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Research Article

GROUND WATER MODELING OF FARIDABAD DISTRICT, HARYANA, INDIA

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Abstract- Groundwater is under stress in almost all parts of India due to rapid development in agricultural activities, industrialization, urbanization, education, improved sanitation and increase in population. These scarcities of water make groundwater more precious. Faridabad district is also marred by off and on water crisis. All the districts of Faridabad are notified by Central Ground Water Authority (CGWA). Faridabad is situated on the Delhi– Mathura National Highway No.-2 at a distance of 32 km. from Delhi, at 28° 25' 16" north latitude and 77° 18' 28" east longitude. The close inspection of four hydrographs reveals that there is distinct pattern in hydrograph behaviour. Ballabhgarh and Bhopani indicates sharp decline in water level because these monitoring wells lies in urban area. Groundwater draft has been increased on the assumption that urbanization, increase in population and industrialization will result into increased groundwater draft. Accordingly, groundwater draft has been increased for 2025 and 2050.The results from numerical groundwater modelling shows that the rate of increase if groundwater draft will adversely affect availability of groundwater resources. The western part of the district comprising Bhankri, Bajri, Ghazipur, Nagla Gujran Faridabad, Sirohi, Fatehpur, Sarurpur, Tikri, Dhoj, Paota, Alwalpur, Alampur, and Zakopur, will face severe water shortage in 2025 and 2050.

Keywords- MODFLOW, DEM, ArcGIS, Pre-post Monsoon, Faridabad.

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Introduction

Groundwater is under stress in almost all parts of India due to rapid development in agricultural activities, industrialization, urbanization, education, improved sanitation and increase in population. These scarcities of water make groundwater more precious. Faridabad district is also marred by off and on water crisis. All the districts of Faridabad are notified by Central Ground Water Authority (CGWA).

In the densely populated semiarid territory in and around Faridabad (India), the water demands is rising continuously, while the surface- and groundwater resources are threatened by contamination and overexploitation. Groundwater, unless contaminated, is generally of better quality than surface water and can be developed incrementally in close proximity to needs, thus avoiding the need for large-scale storage, treatment, and distribution systems (Dapaah-Siakwan and Gyau- Boakye, 2000[4]; Odai and Dugbantey, 2003[15]). In an effort to provide the population with safe, adequate, and sustainable water supply, the significant groundwater resources, which are contained in the sedimentary sequence of the basin, have increasingly been exploited.

Increasing urbanization results into decline in water level. Rapid population growth and increasing urbanisation of Faridabad and Greater Faridabad has added considerable stress on the region's water resource. The impacts of less rainfall and increasing water demand have been evident as declining stores of surface water and ground water within the Faridabad district for the past several decades. All the hydrographs of Ground Water Monitoring stations of Central ground Water Board in the district reveals continuous decline of limited fresh ground water resources and needs immediate remedial measures [2].

Faridabad meets its water demand solely from groundwater. Data exists for the amount of groundwater supplied by the municipal corporation. The Municipal Corporation Faridabad, operates and maintains water supply infrastructure through a private operator while managing revenue collection. According to City Development Planning (CDP), there are 420 deep tube wells, supplying water through a 910 km long network. National Institute of Urban Affairs (NIUA) found that the official water supply in Faridabad increased from 184 mld in 1998-1999 to 229 mld in 2003-2004[10].

Objective

1. To prepare a suitable spatial datasets of aquifer properties and hydrological conditions across the Faridabad district for modelling of aquifer response,
2. To analyse change of aquifer storage during the past ten years to identify areas where artificial recharge will mitigate impacts of water table decline.

Location of Study Area

Faridabad is situated on the Delhi– Mathura National Highway No.-2 at a distance of 32 km. from Delhi, at 28° 25' 16" north latitude and 77° 18' 28" east longitude. The town is bounded on the north by Delhi State, on the east by Agra and the Gurgaon canals and on the west by the Aravali Hills. The Yamuna flows on the eastern side from north to south.

