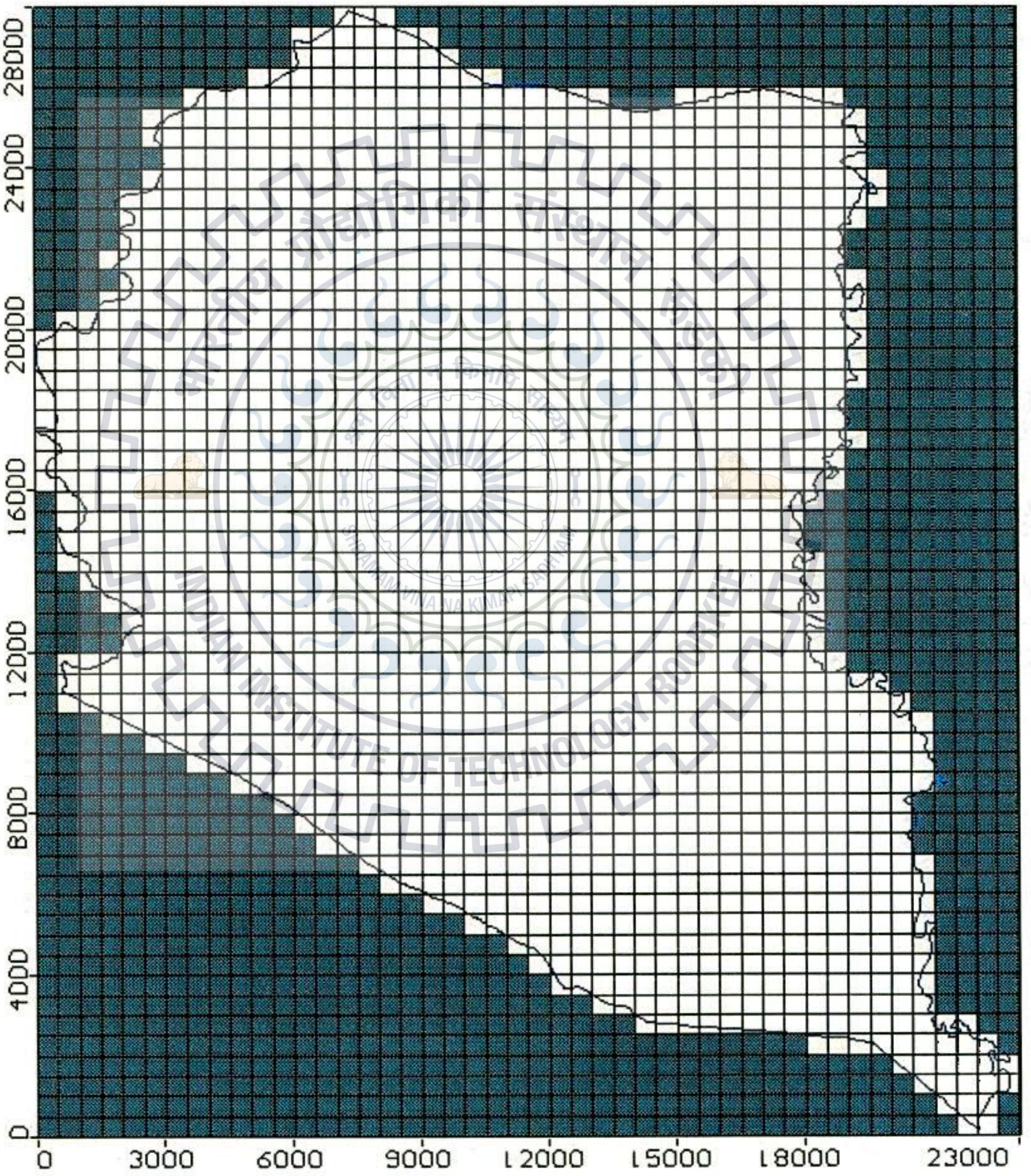


Fig. 4-5: Discretization of Study Area

4.6 Assigning Boundary Conditions

The boundary conditions of the area govern the groundwater flow in the aquifer layers. There are two rivers: Duduwa river to the east and Man river to the west, north and south boundary have no any such water body. Hence there are two types of boundary conditions: Neumann boundary (north and south boundary) of thin wall which allows frequent entry and exit of water flux into the system and the Cauchy boundary (rivers). The effect of flow between the rivers and aquifer was simulated by dividing the rivers into reaches containing single cells. The river bed conductance, C_{river}, was computed by using the equation;

$$C_{river} = \frac{K_r L W_r}{B} \qquad \text{........ 4-3}$$

where, K_r = hydraulic conductivity of the river bed (m/s), W_r = width of the river (m), L = length of the reach/grid size (m), and B = thickness of the riverbed (m). The boundaries of the study area can be seen clearly in the Google map (Fig.3-2).

River bed conductivity had been obtained from similar study conducted by Rahul et al. (2011). These values have been given in Table 4-2 below. The average thickness of the bed material has been taken as 0.5 m. On an average river width of Man river was adopted as 60m and Duruwa river as 30m.

Table 4-2: Monthwise Conductivity of River Bed

S.N.	Month	K_f (m/s)
1	January	2.5×10^{-7}
2	February	2.5×10^{-7}
3	March	2.5×10^{-7}
4	April	2.5×10^{-7}
5	May	2.5×10^{-7}
6	June	1.3×10^{-7}
7	July	1.3×10^{-7}
8	August	1.3×10^{-7}
9	September	1.3×10^{-7}
10	October	1.3×10^{-6}
11	November	7.5×10^{-7}
12	December`	4.4×10^{-7}

4.7 Initial Conditions

There were seven numbers of observation wells in unconfined aquifer and three for semi confined aquifer. If initial condition for groundwater levels were provided, model would easily converge the calculated groundwater level. That is why initial condition is necessary to start calculation. Five years continuous data were available for groundwater table on these observation wells.The data available for groundwater observation wells were from January 2007 to December 2011. Therefore the water level in observation well of January 2007 were taken as initial condition for unconfined aquifers and contours were derived for each cell using those data (Fig. 4-6)

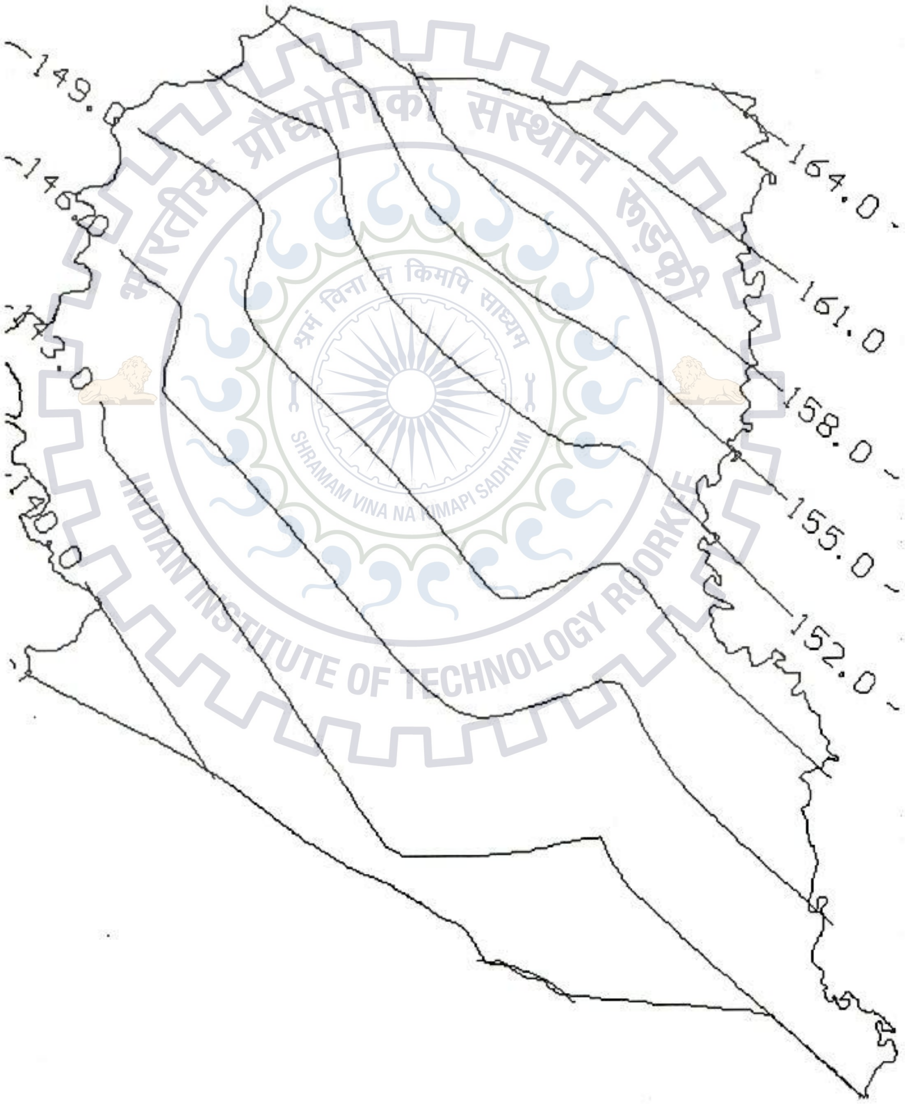


Fig. 4-6: Initial Head

4.8 Hydrogeological Parameters

The study area lies within the gangatic plain. The top layer of the area is composed of alluvial soil. The unconfined aquifer is of fine to medium sand. Other semi confined aquifers were composed of fine and medium sand. The aquitards contains clayey materials. It was not possible to get field measured data for the conductivity and specific yield and specific storage and porosity. Therefore initially these values were taken from literature matching the property of the soil obtained from litho logs. The enviro-Base package has provided characteristics of soil of different types based on different sources to help simulator to choose initial value of the above mentioned properties of soil.

The top and second layers of the study area had divided into three soil zones. These three zones had been taken for assigning the soil property (Fig. 4-7). For research purpose the whole area for rest of the layers have been taken as one zone separately because no experimental data has been found for these layers to assign different aquifer properties..

