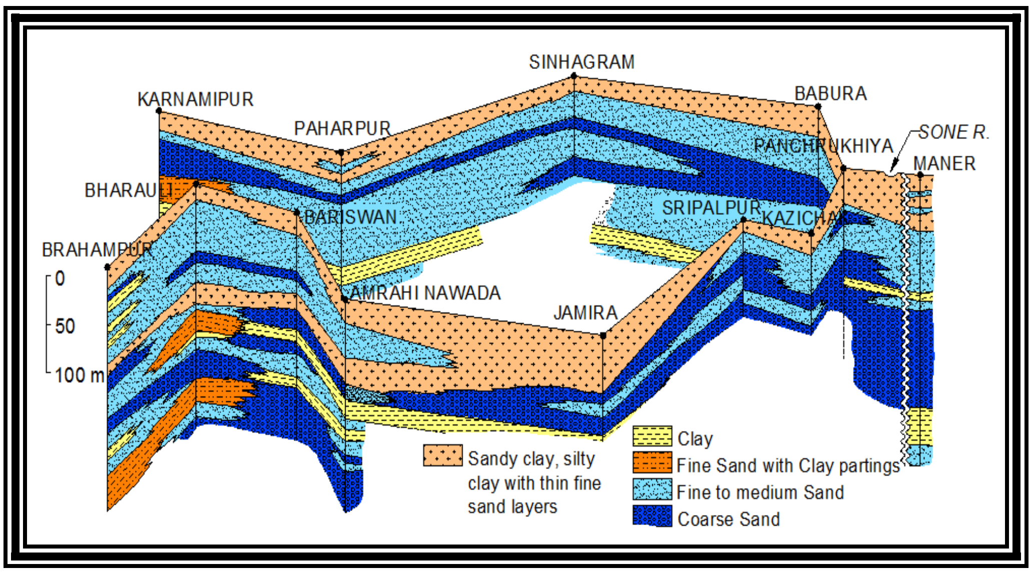
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION

Report on

Ground Water Flow Modelling in parts of Middle Ganga Plain, Bihar

(Bhojpur, Buxar, Rohtas & Kaimur ditrict)



Central Ground Water Board

Mid Eastern Region, Patna

November 2019

Ground Water Flow Modelling in parts of Middle Ganga Plain, Bihar

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CONTENTS

	List of Annexure	Page No

CHAPTER - 1

INTRODUCTION

The population growth, urbanization and effects of global climate change, such as, longer spells of summer and erratic or failing monsoon; have resulted in increasing urban and agricultural water demands. This, in turn, has stressed aquifer systems where groundwater is the dominant source of water supply (Taniguchi et al. 2009, Alam and Umar, 2013). However, Groundwater crisis is not only the result of natural factors, such as, climate change leading to scanty or erratic rainfall; but also due to human action.

Groundwater models are mathematical and digital tools of analyzing and predicting the behaviour of aquifer systems on local and regional scale, under varying geological environments (Balasubramanian, 2001). Models can be used in an interpretative sense to gain insight into the controlling parameters in a site-specific setting or a framework for assembling and organizing field data and formulations of ideas about system dynamics. Models are used to help in establishing locations and characteristics of aquifer boundaries and assess the quantity of water within the system and the amount of recharge to the aquifer (Anderson and Woessner, 2002).

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. Groundwater models, however, even as approximation, are a useful investigation tool for a number of applications. Modelling plays an extremely important role in the management of hydrologic and groundwater systems (www.angelfire.com/cpkumar).

Mathematical models provide a quantitative framework for analysing data from monitoring and assess quantitatively responses of the groundwater systems subjected to external stresses. Over the last four decades there has been a continuous improvement in the development of numerical groundwater models (Mohan, 2001).

Numerical modelling employs approximate methods to solve the partial differential equation (PDE), which describe the flow in porous medium. The emphasis is not given on obtaining an exact solution rather a reasonable approximate solution is preferred. A computer programme or code solves a set of algebraic equations generated by approximating the partial differential equations that forms the mathematical models. The hydraulic head is obtained from the solution of three dimensional groundwater flow equation through MODFLOW software (McDonald and Harbaugh, 1988).

Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, may be described by the partial-differential equation.

$$\frac{d}{dx}\left[K_{xx}\frac{dh}{dx}\right]+\frac{d}{dy}\left[K_{yy}\frac{dh}{dy}\right]+\frac{d}{dz}\left[K_{zz}\frac{dh}{dz}\right]-W=S_s\frac{dh}{dt}$$

Where,

K_{xx}, K_{yy}, K_{zz} are components of the hydraulic conductivity tensor, h is potentiometric head, W is source or sink term, S_s is specific storage, and t is time.

The finite-difference numerical formulation of above PDE was solved for each grid using computer code Visual MODFLOW (McDonald and Harbaugh, 1988) to simulate the groundwater flow in the study area.

CHAPTER- 2

SCOPE AND OBJECTIVE

Earlier works carried out in the area are mainly reappraisal surveys and exploratory drilling. The objective was to decipher aquifer geometry, its characteristics and extensions. However, all these studies were carried out with specific aims and were restricted within their scope.

Population growth, rapid urbanisation and increasing agricultural water demands have stressed the aquifer systems. The increasing water needs require better understanding of hydrogeological set up and future scenario, so that sustainability of resources could be established. Hence, the present study is taken up. The objective of the study is given below.

i) to develop a Groundwater Flow model of the area

ii) to have a better understanding of the hydrogeological set up of area

iii) to study the impact of agricultural draft on groundwater regime

CHAPTER- 3

HYDROGEOLOGICAL FRAMEWORK

3.1 LOCATION / AREA DESCRIPTION

Present study area is a part of "Middle Ganga Plain" representing the Bhojpur, Buxar, Rohtas & Kaimur district of Bihar, bounded by River Ganga, Son and Karmanasa on its northern, eastern and south western side. It lies between latitude 14°30' and 25°46 ' N and longitude 83°19' and 84°51' E and covers an area of about 11470 Sq.km is occupied by Newer Alluvium and Older Alluvium, which are underlain by Vindhyan formations (Fig 3.1).

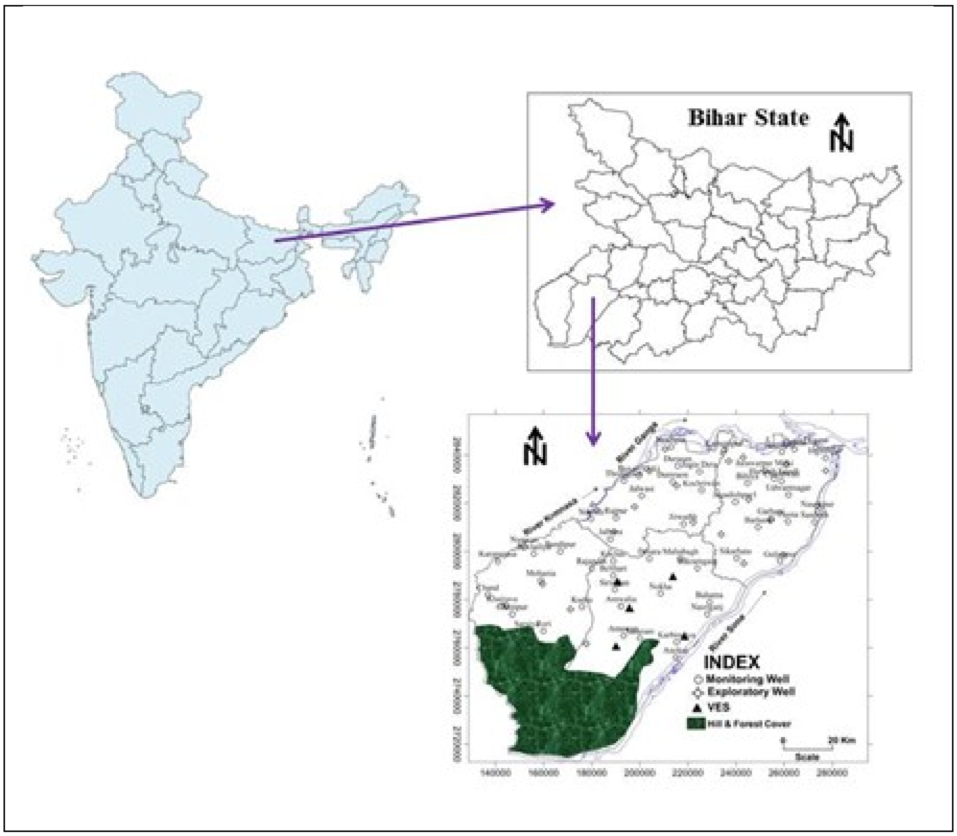

Fig. 3.1: Location map of the study area

3.2 GEOLOGY

Geologically the area is occupied by the principal hard rock units of Vindhyan system comprising limestone, shale, sandstone and unconsolidated alluvial sediments of Quaternary age. The Vindhyans crop out in the southern and southweastern parts by moderately prominent hillocks and flat topped plateaus and often showing conspicuous scarp faces to the plains of the north which is underlain by alluvium of varying thickness. The alluvial basin thickness towards the north almost uniformly. The area to the east and south east of the Kaimur hills forms a second strip of alluvium between the Vindhyans and the Sone River. The Quaternary alluvium is restricted to areas near Ganga river in north, Sone river in east and Karmnasa in west. A generalized geological succession as per Geological Survey of India is as follows:

Group	Members		Lithology
Quaternary			Clay, silt, sand gravels and boulder-alluvium
……………………Unconformity………………………………			
Vindhyan Upper	Kaimur Series	Upper	Dhandraulquartzite scarp sandstone.
		Lower	Bijaigarh shales (Carbonaceous & Pyrites.
Lower	Semri Series	Rohtas Stage	Rohtas limestone alternating with grey and redish shale, Porcellanite bed and glauconite sandstone/quartzite.
		Khenjua Stage	Fawn limestone,oliveshale,Porcellanited bed, Kajarhat limestone, interbedded with calcareous shale.
		Porcella nite Stage	Porcellanite beds.

Older Alluvium

The older alluvium (called Bhangar in the Ganges valley) forms slightly elevated terraces, generally above the flood level. This is dark coloured and in general are rich in concretion and nodules of impure calcium carbonate known as kankar. These kankars are of different shape and sizes.

Newer alluvium

The newer alluvium is light coloured and poor in calcareous matter. It contains lenticular beds of sand and gravel and peat beds.

3.3 TOPOGRAPHICAL DETAILS

Topographically, as well as geographically, study area has three regions, namely

i. Hilly terrain of Kaimur Plateau: rises generally upto 300 to 600 m above the plains trend roughly east-west in the southern part and gradually assumes a N-S trend in the eastern portion

ii. Sub-hilly tract on the south of Grand Trunk road to the foot of the Plateau.

iii. the extensive low lying alluvial plain: upto Ganga river.

General elevation of the alluvial plain ranges from 108 m amsl in south to 55 m amsl in north. The gradient is generally of a gentle nature, the master slope of the ground being towards the narth i.e. towards the Ganga.

3.4 HYDROGEOLOGY

3.4.1 Aquifer Geometry

The panel diagram indicates that the top clay zone is not more clay, but also contains lenses of coarse sands at close aerial distances (Fig 3.2). The sands, gravels and pebbles are pervious and constitute potential water bearing formation or aquifer whereas clay is impervious and non-water bearing formation. In the study area top clay is mixed with kankar and fine sands, and also contains thick and elongated lenses of coarse sands at various depths, which impart a semi-pervious nature to the clay bed which is better termed as aquitard. This is, therefore, has hydraulic continuity with the sands, gravels and pebbles occurring underneath. The ***Lithological data of 20 boreholes*** and ***5 VES*** were utilized for creation of panel diagram of aquifer on regional scale down to the depth of 100 m bgl.

3.4.2 Ground water level variation

Groundwater level in an unconfined aquifer is much sensitive to fluctuation. Thus error may introduce because of pumping influence in nearby area, river stage and also because of groundwater movements. The data collected from observation wells of the study area were used in preparation of depth to water level maps and water table contour maps.

A network of evenly spaced 57 observation wells was established. Repeat measurement of water level was carried out during post-monsoon 2015 to post-monsoon 2018 periods. Water level data was collected from observation wells with the help of steel tape.

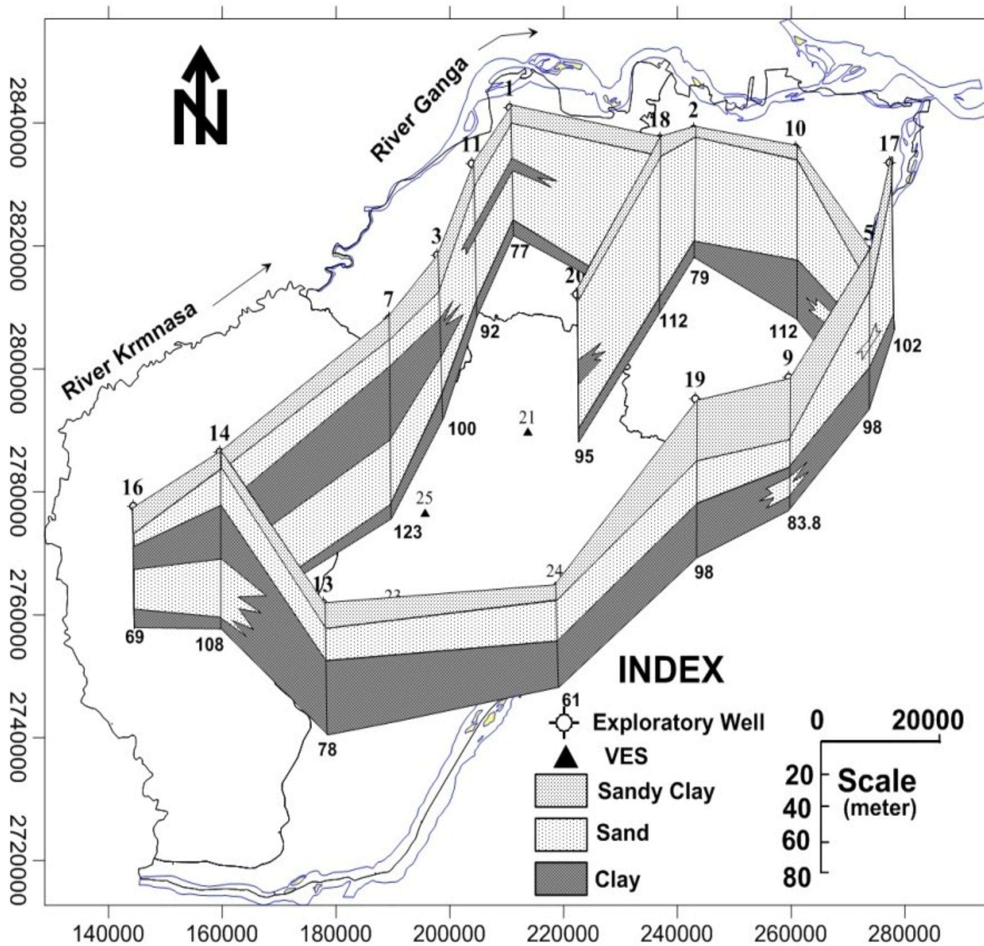

Fig.3.2: Panel diagram of the study area

3.4.2a Depth to water level

The depths to water level maps are useful in deciphering the area of recharge and discharge. Recharge areas are characterized by deeper water table while shallow water table below the land surface indicates discharge area (Fetter, 1988). The depths to water maps, thus, depict the regional variations of the water level with respect to land surface all over the area. In an unconfined aquifer, the water table is the upper surface of the zone of saturation where the pressure is atmospheric. It is defined by the level at which water stands in wells penetrating the aquifer, just enough to hold standing water.

In pre-monsoon seasons i.e. June 2016, June 2017 and June 2018, the depth to water level ranges from 3.49 to 16.1 m bgl (Fig 3.3a), 2.43 to 15.72 m bgl (Fig 3.3b) and 3.6 to 15.81 m bgl (Fig 3.3c), respectively (Annexure-1). A perusal of the maps shows that the deep water table conditions occur in the southeastern part of the area. Relatively shallow water levels are recorded along river Ganga.

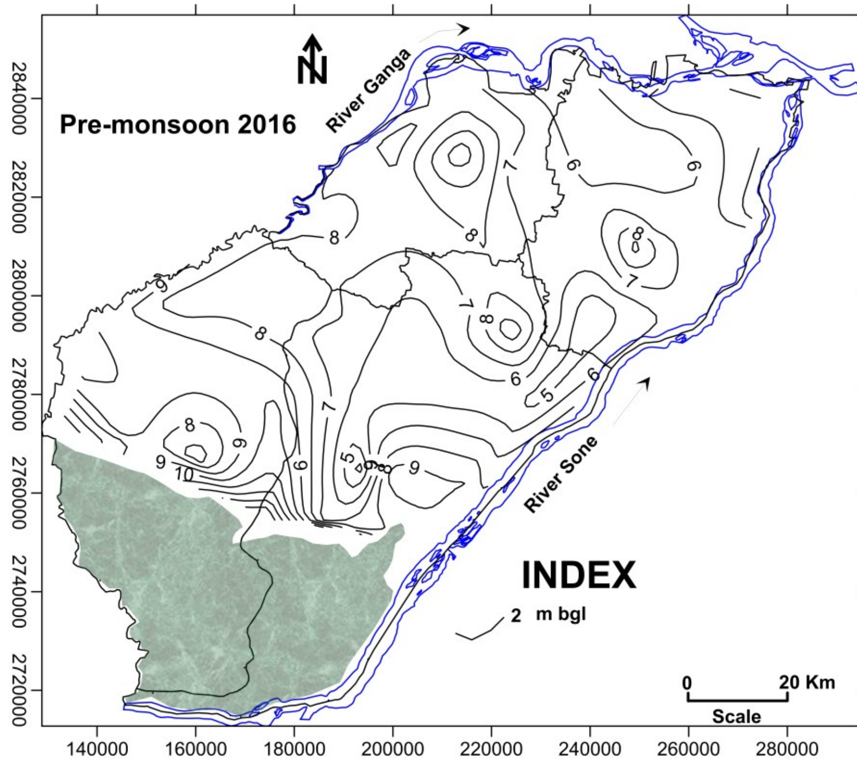

Fig. 3.3a: Pre-monsoon depth to water level map (June 2016)