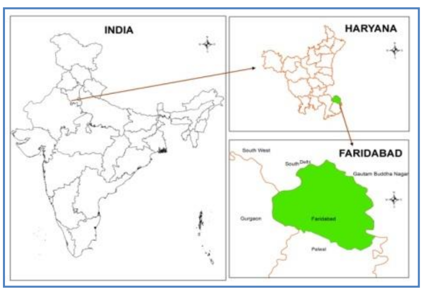


Fig-1 Index map of study area Physiographic and Drainage

The Faridabad district is occupied by the surface exposure of hard rock measuring about 99 square kilometres in the western part comprising of localities like Kot, Ankhir, Badkal and Surajkund etc. [Fig-1]. Besides the hard rock areas, the other parts of the district are occupied by mainly alluvial to fluvio-aeolian deposits.

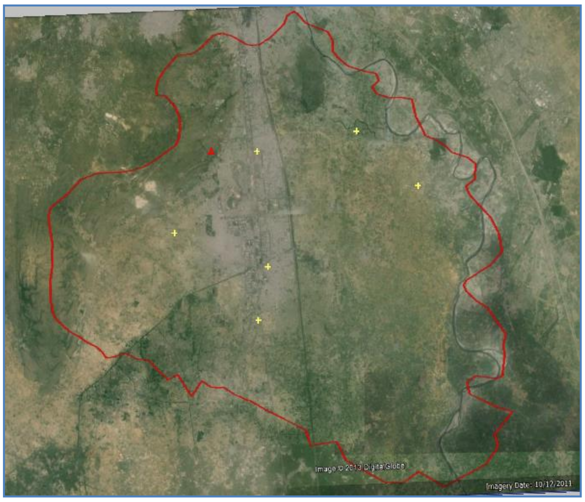


Fig-1 Satellite Image of the study area

The depth to bedrock/ basement topography is defined by steep escarpment at the margin of the hard rock area (where the depth of bed rock follows a steep gradient) and a mild undulation in the rest of the district, where depth to bed rock is found in the range of 300-400 *meters below ground level* (mbgl). The highest value of the topographic contour is found in the range of 317 *meters above mean sea level* (mamsl) in the NW part of the area at Manger village. The hard rock areas slopes steeply in SE direction and has a steeper slope towards east and west direction [Fig-3]. On approaching the alluvium, the lowest elevation is found at Bagpurkalan 180 mamsl. The general gradient of the alluvium is towards the SW and NE. The area is drained mainly by the Yamuna River, which enters the district near Chak Basantpur, flows southwards and exits at Bagpurkalan

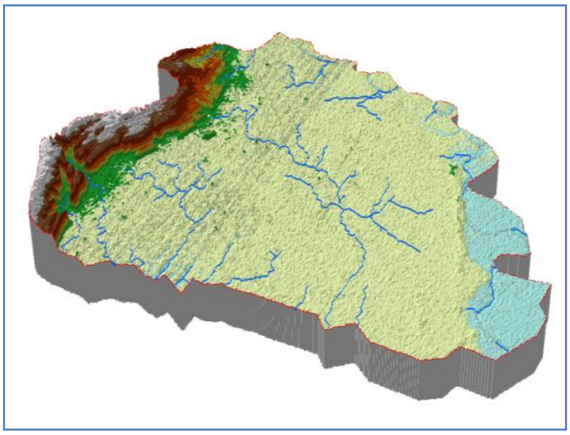


Fig-3 Digital elevation model showing physiographic

Climate and Rainfall

The area has semi-arid type of climate. There are three well defined seasons. The cold season begins in November and extends to the middle of March. Winters are usually very cold and icy winds are common feature.

Soils

Soils of Faridabad district are classified as tropical and brown soils, existing in major parts of the district. They are moderately to well drained. In Hathin block the organic content of soils ran gin g from 0.41 to 0.75 percent which is of medium category. In rest of the area organic contents is 0.2 to 0.4 percent and falls in Low category. The average conductivity of the soil is not more than 0.80 μ mhos /cm and the average pH of the soil is between 6.5 and 8.7.

