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Department of Water Resources, River Development and Ganga Rejuvenation
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भू-जल न्यूज़

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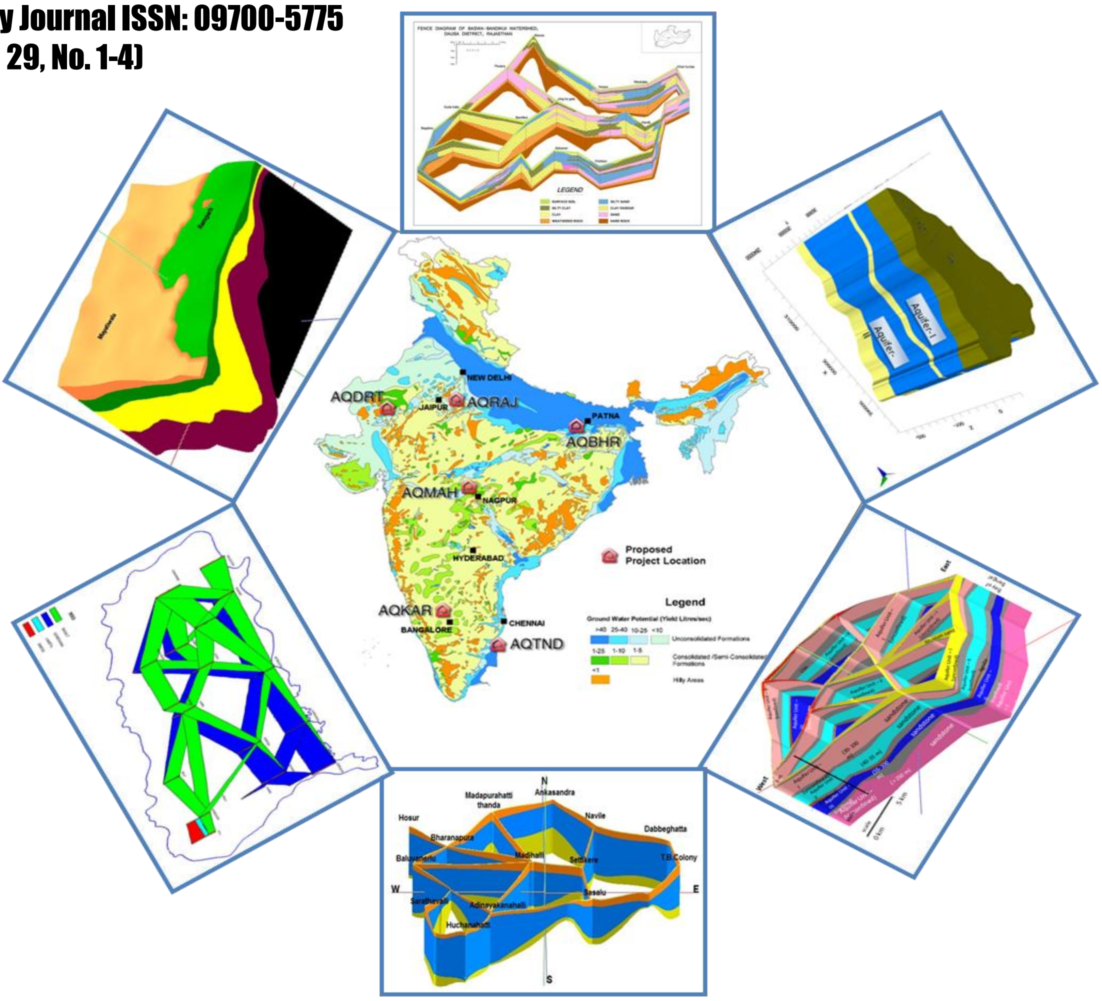

Special Issue

Pilot Studies on Aquifer Mapping

भू-जल न्यूज़

Bhu-Jal News

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All editorial correspondence may be addressed to editor, Bhujal News, Central Ground Water Baord, Bhujal Bhawan, NH-4, Faridabad-121001, Haryana. Email: bhujal-cgwb@nic.in

Patron's Musings

CGWB under Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India, with assistance from the World Bank under Hydrology Project-II had initiated Pilot Project on Aquifer Mapping in Six different Hydrogeological terrains in 2013 covering parts of states of Bihar (Alluvial plains of Ganga basin in Watershed GNDK013, Patna District), Rajasthan (Alluvium overlying hard rocks in Baswa-Bandikui, Dausa District and Parts of Thar Desert Terrain in Jaisalmer district), Maharashtra (Basaltic traps underlain by Gondwanas in Watershed WGKKC-2, Nagpur District), Karnataka (Cystalline rocks in Parts of Tumkur District) and Tamil Nadu (Coastal sediments in Lower Vellar Watershed, Cuddalore District, Tamil Nadu). The objectives of the pilot studies were to define the aquifer geometry, types of aquifers, ground water regime behaviors, hydraulic characteristics and geochemistry of Multi-layered aquifer systems on 1:50,000 scale, application of new geophysical techniques and establishing the utility, efficacy and suitability of these techniques in different hydrogeological setup and thus finalizing the approach and methodology on which National Aquifer mapping programme of the entire country could be implemented. The experiences thus gained could be utilized to upscale the activities to prepare micro level aquifer mapping in the future.

Volume 29, No 1-4 of Bhujal News is dedicated to these pilot studies of National Aquifer Mapping programme which was the precursor to the still ongoing nationwide Aquifer Mapping Programme.

The findings of these pilot studies are relevant even today and I believe that this volume will be of immense help to people working in the ground water sector.

K.C.Naik
(Chairman)

Editorial

There has been a paradigm shift from Aquifer Development to Aquifer management in the thought process of the water managers. As the saying goes "What cannot be measured cannot be managed", CGWB had embarked on an ambitious programme of National Aquifer Mapping & Management (NAQUIM), covering the whole country. As a precursor to this ambitious programme, a pilot study was taken up covering different hydrogeological terrains. The findings were shared in various fora and also the reports were made available in CGWB website for wider audience. It was felt that a special issue on "Pilot Studies on Aquifer Mapping" may be brought, providing a summarized results of the studies to enable the readers to get a bird's eye view of the results of pilot study. Next few issues will be brought out as special volumes on aquifer mapping studies undertaken by CGWB in different terrains. This issue is a harbinger of special issues on various terrains and hope these issues will be of immense use to the readers.

G.C.Pati
Member(HQ)

Contents

1. Model assisted Aquifer Management Plan for a multi-layered alluvial aquifer: Case study from Maner-Khagaul area in Middle Ganga Basin in Bihar 1-28

   S.N. Dwivedi, Fakhre Alam, R.R.Shukla, Shashikant Singh

2. Aquifer mapping and Management in Baswa-Bandikui watershed, Dausa district, Rajasthan, India 29-42

   Rana Chatterjee, A.K. Jain, Subhas Chandra, Vikas Tomar, P.K.Parchure, Shakeel Ahmed

3. Ground Water Modelling for Sustainable Aquifer Management - A Case study of WGKKC-2 Watershed, Nagpur, Maharashtra 43-55

   Bhushan R. Lamsoge and N. C. Nayak

4. Aquifer Mapping for Groundwater Management in Water Stressed Ankasandra Watershed, Tumkur district, Karnataka, Southern India 56-71

   Vittala S.S., Reddy, G.R.C., Krishnamurthy, G., Sooryanarayana, K.R and Sudarshan, G

5. Aquifer Mapping in Lower Vellar Watershed, Cuddalore Coastal Aquifer system, Tamil Nadu 72-82

   D. Gnanasundar, M. Senthilkumar and N. Rameshkumar

6. Aquifer mapping and management in Desert area – a case study from Jaisalmer district, Rajasthan 83-93

   Rana Chatterjee, Binoy Ranjan, Subhas Chandra, P.K. Parchure, Shakeel Ahmed

Model assisted Aquifer Management Plan for a multi-layered alluvial aquifer: Case study from Maner-Khagaul area in Middle Ganga Basin in Bihar

S.N. Dwivedi[1], Fakhre Alam[2], R.R.Shukla[2], Shashikant Singh[3]

1 CGWB, HQ, Faridabad, 2 CGWB, MER, Patna 3 CGWB, NR Lucknow

Abstract

An integrated study for micro-level characterization of a multi-layered alluvial aquifer from a type area in the Middle Ganga Plain (MGP) has been carried out. As part of the study, detailed investigations were carried out in Maner-Khagaul area of the MGP spread over 521 km2 for delineating the aquifer geometry, quantification of the available ground water resources and its quality through exploratory drilling, geophysical investigations, monitoring of the aquifer piezometry and water quality analysis. The generated data were used in conjunction with the available data from earlier studies/records to generate the aquifer maps, the behavior of the aquifer piezometry and evaluation of the water quality. A model assisted aquifer management plan for the study area has been developed using MODFLOW for sustainable development of groundwater resources in the area.

Key words: Middle Ganga Plain, aquifer piezometry, ground water resources, aquifer management plan, MODFLOW

Introduction

Significant part of India's groundwater resources are hosted in the alluvial aquifers of the Ganga Plain. The Ganga Plain extends from Aravalli-Delhi ridge in the west to the Rajmahal hills in the east; Himalayan foothills in the north to Bundelkhand- Vindhyan-Hazaribagh plateau in the south. The length of the Plain is ~1000 km with width varying between 450-200 m being wider in the western and narrower in the eastern part (Singh 2004). The present study focuses on micro-level characterization of the aquifers in a typical alluvial environment from a watershed located in the Middle Ganga Plain falling in the State of Bihar in eastern India. A model assisted aquifer management plan for the watershed has been developed for sustainable development of groundwater resources in the area.

Study area

The study area spreads over 521 km^2 lying between N latitudes $25^0 25'12''$and $25^0 40'48''$ and E longitudes $84^0 49'12''$ and $85^0 13'12''$ falling in Survey of India toposheet nos, 72G/2, 72C/14 and 72C/15. It extends over parts of seven administrative blocks (Patna Sadar, Danapur, Phulwari, Maner, Bikram, Bihta, and Naubatpur) of Patna district (**Fig. 1**) with a mean population density of 3230. The area enjoys a typical subtropical climate. The winter season starts from the month of October and continues up to February. Summer season starts from April and continues up to mid –June. The rainy season continues from mid –June to the end of September, which receives the South-west monsoon and accounts for about 90% of the total rainfall. The area receives an average normal monsoon rainfall of about 1100 mm/year.

The area forms a part of the Gangetic plain underlain by thick alluvial deposits comprising sediments (sand of various grades, gravel and clay) of Quaternary age deposited unconformably over the Precambrian basement (Bose et al 1966, CGWB 2009, Dwivedi et al 2011, Saha et al. 2014). Physiographically, the area represents a monotonously flat topography. The topographical variation within the area indicates that the general slope is from south-west to north-east with minor variations.

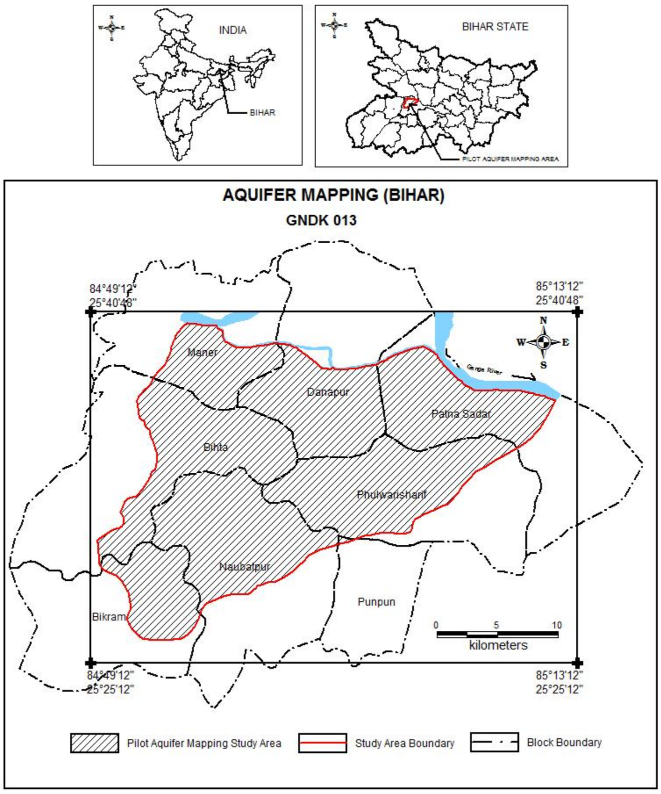


Fig. 1Base map of the study area

Methodology

Micro-level characterization of the aquifers in the area was made through exploratory drilling, detailed geophysical investigations, monitoring of the aquifer piezometry and water quality analysis. As part of the study, exploratory drilling and pumping tests for evaluation of the aquifer parameters was carried out at 6 locations, geophysical investigations including borehole logging (electrical and gamma logging), vertical electrical soundings (VES) at 98 locations, transient electromagnetic method (TEM) survey at 101 locations and electrical resistivity tomography (ERT) of 8.32 line km. Sky borne heliborne survey was also conducted in 52 km^2 in the southern part of area. Eighty one groundwater samples were collected and chemically analyzed from the study area. The generated data were used in conjunction with the earlier available data of exploration for the study area to generate the aquifer maps, the behavior of the aquifer piezometry and evaluation of the water quality. On the basis of the visual analysis of the drill cut samples and electrical borehole logs, lithological sections have been prepared using ROCKWORKS 15 package. Visual Modflow 11.1 has been used for Ground Water Modeling for the area.

Aquifer framework and hydraulic characteristics

A two-tier aquifer system has been delineated in the study area upto the depth of 300 m below ground level (m bgl). Lithological sections along different orientations revealing the two-tier aquifer architecture are depicted in **Fig 2** .

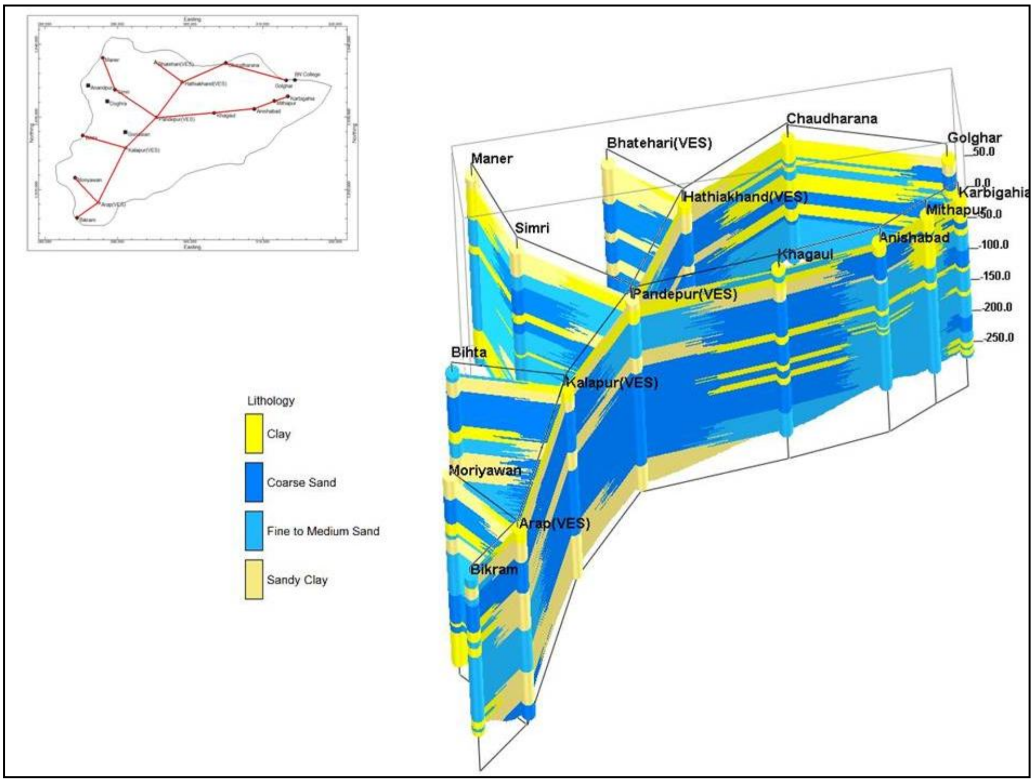


Fig.2 Lithological sections along different orientations.

The alluvial sequence in the study area commences with an aquitard layer consisting of highly heterogeneous admixture of clay, sandy clay and fine sand. The spatial variation of the thickness of the top aquitard layer lies mostly within 20-30 m in major part of the area. In the northern part, along the course of River Ganga, the thickness of this layer increases upto 40 m and beyond. The thickness of the 1st principal aquifer, occurring below the aquitard layer, varies from ~ 50 m in the southern part to ~80 m in the north-western and north-eastern part. The 2nd principal aquifer is comparatively much thicker than the 1st principal aquifer. The general thickness of this aquifer is ~100 m in major part of the area and at places it is even >140 m. The disposition of aquifers may be summarised as:

Top aquitard layer: The top aquitard layer is highly mixed and many a time behaves like a low potential aquifer. The presence of sands in the top zones at places renders it semi-pervious in nature. This layer sustains the dug wells and shallow hand pumps of the area. The thickness of this aquitard is more in the north and north-eastern part closer to river Ganga.

First principal aquifer: The first principal aquifer starts from 35-60m and it goes up to 80 - 130m bgl in general. The thickness of the first principal aquifer in general is about 50m. *First impervious layer*: The 1st principal aquifer is separated from second aquifer by 9 to 60 m impervious layer consisting of clay and sandy clay. This layer is thin in north-eastern part in comparison to the other parts of the area.

Second aquifer: Below the first confining layer, there is a 2nd principal aquifer which is much thicker in comparison to the first principal aquifer. At places, this aquifer zone is intercalated with thin lenses of clay and sandy clay. The depth of occurrence of this principal aquifer is 110 m bgl to 265 m bgl.

Second impervious layer: There is a thick clay and sandy clay bed impervious in nature below the second confining layer. Except at few places, it continues up to depth of 300 m bgl.

On the basis of the aquifer disposition discussed above, a 3-dimesional depiction of the aquifer system in the area using Visual Modflow flex 11 has been prepared which is shown in **Fig. 3.**

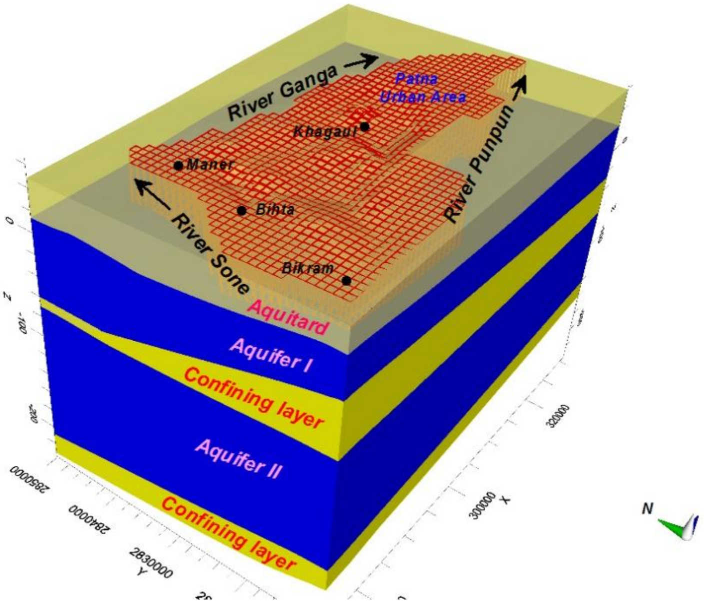


Fig.3 :3-dimesional depiction of the aquifer system in the area using Visual Modflow flex.

The yield of the tubewells tapping first aquifer (within 110m bgl) varies from 160 m^3/hr to 222 m^3/hr for a maximum drawdown of 3.5 m. The transmissivity of the aquifer ranges between 4907and15984 m^2day^{-1} with mean value of 7861 m^2day^{-1}. The specific capacity of the wells ranges from 56 to 100 $m^3hr^{-1}m^{-1}$ and the mean hydraulic conductivity (K) has been found as 113 m/day corresponding to that of coarse sand mixed with gravel. The storage co-efficient of the 1st aquifer has been found varying from 7.7 $x10^{-2}$ to $5.0x10^{-3}$ respectively indicating semi-confined to confined nature of the aquifer.

The transmissivity of the second aquifer ranges between 5892 and 15479 m^2day^{-1} with mean value of 8631 m^2day^{-1}. The mean hydraulic conductivity (K) has been found as 94 m day^{-1} corresponding to that of coarse sand and coarse sand mixed with gravel. The discharge of tube well tapping 2nd principal aquifer varies from123m^3/hr to 224m^3/hr for a maximum drawdown of 4 m. The storage coefficient of the second aquifer varies from 1.48 x 10^{-5} to 4.98x 10^{-4} indicating the confined nature of this aquifer.

Aquifer Piezometry

To study the aquifer piezometry, 76 wells were established for monthly monitoring in the project area, of which, 50 are open dug wells tapping the aquitard layer, 19 are piezometers tapping the first aquifer and 7 are piezometers tapping the second aquifer. The range of the water levels encountered in the dug wells, aquifer I and II for the year 2013 are tabulated as under (Table 1).

Aquifers	Depth to piezometric level (m, bgl)					
	Pre- monsoon			Post- monsoon		
	Min	Max	Average	Min	Max	Average
Aquitard layer	1.36	9.39	4.7	0.48	4.84	2
Aquifer I	5.73	13.16	10.10	1.49	10.08	6.81
Aquifer II	6.64	12.84	9.7	3.56	10.04	6.3

Table 1: The range of the water levels encountered in the dug wells, aquifer I and II for the year 2013

Ground Water flow modeling

Ground water modelling of the area has been carried out using MODFLOW which is a computer program that numerically solves the three-dimensional ground-water flow equation for a porous medium by using a finite-difference method (Waterloo Hydrogeologic Inc. 2005). 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. Based on the available information as discussed above, a conceptual ground water model has been framed. 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).

Grid Design

The area has been divided into 58 columns and 40 rows with a uniform grid size of 1000mX 1000m has been grouped into 5 layers containing 2 main aquifers (Layer 2 and Layer 4 Aquifer 1 and Aquifer 2). The bottom of layer 5 has been considered as the base of modelling depth. Spatial and vertical variations in hydrologic characteristics in the aquifer framework were represented by discrete values in each of the model cells. Model cells extend vertically into the aquifer and divide the aquifer into discrete volumes of aquifer material that are assumed to have uniform hydrologic characteristics. The model grids showing the active and inactive cells are shown in **Fig 4**. Hydrogeological cross section along row 18 & 25 showing five layers system are shown in **Fig. 5a & b.**

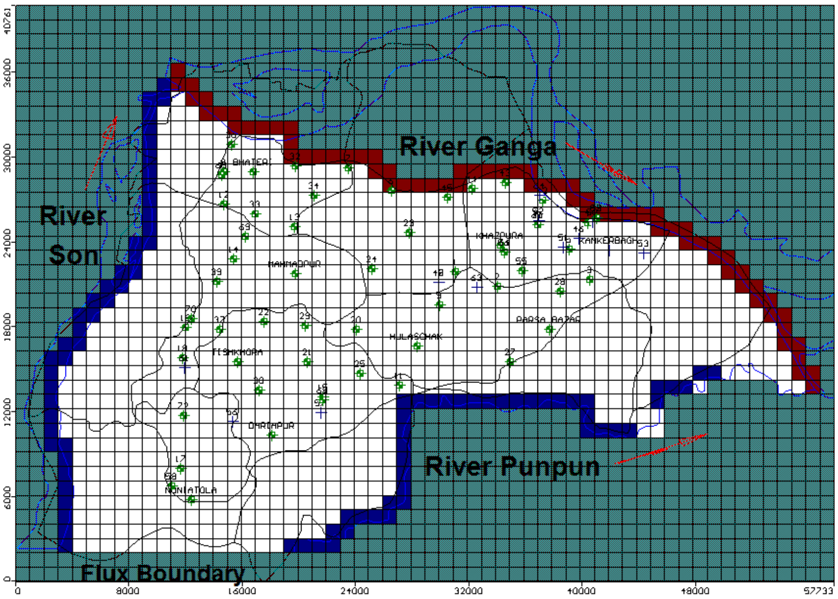


Fig.4 The conceptual model. Green, white, blue and red cells are inactive, active, River boundary, CHB cells respectively.

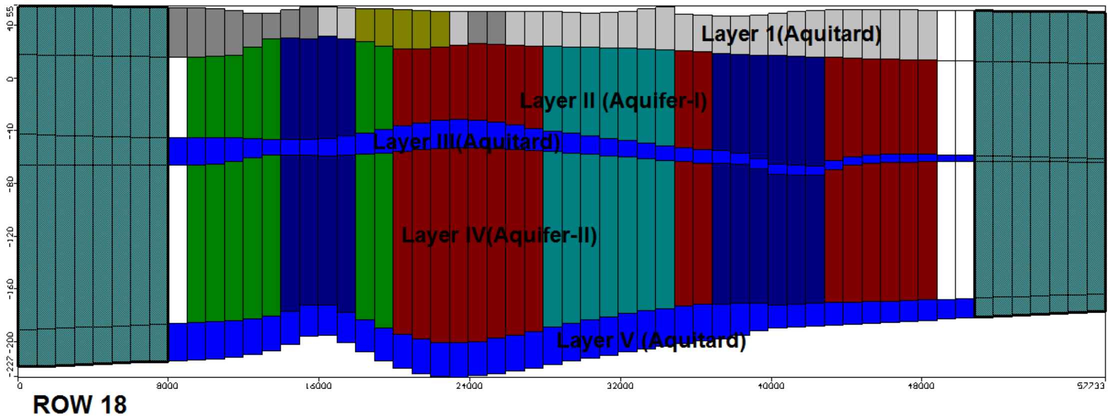


Fig 5a: Hydrogeological cross section along row 18 showing five layers system.

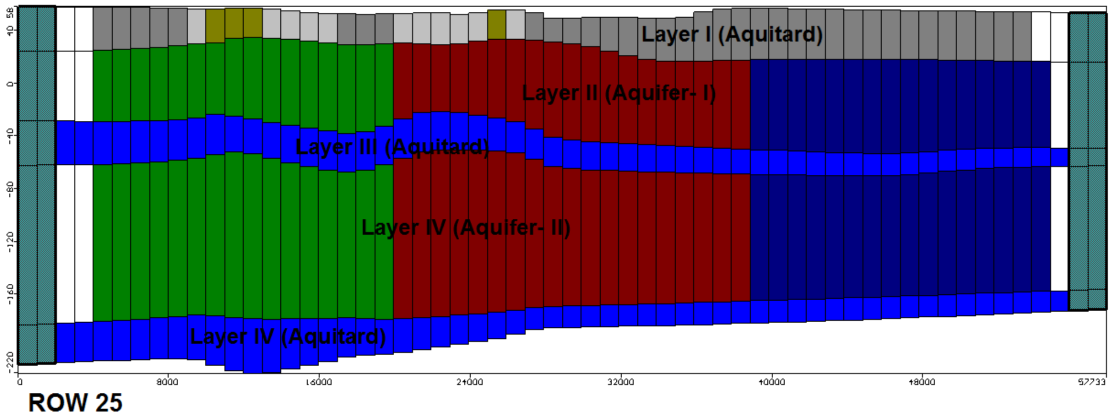


Fig:5b Hydrogeological cross section along row 25 showing five layers system.

The ground elevation data available for 72 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.

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
3. Recharge is invariant over large periods of time;
4. Small scale variations of hydraulic conductivity within cells are negligible.

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 ground water 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). For layer 1, the physical boundary is formed by River Ganga towards the north and north-east. Towards west along the bank of River Son and towards south along the course of

River Punpun, River boundary has been assigned. The model boundaries are depicted in Fig. 6.

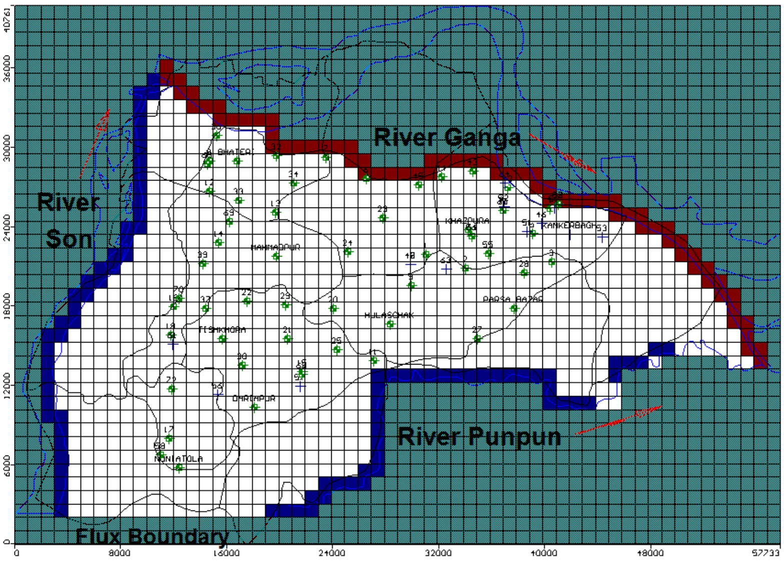


Fig. 6: Model boundaries: the southern (PunpunR.) and the western (Sone R.) boundary are the River boundaries respectively. NW-SE flow of the river Ganga (maroon cells) forms the northern and the eastern boundary.

River boundary condition

The western and southern boundary has been assigned as River Boundary along the present course of River Son and Punpun. The present course of river Punpun is believed to be occupying the eastern most abandoned channel of the River Sone. The Punpun and 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 groundwater 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 transmissive properties of the riverbed and the difference between the head in the aquifer and the river stage. The river stage data pertaining to the period under calibration and validation obtained from the river gauging station of Central Water Commission (CWC), Govt. of India for River Son at Koelwar and Maner, Sripalpur for River Punpun , has been assigned. For the period under the projected scenario, the decadal mean monthly stage of River Sone and Punpun have been assigned.

Constant head boundary

The northern and the north-eastern boundary along the course of the River Ganga have been assigned as Constant Head Boundary. River Ganga within this segment is effluent in nature. The river stage data pertaining to the period under calibration and validation obtained from the river gauging station of Central Water Commission (CWC), Govt.of India at Dighaghat and Gandhighat, has been assigned. For the period under the projected scenario, the mean monthly stage of River Ganga for the pre-monsoon and post-monsoon period has been assigned.

For layer 2 and 4, the northern boundary has been taken as no-flow boundary and flux has been assigned along the southern and south-western part. The flux to the layers has been estimated using the *TIL* equation for different segments in layer 2 (aquifer 1) and Layer 4 (aquifer 2). The estimated flux has been assigned by adding recharge wells along the boundary.

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 first layer has been estimated through grain size analysis. The range of hydraulic conductivity for this layer varies from 5 m/day to 25 m/day. The value of the K for this layer as obtained through grain size analysis has been contoured for the entire layer. For layer 2 which constitutes the first principal aquifer, the hydraulic conductivity distribution map has been prepared based on the available pumping test results. For this layer it varies from 80 to 115 m/day. For layer 3 which separates the aquifer 1 (layer 2) and aquifer 2 (layer 4) and layer 5, K has been taken as 0.087 m/day (Bear 1972). Hydraulic conductivity map for Layer 1 and 2 is given in **Fig. 7a & b.**

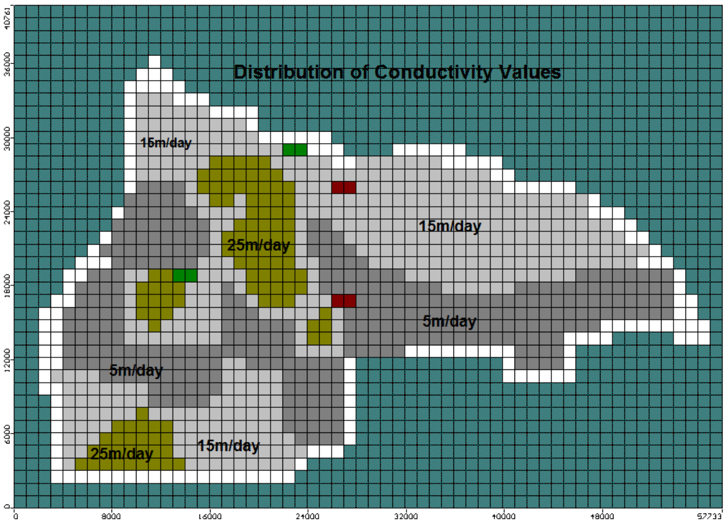


Fig.7a Zone wise distribution of hydraulic conductivity in the study area (for Layer I)

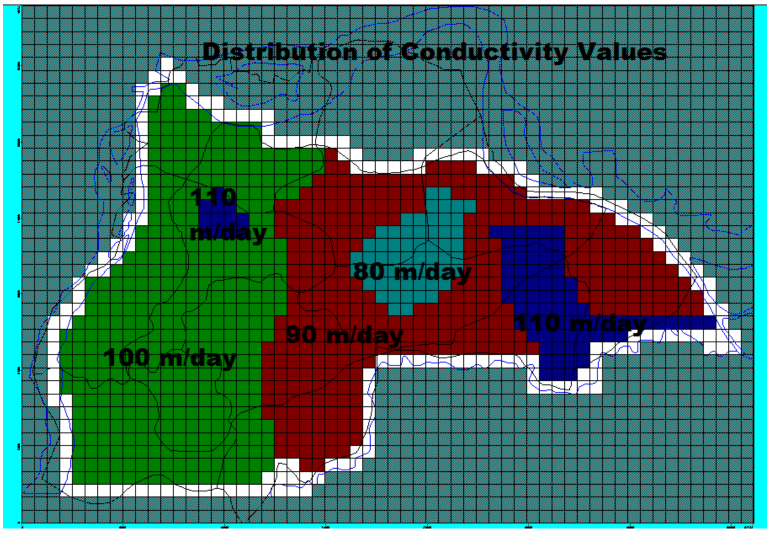


Fig.7b Zone wise distribution of hydraulic conductivity in the study area (for Aquifer I)

Distribution of storage parameters

The values of specific storage have been computed by dividing the field determined storativity values with the thickness of the aquifer. As the number of storativity values determined through pumping test is limited in the study area, an attempt has been made to estimate the specific storage based on the lithology (Younger 1993). The specific storage of the aquifer 1 and 2 has been worked out using the relationship $Ss = \rho w g (\alpha + \theta\beta)$ where ρw = density of water, g = acceleration due to gravity, α = compressibility of aquifer skeleton, θ = porosity of aquifer material and β = compressibility of water (Fig. 6.1l). Where the predominant lithology is of fine to medium sand, the Ss has been considered as 9.82×10^{-2} while for the predominant lithology of medium to coarse sand and fine gravels, Ss has been considered as 1.05×10^{-5} (Younger 1993). The specific storage has been found varying over 3 orders of magnitude in the study domain between 10^{-4} and 10^{-7}. Zone wise distribution of specific storage in the study area (for Aquifer I) are given in **Fig. 8**.

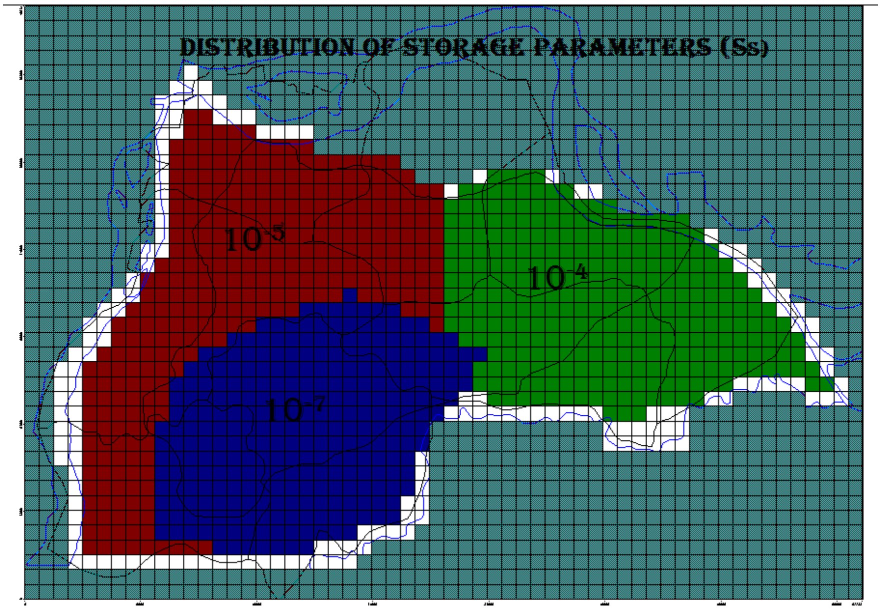


Fig. 8: Zone wise distribution of specific storage in the study area (for Aquifer I)

Recharge

This package is used to simulate surfcially distributed recharge to the groundwater system. Annual precipitation within the study area averages about 1051 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. Three recharge zones have been demarcated considering the nature of the surficial material. At the extreme southern and the western domain of the model monthly recharge considering rainfall infiltration factor of 20% has been assigned. For the central part of the model, monthly recharge considering rainfall infiltration of 10% and for the core urban areas the recharge rate has been considered as 2% of rainfall as these are the most urbanised part with less of open space and the nature of the surficial material here is also more clayey.