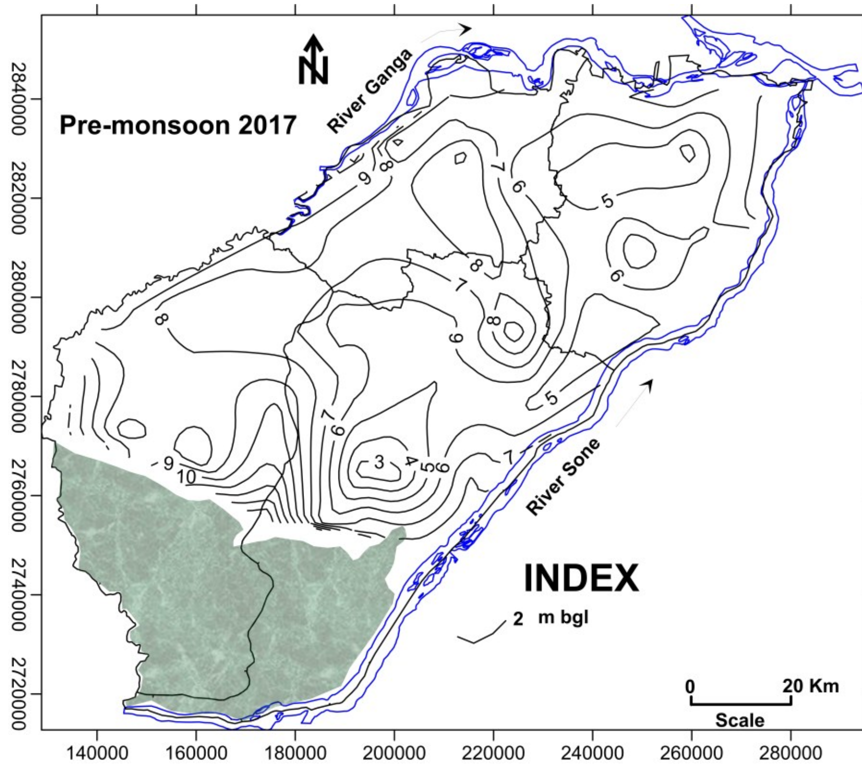

Fig. 3.3b: Pre-monsoon depth to water level map (June 2017)

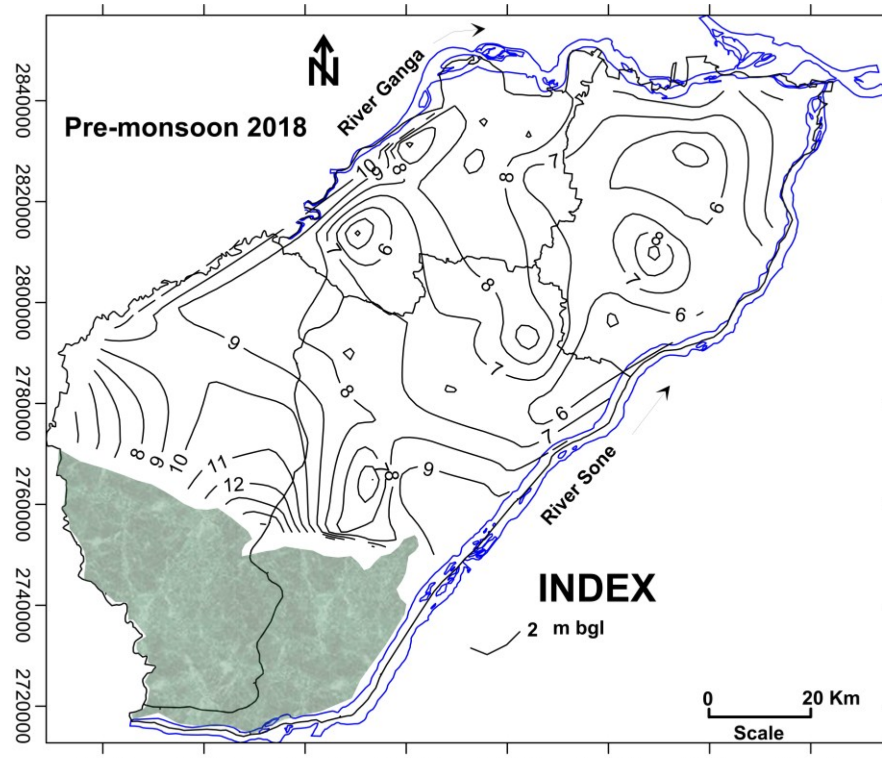

Fig. 3.3c: Pre-monsoon depth to water level map (June 2018)

In post-monsoon seasons i.e. November 2016, November 2017 and November 2018, the depth to water level ranges from 0.7 to 13.12 m bgl (Fig 3.3d), 0.21 to 13.63 m bgl (Fig 3.3e) and 1.25 to 13.85 m bgl (Fig 3.3f), respectively (Annexure-1). A general rise of water table is indicated in post-monsoon periods, resulting in noticeable changes in the contour pattern. It may be due to the scarcity of rainfall over the area, in general, and heavy withdrawal of groundwater for kharif crops.

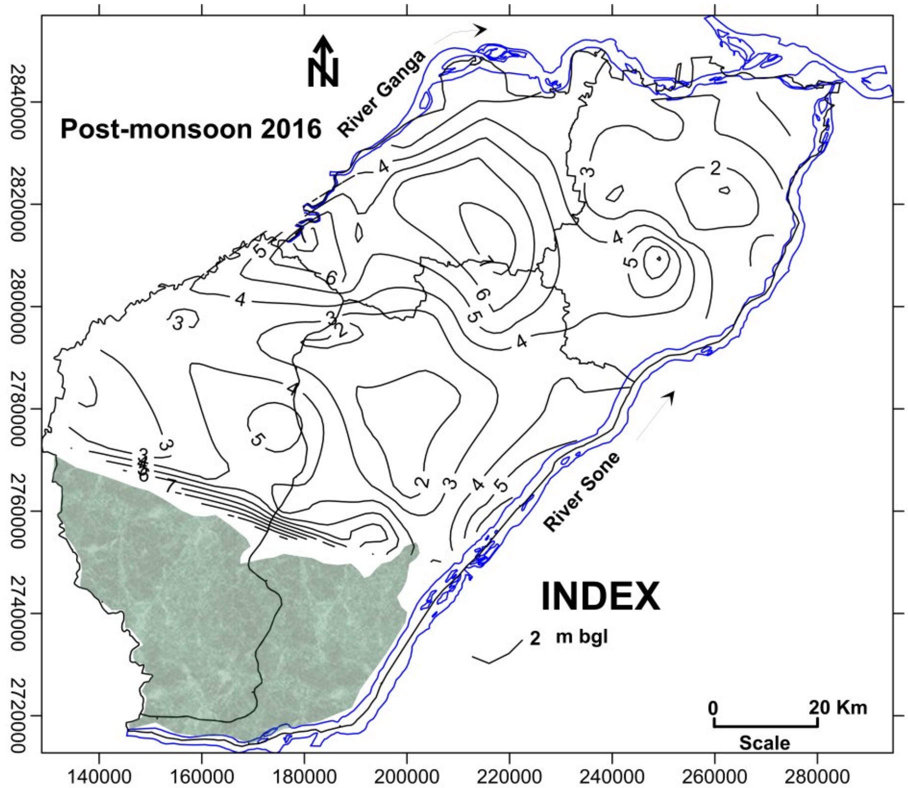

Fig. 3.3d: Post-monsoon depth to water level map (November 2016)

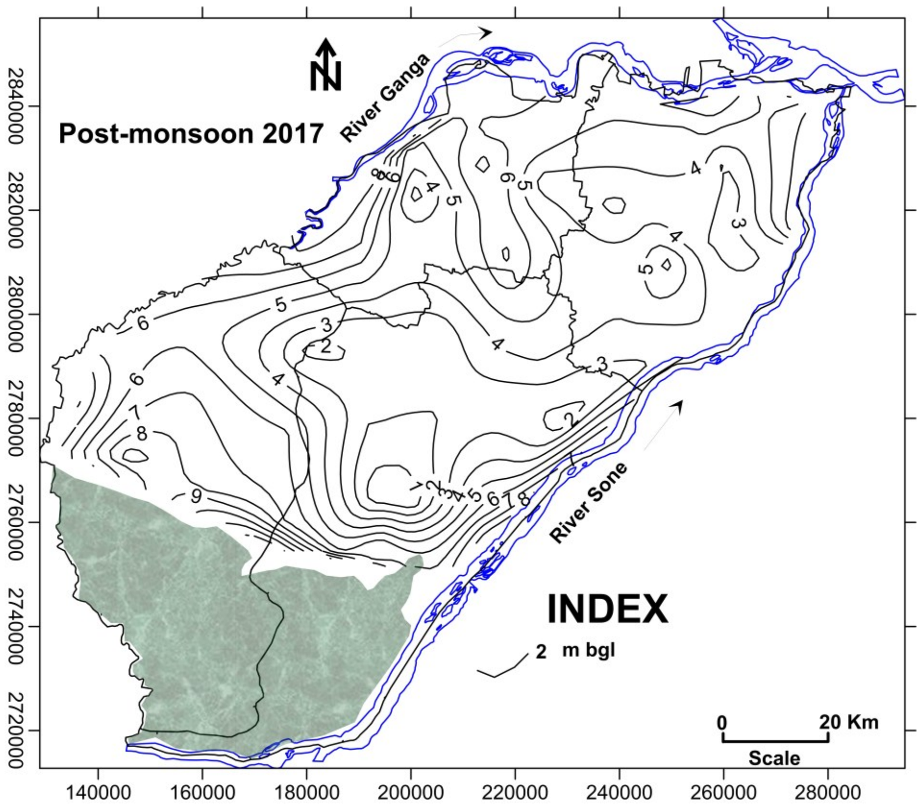

Fig. 3.3e: Post-monsoon depth to water level map (November 2017)

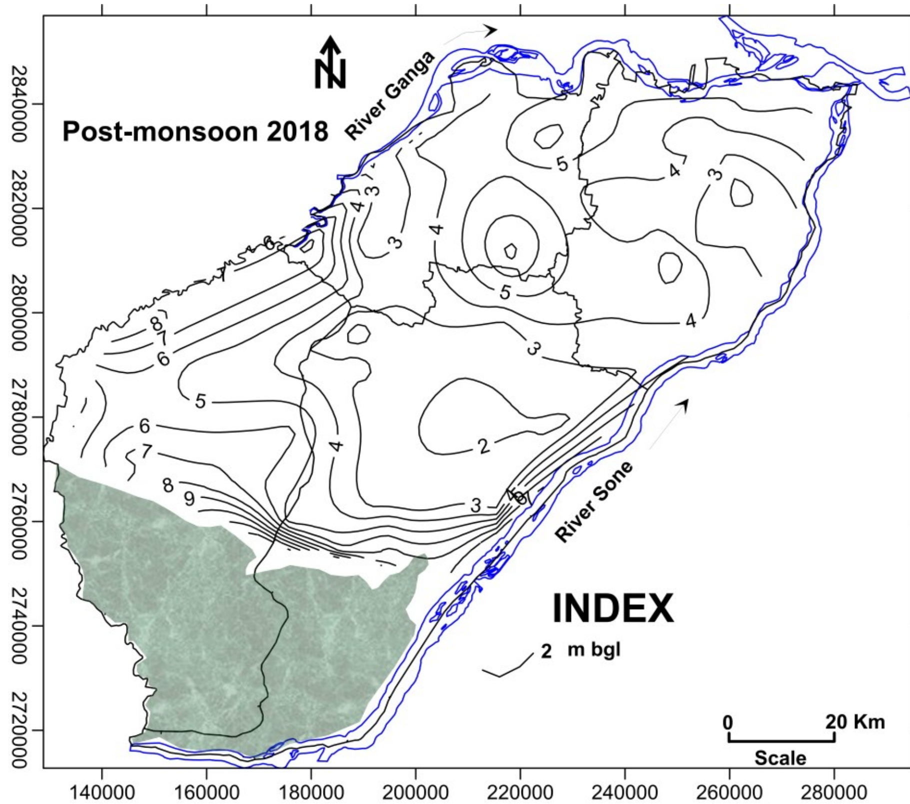

Fig. 3.3f: Post-monsoon depth to water level map (November 2018)

3.4.3 Water table contours and groundwater movement

The water table contour maps are used to decipher the groundwater flow direction, area of recharge and discharge, hydraulic gradient and nature of the river and stream draining the area. In such maps, convex contours and/or convergence of flow lines depict discharge related attributes and divergence of flow lines indicates recharge scenario. In addition, closely spaced contours depict low permeability conditions and relatively steep gradient whereas well spaced contours show an area of high permeability and flat gradient (Todd, 1980; Fetter, 1990).

Water level data of wells collected during pre-monsoon and post-monsoon for the year 2016, 2017 and 2018 were analyzed and altitude of water level with reference to the mean sea level (msl) was worked out for all the sites. These reduced levels were then used to generate water table contour maps.

A perusal of pre-monsoon 2016, 2017 and 2018 water table contour maps (Fig 3.4a, b and c) shows that the elevation of water table ranges from 44.57 to 112.08 m amsl (June 2016), 46.68 to 112.24 m amsl (June 2017) and 42.52 to 112 m amsl respectively. The hydraulic gradient varies between 1 m/km to 2 m/km.

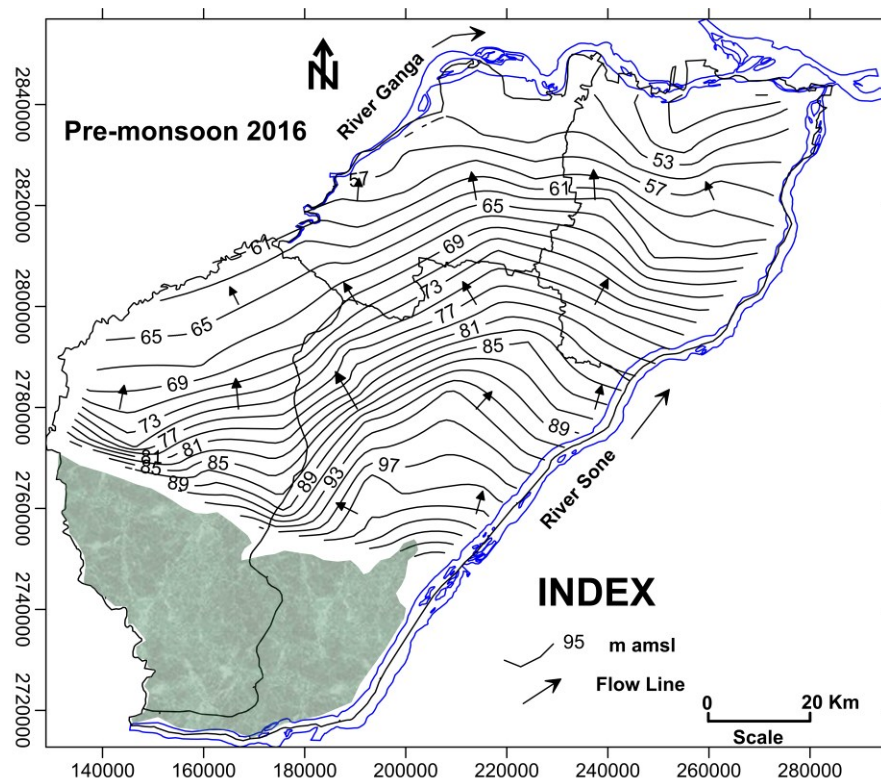

Fig. 3.4a: Pre-monsoon water table contour map (June 2016)

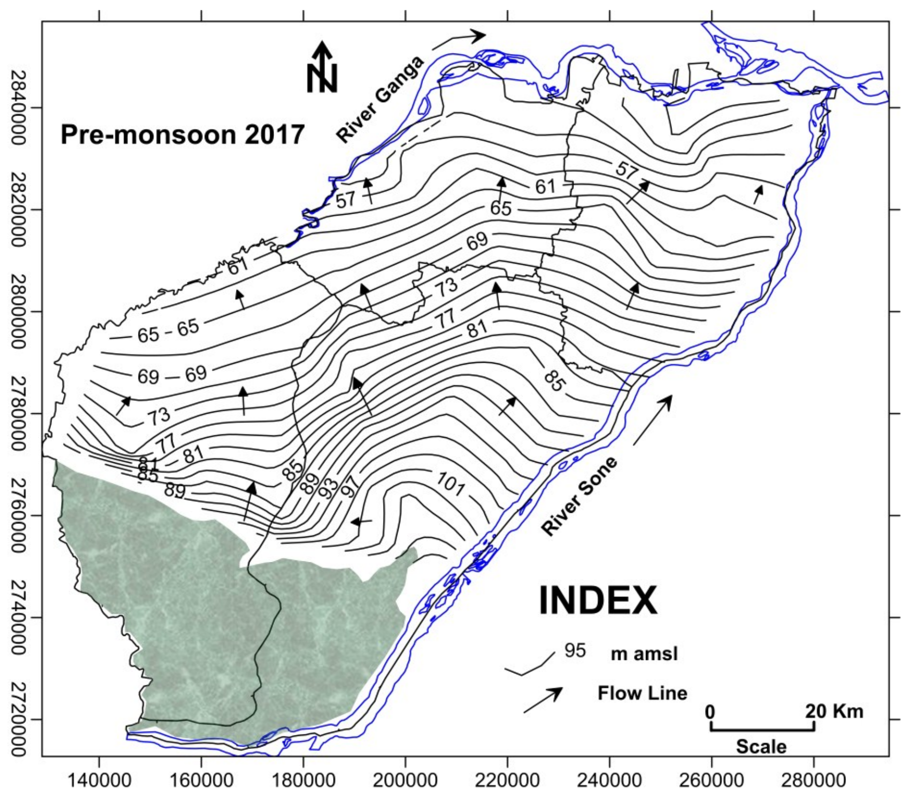

Fig. 3.4b: Pre-monsoon water table contour map (June 2017).

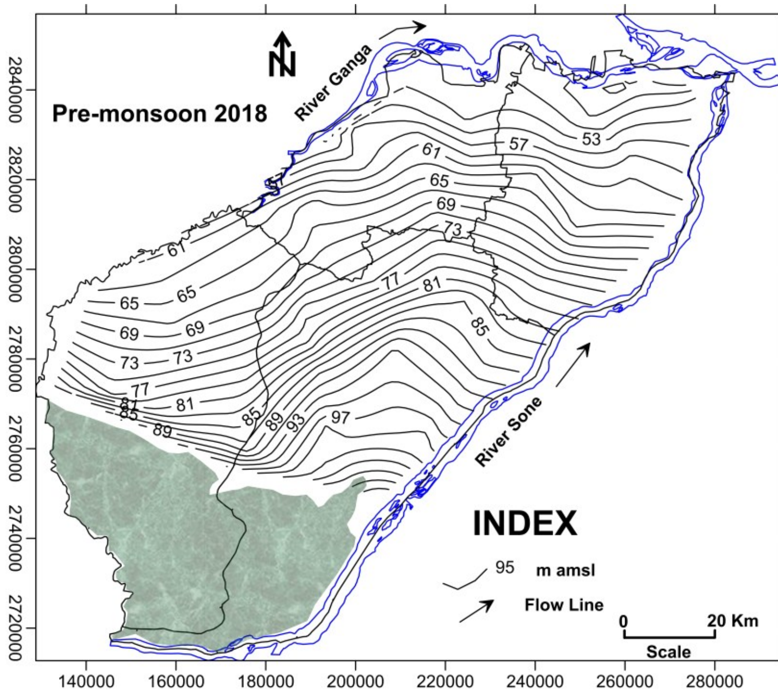

Fig. 3.4c: Pre-monsoon water table contour map (June 2018).

Post-monsoon water table contour maps for years 2016, 2017 and 2018 (Fig. 3.4d,e,f), show trends similar to those of pre-monsoon water table contour maps. However, during post-monsoon periods few changes are noted in the contour behavior. These may possibly be the consequence of increase in groundwater storage during this period as a result of healthy monsoon.