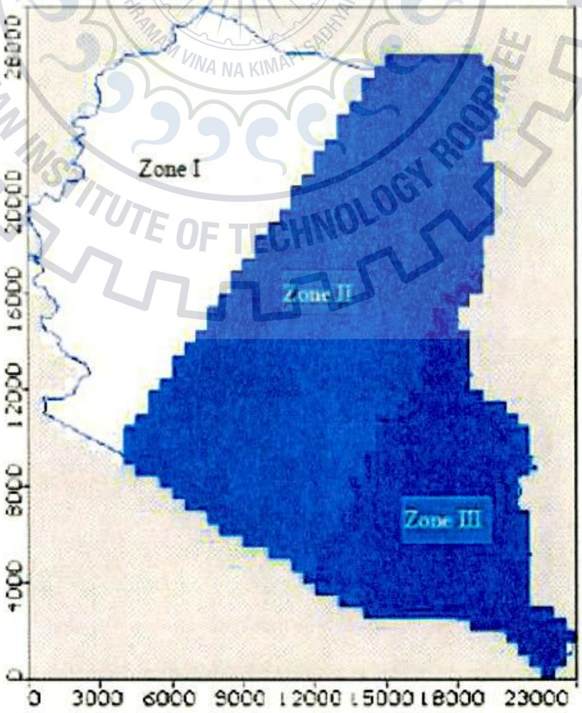


Fig. 4-7: Soil Zone

4.9 Ground Water Recharge

Ground water replenishment is the major event for ground water development. Recharge is that phenomenon which increases the ground water storage. Ground water recharge is related to precipitation, land coverage, river discharge and evaporation (Mao et al.2005, Rao et al.1996, Myrab 1997). The principal sources of groundwater recharge of the aquifers of the study area are precipitation, rivers and interflow from the Siwalik hill side. The recharge package in MODFLOW is designed to simulate areal distributed recharge to the groundwater system (R. Rejani et al. 2008). The rainfall data of simulation period of the area were collected for each stress period and certain percentage of precipitation was assumed as the recharge of ground water. Percentage precipitation that contributes in groundwater recharge was taken from the developed by R.S. Chaturvedi in similar study area of Ganga –Jamuna doab in India. Chaturvedi's formula has been widely used in the area of tropical region. Therefore the modified Chaturvedi's (1973) recharge formula was used for preliminary calculation of groundwater replenishment (R) was in the study area. This empirical formula is as follow:

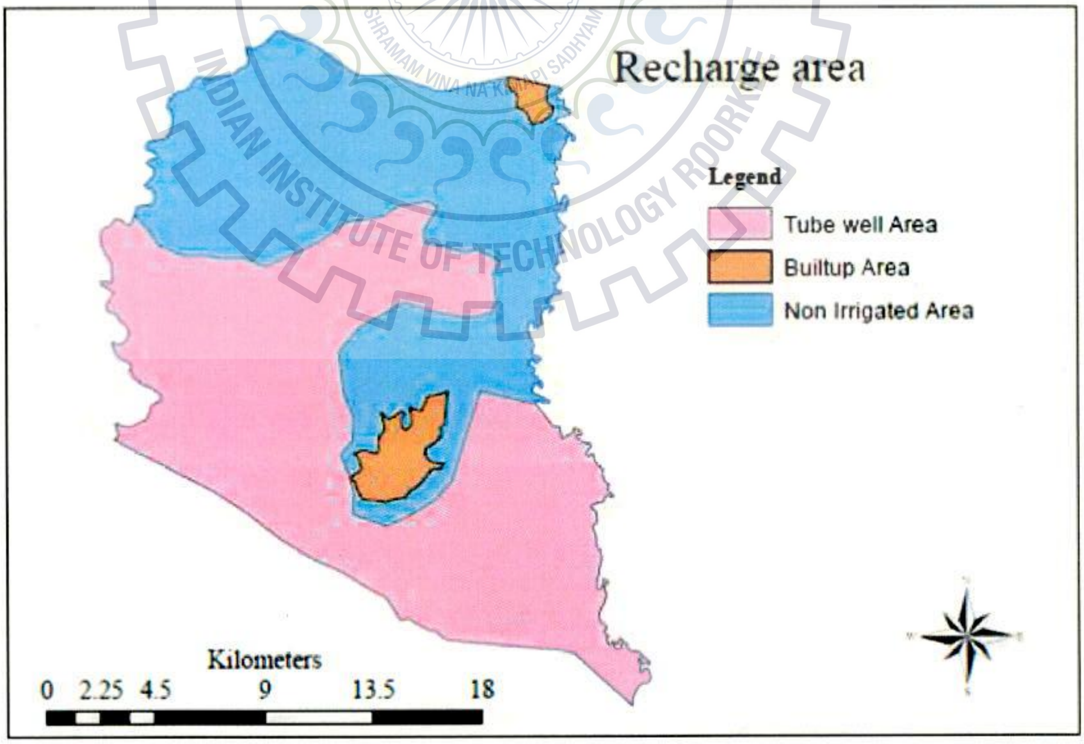


Fig. 4-8: Recharge Zone

$$R = 1.35(P - 14)^{0.5} \qquad \text{........ 4-4}$$

where,

R is the net recharge in inch due to precipitation and P average annual rainfall in inch.

The precipitation data of the area had been taken from three meteorological stations located within the study area. These stations were Sikta (0409), Naubasta (0414) and Khajura(0419). Monthly average data of those stations of simulation period (2007 to 2011) were tabulated in Appendix 2. Annual average precipitation obtained from the data was 1400 mm. Using the modified Chaturvedi's enperical formula, preliminary net recharge of groundwater was worked out around 15% of annual average precipitation. Therefore the recharge of the study area due to rainfall was taken as 15% for irrigated land and 10% for built up area. Recharge areas of the study area are shown in Figure 4-8.

The estimation of recharge from groundwater irrigated field including the losses in field channel was worked out based on the suggested guideline of the Groundwater Estimation Committee (1984) Mumbai India, which are as follows:

(a) Recharge from irrigated rice area is about 35–64% of tubewell discharge, and

(b) Recharge from irrigated non-rice area is about 25–36% of tubewell discharge.

There is no any define area to separate irrigated rice area and irrigated non rice area. That is why an average percentage of 30% was taken as recharge from the tube well discharge. The area within which deep and shallow tube wells were spread was 19000 ha. Though the discharge from the existing tube wells could not irrigate this area but for study purpose groundwater recharge was taken as the recharge of 30 % of tube well discharge would spread evenly throughout the area. Hence the amount of recharge within this tube well area was taken by combining precipitation and tube well recharge depth.

4.10 Evapotranspiration

The evapotranspiration package (ET) of the numerical groundwater flow model simulates the effects of plant transpiration via capillary rise from the saturated zone, i.e. directly from the water table. The ET package approach is based on the assumptions that (S.K. Rahul et al, 2008).:

(i) when the water table is at or above the ground surface (top of layer 1), ET loss from the water table occurs at the maximum rate as specified by the user;

(ii) when the elevation of the water table is below the 'extinction depth', or is beneath the layer 1, ET from the water table is negligible; and

(iii) between these limits, ET from the water table varies linearly with water table elevation

The extinction depth depends upon the root zone depth and capillary rise. Root zone depth is the depth of the soil reservoir that the plant can reach to get plant available water. Crop roots do not extract water uniformly from the entire root zone. Thus, the effective root depth is that portion of the root zone where the crop extracts the majority of its water erquirement. Therefore the average effective root zone depth varies for different crops. The average effective root zone depth for summer crops was taken as 0.7 m and for winter crops 0.5 m for study purpose (S.K. Rahul et al.,2011).

The groundwater can be sucked upward by the soil through very small pores that are called capillars. This process is enhanced by surface tension around soil particles and is called capillary rise. The capillary rise in average condition of soil is about 1.4m (S.K. Rahul et al.,2011). The sum effective root depth and capillary rise is the extinction depth.

This ET package represents only a minor part of evapotranspiration in the phreatic area where the ground water is close to the surface. Therefore extinction depth could be taken zero in monsoon season because rainfall accumulated over crop field satisfies evapotranspiration. There is always downward flow of water to groundwater table from surface where rainfall accumulation occurs in dyke of field in monsoon season. The maximum extinction depth would be the summation of average effective depth and capillary rise. Hence extinction depth varies from zero, during peak monsoon month, to 1.9 and 2.1 m below the ground surface.

Table 4-3: Monthly Maximum ET_0 and Extinction Depth

S.No.	Month	Maximum ET (mm/day)	Extinction depth(m)
1	January	1.87	2.1
2	February	3.13	1.9
3	March	3.13	1.9
4	April	3.44	1.9
5	May	6.95	1.9
6	June	7.26	1.9
7	July	0	0
8	August	0	0
9	September	0	0
10	October	3.75	2.1
11	November	1.93	2.1
12	December	1.15	2.1

As explained above, the ET package used evapotranspiration of preatic zone. Evapotranspiration of monsoon season would satisfy from the ponded water and ET package doesnot deal with this value when the water surface is above the ground surface. Therefore it is reasonable to adopt this value equal zero during monsoon months. The average evapotranspiration of remaining months were calculated based on reference evapotranspiration measured at Khajura station (Appendix 4) within the study area, crop coefficients of recommended by FAO in humid region and existing cropping pattern of the area (Table no .3-1). Monthly maximum evapotranspiration and root zone depths have been tabulated in Table no 4-3.

4.11 Computation of Irrigation Water Requirement

Presently, no irrigation facility is available for 90% of the study area. Within rainfed area of the study area crops experience stress during its growing period due to irregularities of rainfall. To know the extra water to be supplied to the crops during rain water scarcity, water requirement for the existing and future cropping pattern is necessary. The gross irrigation requirement of a crop can be calculated by using the following equation (S. K. Raul et al., 2011).

$$GIR = \frac{(ETc - RFef)}{\eta a} + SPR - SMC - GWC \qquad \text{........ 4-5}$$

where, GIR = gross irrigation requirement in field (mm);

ETc = crop evapotranspiration (ET) (mm) which is equal to (ETo x Kc);

ET0 = reference ET (mm);

Kc = crop coefficient; SPR = special purpose requirements (mm);

SMC = soil moisture contribution;

GWC = capillary contribution from groundwater;

RFef = effective rainfall (mm), and η_a = field application efficiency (fraction). SMC and GWC may be considered negligible under certain localized condition. In this study, these two components are not taken into calculation.

In the above equation ETo is necessary. Various methods of reference crop ET computation is available (Doorenbos and Pruitt, 1977; Allen et al., 1998). The FAO Penman-Monteith method (Allen et al., 1998) has been recommended as the standard method. However, the measured reference ETo was available at Khajura Station (index no 409) which was used for the calculation of crop water requirement (Annex 3). FAO recommended Crop coefficient values (Kc) of humid region were adopted for each crop. Effective rainfall was calculated using US Department of Agriculture Soil Conservation Service (USDA-SCS) method (Smith et al., 1998). Field application efficiency was taken as 32% for rice and 58% for non-rice crops (Doorenbos and Pruitt, 1977).

4.12 Special-Purpose Water Requirements (SPR)

For all crops land, water required for land preparation i.e. pre sowing irrigation. Land preparation includes easy ploughing, land smoothening and disking the undulated land. Nursery raising and transplanting of rice required also required irrigation. These requirements are categorized as special water requirement. For all crops, land preparation requires water of 70mm (Tyagi, 1980) whereas rice requires 200 to 250 mm of water for nursery raising and transplanting. In this study average value of 225 mm for special purpose water requirements of rice. The calculated gross irrigation based on the aforementioned discussion has been presented in Table no 4-4.

Table 4-4: Monthly Gross Water Requirement for Existing Cropping Pattern

S.N.	Month	Gross Irrigation water requirement (MCM)
1	January	36.21
2	February	47.31
3	March	46.49
4	April	19.60
5	May	34.18
6	June	156.69
7	July	39.78
8	August	10.46
9	September	3.34
10	October	48.87
11	November	44.78
12	December	18.15
	Total	505.87

CHAPTER - 5: GROUNDWATER MODELING

5.1 General

The model must be calibrated before the application of model for prediction of observation heads in prevailing and changing scenarios. Calibration is adjustment of model parameters so that calculated heads would closely match with the observed values at selected point in the aquifer; i.e , consistent interpretation of ground water system. This means that the observed data is used to compare with the simulated water head obtained from model. Analysis of the difference between measured and computed head gives an indication as to where adjustment of output parameters may be necessary in order to minimize this difference (Gaaloul, N, 2012).