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. Data from the previous studies like resource assessment and available records of pumping from the municipal corporation besides insights gained from sample draft survey made during the present study have been used to arrive at the pumping estimate for a grid area of 1 sq km from the different aquifers which have been assigned in the model.

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 behaviour. 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.

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). Steady state simulation of the model was carried out using the decadal mean water levels for the period 1999-2008. Calibration involved making minor adjustments to the hydraulic conductivity field of the different layers and the river bed hydraulic conductivity levels until the steady state model was calibrated to a reasonable satisfaction. The preset calibration targets in the present study included

a. A root mean square error between measured and simulated heads of less than 2 m. and
b. A good visual match between the measured and the simulated potentiometric surfaces of Aquifer I and Aquifer II.
c. Quantitatively correct flow directions and flow gradients.

River stage and river bed bottom data of river Son and Punpun for 2008 was considered. In present study steady state model was calibrated for the hydraulic conductivity values to achieve the observed heads. The calibration was made using 19 observation wells monitored during 2008.

The computed groundwater level accuracy was judged by comparing the mean error with mean absolute and Root Mean Squared (RMS) error (Anderson and Woessner, 1992). Mean error is -0.981 m. 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 1.843 m (**Fig.-9**). The absolute residual mean is 1.509 m.

The absolute residual mean $\left|\overline{R}\right|$ is similar to the residual mean except that it is a measure of the average absolute residual value defined by the equation:

$$\left|\overline{R}\right| = \frac{1}{n}\sum_{i=1}^{n}\left|R_i\right|$$

The absolute residual mean measures the average magnitude of the residuals, and therefore provides a better indication of calibration than the residual mean (Waterloo Hydrogeologic Inc, 2005).

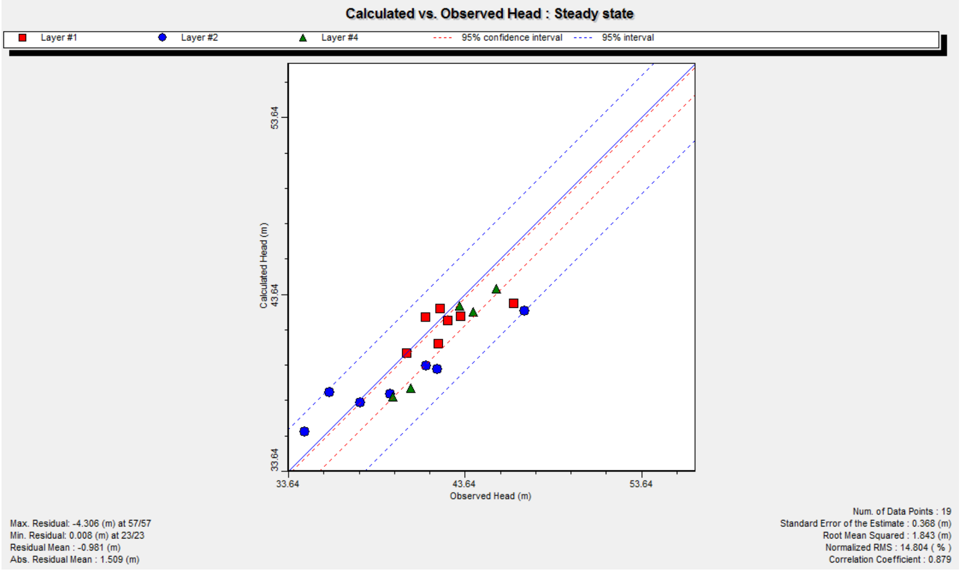


Fig. 9 : Calculated versus observed heads (steady state)

Transient state

In transient state, head changes with time. Transient states are also called time dependent, unsteady, non-equilibrium, or non-steady state problem.

Discharge inputs

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. Data from the previous studies like resource assessment and available records of pumping from the municipal corporation besides insights gained from sample ddraft survey made during the present study have been used to arrive at the pumping estimate for a grid area of 1 sq km from the different aquifers which have been assigned in the model. The abstraction assigned in different blocks falling in the study area is summarized in Table 3.11c

Evapotranspiration of 1100 mm/yr with extinction depth of 2 m has also been considered. The extinction depth has been considered as 2 m only as the area is mainly a paddy growing region.

Recharge inputs

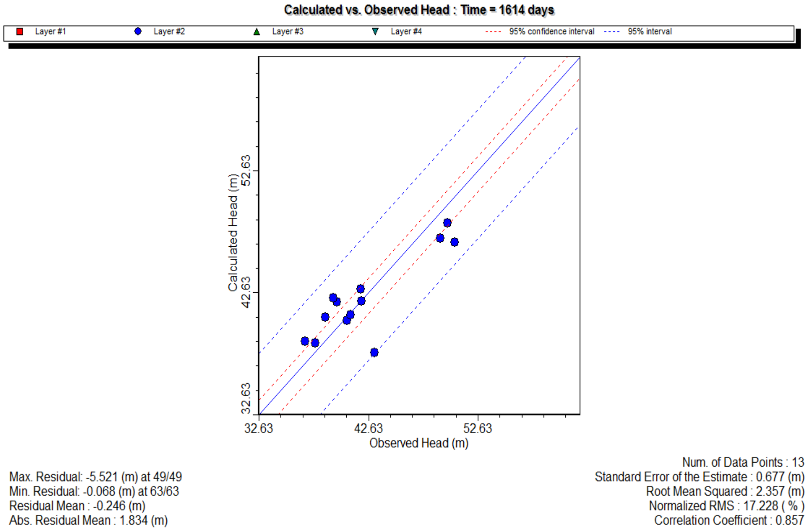
Recharge has been assigned to the first layer as a percentage of rainfall. Based on the hydrogeological characteristics of the layer I, three zones of 20%, 10% and 2% recharge rates has been demarcated and assigned. Low values of 2% recharge has been assigned in the densely urbanized portion of the area and in areas with layer I as predominantly clayey in nature for thickness >10 m.

Constant head/variable head

River Ganga, constituting the northern boundary of the study area for Layer I has been assigned constant head for different time steps. As the river is perennial in nature and has significant base-flow during the lean season, constant head boundary is well justified.

Transient state calibration

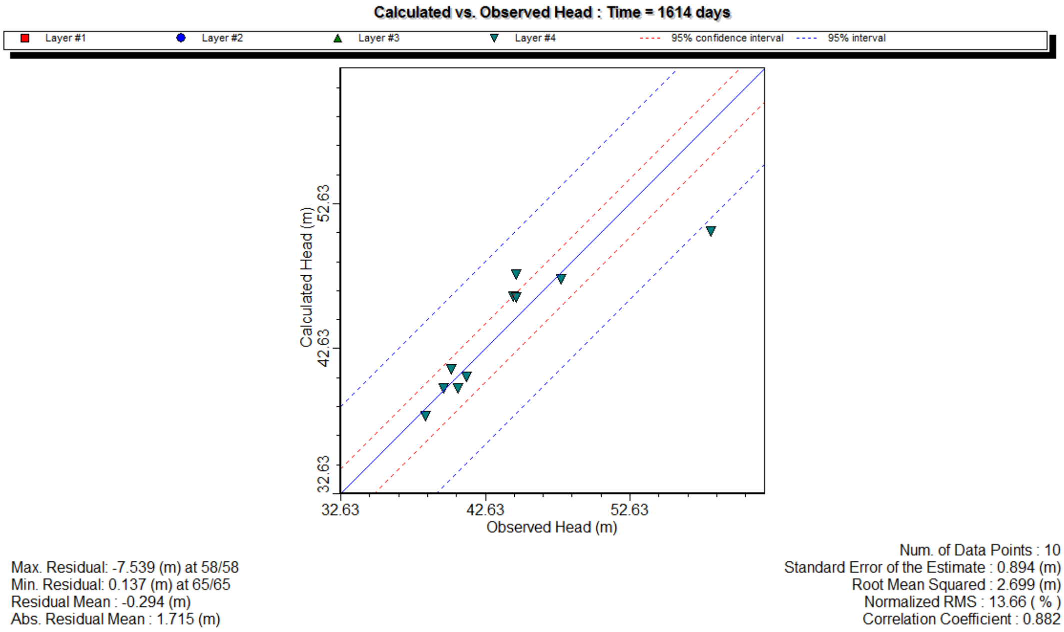
The model was calibrated to transient state from June 2008 to May 2012 and validated for the period under transient state from June 2012 to April 2014. After a number of trial runs, the input/output stresses were varied, till the computed groundwater levels matched fairly reasonably to observed values. The RMS error for the transient state model for layer 2 & 4 at 1614 days (June 2012) is 2.3 m& 2.5m (Fig.-10a & b). The observed pre- and post-monsoon groundwater level for selected observation wells for the period 2008 to 2014 was used for the transient state calibration.



Max. Residual: -5.521 (m) at 49/49
Min. Residual: -0.068 (m) at 63/63
Residual Mean : -0.246 (m)
Abs. Residual Mean : 1.834 (m)

Num. of Data Points : 13
Standard Error of the Estimate : 0.677 (m)
Root Mean Squared : 2.357 (m)
Normalized RMS : 17.228 (%)
Correlation Coefficient : 0.857

Fig. 10a: Calculated v/s observed head of aquifer I (for May 2012)



Max. Residual: -7.539 (m) at 58/58
Min. Residual: 0.137 (m) at 65/65
Residual Mean : -0.294 (m)
Abs. Residual Mean : 1.715 (m)

Num. of Data Points : 10
Standard Error of the Estimate : 0.894 (m)
Root Mean Squared : 2.699 (m)
Normalized RMS : 13.66 (%)
Correlation Coefficient : 0.882

Fig 10b: Calculated v/s observed head of aquifer II (for May 2012)

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). During a sensitivity analysis, calibrated values for hydraulic conductivity, storage parameters, recharge and boundary conditions are systematically changed within the permissible range. In the present study the model has been found sensitive to the river stage data of the Punpun and the Sone, values of hydraulic conductivity, specific storage and recharge.

Model validation

To evaluate the validity of the updated flow model, the groundwater heads simulated by the updated flow model were compared to observed hydraulic heads. The groundwater head observations for the period of 2012-2014 has been used for validating the model. The scatter plot showing the statistics for 2097 days (April 2014) for aquifer I & II is produced in **Fig. 11a & b**. The calibration scatter plot of the validation period at 2097 days (April 2014) exhibits the root mean squared (r.m.s.) of the residuals for aquifer I & II as 2.1m & 2.5m respectively indicating a reasonably good fit of the observed and simulated levels with majority of the data lying close to the 1:1 line. The hydrograph of selected stations for the period under transient calibration & validation are given in **Fig. 12a to d**.

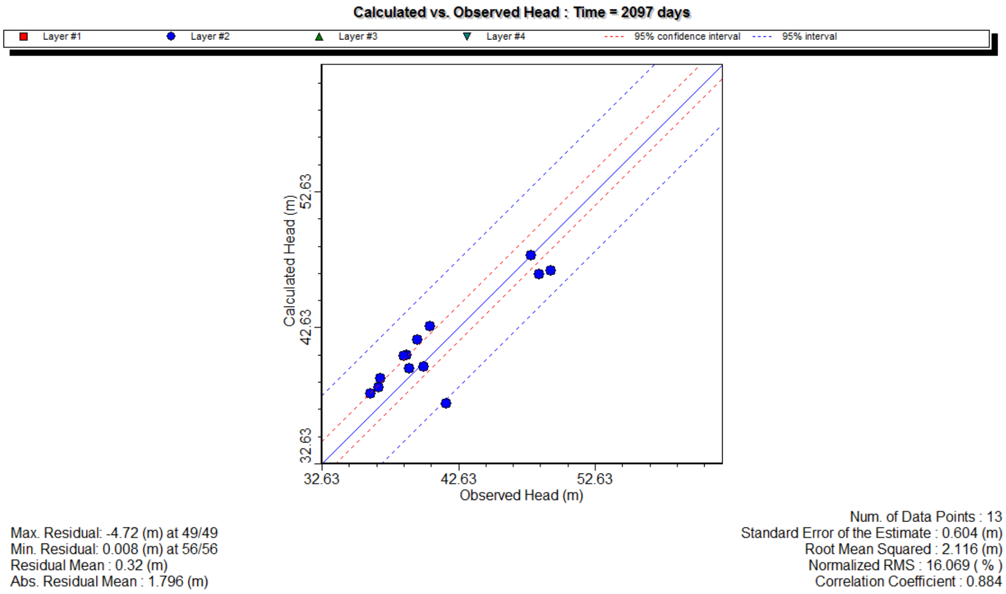
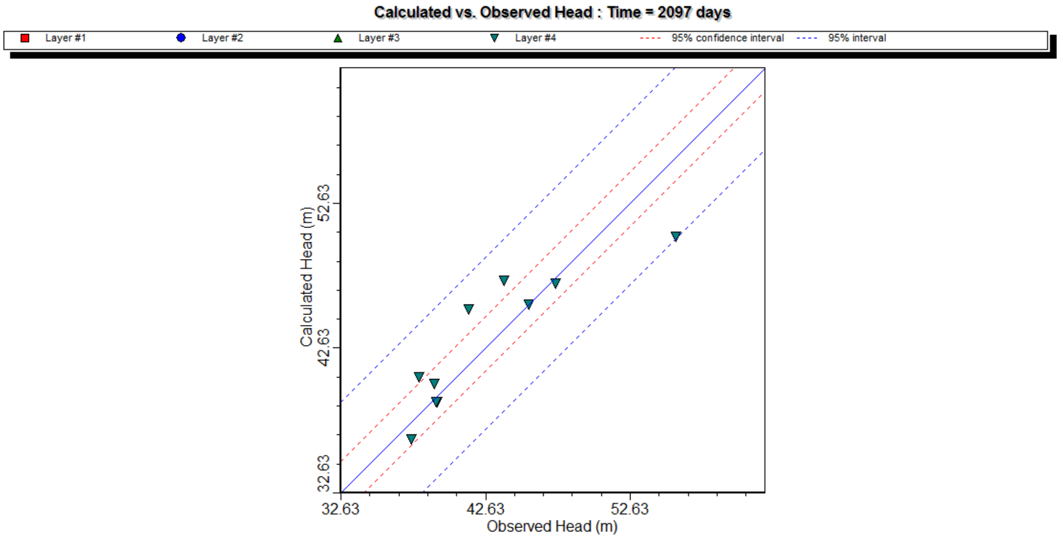


Fig. 11a: Calculated Vs observed head of aquifer I (for April 2014)



Num. of Data Points : 10
Standard Error of the Estimate : 0.843 (m)
Root Mean Squared : 2.549 (m)
Normalized RMS : 13.951 (%)
Correlation Coefficient : 0.886

Max. Residual: -5.455 (m) at 58/58
Min. Residual: 0.032 (m) at 69/69
Residual Mean : 0.308 (m)
Abs. Residual Mean : 1.849 (m)

Fig. 11b Calculated Vs observed head of aquifer II (for April 2014)

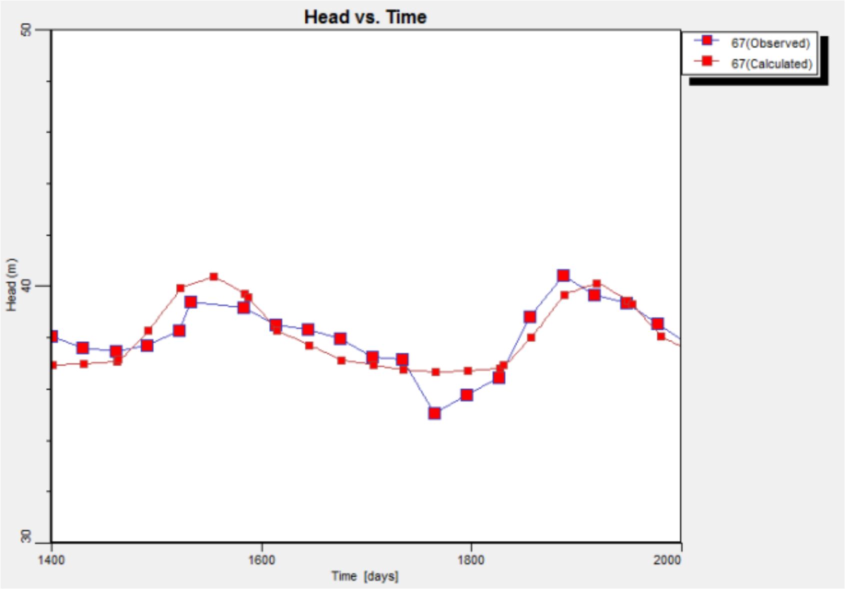


Fig.12a Hydrograph of well no. 67.

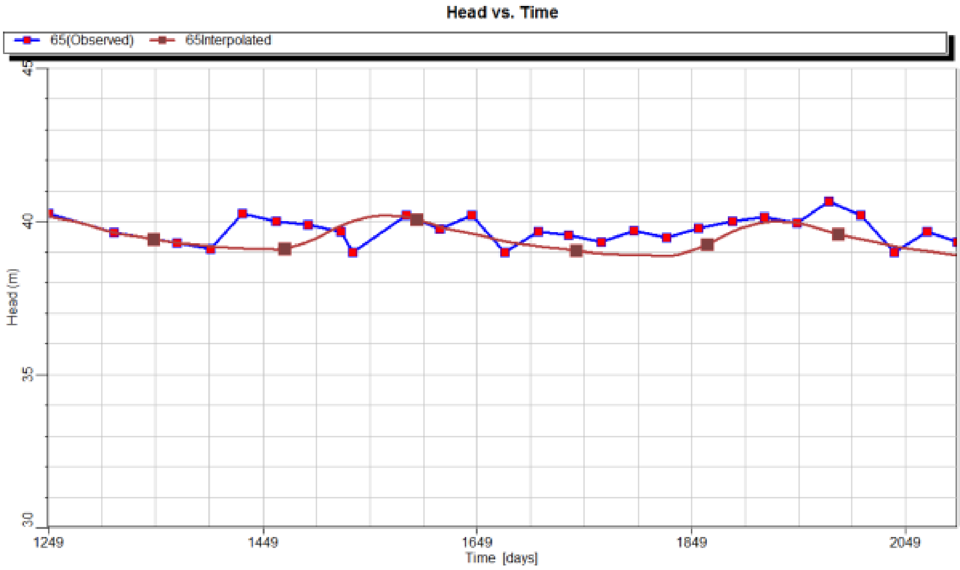


Fig. 12b: Hydrograph of well no. 65.

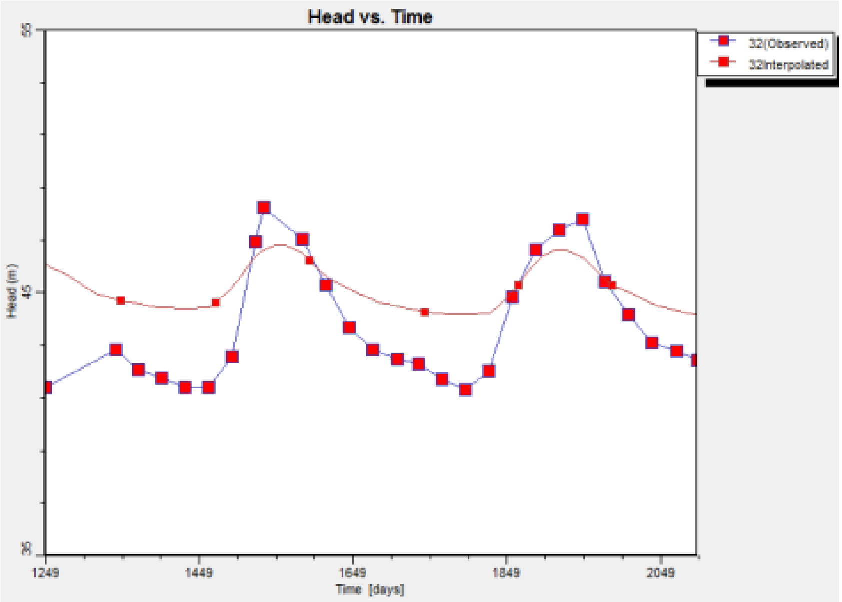


Fig. 12c: Hydrograph of well no. 32.

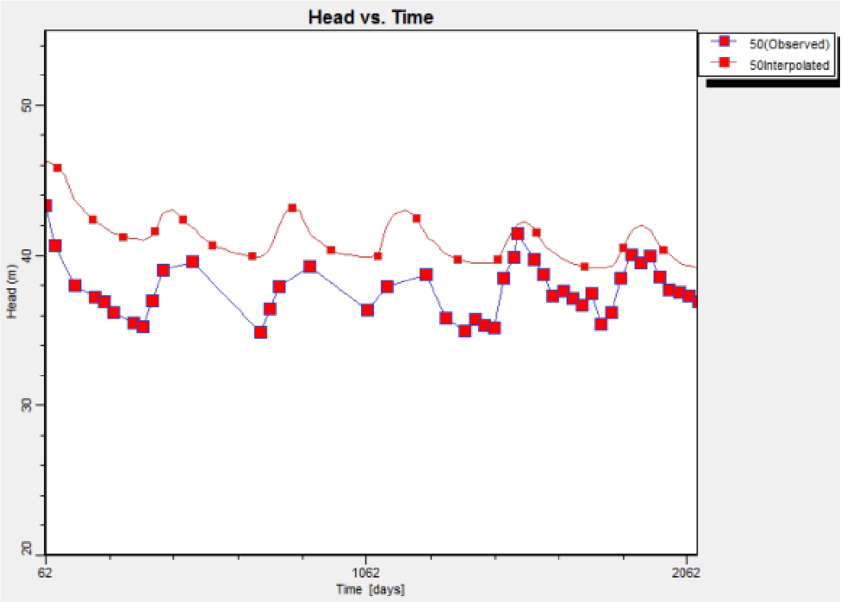


Fig. 12d: Hydrograph of well no. 50.

Aquifer management plan formulation

The study area has a mixed land use pattern. While 20 % is densely urbanized and is under residential land use, major part of the remaining 80 % is under agricultural land use. Further, owing to rapid growth witnessed in Patna urban area during the preceding two decades, the city is expanding at a faster rate and is causing change in the land use pattern. Under the prevailing condition, both in the urban as well as the rural hinterland, the demand for water supply will witness a surge in the days to come. During the past few years there has been an increase in industrial water demand too as owing to groundwater availability in the area and its proximity to the capital city of Patna, water intensive industries like breweries, distilleries and packaged drinking water plants have started coming up.

Considering the above mentioned facts, the calibrated model has been used to assess the impact of future groundwater withdrawal on the groundwater system to examine the projected groundwater withdrawals from the view point of sustainability and the need for possible management interventions.

The following five different scenarios in consonance with the various decisions under consideration by the State Government and few hypothetical scenarios have been simulated. The simulated scenarios are

Scenario1: Increase in cropping intensity (CI) from the present 126% to 200%. This is as per the envisaged road map for agriculture development in the State of Bihar under consideration. The increase in CI has been made @19% /year from 2014 to 2018.

Scenario 2: Increase in groundwater based irrigation efficiency by 15%.

Scenario 3: Reduction in groundwater draft in Patna urban area by 50MCM/yr. This is as per the envisaged plan for reducing dependence on groundwater sources for water supply in Patna Urban area. The State Government is mulling for setting up of two treatment plants with capacity of 50 MCM with source water from Ganga River.

Scenario 4: Under this scenario an allocation of 20 MCM/yr has been made for the industries in the Bihta, Naubatpur and Bikram blocks of the study area located in the south-western part. This has been made considering the surge in the industrial water demand in these blocks in the past few years. This allocation would take care of the demand of 100 industrial units in the area having a demand of 500m^3/day.

Scenario 5: Under this scenario, the impact of draught (-20% deviation from normal rainfall) on the aquifer regime has been modeled. The scenario generated depicts the resilience of the groundwater system to the draught situations.

Scenario 6: In this scenario, the draft has been increased considering the growth in population. The irrigation draft has been increased @2% per year with respect to the prevalent draft during 2008. In this scenario, the normal increase in pumping has been simulated.

Predictive model results of strategies tested

In predictive simulation, the parameters determined during calibration and verification is used to predict the response of the system to future events (Anderson and Woessner, 2002). Faust et al. (1981) suggest that a predictive simulation should not be extended into the future more than twice the period for which calibration data are available. As such, in the present study, the scenarios have been simulated for 11 years into the future i.e upto the year 2025.

Different prediction scenarios were considered to predict the drawdown for the study area during the period of 2008 to 2025. These scenarios are explained below.

Scenario wise detailed discussion with relevant outputs

Scenario1: Increase in cropping intensity (CI) from the present 126% to 200%. The increase in CI has been made @19% /year from 2014 to 2018

For increasing the CI, groundwater draft has been increased by 14.6 MCM/yr during the monsoon and 31.65 MCM/yr during the non-monsoon season. The scenarios depict decline at the end of stress period 236 (6210 days) with respect to the in pre-development condition. Under this scenario, irrigation through groundwater would bring additional 7300 ha under cropping during monsoon season and 10,550 ha during non-monsoon season.

Brief description of the aquifer regime under the Scenario 1.

The projected scenario for the year 2025 reveals considerable change in **g**roundwater flow regime. The river Sone has become strongly influent. Significant flow is also entering from the southern part. Considerable length of the Ganga has also become influent contributing the aquifers. For about half of its length, the Ganga (eastern part of Danapur) has become influent for 26 km length.

The groundwater level varies from > 54 to <40 m above msl (**Fig 13a**). The trough of <44 m above msl expands considerably covering about 80% of the study area invading the south western part also. The < 40 above msl trough also expands considerably covering the entire Patna urban, semi-urban and adjoining rural areas (approx. 225 km^2). In this scenario there is no outflow of groundwater from the study area.

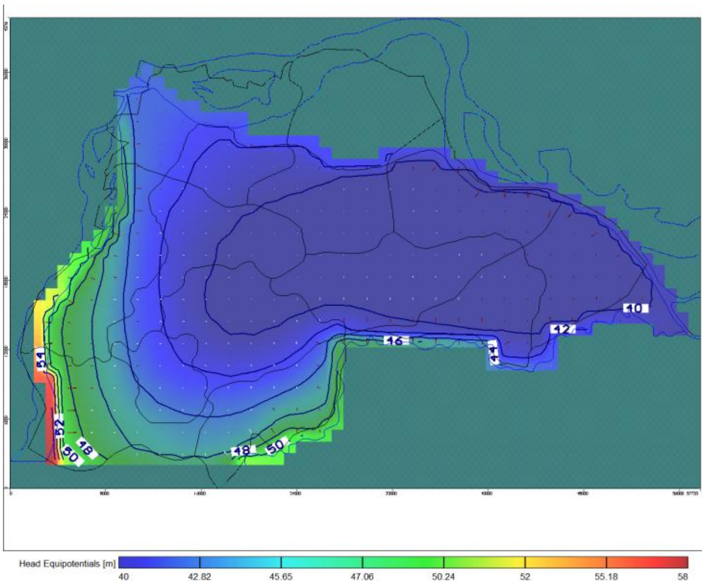


Fig 13 (a): **Projected head distribution of aquifer 1 (June 2025)**

Scenario 2: Increase in ground water based irrigation efficiency by 15%.

The scenario depicts moderate improvement in ground water decline at the end of stress period 236 (6210 days) in both aquifer I and II as compared to Scenario 1 (**Fig 13b**).

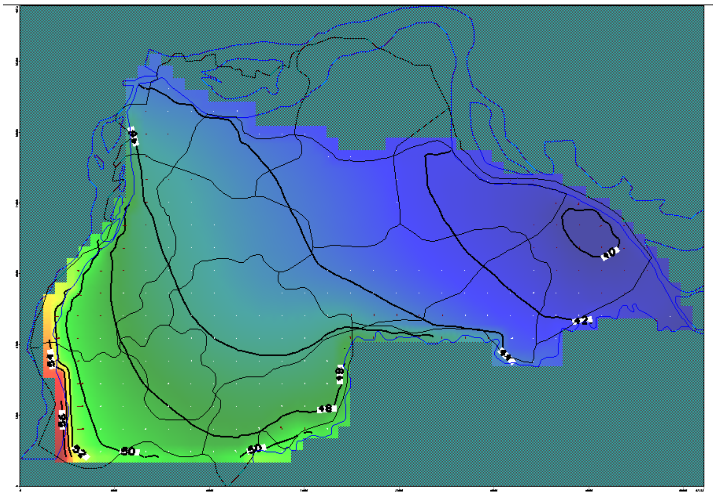


Fig 13(b): **Projected head distribution under scenario 2 of aquifer 1 (June 2025)**

Scenario 3: Reduction in ground water draft in Patna urban area by 50MCM/yr

Reduction in groundwater draft in Patna urban area by 50MCM/yr, as per the envisaged plan of PHED Government of Bihar, to supplement water supply in urban area from the Ganga River is considered as scenario 3. The draft has been decreased from layer 4 (aquifer II), as the groundwater draft for Patna Municipal area is presently being met from this aquifer. The modeled scenarios depict the improvement in head for both aquifer I and aquifer II (**Fig. 13c**)

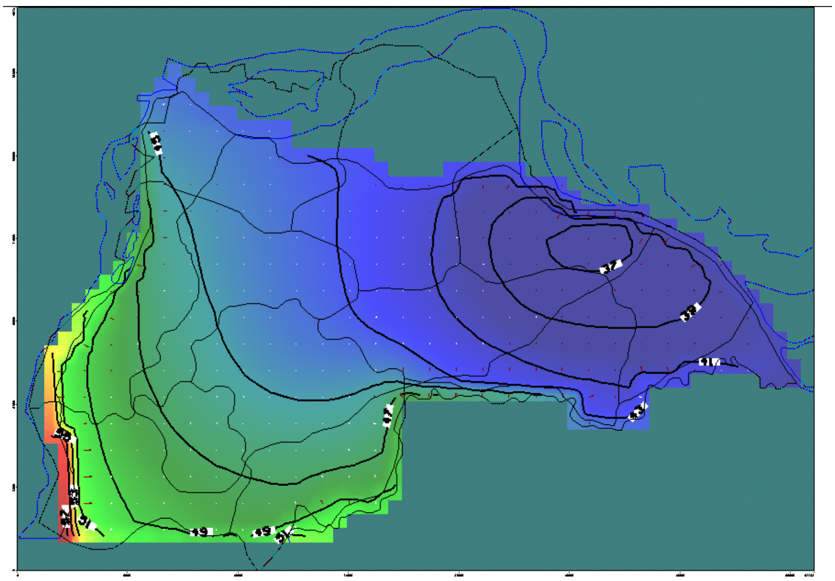


Fig 13(c): Projected Head distribution under scenario 3 of Aquifer 1 (June 2025)

Scenario 4:

Under this scenario an allocation of 20 MCM/yr has been made for the industries in the Bihta, Naubatpur and Bikram Blocks of the study area located in the south-western part. This has been made considering the surge in the industrial water demand in these blocks in the past few years. This allocation would take care of the demand of 100 industrial units in the area having a demand of 500m^3/day (**Fig. 13d**)

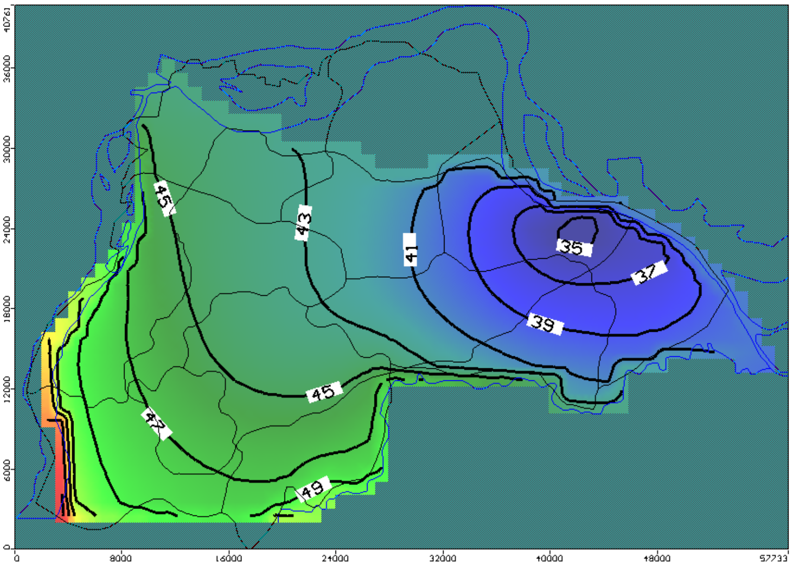


Fig 13(d): Projected Head distribution under scenario 4 of aquifer 1 (June 2025)

Scenario 5:

Under this scenario, the impact of draught (-20% deviation from normal rainfall) on the aquifer regime has been modeled. The scenario generated depicts the resilience of the groundwater system to the draught situations (**Fig. 13e**)

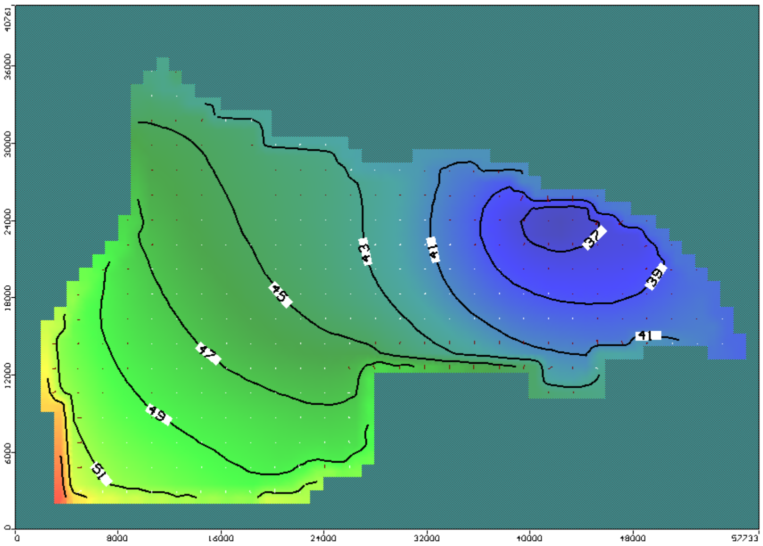


Fig 13e: Projected head distribution under scenario 5 of aquifer 1 after 3 year of continuous drought.

Scenario 6: In this scenario, the draft has been increased considering the growth in population. The irrigation draft has been increased @2% per year with respect to the prevalent draft during 2008. In this scenario, the normal increase in pumping has been simulated (**Fig 13 f**) .

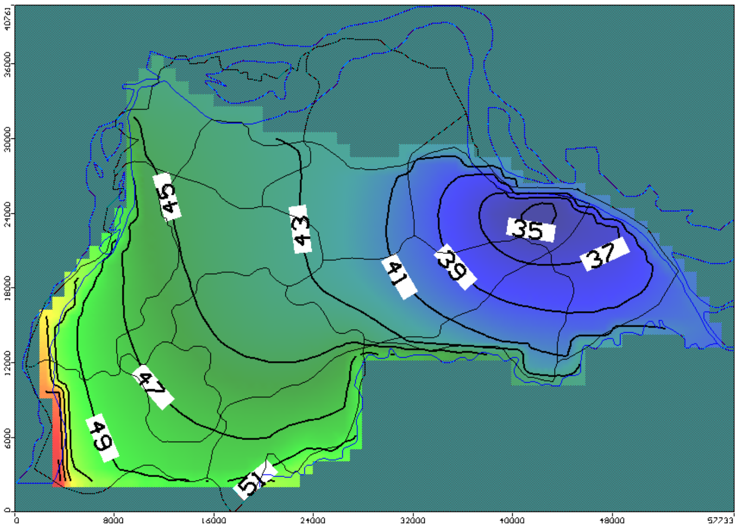


Fig 13 (f): Projected head distribution under scenario 6 of aquifer 1 (June 2025)

Hydrogeological consequence of proposed management interventions

To understand the hydrogeological consequences of the proposed management interventions, the predicted change in the piezometric head of a monitoring station in the urban area under the different scenarios is presented in **Fig.13g**

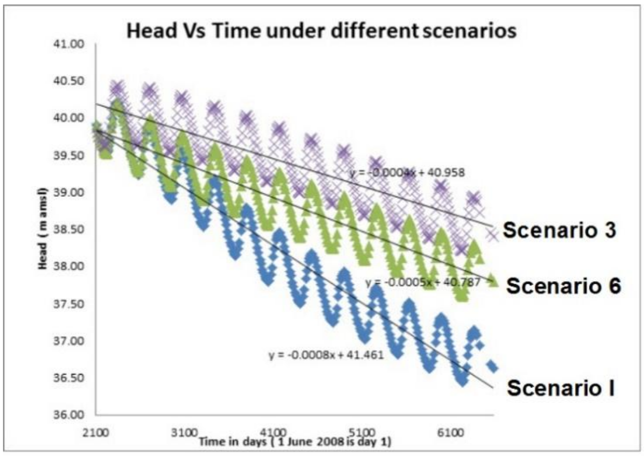


Fig. 13g: Piezometric head of a monitoring station in the urban area under three different scenarios.