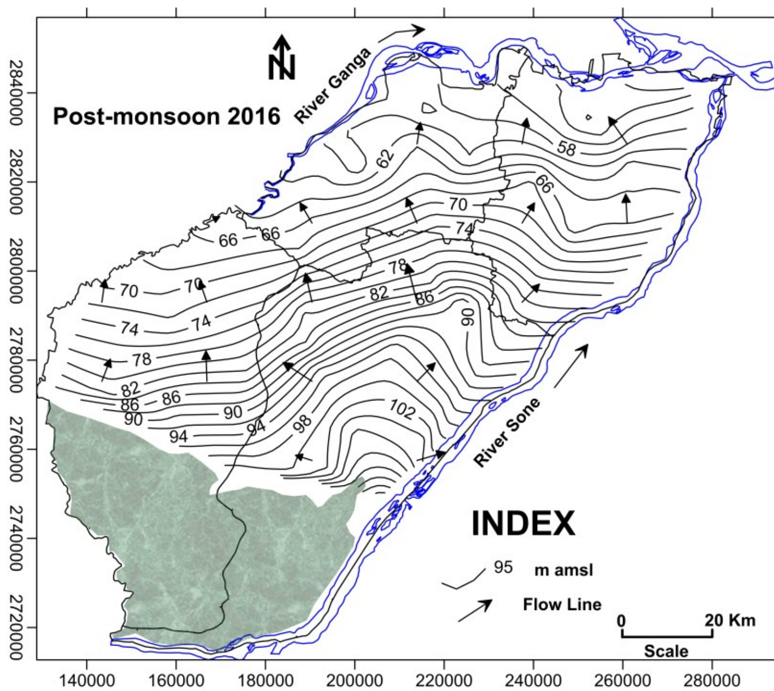

Fig. 3.4d: Post-monsoon water table contour map (November 2016).

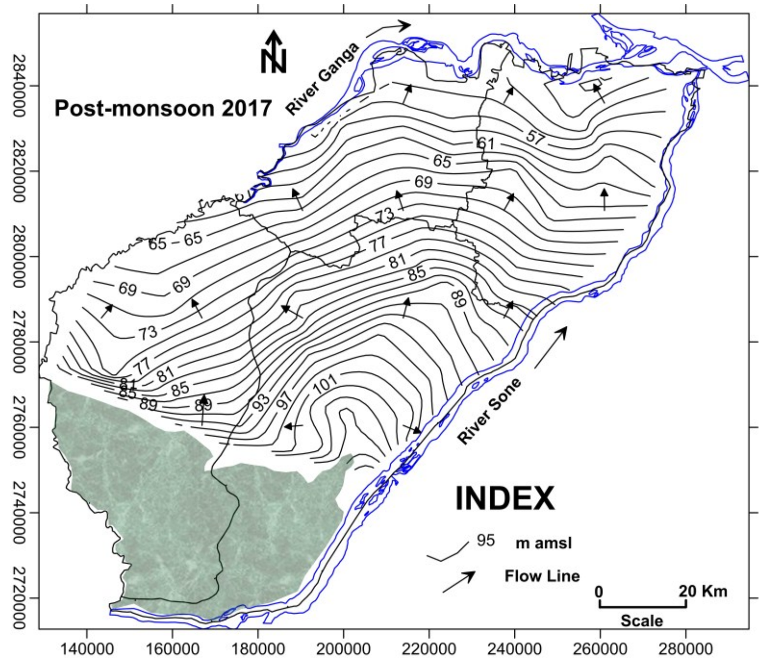

Fig. 3.4e: Post-monsoon water table contour map (November 2017).

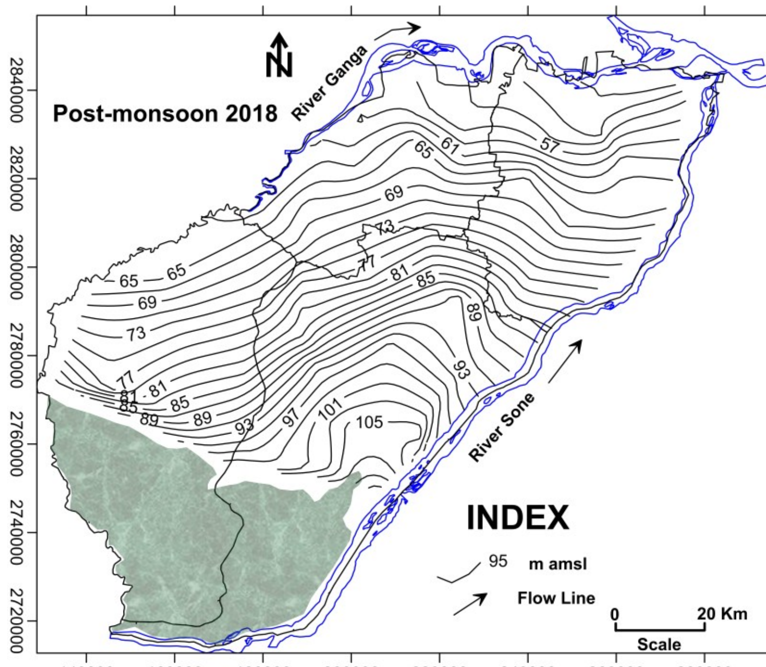

Fig. 3.4e: Post-monsoon water table contour map (November 2018).

3.4.4 Range of aquifer Parameters

The exploratory wells drilled in the area is given in table 3.1. Perusal of these data reveal significant potentiality of the aquifer of the area as the transmissivity ranges between 1098 and 15886 m2/day with mean value of 7711 m2/day. The discharge of the well varies from 29.5 m3/hr (southern part) to 232 m3/hr (northern part) with mean value of 194 m3/hr.

Table 3.1: Summarized salient characteristic of the exploratory wells drilled in the area

S.No.	Location	Longitude	Latitude	Depth drilled (m bgl)	Depth range of tapped Granular zones (m)	Discharge (m3/hr.)	Drawdown (m)	Transmissivity (m2/day)	Storativity
1	Kithpura	83.939	25.544	111.6	70.25-82.3 85.4-109.7	174.6	3.41	3653	
2	Shahpur	84.402	25.589	76.14	29.87-61.13 67.23-74.3	165	1.53	4749	
3	Ratanpur	84.647	25.575	71.6	27.28-36.57 40.23-64.6 68.57-70.10	222.6	1.39	9300	
4	Basantpur	84.598	25.638	81.53	42.8-78.5	220.2	3	15886	
5	Basudeopur	84.493	25.594	76.2	24.38-30.46 33.52-48.92 56.56-60.53 68.58-73.45	232.2	1.72	9685	
6	Nat	84.053	25.617	100.27	27.43-32, 53.34-64.0 70.1-76.20 79.24-85.35 92.0-99.0	--	--	--	
7	Singhai Tola	83.939	25.544	70.1	31.39-36.18 39.62-51.20 56.38-68.58	--	--	--	
8	Barisban	84.436	25.627	205	94-106, 109-115, 128-140, 156-162, 169-181,189-199	189	6.35	10238	4x10-4
9	Shahpur	84.399	25.596	257	134-146, 160-166, 180-192, 196-202, 238-250	194.6	4.75	8552	4x10-5

10	Paharpur	84.471	25.649	256	131-146, 160-166, 180-182, 196-202, 238-250	194.62	4.23	8553	7.49x10-3
11	Nargada Narayanpur	84.422	25.607	234	136-142, 156-162, 179-188, 191-194, 205-208, 214-217, 222-228	188.7	9.62	5529	2.72x10-5
12	Bharauli	84.380	25.631	218	162-171, 174-180, 183-186, 189-196, 203-215	182.79	8.48	8920	
13	Karnamipur	84.358	25.654	205	136-142, 147-153, 161-167, 173-179, 187-199	194.58	9.91	4461	1.98x10-3
14	Amrahi Nawada	84.553	25.544	180	45-51, 55-58, 66-71, 87-92, 125-131, 136-140, 145-149, 166-172	188.7	8.55	5918	
15	Arjurnpur	84.158	25.667	204	150-156, 164-176, 182-188, 194-200	180	8.5	9690	1.13x10-3
16	Brahmpur	84.317	25.605	208	120-132, 156-162, 176-182, 190-202	200	7.04	1098	
17	Churamanpur	84.031	25.581	223	158-164, 176-182, 208-220	197.33	3.62	7884	1.8x10-5
18	Ramgarh	83.6500	25.2833	295.96	76.2-85.34, 124.96-152.4, 164.6-176.7	159	5.8	2505	-
19	Piparia	83.5352	25.1797	195.98	87.44-98.38, 166.23-192.84	241.14	5.31	4162	
20	Mohania	83.6025	25.1500	135.02	73.15-97.99, 123.03-129.47	208.68	4.21	1706	
21	Bhagwanpur	83.7026	25.1800	89.61	29.87-35.96, 42.06-45.341	29.5	.094	-	

CHAPTER- 4

NUMERICAL MODEL DESIGN

The steps in Numerical Model Design includes design of the grid, setting boundary and initial condition, preliminary selection of values for the aquifer parameters and hydrologic stresses (Anderson and Woessner, 2002).

4.1 METHODOLOGY

The process of groundwater modelling involves a number of different steps. The essential steps are shown in the following diagram (Fig 4.1).

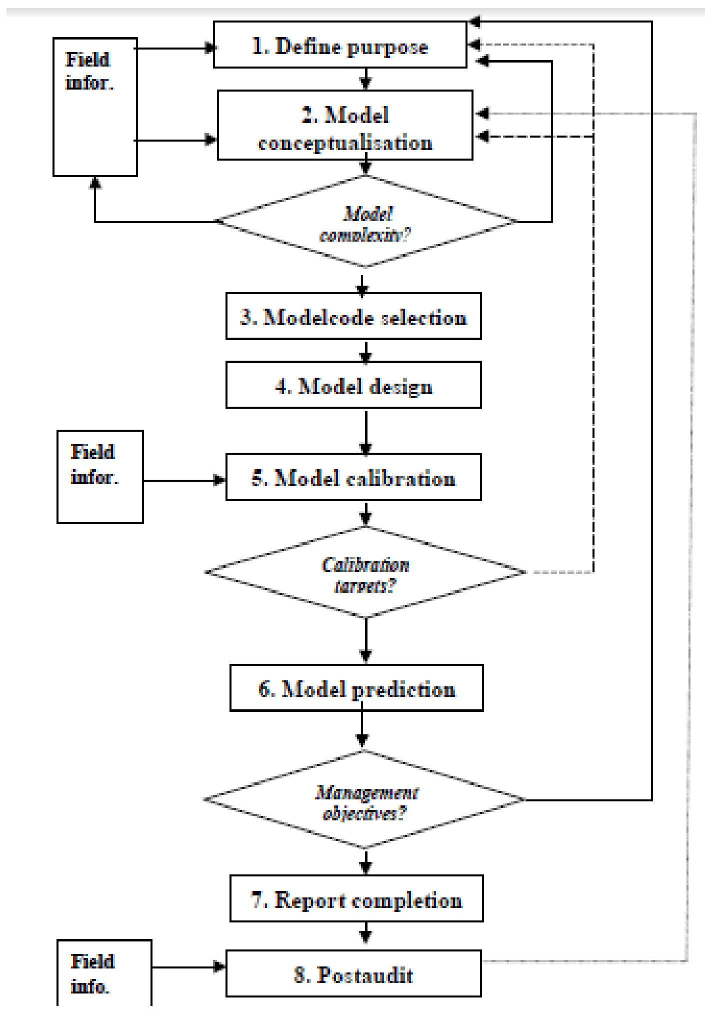

Fig: 4.1: Flow chart of Aquifer Modelling

4.2 About Visual MODFLOW

MODFLOW is a versatile code to simulate groundwater flow in multilayered porous aquifer. The model simulates flow in three dimensions using a block centred finite difference approach. The groundwater flow in the aquifer may be simulated as confined/unconfined or the combination of both. MODFLOW consists of a major program and a number of sub-routines called modules. These modules are grouped in various packages viz. basic, river, recharge, block centred flow, evapotranspiration, wells, general heads boundaries, drain.

MODFLOW is a computer program that numerically solves the three-dimensional groundwater flow equation for a porous medium by using a finite-difference method (Schlumberger Water services 2011). In the finite difference method (FDM), a continuous medium is replaced by a discrete set of points called nodes and various hydrogeological parameters are assigned to each of these nodes.

4.3 MODEL CONCEPTUALIZATION AND DEVELOPMENT

Based on the available information as discussed above, a conceptual ground water model has been framed. The purpose of building a conceptual model is to simplify the field problem and organize the associated field data so that the system can be analyzed more readily. Simplication is necessary because a complete reconstruction of the field system is not feasible (Anderson and Woessner, 2002). The conceptualization includes synthesis and framing up of data pertaining to geology, hydrogeology, hydrology and meteorology.

A conceptual model is a simplified representation of the ground water flow system depicting the hydrostratigraphic unit of interest along with the system boundaries (ERD, 1998). Developing a modelling concept is the initial and most important part of every modelling effort and requires a thorough understanding of hydrogeology, hydrology and dynamics of ground water flow in and around the area of interest. The basic components of a conceptual model are the sources and sinks of water to and from the region, the physical boundaries, their nature and the spatial distribution of hydrogeological properties within the region. Formation of a conceptual model is an essential prerequisite to the successful execution of the more quantitative representation of groundwater flow model such as a numerical model. Further, it also helps identify the knowledge or data gaps that must be filled before attempting a quantitative model. To begin with, it is always better to start with a simpler model as it facilitates model refutability and transparency (Hill, 2006). A model is considered as refutable if the assumptions upon which the model is constructed can be tested whereas transparency refers to the degree to which the model dynamics are understandable (Orskes, 2000).

4.4 MODEL FRAMEWORK

The model domain is bound by River Ganga, Son and Karmanasa on its northern, eastern and south western side (Fig 4.2).

4.4.1 Grid Design

The total area of the model is 11470 Km^2 which is discretized into 70 row and 82 columns, with the dimension of 2000 x 2000 m grid size. Within the area white color cell are considered as active cells. The green color cells outside the model boundaries are assigned Inactive Cells.

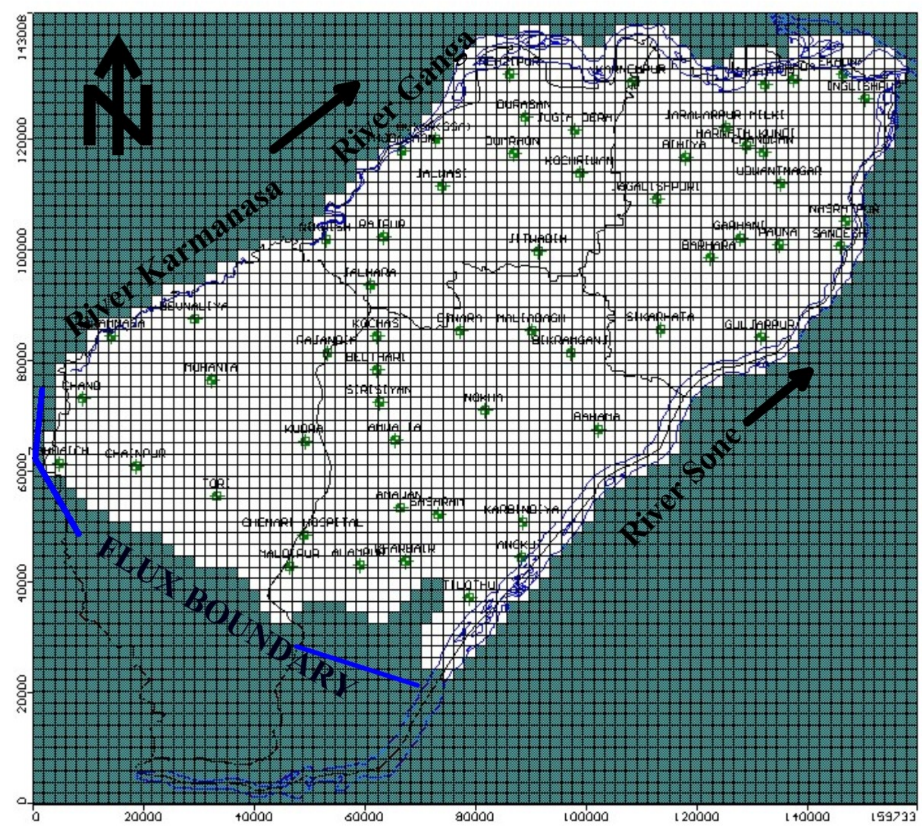

Fig. 4.2: Model grids with active (white) and inactive (green) cells

The ground elevation data available for 57 stations within the study area have been assigned and these were interpolated for other locations through natural neighborhood technique. In similar manner the elevation for other layers were also assigned for known locations and were interpolated.

4.4.2 Layer:

The study area is generally characterized by single layer up to depth of 112 m (sandy clay and sand). The top (Fig. 4.3a) and bottom elevation (Fig 4.3b) of the layer has been taken as 121 m above msl and - 42 m below msl respectively.