5.2 Model Performance Evaluation

There are many goodness of fit parameters to evaluate the performance of model. Generally the output results of calibration and validation could be evaluated by means of errors. Mean error (ME) (Luckey et al. 1986; Ting et al. 1998), mean absolute error (MAE) (Ting et al. 1998), Nash and Sutcliffe model efficiency (Moriasi et al. 2007) and root mean squared error (RMSE) (Kashaigili et al. 2003; Ting et al. 1998; Xu et al.2011) are some performance measuring parameters. However, RMSE is generally adopted as the best measurement of model error, if the errors are normally distributed. In this study, SEE and RMSE were used. These two measure of errors Eqs. 5-1 and 5-2 quantify the average error in the calibration.

$$\boldsymbol{SEE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\overline{\boldsymbol{h}_m} - \boldsymbol{h}_s)_i^2} \qquad \text{........ 5-1}$$

$$\boldsymbol{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(\boldsymbol{h}_m - \boldsymbol{h}_s)_i^2\right]^{0.5} \qquad \text{........ 5-2}$$

Where,$\overline{h_m}$ = Mean of observed ground water level, h_m= observed groundwater level (m), h_s= simulated groundwater level (m) and n=total number of observed data.

5.3 Calibration

The parameters referring to the hydraulic conductivity, specific yield and recharge coefficient, which were relatively uncertain in the study area, were calibrated through an iterative process. There are two methods to calibrate the model parameters that were uncertain; trial and error method and parameter optimization. Trial and error method was used to calibrate uncertain parameters by changing them sequentially (Hill et al. 2000; Xu et al. 2011). This method is cumbersome and takes lots of effort and time. A package WINPest which optimizes the uncertain parameters was included in Visual MODFLOW 4.2 but parameter value should be check for their range.

PEST's role is to minimize the weighted sum of squared differences between model-generated observation values and those actually measured in the field. This sum of weighted, squared, model-to-measurement discrepancies is referred to as the "objective function". Weighting these discrepancies allows to make some observations more important than others. Weights should be inversely proportional to the standard deviations of observations.

For non-linear problems (most models fall into this category), parameter estimation is an iterative process. At the beginning of each iteration, the relationship between model parameters and model-generated observations is linearised by formulating it as a Taylor series expansion about the current best parameter set. Hence the derivatives of all observations with respect to all parameters must be calculated. This "linearised" problem is then solved for a better parameter set, and the new parameters tested by running the model again. By comparing the changes in parameters to the improvement in the objective function, PEST can tell whether it is worth doing another optimization iteration. If so the whole process is repeated.

As it calculates derivatives, PEST records the sensitivity of each parameter with respect to the observations. If PEST's performance is being hindered by the behavior of certain parameters (normally the most insensitive ones), these parameters can be temporarily held at their current values while PEST calculates a suitable upgrade vector for the rest of the parameters. If desired, PEST can be requested to repeat its determination of the parameter upgrade vector with additional parameters held fixed (Doherty J.2005)

5.3.1 Steady State Calibration

The model has been calibrated in two sequential stages; a steady-state calibration followed by a transient calibration (Rahul et al. 2011, Sakiyana et al. 2004). The steady state condition is a condition that existed in the aquifer before any development had occurred. Matching the initial heads observed for the aquifer with the hydraulic heads simulated by Modflow is called steady state calibration. Steady-state calibration was made against January 2007 observed water levels. WinPest subroutine of Visual MODFLOW 4.2 was used to calibrate the study state condition of groundwater. It changes aquifer parameters which are sensitive to groundwater flow by minimizing the objective function so that a smooth consistency would obtain between observed head and calculated head. The model successfully simulated with a root mean square error of 0.346 m and standard error of estimation of 0.126 m (Fig. 5-1). Comparison of simulated head and observed head of groundwater revealed that whether they are compatible with each other. This stage of calibration allowed the adjustment of aquifer parameters and boundary conditions in the aquifer system. It is done by sequential tuning of the model parameters.

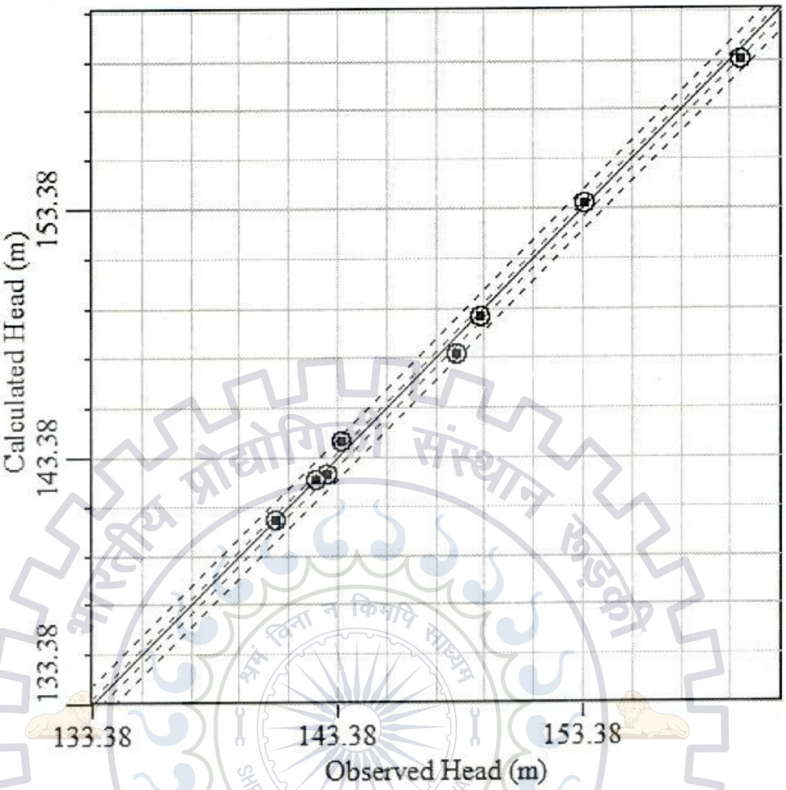


Fig. 5-1: Observed vs Calculated Head in Steady State Calibration

5.3.2 Transient State Calibration

Good estimation of hydraulic conductivities and boundary conditions of the natural system in steady state condition could help successful transient calibration. Generally, storage coefficient for confined aquifers and specific yield for unconfined aquifers are the main parameters that are altered in the transient state calibration.

There are seven observation wells within the study area (Fig. 4-4). Continuous monthly observation well data of January 2007 to December 2011 were available. Three years monthly groundwater head data ranges from January 2007 to December 2009 were taken for transient state calibration purpose. This period was divided into 36 Stress periods. Boundary conditions and stresses of the aquifer system were the input of the model in monthly basis as discussed earlier. The calculated groundwater heads were compared with the observed head at observation points. For proper consistency, Winpest subroutine of Visual MODFFLOW was run to adjust the sensitive parameter so that the objective function would become minimum providing good match of calculated heads with observed one at particular observation points.

Winpest itself checks the sensitivity of the parameter and withholds the non sensitive parameters temporarily to their previous iteration value. Sensitive parameters go on changing by certain predefined increment at each iteration to reduce objective function. The iteration process continued until the best match of simulated and observed heads were obtained.

Time series plots of observed heads at observation well points were compared with the simulated head to understand interpretation of model with actual groundwater condition based on aquifer characteristics. The parameters of aquifer were tested after calibration of model evaluating the best match with the help of goodness of fit parameters such as standard error of estimation (SEE), root mean square error (RMSE) and correlation coefficient.