Comparison of the rate of annual decline in piezometric head under the projected scenario from the current level reveals that under scenarios 1, 3 and 6, the rate of annual decline would be 0.3, 0.14 and 0.18 m/year. Thus of the various scenarios modeled, the one having the most favourable impact is the one under scenario 3 wherein the effects of the reduction in annual draft from the municipal wells by 50 MCM has been modeled.

The other discernible impact on the aquifer regime is the change in the characteristics of the imposed boundary conditions as made out through the following **Fig. 13 h(i to iv)** which depict the pre and post-monsoon scenario of year 2008 and 2025 respectively. From the figure 13j (i) it is apparent how the River Ganga changes its behavior from predominantly effluent to influent within its flow stretch in the core Patna Urban area. Similarly the Sone and the Punpun Rivers also exhibit the change under the simulated scenario.

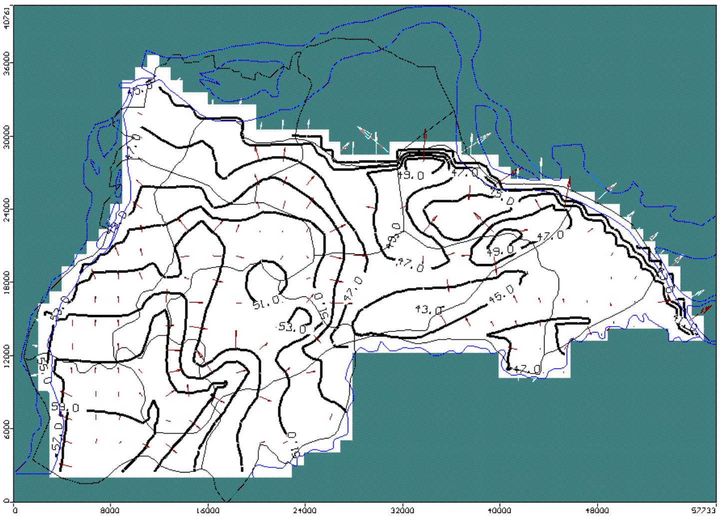


Fig. 13h(i): Flow regime in aquifer I during pre-monsoon 2008.

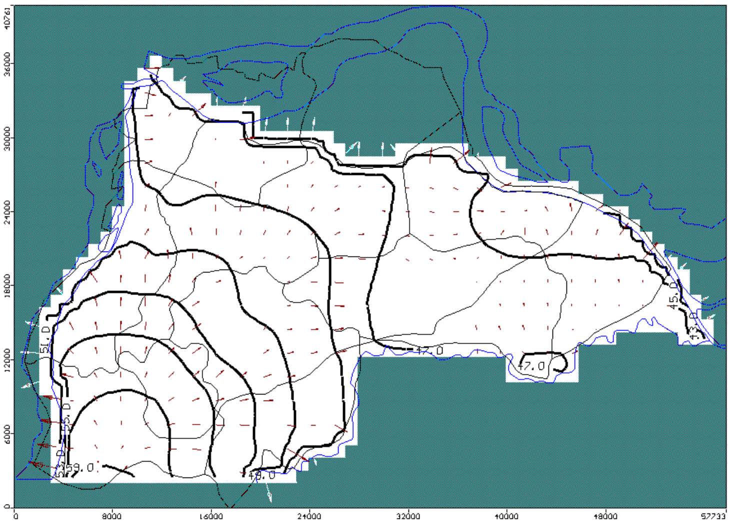


Fig.13h(ii) : Flow regime in aquifer I during post-monsoon 2008.

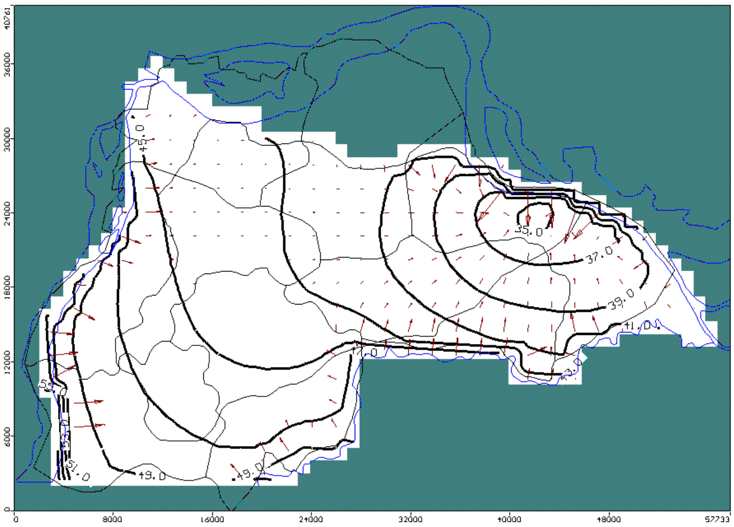


Fig.13h(iii) Flow regime in aquifer I during pre-monsoon 2025 (model simulated).

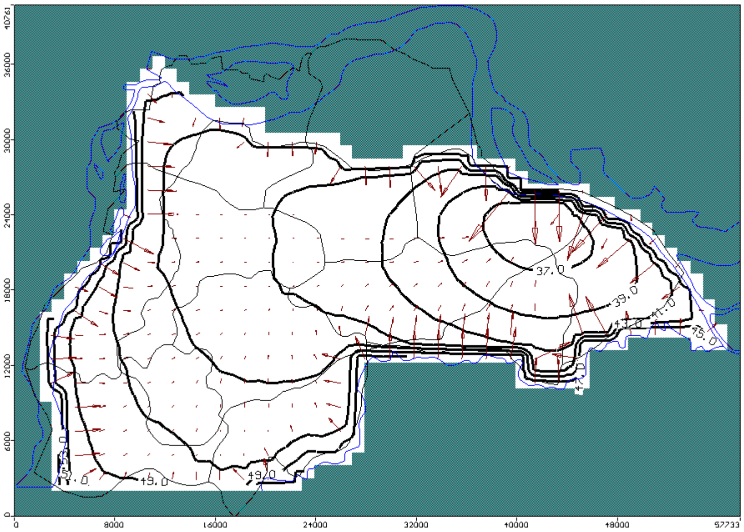


Fig.13h(iv): Flow regime in aquifer I during post-monsoon 2025 (model simulated).

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 mass balance graph for 1 year and the cumulative mass balance graph for 17th year, the changes in the percentage contribution from various sources have been computed. From the table below, it can be seen how the percentage contribution from various sources changes in the projected scenario for year 2025 from that of year 2009. The most important changes are in the contribution from CHB (Ganga River) which contributes 4.3% in 2009 and in the projected scenario for 2025 contributes 18.74% (in cumulative mass balance budget). This reflects upon how the nature of the river which changes its characteristics from net effluent on an annual basis to net influent under the projected scenario. Changes are also apparent in the flow from the river boundaries where the contribution changes from 15.7% in 2009 to 27.2% in 2025 (in cumulative mass balance budget). The inflow and outflow from various sources and sinks for the scenario with normal increase in pumping (scenario 6) are presented in Table 2 a and b respectively

Sources	Volume (MCM) 1 year	%	Volume (MCM) 17 year	%
CHB	38.7	4.355656	2036.7	18.74206
Rivers	140.2	15.7794	2965.4	27.28812
Flux	98.2	11.05234	1666.2	15.33266
Recharge	36.5	4.108047	612.3	5.631
Storage	574.7	64.68205	3587.4	33.0081
Total (In)	888.5		10867	

Table 2a: Inflow from various boundaries in year 1(2009) and year 17 (2025)

Sinks	Volume (MCM) 1 year	%	Volume (MCM) 17 year	%
CHB	71.9	8.09229	455.2	4.188829
Rivers	284.5	32.02026	2156.5	19.84448
Pumping Wells	265	29.82555	5446.5	50.11963
ET	45.9	5.16601	98.5	0.906414
Storage	210.3	23.66911	2710.3	24.94065
Total (Out)	888.5		10867	

Table 2b: Outflow from various boundaries in year 1(2009) and year 17 (2025)

The mass balance graphs at the end of year 1 (2009) and for scenario 1, 2 and 3 at the end of year 17 (2015) are shown in **Fig. 13i(i to iv).**

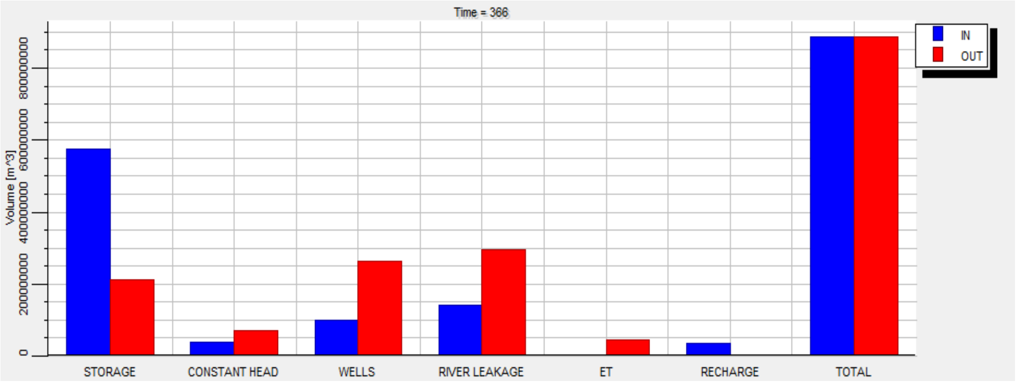


Fig. 13i(i) Scenario 1 (yearly mass balance)

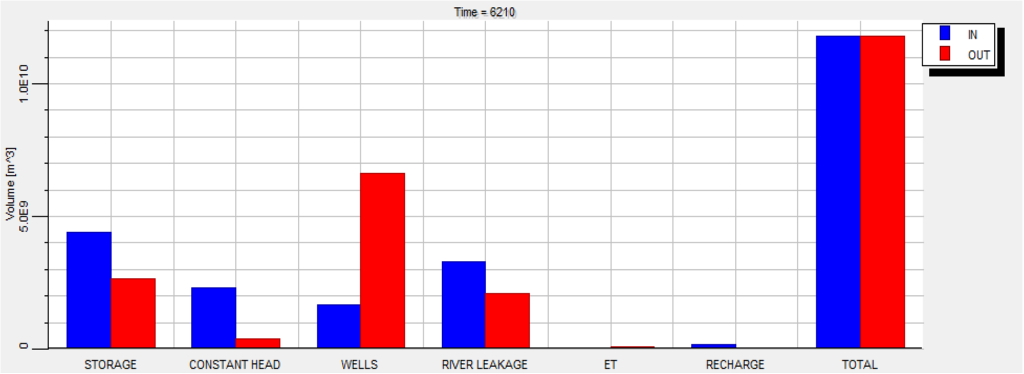


Fig.13 i (ii) Scenario 1 (mass balance at the end of year 17)

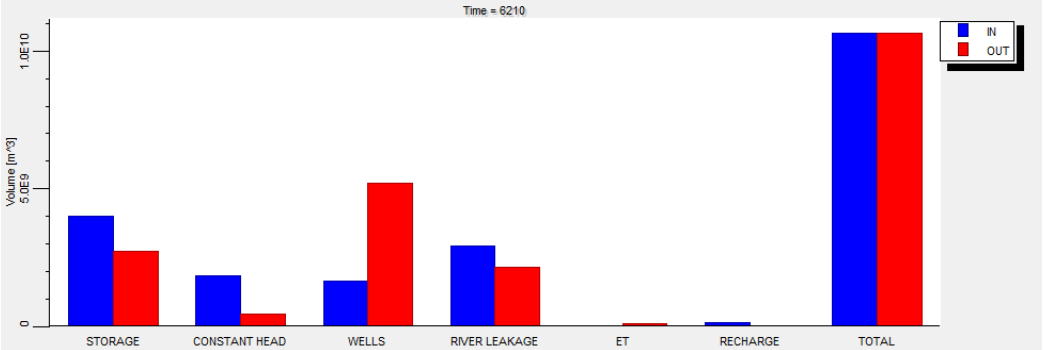


Fig. 13 i (iii) Scenario 2 (mass balance at the end of year 17)

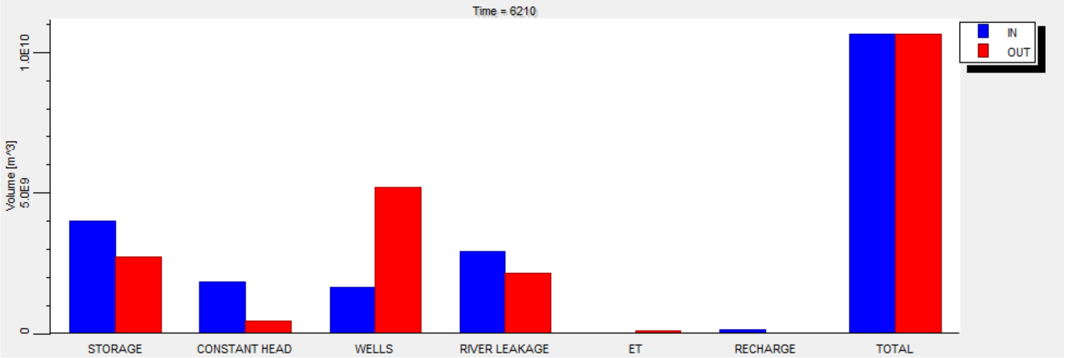


Fig. 13 i (iv) Scenario 3 (mass balance at the end of year 17)

Desirable management interventions

Considering the various issues pertaining to groundwater development as emerged from the simulated scenarios, the modeled area has been divided into five zones (Zone A to E, **Fig. 14**).

Zone A: This zone extends over Bihta, Naubatpur and Punpun blocks where significant demand of groundwater for agricultural use exists.

Zone B: This zone extends over Patna Sadar block characterized by very high population density and significant demand for municipal water supply.

Zone C: This zone extends over Danapur and Punpun block where in most of the scenario simulated the decline in groundwater level has been indicated in moderate range of 4 to 6 m.

Zone D: This zone extends over northern part of Maner block where problem of arsenic contamination of groundwater has been detected in the shallow aquifer.

Zone E: This zone extends over southern part of Naubatpur, Bihta and Bikram blocks where significant decline in groundwater level has been indicated in one of the scenario simulated wherein cropping intensity has been increased from 126% to 200%.

On the basis of the simulated scenarios and the insights into the aquifer dynamics gained through the modeling, it can be concluded that the area is already witnessing intensive groundwater draft both from aquifer 1 & 2. Besides there is extraction from sand layers embedded in the aquitard zone also by dug wells and shallow tube wells. The current draft already exceeds the safe yield limit of the aquifers. However, considering the prolific nature of the aquifer, an allowance for planned depletion from aquifer storage for a drawdown upto 6 m till the year 2025 may be made subject to compliance to the following outlined recommendations (Ref Fig 14 for designated zones for suitable management interventions).

a. Continuation of increase in pumping @ 2% per annum in the study area can be made upto year 2025, however, it is recommended to relocate the heavy duty municipal water supply wells concentrated in zone B (Fig. 14) to suitable locations in zone C to avoid concentrated extraction (Fig. 14). Zone B is suitable for recharging of the deeper aquifer through injection wells.
b. Reduction in groundwater draft in Patna urban area by 50MCM/yr, as per the envisaged plan of PHED Government of Bihar, to supplement water supply in urban area from the Ganga River would have a significant positive impact on the aquifer drawdown behavior as such this step is strongly recommended. This would lead to improvement in the hydraulic head for both aquifer I and aquifer II.
c. Increase in cropping intensity to 200% from the current 126% (Scenario 1) would lead to decline in hydraulic head in the agricultural belt by 6 m on an average and even upto 10 m in certain pockets. This scenario may be accepted by sinking additional tube wells for irrigation in zone A, however, a comprehensive artificial recharge plan is desirable in zone E (Fig 14). The management strategy under scenario 1 is tabulated as under (Table 7.0).
d. Industrial allocation and heavy duty deep tube wells in aquifer 1 should be discouraged in zone D (Fig.14). This is because the arsenic affected blocks are located here and an increase in groundwater draft would lead to lowering of hydraulic head and possible mixing of arsenic safe water with that of the overlying layers with contaminated groundwater.

Conclusion and Recommendations

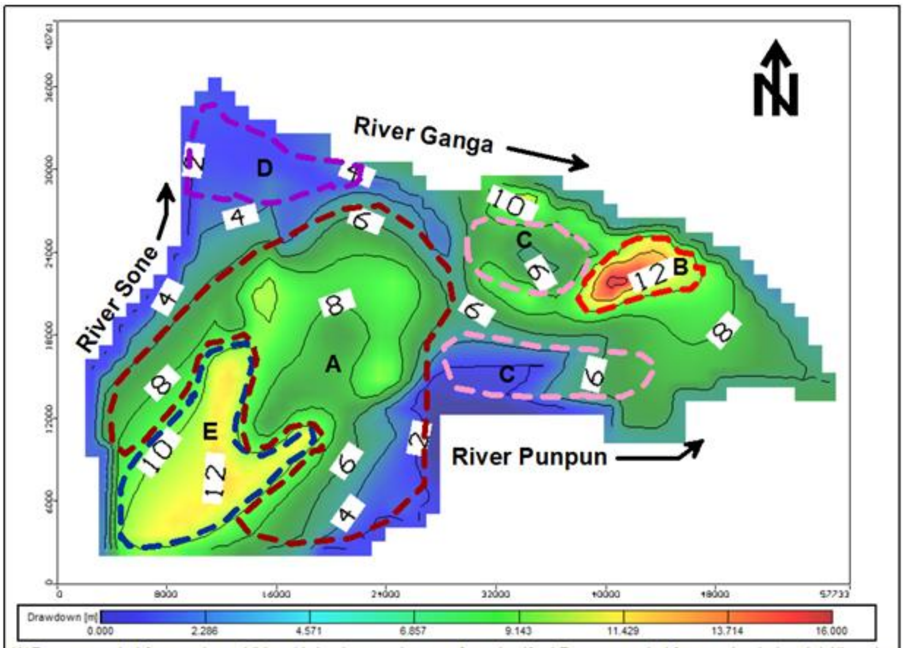
The results of mathematical modeling have thrown light on the strategies that need to be adopted in different parts of the study area for invoking sustainable aquifer management plan.

As the economy of the area is predominantly agrarian, emphasis on agriculture is likely to continue. In one of the strategy tested in modeling, it has been found that upon increasing the cropping intensity from the present 126% to 200% by allocating the enhanced water requirement from the aquifer I, groundwater level in Zone A and E (Fig 14) is projected to decline by about 8-12 m with respect to that of the year 2008. The yield potential of aquifer I range from 150- 250 m^3/hr for a modest drawdown of 3-5 m. For placement of screens, the suitable depth zone in aquifer I is from 40- 100m. For aquifer II, the yield potential also varies from 125- 225 m^3/hr for comparable drawdown. Wells in aquifer II can be screened in the depth range of 140-215m bgl.

However, development of groundwater in Zone A would require an elaborate artificial recharge plan particularly in Zone E. As the area is rural large scale roof top rainwater harvesting is not a feasible proposition. Artificial recharge in this area can be attempted through on-farm water conservation practices. In an injection well experiment conducted in Patna urban area, it has been found that a tubewell with screen of 6”diameter and slot length of 12m can receive recharge @ 10m^3/hr. Thus one injection well can recharge ~200m^3/day.

Concentration of Municipal water supply wells and their round the year pumpage in Zone B renders the aquifer II in the urban area vulnerable to piezometric level decline even at the present level of pumping. To tide over this challenge, it is suggested to decongest the existing concentration of municipal water supply wells in Zone B to Zone C. Other measures like shifting to surface water supply from the Ganges as mooted by the State Government would also de-stress the aquifer II in the urban area. Groundwater regulation in the urban area particularly to check the unabated extraction by individual housing societies, apartments, commercial complexes also requires consideration.

From the point of groundwater quality, only a small pocket in the extreme north-western and north-central part where arsenic contamination has been detected in the aquitard zone and the upper slice of the aquifer I (Zone D, Fig14) is vulnerable. For this area, it is recommended that aquifer II should exclusively be used only for drinking and domestic uses. Care should also be taken to restrict any groundwater allocation for industrial requirement from this area. For meeting the agriculture water requirement in this area, blending of groundwater from aquifer I and II in requisite proportion may be attempted to ward off any possible threat of proliferation of arsenic in the food chain.



(A)Recommended for meeting additional irrigation requirement from Aquifer I;Recommended for meeting Industrial Allocation upto 20 MCM from Aquifer II; Recharge by Industries to be made to Aquifer I.(B) Recommended for decongestion of pumping network of Municipal supply well from this area. (C) Suitable location for shifting/dispersing of Municipal supply well.
(D) Recommended only for abstraction for drinking and domestic purpose from AquiferII. (E) Recommended for large scale adoption of Artificial Recharge in Aquifer I if Scenario 1 is permitted.

Fig. 14: Zonation of area for management plan

Acknowledgement

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Aquifer mapping and Management in Baswa-Bandikui watershed, Dausa district, Rajasthan, India

***Rana Chatterjee*[1], *A.K. Jain*[2], *Subhas Chandra*[3], *Vikas Tomar*[4], *P.K. Parchure*[5], *Shakeel Ahmed*[6]**

1 Scientist 'D', Central Ground Water Board, New Delhi, 2 Scientist 'D', Central Ground Water Board, Ahmedabad, 3 Scientist, National Geophysical Research Institute, Hyderabad, 4 Assistant Hydrologist, Central Ground Water Board, Dehradun, 5 Member, Central Ground Water Board, Faridabad, 6 Former Chief Scientist, National Geophysical Research Institute, Hyderabad

Abstract

Baswa – Bandikui Watershed in Dausa district is part of Banganga river basin located in eastern Rajasthan. The aquifers in the area are characterized with alluvium underlain by hard rock consisting of quartzite, schists, phyllites, granite and gneisses. Ground Water Resources in the area is continuously depleting and the Bandikui block has been categorized as 'Over-exploited'. As a result of declining water level, the upper alluvium aquifer which was more potential than the lower Hard rocks got desaturated in the Western portion. Micro-level 3-Diamentional aquifers mapping and characterization was carried out with the use of hydrogeological survey, surface, air-borne and sub-surface geophysical investigation to evolve Aquifer Management Strategy to control the water level decline. Numerical Ground Water Simulation Studies indicate that if present rate of ground water extraction continues unabated, more areas in Central part of the area would get desaturated. Therefore, the aquifer management interventions suggested for Baswa-Bandikui Watershed include 'Notification' of Bandikui block for regulation on ground water extraction. In addition, ground water modelling studies suggest that artificial recharge measures and on-farm management practices would help in controlling further depletion of ground water resources.

Key Words: Baswa-Bandikui, Over-exploitation, Heliborne Survey, Aquifer Mapping

Introduction

A large part of northern Indian sub-continent characterized with semi-arid climate, suffers from the problem of depleting ground water resources due to its over-exploitation. This situation is leading to ecological and social crisis in the region. The aquifers and ground water dependent ecosystems are gradually drying up. Farmers whose agricultural crop production is dependent on ground water irrigation are finding it economically distressful to cope up with failures of tubewells due to lowering of water table and putting investment of drilling of substitute wells to maintain their agricultural livelihood. Ground water resources assessment (for 2013) jointly carried out by State Governments and Central Ground Water Board, Government of India (CGWB, 2017) has revealed that about 65% of assessment units (Blocks) in North West India are 'Over-exploited', where quantity of annual ground water extraction is more than net annual recharge and long-term decline in water level has set in. Satellite based GRACE studies (Rodell et. al., 2009, Tiwari et. al., 2009, Pradhan, 2014) have also revealed that the ground water resources are depleting at an alarming rate in Northern India. As per the Statistics provided in the fifth Minor Irrigation Census (2006-07) (Ministry of Water Resources, 2007) nearly 5% of the dugwells in Rajasthan have gone into disuse because of drying up which indicates that water level is going deeper than the dug well depth. Government of India in view of the serious problem of ground water depletion in the North West India and other ground water related issues in rest of the country has taken up the project of Aquifer Mapping and Management to devise area-wise sustainable aquifer management plan. One of the initial pilot studies was taken up in Baswa-Bandikui watershed in Dausa district in eastern Rajasthan (CGWB, 2015, Chatterjee et. al. 2018).

In order to evolve the aquifer management plan, the aquifer disposition and its characterization are established at 1:50,000 scale using latest state of art technology in the field of hydrogeology and geophysics. The availability of the ground water resources over the time horizon starting from the study period (2012) to the futuristic scenario of 2024 was estimated using Numerical Ground Water flow modeling. Ground water management plans are recommended based on predictive scenarios of ground water availability and efficacy of the recommended management options are tested through simulating ground water flow model.

Description of the study area

The study area is located in eastern part of Rajasthan, India, around 80 km east of Jaipur, the capital city of Rajasthan state. Baswa-Bandikui watershed is a part of Banganga basin. The project area is about 647 sq.km. The area lies within 26^0 56’ 36’’ N and 27^0 10’ 36’’ N and 76^0 25’ 00’’ E and 76^0 49’ 31’’ E, topo sheets 54A/8, 54A/12, 54A/16, 54B/5 and 54B/9. The study area falls in Dausa district covering entire Bandikui block and a very small portion of western edge of Mahuwa block. The location of the project area is depicted in Figure 1.

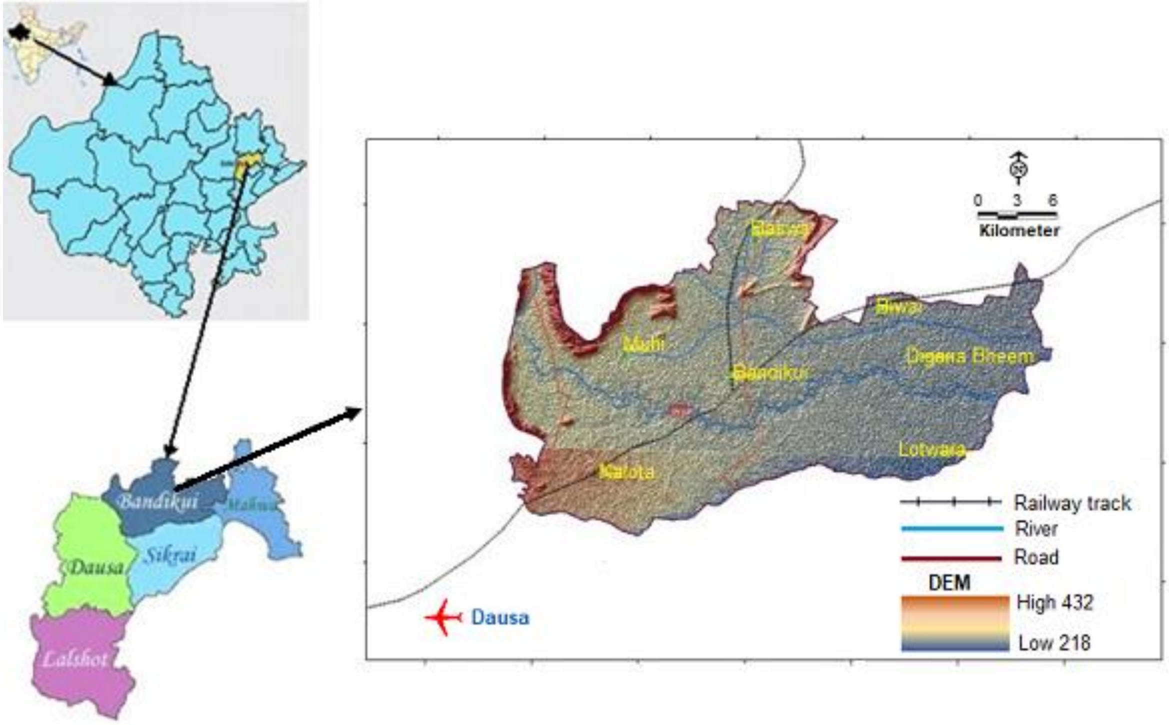

Figure 1. Location map of Baswa-Bandikui watershed, Dausa district, Rajasthan

The Baswa-Bandikui Watershed forms part of East Rajasthan upland flanked by hillocks in the North eastern border and in the northern part. Central part consists of fairly open undulating plain with low land topography and sheet & gully erosion of moderate to severe order. The rainfall is mainly contributed by South-west monsoon. The average (1971-2013) annual rainfall in the area is 663 mm (www.waterresources.rajasthan.gov.in). It is observed that potential evapotranspiration is more than rainfall in all the months except in July and August. Therefore, ground recharge is possible only during the peak period of monsoon.

The agrarian economy of the area mainly depends on ground water irrigation. More than 90% of the wells existing in area, are used for irrigation purpose. The aquifers in the area are represented by alluvium underlain by hard rocks. The area is categorized as ‘Over-exploited’ as per ground water resources estimation (2013) (CGWB, 2017) since the annual extraction is more than annual ground water recharge and there is long term decline in ground water level.

Methodology

The study involves collection of existing data from various sources including Central and State Government agencies records, literature available in the libraries and internet, NGOs and other sources relevant for the purpose of aquifer mapping and management. Some of the baseline reports on the project area include Banganga River Basin Project Report, Central Ground Water Board (1980), Water Resources Planning for Banganga River Basin, TAHAL (1998) and District report of Dausa district, Rajasthan (Sharma, 2008).

The data from the available sources are assembled, analysed, and interpreted and the integrated database is transformed in GIS platforms. Additional data are generated through hydrogeological surveys, exploratory drilling, advanced geophysical techniques, hydro-geochemical analysis, remote sensing etc. that broadly established the aquifer system prevailing in the area.

Micro-level hydrogeological survey was conducted through geological mapping, monthly monitoring of ground water level and quality using 53 monitoring wells which includes existing Public/ Private dug wells and tubewells as well as wells constructed during the project study, soil infiltration study, assessment of ground water recharge and withdrawal pattern. Geophysical studies include surface, airborne and sub-surface geophysical investigations. Surface geophysical techniques employed in the present study include – Vertical Electrical Sounding (VES), Transient Electromagnetic Method (TEM), Electrical Resistivity Tomography (ERT). Airborne geophysical technique employed in the region is SkyTEM (proprietary item of Arhass university, Denmark). Sub-surface geophysical method includes Borehole geophysical logging.

Information of 15 Exploratory boreholes constructed during the project and 20 exploratory boreholes constructed prior to commencement of the project were used to validate the ground hydrogeological and geophysical analysis. Pumping tests were carried out through Aquifer Performance Tests (APT) and Slug Tests to decipher the aquifer characteristics.

Fence diagram drawn based on Borehole exploration data (figure 2) broadly reveal that that there are two major litho-units in the area – upper alluvium underlain by lower hard bedrock.

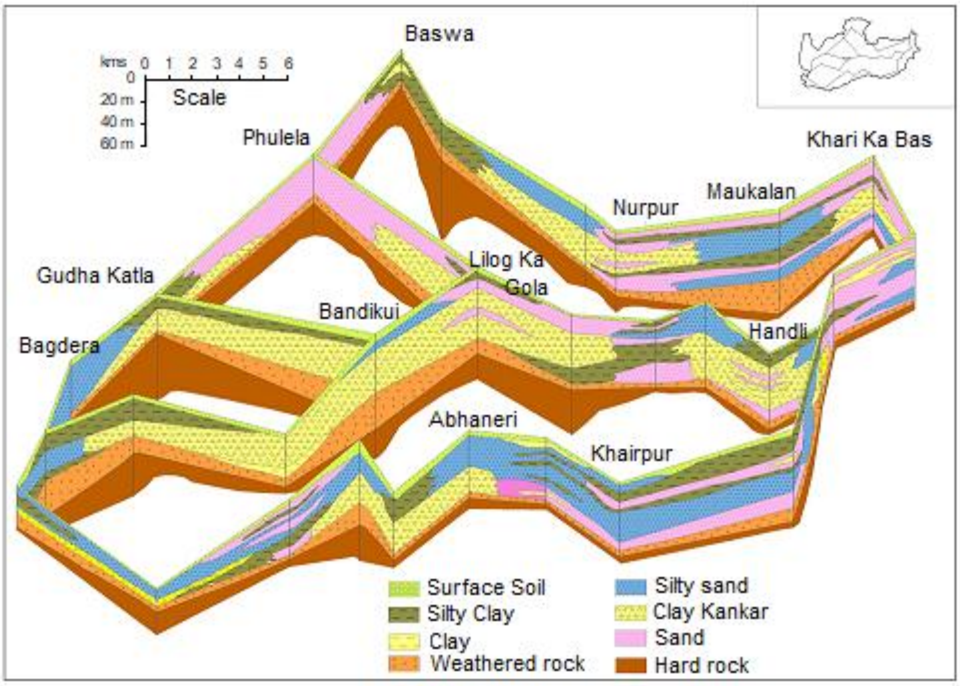

Figure 2. Fence diagram depicting lithological assemblage in three-dimension

Alluvium is predominantly finer grained in the range of silty sand, silty clay, clay kankar in the central part. However, dominantly sandy horizons have also been encountered in few sections in the north western and north eastern part. The thickness of alluvium is more towards the eastern part of the project area. The underlying hard rock formation consisting quartzites, schists, phyllites, granites, gneisses etc., has two layers – weathered portion followed by crystalline formation. Thickness of weathered hard rock in major part of the study area is between 5m to 20m. The water level varies from 3.95 meter below ground level (mbgl) to 66.00 mbgl.

The basic chemical parameters determined for evaluating the groundwater quality of Baswa-Bandiqui watershed include pH, EC, TDS, CO_3, HCO_3, Cl, NO_3, $S0_4$, PO_4, F, Ca, Mg, TH, Alkalinity, Na, K, and Fe. These elements are determined using - pH meter, EC Meter, Flame Photometer, UV/Visible spectrophotometer and titrimetric methods.

Conceptual model on aquifer performance is developed and applied to a numerical flow model to determine the overall water budget and generate predictive scenarios for a period from 2012 (study period) to 2024 (with the assumption that population would be stabilized by this period) for the proposed aquifer management strategies. The groundwater flow model for the alluvium and weathered rock formation is based upon MODFLOW, the USGS developed modular three-dimensional finite-difference computer code commonly used to simulate groundwater flow and determine hydrologic budgets in various physiographic regions (McDonald and Harbaugh, 1988). Finally, the aquifer management plan for the study area is formulated.

Results

Soil cover plays an important role in the ground water recharge. Two types of soil cover are observed in Baswa-Bandikui watershed - Loamy soil which covers major part of the area and Alluvial soil. The soil infiltration rates are determined at 23 sites in Baswa-Bandikui Watershed project area using double ring infiltrometer. The infiltration rate varies from 0.04 cm/min to 0.70 cm/min in the project area. Loamy soils have higher infiltration rate as compared to alluvial soil. The soil infiltration rates were used in demarcating areas suitable for artificial recharge to ground water and also for deriving the potential Recharge Factor.

Geophysical investigations are broadly correlated with three types of lithologic formations - High resistivity (≥100Ωm) indicative of hard, and compact quartzite and other crystalline formations, moderate resistivity (30-50 Ωm) correlating with granular sandy zones and lower resistivity indicating clay or silt (figure 3).