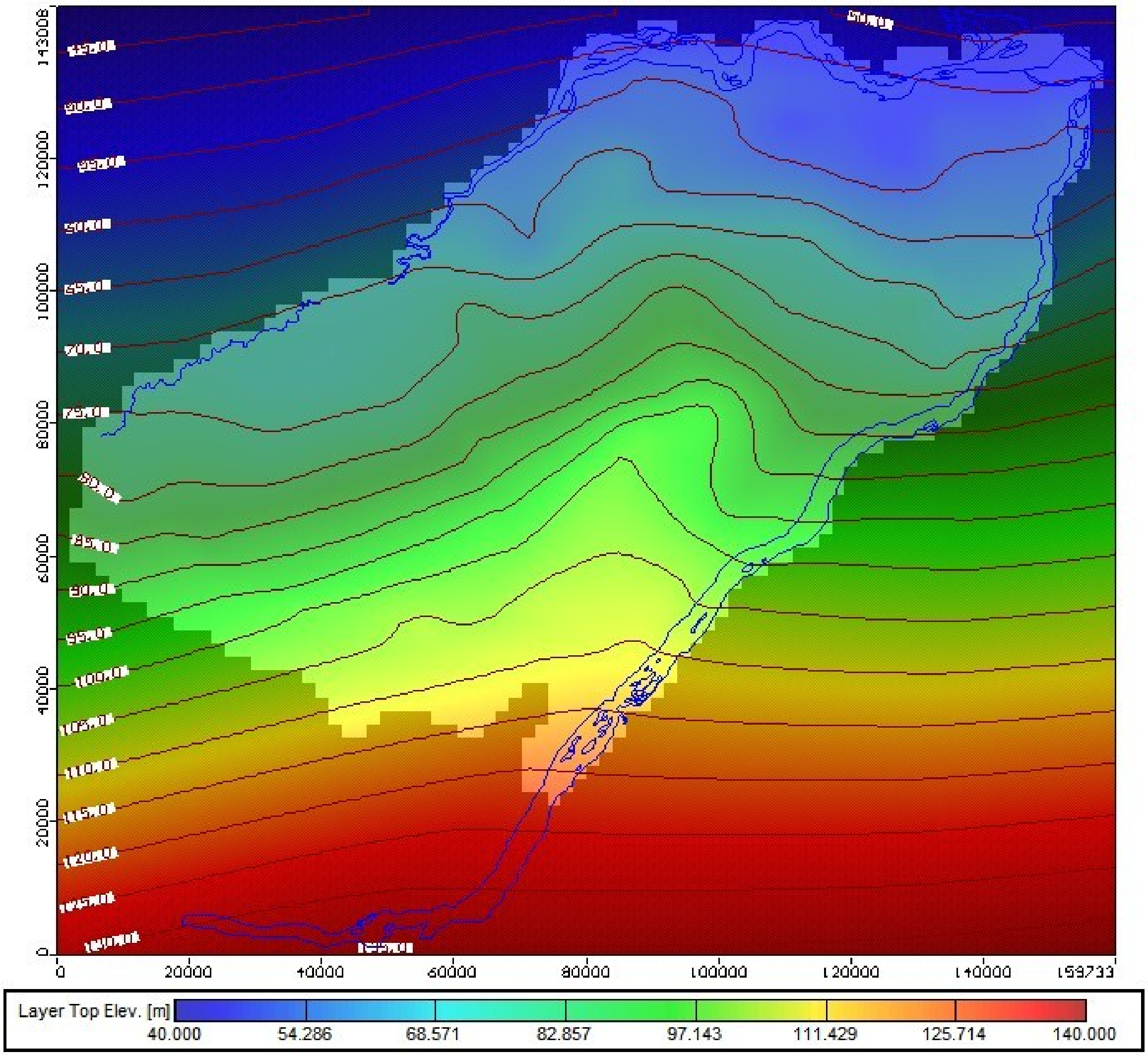

Fig. 4.3a: Top Layer of the area

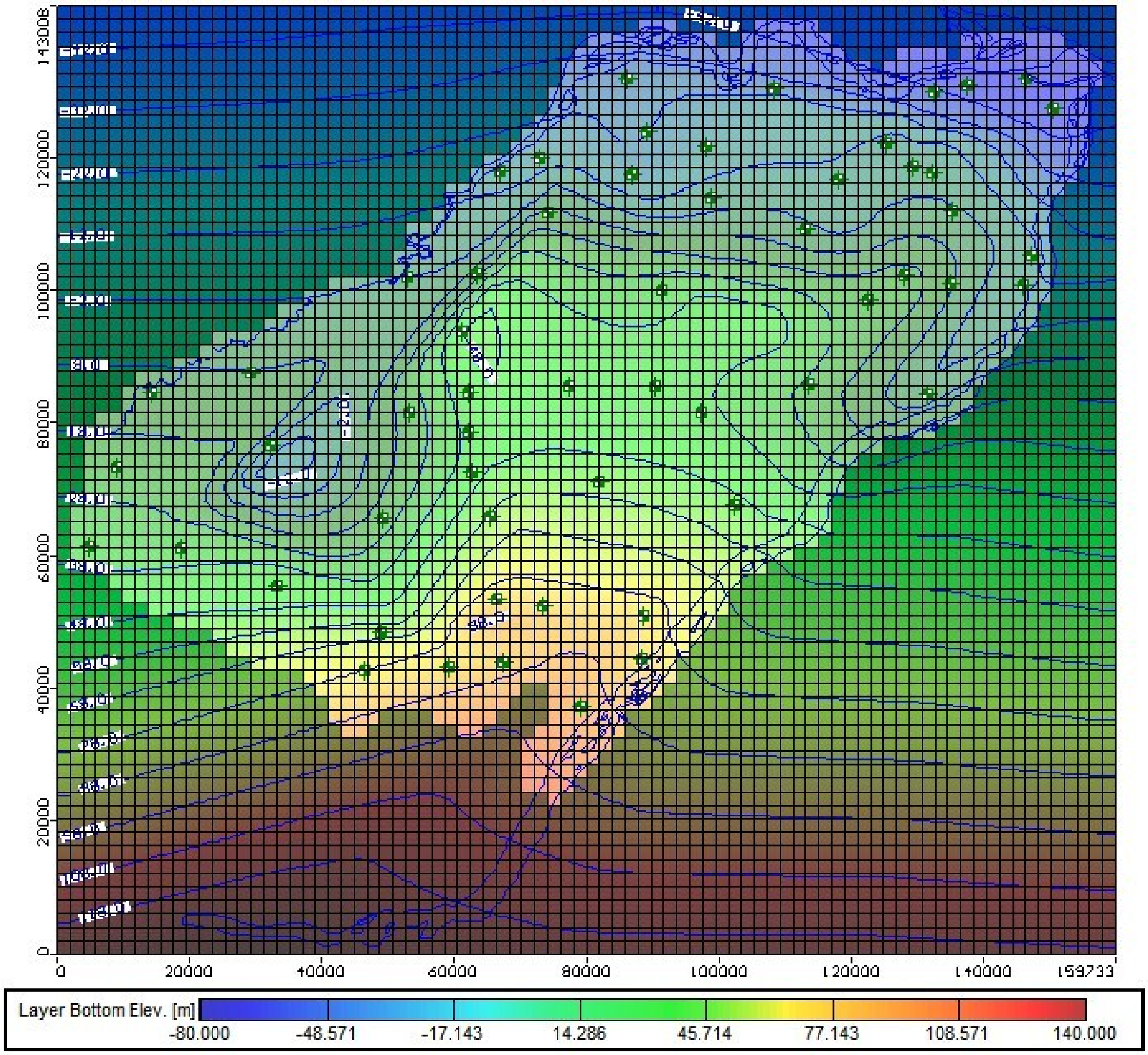

Fig. 4.3b: Bottom Layer of the area

4.5 Aquifer Geometry and Boundary Conditions

4.5.1 *Aquifer Geometry*

Geologic information including geologic maps, cross sections and well logs are combined with information on hydrogeologic properties to define hydrostratigraphic units for the conceptual model (Anderson and Woessner, 2002). The Lithological data of fifteen boreholes were utilized for sketching horizontal and vertical disposition of aquifers and aquitards in the study area to a depth of 112 m bgl (Fig. 3.2).

4.5.2 Boundary Conditions

Boundary conditions are defined along the edges of the simulation domain including the top and the bottom. Their main function is to separate the model region from the rest of the world and are required for solution of the groundwater flow equation. Model boundaries are either Physical (real) and hydraulic (artificial). While the physical boundaries are well defined geologic and hydrologic features that permanently influence the pattern of groundwater flow, hydraulic boundaries are artificial and are derived from groundwater flow nets (Kresic, 1997). Mathematically, they are necessary for arriving at a unique solution of a differential equation. Conceptually, they can be visualized as the influence of the hydraulic conditions occurring across the boundary of the domain, of the solution. Thus, to obtain a unique solution of the differential equation, it is necessary to define boundary conditions all along domain boundary. The boundary condition may either be a known head (head assigned) or a known flow rate (flow assigned) across the boundary. It can be thus concluded that for obtaining a unique solution it is necessary to know either the head or normal flows all along the boundary. In general there are two commonly used boundary conditions: (a) specified hydraulic head boundaries and (b) specified flow boundaries. A no-flow boundary is a special case of specified flow boundary and a constant head boundary is a special case of specified head boundary. Out of the two types of boundary conditions, the head assigned boundaries are more suitable for forecasting since the water elevations in the hydraulically connected water bodies may generally not be significantly influenced by the pumping/recharge pattern in the aquifer. With head assigned boundaries the known prevalent water elevations may be assumed to hold good under the projected conditions (i.e., the pumping/recharge rates different from the prevalent ones) as such the same has been used in the present study. On the other hand, the lateral inflows across the boundary are very sensitive to any change in pumping/recharge. Thus, the inflow rates under the projected conditions may vary significantly from the prevailing ones. In other words the known prevalent inflow rates may not provide the necessary boundary conditions.

4.5.2.1 River Boundary: River Son and Karmanasa are assigned as a river boundary on its eastern and south western side.

In the present case the western and eastern boundaries representing the Son and Karmanasa rivers, respectively, were assigned as river boundaries (Fig. 4.4a & 4.4b). For these boundaries, river head and river bed bottom elevations were assigned to appropriate grids after carrying out surveys. The river head and bed bottom elevations at the initial and final point of river Sone are 104 and 69 m amsl and 101 and 48m amsl, respectively. For river Karmanasa the river head and bed bottom elevations at the initial and end points are 64 and 60 m amsl and 63 and 56 m amsl, respectively.

Fig. 4.4a: River Sone in Eastern part of the area

Fig. 4.4b: River Karmanasa in western part of the area

5.5.2.2 Constant Head Boundary

The northern and the north-western boundary along the course of the River Ganga have been assigned as Constant Head Boundary (Fig. 4.5). River Ganga within this segment is effluent in nature. The data obtained through GPS as well as bridge crossing the river Ganga.

Fig. 4.4c: River Ganga in northern part of the area

4.5.2.3 Flux boundary:

The flux to the layers has been estimated using the *TIL* equation for different segments. The estimated flux has been assigned by adding recharge wells along the southern boundary. The model boundaries are depicted in Fig 4.5.

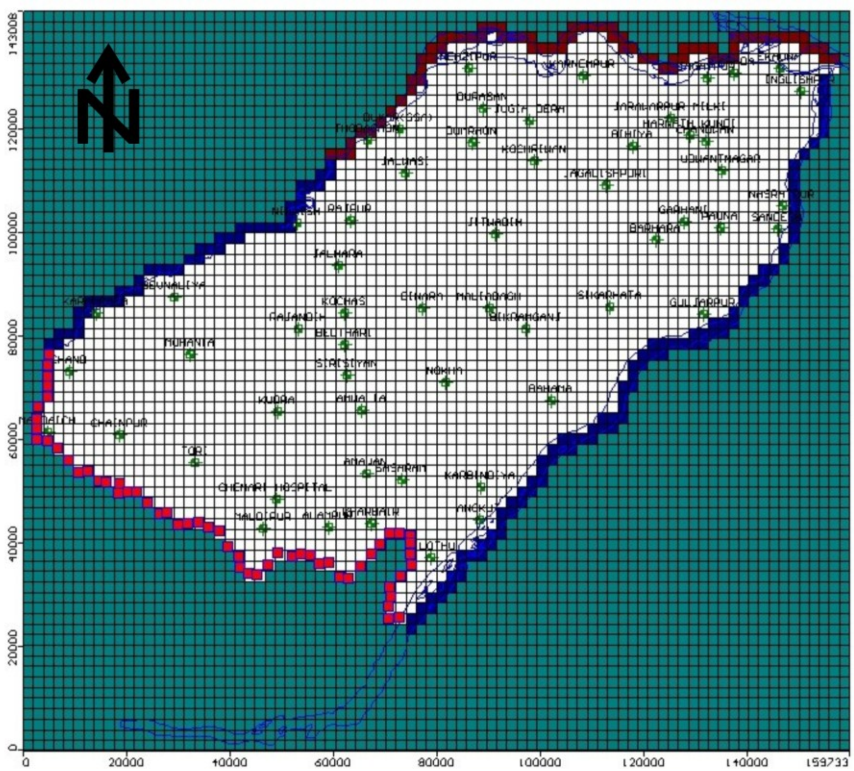

Fig. 4.5: The conceptual model. Green, White, Blue, Red and Pink colours indicate inactive, active, River boundary, Constant head boundary and flux boundary (recharge well) respectively.

The Sone Rivers are presumed to have a good hydraulic connection with the aquifer as these are adequately incised into the aquifer and have sandy river banks. Also the water level in the aquifer adjacent to the river in general corresponds to the river stage.

The river boundary condition is used to simulate the influence of a surface water body on the groundwater flow. The required data for assigning this boundary condition includes data pertaining to the river stage, river bed bottom (i.e the elevation of the bottom of the seepage layer of the surface water body), and thickness of the riverbed and river width. The flow of water through riverbeds is dependent on the transmissivity properties of the riverbed and the difference between the head in the aquifer and the river stage.

4.6 Distribution of Conductivity Values

The hydraulic conductivity data obtained from pumping test were utilized in the preparation of model. Vertical hydraulic conductivity has been taken as 10% of the horizontal hydraulic conductivity.

The hydraulic conductivity of the model has been assigned in two zone i.e. in younger alluvium and older alluvium (Fig 4.6). The range of hydraulic conductivity for this layer varies from 10 m/day to 24 m/day.

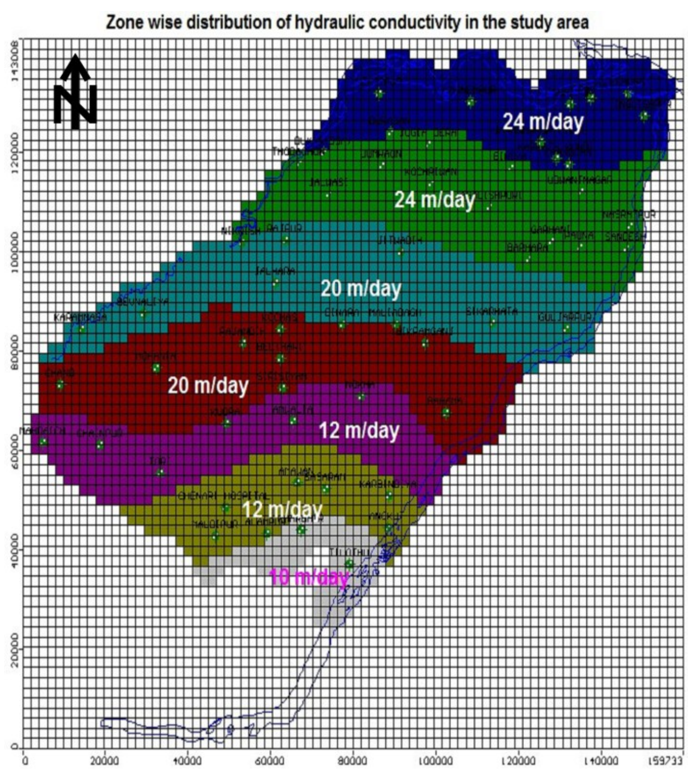

Fig. 4.6: Zone wise distribution of hydraulic conductivity in the study area.

4.7 Groundwater level data

During the selection of monitoring stations, 110 monitoring station was selected but after validation of monitoring data it was decided to use only 57 monitoring station (Annexure 1). The water level monitoring programme was initiated in post-monsoon 2015 for steady state condition. The monitoring was carried twice a year i.e. pre-and post-monsoon.

In post-monsoon seasons i.e. November 2016 (Fig 4.7a), the depth to water level ranges from 1.11 to 13.34 m bgl. Water table contour map for the period of post-monsoon 2015 ranges between 47.18 to 112.56 m bgl (fig. 4.7b). Groundwater flow direction in the study area from south to towards north direction.

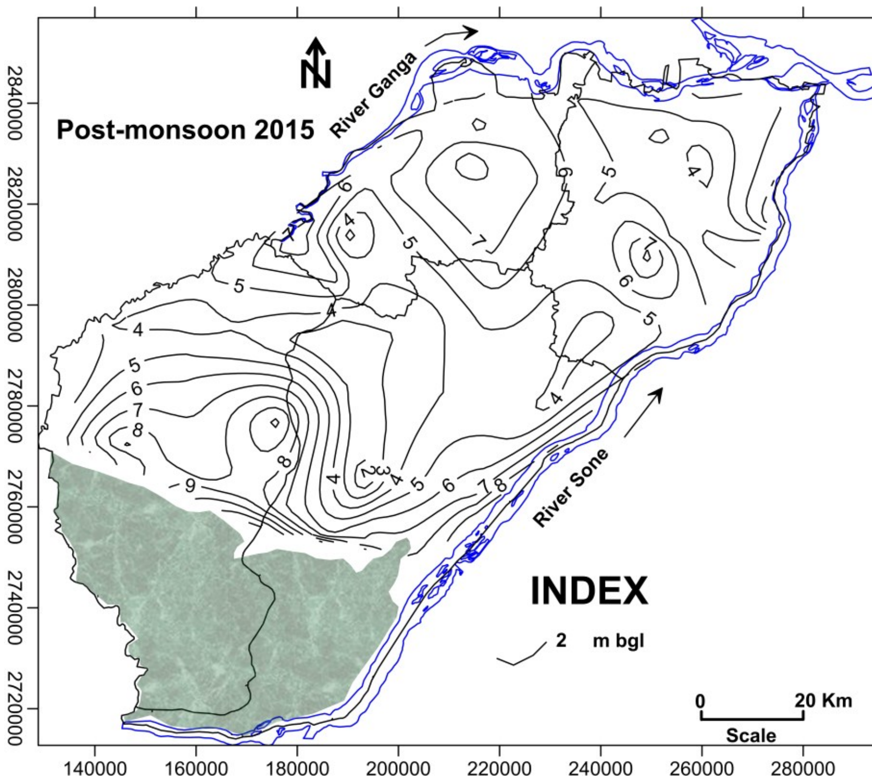

Fig. 4.7a: Post-monsoon depth to water level map (November 2015)

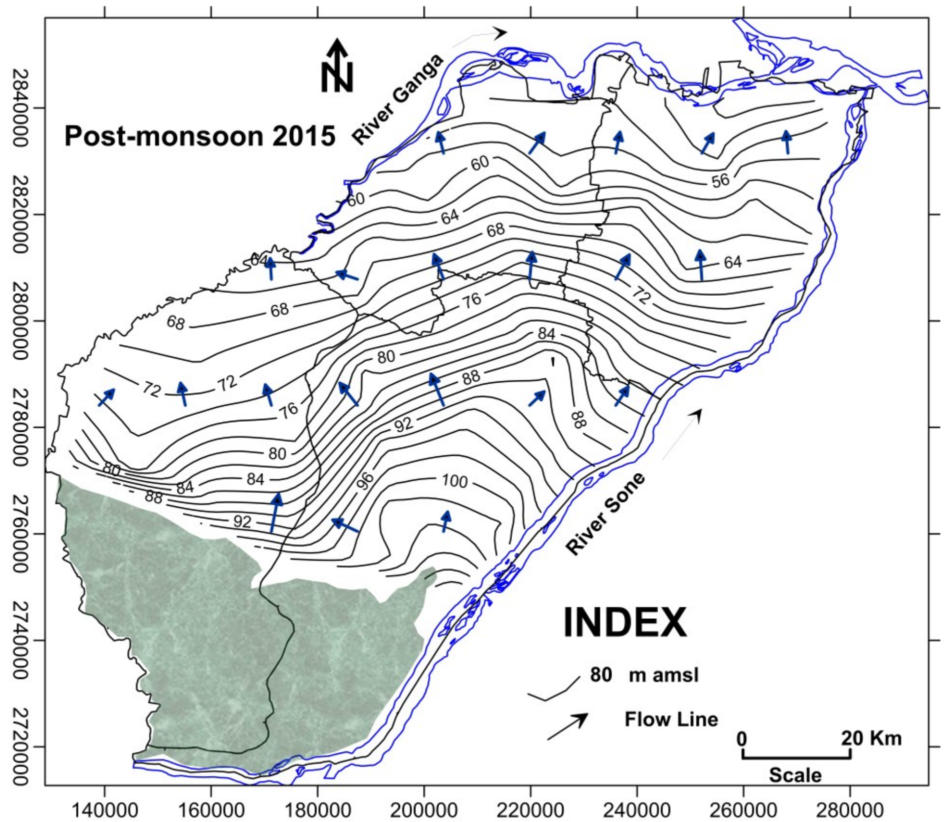

Fig. 4.7b: Post-monsoon water table contour map (November 2015)

Care was taken to try to obtain static groundwater levels. However errors may have been introduced because practically it was impossible to stop all pumping in an extensively cultivated area where concentration of groundwater abstraction structures is so high. The heads of these wells were used as model input data.