Table-1 *Rainfall and temperature data of Faridabad*

Rainfall (mm)		Temperature (°C)		Normal Rainy days
Normal Annual	Normal Monsoon	Mean Maximum	Mean Minimum	
542	460	41 (May & June)	8 (Jan)	27

Geology

Table-2 *The General Stratigraphic Profile of Faridabad region*

Period	Formation	Description
Quaternary	Fluvio Aeolian deposits	Consists of unconsolidated interbedded, inter fringing deposits of sand, clay, gravel and kankar, moderately sorted with alternation of fluvial fine sediments.
Pre Cambrian	Alwar quartzites	Massive gray coloured with buff to brown frequently leached surfaces at places, highly fractured and jointed. It is intruded locally by pegmatites and quart/, veins and is inter bedded with mica schist at places.

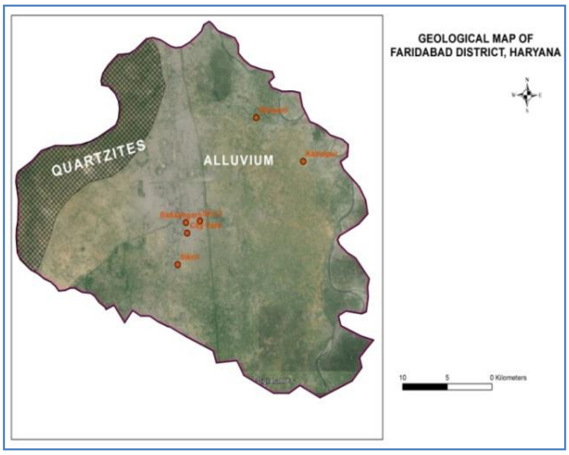


Fig-4 Geological of Faridabad District

Purpose and Scope

The analysis of hydrographs of groundwater monitoring wells, in this research, have established that there is continues long term decline of water level. In view of this the present ground water modeling study has been carried out to predict future groundwater level scenario in Faridabad district, if the rise in groundwater draft continues to increase [11]. Here a maiden attempt has been made to predict the water level for 2025 and 2050 and assess the sustainability and availability of groundwater using numerical simulation technique to comprehend the present and future water security.

Materials and Methods

The data required for aquifer evaluation and groundwater modeling study can broadly classify in physical and hydrological framework [Table-3].

Physical framework

I. Topography-Elevation using SRTM data
The SRTM (Shuttle Radar Topography Mission) elevation data having 90m resolution is used to prepare topographic elevation and digital elevation model after processing in ArcGIS software. This data is utilized for preparation of water table contour map. Location of streams, divides, ponds and so on are derived from Satellite Imagery-Google Earth.

II. Geological map
Geological map on 1:50,000 scale has been acquired from Geological Survey of India.

III. Aquifer type, Aquifer Geometry and parameters -
Based on basic data reports of CGWB reports, analysis and interpretation of borehole lithologs, pumping test data are

Table-3 *Data required for aquifer evaluation and groundwater modeling*

S. No	Physical framework	S. No	Hydrological stress
1	Topography-Elevation using SRTM data	1	Water table elevation
2	Geological map	2	Delineation and rate of recharge and discharge areas
3	Types of aquifers-Unconfined /confined	3	Groundwater draft from tube wells
4	Aquifer thickness and lateral extent- from litho log		
5	Aquifer boundaries		
6	Lithological variations , within the aquifer		
7	Aquifer characteristics(Hydraulic conductivity, Specific storage, specific yield etc.)- from Pumping test data		

Hydrological stress

I. Water table elevation- A discretized projected spatial dataset, representing the water table depth below ground surface in Post Monsoon, 2013, was constructed by subtracting the Post Monsoon, depth to water level for November, 2013 from the ground surface elevation model.

II. Delineation/ rate of recharge and discharge areas – Water table contour map, satellite image and field survey have been used to delineate/ rate of recharge and discharge areas.

ArcGIS

ArcGIS (ESRI, USA) is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps; compiling geographic data; analyzing spatial information and managing database in GIS platform. It is used for making DEM, water table contour map interpolation, spatial analysis and raster analysis etc.