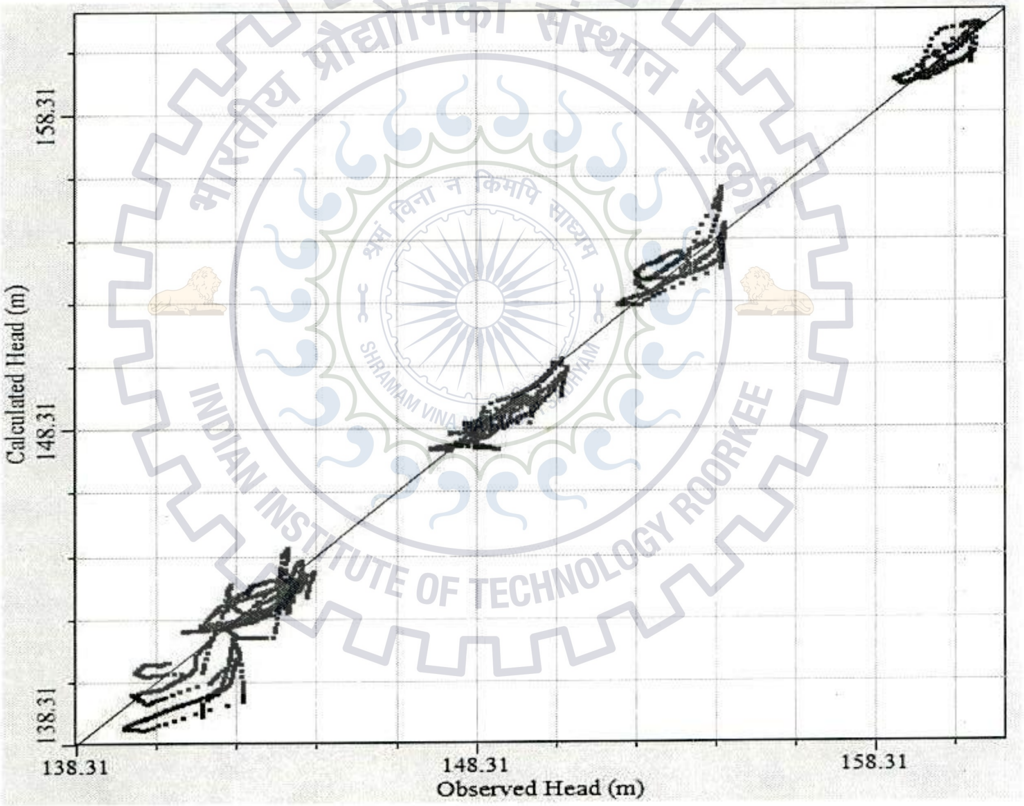


Fig. 5-2: Observed vs Simulated Groundwater Level in Calibration

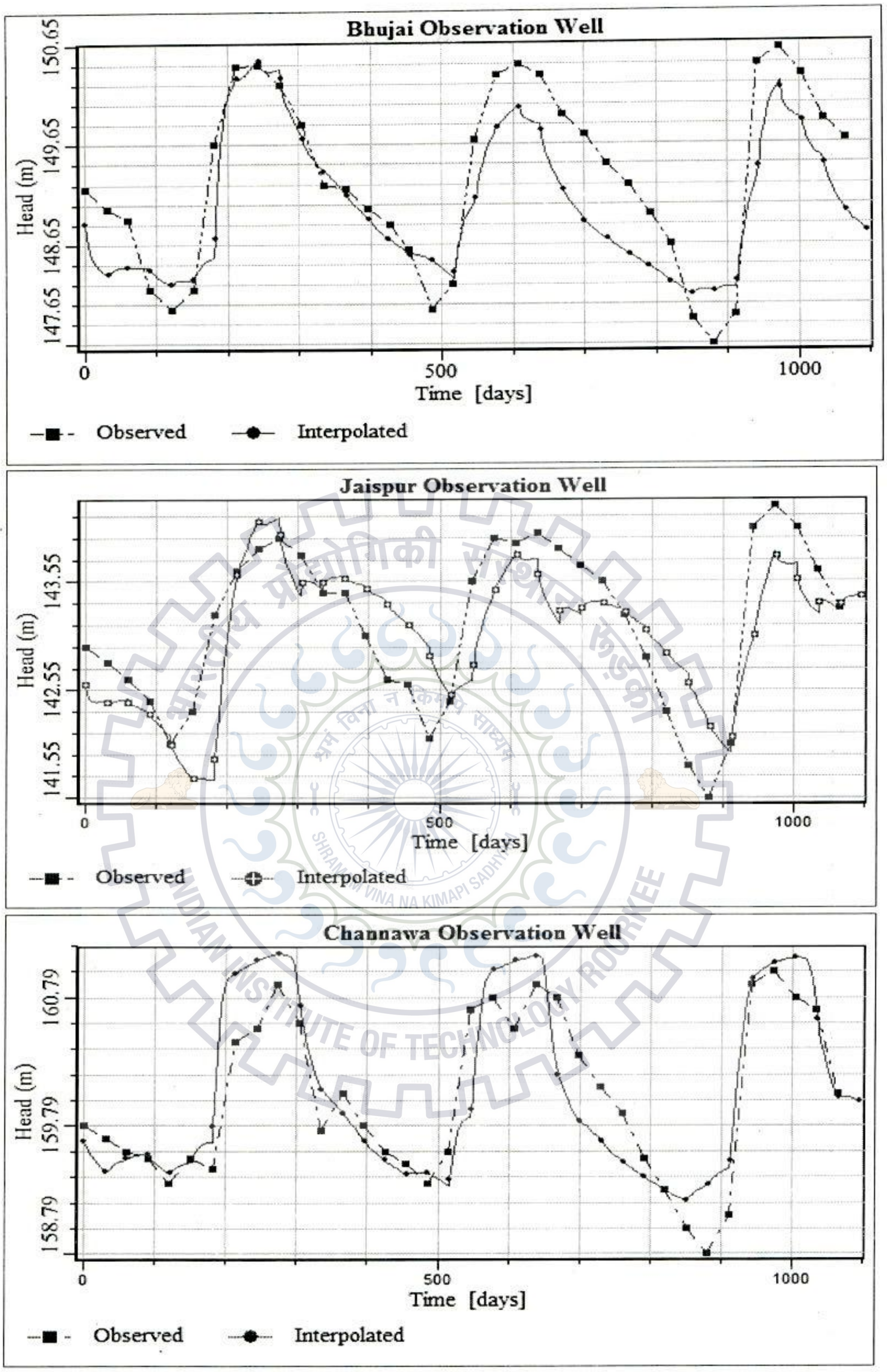


Fig. 5-3: Times Series Plot of Observation vs Simulated Head (Cali.)

A plot of observed vs simulated groundwater level of six observation well points was shown in figure no. 5-2 which had shown satisfactory match with standard error of estimation (SEE) 0.01 m, root mean square error (RMSE) 0.57 m and correlation coefficient (r) 0.996. The time series plots of observed and simulated groundwater level of each individual observation points have shown in Figures 5-3. Their goodness of fit parameters were presented in Table no.6-4.

5.4 Validation

Models are used to interpretation of actual natural system for experimentation. If model are fail to surrogate the actual system, any conclusion abstract from the output would ne erroneous and lead to imperfect decision. Therefore validation is done for all calibrated model whether the calibrated model would represent the real groundwater system in some form or will be built in future. Validation always depends on the intended use. Therefore it can be defined as the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation.

Groundwater models were validated in different methods. Rehul et al. (2011) had validated the model using data of stress periods different from calibrated data using same observation wells. But Xu et al. (2011) had validated his model using same stress period that used for calibration of model. However they used different observation wells which were not used for calibration. In this study different stress periods were used using same observation wells both in calibration and validation processes.

The groundwater observation data, other boundary conditions and stresses of December 2009 to December 2011 were used for validation purpose. The groundwater observations at observation wells of December 2009 were used as initial head and model was run using other aquifer parameters obtained from model calibration. The simulated monthly groundwater levels agree well with the observed groundwater level. A graph of observed verses simulated head (Fig. 5-4) for stress periods shows a satisfactory result with SEE 0.01 m and RMSE 0.556 m, hence indicating that the parameters were calibrated properly.

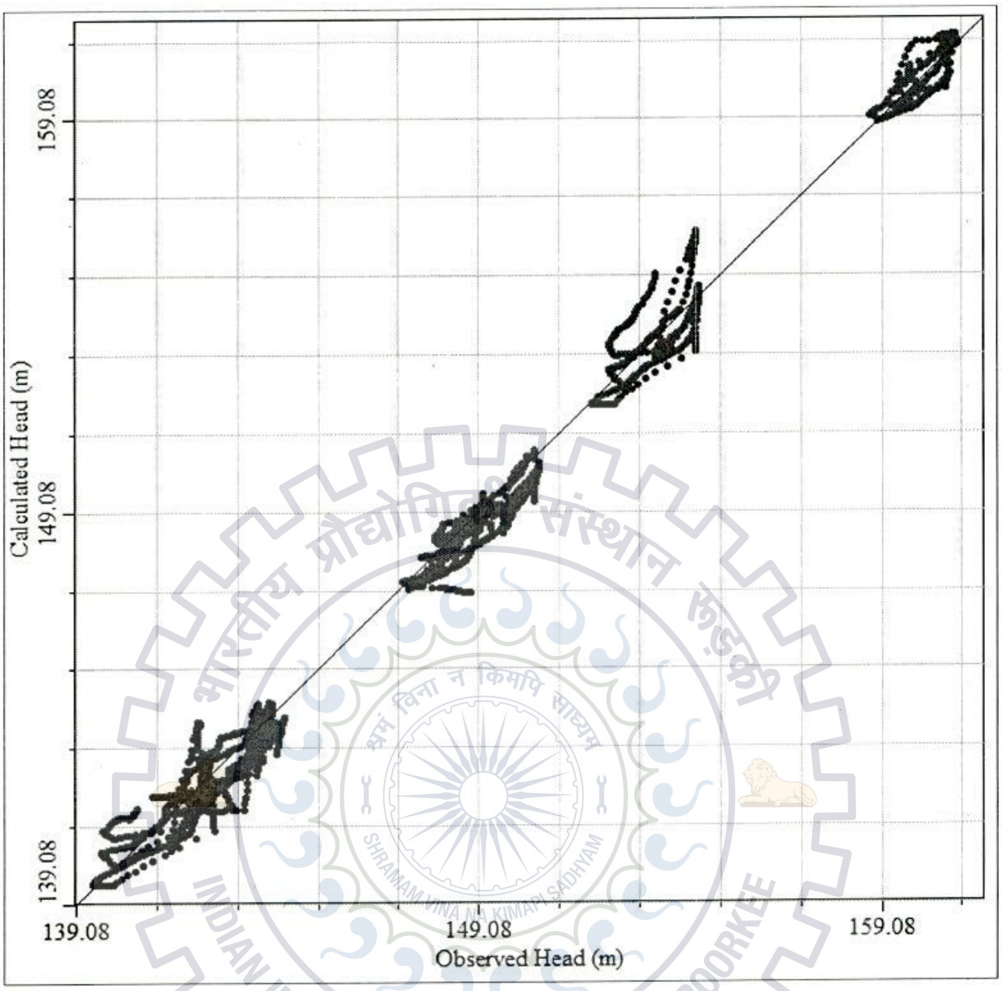
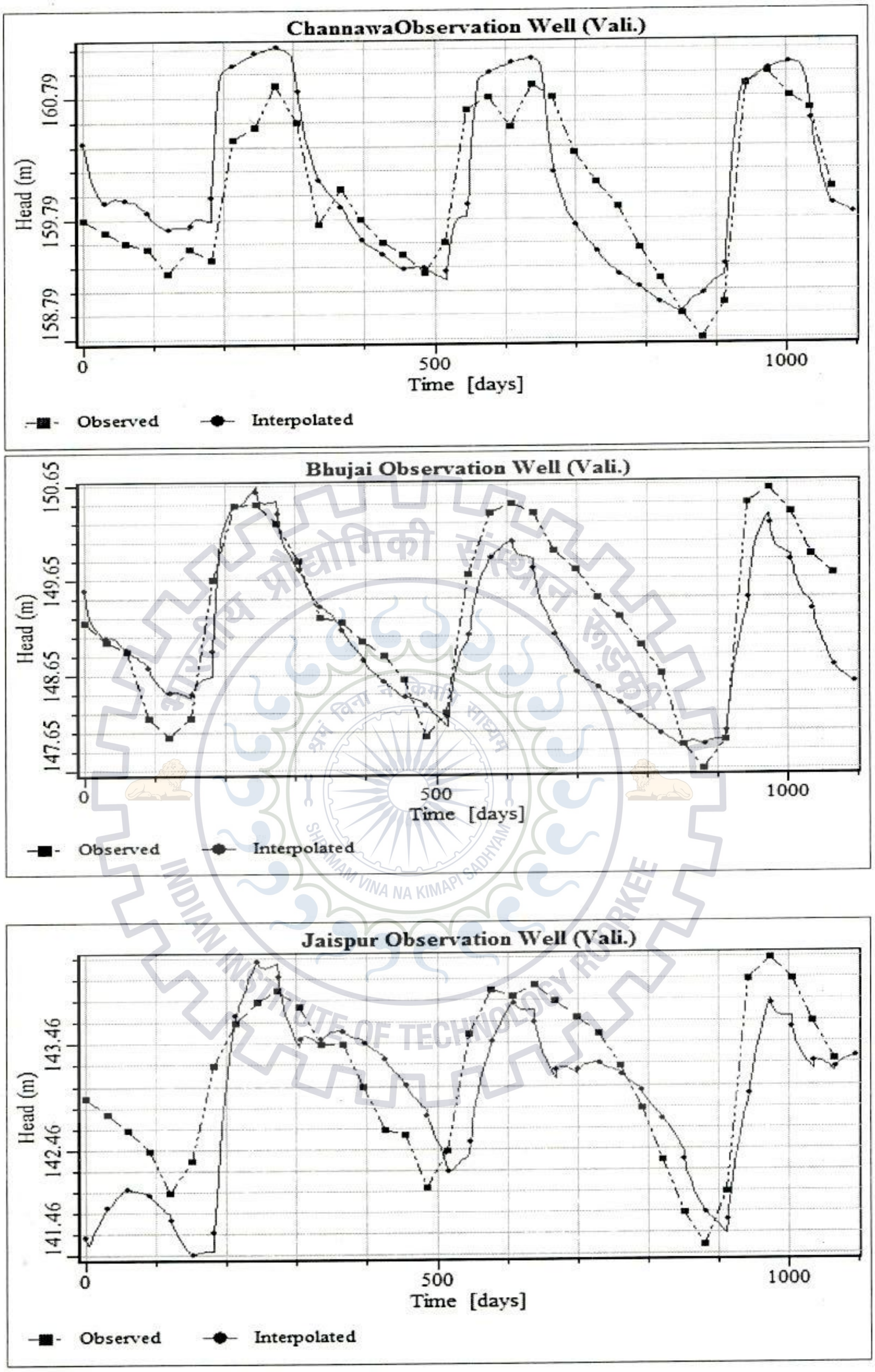


Fig. 5-4: Observed vs Simulated Head in Validation

Time series plots of measured and simulated head at Channawa observation well, Bhujai observation well and Jaispur observation well have been shown in Figure 5-5. These well are in the upper, middle and lower part of the study area respectively. This plots showed a fair match of observed and calculated head at that particular point at different stress periods. The value of performance criteria at all individual observation well has been shown in Table 6-4. These values showed that the model has been calibrated satisfactorily and can be used to predict future scenario of groundwater different boundary and stress condition of the system.



ChannawaObservation Well (Vali.)

Bhujai Observation Well (Vali.)

Jaispur Observation Well (Vali.)