4.8 Recharge

This package is used to simulate surficially distributed recharge to the groundwater system. Annual precipitation within the study area averages about 1210 mm, part of which seeps through the fine-grained material overlying the aquifer to the water table. Areal recharge to the aquifer is equal to precipitation minus (1) runoff into streams, (2) evaporation, and (3) evapotranspiration from plants in the soil zone. Infiltration of precipitation probably accounts for the largest amount of recharge. Recharge estimates are a function of vertical hydraulic conductivity which is a function of geology. Hence, surficial geologic units are likely to represent a reasonable initial distribution of recharge. Recharge was assigned as per groundwater resource estimation 2017 carried out in the area.

4.9 Discharge Data

Within the study domain the main discharge input is the groundwater pumping from the area. The time variant groundwater draft has been assigned to each grid. The abstraction has been worked out using the unit area groundwater draft from the study area (Fig 4.8). Data from the previous studies like resource assessment was utilized. The abstraction assigned in different Blocks falling in the study area is summarized in Table 4.1.

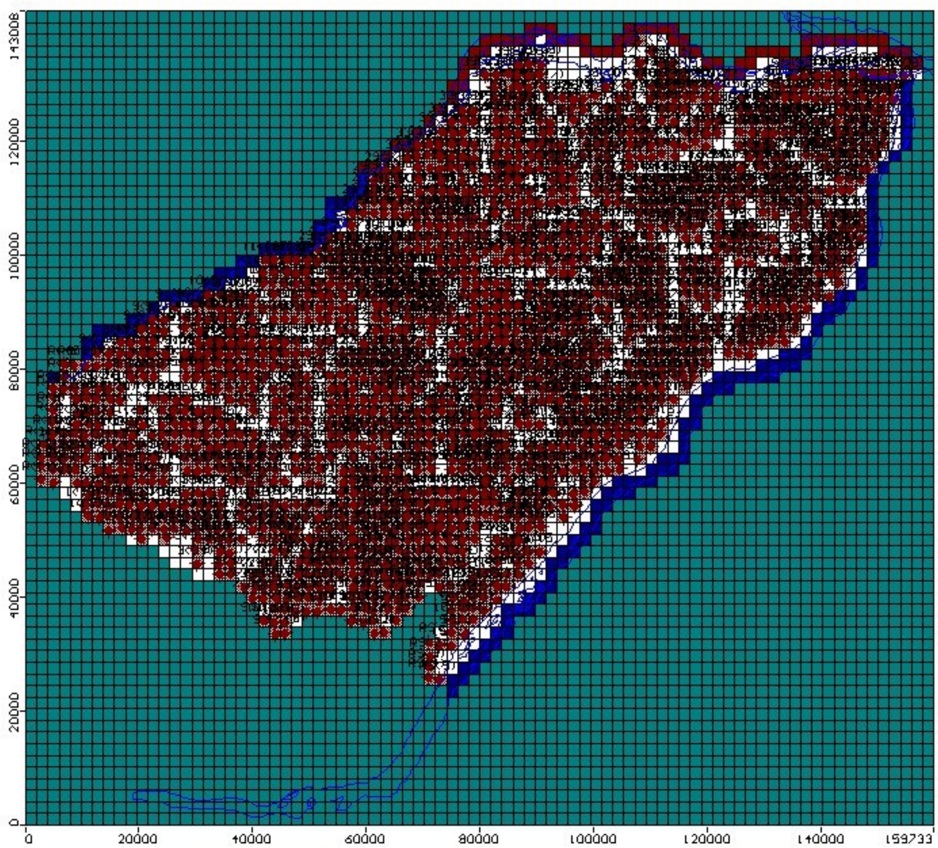

Fig.4.8 : Simulated groundwater pumping locations in the study area

Table 4.1: Block wise unit area groundwater draft in the study area

S.No.	District	Block	Draft		
			Ham	MCM	m^3/day
1	Bhojpur	Agioan	1747.40	17.474	47873.97
2		Ara	3025.00	30.25	82876.71
3		Barhara	1667.60	16.676	45687.67
4		Bihiya	3246.80	32.468	88953.42
5		Charpokari	1517.40	15.174	41572.6
6		Garhani	1342.60	13.426	36783.56
7		Jagdishpur	4968.60	49.686	136126
8		Koilwar	2279.20	22.792	62443.84
9		Piro	4512.20	45.122	123621.9
10		Sahar	880.40	8.804	24120.55
11		Sandesh	2099.00	20.99	57506.85
12		Shahpur	1998.60	19.986	54756.16
13		Tarari	3691.20	36.912	101128.8
14		UdwantNagar	2197.60	21.976	60208.22
15	Buxar	Brahmpur	3804.94	33.258	91117.81
16		Buxar	3641.93	30.066	82372.6
17		Chaungai	1627.89	14.763	40446.58
18		Chakki	413.92	3.3	9041.096
19		Chausa	2301.43	20.343	55734.25
20		Dumraon	2789.16	22.923	62802.74
21		Itarhi	5720.81	51.891	142167.1
22		Kesath	782.24	6.936	19002.74
23		Navanagar	2395.11	20.28	55561.64
24		Rajpur	6171.98	55.536	152153.4
25		Simri	3850.45	33.522	91841.1
26	Rohtas	Akhorigola	1198.90	11.989	32846.58
27		Bikramganj	1305.60	13.056	35769.86
28		Chenari	1217.80	12.178	33364.38
		Chenari	323.60	3.236	8865.753
29		Dawath	1560.70	15.607	42758.9
30		Dehari	366.20	3.662	10032.88
31		Dinara	1336.60	13.366	36619.18
32		Karahgar	1883.90	18.839	51613.7
33		Karakat	1282.70	12.827	35142.47
34		Kochas	1218.70	12.187	33389.04
35		Nasariganj	842.70	8.427	23087.67
36		Nauhatta	365.20	3.652	10005.48
		Nauhatta	463.40	4.634	12695.89

37		Nokha	1226.70	12.267	33608.22
38		Rajpur	685.90	6.859	18791.78
39		Rohtas	71.50	0.715	1958.904
		Rohtas	29.10	0.291	797.2603
40		Sanjhauli	204.70	2.047	5608.219
41		Sasaram	882.80	8.828	24186.3
		Sasaram	249.90	2.499	6846.575
42		Sheosagar	2000.20	20.002	54800
43		Suryapura	486.40	4.864	13326.03
44		Tilawthu	354.00	3.54	9698.63
		Tilawthu	402.10	4.021	11016.44
45	Kaimur	Adhaura	586.80	5.868	16076.71
46		Bhabhua	2091.60	20.916	57304.11
47		Bhagwanpur	319.20	3.192	8745.205
		Bhagwanpur	794.40	7.944	21764.38
48		Chainpur	1845.60	18.456	50564.38
		Chainpur	25.80	0.258	706.8493
49		Chand	1701.60	17.016	46619.18
50		Durgawati	3297.00	32.97	90328.77
51		Kudra	3783.00	37.83	103643.8
52		Mohania	2810.40	28.104	76997.26
53		Nuaon	1959.00	19.59	53671.23
54		Ramgarh	1435.80	14.358	39336.99
55		Rampur	1032.60	10.326	28290.41
		Rampur	306.60	3.066	8400
Total			**110622.2**	**1064.041**	**29,15,181**

4.10 Assumptions Used in the Conceptual Model

Some of the major simplifying assumptions in the present modelling study include

1. all pumpage in a model cell has been simulated as coming from the cell center;
2. the pumpage throughout a stress period is applied equally throughout the stress period;
3. recharge is invariant over large periods of time;
4. small scale variations of hydraulic conductivity within cells are negligible.

4.11 Limitations of the model

1. The model showed that some limitations will have to be taken into account whenever the time comes to build up a more robust model aiming at reducing uncertainties.

2. During the selection of monitoring stations, 110 monitoring station was selected but after validation of monitoring data it was decided to use only 57 monitoring station.

3. Except along the river Ganga only drilling depth of about 100 m bgl. wells are available and as per lithology of the area single layer model was developed up to depth of 112 m bgl.

4. First, Block wise draft was calculated in the area and by dividing in the total draft of the block by no. of grid fall in the block, we know about draft values for each grid for particular block.

5. River Stage data was not available due to this we have assigned the river stage data with the help of GPS, collected during particular period.

CHAPTER- 5

MODEL CALIBRATION

An important part of any groundwater modelling exercise is the model calibration process. In order for a groundwater model to be used in any type of predictive role, it must be demonstrated that the model can successfully simulate observed aquifer behavior. Calibration is a process wherein certain parameters of the model such as recharge and hydraulic conductivity are altered in a systematic fashion and the model is repeatedly run until the computed solution matches field-observed values within an acceptable level of accuracy.

The purpose of model calibration is to establish that the model can reproduce field measured heads and flows. Calibration is carried out by trial and error adjustment of parameters or by using an automated parameter estimation code. In this study, trial and error adjustment has been used.

5.1 STEADY STATE CALIBRATION

Steady state conditions are usually taken to be historic conditions that existed in the aquifer before significant development has occurred (i.e., inflow are equal to outflows and there is no change in aquifer storage). In this model, quasi-steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW during a period of unusually high recharge.

Steady state simulation of the model was carried out using the specified hydraulic heads of post-monsoon 2015. River stage and river bed bottom data of river Son and Karmanasa for post-monsoon 2015 was considered. In present study steady state model was calibrated for the hydraulic conductivity values to achieve the observed heads.

Figure 5.1a show observed and computed heads of Post-monsoon 2015. The computed water level of post-monsoon 2015 (steady state) indicate prevailing trend of groundwater flow in the interfluves region.

The computed water level accuracy was judged by comparing the mean error with mean absolute and Root Mean Squared (RMS) error (Anderson and Woessner, 1992). RMS error is the square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 3.492 m (Fig. 5.1b). The absolute residual mean is 2.674 m.

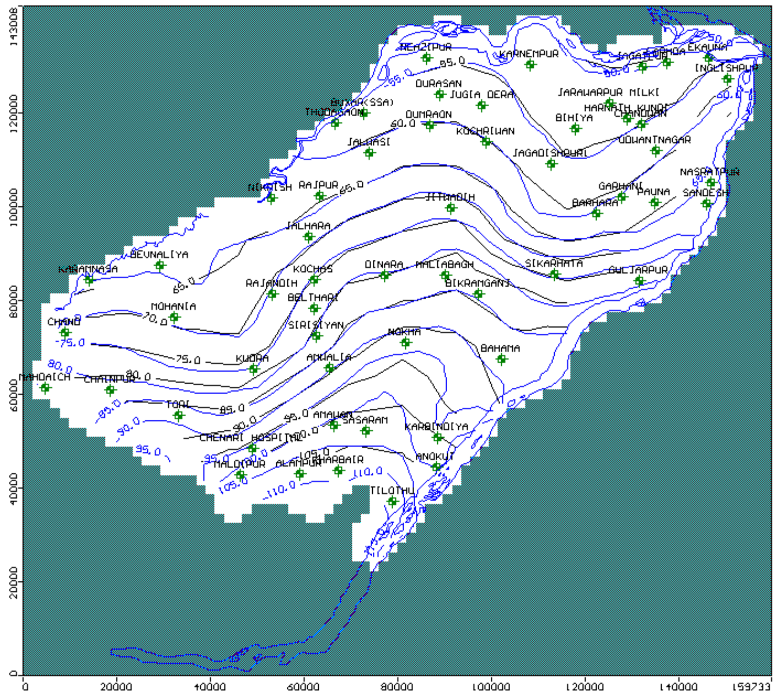

Fig. 5.1a: Computed heads (blue colour) and Water Table Elevation (black colour) for Nov 2015.

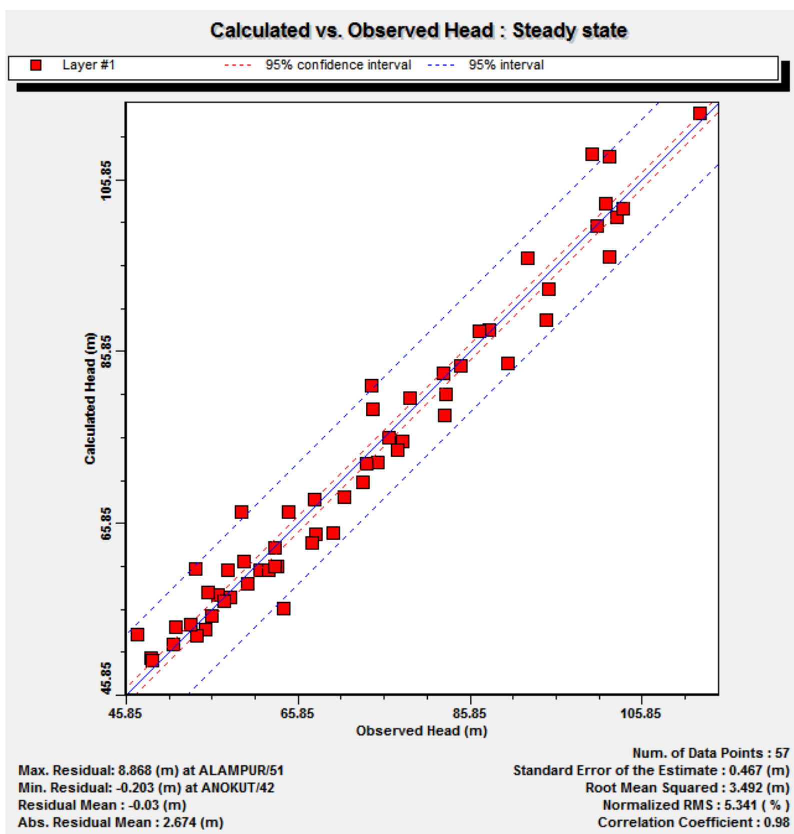

Fig. 5.1b: Comparison of Calculated versus observed heads (November 2015)

5.1.1 Water Budget – Steady State

Water Budget have been calculated for steady state (November 2015), so that water transfer mass balance may be understood. Total mass balance in steady-state is given table 5.1 and model generated water budget are given in table 5.2. The river-aquifer relations were also studied during model simulation.

Table 5.1: Mass-Balance in Steady-state

ITEMs	IN FLOW (m3/day)	OUT FLOW (m3/day)
Constant Head	2637.2	167090
Wells	7000	1107400
Recharge	1158900	0
River Leakage	248010	148030
Total	**1416547.2**	**1417170**

Table 5.2: Model generated water budget of the study area

```
zone budget - Notepad
File  Edit  Format  View  Help
Zone 1 [Zone1] [Zone1]
----------
Output Time: 1
Stress Period: 1

Input Report
Storage = 0 [m^3/day]
Constant Head =  2637.2  [m^3/day]
Wells = 7000 [m^3/day]
Drains =  0  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  1158900 [m^3/day]
ET = 0  [m^3/day]
River Leakage = 248010 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]
Total IN = 1416600 m^3/day

Output Report
Storage = 0 [m^3/day]
Constant Head =  161740  [m^3/day]
Wells = 1107400 [m^3/day]
Drains =  0  [m^3/day]
MNW = 0 [m^3/day]
LAKE  SEEPAGE = 0 [m^3/day]
Recharge =  0 [m^3/day]
ET = 0  [m^3/day]
River Leakage = 148030 [m^3/day]
Stream Leakage = 0  [m^3/day]
Surface Leakage = 0.00  m^3/day
General-Head = 0 [m^3/day]

Total OUT =  1417200 m^3/day
Difference: IN - OUT = -663.43 [m^3/day]
Percent Discrepancy = -0.05%
```

5.1.2 Sensitivity Analysis

Sensitivity analysis is the process to test the effect on the model if one parameter is slightly changed keeping other parameters unchanged (Bihery, 2008).

The purpose of the sensitivity analysis is to demonstrate the sensitivity of the model simulations to uncertainty in values of model input data. The sensitivity of one model parameter relative to other parameters is also demonstrated. Sensitivity analyses are also beneficial in determining the direction of future data collection activities. Data for which the model is relatively sensitive would require future characterization, as opposed to data for which the model is relatively insensitive. Model-insensitive data would not require further field characterization

In the present study the model has been found sensitive to the values of hydraulic conductivity. When hydraulic conductivity changes from 24 to 26 then RMS become 3.514 in place of 3.492. The Comparison of Calculated versus observed heads (November 2015) are given in figure 5.2.

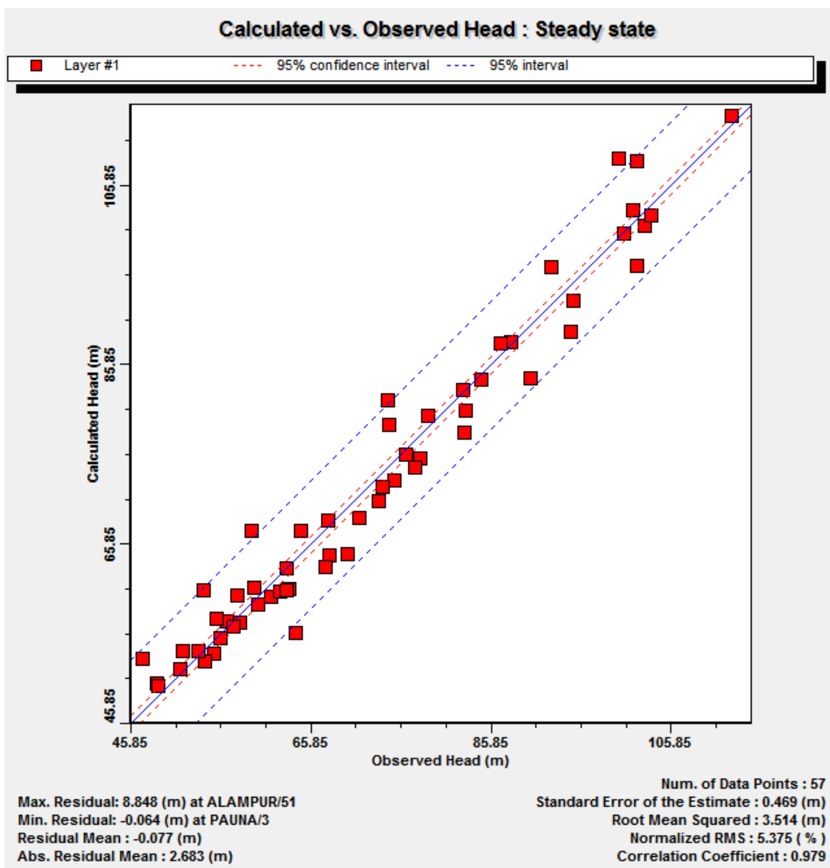

Fig. 5.2 : Comparison of Calculated versus observed heads (Nov 2015) after increasing hydraulic conductivity.