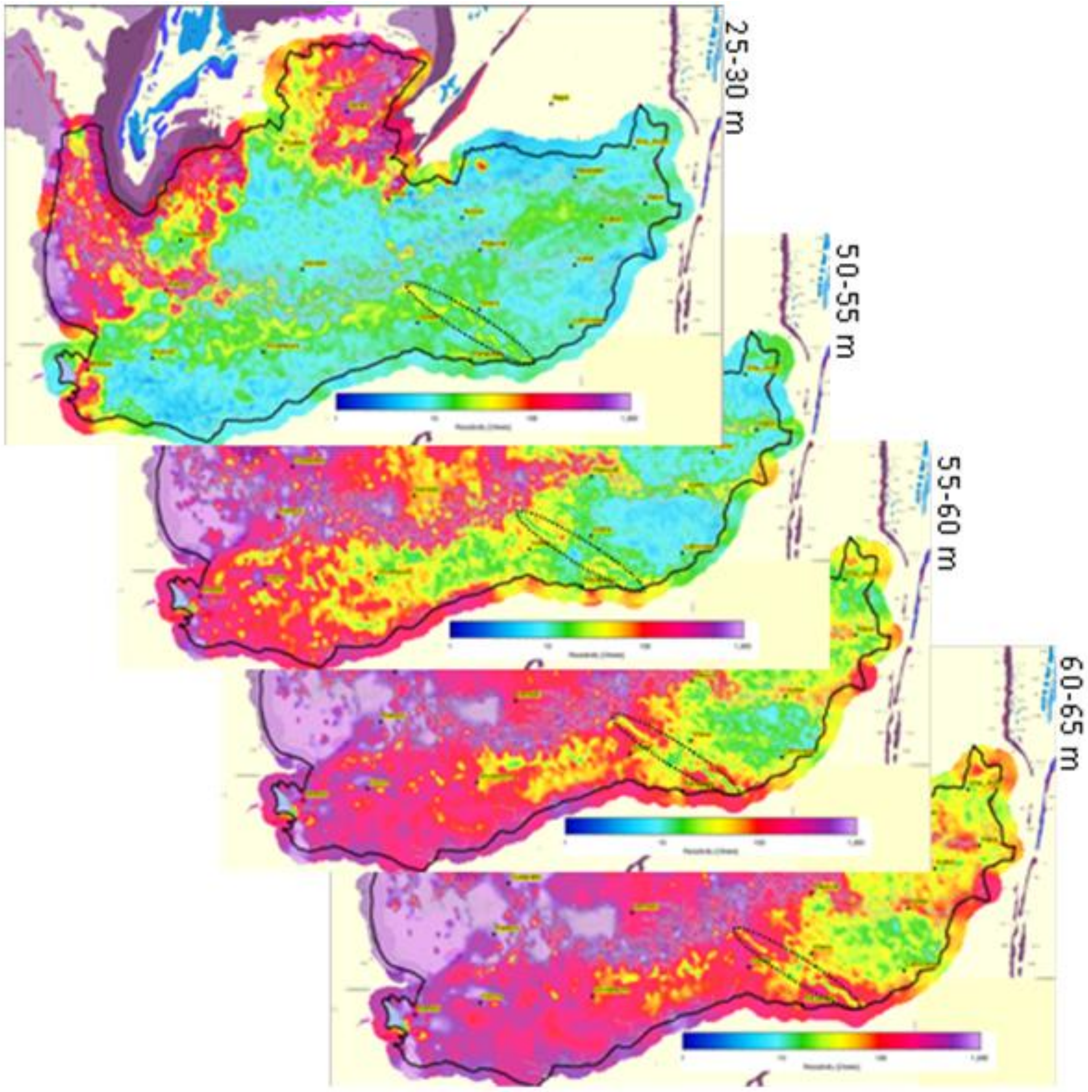

Figure 3. Mean resistivity maps: from top 25-30 m, 50-55 m, 55-65, 65-70 m depths (Chatterjee et. al. 2018)

The sub-surface structural features were deciphered through geological mapping and geophysical Magnetic mapping. Broadly three sets of faults running NS and NE-SW, folds and palaeochannel are demarcated (figure 4).

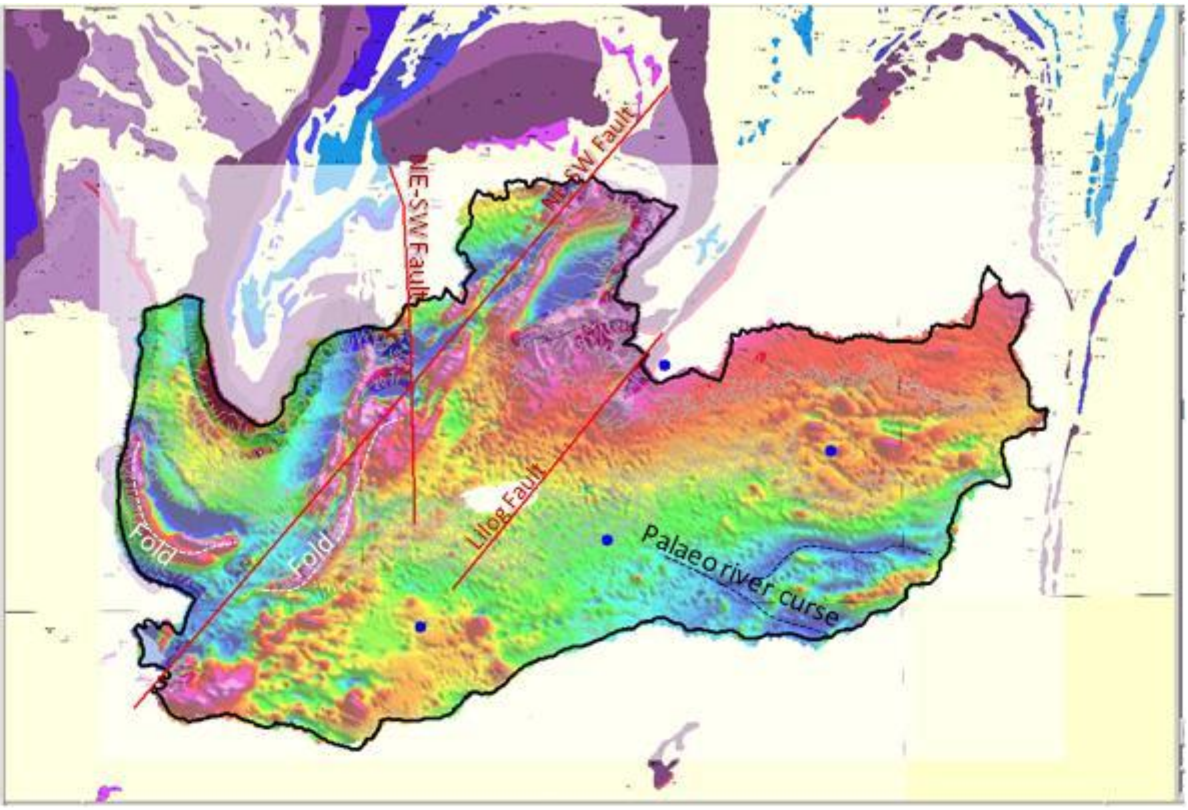

Figure 4. Helimag map superimposed over geological map showing the inferred structural features (Chatterjee et. al. 2018)

Water level data was super-imposed over integrated lithological layers constructed based on geophysical and borehole investigations to develop three-dimensional aquifer geometry (figure 5). The aquifer system of the area is broadly constituted of – Aquifer I - upper alluvium formation which is in unconfined condition and Aquifer II - underlying hard rock formation which is in semi-unconfined to semi-confined condition. All the layers are hydraulically connected. In major part of the western portion of Baswa-Bandikui watershed, the weathered portions of the hard rock aquifer constitute the top-most saturated aquifer as the overlying alluvium formation is de-saturated (figure 5, figure 6).

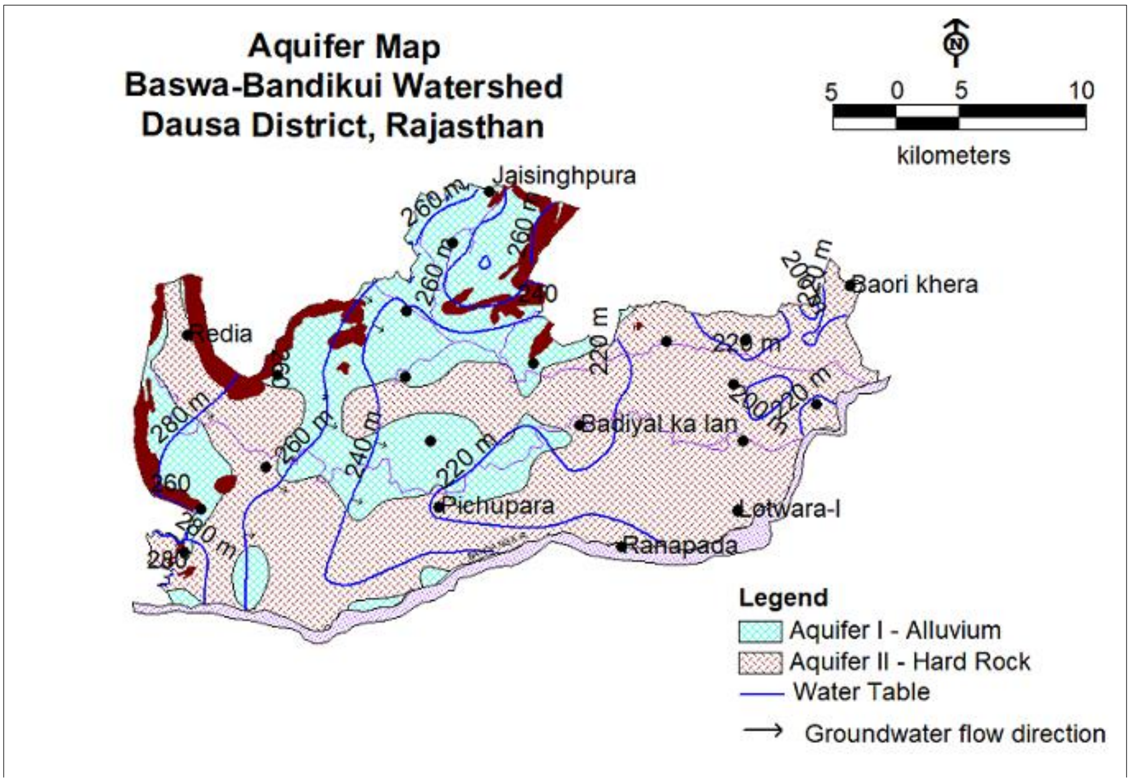

Figure 5. Aquifer map of Baswa-Bandikui watershed, Dausa district, Rajasthan (Chatterjee et. al. 2018)

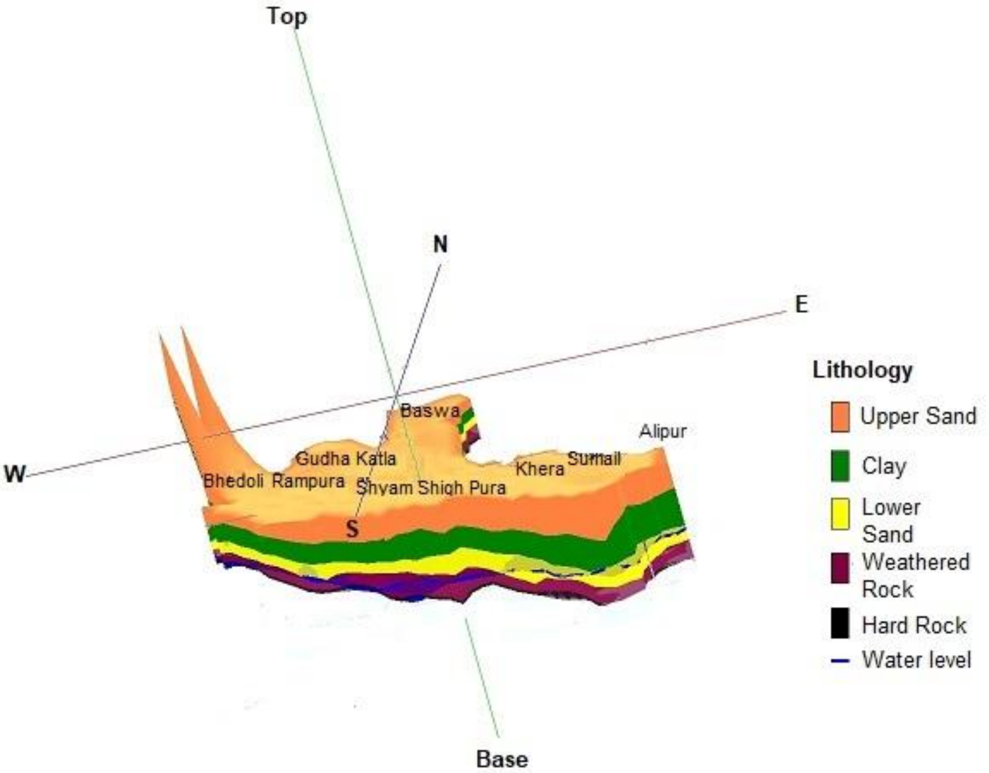

Figure 6. 3-D depiction of Water table within aquifer systems in Baswa-Bandikui watershed, Dausa district, Rajasthan (Chatterjee et. al. 2018)

The water level generally varies from 40 to 60 m bgl. Eastern part of the study area has comparatively shallower water level. Shallowest ground water level upto 20 m bgl is observed in the downstream of Redia dam at the North Western corner of the study area.

Shallow water level in the area is because of the canal seepage which adds to the ground water recharge in the vicinity and in turn raises the water level. Since both the Aquifers are in hydraulic continuity, water level in the second aquifer almost mimics the trend of the upper Aquifer I. The general ground water flow direction in Aquifer I is from west to east.

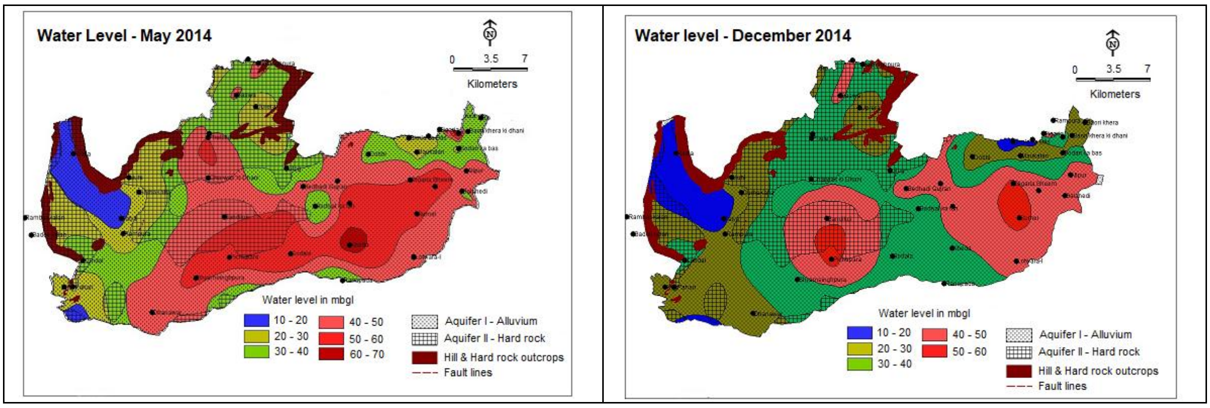

Figure 7. Groundwater level in Baswa-Bandikui watershed, Dausa district, Rajasthan

Long term water level trend of the monitoring wells used in the ground water resources estimation by State Government show decline in ranging from 0.16 m to 2 m for the period of 2003-2012 (figure 8) in-spite of rising trend of rainfall during the same period. Hence it may be inferred that the decline in ground water level is due to over-exploitation of the resources.

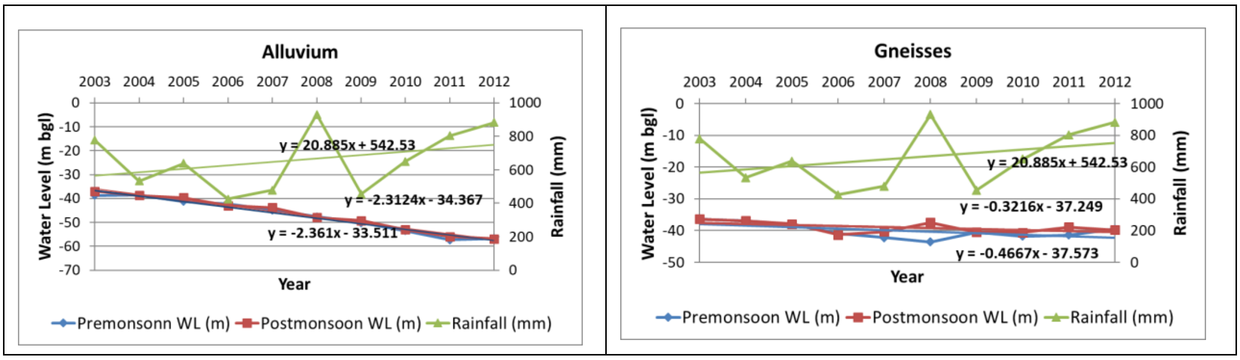

Figure 8. Hydrographs of Rainfall data vis-a-vis long term Water level trend monitored by State Government

The scarcity of the resources has also led to compromise in the ground water quality criteria. The standards adopted for setting the permissible limit of Salinity contamination has been made flexible in view of the fact that groundwater in this entire region is generally slightly brackish and crops are being grown even with this brackish water. Therefore the salinity limit has been kept at 3000 micromhos/ ^{o}C. The fluoride permissible limit is 1.5 mg/l and that of Nitrate is 45 mg/l as per BIS standards for drinking and domestic water. Ground water quality in Aquifer I and II are in general good, except that in the north-eastern corner around Biwai, Maukalan, and also around south-western corner around Kora-Kalan, ground water is of poor quality, suffering from Salinity and fluoride contamination in Aquifer I (Alluvium). Ground water with high values of fluoride have been recorded at few localities in the eastern part of the project area. The north-eastern pocket also suffers from localized Nitrate contamination. Salinity hazards is geogenic in origin. Predominance of silt-clayey lithology and semi-arid condition in association with restricted circulation of ground water has resulted in evaporation losses, precipitation of salt in aquifer and subsequently it getting dissolved into the ground water. This has resulted in high salinity in ground water. High Fluoride in groundwater is contributed by the host rocks rich in fluoride (granite, gneisses, schist). Because of rock water interaction, long residence time and evapotranspiration, the concentration of fluoride increase. Nitrate contamination is caused due anthropogenic reasons viz. contamination due to biologic waste materials.

The potentiality of the Alluvial aquifer decreases towards east where finer-grained sediments are encountered in the aquifer zones. The yield potential in the eastern part is within 60 lpm. The yield potential map of the hard rock aquifer in contrast show that major part of the aquifer is poor yielding viz. within 60 lpm. The poor yield of the hard rock aquifer is because of less thickness of weathered zone and lesser frequency of fractured zones tapped in the exploratory wells. The permeability of Aquifer I (Alluvium) is more in the western portion of the project area, in the range of 4 to 20 m/day, mainly because of the coarser lithological formations in the area as compared to the eastern portion. Permeability of hard rock aquifer (Aquifer II) in general is less than the alluvial aquifer (Aquifer I). Specific Yield of the Aquifer I is between 8% to 12% and that of Aquifer II is 1.5% to 2%. Thus storage capacity of alluvium aquifer is more than hard rock aquifer. This Aquifer Property is significant for the assessment of ground water resources and artificial recharge plan. Another property which determines the ground water recharge rate in an area is the Rainfall Infiltration factor. This factor is used in the estimation of dynamic ground water resources in an area. Therefore, an evaluation of the Rainfall Infiltration Factor (RIF) used in the resources estimation of 2011 was carried out using the Infiltration rates arrived during soil infiltration test. The average Infiltration / Recharge factor of the soil overlying the various ground water potential zones as estimated from the infiltration study are - Alluvium – 0.06; Phyllites/ Schists/ Quartzites – 0.03 and Granite Gneisses – 0.02. Though the infiltration factor arrived at can mainly be attributed to the soil cover, nevertheless, it act as a check to the RIF figures used in resources estimation. For example in Ground water Resources estimation 2011, RIF used are – Alluvium – 0.12, Quartzite – 0.07 and Granite Gneisses – 0.07 which are much higher the rates arrived at for the top soil cover. Since the Recharge factor of the aquifer should be less than the soil cover (to meet the soil moisture balance), our study indicates the RIF used for Ground Water Resources estimation needs to refined. Ground water discharge in the study area is mainly through ground water abstraction by wells. Unit draft study was carried out in the project area to determine the average unit draft of various ground water structures used for irrigation and domestic purposes. The information collected include type of lifting device, engergination details, discharge, use of the inventoried well, utilization pattern including area irrigated/ number of persons using the structure, cropping pattern, irrigation details and other relevant information required for analysis of estimation of unit draft of wells. The unit draft of the wells are computed taking into consideration the discharge of the well and consumptive utilization pattern. The average unit draft of Dug wells in the area ranges from 100 m^3 to 2067 m^3, Dug cum Borewell from 700 m^3 to 1400 m^3, Borewell from 730 m^3 to 1325 m^3, Shallow tubewell from 1410 m^3 to 3210 m^3 and Deep tubewell from 2175 m^3 to 5120 m^3.

Ground Water resources Assessment carried out in the study area jointly by the State Ground Water Department and Central Ground Water Board for the base year of 2011, indicate that Annual Replenishable Ground Water Resources is about 43 million cubic meter (mcm). Keeping an allocation of natural ground water discharge during non-monsoon period (June of one year to April of next year), the Net Annual Ground Water Availability is 38.70 mcm. Annual Ground Water Draft (abstraction for various uses including irrigation, domestic and industrial) has been estimated to be 74.20 mcm. The percentage of annual ground water withdrawal in respect to the net annual ground water availability which is termed as Stage of Ground Water Development is 192%. The long-term water level trends are decline. The area has been categorized as ‘Over-exploited’.

The water balance in the study area is simulated using application of numerical groundwater flow model to design predictive scenario of ground water regime and optimization of ground water development in the area. The computer program uses finite-difference technique and block centered formulation to solve the groundwater flow equation for three-dimensional, steady state flow in the anisotropic, heterogeneous, porous media of the Baswa-Bandikui micro watershed. The mathematical model of the study area is conceptualized as a One layer model including alluvium as well as underlying weathered residuum, in which the depth of the layer is considered up to the bottom of the weathered hard rock formations. The boundary conditions are specified for the upper surface, sides and bottom of the modeled area. The topographic divide (hill ranges) to the western & north-western part of the study area which coincide with ground water divides are represented by no-flow boundary. River boundary to the southern and part of the eastern side of the area represented by a General Head Boundary. Most of the ground-water flow in the basin occurs within the alluvium as well as in the underlying weathered hard rocks and also deeper fractures. The ground water heads simulated by the model for the known stresses of the past are calibrated to match with the observed heads. Ground water heads for June, 2012 are used as the starting heads for steady state calibration. The hydraulic conductivity and other parameters arrived from steady state calibration is then used as the initial condition in the transient model calibration. Transient state simulation is carried for a period of 4 stress periods for 2 years (2012-13 to 2013-14). Each stress period is taken to be of first 4 months starting from June to September and second period is taken next 8 months from October of one year to May of the next year.

The numerical ground water flow model is then calibrated to predict the response of the aquifer system to the anticipated changes in hydrogeological stresses for the 10 years duration commencing from June 2014 to May 2024.

Discussion

The ground water management interventions suggested, include both demand side measures like regulation and conservation of resource as well as supply side measures like augmentation of resource.

I. Notification of the Baswa-Bandikui watershed for ground water regulation – the first ground water scenario simulated through numerical flow modeling assumed that the ground water withdrawal will remain same in year 2024 as it is on the initiation of the simulation period i.e. 2012. Even though the ground water extraction rate remained same, the continued extraction progressively desaturated the top alluvium aquifer and also the weathered portion of the hard rock.

In the first predictive numerical modeling scenario, the northern part of alluvium areas close to hard rock aquifer started drying up from the second stress period and progressively the area increased till the end of this scenario. Drying of cells covered an area of 59.50 sq.km. The scenario implies that the present rate of ground water development would lead to future drying up of the aquifers (figure 11).

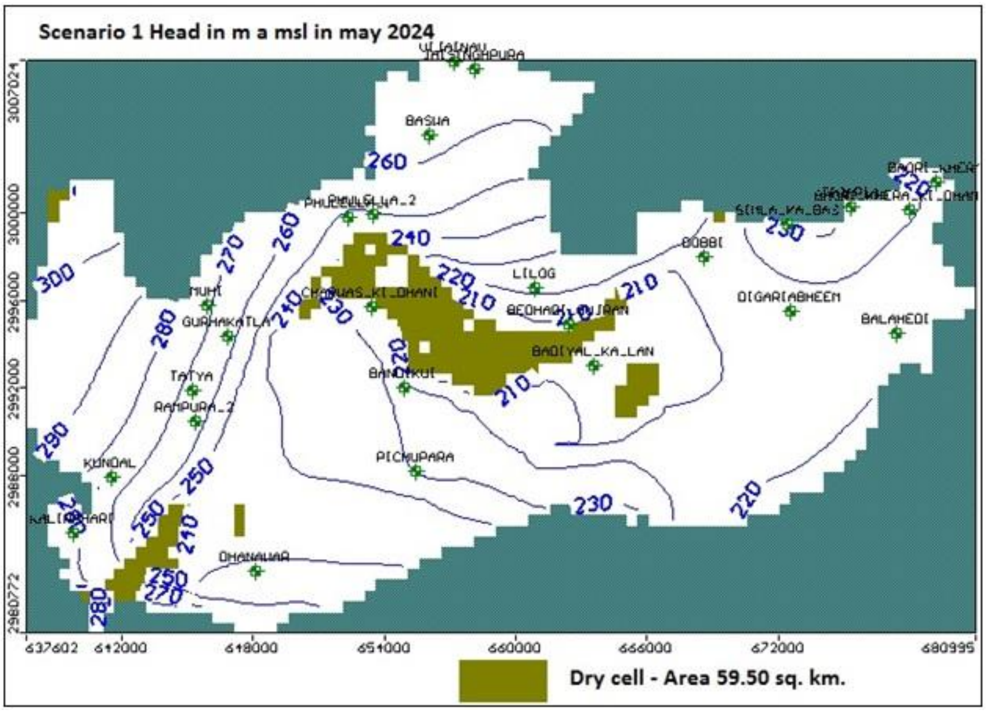

Figure 9. Water level head in the last stress period (May 2024) in Scenario 1 (Chatterjee et. al. 2018)

The first management intervention therefore should be to control the withdrawal of ground water. The Bandikui block have to be 'Notified' by either the State Government in case Ground Water legislation is enacted in the state or alternatively, the development block has to be notified under Environment (Protection) Act, 1986 by Central Ground Water Authority, the Central Government Agency empowered to regulate ground water extraction in the states where Ground Water Legislation has not been enacted.

2. Artificial Recharge to Ground Water and Rainwater Harvesting – Since ground water regulation is not sufficient enough to control water resource depletion in the area, artificial recharge to ground water and rainwater harvesting are proposed as a supply-side management option. Precise demarcation of the area suitable for artificial recharge has been carried out based on following criteria –

i. semi-arid climate (~585 mm monsoon rainfall)

ii. topography with moderate to gentle slope

iii. loamy soil with high infiltration rate (avg. 39 mm/hr)

iv. unconsolidated alluvium, water level > 35 mbgl (post-monsoon) and

v. ground water quality – EC<3000µmhos/cm

All the above parameters are superimposed on GIS platform to delineate the area feasible for artificial recharge which is 253 sq.km. The feasible artificial recharge structures are – Percolation Tank, Recharge Shafts and Roof Top Rainwater Harvesting Structures.

Percolation Tanks are proposed to be constructed in the upper catchment area on second order and third order streams in an area of about 74 sq.km. The Recharge Shafts in the project area are proposed to be constructed in combination with Percolation Tank, village ponds and also individual structures in an area of about 253 sq.km. The Roof Top Rainwater Harvesting is proposed in more than 400 Government buildings existing in the entire project area. The additional ground water recharge expected to be generated through proposed Artificial

Recharge structures is given in table 2. Only 3.62 mcm of water is expected to recharge the aquifer in this supply side management intervention.

The artificial recharge and rain water harvesting would result in reduction in dry cells from 59.50 sq.km. in scenario–1 to 48.50 sq. km in scenario-2 (figure 12) and rise of water level head from 0.01 Scenario 1 to 10.27 m in Scenario- 2.

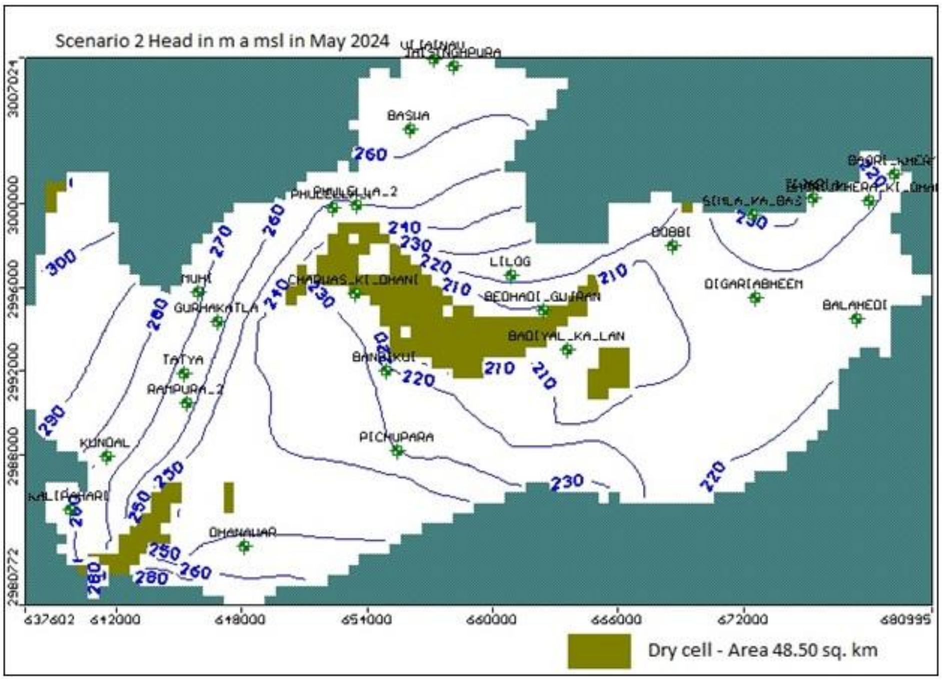

Figure 10. Water level head in the last stress period (May 2024) in Scenario 2 (Chatterjee et. al. 2018)

3. Adopting On-Farm Water Management practices including Micro-irrigation in agriculture sector –

In order to further reduce the dry cells and consequently check ground water depletion, a third Aquifer management intervention is suggested, which is water use efficiency measures adopting On-farm management practices including Micro Irrigation. Micro-irrigation practices like drip irrigation system and mini-sprinkler are suitable for the soil condition (loamy and alluvial soil) and cropping pattern (wheat, mustards etc.) of Baswa-Bandikui watershed area. Adopting water saving micro-irrigation techniques will reduce demand for ground water by 35 % (adopted from Master Plan for Artificial Recharge to Ground Water, Central Ground Water Board, 2013). Thus considering the Rabi ground water draft for irrigation purpose in the area as around 70 mcm (as per Ground Water Resources Estimation of 2011), about 25 mcm of ground water is envisaged to be saved in case proper on-farm water management practices are adopted. This will result in reduction of the ground water draft (extraction) considerably.

Conclusion and recommendation

Ground water resources in Baswa-Bandikui watershed in Dausa district of eastern Rajasthan suffers from ‘Over-exploitation’ due to excessive withdrawal of the limited resource. Geologically the area is having alluvium underlain by hard rocks of Archean/ Proterozoic age. The aquifer mapping studies in this watershed revealed that the thickness of alluvium aquifer, with aquifer characteristics more promising than the underlying hard rock, is in the range of 5 m to 72 m. The over-dependence on ground water is gradually lowering the water table in the area. At many places, particularly in the western part of the study area, the water level has gone below the alluvium layer, wherever the thickness of alluvium is less. The consecutive ground water resources assessment carried out for the Bandikui block for the year 2009, 2011 and 2013 (provisional) has categorized the area as ‘Over-exploited’. The Numerical Ground water Flow Model simulated for the study area to generate predicative scenarios indicate that even if the ground water withdrawal is kept as present level, about 60 sq.km of presently saturated alluvium aquifer will be dried up additionally by 2024. Thus it is recommended that the Bandikui block may be Notified to restrict ground water withdrawal. Further, the conceptual Artificial Recharge plan proposed for the area be implemented alongwith On-Farm Water Management Practices including Micro-Irrigation additional ground water management intervention. These measures would cumulatively result in reduction of dry cells upto about 13 sq.km.

It is therefore highly recommended that the local people residing in the Baswa-Bandikui watershed may be sensitised about the depleting ground water resources situation in the area. Radical changes in the water conservation measures and water utilization pattern are required with general consensus of the people of the area to stop further depletion of this pristine resource.

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Ground Water Modelling for Sustainable Aquifer Management - A Case study of WGKKC-2 Watershed, Nagpur, Maharashtra

Bhushan R. Lamsoge and N. C. Nayak

Senior Hydrogeologist, CGWB

Abstract

The Chandrabhaga watershed (WGKCC-2), Nagpur district, Maharashtra is experiencing high risk due to ground water withdrawal for water intense crop like orange which leads to stage of ground water development upto 89 %. Central Ground Water Board (CGWB), under 'pilot project on aquifer mapping' (AQMAH) carried out detailed multi-disciplinary hydro-geological survey in Chandrabhaga watershed for formulation of sustainable aquifer management plan. As a part of AQMAH, ground water modeling has been carried out to know the present scenario and future strategies to be adopted for better ground water management. Based on ground water modeling, two strategies were proposed i.e., Scenario-1: Construction of a check dam on Chandrabhaga river & Scenario-2: Construction of 25 recharge wells to enhance ground water recharge and arrest declining ground water levels .

It is observed that ground water recharge will be increased by 9%, if a check dam of 1.5m height will be constructed on Chandrabhaga river. Likewise, the specially designed 25 recharge wells tapping the full thickness of the aquifer (20-30 meters) can be constructed, with a recharge rate of 300 m^3/day for the full rainy season and zero recharge rates for the rest of the period. This will enhance the ground water resources of the area by 1125000 m^3 annually which will ultimately arrest the present declining trend of water levels as well as increase the ground water potential.

Key Word*:* Basalt, Aquifer mapping, Ground water modelling, WGKCC-2 watershed, Nagpur

Introduction

Ground water simulation modeling is a powerful management tool to study such problematic areas. At present, most of the investigations related to ground water modeling are carried out by MODFLOW (Anderson and Woessner 1992; Strom and Mallory 1995; Gnanasundar and Elango 2000; Singh and Woolhiser 2002; Zuquette et al. 2005; Kushwaha et al. 2009, Lalehzari et al. 2010; Senthilkumar and Elango 2004, 2011; Wu and Tang 2010; and Yang et al. 2012). Ground water modeling for the hard rock area of Deccan Trap Basalt is always a challenging task as it is very difficult to run the model because of the heterogeneity in the aquifer parameters and unpredictable basaltic aquifer geometry. Ground water management in such areas needs multi-disciplinary approach. The highly diversified occurrence and considerable variations in the availability and utilization of ground water in India makes its management a challenging task. Lamsoge et al, (2014) developed a ground water model and simulated scenarios in basaltic over-exploited watershed to study the effect of ground water over-exploitation and effective management of ground water. In the present paper an attempt has been made to formulate aquifer management plan by simulating single layer ground water model for basaltic unconfined aquifer of *Chandrabhaga* watershed (WGKCC-2), Nagpur district, Maharashtra.

Study area

India in general and Maharashtra in particular has diversified hydrogeological terrains, having unique issues/problems like over exploitation of ground water, declining ground water levels, waterlogging in canal command areas, ground water quality deterioration, irregular rainfall pattern, and scarcity of drinking water during summer period etc. (Aghase, 1994, Karanth 1999, CGWB, 2013).

To establish a methodology for the *National Project on Aquifer Mapping & Management* (NAQUIM) Central Ground Water Board (CGWB), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India has undertaken a pilot study of six areas in different hydrogeological terrains under 12th five-year plan. Out of six, a pilot project in the State of Maharashtra (AQMAH) targeting Basaltic aquifer has been taken up in the Chandrabhaga Watershed of Nagpur district, Maharashtra (CGWB, 2012). Chandrabhaga Watershed (WGKKC-2)with an area of 360 sq. km. is situated in the north western part of Nagpur district covering about 60 villages in parts of Nagpur (rural), Kalmeshwar and Katol talukas (**Fig. 1**). It lies between north latitudes 21°10’ and 21°20’ and east longitudes 78°42’ and 78°59’ and falls in parts of Survey of India toposheets 55 K-11, 12, 15 & 16. The watershed is well connected by all season motorable roads.

The watershed is characterized by high ground water withdrawal for agricultural and industrial uses with the stage of ground water development touching 89%. No declining trend is observed in the well hydrographs of the region (CGWB, 2015). However if ground water withdrawal goes unabated at this pace then the ground water condition in the watershed will become critical in near future. Thus, modelling has been taken up with the objective to understand the hydraulics in the aquifer system in the watershed and plan for sustainable aquifer management strategy.