Hydrogeology

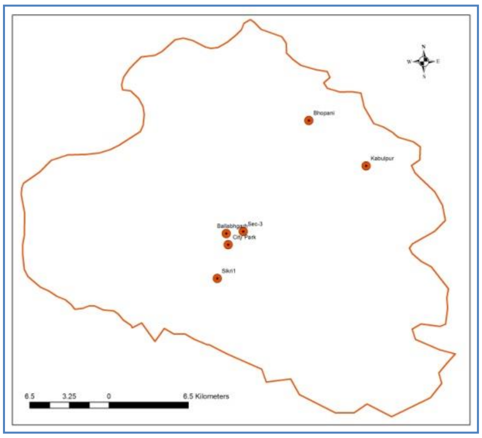


Fig-5 Location of monitoring wells, Faridabad

Modeling Approach

The equation that describes the three dimensional movement of groundwater of constant density through a porous earth material under anisotropic steady state conditions is the partial differential equation (Don et al 2006)[6].

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)=0$$

Where Kxx, Kyy, and Kzz are the hydraulic conductivities in the x, y and z directions respectively which are assumed to be parallel to the axes of hydraulic conductivity (LT-1), h is the potentiometric head (L). The finite difference code, MODFLOW (McDonald and Harbaugh 1988)[14] was chosen to solve [Eq-1] for hydraulic heads in the area. The MODFLOW model, which has been improved and verified by academia and engineers in many countries, has been used for 20 years. The model is extremely accurate and its suitability has been verified (Laronne Ben-Itzhak and Gvirtzman 2005)[13]. In MODFLOW model, layers can be simulated as confined or unconfined. Flow associated with external stresses, such as wells, areal recharge, evapotranspiration, drains, and rivers, can also be simulated (Harbaugh et al 2000)[9]. Some model assumptions are stated as: The density of the fluid is constant; water movement can be in three (orthogonal) directions (x, y, z) and properties within a cell are assumed to be homogeneous (El-Bihery 2009)[8].

A two-dimensional (2D) steady state groundwater flow model was constructed using Mod flow (**Harbough and McDonald 2000**) [9], and transport was modelled with MT3DMS (Zheng and Wang 1999)[18] under the graphical user interface of GMS software. The model accounts for infiltration into and processes in the saturated zone, but does not simulate surface runoff and percolation through the unsaturated zone. The model was calibrated for steady state by trial-and error and PEST (Parameter Estimation) methods. Prior to the transport modelling with MT3DMS, ModPath (Pollock 1994) [16] was used to visualize groundwater flow directions and pure advective travel times.

Conceptual Model

Geologically, the area is occupied with Alwar quartzites in the west and fluvio-aeolian deposits in the east of the district. The borehole data of Central ground Water Board (CGWB) shows alternation of fluvial bands with Aeolian bands in sporadic manner. The sediments are mostly silt with medium to find sand, clay and Kankar. The depth to bedrock data indicates towards steep subsurface escarpment on eastern side of the Faridabad ridge (AlwarQuartzites) exposed in the district. The general trend of groundwater flow direction of shallow aquifer is in the north and northeast directions **[Fig-3.5]**. The most significant hydrostratigraphic unit in terms of water supply considerations is the alluvium unit since it represents the water source for the vast majority of the domestic wells in the area were constructed through this unit. Information pertaining to the hydrogeological characteristics of this unit was available from the geological studies carried out by GSI.[5]

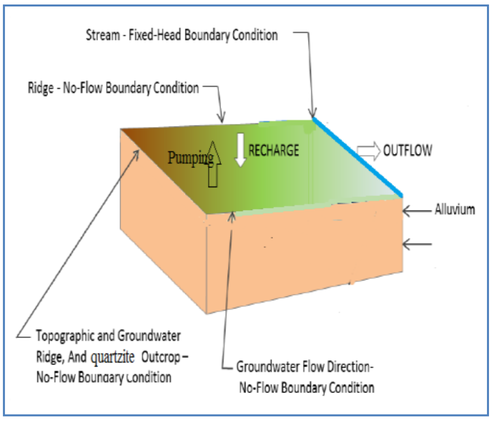


Fig-6 Conceptual Model of the study area

Hydraulic Heads

Data on hydraulic head distributions of groundwater monitoring station in the study area is available in CGWB. Most of these wells are restricted to shallow aquifer.

Hydraulic heads are defined by the spatially distributed groundwater levels/ piezometric heads of the aquifer at the start of the model period. In the present case, hydraulic heads are assigned by interpolating water table data of 2013 (pre monsoon) for 5 hydrograph stations falling within the study area [Fig-5].