Fig. 5-5: Time Series Plot of Observation vs Simulated Head (Vali.)

CHAPTER - 6: RESULT AND DISCUSSION

6.1 Gross Irrigation Requirement

Only two season crops; monsoon and non monsoon, are grown in the study area. The evapotransipration of these crops were calculated based on the reference evapotranspiration measured in Khajura (409) station of DHM/N and crop coefficient of humid region for respective crops. The major crops growing in the area has been listed in Table no. 3-1. The monthly water requirement for different crops was calculated based on the concept of Equation 4-5. Seasonal gross irrigation water requirement of the crops was estimated. Paddy, vegetable and corn are the main crops grown in monsoon season and wheat, pulse, oil seeds, potatoes and vegetables are the non monsoon crops. The monsoon net irrigation water requirement of crops from sowing to harvesting varies from 32 mm to 430 mm where as in non monsoon crops net irrigation water requirement ranges from 160 mm to 320 mm.

Seasonal weighted average depth of irrigation water requirement for whole crop period was computed from the gross irrigation requirement of all the crops grown in the command area for existing cropping pattern. The weighted average crop delta varies 650 mm in winter to 979 mm in monsoon season. Based on this weighted average delta, the irrigation water was estimated as 165 MCM in winter and 341 MCM in monsoon season. For existing cropping pattern, water requirement was also calculated based on the monthly gross crop water requirement using Equation 4-5 and annual gross irrigation water requirement was found to be 506 MCM (Table. 4-4). This value is equal to the annual GIR based on average weighted methods.

Table 6-1: Proposed Cropping Pattern

Sl.	Crop	Percentage of command area	
		Summer Crop	Winter Crop
1	Paddy	86	
2	Wheat		28
3	Maize	6	
4	Pulses +		31
5	Potato		8
6	Oilseeds Crops *		22
7	Summer Vegetables	8	
8	Winter Vegetable		6
	Sub Total	100	95
Total		195 %	
+ include : red gram (Cajanuscajan), gram, lentil, peas and latharus			
* include : mustard, linseed, sunflower, sesame			

Crops are in stressed condition in rainfed area. When the rainfed command area receives irrigation facility, the existing cropping pattern would change and cropping intensity will reach more than 200 %. Demand of irrigation water will increase. If the cropping pattern would be as a scenario as shown in the Table 6-1, the monsoon and non monsoon net water requirement will be 196.6 MCM and 380 MCM respectively (Table .6-2).

Table 6-2: Gross Irrigation Requirement for Proposed Cropping Pattern

S.N.	Month	Gross Irrigation water requirement (MCM)
1	January	48.56
2	February	63.42
3	March	60.51
4	April	4.75
5	May	8.29
6	June	181.58
7	July	50.25
8	August	13.22
9	September	4.23
10	October	61.98
11	November	55.73
12	December	24.10
	Total	576.6

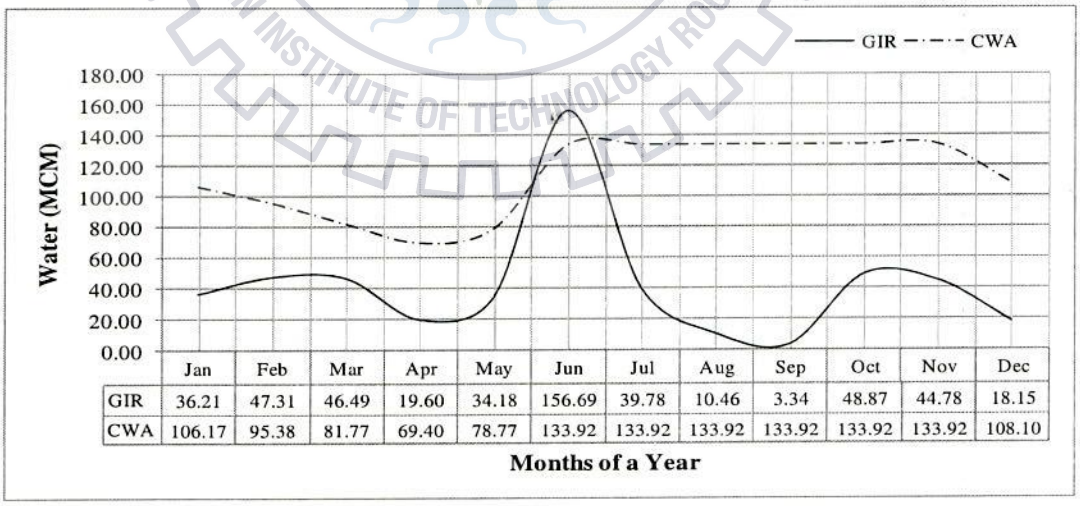
6.2 Irrigation Water Supply and Demand

Sikta irrigation project being implemented to convey irrigation water at Sikta from Rapti river in order to reduce stresses in crops. It is under construction. The main canal of the system supposed to carry 50 cumec of water. Therefore diverted water from head work to main canal is 50 cumec. Available monthly discharge of Rapti river was calculated from the daily discharge of Rapti river at Jalkumbhi a few kilometer upstream of headworks at Sikta. The monthly available discharge at the intake of Sikta irrigation system has been tabulated in Table 6-3. Diversion discharge at intake was calculated based on availability of water in the river and canal capacity. If the discharge in the river is more than the canal capacity, monthly discharge were adopted and when the river discharge after environmental provision is less than the canal capacity, available river discharge after environmental and biological need was taken as monthly available water in the canal at intake i.e. gross irrigation water available.

Table 6-3: Available Irrigation Water

S.N.	Month	Gross Irrigation water available (MCM)
1	January	95.46
2	February	76.47
3	March	71.06
4	April	56.79
5	May	68.06
6	June	129.60
7	July	133.92
8	August	133.92
9	September	129.60
10	October	133.92
11	November	129.60
12	December	97.39

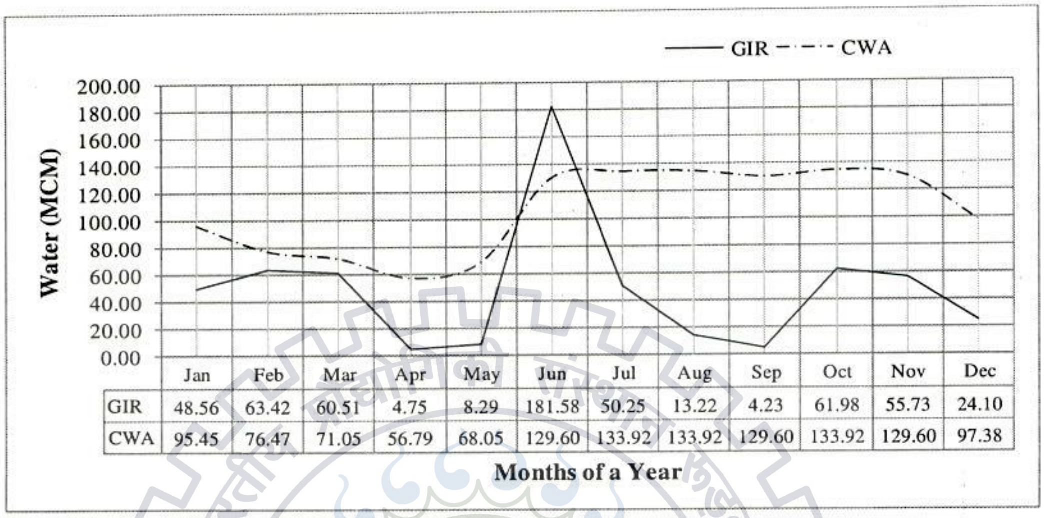
The crop water requirement is the irrigation water requirement for crops. If we compared the irrigation requirement for existing cropping pattern and water available in proposed canal system, it delineates that water scarcity is only in the month of June (Fig.6-1). The alternative source of irrigation water is necessary for that month only. There are not other surface water sources available for augmentation within or near the study area. Hence groundwater extraction is the only alternative sources of water for irrigation.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GIR	36.21	47.31	46.49	19.60	34.18	156.69	39.78	10.46	3.34	48.87	44.78	18.15
CWA	106.17	95.38	81.77	69.40	78.77	133.92	133.92	133.92	133.92	133.92	133.92	108.10

Fig. 6-1: Comparison of GIR and Canal Water Availability (CWA) for existing Cropping Pattern

For proposed cropping pattern, same scenario was seen as in the existing cropping pattern. Scarcity is only in the month of June (Fig.6-2). This month is dry and generally rice nursery raising and paddy transplanting is practiced during this month. Hence the requirement of water for crop plant is high and crucial. Groundwater extraction would be high in this month because other surface irrigation sources are not available.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GIR	48.56	63.42	60.51	4.75	8.29	181.58	50.25	13.22	4.23	61.98	55.73	24.10
CWA	95.45	76.47	71.05	56.79	68.05	129.60	133.92	133.92	129.60	133.92	129.60	97.38

Fig. 6-2: Comparison of GIR and Canal Water Availability (CWA) for Proposed Cropping Pattern

6.3 Calibration and Validation Output

In ground water model, calibration performance was checked by comparing observed vs simulated groundwater level in graph. Latter its appropriateness was evaluated by observing the goodness of fit parameters. Model calibration showed reasonably good match between the observed water table and simulated output. A scatter plot (1:1 plot) of the measured groundwater level against the calibrated head, as illustrated in Figure 5-2, has showed reasonably better fit between these two data sets. Results of the model calibration in steady state condition have showed that the calibrated values reasonably have matched with the measured ones (r = 0.99). Standard error of estimation (SEE) and Root mean square error (RMSE) of calibrated model for different well points varied from 0.016 to 0.05 m. and 0.307 to 1.117 m respectively whereas those for validation model varied from 0.016 to 0.037 m and 0.369 to 0.722 m respectively. Observation point wise SEE and RMSE are tabulated in Table no. 6-4. These values are within acceptable limits.

After successful calibration and validation of model, the hydraulic conductivities of first layer ranged from 3.57×10^{-3} m/s to 1.06×10^{-6} .m/s. This value for second layer varied from 1.83×10^{-5} m/s to 5.35×10^{-5}m/s. The third layer had the conductivity of 3.08×10^{-7} m/s. The specific yield of the first, second, third and fourth layers are 0.06, 0.3 and 0.1 respectively whereas specific storage of these layers are 0.001 m^{-1}, 0.0001m^{-1}, 0.009 m^{-1} and 0.001 m^{-1} respectively. The annual recharge for different recharge zones was found to be varied between 194 .mm to 380 mm providing an average annual recharge of 217 mm.

Table 6-4: Comparision of Model Evaluation Parameters

S.N.	Location	SEE (m)		RMSE (m)	
		Calibration	Validation	Calibration	Validation
1	Bhujai	0.02	0.023	0.47	0.515
2	Channawa	0.016	0.019	0.307	0.369
3	Gaughat	0.05	0.037	1.117	0.722
4	Jaispur	0.024	0.027	0.47	0.546
5	Kalsangaun	0.016	0.018	0.324	0.539
6	Piprahawa	0.027	0.036	0.537	0.693
7	Sikhanpurwa	0.017	0.016	0.456	0.49

6.4 Ground Water Availability

In existing situation, water table fluctuation study showed that the water table remains within 2 m below the ground surface in around 24000 ha of study area during peak monsoon months (Fig. 6-3). Just after the monsoon period, the water table starts depleting and reached up to 5.2 m below the ground surface. About 6 percent of the area has water table within 2 m of depth in winter. Therefore this six percent area is in waterlogged condition in non monsoon season too.