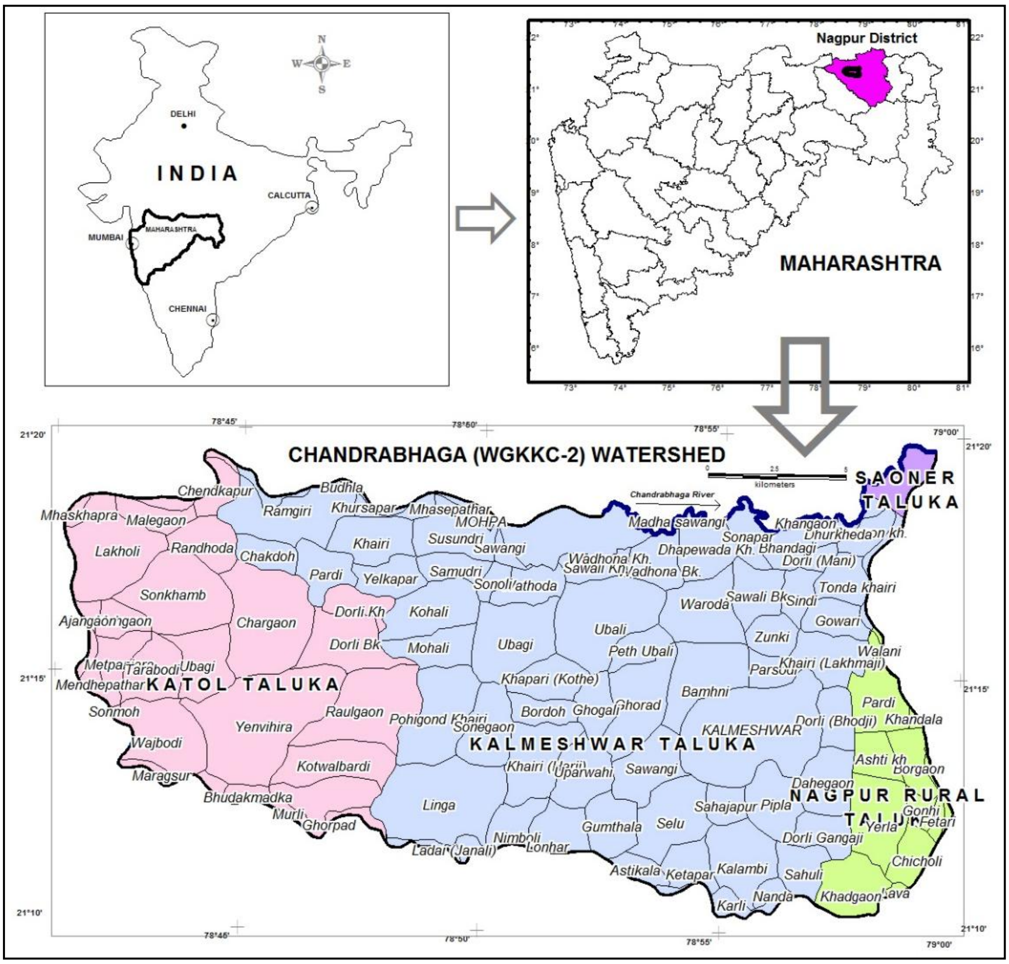

Fig. 1: Administrative and location map of Chandrabhaga Watershed (WGKKC-2)

Aquifer System

The primary aquifer system in the Chandrabhaga watershed is unconfined Basaltic Aquifers and classified as Aquifer-I (**Table 1**). It occurs in entire area except in northeastern part of the area where the Sandstone of Gondwana formation constitutes the unconfined aquifer. The remaining two aquifers i.e. Aquifer II and Aquifer –III are semi-confined to confined in nature and spread all over the area (**Fig. 2**) (CGWB, 2012a; 2012b; 2015, NGRI, 2013).

Number of Aquifer	Type of Aquifer	Aquifer Condition
Aquifer I	Unconfined aquifer	Occurs in Deccan trap basalt which is exposed in major parts and Gondwana Supergroup in the NE part. It generally occurs to the depth of 20 to 30m bgl, mostly tapped by the shallow dug wells occupied by basaltic and sandstone terrain.
Aquifer II	Semi-confined to confined aquifer	Generally occurs in Deccan trap basalt which is exposed in major parts and Gondwana Supergroup in the NE part. The thickness of aquifer varies from 0.50 cm to 6 meters in Basaltic formation and 3m to 34 m in Gondwana formation, mostly tapped by the deep bore/tube wells in area occupied by basaltic and sandstone terrain.
Aquifer III	Semi-confined to confined aquifer	It is mostly 'Trap Covered Gondwanas or Gneisses' (TCG). Generally occurs as semi-confined to confined conditions but at places, they exhibit unconfined condition and occur where the thickness of basalt is less, and tapped by the shallow dug wells or deep bore/tube wells in area occupied by basaltic and sandstone terrain.

Table 1: Aquifer types and conditions, Chandrabhaga Watershed (WGKKC-2) of Nagpur district, Maharashtra

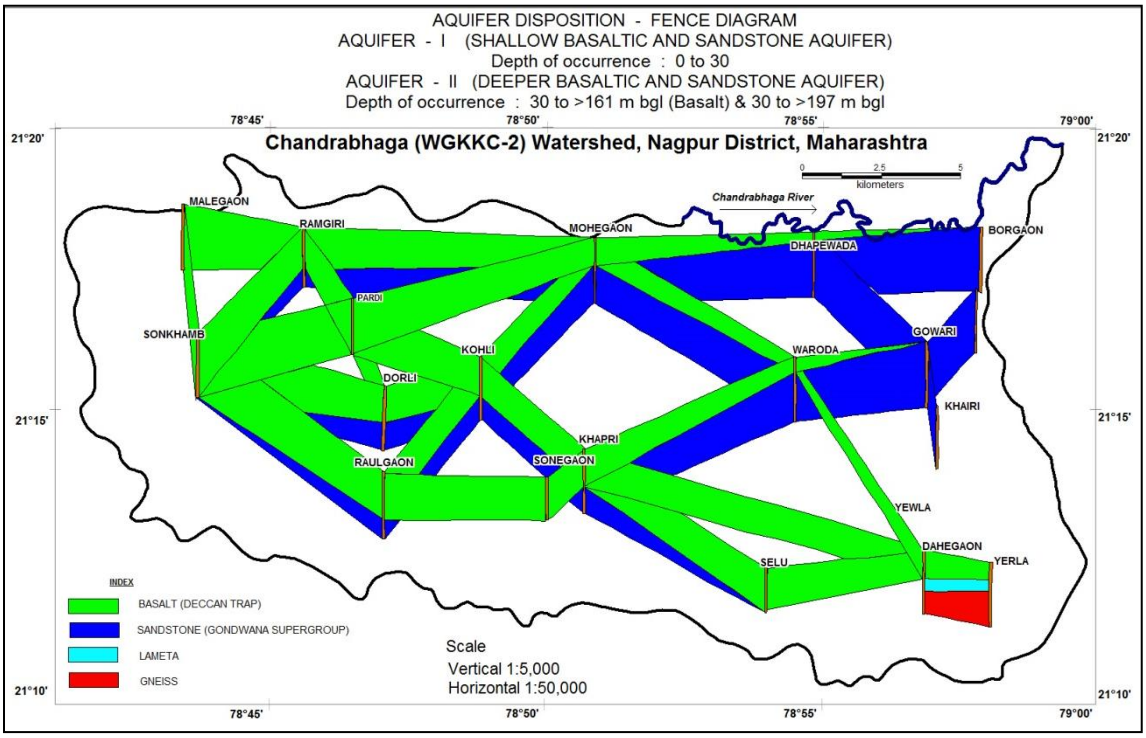

Fig. 2: Aquifer disposition with lithological fence diagram of the area based on ground water exploration

Methodology

For successful ground water modeling, there are some modeling protocols that have to be followed. Aderson and Woessner (1992) established a protocol for modeling, which includes model design, calibration, sensitivity analysis and finally prediction which has been adopted during the study.

During the project period, available data pertain~~s~~ing to study area was complied, data gap analysis was carried out and data generated to fill these gaps. The various thematic maps like drainage, soil, geomorphology, landuse/landcover, hydrology, lineaments, geology etc. were prepared based on data available using software like Arcmap, Mapinfo discover, Rockworks etc. Extensive hydrogeological surveys have been carried out. A total 16 exploratory wells were constructed through outsourcing to decipher the aquifer geometry, its lateral and vertical exten~~d~~t and determination of deeper aquifer parameters. All the boreholes were logged upto drilled depth through gamma logging to get the accurate disposition of fracture geometry. The entire data has been used to formulate the ground water flow model using MODFLOW code in Visual Modflow 4.2 software (McDonald and Harbaugh, 1988).

Conceptualisation of Model

Weathered and fractured residuum underlain by massive basaltic flow serves as the main aquifer system in the area. Ground water occurs under unconfined condition and the head is reflected as water level in the dug wells. Though the dug wells are of 10 to 15 meters of depth, they have not fully tapped the phreatic aquifer. Hence, the thickness of the aquifer is taken as 20 to 35 meter as deciphered from the geophysical and well inventoried data and is considered as first layer in the model. Similarly, the top weathered and fractured zone on the Gondwana sandstone present in the north eastern part is also included in the first layer of the model. The aquifer characteristics and water level data is available for this layer. Ground water exploration carried down to depth of 200 m, shows number of basaltic flows with ground water contribution mainly from fractures and contact of different flows. Similar is the condition in the Gondwana sandstone and thus a second layer comprising of basalt, Gondwana sandstone and trap covered sandstone is conceptualized to the depth of 200 meter with very low permeability value unless until good fractures are encountered. However, due to paucity of data the second layer is not being modelled. The assumptions made in the model are as follows

- Most part of the watershed boundary serves as hydrological boundary for the modeled area and thus contributes negligible flow to or from the modeled area.
- The river Chandrabhaga flowing along the northern part of the study area contains good amount of surface water in the form of flow so that it can be treated as a source of water at least for part of its course.
- Rainfall is the only source of recharge for the top phreatic aquifer. Recharge due to the return flow from irrigation is not considered.
- The ground water flow system in the western hilly area is local and is confined to small valleys interspersed in hills and ~~is~~has nothing to do with the regional flow system depicted in the model. Hence ground water draft from these areas is not considered in the model.
- Due to the limited size and extent of the river flowing through the watershed, its contribution to the model is limited to a drain.

In the present study, conceptual models were developed (**Fig. 3**) assuming different boundary conditions specially for hilly area in western end and river boundary in northeast of the study area (Bredehoeft J., 2005).

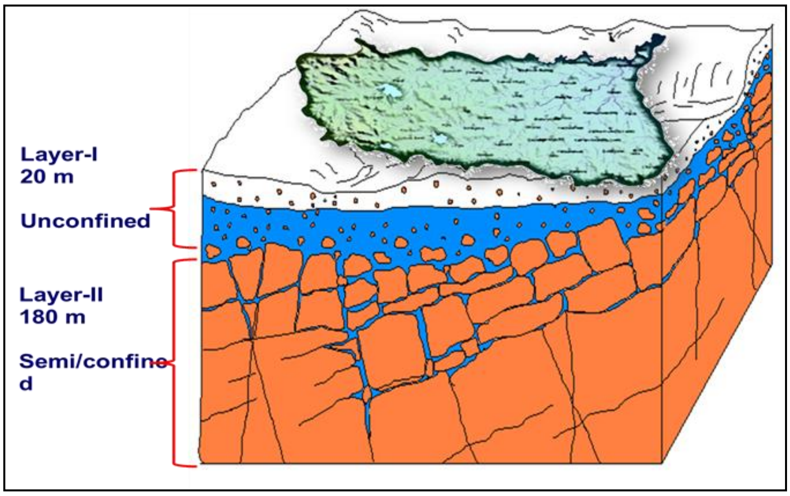

Fig. 3. Conceptualization of area based on aquifer type

Model Design & Model Boundaries

Based on the available data, a coarse uniform grid of 1000 ×1000 m is designed and the layer top elevation of the model is imported from the SRTM data after refining to accommodate to the model grid size. The area is discretized into 612 grids of 1000 × 1000 meter grid size. A total 18 rows and 34 columns were considered. Out of 612 grids, 392 grids are kept active following the watershed boundary. By making the rest of the grids inactive, the no flow boundary is created at the watershed boundary.

The river flowing along the north-eastern part is modeled as a linear gradient river assigning river stage of 332 to 305 m amsl at the western and eastern part respectively. To simulate the large reservoirs present in the eastern part of the watershed, a constant head boundary is assigned to the cells underlain by reservoirs. Three big reservoirs are considered for the purpose. To simulate the river draining the watershed, a drain boundary is revoked so that it will imitate an ephemeral stream. All these boundaries are shown in the **Fig 4.**

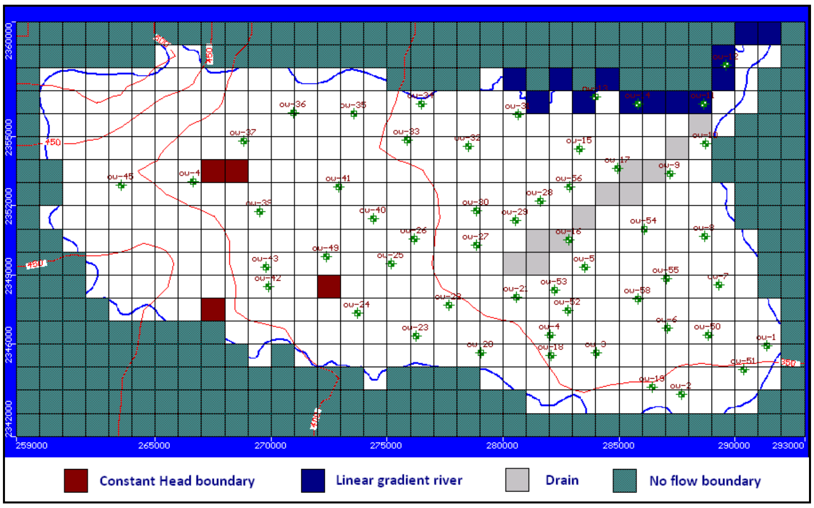

Fig. 4: The conceptual model Layer -1 plan view, the surface elevation contour with an interval of 25 meter is shown as red line. The green points are monitoring well locations.

Assigning Parameter Values

Distribution of Conductivity Values :

Based on the pumping test data analysis in the study area, the hydraulic conductivity of around 12 m/day was considered for most part of the phreatic aquifer. Vertical hydraulic conductivity has been taken as 10% of the horizontal hydraulic conductivity. The hilly area in the western part is highly sloping and is not practically considered for modeling purpose. Thus, to simulate the area in the model, a very low permeability value of 0.01 m/day is assigned.

Distribution of Storage parameters:

Presence of good yielding dug wells sustaining to long duration of pumping indirectly indicates high conductivity and storage value of the phreatic aquifer. Since the weathered and fractured zone is very productive and devoid of much clay content, a specific yield value of 0.04 is considered for the major part of the model area. However the storage value of massive basaltic horizons underlain by fractured basalt as deciphered from geophysical investigation is low and is taken as 0.02. The hilly area present in the western part is underlain by massive basalt and hence a very low storage value of 0.0001 is assigned to this zone.

Recharge to Ground water: The recharge to the watershed is only from precipitation and thus vertical recharge is the only source of ground water in the basin. The actual rainfall data of Kalmeshwar rain gauge station of 2012, 2013 & 2014 is used whereas the normal monsoonal rainfall is considered for predicted period. Due to more rainfall in the watershed under study, a low recharge value of around 16% is considered for most part of the study area. The western hilly area is assigned a very low recharge value of only 1%. A somewhat lower recharge of 13% is assigned to the valley area since they fall under ground water discharge zone at least during peak monsoon season. A less recharge of 8% is assigned to the north-western part which is characterized by undulating hills and valleys.

Model Calibration

As recharge and ground water withdrawal occurs at different periods, the steady state condition is not applicable for the present study. Hence, it is imperative to design a transient model to accommodate different periods of recharge and discharge and to get the ground water scenario and budget at different stress periods.

For the purpose of calibration 52 observation wells out of 58 established wells were selected excluding wells in hilly areas. The water level data of these well is available from October 2011 onwards on monthly basis. Hence, for transient state calibration, water level data from June-2012 to October-2014 has been used. A comparison of observed and simulated contours was used for spatial variation and RMS error for matching of computed and observed heads of observation wells were used for calibration and validation purposes. A comparison of observed and simulated contours for the month of June 2012 and November 2012 is presented in **Fig 5** and **Fig. 6** respectively.

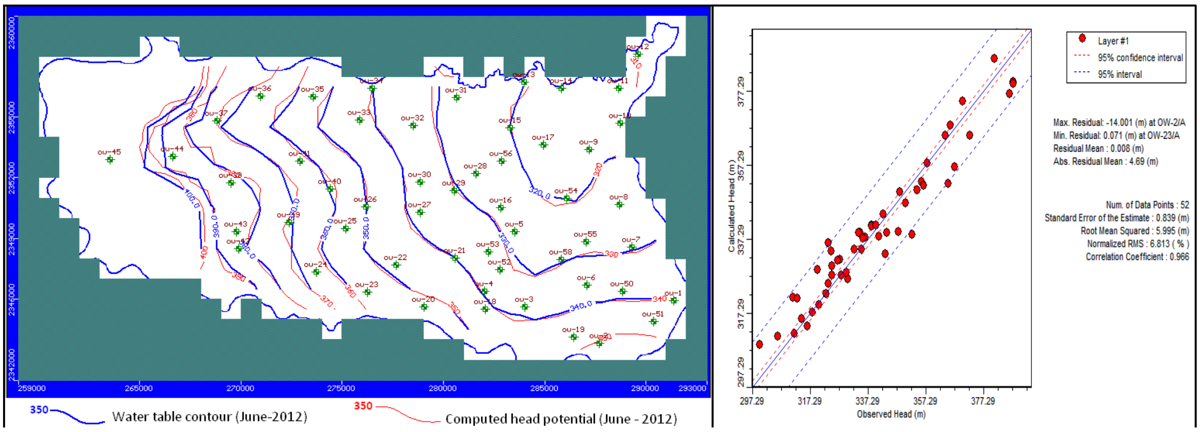

Fig. 5: Goodness of fit of water table contours and computed head potential for June-2012

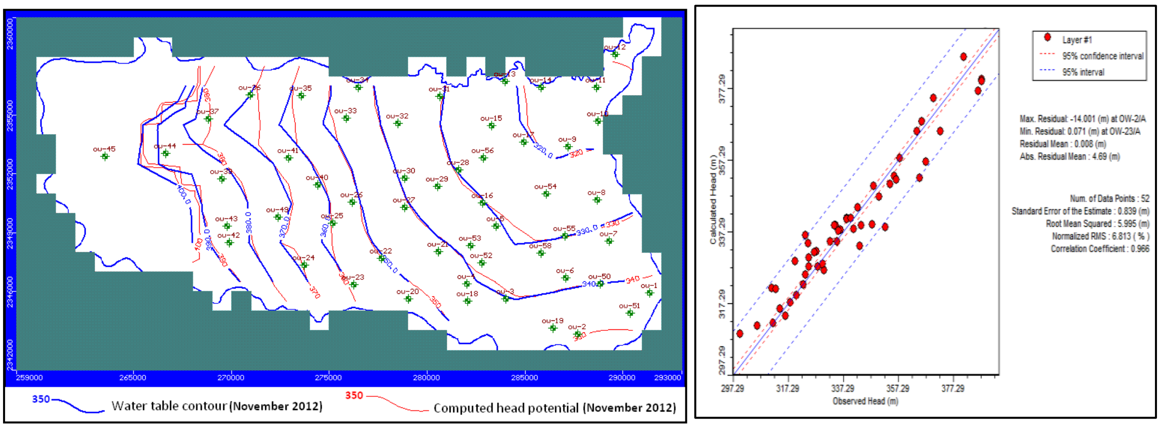

Fig. 6: Goodness of fit of water table contours and computed head potential for November 2012

Sensitivity analysis of the model was carried out by changing hydraulic conductivity & specific yield values. It is found that hydraulic conductivity values are found to be sensitive while the model is found to be less sensitive to specific yield values.

Results & Discussion

After successful calibration of the model, water budget of the model area with reference to various stresses, recharge and discharge component based on field observations were simulated and tested.

Water Budget

Aquifer Response model also brings out the budget for the model area. Quantification of inflow and outflow components (M.Cu.m) for the aquifer during different stress periods has been tabulated in **Table 2**.

Stress Period (in Days)	30	60	90	120	150	180	210	255	320	365	Total
Inflow											
Storage	0.08	0.08	0.08	0.08	0.60	6.62	6.33	9.13	12.78	8.72	44.48
Constant Head	0.11	0.07	0.04	0.01	0.03	0.10	0.12	0.21	0.36	0.28	1.33
Well	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recharge	8.43	11.22	11.27	10.04	2.36	0.00	0.00	0.00	0.00	0.00	43.33
River Leakage	0.08	0.01	0.00	0.00	0.03	0.33	0.40	0.72	1.25	0.95	3.78

Stress Period (in Days)	30	60	90	120	150	180	210	255	320	365	Total
Total inflow	*8.71*	*11.38*	*11.39*	*10.12*	*3.02*	*7.05*	*6.85*	*10.07*	*14.39*	*9.95*	*92.92*
Outflow											
Storage	8.08	10.17	9.52	7.74	1.34	0.00	0.00	0.00	0.00	0.00	36.86
Constant Head	0.18	0.23	0.29	0.34	0.29	0.22	0.20	0.26	0.31	0.19	2.51
Well	0.00	0.00	0.00	0.00	0.00	6.42	6.42	9.64	13.92	9.64	46.03
Recharge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
River Leakage	0.38	0.66	0.82	0.91	0.47	0.14	0.11	0.13	0.17	0.12	3.91
Drain	0.07	0.32	0.76	1.14	0.92	0.26	0.11	0.04	0.00	0.00	3.63
Total Outflow	*8.71*	*11.38*	*11.39*	*10.12*	*3.02*	*7.05*	*6.85*	*10.07*	*14.40*	*9.94*	*92.93*

Table 2: Cumulative Water Budget in M.Cu.m

A perusal of the table shows that there was an initial storage of 44.48 M.Cu.m in the aquifer and with the inflow of 48.44 M.Cu.m and outflow of 56.07 M.Cu.m, the resultant storage in the aquifer at the end of 365 days is of the order of 36.85M.Cu.m. Various inflow and outflows as a part of 'ground water budget' at the end of 365 days have been furnished as **Fig. 7 & Fig. 8**.

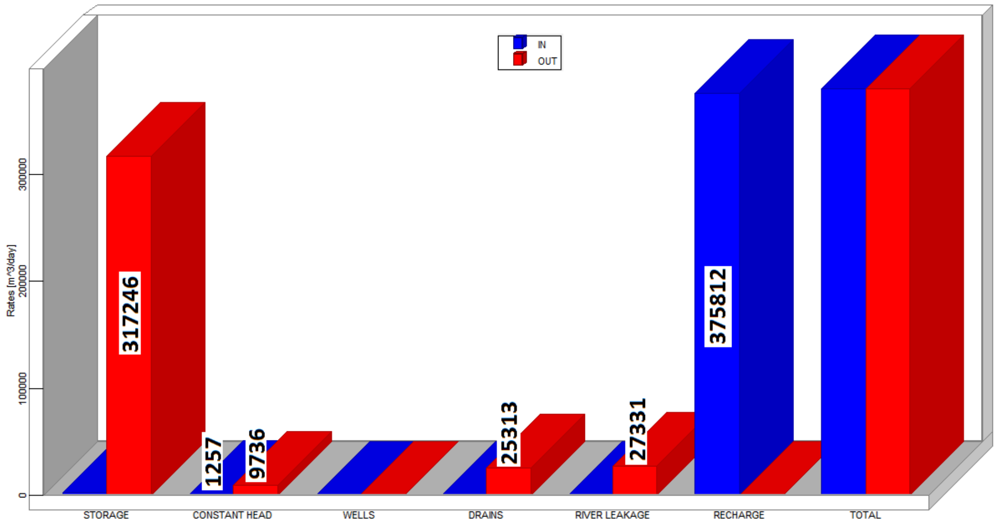

Fig. 7: Ground water budget for August

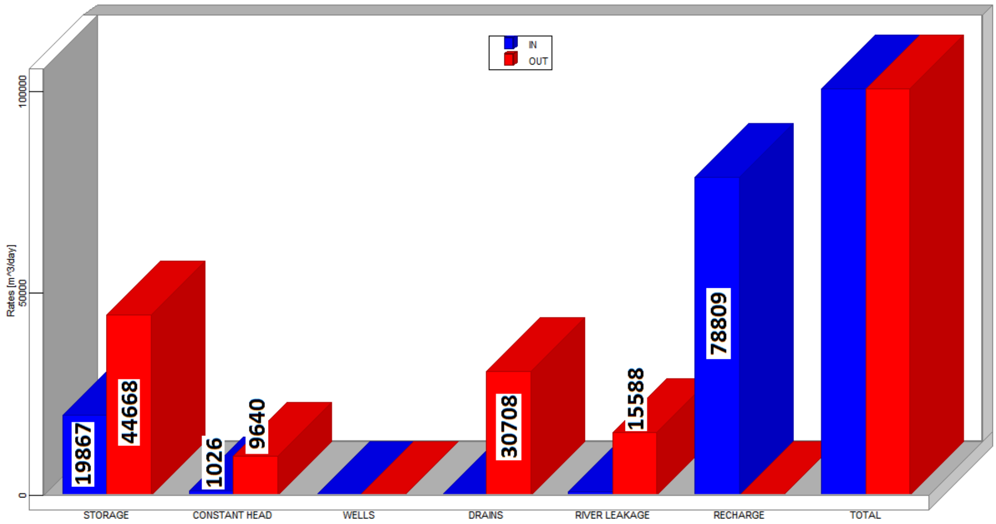

Fig. 8: Ground water budget for Early November

Aquifer Management Plan

The calibrated model has been used to assess the impact of recharge improvement and enhancement on the aquifer system so that the aquifer can sustain to the ever increase in ground water demand for agriculture and industries situated in the watershed. Two scenarios have been studied using the model to augment the aquifer and the strategy adopted and the results from the model are described below.

Scenario -1: *Construction of check dam/weirs on Chandrabhaga river at selected locations to raise the river stage so as to reduce base flow and to increase recharge to the aquifer.*

The Chandrabhaga river plays a major role in supplying water to the underneath aquifer and thus if its stage is improved at certain conducive locations by means of the construction of suitable check weirs, then recharge to the aquifer will improve and the aquifer contribution to the river will be reduced. This concept is tried to be replicated in the model by increasing the river stage by 1.5 meters at grids where during post monsoon season the river is out flowing or else is contributing very little recharge.

Parameters	Days									
	30	60	90	120	150	180	210	256	320	365
River Leak. In	2806	248	0	0	867	11117	13490	16065	19248	21176
River Leak. out	12652	21880	27331	30230	15588	4751	3761	2834	2674	2640
River Leak. In	3440	767	441	370	1776	11764	14132	16734	19474	21109
River Leak. out	13090	21892	27237	29742	15209	3850	3069	2541	2196	2014
Ground water Improvement	634	19	441	370	909	647	642	669	226	-67
	-438	-12	94	488	379	901	692	293	478	626
Overall improvement	196	7	535	858	1288	1548	1334	962	704	559

Table 3: Improvement in the river leakage, Scenario 1, Chandrabhaga Watershed (WGKKC-2)

Nb:

1. Values are given in meter^3/day

2. The underlined values are the predicted values for the management strategy-1 as compared to the existing scenario given in the row above

The total improvement will be around 289273 m3, which is 9 % of the total recharge from the river to the aquifer before construction of the structures. Though the improvement seems to be quite low, but as the area is falling in a heavy ground water withdrawal zone, this will of immense help during the dry seasons.

Scenario - 2: Construction of check dams and recharge wells along the ephemeral river and its tributaries draining through the watershed to enhance ground water recharge

The River draining the watershed is ephemeral in nature and flow exists till the end of monsoon season. Hence, a second strategy can be adopted by harvesting the run off generated during the rainy season with the construction of check dams/weirs at suitable locations and to divert the harvested water to the phreatic aquifer by means of recharge wells. Tentative locations showing the proposed water conservation/augmentation structures are given in **Fig 9a**.

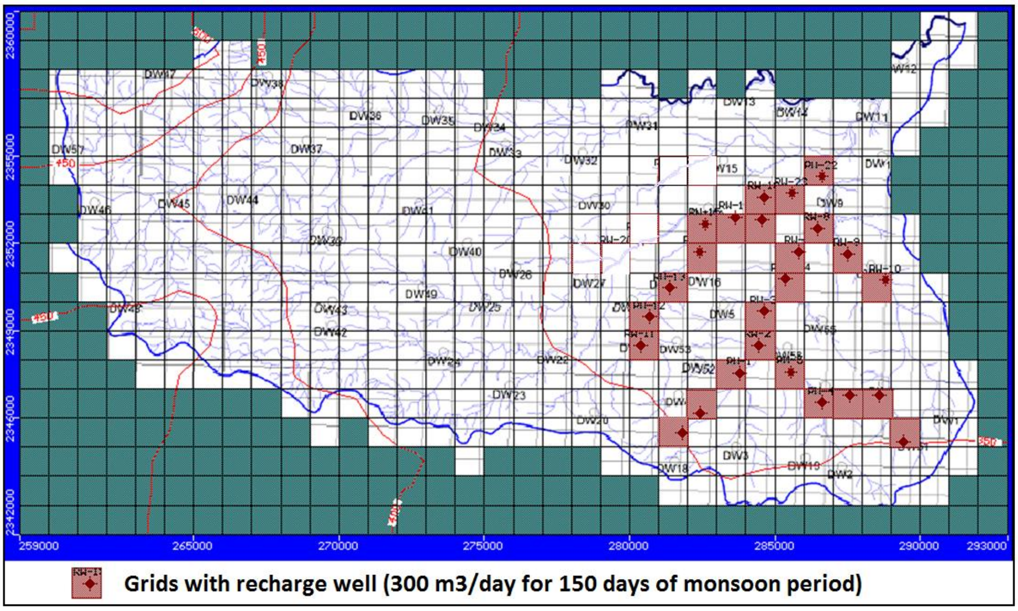

Fig. 9a: Location of proposed recharge wells (25 recharge wells)

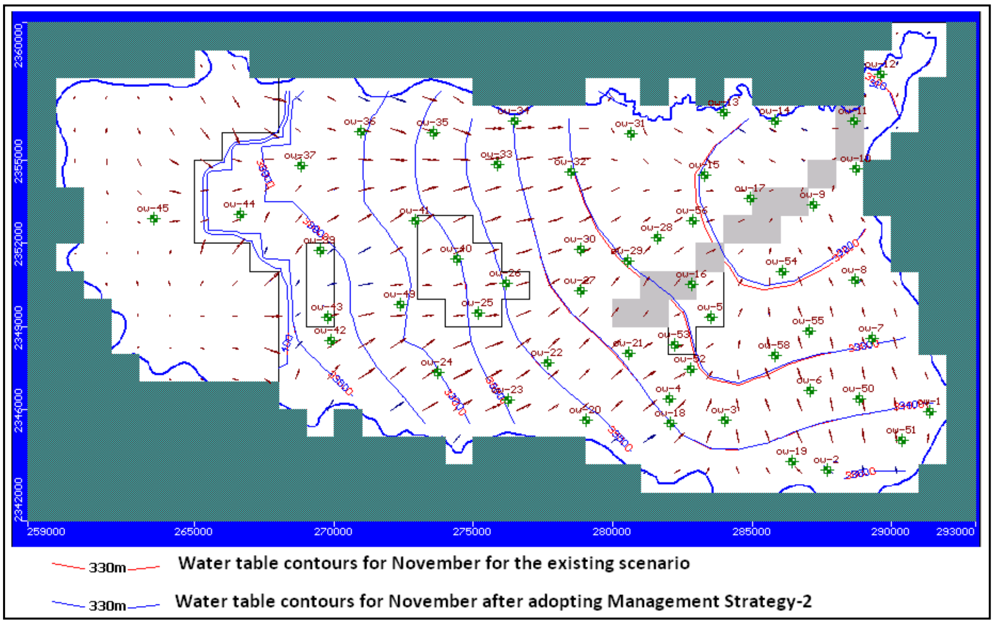

Fig. 9b: Impact of the improved recharge on the predicted water table of November

Appreciable change is not observed in the overall pattern; however slight down gradient movement of 320 & 330 meter water table contours indicates the improvement of water table by the extra recharge (**Fig. 9b**). Though the declining trend in water level is not reversed, but its slope has been improved (**Fig. 9c)**. Since this is an area with heavy ground water draft, more and more recharge structures can be created subject to the availability of surface water so that the ground water regime can be improved.

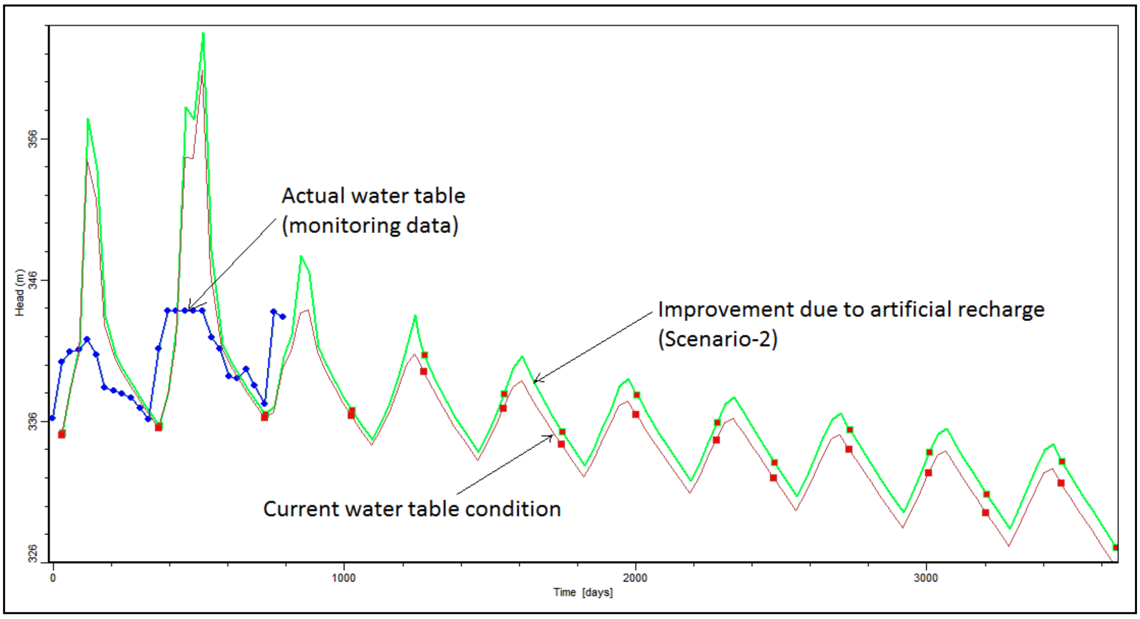

Fig. 9c: Impact of the improved recharge on the predicted water table of well-6

Conclusion

CGWB has taken a pilot project for aquifer mapping (AQMAH) to establish a protocol for hard rock aquifer mapping and sustainable aquifer management plan in Basaltic terrain of Maharashtra. The Chandrabhaga watershed (WGKCC-2), Nagpur district, Maharashtra is characterized by high ground water withdrawal for agricultural with the stage of ground water development touching 89%. If ground water withdrawal goes abated at this pace then, the ground water condition in the watershed will become critical in near future.

The hydrogeological data including various thematic maps like drainage, soil, geomorphology, landuse/landcover, hydrology, lineaments, geology etc. were analysed. The primary aquifer system in the Chandrabhaga watershed is unconfined Basaltic Aquifers and classified as Aquifer-I. It occurs in entire area except in northeastern part of the area where the Sandstone of Gondwana formation constitutes the unconfined aquifer. The rest two aquifers i.e., Aquifer II and Aquifer –III, are semi-confined to confined in nature and spread all over the area. The entire data has been used to formulate the ground water flow model using MODFLOW code.

Based on the hydrogeological studies, input parameters were decided and assigned parameter values accordingly for recharge, groundwater draft, hydraulic conductivity and specific yield.

The parameters determined during transient calibration and verification is used to predict the response of the system to future events and model was run for predictive simulation. Two scenarios were suggested for shallow unconfined Aquifer-I comprising of Basalt and Sandstone. The simulated results were found more realistic for the Aquifer-I.

The simulated result of scenario -1 i.e., construction of check dam of 1.5 m height, infers that it will raise the water level in the area. The total improvement will be around 289273 m^3, which is 9 % of the total recharge from the river to the aquifer before construction of the structures. Similarly, the simulated result of scenario -2 i.e., 25 recharge wells (20-30 m depth) with maximum recharge rate of 300 m^3/day during monsoon period, infers that there would be increase in ground water recharge estimated about 1125000 m^3 annually.

Based on the groundwater modeling simulation in *WGKCC-2* watershed, it is recommended to adopt aquifer management plan for sustainable ground water resources.

Acknowledgement

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Aquifer Mapping for Groundwater Management in Water Stressed Ankasandra Watershed, Tumkur district, Karnataka, Southern India

Vittala, S.S., Reddy, G.R.C., Krishnamurthy, G., Sooryanarayana, K.R and Sudarshan, G

CGWB,SWR, Karnataka
****Corresponding author's e-mail: srisrivittala@gmail.com, vittala_99@gmail.com***

Abstract

The study is carried out during the period from September 2011 to April 2014 in the Ankasandra watershed covering an area of 375 sq.kms falling in parts of Tiptur and C.N.Halli taluks of Tumkur district, Karnataka which is typically a hard rock terrain of Peninsular India. Three principal aquifers (hark rock aquifers) namely Gneiss, Schist and Granites were identified which belong to the Archaean group of formations. Ground water is under severe stress in the area as the present stage of ground water development is 187%. The knowledge gaps in the sub-surface aquifer, ground water levels, water quality, soils, land use/land cover, geomorphology were analysed and identified. To study the behaviour of ground water, 104 observation wells were established to monitor the water levels on monthly basis from September 2011 to April 2014. A total of 125 VES were carried out and the results were analysed. During the study, 17exploratory wells were constructed in the Gneissic aquifer, 3 wells in the Schistose aquifer and one well in the Dolerite dyke. The results of the studies together with the groundwater management options in the water stressed area are discussed in this paper.A resource-based approach has been adopted through an integrated study at village level. Two major aquifer management plans have been recommended viz., 'villages favourable for groundwater development' and 'villages not favourable for groundwater development'. Various water stress mitigation options based on a multidisciplinary approach integrating technical and non-technical measures are recommended for sustainable groundwater development in these villages.