As shown on [Fig-10] the groundwater flow direction in the study area is generally eastwards, towards the south –east direction. However, Faridabad acts as a significant local influence on groundwater levels and clearly acts as a point of groundwater discharge under steady-state conditions (i.e. is gaining). The contour plot also shows a small number of anomalous data points, indicative of some mounding of water levels at a couple of locations. It is likely that this effect reflects the fact that the data is derived from wells screened at different depths in the presence of a vertical gradient.

Aquifer Top Elevation

For the purpose of this study, top elevations for the alluvium/bedrock unit were collated SRTM data since RL values from groundwater monitoring station and borehole logs were limited. The aquifer top elevations across the site varied between approximately 317 and 179 m.a.s.l. Based upon the inferred aquifer top elevations at the Yamuna River, and the known depth of the river in this area, the Faridabad partially penetrates the alluvium unit along most of its length across the site. With respect to the Yamuna River, the available elevation data was insufficient to conclusively determine whether such a relationship also exists along its length. However, water level evidence from water level records adjacent to the Faridabad suggested that the alluvium /bedrock unit is hydraulically connected to the river.

Hydraulic Conductivity

Aquifer Hydraulic Conductivity values was calculated from data collected during pumping tests and basic data reports of CGWB. The values were assigned zone wise. Since the steady state model was developed therefore storability value was not assigned [12].

Results and Discussion.

The Depth to Groundwater Levels:

Pre Monsoon May 2013

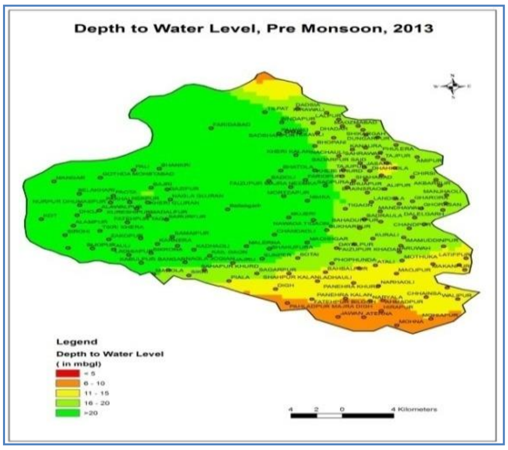


Fig-7 Depth to water level map (Pre-Monsoon, 2013)

Groundwater draft is a major controlling factor in the spatial variation of the depth to water level zones. But the fact that the area of recharge in the hard rock domain shows deeper groundwater levels is also established.

Post Monsoon November 2013:

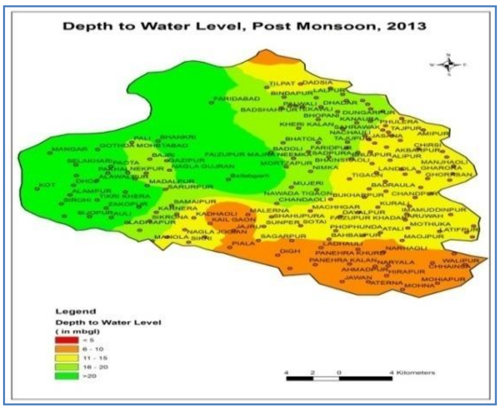


Fig-8 Depth to water level map (Post-Monsoon, 2013)

Seasonal Fluctuation in Water Levels (Pre and Post Monsoon)

The depth to water levels during the monitoring of the key wells in post monsoon period of the year 2013 was compared to the depth to water level values monitored during the pre-monsoon period of the year 2013. The point values for the fluctuation in the water level was noted and plotted on a map to obtain the water level fluctuation map of the district for the pre and post monsoon period of year 2013 [Fig-9]. The post monsoon observation of the depth to water level with respect to that of the pre monsoon for the year 2013 shows rise in the water level throughout the district. Maximum rise in water. While the area adjoining to Yamuna River have minimum rise within the range of 0-5 meters [Fig-9].

The small area around north of Faridabad town showing post monsoon rise in water level to the tune of 16-29 meters [Fig-9] could be on the account of localized recharge the surrounding areas and the natural recharge from the numerous stone quarries in the region around Pali, Mangar and Ankhirarea. The area covered in the above zone is barren with very little habitation. The analysis of the water table contour map shows convergence of the ground water flow to the areas showing significant post monsoon rise in the water levels [Fig-9]. As regards to the narrow strip along the Yamuna River and its tributaries showing post monsoon rise in the water levels ,the causative factor could be recharge from the water flowing through the Yamuna River system.