5.2 TRANSIENT STATE CALIBRATION

Transient condition was simulated from November 2015 to Nov 2018. The time steps in transient simulations run from 2015 to 2018 were divided in to 6 time steps. Recharge boundaries were set using a stress period of 183 and 182 days. The actual amount of recharge was calculated for each year using GEC-2015 methodology and assign to each stress period for the year 2015 to 2018.

After a number of trial runs, where the input/output stress were varied, calculated water levels were matched fairly reasonably to observed values. The RMS error for the transient state model is 4.243 m (Fig. 5.3). The observed pre- and post-monsoon water level for selected observation wells for the period 2015 to 2018 was used for the transient state calibration.

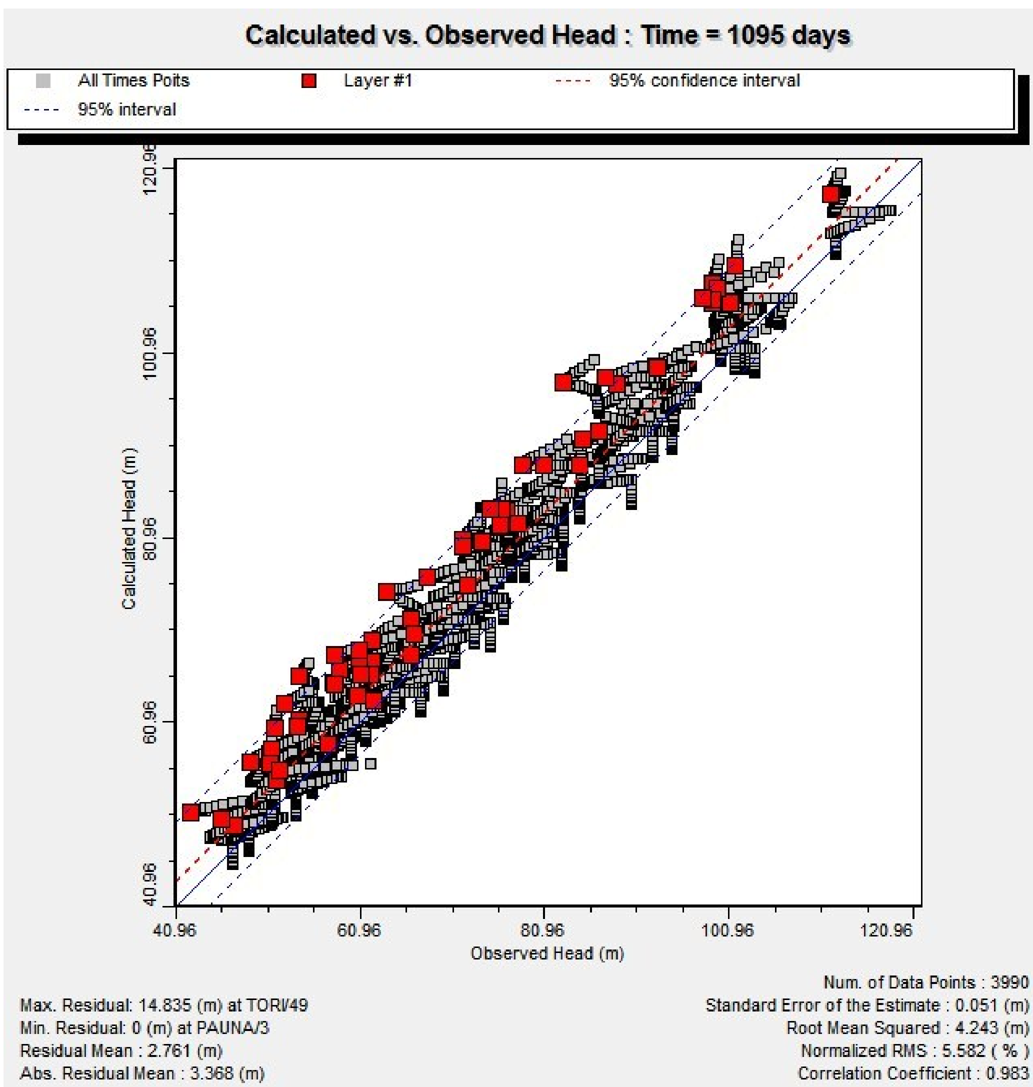

Fig. 5.3: Calculated versus observed heads (2015-2018)

5.2.1 Model Validation

To check the validity of the model, computed water table heads are compared with field observed heads for time periods from post-monsoon 2015 to post-monsoon 2018 (i.e. 1095 days) and good match is found during this periods. A comparison of observed and calculated heads at different observation wells are shown in figure 5.4a, b & c.

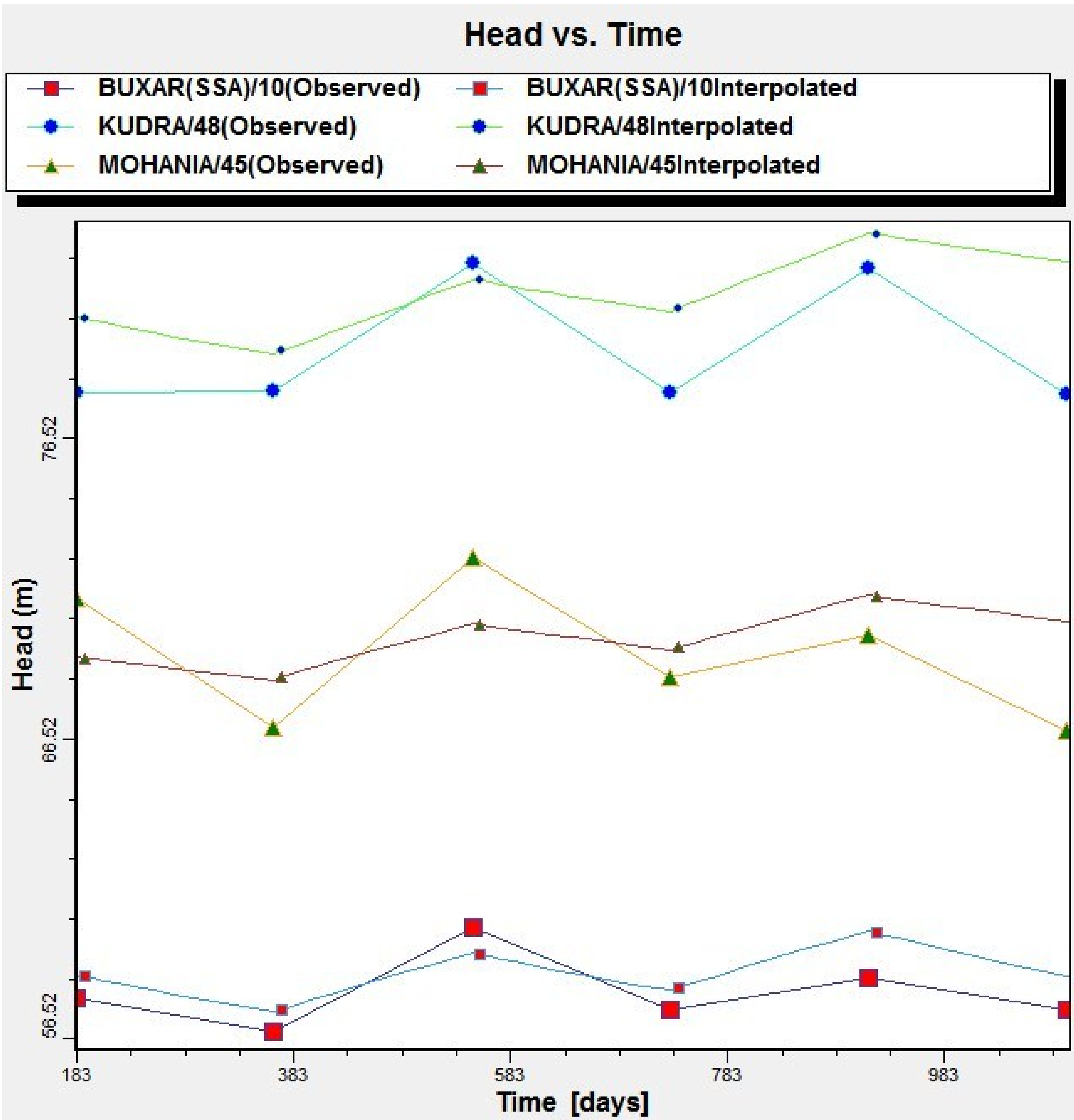

Fig.54a: Observed and simulated heads at Buxar, Kudra & Mohania.

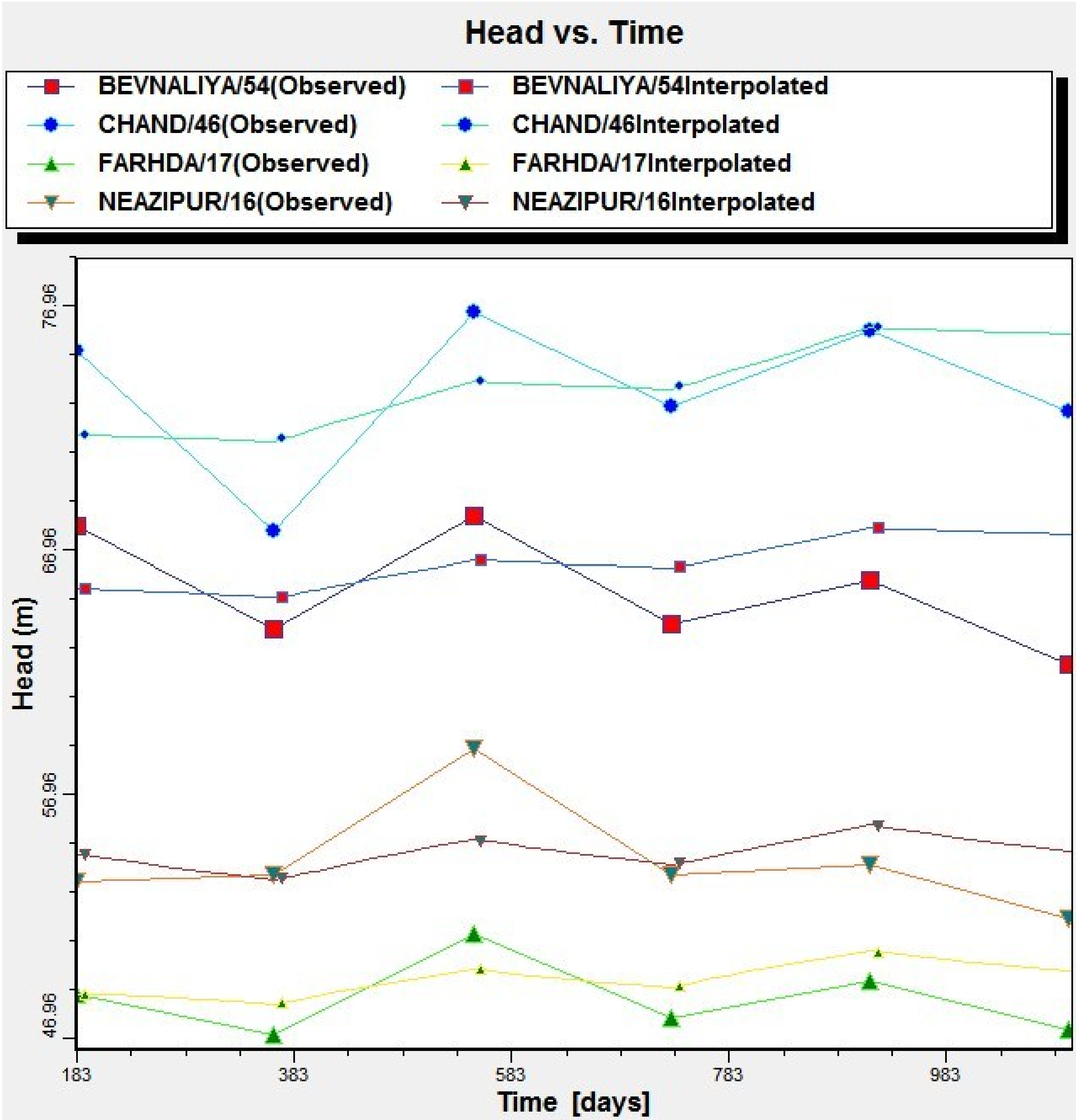

Fig.5.4b: Observed and simulated heads at Bevnaliya, Chand, Farhda and Neazipur.

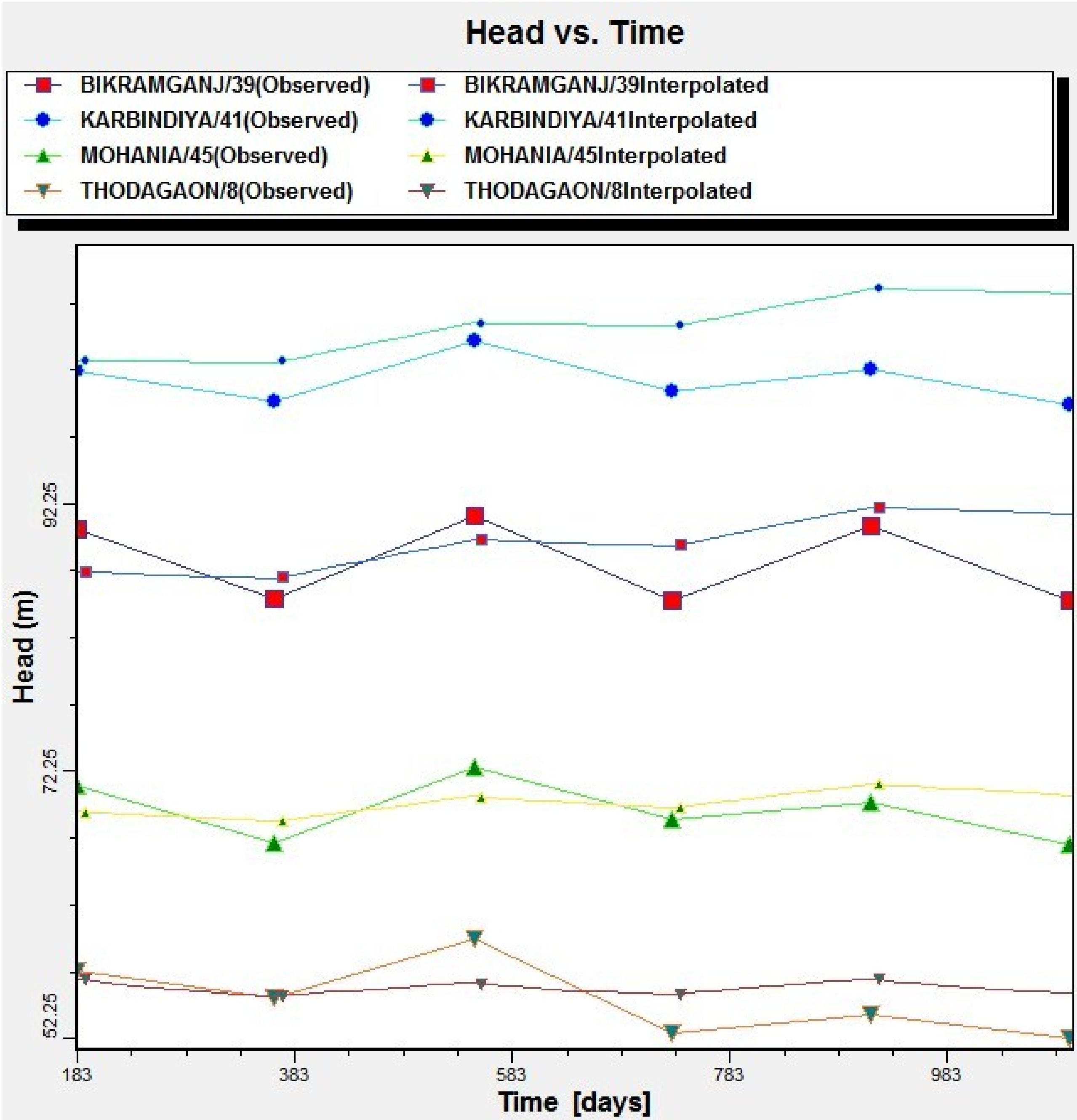

Fig.5.4c: Observed and simulated heads at Bikramganj, Karbindiya, Mohania and Thodagaon.

CHAPTER- 6

EVOLVING MANAGEMENT STRATEGIES AS PREDICTIVE SCENARIOS

6.1 Aquifer Management plan

In order to understand the response of the aquifer to various stress conditions the model was run upto 2025 by varying the recharge and discharge according to the future scenarios.

6.1.1 Scenario 1: *Gradual Increase in Agricultural draft (2019 to 2025) with 2% annual increment*

The model area is under intensive irrigated agriculture since decades. Almost all the tube wells are tapping ground water from aquifer I. In this scenario, in order to bring out the response of Aquifer I, the agricultural draft has been increased with 2% per year increment (over a period of 7 years) with respect to the prevalent draft during 2018, the model was run up to 2025 by keeping the recharge rate same. Impact on the aquifer system in terms of water level can be visualized by comparing post-monsoon scenario of year 2018 and 2025 as given in figures 6.1a and b respectively.

The ***comparision*** of flow patterns during 2018 and 2025 depicts significant changes in flow pattern near river Karmanasa. In 2018, the flow contours ran from southwest to northeast with apex towards upstream of the river. This indicate recharge of river from groundwater. In contrast, during 2025, flow contours in the southern sector of the river moved upstream with apex towards downstream of the river. This indicates that in this part groundwater will be overdeveloped in course of time. The de-saturated aquifer will be recharged from river, and hence a change in ground water flow regime will take place.

In the northern-eastern sector, in areas neighbouring river Sone, significant changes can also be observed. A groundwater trough is gradually being formed. This trough will change the groundwater flow direction locally.

Along the hilly area, in Southern sector, groundwater flow patterns will remain more or less same during the period *i.e.* 2018 to 2025.

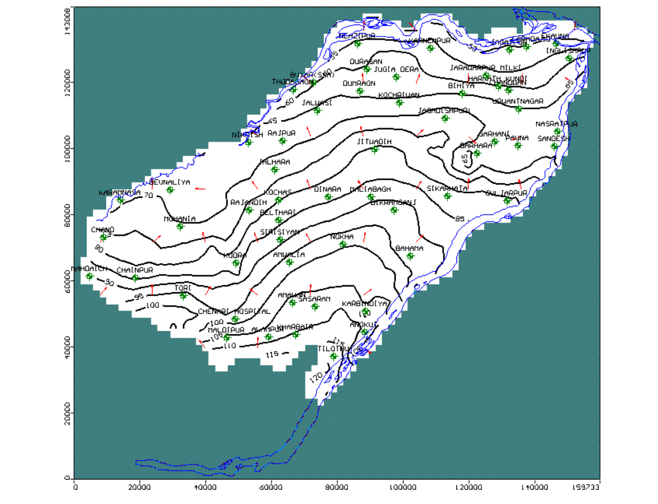

Fig 6.1a Flow regime during post-monsoon 2018.