In June, maximum irrigation water is required and groundwater withdrawal is high so that the ground water table falls below 2.5 to 5.2 m from the surface. In the month of May and June, the ground water table remains at maximum depth.

Water table declination is not significant in northern part of the area. The graph of observed water table against the year 2002 to 2011 AD of particular month has showed the scenario of stable ground water table in prevailing condition (Fig. 6-4). The observation well in the northern part of the study area shows that the water table level in non monsoon season is stable. However the groundwater level in monsoon season showed an increasing trend.

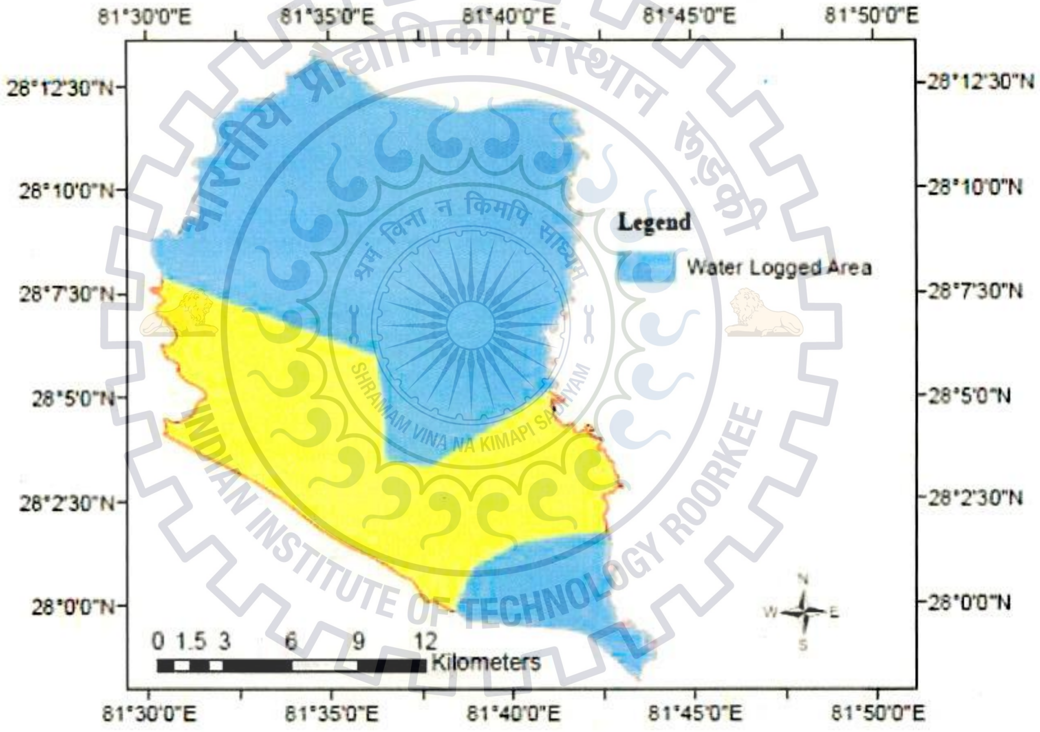


Fig. 6-3: Waterlogged Area in Monsoon in Existing Condition

Present groundwater withdrawal from unconfined aquifer was maximum in southern part of the study area (Fig. 4-3). An observation well, Gaughat, in the south west part of the area (Fig. 4-4) showed that ground water depth from the surface is declining with year. This declination is more pronounce in non monsoon season than in monsoon season (Fig. 6-5). If this scenario exists or increases, the ground water table will decrease alarmingly in this area.

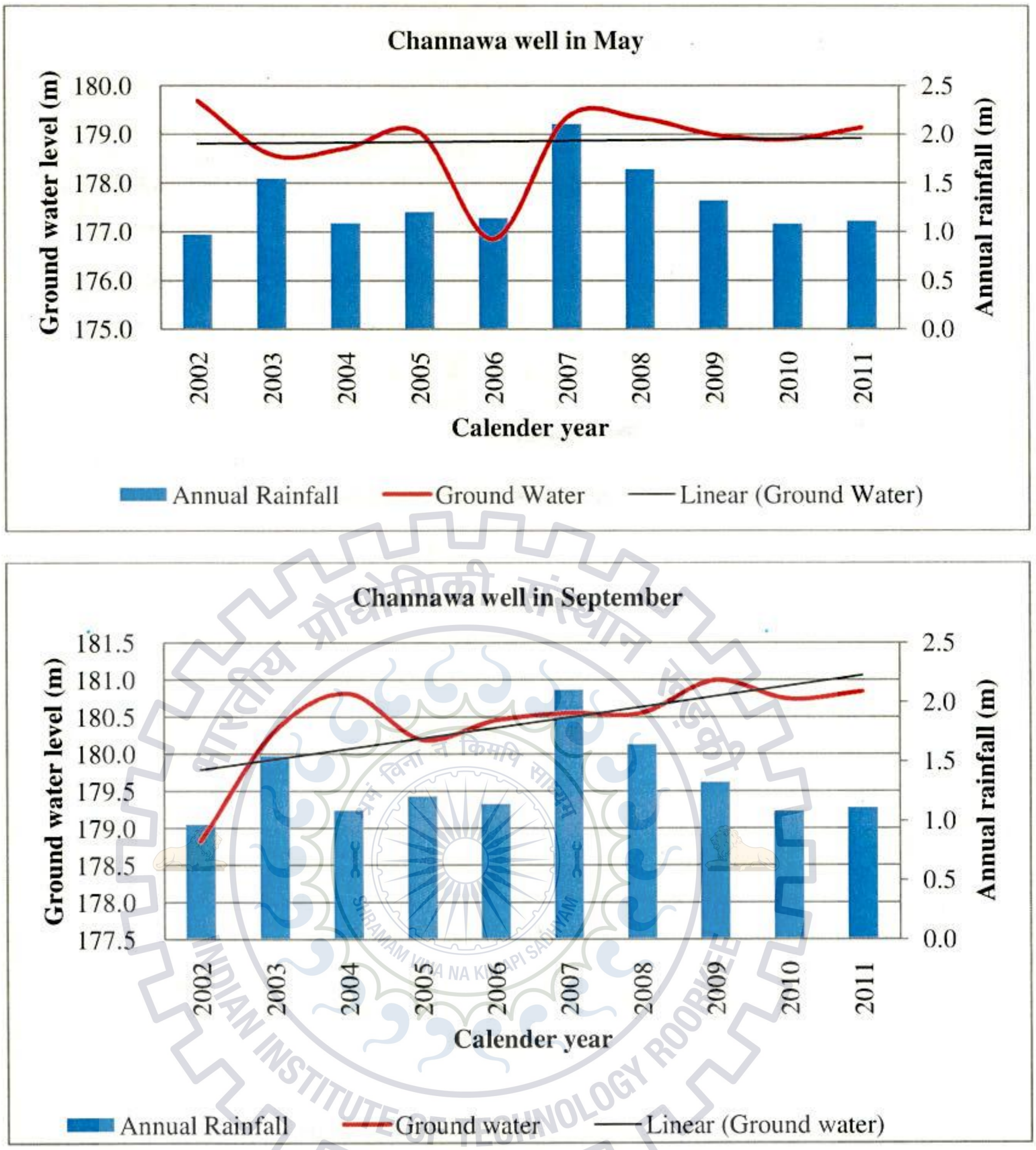


Fig. 6-4: Groundwater Scenario at Channawa Observation Well in Monsoon and Non Monsoon Season

The unconfined aquifer thickness varies from east to west in the study area. The average thickness of unconfined aquifer was 18 m in the east whereas in the west it had thickness of 23 m. This thickness includes the top layer and second layer of stratification i.e. alluvial and sandy layer. The thickness of second layer (aquifer) varies from north to south. Aquifer thickness in the north is 18 m whereas 8 m in the south. Aquifer thickness is more in the northern part where ground water table has increasing trend. However, ground water level in the northern part of the study area, where aquifer thickness is less, is decreasing due to high groundwater exploitation.

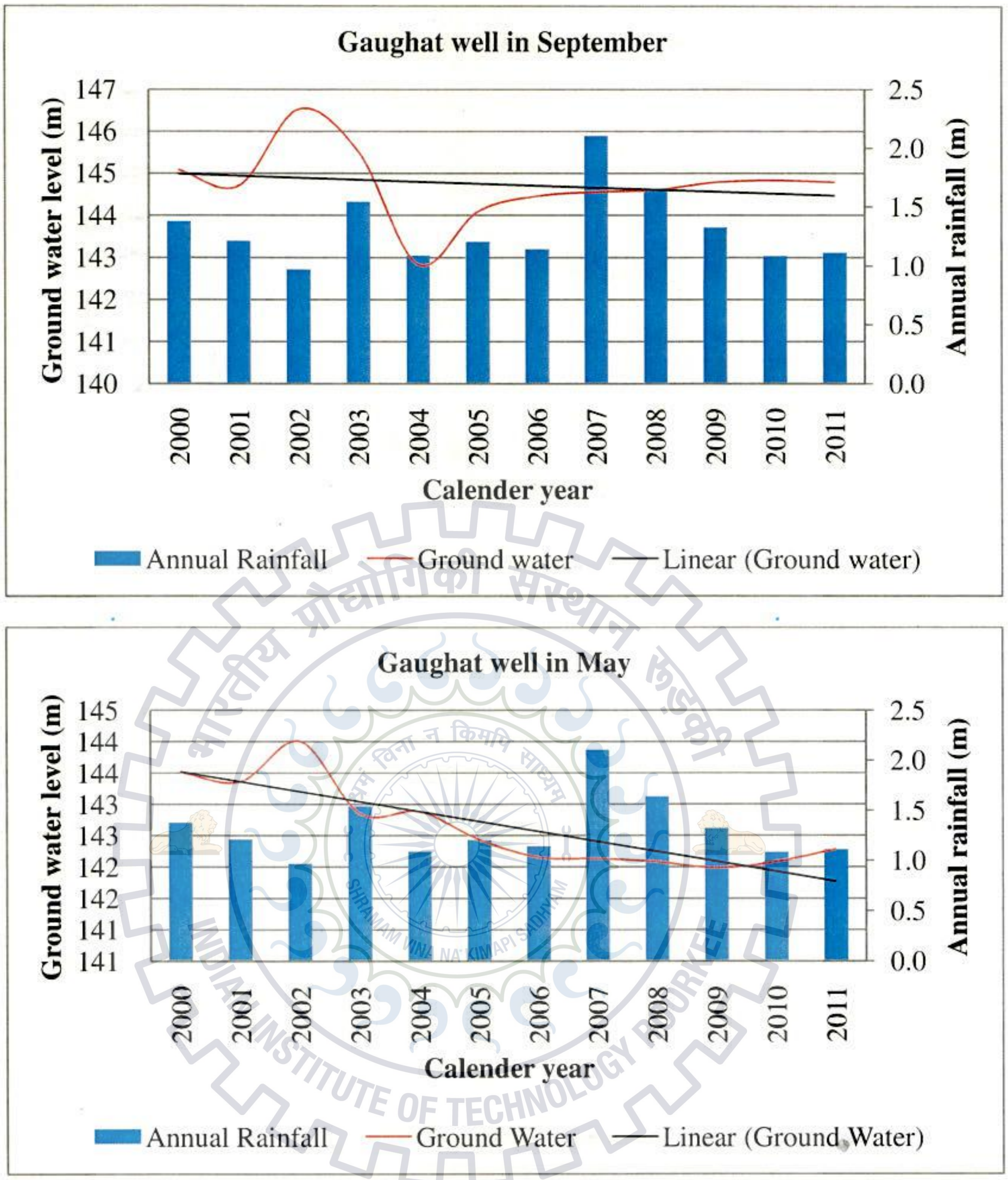


Fig. 6-5: Groundwater Scenario at Gaughat Observation Well in Monsoon and Non monsoon Season

It is obvious that groundwater banking in this area is less due to thin aquifer thickness. Therefore increase in small amount of groundwater extraction will decrease the ground water table considerably.