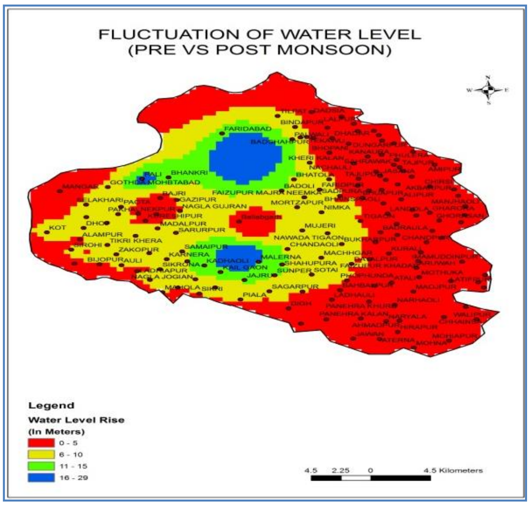


Fig-9 Groundwater level Fluctuation (Pre-Post Monsoon, 2013)

Groundwater flow

The water table contour map of the district has been prepared for the pre monsoon season of the year 2013 [Fig-10]. An analysis of the water table contour and the flow directions brings out the basic groundwater flow direction in the district. The region to the west of the Yamuna River have major cone of depression around Faridabad city area. Groundwater flows into this zone from the surrounding areas. This is caused by heavy abstraction for domestic use; it attracts groundwater flow towards it. The hydraulic gradient is comparatively steep in these depressions on the account of them being mostly in sweet water belt and on the fringes of the hard rock areas. The elevated ridge in the Ankhirarea and further western has emerged out as major areas of recharge with ground water flowing in the North East and East directions from it. The presence of depressions near Pali village located at western boundary of the district attracts groundwater flow in to these depressions [Fig-10].

The another cone of depression in Tekwali area [Fig-10] developed on account of heavy discharge from agricultural and farmhouses activity, attracts groundwater flow from all directions towards it.

Hydrograph

The ground water level monitoring data for Ballabhgarh monitoring station is available for last 20 years. The hydrograph analysis of this monitoring station [Fig-11.a] shows that decline in ground water level is continuous phenomenon. In the last 20 years there is a decline of 12 meters. This decline is directly linked with increase in groundwater draft due to increase in population. Similarly, Bhopani hydrogrpah [Fig-11.b] decline of 7 meters in last 12 years. Land use around Bhopani has changed from agriculture to urban area. This has resulted in increased groundwater draft for construction purpose and further leading to decline of water level.