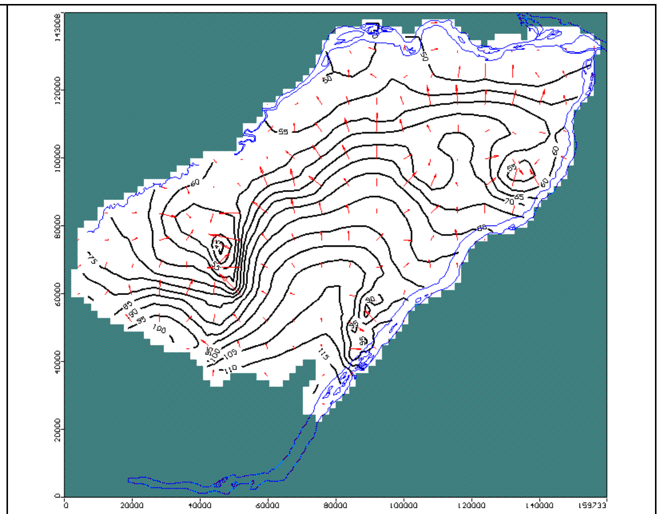

Fig. 6.1b Flow regime during post-monsoon 2025.

The drawdown map (fig 6.1c) indicates that drawdown is < 5m in maximum part of the area. In small patches towards the Sone River, drawdown is > 10 m. Maximum drawdown was observed in south western part of the area.

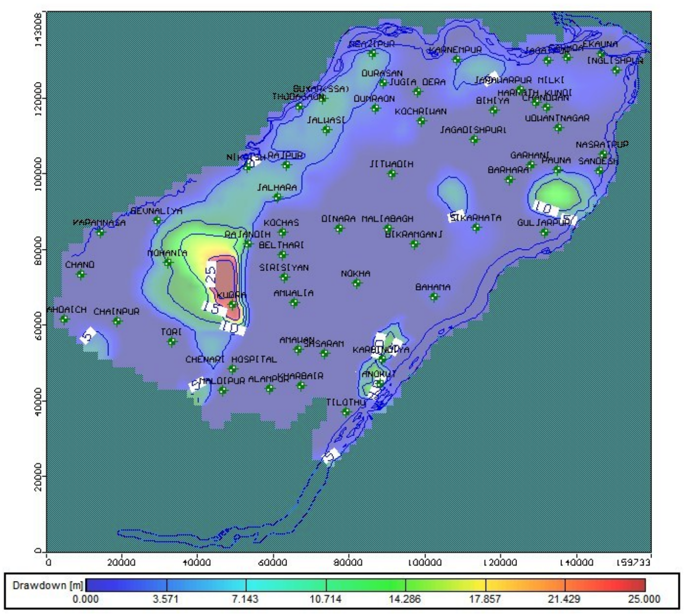

Fig. 6.1c Drawdown during post-monsoon 2025.

Behavior of well hydrograph up to 2025 has been also analyses for various locations (Anokut, Bahama, Dumrao,Farhda, Mohania and Neazipur). Hydrograph of the area is also indicate that continuous decline in head. The hydrograph of selected stations for prediction scenario- 1 are given in figure 6.2.

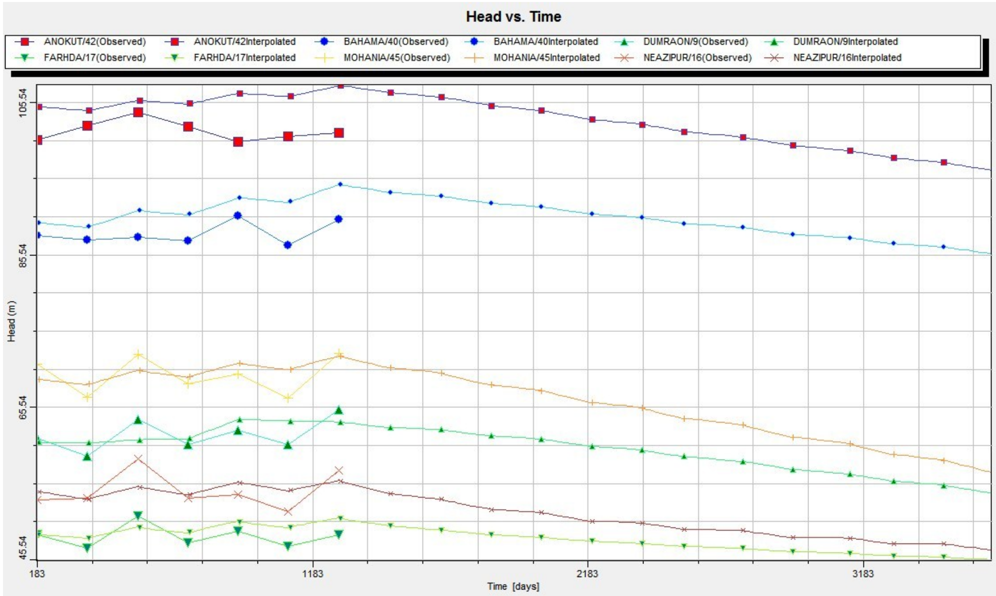

Fig. 6.2: Behavior of well hydrograph up to 2025

6.1.2 Scenario 2: *Gradual Increase in Agricultural draft (2019 to 2025) with 1% annual increment*

In this scenario, the agricultural draft has been increased @1% per year (over a period of 7 years) with respect to the prevalent draft during 2018, the model was run up to 2025 by keeping the recharge rate same. It was observed that the change in the characteristics of the imposed boundary conditions is less in comparison to scenario 1, as made out through the following figures 6.3a and b which depict the post-monsoon scenario of year 2018 and 2025 respectively.

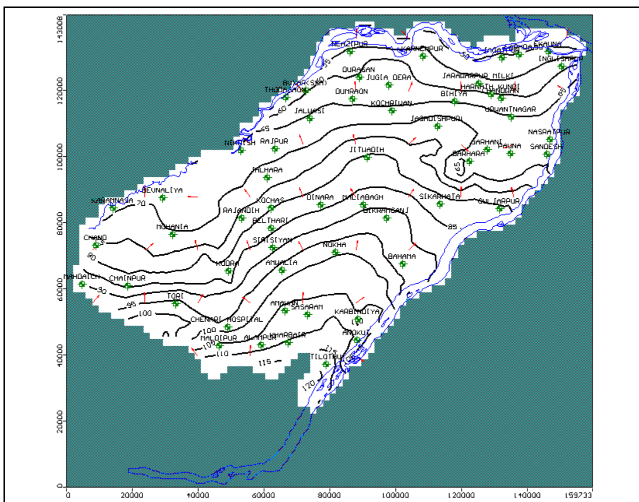	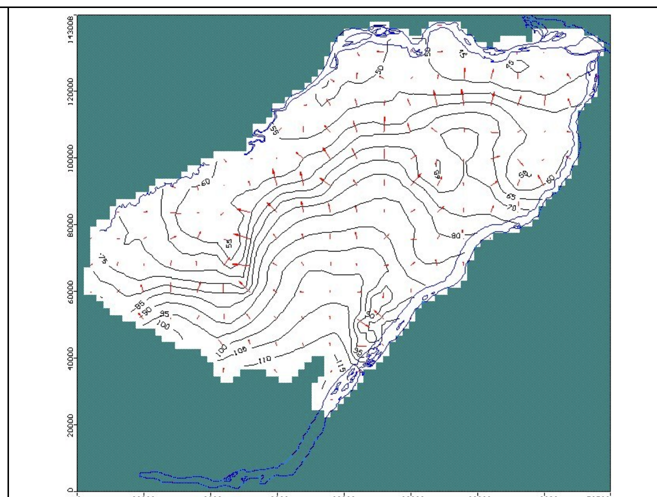
Fig 6.3a Flow regime during post-monsoon 2018.	**Fig. 6.3b Flow regime during post-monsoon 2025.**

The drawdown map (fig 6.3c) indicates that drawdown is < 3m in maximum part of the area. In small patches towards the Sone River, drawdown is < 10 m. Maximum drawdown was observed in south western part of the area.

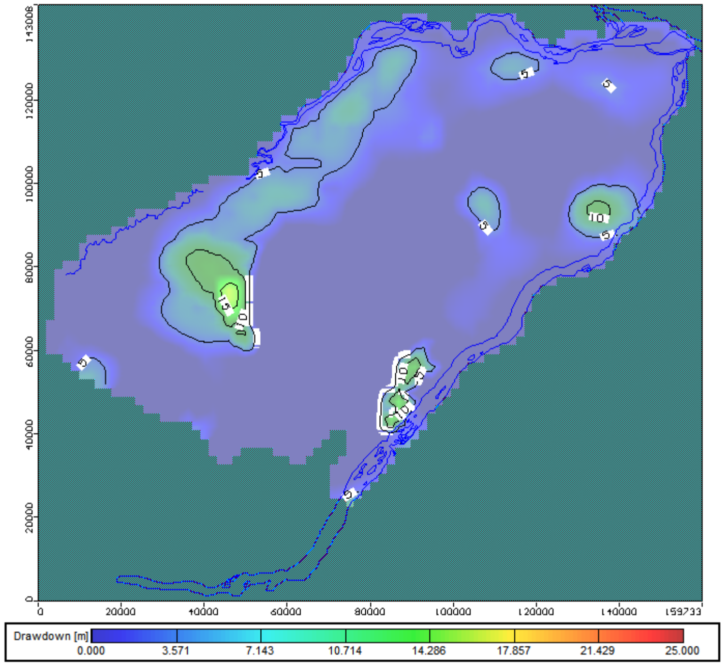

Fig. 6.3c Drawdown during post-monsoon 2025.

Behavior of well hydrograph up to 2025 has been also analyses for various locations (Anokut, Bahama, Dumrao,Farhda, Mohania and Neazipur). Hydrograph of the area is also indicate that continuous decline in head. The hydrograph of selected stations for prediction scenario- 2 are given in figure 6.4.

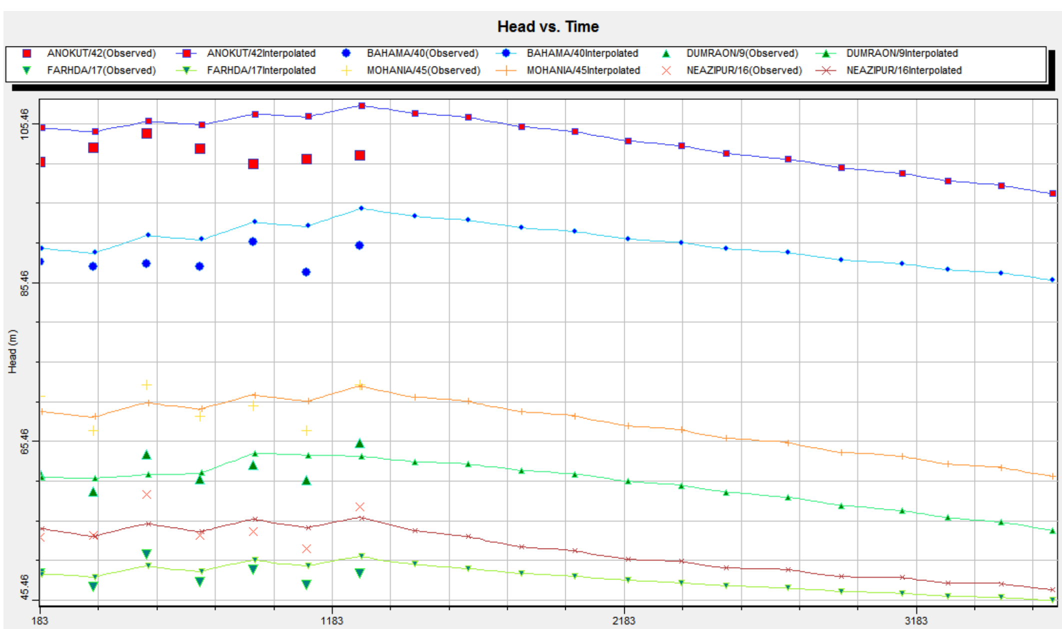

Fig. 6.4: Behavior of well hydrograph up to 2025

6.1.3 Scenario 3: *If no changes in Current Agricultural draft (2018) in Kudra, Bhabhua, Mohania block (Kaimur district), Dehri, Akhorigola block (Rohtas district) and Agion, Bihiya block (Bhojpur district) from 2019 to 2025.*

In this scenario, no change in the current agricultural draft (2018) in Kudra, Bhabhua, Mohania block (Kaimur District), Dehri, Kudra block (Rohtas District) and Agioan, Bihiya block (Bhojpur District), the model was run up to 2025 by keeping the recharge rate same.

It was observed that the change in the characteristics of the imposed boundary conditions is less in comparison to scenario 1, as made out through the following figures 6.5a and b which depict the post-monsoon scenario of year 2018 and 2025 respectively.

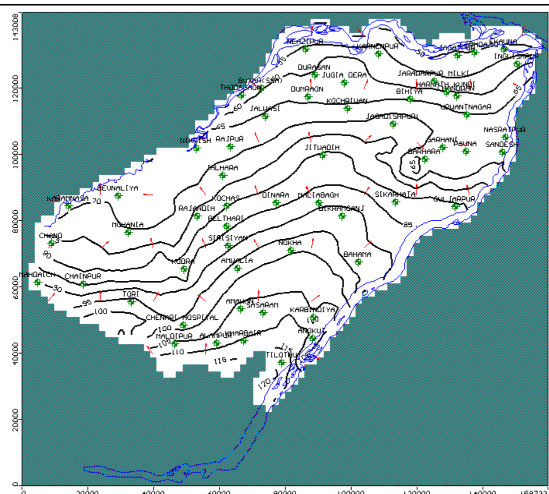

Fig 6.5a Flow regime during post-monsoon 2018.

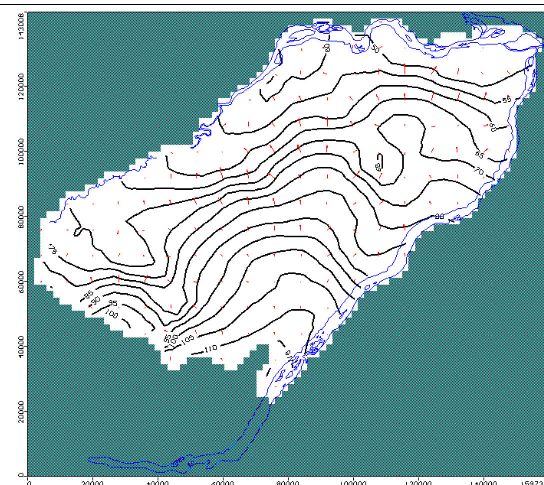

Fig. 6.5b Flow regime during post-monsoon 2025.

The drawdown map (fig 6.5c) indicates that drawdown is < 5m in all the study area.

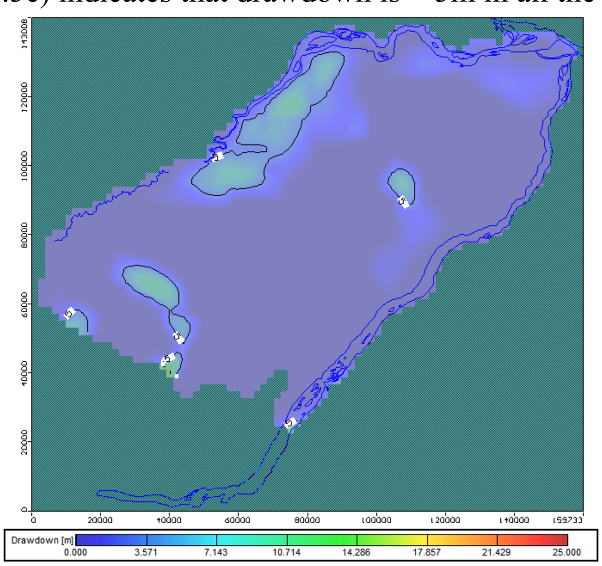

Fig. 6.5c Drawdown during post-monsoon 2025.

Behavior of well hydrograph up to 2025 has been also analyses for various locations (Anokut, Bahama, Dumrao,Farhda, Mohania and Neazipur). Hydrograph of the area is also indicate that continuous decline in head. The hydrograph of selected stations for prediction scenario- 3 are given in figure 6.6.

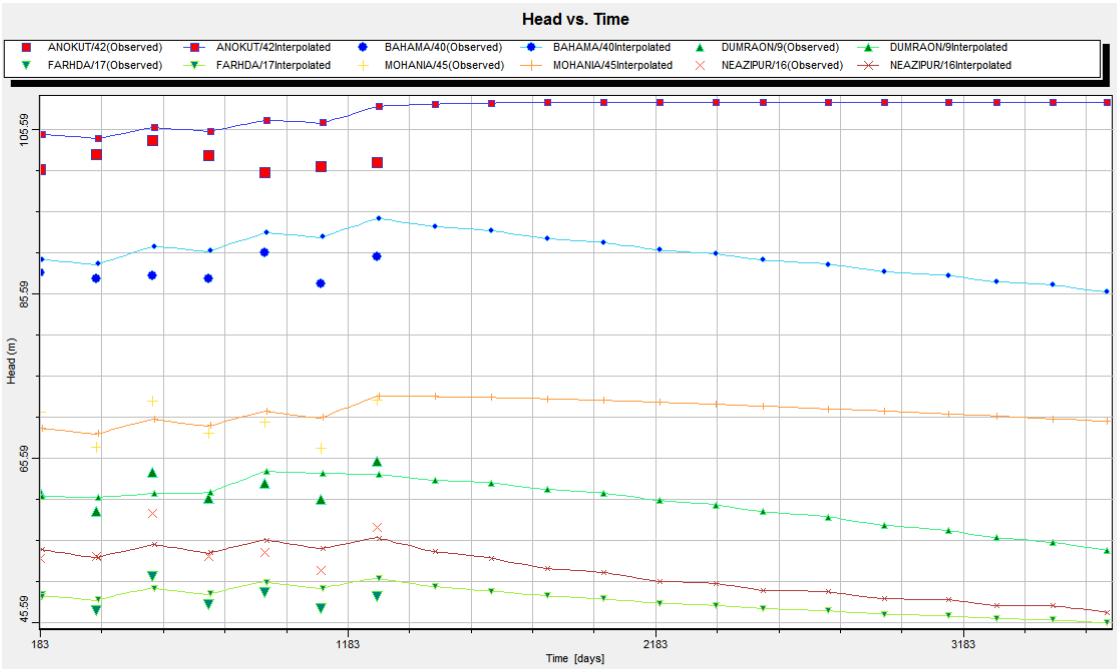

Fig. 6.6: Behavior of well hydrograph up to 2025

6.2 Quantification of Inflows/Outflows of various Boundary conditions imposed.

One of the main benefits of using the MODFLOW code is that its mass balance calculations provide a very useful way to examine the source of water provided to a system of pumping wells. From the table below (Table 6.1a & b), it can be seen how the percentage contribution from various sources changes in the projected scenario for year 2025 from that of year 2018. The most important changes are in the CHB (Ganga R) which receive 3.08% in 2018 and in the projected scenario for 2025, is 5.7% from area. This reflects upon how the nature of the river which changes its characteristics. Changes are also apparent in the flow from the River boundaries where the contribution changes from 28.11% in 2018 to 19.78% in 2025. The inflow and outflow from various sources and sinks for the scenario with normal increase in pumping (scenario 1) are presented in Table 6.1a and b respectively.