The model had provided total annual recharge of groundwater from precipitation as 14.7 MCM in prevailing situation. Recharge per annum from river was 0.2 MCM. Annual extraction of ground water was 7.4 MCM. Return flow to the river was 1.6 MCM.

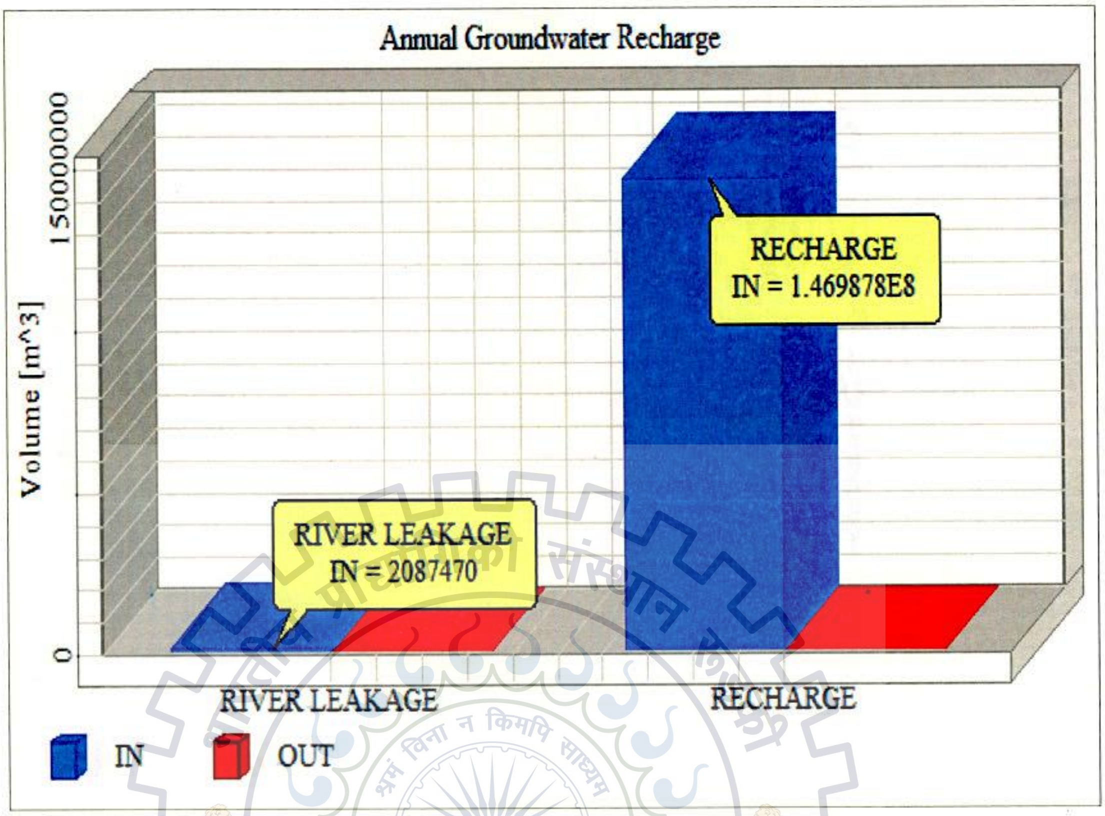


Fig. 6-6: Annual Ground Water Recharge

6.5 Sensitivity of Model Parameters

Winpest package of Visual MODFLOW 4.2 analyses the sensitivity of model parameter. During parameter estimation, it checks the sensitivity of parameter and holds insensitive parameter at their initial value. Sensitive parameters are increased or decreased by some predetermined value in each iteration so that new parameters are obtained for new objective function which is to be minimized.

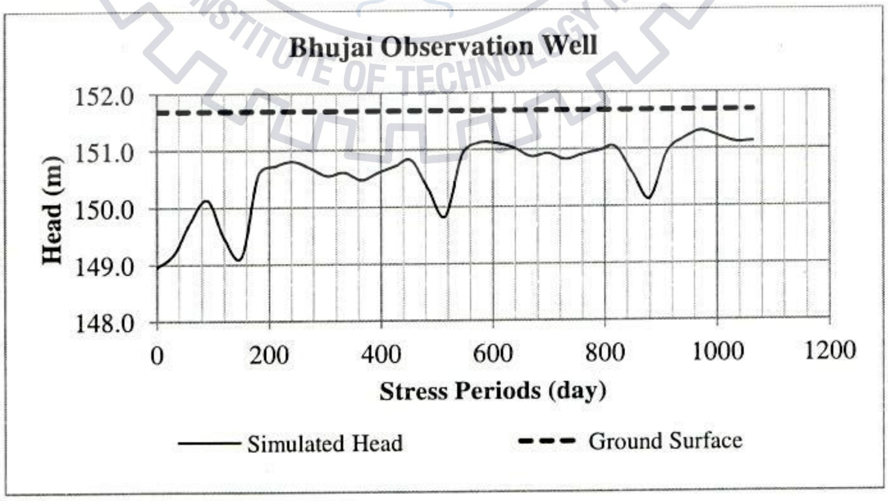
The record of sensitivity of Pest had shown that hydraulic conductivities and recharge were most sensitive parameters of the aquifers at almost all sites of the command area. The model was comparatively less sensitive to specific storage and specific yield but river bed conductivity did not show any visible effect except at nearby area to the river.

6.6 Scenario Analysis

From the fact that discussed earlier, it is obvious that the 64 % of area is in water logged condition in peak monsoon season in prevailing condition of aquifer. This level would further rise after irrigation water application. Groundwater recharge due to irrigation water varies from 60- 67 % of irrigation water (Scot et al. 2005). Therefore it would be reasonable to adopt the recharge due to application of irrigation water in the study area after the commencement of ongoing Sikta irrigation system as 65% of applied irrigation water.

In the calibrated model of the study area, the above recharge boundary condition was applied to get probable groundwater scenario for three years. The model outputs showed that the ground water level remains within 2.0.m below the ground surface in entire area in peak monsoon period. This fact is alarming the water logging condition that would be there in monsoon season after the application of irrigation water.

In winter season, ground water table would decrease up to the depth of 2.5 m from ground surface (Fig. 6-7). Predicting scenario showed that the water table remains within 2 m in 64 % of the area upto one year. After three years of irrigation water application, whole area would be in waterlogged situation in monsoon. However the water table would rise to reach within root zone depth for 85% percent of area in winter within 3 years. Only 5800 ha of land remain with water table below 2 m. But the water table rising scenario warns the whole area would be in water logged condition within 4 to 5 years of irrigation water application.



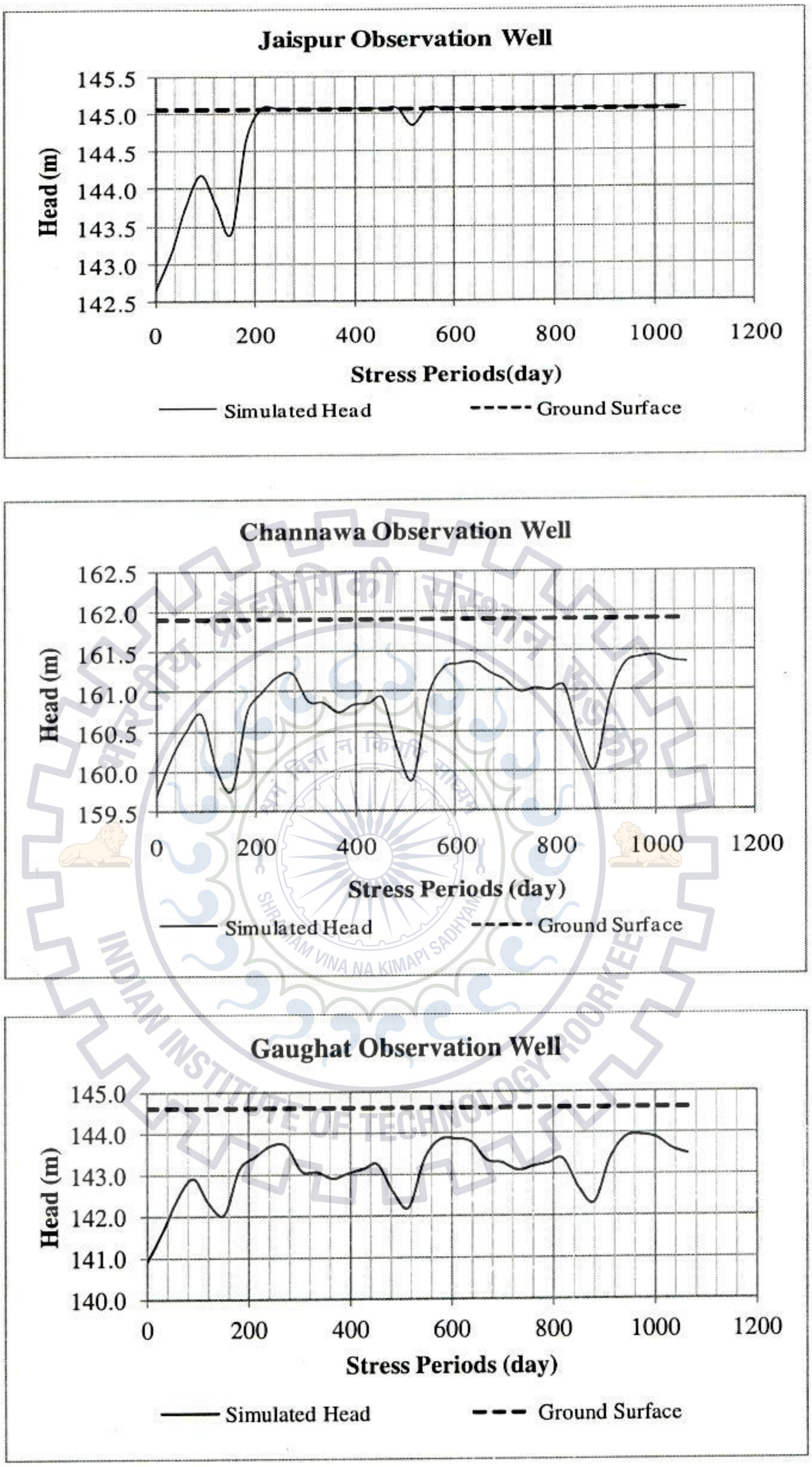


Fig. 6-7: Time Series Plot of Observed vs Simulated Head After Irrigation

Annual availability of groundwater after irrigation water application provided by model would be 42.58 MCM whereas this value was 28.51 MCM in existing situation of stresses (Fig. 6-8). June is the driest year of the month and canal supply is insufficient. The supplement of deficit amount for irrigation regarding proposed cropping pattern in June was 52.0 MCM (Fig. 6-2) and should be balanced from reliable groundwater. But the available water during this month in unconfined aquifer would be almost 27.22 MCM. This quantity is insufficient to meet the irrigation water demand in the driest month of the year.