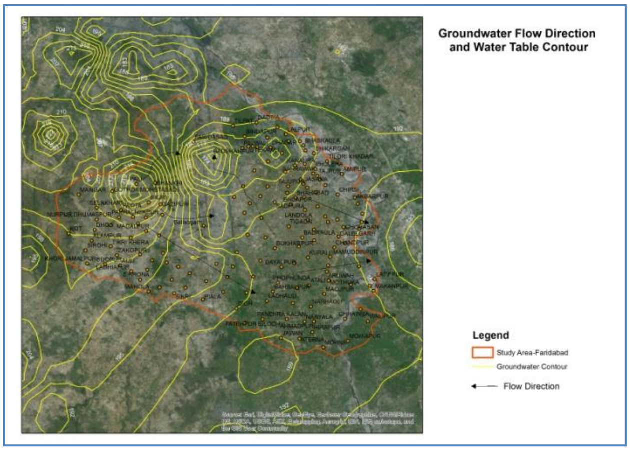
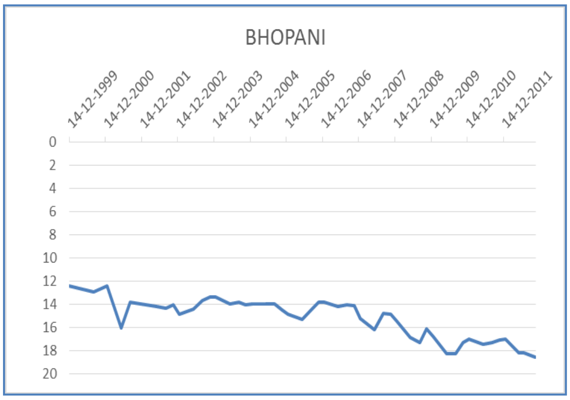
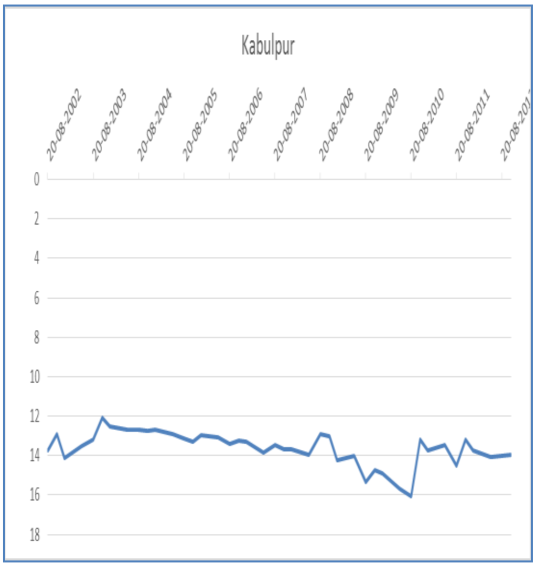


Fig-10 Water Table Elevation contour, Faridabad district

The close inspection of four hydrographs reveals that there is distinct pattern in hydrograph behaviour. Ballabhgarh and Bhoapni indicates sharp decline in water level because these monitoring wells lies in urban area. Whereas Kabulpur and Sikri water level is almost constant as these two well fall in rural/agricultural area. In urban area paved area restricts recharge whereas in rural area return flow from irrigation recharge the aquifer.



a.



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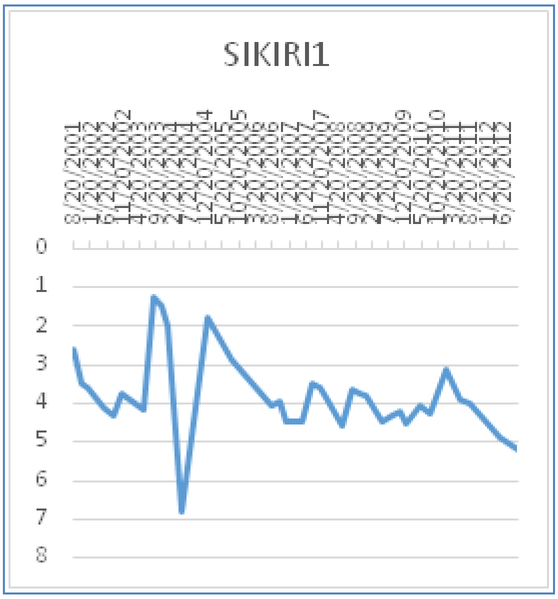


c.

Fig-11 Hydrograp of groundwater monitoring station

Model Design

Based upon the conceptual model outlined above, a numerical model was designed. The model code, input parameter values, and relationship to the conceptual model are described hereafter.

Model Domain& Model Grid

The model domain consisted of a grid of 80 rows and 80 columns. Total no of active cells and inactive cells were 3025 was 3325, respectively, covering an area of 728.42 square kilometres. The full model domain is depicted on [Fig-12].