Key words: Aquifers, Ground water management, Hard rocks, Vedavathi River

Introduction

Hardrocks (granites, metamorphic and volcanics) occupy large tracks throughout the world (Africa, South and North America, India, Korea, several areas in Europe, etc.) but their ground water potentials are rather modest with well yields in the range of 2 to 20 m^3/hr as compared to the sedimentary or karstic aquifers. However, in arid and semi-arid areas where the surface water resources is limited, the economic development depends largely on ground water resources though it is highly heterogeneous and discontinuous. For example, two neighboring wells may have contrasted yields and their hydrodynamic properties too may be quite unpredictable (Karanth, 1987; Singhal & Gupta, 1999; Hegde et al., 2012).There has been rapid and unplanned development of groundwater resources for varied usages resulting in its depletion from many parts of hard rock terrains (Anonymous, 2013). In India, the contribution of groundwater towards total irrigation is about 70%, for domestic use it is about 80% and ground water contributes nearly 9% towards gross domestic product of the Country ((Gandhi and Namboodari 2009; Burjia and Romani 2003). Hence, any adverse impact of development on groundwater resources will have far reaching consequences on the economy.

The unregulated development of groundwater, particularly in the arid and semi-arid areas have often resulted in groundwater over-draft and associated quality problems raising its sustainability issues. One of the challenges facing the humankind is the concept of sustainable development, which is in turn is related to economic development, water scarcity, and environmental degradation. This has led to a paradigm shift from development to management of groundwater in the last one decade. The latter needs reliable and comprehensive large scale aquifer maps at village level. Growing water demand and increasing climate variability confronting groundwater storages are causes for the concern of water managers. Sustainable water resources management includes supply and demand aspects, policy implementation and participatory planning and implementation. Traditional supply-oriented management has led to the over-exploitation and depletion of freshwater resources. Therefore new sustainable schemes with a good balance between water conservation and demand management needs to be formulated (Yoganand and Gebremedhin, 2006).

Obectives And Scope

The previous studies in the area under reference show that the groundwater investigations had been carried out by Central Ground Water Board (CGWB) as a part of Vedavathi River Basin Project. Systematic and Reappraisal hydrogeological surveys, ground water management studies and exploratory drilling were also carried out during different periods as part of CGWB's Annual Field Season Programs. In addition, CGWB has been undertaking groundwater and quality monitoring through permanent groundwater observation wells and piezometers established in the area. (VRBP, 1980; Kumaresan, 1996; Balachandra, L.J., 2005)The main objectives of the present study are to define the aquifer geometry, types of aquifers, groundwater regime behaviour, hydraulic characteristics and geochemistry of multi-layered aquifer system and finally framing methodology for micro level aquifer mapping at village level. The activities of the aquifer mapping were envisaged as (i) data compilation and data gap analysis, (ii) data generation, (iii) aquifer map preparation, (iv) aquifer response modeling and (v) formulation of aquifer management for its sustainable development.

Study Area

"Ankasandra watershed", the study area covers 375 sq.kms in parts of Tiptur and C.N.Halli taluks of Tumkur district, Karnataka lies between North latitudes 13° 15' 15" to 13° 28' 30" and East longitudes 76° 23' 00" to 76° 39' 00"(**Fig. 1**). The watershed covers about 108 villages and is drained by 1st to 5th order streams which form part of the Vedavathi sub-basin of the Krishna basin with dendritic to sub-dendritic drainage flowing from south to north and ultimately joining the Torehalla stream (**Fig. 2).** The southern boundary of the watershed forms the surface water divide between the Cauvery and Krishna basins. It has an undulating terrain with gentle to moderate slope towards north. The highest elevation of 941 m above MSL (m amsl) is at the southern part of the watershed located just south of the Adinayakanahalli state forest. The lowest elevation of 720 m amsl is noticed at Ankasandra village in the northern part of the watershed.

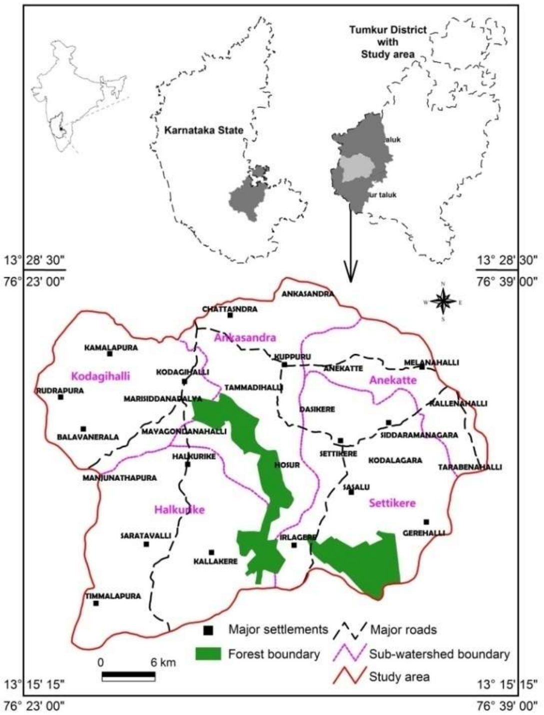


Fig. 1: Location map of the study area

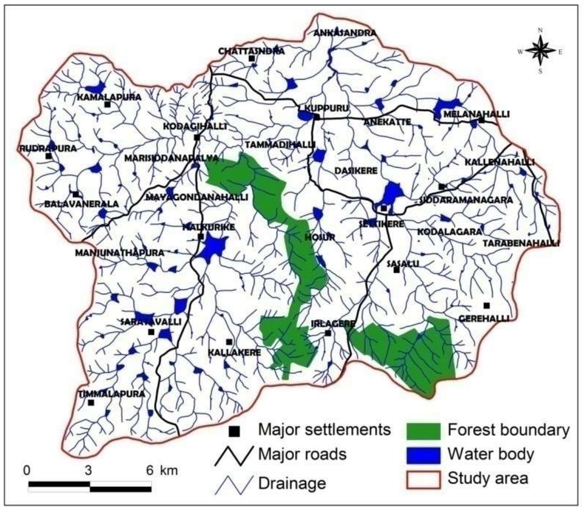


Fig. 2: Drainage map of the study area

The area receives about 680 mm rainfall with hot weather and semi-arid climate. The potential evapotranspiration is more than 1500 mm annually.The temperature starts rising from March and reaches its peak in April or May.The mean maximum temperature is around 34°C and occasionally goes up to 40°C, there after it declines with the onset of monsoon. The mean minimum temperature is around 22°C. Various soils types viz., clayey, clayey skeletal, clayey mixed, sandy clayey soil and gravely clayey soils are found in the study area. Agriculture is the mainstay of the people and the important crops grown are coconut, arecanut under irrigation and ragi, castor, red gram, etc., under rain fed cultivation.As per the statistics of 2010-11, forest covers about 4.65% of the total geographical area, while lands not available for cultivation (non-agricultural land and barren land) account for 11.78%, other uncultivable lands (cultivable waste, permanent pastures, trees and groves) are20.53%, and fallow lands cover about 3.11% of the total area. The net area sown is 59.90% and the area sown more than once is 12.53%. In the past , dug wells were preferred as groundwater abstraction structures. The increase in the number of dug wells and groundwater draft, with consequent lowering of the groundwater level resulted in drying up of phreatic aquifers and finally led to borewells replacing dugwells. The weathered portion in the major part of the area is desaturated due to groundwater over draft. Presently in certain locations, the depth to water level is more than 100 meters below ground level (m bgl) and groundwater development is mostly through bore wells which are more than 200 m deep. The field studies indicate that most of the farmers are using groundwater for growing perennial crops like coconut and areacanut. Very few farmers are practicing drip irrigation. The source of drinking water is mainly through bore wells.

Hydrogeological Framework

Three principal hard rock aquifers occur in the study area viz., Gneisses (270 sq.km i.e 72%), Schists (94 sq.km i.e 25%) and Granites(11 sq.km i.e 3%) which belong to the Archaean group of formations. The detailed hydrogeological map is given in **Fig. 3**. These aquifers are devoid of primary porosity. Subjected to weathering and tectonic activities, these aquifers have developed secondary porosity in the form of fractures/joints with regolith on the top.The depth to weathering varies from place to place, being shallow around Halkurike village in the central part and deep around Madapurahatti thanda and Tigalanahalli villages (30 to 45 mbgl), while it is moderate in the plain lands with limited fractures. Groundwater occurs mostly in the fractured system under semi-confined to confined condition (110 to 200 mbgl). The area has deep to very deep groundwater levels and the phreatic aquifer is desaturated in most parts of the study area. The Gneissic aquifers are the most dominant (72%). Borewells are the common groundwater abstraction structures with density of more than 10 to 15 per sq.km in the plains whereas it is more than 30 per sq.km in the fringe areas of the Torehalla stream. The average borewell yield is 1 to 2 litres per second (3.6 to 7.2 m^3/hr).Well interference is common in the Gneissic aquifers. Schistose aquifers occupy the central portion in NW-SE direction covering an area of 94.sq. km (25%). However,most parts of this aquifer come under the forest cover, and are highly undulating. The well density is about 5 to 10 wells per sq.km with an average yield of about 1 litres per second (lps) (3.6 m^3/hr).Granitic aquifers occupy the southern part of the area as a small patch covering11 sq.km (3%) which is highly undulating with isolated hills around Bandegate village. It is observed that the depth of weathering is very limited and mostly covered with exposures and fractures are limited to shallow to moderate depths (upto 150 mbgl) and very rarely at deeper depths (around 180 mbgl). The average yield of the bore wells is also limited to 1 lps (3.6 m^3/hr). The swarm of dolerite dykes were also noticed all over the area.

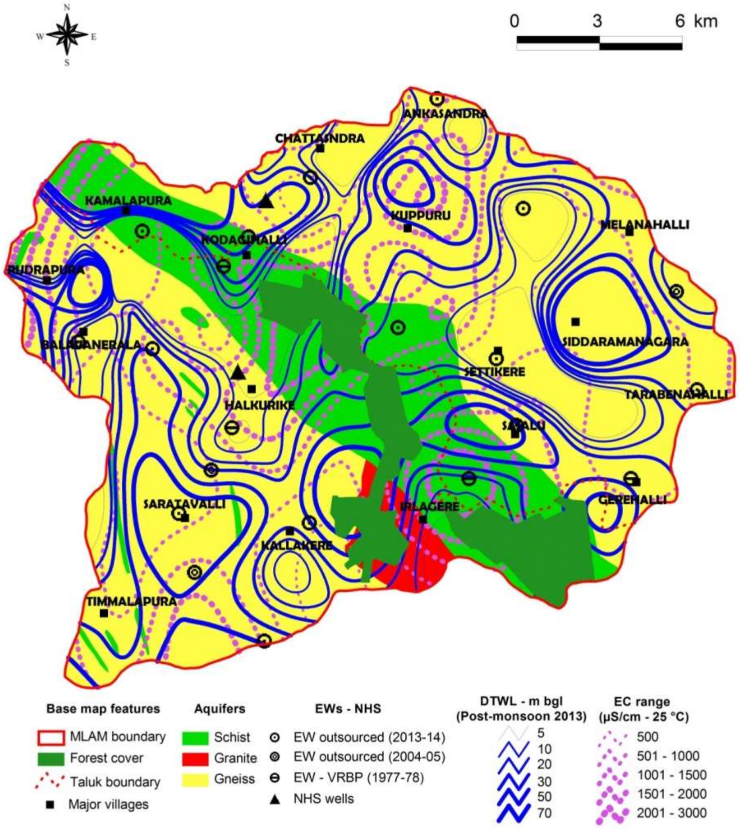


Fig. 3: Hydrogeological map of the study area

Recent Scenario

Groundwater in the area is under severe stress because of continuous drought resulting in its over-exploitation. The present stage of groundwater development is 187%. The average depth to water level during the last two-and-half years has depleted from 10 to 40 mbgl in irrigation bore wells. Due to the increase in number of bore wells over a period of time, the depth to groundwater levels have gone deeper and deeper and are now found to be more than 100 m bgl at certain locations (Siddaramanagara, Ankasandra villages) **(Fig. 4**). However, groundwater around the village Halkurike occurs under phreatic condition with shallow water levels ranging from 5 to 10 mbgl (Fig. 4). The borewell yield has also decreased from 2 - 3 lps to 1 - 1.5 lps and they sometimes become dry during summer. The shallow borewells are dried-up due to lowering of water table. In most cases, the tanks are not receiving any inflows from rainfall and hence, no additional recharge to groundwater.

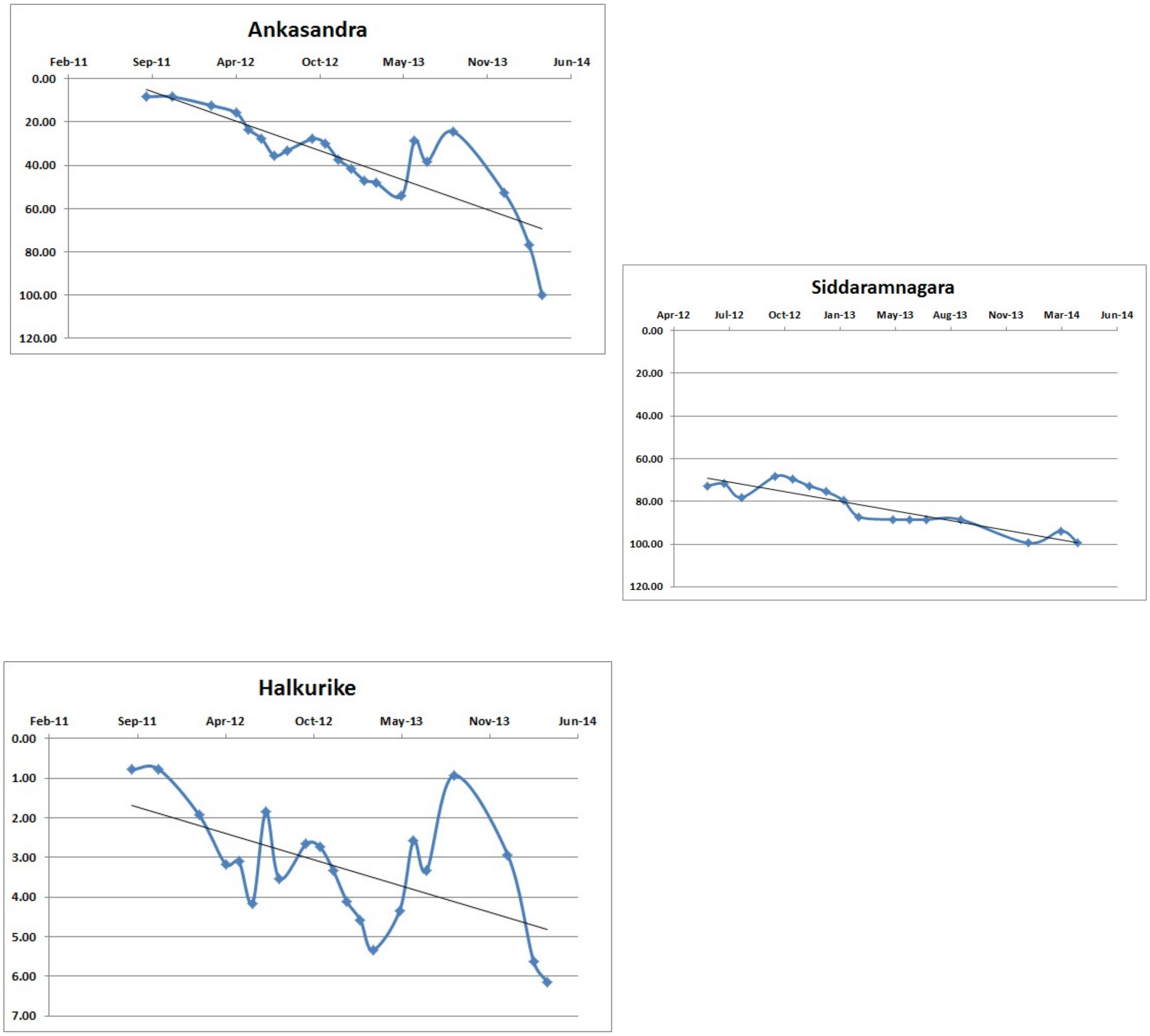


Fig. 4: Hydrographs showing depth to water levels from the representative locations

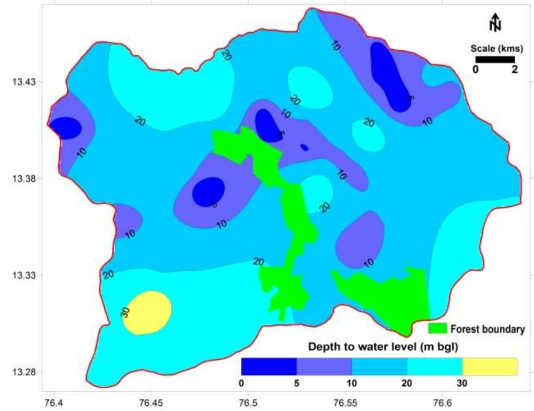
Data Used & Methodology

The relevant parameters for village level aquifer management plans were compiled from the natural resources thematic base map data including drainage, geomorphology, soils, hydrogeology, etc., derived from the satellite imageries of IRS 1C and 1D on 1:50,000 scale(Anonymous, 2000; Lillesand and Kiefer, 2002). The Survey of India toposheet nos. 57 C/7 and 57 C/11 were used as reference maps to prepare the various thematic maps as well as to collect other relevant data in the field required for the study. For better accuracy of the thematic map, ground truthing was done in the field and necessary updations were made in the thematic maps.The study also used the unpublished geological maps of Geological Survey of India on 1:50,000 scale. For thedata gap analysis, existing data were plotted over the map (Vittala et al. 2013). The data gaps in hydrogeology were addressed by detailed surveys aided by vertical electrical soundings (VES), exploration, water sampling, micro-level hydrogeological inventory and periodical water level monitoring. The aquifer management plans were based on the results of interpreted analysis of these parameters.The ArcGIS and ArcView softwares have been used for analysis and integration of thematic maps to derive aquifer management plans at village level.

Results And Discussions

Groundwater Level Monitoring

To study the behaviour of groundwater in time and space, 104 key observation wells were established and monthly water levels were monitored from September 2011 to April 2014.As the phreatic aquifer is completely desaturated due to over exploitation except at Halkurike and in a few other pockets, bore wells fitted with hand pumps (depth varying from 70 to more than 140 m bgl) for rural water supply constructed by State Government and piezometers constructed by CGWB were established as key observation wells. Few observation wells were also established outside the study area to get an optimum monitoring network. A perusal of the water levels indicated continuous declining trend in the larger part of the study area from September 2011 to April 2014 (**Fig. 5**). The deepest water level of45.41 m bgl recorded in April 2012 declined to 133 mbgl in April 2014. During the study, the depth to water levels in 92% of wells were within 30 m bgl in September 2011 but in 56% of wells, the water levels were observed to be more than 30 mbgl during April 2014.



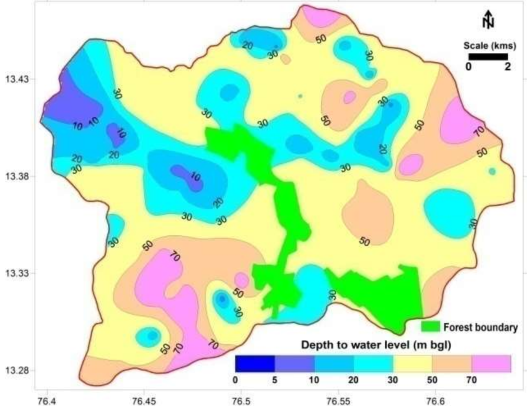


Fig. 5: Depth to water level maps of September 2011 and April 2014

Geophysical Investigation

A total of 125 Vertical Electrical Soundings (VES) were carried out with an interval of 2 km x 2 km grid pattern using Resistivity meters of IGIS Hyderabad with maximum current electrode separation of AB/2=300 m. The standard procedures and guidelines were followed in the interpretation of results (Orellana and Mooney 1966; Kelly and Mares 1993; Parasnis 1962) and the data were used in the selection of sites for exploratory wells. The apparent field resistivity plotted on a log-log graph paper shows that most of the sounding curves reflect the presence of three to four geo-electric layers AH and HA types curves. The initial interpretation of the VES data was accomplished using a conventional partial curve matching technique with a two layer master curve and auxiliary diagrams. The computer aided interpretation (Schuman and IP2WIN) based on optimization techniques were used to analyse the data.

It was found that in 70% of the area, the depth to weathering is around 10 m. In the north eastern and eastern parts of the study area, the weathered thickness ranges from 30 to 40 m (**Fig. 6**).

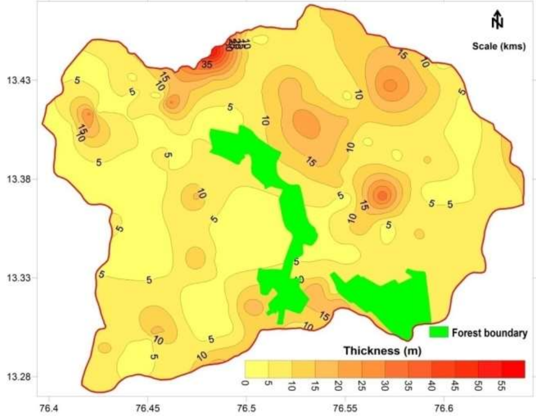


Fig. 6: Weathered thickness contour map obtained from geophysical survey

The depth to hard rock is in general varies from 20 to 60 m. In the Schistose aquifers,the thickness of weathering is less than 30 m. In areas of the Gneissic aquifers, it is between 30 and 60 m. In the eastern and south eastern parts, the depth to hard rock is more than 100 m.

This zone can be demarcated as fractured wherein the resistivity values are in the range of 130 to 600 Ohm m (**Fig. 7**).

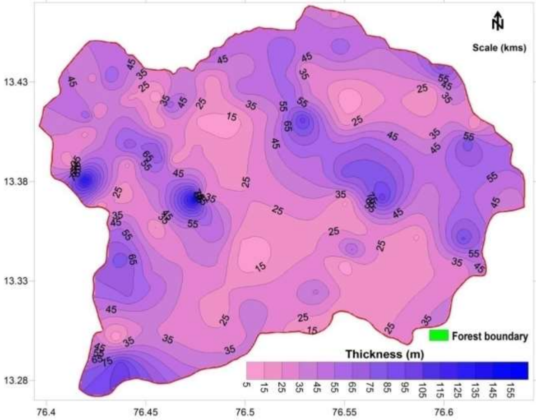


Fig. 7: Depth to basement contour map

Further, the apparent resistivities at AB/2=100m and AB/2=200m indicate presence of fractured zones both at shallow and at deeper depths. The resistivity value ranges from 110 to 190 Ohm m in the Schists and 130 to 600 Ohm m in the Gneisses which indicate shallow fractures. Deeper fractures are indicated by the resistivity values of 300 to 600 Ohm m. The details of resistivity values observed in the weathered, fractured and massive rocks in different aquifers are given in Table 1.It is observed that a in sizable portion in the southern part, the hardrocks are indicated by the resistivity of > 400 Ohm m where as in the north western (Gandhinagar) and south eastern (Bandegate) fringe area, the hardrocks are indicated by the resistivity of > 600 Ohm m. The borehole logging was carried out in 13 borewells drilled by CGWB using Spontaneous Potential and resistivity logging with N16” and N64” methods to determine the quality of ground water and fracture dispositions at the sub-surface respectively. The results show that the fractures are encountered at Shallow depths (52-56 m bgl) in Settikere and Sasalu exploratory well sites. The deeper fractures (between 150 - 198 m bgl) are indicated at Huchanahatti, Adinayakanahalli, Navule, Hosur, Madihalli, Balavaneralu, Bommanahalli thanda, and Sasalu sites. The results of the representative geophysical logging along with the litholog of Sarathavalli exploratory well site is given in **Fig. 8.**

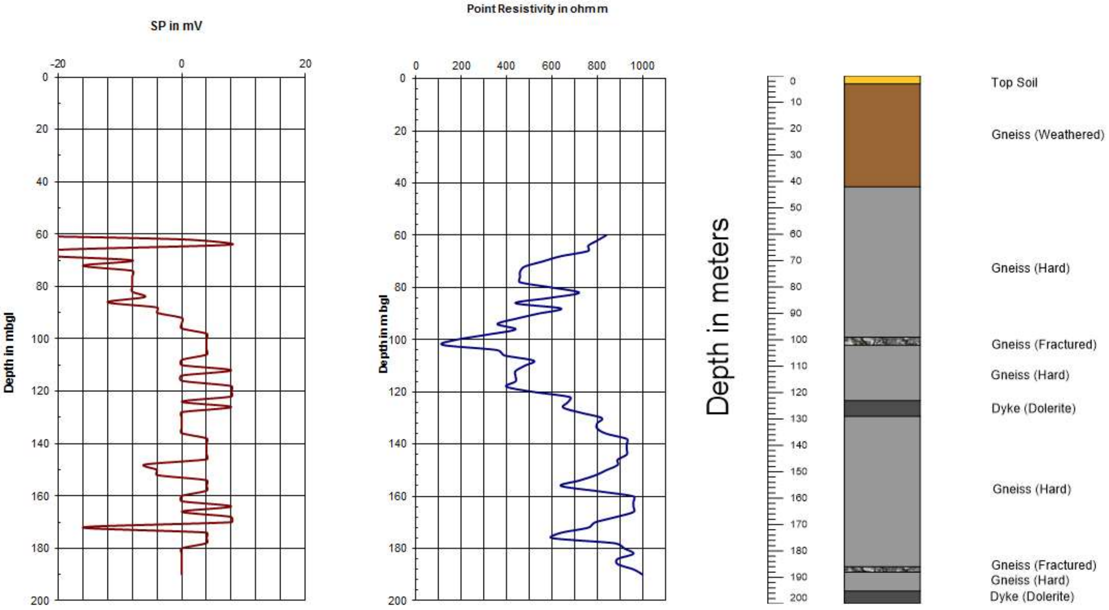


Fig. 8: Geophysical logging along with litholog of Sarathavalli exploratory well

Aquifers	Resistivity range (Ohm m)		
	Weathered zone	Fractured zone	Basement
Granite	Only exposures	190 – 350	> 400
Schist	30 - 90	113 - 190	> 200
Gneiss	40 – 120	131 – 562	> 600

Table 1: Details showing resistivity value ranges: weathered zone/fractured zone / basement in different aquifers.

Groundwater Exploration

CGWB drilled 21 exploratory wells in three phases during the years 1977-78 (4 wells up to 90 m depth), 2004-05 (3 wells up to 200 m) and during 2013-14 (14 wells up to 200 m). The results of these drillings revealed that the depth of weathered zone varies from 2.6 m(Gopalanahalli) to 51.62 mbgl (Madapurahatti thanda). The static water level (SWL) varied from 0.3 m (Bairapura) to 80.10 m bgl (Sarathavalli). The drilling discharge ranged from negligible (Choulahalli thota) to 5.54 lps (Sasalu).Out of 21 exploratory wells 17wells were constructed in the Gneissic aquifer, 3 wells were constructed in the Schistose aquifer(Hosur, Kodigehalli and Gopalapura)and 1 well in the Dolerite dyke(Bharanapura). At Sasalu (181 m) and Huchanahatti sites (189.63 m), the exploratory wells could not be drilled down to the targeted depth of 200 m due to potential fractures encountered with very high drilling discharge (**Fig. 9a**). The field photographs showing the typical litholog samples and fractured zone samples at deeper depths of the representative exploratory well sites are given in **Fig. 9b & c**. It is also found that there are intrusions of dolerite dykes at various depths at several locations with varying thickness. The contact between Gneiss and Dolerite is not productive. The results of the fracture analysis from the 14 exploratory wells drilled by CGWB during the project period (2013-14) show that only five percent (5%) of the fractures are encountered within the depth of 50 m bgl whereas about 35% of fractures are encountered in the depth ranges of 50 to 100m and 150 to 200 m each. Another 25% are in the depth range of 100 to150 m thereby, indicating the presence of deep seated fractures in the area. The analysis reveals that the deeper zones up to 200 m are productive and high yielding when compared to shallow aquifers.

Fig. 9a: High drilling discharge at deeper fracture encountered at Sasalu EW site

Fig. 9b: Litholog samples collected during drilling at T.B.Colony EW site

Fig. 9c: Fractured litholog sample at deeper depth (162 m bgl) collected during drilling at Sasalu site

Water Quality

52 and 73 groundwater samples were collected from hand pumps during September 2011 and May 2012 respectively. Out of 52 samples, 45 samples were collected from the wells in the Gneisses, 6 samples in the Schists and 1 sample in the Granitic aquifers. Out of 73 samples, 64 samples were collected from the Gneisses, 8 samples from the Schists and 1sample from the Granitic aquifer. The analytical results show that pH, calcium, magnesium, total hardness, chloride, nitrate, sulphate and fluoride are within the acceptable limits (Reddy, et al., 2013). EC too is within the permissible limits (420 – 2340 µS/cm-25°C) in all the samples during both the seasons except in B.Hosahalli where the EC is 4440 µS/cm-25°C during May 2012 and this is because of brackish nature at the localized point source. The concentration of iron during September 2011 is mostly beyond acceptable limits (0.3 to 5.4 mg/l in 30 of 52 samples) which may be due to the presence of iron ores after crossing the eastern part of the study area, and also may due to the presence of banded ferruginous quartzites as linear patches in the area. Overall, the quality of groundwater is mostly suitable for drinking, irrigation and industrial purposes.

Aquifer Disposition using micro level bore well inventory data

955 irrigation bore wells were inventoried covering the entire area . The database collected revealed that in majority of the villages, farmers drilled their borewells in the depth range from 150 to 200 mbgl and in some areas the depth drilled varied from 200 to 250 mbgl. In villages like Agasarahalli, Bhairanayakanhalli, Chikkenahalli, Hulihalli, Kedigahalli, Manjunathapura, Navule and Tigalanhalli, the farmers drilled borewells beyond 250 mbgl.As revealed by the data of casing details collected from the farmers, in most of the villages the

weathering thickness varied from 20 to 30 mbgl in the central, north-eastern and south-western parts of the area. 30 to 40 m weathering is observed in the eastern, south-eastern and south-western villages. More than 40 m weathering is noticed in selected villages like Navule and Tigalanhalli.

The analysis of depth vs. fractures from the well inventory data reveals that the maximum numbers of fractures are encountered in the depth range of 100 to 200 m bgl which is the most potential zone in the area. It is also noticed that as the depth increased beyond 200 m bgl, the presence of fractures were limited and negligible. The analysis of depth vs.yield shows that the zone in 0 - 50 m depth range yields 0.5 to 1 lps, 50 – 100 m depth range yields 0.5 to 2 lps, 100 - 150 m depth range yields 0.5 to 3 lps, 150 - 200 m depth range yields 0.5 to 2 lps, 201 - 250 m depth range yields 0.5 to 2 lps and the zone of more than 250 m depth range yields 0.5 to 1 lps. The overall analysis of well inventory data in the study area reveals that the depth of weathering, in general, is 10 – 20 m only and it is still lesser in granitic aquifer. The average borewell yield varies from 1 to 2 lps, and the high yielding wells are recorded in the Gneissic aquifers in comparison with Schists and Granites. Potential fractures are encountered between the depths of 100 to 200 m bgl.

Aquifer Management Plans

Considering the massive investment in the watershed development programme, it is important to plan the activities in a systemic manner for achieving fruitful results. The resource-based integrated approach using the input of all the above parameters is found to be realistic for watershed treatment (Vittala et al. 2008).The upper phreatic zone is completely dry in all the three aquifers and the current groundwater extraction is only from the fractured zones. The majority of the observation wells showed decline in water levels during the project period, which is testimony towards excessive extraction. In this context, special emphasis is laid on “Management Strategies”. Two major aquifer management plans are recommended at village levels for sustainable aquifer development,namely (i) villages’ favourable for groundwater development and (ii) villages’ not favourable for groundwater development based on field studies as well as analysis of various themes(Table 2). The system adopted here is completely location specific and may vary from place to place.

Sl. No.	Themes	Characteristic features	
		Favourable for GW development	Not favourable for GW development
1	Depth to water levels	Shallow	Deep
2	VES	Shallow to moderate weathered thickness with expected fractures	Deep weathered thickness
		Depth: Drilled up to depth of around 150 m bgl.	*Depth:* Drilled up to depth of 283 m bgl.
		Weathering: Shallow to moderate	*Weathering:* Deep
		Fractures: further development may prove existence of fractures.	*Fractures:* Experienced dry fractures.
		*Yield (lps):*0.5 to 2	*Yield (lps):*0.5 to 1.5
		Development: Low	*Development:* High
		*Density:*Wells relatively less and scope for further development	*Density:* Wells are abundant resulting in over-exploitation
		Yield: Scope for development	*Yield:* Drastically reduced
4	Groundwater quality	Potable	Potable
5	Groundwater exploration	Scope for development	No scope for development

Table 2: Parameters and its field characteristics considered for formulation of Aquifer management plans

(i) Villages favourable for groundwater development

Out 108 villages, 7 villages in Tiptur and 9 villages in C.N.Hallitaluks are found to be favourable for further groundwater development coupled with management practices (Fig. 10)based on the general depth of existing bore wells, weathering thickness, depth to water level, well density, water yielding fractures and present level of groundwater development. Further, these villages are under the influence of Halkurike tank which helps recharge to groundwater system.Bore well wise safe yields are recommended in the order of about 6000 to 6500 m^3/year or 0.6 to 0.65 ha.m per year [(1.5 lps X 4 hr/day) * 300 days/year].In addition, contour bunding; check dams, gully plugs, percolation ponds, etc., are suggested for augmenting groundwater resources through artificial recharge. Safespacing of 200 m between two productive wells needs to be maintained to avoid mutual interference.The practice of drip irrigation is also recommended on a larger scale for water economy and irrigation efficiency.

(ii) Villages not favourable for groundwater development

Based on the results of piezometric level of the aquifer, aquifer yield, density of wells, etc., the list of susceptible villages is assessed.The depth to water level at certain places under this category is more than 100 m bgl which reflects groundwater depletion or drawdown due to pumpage creating severe groundwater stress conditions. The borewell yields also drastically reduced over the years. Further, the study reveals that out of 108 villages, 92 villagesare falling under water stressedcategory, of which 44 villagesoccur in Tiptur taluk and 48 villages in C.N.Halli taluk (**Fig. 10**). Various water stress mitigating options using a multidisciplinary approach and integrating technical and non-technical measures are recommended for sustainable groundwater development in these villages.The measures include artificial recharge through recharge wells, percolation ponds, watershed treatment through contour bunding and check dams. Gully plugs and sub-surface dams are also recommended at hydrogeologically suitable places. In addition, other mitigation measures may be as below.

- De-silting of existing minor irrigation tanks with people's participation through the Mahatma Gandhi National Rural Employment Guarantee Scheme (NREGA 2005) may also help in increasing the infiltration rates and restore natural recharge from these tanks and hence sustainable management of groundwater resources.
- Drip irrigation increases the irrigation efficiency up to 90%. There is a need to promote the micro-irrigation system which is most suitable for dominant horticulture.
- Farmers may change to profitable low water intensive crops like groundnut, sunflower, cotton, red gram instead of high water intensive crops such as coconut, aracanut, banana, sugarcane, paddy to effect irrigation water economy.
- Participatory groundwater management (PGWM) system is very much necessary to be adopted among the villagers. The concept of "Know your aquifer" and "Manage your aquifer" is ideal to have optimum results in water management that necessitates an understanding of the resource potential.
- A participatory approach in the sharing of groundwater and monitoring resources (Govardhan Das and Burke 2013) along with effective implementation of the existing Andhra Pradesh 'Water, Land and Trees Act' of 2002 (APWALTA 2002) are the other measures suggested.
- The 'mulching method' may be adopted extensively which helps in conservation of soil moisture, to improve the fertility and health of the soil, to reduce weed growth, etc.