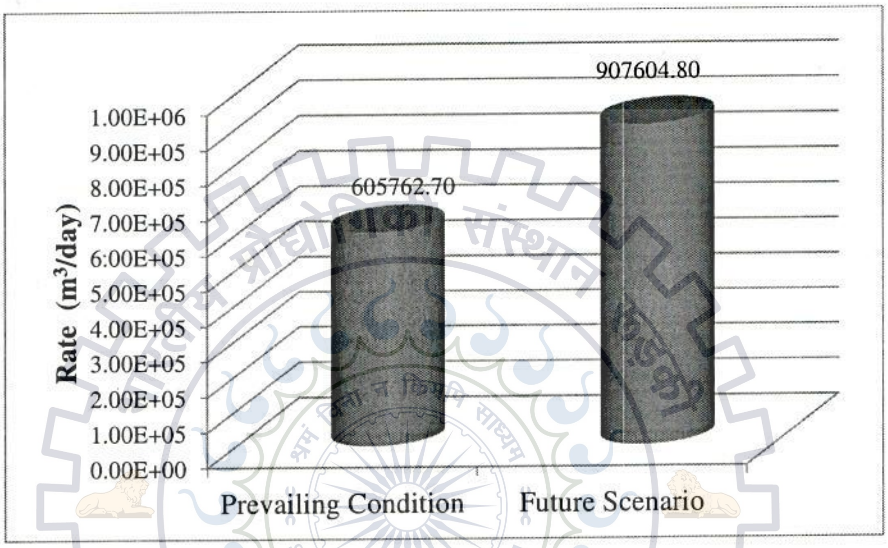


Fig. 6-8: Available Groundwater in the Aquifer in June

CHAPTER - 7: CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The study area is part of ongoing Sikta irrigation system. At present 90 % of the area has totally relied on rain for irrigation. Rainfall cannot fulfill the entire evapotraspiration requirement. So the crops are always in stressed condition. Around 10% of the area has irrigated using groundwater in southern part of the area where water table is declining because of over exploitation of ground water whereas the ground water table in north east part of the study area is rising upto root zone of crops. The salient features of the study area is summerised as below

i) Groundwater fluctuation study revealed the existence of ground water table within 2 m below the ground surface in more than 64 % of area in monsoon season whereas the same declined up to 5.2 m below the surface level in non monsoon season in existing stress and boundary condition. Therefore there is enough scope of ground water development.

ii) A numerical quasi three dimensional groundwater simulation model was developed using visual MODFLOW 4.2 for realistic interpretation of groundwater flow and detailed investigation of hydrological consequences. Steady state and transient state of the developed model was used to detect the hydraulic head and storage of change in the aquifer due to transient recharge and withdrawal stresses. The model was calibrated based on the boundary condition and stresses and validated.

iii) The evaluation of calibration and validation was performed by means of plots of measured and simulated groundwater level as well as statistical goodness of fit parameters like standard error of estimation (SEE) and root mean square error (RMSE). SEE and RMSE for calibrated model varied from 0.016 to 0.05 m and 0.307 to 1.117 m respectively. Hydraulic conductivity, specific yield and specific storage of the layers were $3.57x10^{-3}$ to $3.08x10^{-7}$m/s, 0.06 to 0.3 , 0.009 to 0.001.m^{-1} respectively. Annual recharge had spatial and temporal variation in different zone. It varied from 194 mm per annum to 380 mm per annum (Average 217 mm).

iv) Ground water recharge was most sensitive parameter to model output groundwater flow flowed by conductivities of first and second layer (aquifer) almost all sites of the study area. The model outputs were comparatively less sensitive to specific storage and specific yield. The river bed conductivity has no effect to the sites except the sites nearby rivers.

v) After the application of canal water to the study area, most of the (85 %) area would be in waterlogged condition within three years of irrigation water application. Only 15 % of land in south west part of the area has water table upto 2.5 m below the ground surface in monsoon. However the increasing scenario of groundwater table in all observation wells predicts that the entire area would be in waterlogged condition after four to five years of irrigation water application.

vi) In the month of June, canal water is insufficient to meet the crop water requirement. The deficit would be 52 MCM. This requirement could not meet from unconfined aquifer. So extraction of groundwater from semi confined and deep aquifer at its driest condition without exploiting the environment of aquifer is necessary.

7.2 Recommendation

When groundwater is pumped from the top unconfined aquifer for the irrigation water supplement, it is faced immense stress due to non conventional use of water and scheduling. The thickness of unconfined aquifer is comparatively less and starts drying just after the non monsoon stress period (November) and the groundwater table reaches maximum (5.2 m from ground level) in first stress period of monsoon season (June). During monsoon season the groundwater table starts building up due to recharge from rainfall and remains within 2.5 to 4.5 m existing aquifer stress.

The ground water level in south and western part of the study area is declining with year. Aquifer cannot cope with the stress of present withdrawal of ground water for this area. Therefore, either groundwater extraction for irrigation should be done in northern part of the aquifer where the aquifer thickness is relatively more and convey to fulfill the demand for irrigation where ground water could not able to meet the demand or deep tube wells should be installed upto lower semi confined and deep aquifers. Hence combined simulation –optimization modeling is necessary to find out the maximum permissible pumpage from the ground water reservoir.

Irrigation water will be applied to the crop field after the completion of Sikta irrigation system. The calibrated groundwater model was run using recharge boundary condition after irrigation. It showed that the 85 % area had water table within the crop root zone depth in monsoon period after three years of continue irrigation whereas it reaches up to 2.5.m from ground level (Fig. 6-7). Water level within the root zone is waterlogged situation which does not provide conducive environment in root zone depth thus reducing crop growth consequently yield.

Northern part of the study area is already in waterlogged condition in monsoon season and southern part has comparatively thin aquifer. These two conditions would be favorable for high water table after the application of surface irrigation because high amount of recharge from irrigation water could not be accommodate by less volume of ground water reservoir. However, reliable strategies to combat the upcoming disaster should be adopted. The following strategy should adopt for preventing the water logging, increase in water storage in aquifer and integrated water resources management within the aquifer level.

i) Maximum groundwater ground water extraction should be undertaken in non monsoon period so that ample space would be available in aquifer for storing recharge water in monsoon season.

ii) A conjunctive use water management for irrigation should be practiced to reduce the water table level below the root zone depth to get rid of water logging problem after the irrigation water application begin.

iii) Sowing time of crops which are sown in June should be shifted to July with of high yield variety seeds which has July as sowing or transplanting time.

iv) Combined simulation optimisation modelling study has to be under taken to find out the maximum possible pumpage.

v) Water resource planning and management of canal command area should be done to reduce the future risk after application of irrigation water.

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Appendices

Appendix 1: Litholog Points

S.N.	Place	X coordinate in degree	Y coordinate in degree	Remarks
1	Agaon	81.549	28.106	
2	Kgaon	81.539	28.085	
3	Kgaon	81.547	28.082	
4	Kgaon	81.544	28.079	
5	Lgaon	81.522	28.100	
6	Agaon	81.545	28.096	
7	Lgaun	81.521	28.096	
8	Lgaun	81.531	28.100	
9	Gaughat	81.511	28.119	
10	Lgaun	81.517	28.122	
11	Agaun	81.550	28.100	
12	Agaun	81.539	28.085	
13	Gaughat	81.517	28.113	
14	Gaughat	81.515	28.108	
15	A gaun	81.543	28.101	
16	Lgaon	81.549	28.090	
17	Gaughat	81.510	28.115	
18	Gaughat	81.533	28.081	
19	Gaughat	81.526	28.106	
20	Bhawaniyapur	81.634	28.030	
21	Babugaun	81.621	28.036	
22	Kariyatipurwa	81.628	28.035	
23	Balegaun	81.619	28.026	
24	Hirminiya	81.642	28.012	
25	Loharpurawa	81.665	28.017	
26	Dittapur	81.683	28.016	
27	Dittapur	81.676	28.015	
28	Dittapur	81.682	28.010	
29	Udaya pur	81.682	28.010	

30	Surya pur	81.672	28.022	
31	Parsanpur	81.644	28.040	
32	Lodhegaun	81.642	28.034	
33	Lalpurwa	81.649	28.037	
34	Piparhawa	81.621	28.013	
35	Piparhawa	81.622	28.008	
36	Tankpaseri	81.609	28.024	
37	Bhawaniya pur	81.634	28.030	
38	Babugaun	81.621	28.036	
39	Kariyatpurwa	81.628	28.035	
40	Balegaun	81.619	28.026	
41	Puraini	81.628	28.062	
42	Puraini	81.654	28.066	
43	Puraina	81.647	28.050	
44	Birta	81.663	28.051	
45	Jodha purwa	81.679	28.056	
46	Kingaranpurwa	81.673	28.055	
47	Padampur	81.705	28.076	
48	Sahapurwa	81.688	28.063	
49	Futaha	81.657	28.071	
50	Lohinpurawa	81.677	28.068	
51	Molahapurwa	81.683	28.067	
52	Aamarawa	81.675	28.075	
53	Banghusra	81.661	28.086	
54	Kanthipur	81.670	28.079	
55	Phutaha	81.661	28.062	
56	Kataliya	81.468	28.068	
57	Gaver	81.681	28.268	
58	Gaver	81.679	28.274	
59	Baniyabhar	81.690	28.238	
60	Karelekhola	81.654	28.284	

Appendix 2: Average Monthly Precipitation in mm

Khajura (409)   Lat. 28^0 6" N   Long. 81^{0}34" E

Year	Jan.	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	0	53.1	37.1	16.8	65	139.1	957.4	554.9	261.7	17.7	0	1
2008	0	0	0	21.7	47.8	364.5	458.4	417.7	301.1	30.9	0	0
2009	0	6.2	0	0	73.9	70.7	276.2	476.4	176.5	241.4	2	0
2010	1	21	0	0	40.1	86.3	459.1	323.1	123.2	7	21	0
2011	2.3	24.6	23.4	5.2	126	208.2	266.1	248.2	207.7	0	0	0

Baijapur (414)   Lat. 28^{0}03"N   Long. 81^{0}54"E

Year	Jan.	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	0	41.2	32.3	9.4	36.1	190.1	1022	602.8	306.7	9.45	0	0.5
2008	0	0	0	12.5	23.6	224.7	237.5	108.6	36.1	0	0	0
2009	0	0	0	5.3	46.3	68.8	380.9	707.1	161.2	73.6	0	0
2010	12	81.3	0	0	25	111.8	222.9	289.4	291.3	201.1	0	0
2011	0	0	0	33.8	74.3	211.8	664.2	402.6	0	0	0	0

Sikta (419)   Lat. 28^0 2" N   Long. 81^{0}47" E

Year	Jan.	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	0	63.4	87.8	44.6	134	165.5	416.4	400.3	305.3	36.6	0	0
2008	0	0	0	38.8	0	293.5	330.4	464.5	173	67.5	0	0
2009	0	0	0	0	54	131	310.2	476.5	203.4	78.7	0	0
2010	0	0	0	0	77.1	90	434.4	329.3	271.1	32	0	0
2011	3.6	13.4	0	0	144	152.4	532.6	205	216	0	0	0

Source : DHM/N

Appendix 3: Monthly Measured Reference ETo

Station: Khajura Latitude: 28^{0} 06” N

Index No.: 409 Longitude: 81^{0} 34”E

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eto(mm/day)	2.00	3.03	4.65	6.61	7.72	7.09	5.09	4.92	4.50	3.97	2.75	1.89

Source : DHM/N