Table 6.1a: Inflow from various boundaries in year (2018) and (2025)

Sources	Volume (MCM), 2018	%	Volume (MCM), 2025	%
CHB	0	0.00	0	0.00
Rivers	28.11	0.58	19.78	0.41
Flux	0.85	0.02	71.26	1.49
Recharge	4772.38	99.19	4673.46	97.97
Storage	9.93	0.21	5.79	0.12
Total (In)	4811.27	100.00	4770.29	100.00

Table 6.1b: Outflow from various boundaries in year (2018) and (2025)

Sinks	Volume (MCM), 2018	%	Volume (MCM), 2025	%
CHB	148.07	3.08	272.17	5.70
Rivers	170.13	3.54	373.24	7.82
Pumping Wells	994.47	20.66	1644.58	34.46
Storage	3499.94	72.72	2482.4	52.02
Total (Out)	4812.61	100.00	4772.39	100.00

CHAPTER- 7

RECOMMENDED MANAGEMENT INTERVENTIONS

On the basis of the simulated scenarios and the insights into the aquifer dynamics gained through the modeling study, it can be concluded that the area is already witnessing intensive groundwater development from the top aquifer horizon. However, considering the prolific nature of the aquifer, an planned depletion from aquifer storage may be made as per the following recommendations (Fig 7.1 for designated zones for suitable management interventions).

a. Continuation of increase in pumping @ 2% per annum would lead to a decline in hydraulic head by 3 m on an average and upto 10-25 m in certain pockets in the study area (Fig. 7.1 a).

b. To stop this decline, no additional irrigation tube wells should be constructed in zones marked as “A”. Effect of non-sinking of additional irrigational tube wells in Zone A *i.e.* in Kudra, Bhabhua, Mohania block (Kaimur District), Dehri, Kudra block (Rohtas District) and Agioan, Bihiya block (Bhojpur District), have been simulated in the model (Fig. 7.1 b). The results indicate an uniform decline in hydraulic head by 3 m on an average without formation of excessive fall in water level in certain pockets.

c. In addition to it, artificial recharge may be planned in those areas.

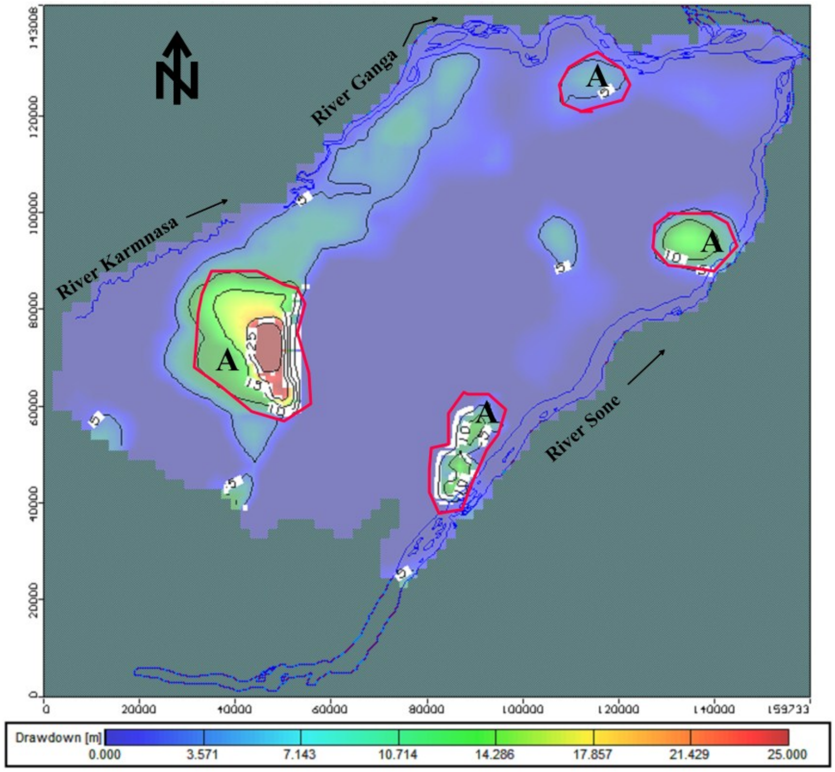

Fig. 7.1a: Area demarcated for adoption of suitable management interventions/Plans.

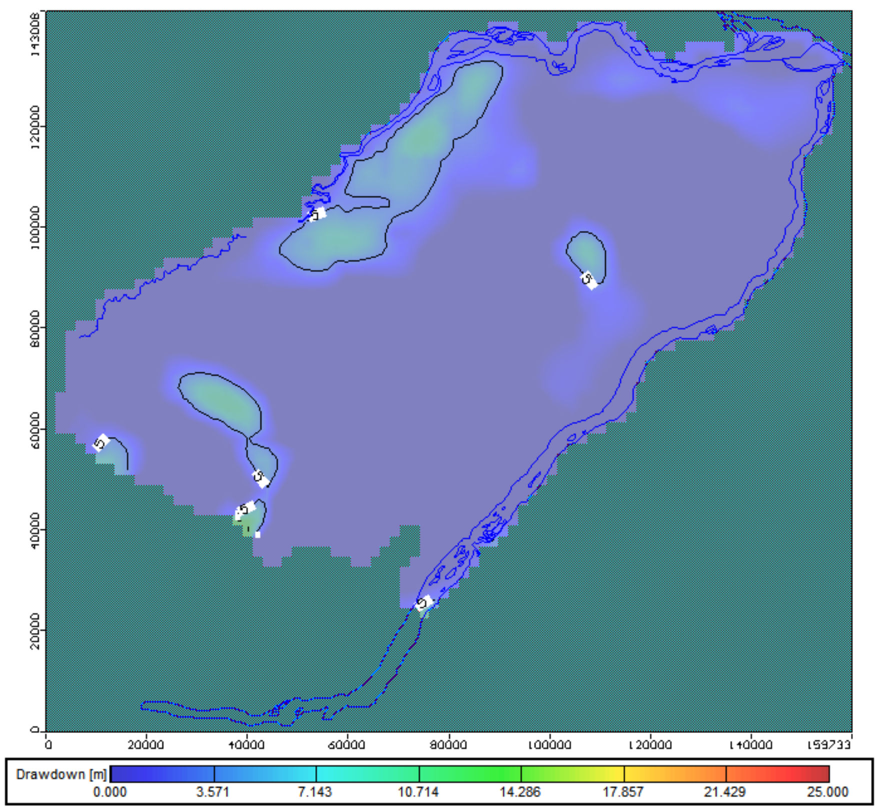

Fig. 7.1b After sinking of additional tube wells for irrigation in Zone A.

CHAPTER- 8

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Location of monitoring wells and their coordinates

S No.	Location	x	y	RL
1	Guljarpur	258283.57	2795898.8	80
2	Sandesh	272669.16	2812272.2	68
3	Pauna	261600.47	2812464.2	67
4	Garhani	254576.73	2813699.2	67
5	Nasratpur	273750.15	2816686.8	67
6	Jagadishpur1	239612.12	2820632.2	70
7	Udwantnagar	261797.6	2823543.8	64
8	Thodagaon	193518.07	2829371.2	63
9	Dumraon	213626.1	2828924.3	70
10	Buxar(SSA)	199600.68	2831450.6	63
11	Harnath Kundi	255886.53	2830300.7	56
12	Jarawarpur Milki	251928.57	2833699	55
13	Durasan	215778.7	2835530.6	62
14	Inglishpur	277138	2838794	60
15	Jagatpur	259102.2	2841325.7	55
16	Neazipur	212931.92	2843353.1	61
17	Farhda	264142.39	2842343.5	55
18	Ekauna	273197.2	2843293.8	53
19	Barhara	249091.72	2810033.3	72
20	Jalwasi	200810.61	2823106.9	66
21	Jitwadih	218035.27	2811430.1	81
22	Sikarhata	240200	2797200	81
23	Nikrish	179800	2813400	71
24	Jalhara	187800	2805200	74
25	Kochriwan	225622	2825346	65
26	Karnempur	235002.2	2841785	59
27	Rajpur	190142.5	2813924	70
28	Chandwan	258881.4	2829138	59
29	Jugia Dera	224776	2833124	62
30	Bihiya	244789	2828292	60
31	Kochas	189000	2796000	79
32	Rajandih	180000	2793000	76
33	Belthari	189000	2790000	85
34	Sirisiyan	189500	2784100	86
35	Amawan	193200	2765000	104
36	Nokha	208600	2782500	99
37	Dinara	204000	2797000	82
38	Maliabagh	217000	2797000	88

39	Bikramganj	224000	2793000	95
40	Bahama	229000	2779000	92
41	Karbindiya	215300	2762400	109
42	Anokut	215000	2756000	111
43	Amwalia	192200	2777300	97
44	Sasaram	200100	2763900	108
45	Mohania	159000	2788000	76.7
46	Chand	135879.4	2784834	78.1
47	Chainpur	145503.1	2772525	83.7
48	Kudra	176000	2777000	88.4
49	Tori	160000	2767000	94
50	Kharbair	194100	2755400	109
51	Alampur	185800	2754700	106
52	Maldipur	173300	2754300	115
53	Chenari Hospital	175800	2760000	100
54	Bevnaliya	156000	2799000	71
55	Karamnasa	141000	2796000	74
56	Mahdaich	131627	2772972	88.9
57	Tilothu	205775	2748621	121

Annexure II

Water level data of monitoring wells

S No.	Location	Post-monsoon 2015		Pre-monsoon 2016		Post-monsoon 2016		Pre-monsoon 2017		Post-monsoon 2017		Pre-monsoon 2018		Post-monsoon 2018	
		bgl	**amsl**	**bgl**	**amsl**	**bgl**	**amsl**	**bgl**	**amsl**	**bgl**	**amsl**	**bgl**	**amsl**	**bgl**	**amsl**
1	Guljarpur	5.45	74.55	6.4	73.6	2.88	77.12	5.12	74.88	3.63	76.37	5.81	74.19	3.71	76.29
2	Sandesh	3.26	64.74	6.02	61.98	1.45	66.55	4.84	63.16	3.12	64.88	7.22	60.78	2.52	65.48
3	Pauna	3.8	63.2	6.6	60.4	2.46	64.54	6.14	60.86	2.58	64.42	6	61	3.06	63.94
4	Garhani	4.6	62.4	6.45	60.55	2.15	64.85	5.5	61.5	3.22	63.78	6.22	60.78	2.7	64.3
5	Nasratpur	7.8	59.2	8.77	58.23	2.75	64.25	7.73	59.27	6.77	60.23	8.77	58.23	2.89	64.11
6	Jagadishpur1	4.83	65.17	6.1	63.9	1.76	68.24	4.38	65.62	2.66	67.34	6.1	63.9	2.85	67.15
7	Udwantnagar	4	60	5.95	58.05	0.7	63.3	5.05	58.95	2.58	61.42	5.72	58.28	1.55	62.45
8	Thodagaon	5.7	57.3	7.75	55.25	3.28	59.72	10.29	52.71	9.02	53.98	10.75	52.25	2.18	60.82
9	Dumraon	8.54	61.46	10.9	59.1	6.11	63.89	9.3	60.7	7.44	62.56	9.4	60.6	4.73	65.27
10	Buxar(SSA)	5.1	57.9	6.24	56.76	2.75	60.25	5.52	57.48	4.46	58.54	5.5	57.5	4.11	58.89
11	Harnath Kundi	4.37	51.63	5.15	50.85	2.1	53.9	4.8	51.2	4.49	51.51	4.38	51.62	4.09	51.91
12	Jarawarpur Milki	3.66	51.34	5.94	49.06	3.32	51.68	5.94	49.06	4.29	50.71	5.94	49.06	3.28	51.72
13	Durasan	5.55	56.45	8.24	53.76	4.43	57.57	6.45	55.55	5.57	56.43	7.8	54.2	4.47	57.53
14	Inglishpur	6.1	53.9	7.9	52.1	4.69	55.31	7.54	52.46	6.54	53.46	8.65	51.35	5.15	54.85
15	Jagatpur	6.18	48.82	8.01	46.99	2.47	52.53	7.78	47.22	7.1	47.9	9.1	45.9	4.58	50.42
16	Neazipur	7.61	53.39	7.37	53.63	2.17	58.83	7.35	53.65	6.9	54.1	9.1	51.9	3.79	57.21
17	Farhda	6.21	48.79	7.88	47.12	3.76	51.24	7.2	47.8	5.7	49.3	7.65	47.35	6.2	48.8
18	Ekauna	5.82	47.18	8.43	44.57	4.28	48.72	6.32	46.68	2.22	50.78	10.48	42.52	4.83	48.17
19	Barhara	8.53	63.47	9.5	62.5	7.45	64.55	8.21	63.79	6.42	65.58	9.65	62.35	5.65	66.35
20	Jalwasi	6.46	59.54	7.1	58.9	6.91	59.09	7.8	58.2	2.48	63.52	7.93	58.07	3.21	62.79
21	Jitwadih	7.21	73.79	8.1	72.9	7.98	73.02	8.87	72.13	7.27	73.73	8.92	72.08	7.37	73.63
22	Sikarhata	3.62	77.38	4.1	76.9	3.81	77.19	4.23	76.77	3.76	77.24	4.81	76.19	3.89	77.11
23	Nikrish	7.88	63.12	8.12	62.88	7.68	63.32	8.86	62.14	8.33	62.67	8.92	62.08	8.36	62.64
24	Jalhara	6.28	67.72	7.1	66.9	6.18	67.82	7.58	66.42	4.87	69.13	7.63	66.37	4.81	69.19

25	Kochriwan	7.4	57.6	6.19	58.81	4.9	60.1	5.2	59.8	3.44	61.56	6.25	58.75	4.38	60.62
26	Karnempur	4.94	54.06	5.17	53.83	3.47	55.53	6.63	52.37	5.42	53.58	7.78	51.22	5.4	53.6
27	Rajpur	2.52	67.48	8.37	61.63	4.87	65.13	7.58	62.42	7.19	62.81	3.6	66.4	2.22	67.78
28	Chandwan	3.24	55.76	5.8	53.2	3.04	55.96	3.14	55.86	2.95	56.05	4.72	54.28	2.66	56.34
29	Jugia Dera	6.66	55.34	7.45	54.55	3.6	58.4	6.55	55.45	5.56	56.44	9.2	52.8	6.55	55.45
30	Bihiya	4.9	55.1	5.51	54.49	2.17	57.83	4.42	55.58	4.15	55.85	5.61	54.39	4.55	55.45
31	Kochas	2.6	76.4	7.1	71.9	1.62	77.38	5.37	73.63	2.05	76.95	7	72	1.25	77.75
32	Rajandih	2.65	73.35	7.32	68.68	1.85	74.15	7.07	68.93	1.72	74.28	7.87	68.13	2.95	73.05
33	Belthari	2.12	82.88	6.32	78.68	2.37	82.63	5.99	79.01	2.08	82.92	8.17	76.83	3.47	81.53
34	Sirisiyan	3	83	6.38	79.62	1.96	84.04	6.88	79.12	2.56	83.44	7.49	78.51	2.67	83.33
35	Amawan	1.11	102.89	3.49	100.51	2.98	101.02	2.43	101.57	0.21	103.79	4.86	99.14	1.98	102.02
36	Nokha	4	95	5.01	93.99	1.67	97.33	4.94	94.06	2.12	96.88	5.87	93.13	1.57	97.43
37	Dinara	3.18	78.82	5.59	76.41	2.42	79.58	5.6	76.4	2.14	79.86	6.87	75.13	2.9	79.1
38	Maliabagh	5.2	82.8	7.18	80.82	5.93	82.07	6.32	81.68	4.44	83.56	7.04	80.96	2.56	85.44
39	Bikramganj	4.7	90.3	9.89	85.11	3.65	91.35	9.9	85.1	4.42	90.58	9.9	85.1	3.16	91.84
40	Bahama	3.88	88.12	4.55	87.45	4.21	87.79	4.58	87.42	1.4	90.6	5.21	86.79	1.86	90.14
41	Karbindiya	6.88	102.12	9.05	99.95	4.58	104.42	8.3	100.7	6.71	102.29	9.33	99.67	2.7	106.3
42	Anokut	10.37	100.63	8.51	102.49	6.78	104.22	8.63	102.37	10.63	100.37	9.94	101.06	9.45	101.55
43	Amwalia	2.22	94.78	5.72	91.28	1.87	95.13	5.65	91.35	1.82	95.18	8.2	88.8	2.4	94.6
44	Sasaram	4.33	103.67	9.65	98.35	1.44	106.56	2.43	105.57	0.21	107.79	9.84	98.16	2.08	105.92
45	Mohania	5.5	71.2	9.81	66.89	4.16	72.54	8.09	68.61	6.73	69.97	9.9	66.8	4.05	72.65
46	Chand	3.03	75.07	10.4	67.7	1.43	76.67	5.3	72.8	2.18	75.92	5.5	72.6	3.45	74.65
47	Chainpur	9.26	74.44	9.7	74	2.26	81.44	9.7	74	9.66	74.04	7.48	76.22	7.35	76.35
48	Kudra	10.35	78.05	10.3	78.1	6.01	82.39	10.35	78.05	6.17	82.23	10.41	77.99	6.27	82.13
49	Tori	7.14	86.86	6.25	87.75	3.42	90.58	7.18	86.82	7.53	86.47	11	83	7.6	86.4
50	Kharbair	6.99	102.01	7.32	101.68	7.1	101.9	7.22	101.78	6.98	102.02	7.31	101.69	7.1	101.9
51	Alampur	5.97	100.03	6.56	99.44	5.98	100.02	6.2	99.8	5.9	100.1	6.81	99.19	6.16	99.84
52	Maldipur	13.34	101.66	16.1	98.9	13.12	101.88	15.72	99.28	13.63	101.37	15.81	99.19	13.85	101.15
53	Chenari Hospital	7.38	92.62	12	88	3.27	96.73	12.6	87.4	7.03	92.97	12.4	87.6	4.47	95.53

54	Bevnaliya	3.1	67.9	7.3	63.7	2.63	68.37	7.08	63.92	5.26	65.74	8.7	62.3	7.53	63.47
55	Karamnasa	4.11	69.89	9.86	64.14	3.83	70.17	10.03	63.97	6.13	67.87	11.75	62.25	8.88	65.12
56	Mahdaich	4.1	84.8	4.32	84.58	3.86	85.04	3.95	84.95	3.92	84.98	4.12	84.78	3.98	84.92
57	Tilothu	8.44	112.56	8.92	112.08	2.46	118.54	8.76	112.24	7.5	113.5	9	112	8.02	112.98

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