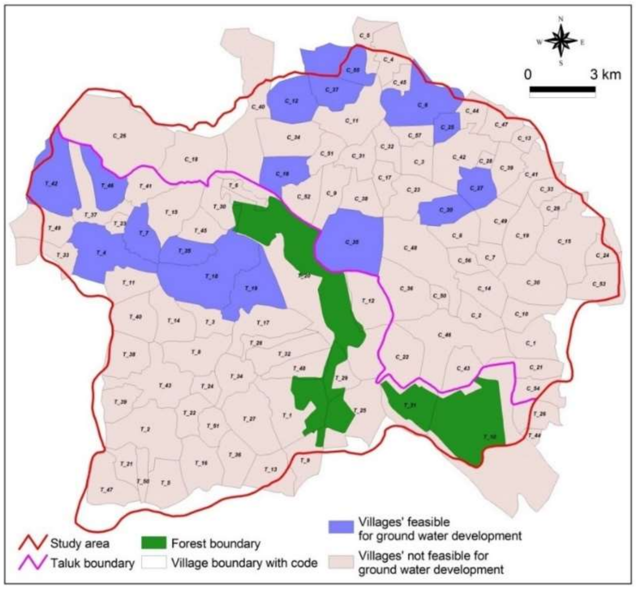


Fig. 10: Aquifer management plans

Assessment of In-storage groundwater resources

An attempt has been made to assess the in-storage groundwater resources for the study area. The areas covered under various depth to water level ranges like 0 - 10, 10 - 20, 20 - 30, 30 - 50, 50 - 70 and > 70 m bgl were calculated under GIS environment and considered for assessment. The in-storage groundwater resources assessment has been done down to the depth of 200 m bgl as the potential fractures were encountered down to the same depth of 200 m bgl during exploration. The depth of groundwater levels of April 2014 (pre-monsoon) were taken for assessing the in-storage groundwater resources assessment. The specific yield value of 0.2% is considered for the depth of 0 - 10, 10 - 20, 20 - 30 m bgl where as 10% of the 0.2% i.e. 0.02% is considered for the remaining depth range (Anonymous, 2009; Anonymous, 2011). The assessment of in-storage groundwater resources has been calculated for each depth range and given in Table 3. Accordingly, the water required to raise the water level or to fill in evacuated or unsaturated vadose zone from the present status (i.e. depth to water level of April 2014) to 5 m bgl is quantified and the total amount of water required is 5345 ha m (53.45 MCM) for the entire study area which may be supplied from the adjacent basin reservoirs.

A	B	C	D	E	F	G	H	I	J	K
Sl. No.	DTWL range (m bgl)	Area (Sq.km) (Excluding forest)	Area (ha m) (Excluding forest)	Average Depth of water level (m bgl)	Avg. water level height required to be raised (m)	Sub-surface storage availability (ha m) (D*F)	Sub-surface storage availability (m^3) (G * 10000)	Specific yield (%)	Water required for raising the water level up to 5 m bgl (ha m) (G * I)	Water required for raising the water level up to 5 m bgl (MCM) (J/100)

1	0 to 10	8.22	822	5	0	0	0	0.02	0	0
2	10 to 20	31.24	3124	15	10	31240	312400000	0.02	624.8	6.248
3	20 to 30	63.55	6355	25	20	127100	1271000000	0.02	2542	25.42
4	30 to 50	163.59	16359	40	35	572565	5725650000	0.002	1145.13	11.4513
5	50 to 70	58.62	5862	60	55	322410	3224100000	0.002	644.82	6.4482
6	> 70	20.43	2043	100	95	194085	1940850000	0.002	388.17	3.8817
	Total	345.65	34565			1247400	12474000000		5344.92	53.45

Table 3: Availability of sub-surface storage space in Vadose zone (down to 5 m depth)

Conclusions

The Ankasandra watershed, a hard rock terrain in Tumkur district of Karnataka with an area of 375 sq.kms covering 108 villages is experiencing over-exploitation of groundwater. The groundwater levels are deep and rainfall is low with prevailing drought conditions. Based on the detailed village level surveys and exploration with integration of accrued field level data, two major aquifer management plans are prepared and recommended for sustainable development.'Villages favourable for groundwater development' and 'villages not favourable for groundwater development' are identified.Out of 108 villages in the watershed, 16 villages (7 villages in Tiptur taluk and 9 villages in C.N.Halli taluk) are falling under first category and 92 villages (44 Tiptur taluk and 48 C.N.Halli taluk) under the second category. Water conservation measures such as soil moisture conservation (mulching, etc.), construction of recharge wells, percolation ponds, contour bunding, check dams and gully plugs, sub-surface dams, de-siltation of tanks, safe well spacing and promotion of micro-irrigation with change of cropping pattern are recommended. Participatory groundwater management (PGWM) programmesare indispensable for sustainable development of water resourcesin the area.

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Aquifer Mapping in Lower Vellar Watershed, Cuddalore Coastal Aquifer system, Tamil Nadu

D. Gnanasundar, M. Senthilkumar and N. Rameshkumar

Central Ground Water Board, SECR, Chennai India

Abstract

Aquifer mapping was carried out in parts of Lower Vellar water shed, Cuddalore Coastal Aquifer system, Tamil Nadu under pilot project study. The data obtained from the exploratory drilling and recent field surveys wherewere used in bringing out the lateral and vertical disposition of the aquifer system. The study reveals the existence of multilayered aquifer system with four aquifer units (Aquifer I - Phreatic aquifer; Aquifer II – Leaky/confined aquifer; Aquifer-III & IV - Two Confined aquifers)down to a depth of 300m bgl. The determined disposition of the aquifer system can be efficiently used for management of the coastal aquifer. Aquifer management plan through numeric modeling was carried out to prepare decisive plan for efficient management of groundwater resources in the Cuddalore coastal aquifer system

Key words: Aquifer mapping, Disposition, Confined aquifer.

Introduction

The part of lower Vellar water shed (Study area), Cuddalore District, Tamil Nadu state lies 250 km south of Chennai city. The Administrative blocks that come within the study area are Kurunjipadi, Cuddalore and parts of Kammapuram of Cuddalore District. The Part of lower vellar water shed comprises the catchment and command areas of Perumal‘Eri’ extended upto the Bay of Bengal in the East. The pilot study *area* with an aerial extent of 428 Sq.km lies between North latitudes 11° 30’ 10’ and 11° 42’ 16” and East longitudes 79° 30’ 00” and 79° 46’ 36”and falls is survey of India toposheet No.58 M/10 &M/14.The largest known deposit of fossil fuel (lignite) occurs in the western margin of the study area. The area experiences tropical humid climate with an average annual rainfall of 1400 mm which is received during both southwest and northeast monsoons. The area is drained by Paravanar and Uppanar rivers.

Objectives and approach

Prior to the Pilot Project study, groundwater hydrology has been studied in separate parts with many areas left untouched. As a result, there was no hydrogeologic framework developed so as to understand the regional effects of groundwater development in the pilot project area. During 1943-46, the Geological Survey of India (GSI) carried out exploratory drilling activity for Lignite around Neyveli and its surroundings. Subsequently, in 1954-55, GSI again carried out detailed Geological and groundwater surveys nearby Neyveli in order to determine the structure of Lignite deposits and groundwater aspects of the overlying aquifer and economic mining of lignite deposits. Central Ground Water Board (CGWB) during 1986-87 carried out hydrogeological surveys to study the changes in groundwater regime. Since then CGWB has carried out exploratory drilling in the region especially during 2006-2010. Under pilot project study aquifer mapping was carried out during 2010-2014 in lower Vellar watershed. This paper brings out the aquifer disposition of the lower Vellar water shed, Tamil Nadu

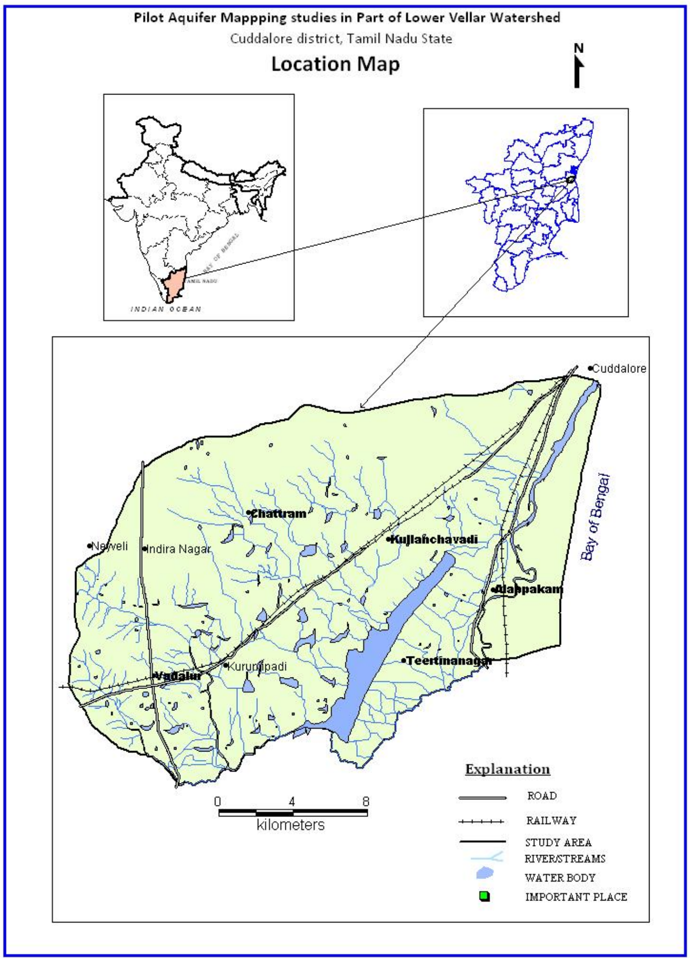

Figure. 1. Study area showing the Lower vellar water shed.

The aquifer mapping study primarily depends on the existing data that are assembled, analysed and interpreted from available sources. The data gaps analysis carried out helped to generate data from new data-collection activities such as exploration drilling, water level measurements and groundwater quality analysis. By analyzing the existing data and the data generated cross-sections, 2-D and 3 –D aquifer dispositions were generated.

Deciphering hydrogeological framework

The hydrogeological framework for the part of Lower Vellar watershed is generated based on the inputs generated from geological, geophysical, hydrogeological, and hydrochemical studies. The aquifer disposition and aquifer characterization has been brought by analysis of 45 lithologs, 22 electrical logs, 56 hydrograph of dugwells, 35 piezometric head 61 hydrochemical data, previous literatures and field inputs carried out from December 2011 to March 2014. The approach in this study is to decipher principal aquifer and to delineate the vertical and lateral extent of the aquifer units existing within the principal aquifer (sandstones). Geologically the area has three distinct formations: Recent Alluvium, Cuddalore sandstone of Mio-Pliocene age and Sandstones of Eocene age.

Results and Discussion

Aquifer Disposition:

The sandstone is the principal aquifer system upto 400 m below ground level. The principal aquifer system constitutes sandstones of mio-pliocene named as Cuddalore aquifer and sandstones of Eocene age named as Neyveli Aquifer. Four aquifer units (I, II, III and IV) have been deciphered (CGWB, 2015) within the principal aquifer system (sandstones). Aquifer I and II occurs within the Cuddalore sandstones (younger) and Aquifer III and IV occurs within the Neyveli sandstones (older). The thickness of each aquifer units, their lateral extent and their characteristics are described in the following paras. The 2-D aquifer disposition of the lower velar water shed along West – East and North – South is given as figures 2.1 and 2.2 respectively.

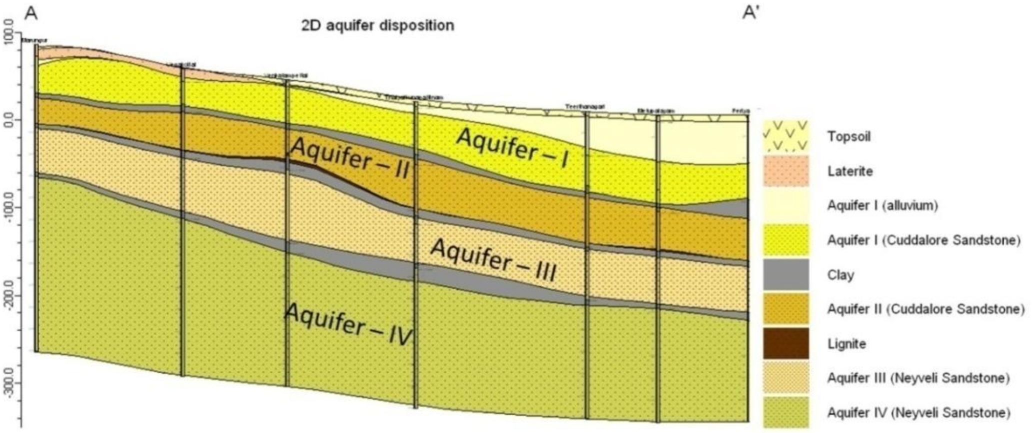

Figure 2.1. 2-D aquifer disposition of Lower Vellar water shed (West to East)

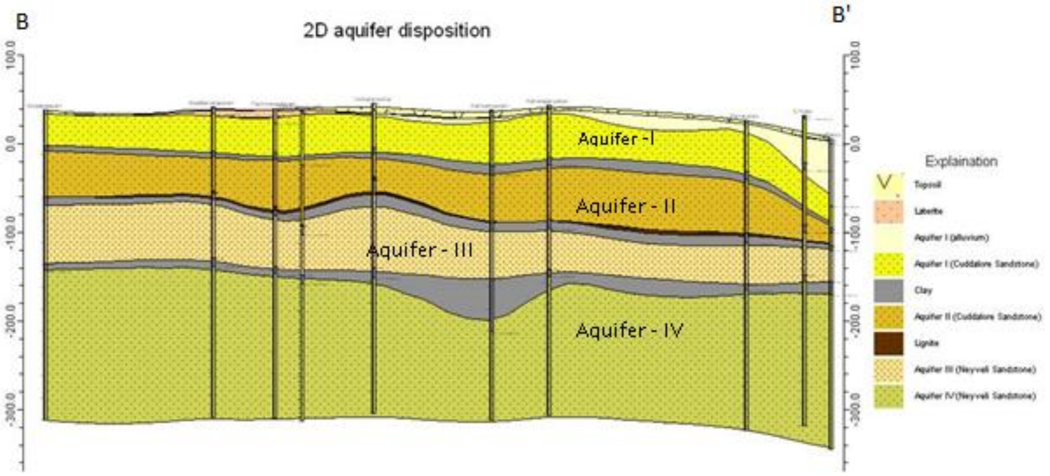

Figure 2.2. 2-D aquifer disposition of Lower Vellar water shed (North to South)

Aquifer Unit – I

The top most aquifer is the Aquifer Unit – I and is composed of sandstones (referred as Cuddalore sandstone), alluvium and Laterite formations.The sandstones of Aquifer unit –I are of mio-pliocene age and are friable and ferruginous in nature. Laterite occurs as capping over the Cuddalore sandstones and mainly occurs in the central and northern portion. The alluvium formation lie over the Cuddalore sandstones towards the eastern portion and its thickness increases towards the coast. The thickness of the alluvium ranges from 1 m to 80 m. At many places clay occurs as intercalations within the alluvium. The thickness of the Aquifer Unit – I varies from 30 to 110 m. The aquifer thickness in less in the western portion and gradually increased towards the coast. The strike directions of sandstones are NE-SW and dips towards SE. Clay occurs as intercalations within the sandstones at some locations. Clay stones occur as localized pockets at south of Perumal Eri.

Aquifer Unit – II:

The aquifer unit – II lies below the Aquifer unit – I and the aquifer is composed of Cuddalore sandstones only. The sandstones of Aquifer – II are Miopliocene in age are also ferruginous in nature like that of sandstones of Aquifer unit - I. The impermeable layers (Clay) separate aquifer I and II and are discontinuous at many places. Clay occurs as intercalations within the sandstones at some locations..The top of the aquifer – II lies at 35 to 110 m bgl. The thickness of the Aquifer Unit – II varies from 40 to 55 m. The thickness is less in the western portion and gradually increases towards east. The strike direction of the sandstones is NE-SW and dips towards SE.

Aquifer Unit –III:

The aquifer unit – III underlies the Aquifer –II and is composed of sandstones of Eocene age. Lignite (Brown Coal) occurs on top of the sandstones and is considered as marker bed. However, Ligniteseamsdooccur within the Eocene sandstones at few places.Clay occurs as intercalations within the sandstones as well within the lignite deposits. The top of the Aquifer unit – III lies at 90 to 160 m bgl. The thickness of the Aquifer Unit – III varies from 55 to 100 m. The thickness is less in the western portion and gradually increases towards east or south-east. The strike directions of the sandstones are NE-SW and dips towards SE.

Aquifer Unit – IV:

The aquifer unit – IV lies below the Aquifer – III and is almost similar to aquifer – III in its composition. This aquifer is composed of Eocene sandstones. The clay or sandy clay occurs between the aquifer III and IV. However, these clays are discontinuous at many places. Within this aquifer, at few locations, thick clay exists ranging from 20 to as high as 80 m in thickness. The top of the Aquifer – IV lies at 150 to 280 m bgl. The thickness is minimum in the western portion and gradually increases towards east/southeast. The strike directions of the sandstones are NE-SW and dips towards SE. The aquifer unit –IV is thicker than the other aquifer units and extends beyond 400 meters bgl.

Aquifer Characterization

The aquifer characterization of the four aquifer units (Aquifer – I, II, III & IV) is brought out to enable to bring out aquifer management plan for all the four aquifer units. The 3-D aquifer disposition (hydrogeological framework) developed from the aquifer mapping study is given as figure 3.

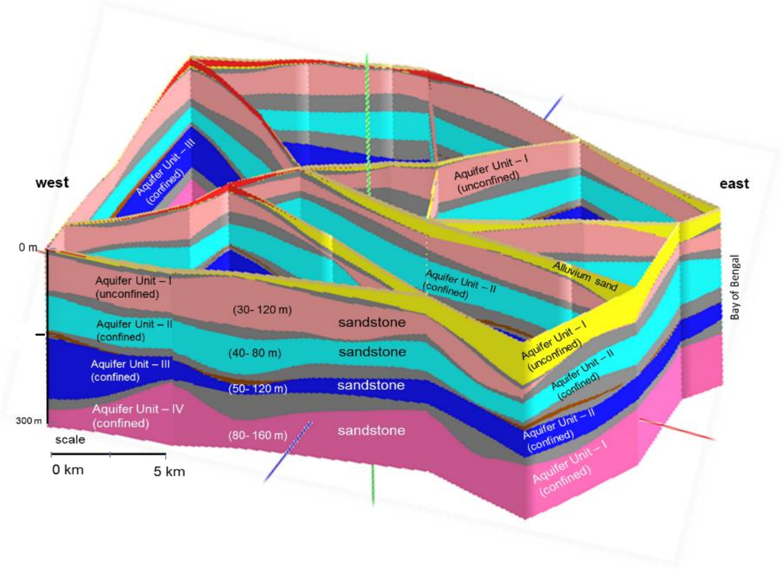

Figure 3. 3-D aquifer disposition and hydrogeological framework

Aquifer unit – I

The groundwater in the aquifer – I occur under unconfined conditions and are phreatic in nature. Groundwater development is mostly by dugwells and dugcum-borewells. Few tubewells also tap groundwater from this aquifer. The dugwells range from 1 to 4 m in diameter and are lined by bricks or concrete concentric rings. The depth of the dugwells ranges from 3 to 35 m bgl. The dugwells are energized mostly by electric pumps. However, the dug-cum-borewells in the sand dunes (located 1 – 3 km from the coast) are shallow in depth and ranges from 2 to 10 m. Most of the dugwells are owned by the farmers. The groundwater is abstracted mainly for irrigation (80 %), domestic (15 %) and Industrial purpose (5 %).

The groundwater level of the aquifer – I ranges between 1 and 26 m bgl. The aquifer – I is highly potential and its yield varies from 5 to 10 lps. The dugwells within the alluvium sands along the eastern portion yield 3 to 7 lps. The dug-cum-borewells in the sand dunes yield 2 to 5 lps and groundwater abstraction is partially restricted during non-monsoon periods by the farmers.

The groundwater quality of the aquifer is good and is used for drinking, domestic, agriculture and irrigation purpose. The Electrical Conductivity (EC) of the groundwater ranges from 500 to 1500 micro simens/cm. However, the groundwater along the course of the Uppanar river and a small pocket south of Perumal Eri has moderate to poor groundwater quality. The EC in these zones ranged between 2000 to 3500 micro simens/cm. The high EC in these zones are due to insitu salinity and also due to the influence of the backwaters along the Uppanar river. The EC of the backwater ranges from 12000 to 19000 micro seimens/cm. During monsoon periods, the Uppanar river gets flushed or diluted and the EC during the period ranged between 900 and 1200 micro simens/cm.

The groundwater fluctuation is high in the western portion (recharge area) than the central and eastern portion. The annual groundwater fluctuation of the dugwells in the western portion ranges from 5 to 25 m while in the intermediate and discharge area (eastern portion) the groundwater fluctuation is ranges from 3 to 10 m. The groundwater decline is not much significant in the dugwells existing in the intermediate and eastern portion however, the dugwells in the recharge zone (western portion) show marginal decline in groundwater level over the years. The transmissivity of the aquifer unit – I ranged between 450 and 950 m2/day and the specific yield ranges between 11 to 17 %. The transmissivity of the aquifer unit – I along the south eastern margin is marginally less (350 to 750 m^2/day) in comparison with rest of the aquifer. The hydraulic conductivity of the sandstones range from 40 to 60 m/day and the hydraulic conductivity of the alluvium formation is existing between Ponnaiyar and Gadilamriver ranged between 40 and 90 m/day. The hydraulic conductivity along the south eastern portion of the aquifer is comparatively less (20 to45 m/day) than the sandstones due to the dominance of clay within the alluvium sand.

Aquifer unit – II

The groundwater in the aquifer –II occurs under confined conditions. The groundwater abstraction from the aquifer is by tubewells. The tubewells range from 40 to 100 m in depth and are energized by electric submersible pumps. The groundwater is abstracted mainly for irrigation (85 %), domestic (5 %) and Industrial purpose (10 %). The peizometric level of the aquifer – II ranges between 15 and - 20 m w.r.t. msl. The aquifer – II is highly potential aquifer and its yield varies from 20 to 40lps. The groundwater quality of the aquifer is good and is fit for drinking, domestic, agriculture and irrigation purpose. The Electrical Conductivity (EC) of the groundwater ranges from 500 to 1000 microsimens/cm. The major source of replenishment to the aquifer is by rainfall. Apart from rainfall, groundwater recharge occurs from leakage from aquifer – I. The annual groundwater fluctuation of the piezometers range from 5 to 12 m and the groundwater decline is quite significant in the piezometers. The hydraulic conductivity of the sandstones range between 40 and 50 m/day. The transmissivity of the aquifer – II range between 1000 and 2200 m^2/day and the storativity ranges between 1.2×10^{-3} to 4.1×10^{-4}.

Aquifer unit – III

The groundwater in the aquifer –III occurs under confined conditions and is mainly developed by deep tubewells. The tubewells range from 130 to 160 m in depth and are energized by electric submersible pumps. The groundwater is abstracted mainly for mining activity (depressuration)in and around Neyveli lignite mine since 1950. Since 2010 tubewells have been constructed tapping groundwater from this aquifer for irrigation activity by the farmers. The peizometric level of the aquifer – III ranges between -15 and - 35 m w.r.t. msl. The aquifer – III is highly potential aquifer and its yield varies from 40 to 60lps. The groundwater quality of the aquifer is good and is fit for drinking, domestic, agriculture and irrigation purpose. The Electrical Conductivity of the groundwater ranges from 200 to 1000 µS/cm. The annual groundwater fluctuation of the piezometers range from 2 to 6 m and the groundwater decline is quite insignificant in most part of the aquifer. The transmissivity of the aquifer – III range between 1000 and 2500 m^2/day and the storativity ranges between 1.6×10^{-4} to 2.9×10^{-5}. The hydraulic conductivity of the sandstones range from 35and45 m/day.

Aquifer unit – IV

The groundwater in the aquifer –IV occurs under confined conditions. The groundwater abstraction from the aquifer is by deep Tubewells. The tubewells range from 170 to 250 m in in depth and are energized by electric submersible pumps. The groundwater is abstracted mainly for drinking water supply to Chennai city during lean periods. The aquifer – IV is highly potential aquifer and its yield varies from 20 to 70 lps. The annual groundwater fluctuation is almost negligible in most part of the aquifer. The groundwater quality of the aquifer is good and is suitable for drinking, domestic, agriculture and irrigation purpose. The Electrical Conductivity of the groundwater ranges from 500 to 1500 µS/cm/cm. The transmissivity of the aquifer – IV range between 1000 and 2500 m^2/day and the storativity ranges between 4.3 x 10^{-4} to 9.1 x 10^{-5}. The hydraulic conductivity (K) of the sandstones range between35and40 m/day.

The clay layers (aquicludes) at many places are so thin and at few places are absent. The hydraulic continuity is quite prominent within the aquifer units where the clay is thin or absent. As a result the deeper aquifers are recharged by the overlying aquifers by the downward movement of water through vertical interconnection between the different aquifer units or by lateral inter connection due to thinning of clays. As the deeper aquifer units (II, III & IV) are confining aquifers with high hydrostatic pressure the upward movement of groundwater within the aquifer units do exists.

Aquifer management plan through numeric modeling:-

The numerical model developed for Cuddalore aquifer system was subjected to various stress scenarios (all groundwater development scenarios) so as to understand the implications of groundwater withdrawal. All the four aquifer units of the Cuddalore aquifer system are needed to be managed. The aquifer unit – I is utilized for domestic and irrigation purpose, aquifer unit – II is used mainly for irrigation , aquifer unit – III is for mining activity and aquifer unit – IV is for drinking water supply to Chennai city during lean periods. Predictive simulations are carried out taking into consideration of the utility of the aquifer for different sectors. The response of the four aquifer units (I, II, III and IV) of the Cuddalore aquifer system to various hydrological stresses has led to establish aquifer management plan.

Predictive simulations

The calibrated model was used to simulate the impacts of projected rates of groundwater pumping for the next 12 years (from 2013 to 2025) upon water levels and flow rates within the Cuddalore aquifers system. This was done in five scenarios using different assumptions, mainly change in groundwater withdrawal that is likely to happen in future.

(a) Model forecast with present rate (Year 2013) of groundwater withdrawal

The Cuddalore aquifer system is the most potential aquifer in Tamil Nadu state, India. As more than 80 percent of groundwater withdrawal from the Cuddalore aquifer system accounts for irrigation, there has been much concern amongst farmers regarding decline of groundwater level. In specific, the decline in the Piezometric head of Aquifer Unit – II is of great concern` to the water managers, planers and general public.

The model was run to predict the groundwater head upto 2025 by assuming that the annual groundwater withdrawal from the Cuddalore aquifer system is 1231.58 mcm continues upto 2025. The monthly average rainfall computed for normal year is given as input to the model. The groundwater withdrawal pattern for the year 2013 was given to the model upto 2025. The projected groundwater head shows that no noticeable change in the peizometric head and flow pattern and in all the four aquifer units.(figure)However, the projected groundwater head for aquifer unit – II at few pockets where withdrawal is high.

This implies that, for the annual groundwater withdrawal of 1213.58 MCM the Cuddalore aquifer system is safe.

(b) **Increase in groundwater pumping for irrigation**

As mentioned earlier in the report, the Cuddalore aquifer system is subjected to stress since 1961. Since then the groundwater withdrawal (depressurization activity) for safe mining of lignite around Neyveli started. The groundwater withdrawal increased multifold for irrigation with the energisation of wells since 1970. The total annual groundwater withdrawal in the model is 1213.58 MCM. About 97 percent of annual groundwater withdrawal (1034 MCM) for irrigation is from Upper Cuddalore aquifer (Aquifer Unit – I) and Lower Cuddalore (Aquifer Unit - II). While the Upper Neyveli aquifer (Aquifer Unit – III) substantiates only 3 percent for groundwater withdrawal for irrigation. The Middle Neyveli Aquifer (Aquifer Unit –IV) is devoid of groundwater withdrawal for irrigation activity. Thus, the Aquifer Unit I and II have been subjected to stress (groundwater withdrawal for irrigation) since 1970. As a result, groundwater decline has been noticed in very few isolated pockets in aquifer unit – I and few locations in aquifer unit – II.

The above situation infers that the groundwater withdrawal for irrigation in Lower Cuddalore aquifer (Aquifer Unit – II) exceeds the natural recharge by 0.15 times and most pumping is supplied by depletion of aquifer storage. Therefore, the groundwater withdrawal from Aquifer Unit I and II need to be carefully managed to prevent pumping water levels in wells from declining to the depth near the bottom of wells making them unusable (low yield). In areas with low recharge and high pumpage, the water managers need to consider pumping rates, pumping times and areal distribution of wells, so that water level decline due to pumping well will not go dry. The calibrated model developed for Cuddalore aquifer system were thus used to project the future groundwater levels/heads in Aquifer Unit I and II as this would lead to formulate groundwater management strategies or aquifer management plan.

The farmers in the model area tap groundwater for irrigation activity from Aquifer Unit I and II. Paddy and sugarcane are the major crops irrigated by groundwater. The demand for cultivating more sugarcane has increased amongst farmers during the last 10 years. This shall lead to withdraw more groundwater by the farmers for irrigation and if the yield of the existing tubewells decline, the farmers may construct additional new tubewells more particularly in Aquifer Unit – II. Thus, the demand for groundwater withdrawal for irrigation shall escalate from 1034 to 1384 mcm annually. As mentioned earlier, the dugwell/open well of the aquifer unit –I and Tubewells of the aquifer unit – II show marginal decline in groundwater head by 0.10to 0.20 m annually. If the groundwater withdrawal by farmers is increased to 1384 mcm/year (i.e., 30 % increase) the rate of groundwater decline shall be more that the present rate.

With this background the calibrated model of the Cuddalore Aquifer system was subjected to stress so as to find out the response of the aquifer system to the increase in pumping rate by 350 mcm from the present groundwater withdrawal of 1213.50 mcm/yr. The aquifer – II was subjected to additional annual groundwater withdrawal of 350 mcm. Thus the total annual groundwater pumping from all the four aquifer units is 1563.58 mcm. The recharge rates and other parameters remained the same. The projected groundwater head though mimics the groundwater head pattern but the rate of decline of the peizometric head of Aquifer Unit – II increased by 0.20and0.30 m annually.

Before predevelopment, the tubewells constructed in aquifers unit –II were free flowing wells *(the piezometric heads were 20 to 30 m amsl).* The present piezometric head of Aquifer Unit – II ranges between 10 and 15 m amsl. The predevelopment saturated thickness of Aquifer Unit – I was around 30 to 50 m. The saturated thickness of the Aquifer Unit – II (confined) ranged between 25 and 80 m. The model had predicted that the decline in piezometric head for groundwater withdrawal of 1563.58 mcm for 12 year period was 0.20 to 0.30 m annually.

The aquifer unit – II becomes unsafe by 2045 for the groundwater withdrawal rate of 1563.58 mcm annually while the remaining aquifer units (I, III and IV) remains safe throughout.

(c) Increase in pumping for mining activity

The groundwater withdrawal in Aquifer Unit – III is confined to Neyveli lignite mine area and nearby. The total groundwater pumping *(depressurization)* for mining of safe lignite is 133.10mcm.In near future, there is a plan to expand mine activity by going in for new mines. This might led to pumping of mine groundwater for safe mining of lignite. With this background, the aquifer Unit III was subjected to stress wherein the annual groundwater withdrawal in aquifer Unit –III was increased by 60 and 130 mcm. The model was run upto 2025 with the recharge rate of 2013. The projected piezometric head of Aquifer Unit – III show no change in head and groundwater flow pattern. However, there was a minimal shift of contour which on analysis infers that the cone of depression enlarged by 100 m for an increase in groundwater pumping by 60 mcm and 200 m for increase in groundwater pumping by 133 mcm annually. It can be concluded; the aquifer unit III remain safe for an increase in groundwater withdrawal by 60 and 130 mcm annually.

(d) Increase in pumping for Drinking water supply.

The groundwater in the aquifer unit – IV is withdrawn for drinking water supply to Chennai city during lean periods or during period when the water level in the reservoirs around Chennai city goes alarmingly low due to failure of monsoon.The groundwater withdrawal in Aquifer Unit –IV occurs in the central portion of the area which is 20 to 25 kms away from the coast. The total annual groundwater withdrawal is 12.79 mcm. If in near future, drought persists around Chennai city, the demand for drinking water from this aquifer shall increase. Anticipating this scenario, the model was run upto 2025 with an increase in annual groundwater withdrawal by 6 mcm. The total annual groundwater withdrawal of the model was 1231.58 mcm. The model predicted no significant change in piezometric head indicating that the aquifer unit – IV continues to be safe with annual groundwater withdrawal of 18.79 mcm from aquifer unit – IV.

The aquifer management plan (Zone wise) of the cuddalore aquifer system is depicted as figure below. The zone A and B are the intensively irrigated region, where the farmers solely depend on groundwater for irrigation. Paddy and sugar cane are the major crops cultivated apart from cashew nuts. The groundwater for irrigation is presently tapped from Aquifer I and II and can be continued in future also for irrigation and domestic purpose including drinking water supply. Zone C and Zone D are along the coast and are vulnerable to sea water intrusion. Presently within the zone C many industries exists. Zone D is the region between coast and 10 km inland. The waste water released from the industries should be treated properly as aquifer – I and II shall be contaminated if the waste water is let out without treating within the aquifer system. Further industries tapping groundwater can lower the groundwater/peizometric head of these aquifers below the recommended limit. Hence industries tapping groundwater may be restricted within the aquifer and more particularly along the coast (0 to 10 km from sea). Zone E is the region where lignite is excavated through open case mine activity. Groundwater is pumped from aquifer – III for safe mining of lignite. As local cone of depression exists around lignite mine due to continuous pumping since 1950, continuous monitoring around lignite mine and upto the coast is essential. Zone F exists at the central portion of the aquifer system wherein groundwater is pumped from Aquifer –IV by battery of wells along North-South direction by metro water to Chennai city through pipelines during lean periods. The aquifer – III and IV of the Cuddalore aquifer system are to be kept for future use and Aquifer – I & II should to be monitored continuously as discussed in the report.

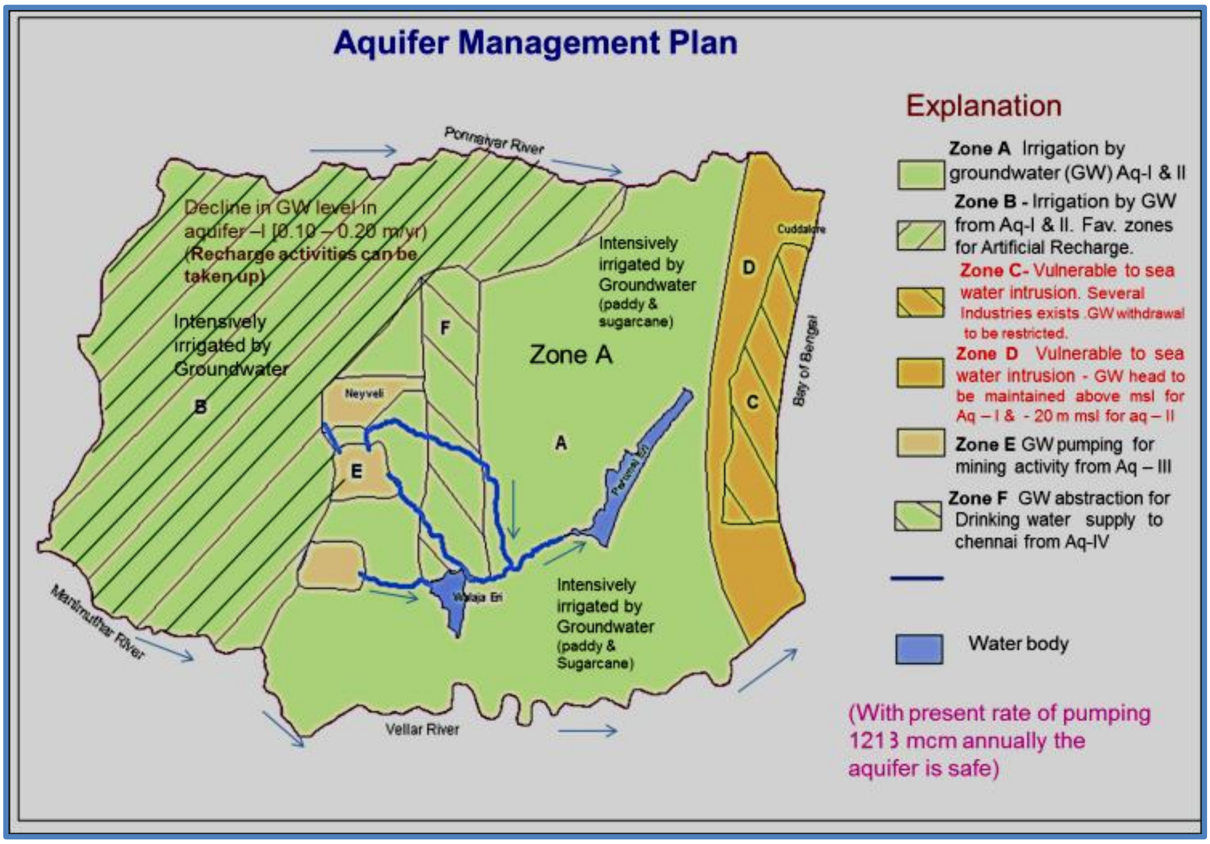

Fig 4. Aquifer Management Plan

Conclusion

The aquifer mapping study carried out in the parts of Lower vellar water shed under pilot project inferred the presence of four potential aquifer units (Aquifer unit – I, II, III & IV) . . The results of the aquifer mapping studies inferred that the sandstones are the principle aquifer and are highly potential. Four aquifer units were decipher within the sandstones down to the depth of 400 m bgl viz. aquifer-I (Phreatic), Aquifer-II (Leaky/confined), Aquifer-III (Confined) and Aquifer-IV (Confined). As the study area being the coastal aquifer and groundwater withdrawal from the aquifer II & III is quite extensive, the information on the thickness and the lateral extension of the aquifer units obtained from this study is currently used in planning and management of the Coastal aquifer effectively. The hydrogeological information/hydrogeological framework of the individual aquifer units generated from the aquifer mapping study is primarily used to develop conceptual model so as to develop aquifer management plan through numerical modeling. The Cuddalore coastal aquifer is the most prolific and potential aquifer in the state as well as in the country. Due to its vulnerability to sea water intrusion, heavy groundwater abstraction along the coast (0 – 10 km) shall invite sea water intrusion. Further, the industries that exist near the coast shall contaminate the precious groundwater available. Hence, industries that withdraw groundwater near the coast (0 to 10 km from sea) may not be permitted and industries that release toxic chemicals may not be permitted to operate within the coastal aquifer system. Once the precious aquifer system is damaged or contaminated, recovery or reclamation is almost impossible.

Acknowledgement

The authors thank the Chairman, Central Ground Water Board, New Delhi, Regional Director, SECR, Chennai and all the officers/staffs of CGWB for their support in successful completion of the work. Special thanks to Dr. S. Suresh, Scientist –D and Dr. S. K. Sinha, Supdt. Hydrologist, CGWB. This paper forms a part of the work (National Award by Government of India) wherein the authors was conferred National Geoscience Award by his Excellency The President of India on 6th April 2015.

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Aquifer mapping and management in Desert area – a case study from Jaisalmer district, Rajasthan

Rana Chatterjee[1], Binoy Ranjan[2], Subhas Chandra[3], P.K. Parchure[4], Shakeel Ahmed[5]

[1]Senior Hydrogeologist, Central Ground Water Board, New Delhi, [2]Senior Hydrogeologist, Central Ground Water Board, Jodhpur, [3]Principal Scientist, CSIR-NGRI, Hyderabad, [4]Former Member, Central Ground Water Board, Faridabad, [5]Former Chief Scientist, CSIR-NGRI, Hyderabad

Abstract

Ramgarh area in the desert land of Jaisalmer district, Western Rajasthan is in the midst of one of the most arid climatic region of the World. Water Management in this part of the area therefore poses a touch challenge. Aquifer mapping with the aid of hydrogeologic survey and Surface and heliborne Geophysical Survey reveals the existence of multi-layerd aquifer system under both unconfined and confined condition. Aquifers are consisting of sandstone, shale and lime stone. The water level in the aquifers are generally quite deep, in the range of 50m to 70m. Water quality in the wells tapping upper perched aquifer is generally potable as compared to the deeper principle aquifer system which is having brackish to saline ground water. Water in this region is so scarce, that traditionally the local people have developed wisdom to conserve the meagre precipitation falling in the ground. The most important ground water management intervention in this terrain is therefore upscaling of the traditional rainwater harvesting practices. Khadins, Kunds, talab with beri are some of the effective rainwater harvesting structures in the region. Though the ground water level in general is deep in this region, however water logging problem has occurred along the Indira Gandhi Nahar Pariyojna due to canal seepage which needs to be talked through conjunctive use of surface and ground water resources.

Key words: Ramgarh, Desert, Aquifer mapping, Salinity, traditional water harvesting practices

Introduction

Management of scarce water resources in Desert areas poses a specific challenge to the water scientists, engineers and planners. In the Indian context, the Thar desert in Western Rajasthan is one such arid area where annual rainfall is less than 150 mm. In order to find a pragmatic solution to the problem of water deficiency in this region, Government of India launched National Aquifer Mapping programme for developing aquifer based Sustainable Groundwater Management Plan through multi-disciplinary scientific approach (CGWB, 2015). This paper brings out the results of the study highlighting the aquifer geometry, their characterization and management interventions required for its long term sustainability.

The study area lies within Latitude: 27°16'N and 27°30'N and Longitude: 70°20'00"E and 70°36'20"E, in Sam Panchayat Samiti (block), Jaisalmer district, in Western Rajasthan (Figure 1). It forms a part of Western Arid Plain. The total study area is about 675 sq.km. The area is approximately 25 km in North-South stretch and 25 km in East-West stretch with Ramgarh almost at its centre.

The area lies in arid tract of Thar desert characterised by extremes of hot and cold weather. Rainfall is erratic,in some years annual rainfall is as low as even 9 mm. Almost 90% of the total annual rainfall is received during the southwest monsoon, during July to mid of September. Droughts are frequent in the region. Major part of the study area is covered with blown sand sheets and dunes. NNE-SSW trending barchans and longitudinal dunes are important dunal landforms present in the area. Another characteristic landform feature in the area is flat, limestone terrain. No stream worth mention is present in the area. Indira Gandhi

Nahar Pariyojna branch canal flows north of Ramgarh town. Water logging and agricultural activities are observed along canal. The region is otherwise thinly vegetated.

Geologically, the area is underlain by Mesozoic and Tertiary formations consisting of sandstone, shale, conglomerate. Mesozoic rocks consists of Parewar and Abur formations and Tertiary rocks include Sanu sandstone and limestone. These formations are overlain at places by Pleistocene to recent alluvium consisting mainly clay, sand and silt and aeolian sands.

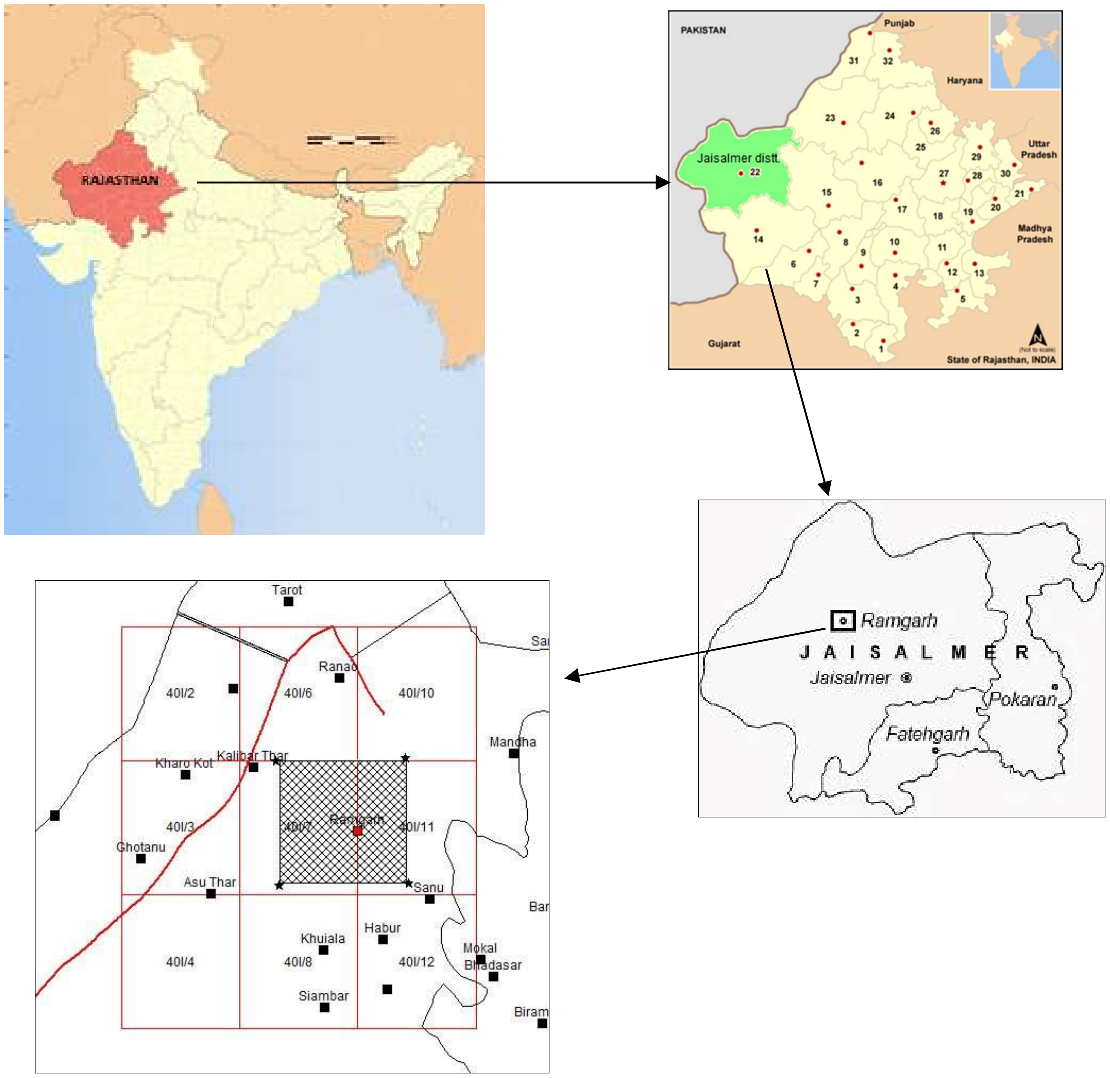


Figure 1. Location map of Ramgarh area, Jaisalmer district, Rajasthan

Methodology

The existing data were compiled from various sources including records of CGWB and State Government agencies, literature available in the libraries and internet, NGO and other sources relevant for the purpose of aquifer mapping and management. Some of the baseline reports on the project area include Status report on search of palaeochannels in Western Rajasthan, CGWB (2002) and District Ground water Brochure (CGWB, 2011). Water levels were periodically monitored, soil infiltration studies, ground water exploration were carried out. Advanced geophysical investigation was carried out through Heliborne Geophysical studies in view of inhospitable terrain conditions.

Heliborne geophysical survey include electrical resistivity and magnetic survey. The mean resistivity maps have been generated at 5 m depth intervals down to a depth of 300 m. HeliMag survey was carried out along with the Heliborne Transient Electromagnetic Method (TEM) using Geometrix Caesium vapour type having sensitivity 0.1 nT. Magnetic sensor was synchronized with TEM measurements. The Total magnetic field intensity map has been prepared after all correction and data leveling (NGRI, 2015).

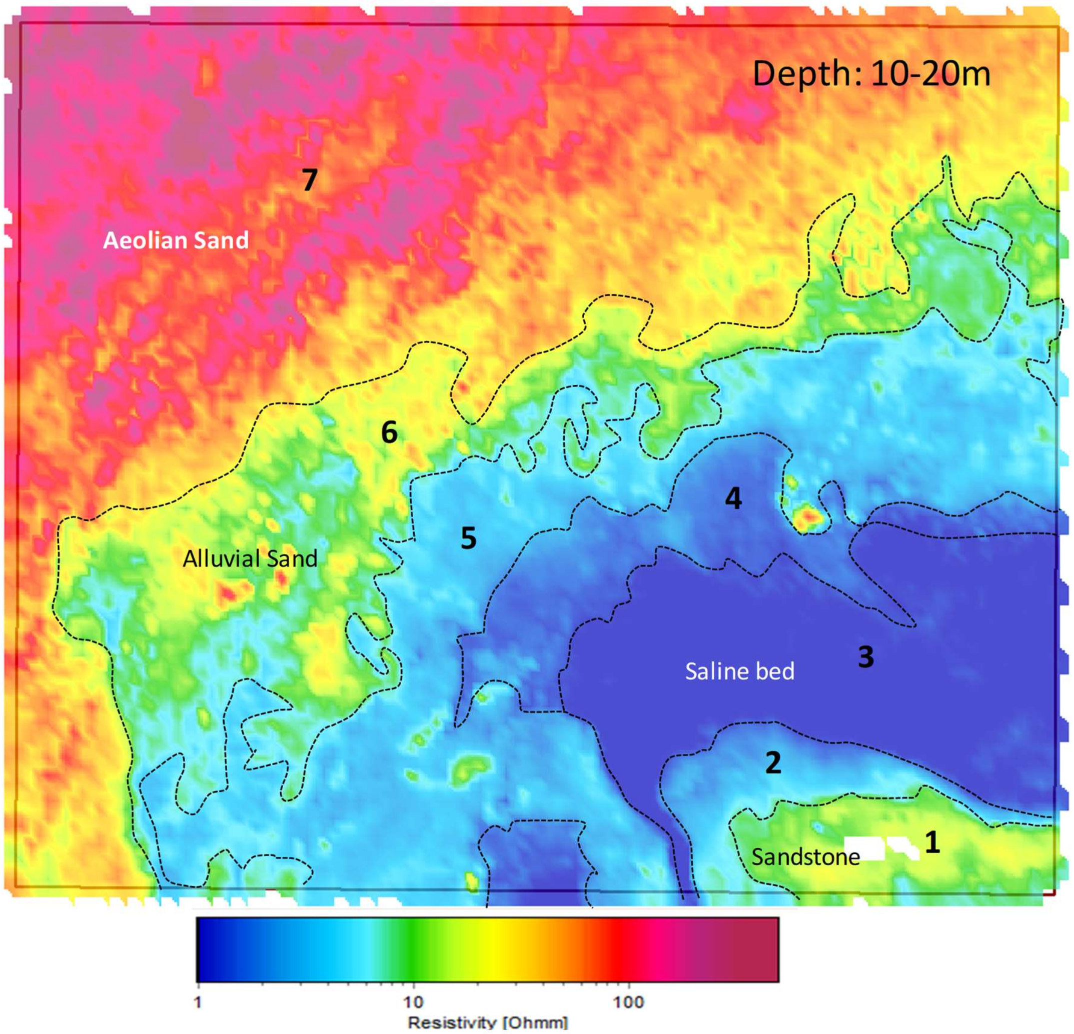
Geophysical investigations are correlated with ground hydrogeological surveys and borehole logs to reconstruct the three-diamentional aquifer geometry. 3-D Aquifer models are generated through Rockworks and GIS softwares namely MapInfo and ArcGIS. All the aquifer parameters are projected on GIS maps. Aquifer management plan are suggested based on local success stories.

Results

The aquifer disposition is obtained through integration of geophysical and geological findings. Mean resistivity map obtained through Heliborne TEM studies is found well corresponding to the geological map of the area. Following resistivity range are taken to interpret the geophysical image to lithological model.

S.No.	Lithology	Resistivity (Ωm)
1	Sandstone, sandy limestone, ironstone shale	8-40
2	Sandstone	6-15
3	Limestone, marly Limestone, bentonitic, gypseous clay	1-3
4	Crystalline Limestone, chalky limestone	2-6
5	Gypseous limestone	2-8
6	Conglomerate, ferruginous sandstone	10-100
7	Aeolian sand and kankar	70-1000 or more

Table 1 Resistivity scale used for litho characterization



1. Sandstone, sandy limestone, ironstone shale
2. Sandstone
3. Limestone, marly Limestone, bentonitic, gypseous clay
4. Crystaline Limestone, chalky limestone
5. Gepseous limestone
6. Conglomerate, ferugenous sandstone
7. Aeolian sand and kankar

Figure 2. Mean Resistivity Maps of 10-20 M Depth

Figure 2 shows that the inferred litho boundaries are increasing and extending towards north and north-west. This reveals that the beds are dipping towards north and north-west. The saline bed which is primarily dominated by limestone and gypsiferous clay acts as marker bed separating unconfined and confined aquifer in north and north-west.

Mean resistivity map revealed a NW-SE running fault in the east of Ramgarh town (hereafter called Ramgarh fault). The Ramgarh fault continued even in the south ward almost maintaining the same strike which divides Khara Runn and Meetha Runn villages located roughly 12 km in NW of Jaisalmer city. Lithological layer boundaries are prepared based on Heliborne TEM studies (figures 3).

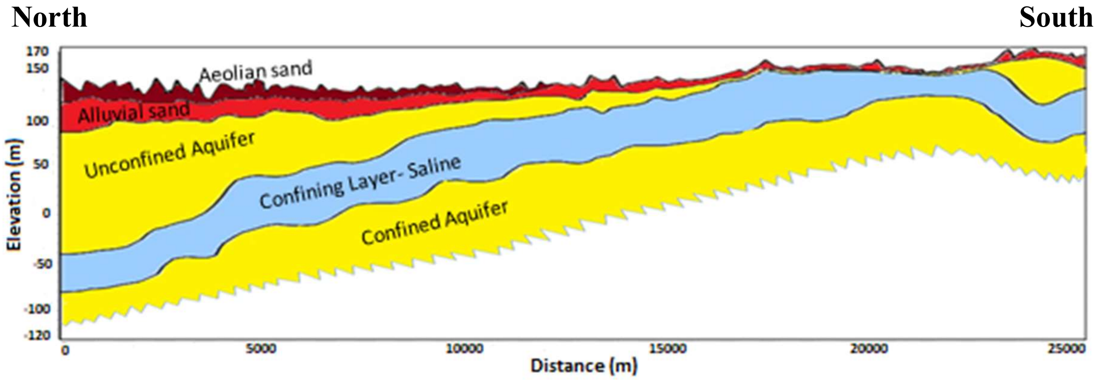


Figure 3. Interpretation of Aquifer disposition based on Geophysical investigations

The geophysical studies reveal the existence of:

- Saline groundwater zone that dips and thickens towards north,
- SE-NW trending Ramgarh fault that passes through the area,
- The role of Ramgarh fault in controlling the groundwater condition. The fault separates the Khara-Rann (i.e. brackish water) and Meetha-Rann (sweet water) and
- Thick sediments deposited in a linear alignment (could be structurally controlled) forming isolated pockets of fresh water aquifer within the saline water zone.

The composite 3-D aquifer models are generated through integration of advanced geophysical studies and hydrogeological investigations (Figure 4). The lithological layers are broadly classified into – sand dunes, unsaturated sand, un-confined aquifer, saline bed and confined aquifer. Thickness of un-confined aquifer in major part of the study area is upto 30 m. However, thickness of 90 m to 180 m have also been encountered in the northern and eastern part of the project area. Saline bed of 40 m to 60 m thickness have been encountered in major part of the project area. Thickness of saline bed is within 20 m in a small linear belt along the eastern boundary of the study area.

Attributes of Aquifer Systems – Water level, Quality, Recharge and discharge properties

The water levels in the perched aquifers are generally shallow, mostly within 5 m below ground level (bgl). The depth to water levels of the principle aquifer ranges between 50 m and 70 m below ground level.

In the month of May, 2014, the depth to water level in the principle aquifer system of the area varies from 65 m bgl at Gamnewala outside the north-west border of the study area to 81 m bgl at Naval Singh Ki Dhani in the south-east corner of the study area. The thematic water level map for the month (figure 5) shows that the depth to water level gradually increases from north-west to south-east.

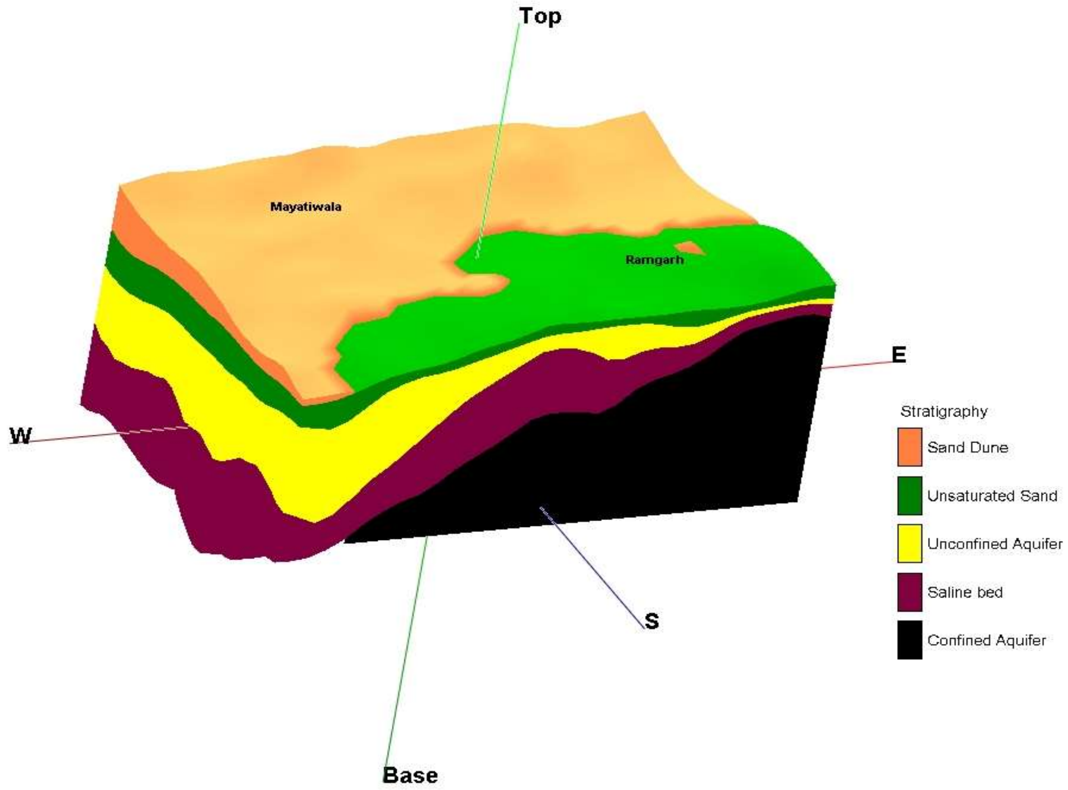


Figure 4. 3-D Aquifer Model, Ramgarh area, Jaisalmer district, Rajasthan

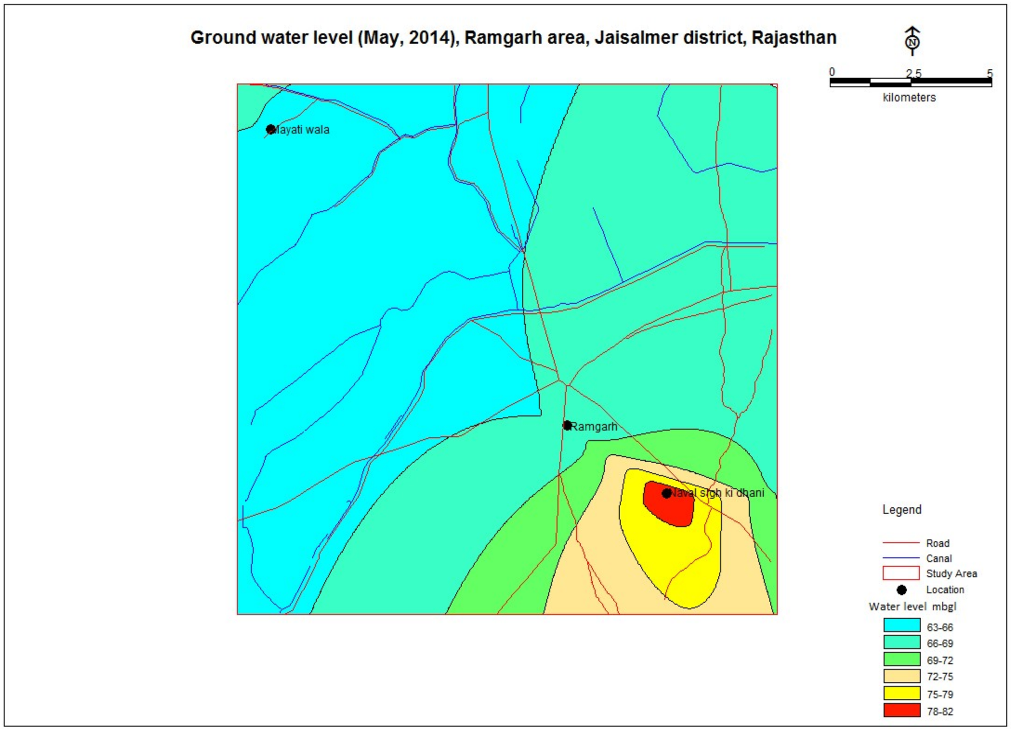


Figure 5. Depth to water level map of pre-monsoon (May), 2014, Desert Area, Jaisalmer district, Rajasthan

The depth to water level scenario during November, 2014 (figure 6) has changed due to the seepage from IGNP canal system which has resulted in shallower ground water level in the central portion of the project area through which the canal is flowing. The depth to water level in the area varies from 43 m bgl at Ramgarh to 67 m bgl at Joga, on the south-east boundary, just outside the project area. As described above, the shallower ground water level in the range of 43 m bgl to 45 m bgl have been recorded in the central portion of the project area and deeper water level of more than 63 m bgl have been recorded at Mayatiwala, Gamnewala sites in the north-west corner and Joga in south-east corner.

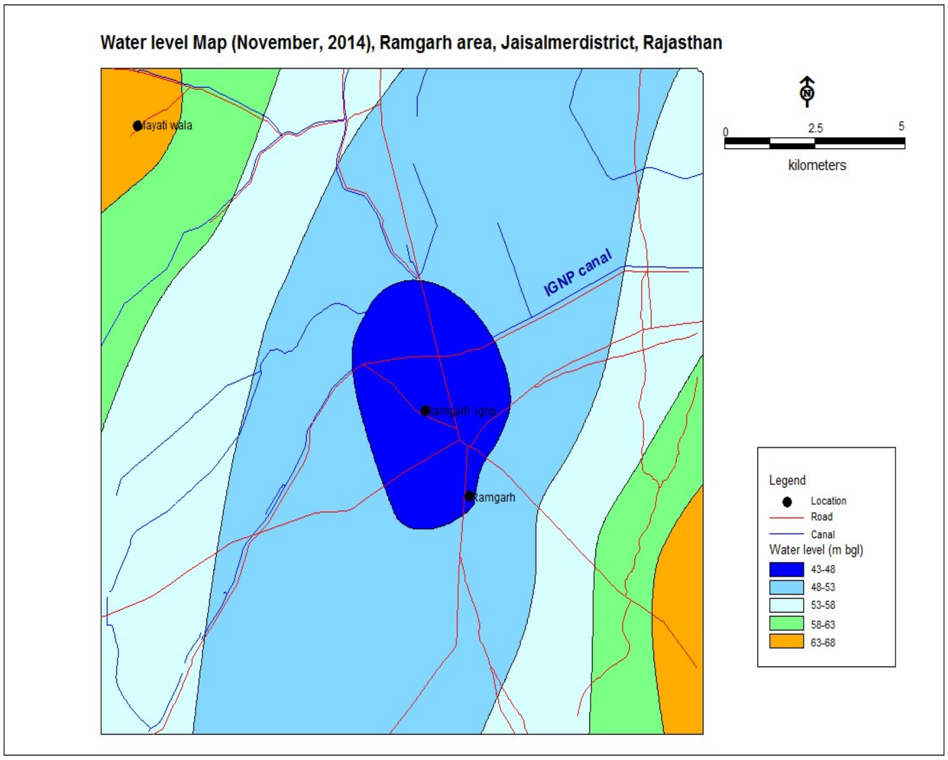


Figure 6. Depth to water level map of post-monsoon (November, 2014), Desert Area, Jaisalmer district, Rajasthan

A representative hydrograph showing water level fluctuation during project period is presented in figure 7a and the long-term trend of water level in the area as used in Ground Water Resource Estimation (CGWB, 2016) is depicted in figure 7b.

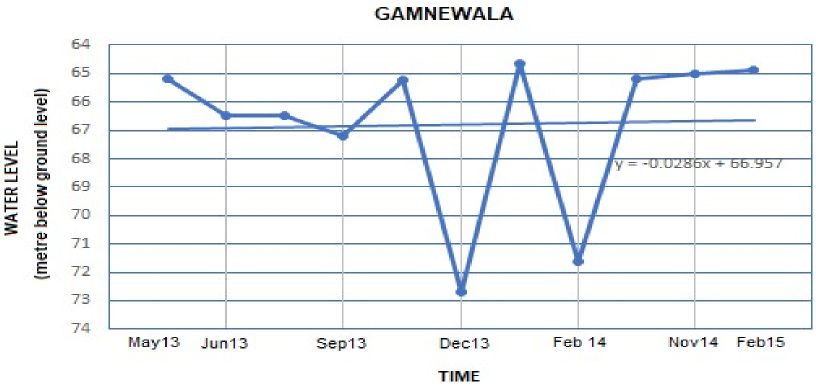


Figure 7a. Hydrographs showing monthly water level of representative monitoring stations in Desert Area, Jaisalmer district, Rajasthan

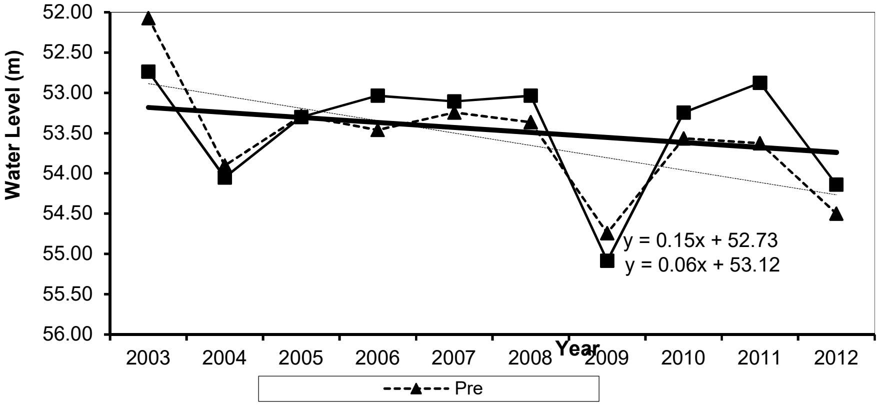


Figure 7b. Long term Water level trend used in Ground Water Resources Assessment in Ramgarh area, Sam block, Jaisalmer district, Rajasthan

The electrical conductivity in the study area varies distinctly between water samples collected from shallow perched aquifer and deep principle aquifer system. The perched aquifer has EC ranges from 440 µmhos/cm to 3710 µmhos/cm, indicating potable nature of the water. In contrast, the deeper principle aquifer system has EC range between 4660 µmhos/cm and 7010 µmhos/cm. The high salinity content of the aquifer is attributed to the intrinsic chemical composition of the sediments which are marine deposits.

Infiltration properties, Recharge and Withdrawal

Soil cover plays an important role in the ground water recharge. Soil infiltration tests have been conducted using double ring infiltrometer in different types of soils across the project area to determine the infiltration rate of the soil (table 2).

Sl. No.	Location	Soil Type	Season	Infiltration Rate (cm/min)
1	Ramgarh	Desert soil	Post-Monsoon'13	0.07
2	Gamnewala	Desert soil	Post-Monsoon'13	0.02
3	Navalgaon	Desert soil	Post-Monsoon'13	0.04
4	Khirar Beri	Desert soil	Pre-Monsoon'14	0.39
5	Ali Ki Dhani	Desert soil	Pre-Monsoon'14	0.10
6	Biprasar Netsi	Desert soil	Pre-Monsoon'14	0.04

Table 2. Soil Infiltration test results, Ramgarh area, Jaisalmer district, Rajasthan

The wide range of Infiltration rate of Desert sand depends on whether the top soil is compact because of hard pans or carbonate deposits like in the case of Gamnewala, which results in low infiltration rate. In case, the soil is loose, the infiltration rate is high as in Khirar Beri.

The desert area around Ramgarh, Sam block, Jaisalmer district has meagre ground water resources. As per the estimation carried out jointly by CGWB and State Ground Water Department, Rajasthan for 2013 (CGWB, 2016), the unit annual ground water recharge is only around 3.46 mm per year. This constitutes to be only 2% of the annual rainfall which is around

146 mm. Even this meagre resource is generally brackish in nature due to intrinsic property of the lithologic formations, thus rendering it to be unsuitable for use. The assessment of dynamic ground water resources in the study area is presented in table 3.

Potential zone	Annual Replenishable ground water Resources	Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for Irrigation	Existing Gross G.W. Draft for Dom. & Ind. Use	Existing Gross Ground Water Draft for all uses	Stage of G.W. Develop-ment
	(mcm)	(mcm)	(mcm)	(mcm)	(mcm)	(mcm)	(%)
Alluvium (A2/1)	1.07	0.11	0.96	0.00	0.28	0.28	29.53
Tertiary Sandstone (T1/4)	0.52	0.05	0.47	0.00	0.45	0.45	96.50
Parewar formation (P1/2)	1.22	0.12	1.10	0.00	1.05	1.05	95.59
TOTAL	**2.81**	**0.28**	**2.52**	**0.00**	**1.78**	**1.78**	**70.64**

Table 3. Dynamic Ground Water Resources of Desert Area project area, Jaisalmer district, Rajasthan (2013)

Note: mcm – million cubic meter

Discussion

Considering the scanty rainfall and meagre water resources in the Thar desert, the management interventions proposed in the desert project area are – a. upscaling the traditional water harvesting system in the area, b. controlled use of limited fresh ground water pockets around IGNP canal command area.

a. Upscaling of Traditional water harvesting practices

In the desert area, the traditional water harvesting practices involve collection of rain water howsoever meagre and it's storage for long time use. During the monsoon, the rain collects in a catchment or khadin, which is often walled up in a semi-circular fashion by the farmers using stones and mud, just so that the water does not escape. Even when the top layer of water evaporates, the soil retains the moisture and is ideal for sowing a variety of crops including wheat, mustard, melons, and millets like jowar and bajra. These help to maintain the groundwater levels too. The outlets from one khadin let out excess water to fill up farms on the otherside too, so that farmers on both sides benefit equally.

Within villages and around pasture lands, one finds kunds or tanks to store water. Every open space in the home is used to collect precious rainwater. Every terrace slopes to one side, where surakhos (openings) let rainwater in through netted filters. The water is then collected in tanks small or big and used the year round for drinking, washing and cooking. Wherever sweet water occurs, it is collected and cared for by the community. Large kunds have a door for people to come in and collect water. Every kund or tanka (large tank) is covered and kept clean. These harvesting structures are cleaned regularly and maintained spotless by families or communities.

The natural pond or talaab, are associated with beris (plate 1). Since the pond is an open body, the heat of the desert can dry it up in summer. This is when the beris continue to retain water for use by communities. These are shared assets. There are several exemplary success stories on reviving traditional water harvesting systems in the Thar desert like Sambhav which is an organization working for Water Conservation movement in the Thar desert in Jaisalmer district. Established in 2006 by Sh. Chattar Singh Jam, it has revived old traditions of water harvesting in dozens of hamlets across 20 km radius in Jaisalmer district, Rajasthan.

Plate1. Beris in Biprasar talav, Jaisalmer district, Rajasthan

The traditional water harvesting structures can be build in the isolated pockets of fresh water aquifer as identified through advanced geophysical and hydrogeological studies. This will not only help in surface pondage of rainwater but will also recharge the fresh aquifer. As indicated above, sub-surface storage of ground water has the added advantage of less evapotranspiration loss than the surface ponds/ talavs.

b. Controlled use of fresh ground water resources

Along the Indira Gandhi Nahar Pariyojna (IGNP) canal, fresh water pockets are formed due to seepage from the lined canal which sometimes even amount to water-logging situation as shown in the following photograph (plate 2).

Plate 2. Water logging situation along IGNP Canal, Ramgarh area, Jaisalmer district, Rajasthan

It is recommended that in such areas which are suffering from water logging problems and where ground water level is within 8 m, ground water be used in a controlled manner to mitigate the water logging situation. However, at the same time caution to be adopted to avoid over-pumping which may lead to salinity ingress from the brackish water of the principle aquifer system.

Conclusion

The Thar desert of Jaisalmer is one of the most arid areas of the world. At the same time, it is also most densely populated desert in the world with 83 person per sq.km. The water requirement in this region is mainly met through traditional water harvesting practices since ages. In order to merge the traditional wisdom with the modern science and technology to find the solution of water scarcity in the region, Aquifer mapping and management study was taken up. Advanced geological applications like remote sensing and geophysical techniques like Heli-borne electromagnetic and magnatic surveys were applied to map the areas suitable for traditional water harvesting practices. In addition, conjunctive use of canal water from IGNP network and ground water in the canal command area would also boost the water supply for agriculture and domestic uses. The study reveals that aerial surveys like remote sensing and Heliborne geophysical surveys are effective in groundwater exploration in the sand dune tracts of the desert area where ground surveys are difficult task.

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All editorial correspondence may be addressed to editor, Bhujal News, Central Ground Water Baord, Bhujal Bhawan, NH-4, Faridabad-121001, Haryana. Email: bhujal-cgwb@nic.in