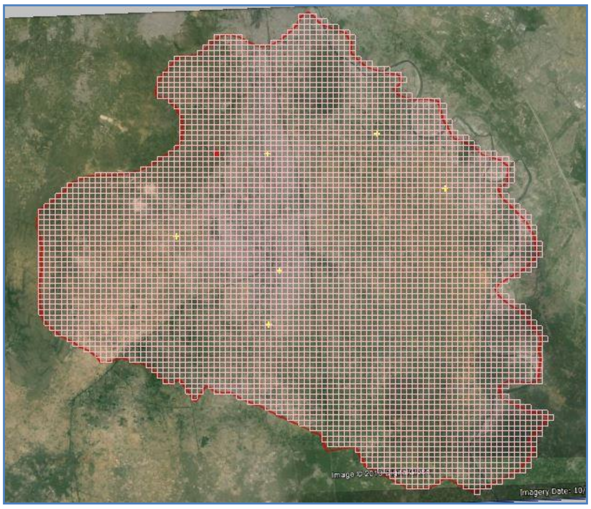
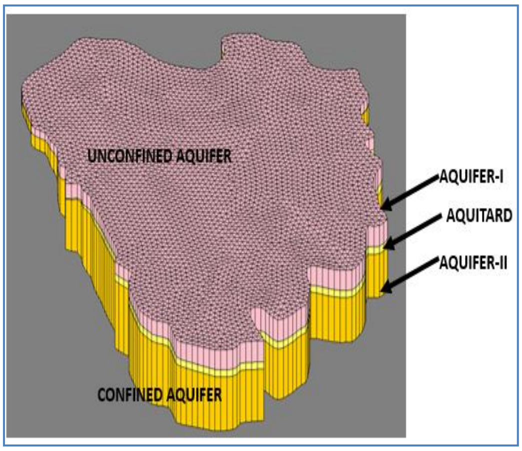
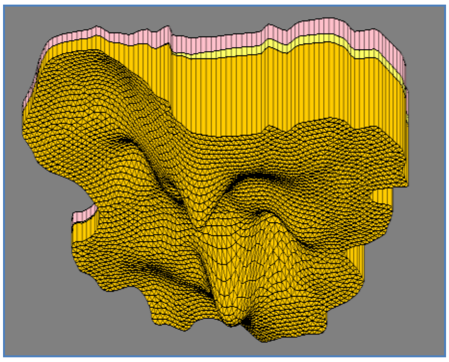


Fig-12 Model Design of the study area

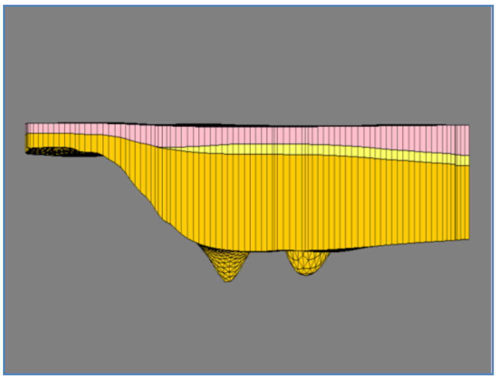
n a numerical groundwater model, the continuous groundwater flow field is approximated by a discretized domain consisting of an array of grid nodes and associated grid blocks. This nodal grid forms the frame work of the numerical model. MODFLOW uses a block-centered, finite-difference grid to simulate a continuous groundwater flow field (McDonald and Harbaugh 1988) [14]. With this method, the grid blocks are rectangular in shape and the grid nodes are located at the centers of the grid blocks. The model grid is a three-layer, uniformly spaced, finite-difference grid. The row and column spacing of the model grid are not uniform.



(a) Top view



(b) Bottom view



(c) Side view

Fig-13 Three-dimensional Aquifer geometry of Faridabad district

Number of Layers

The aquifer geometry is delineated based on litho log of exploratory well data [Fig-13]. It shows that there is two aquifers in the district separated by a clay layer. The thickness of Clay layer increases from West to East. Near aravali hill thickness of aquifer is minimum and maximum at Yamuna river. However, the data is available for phreatic aquifer. Hence, for the modelling purpose it is considered as single layer aquifer. The model consisted of a single layer representing the alluvium unit. The layer type was specified as unconfined. As such, the hydraulic conductivity of the layer were held constant throughout the simulations.

The model grid layers represent the single hydro-stratigraphic units identified during the development of the conceptual hydrogeologic model for the model area. The bottom elevation of the model layers are based on geologic logs of well borings in the model area and on adjacent properties. Two-dimensional IDW was used to interpolate the layer bottom elevations between well logs and to the edges of the model grid. The top elevation of this layer, which represents the water table, is calculated by MODFLOW during the model simulation period (McDonald and Harbaugh 1988)[14].

Flow Conditions

Flow conditions in Layer 1 (Shallow Zone) are simulated as unconfined (MODFLOW layer type LAYCON=1). The transmissivity of this layer varies during the model simulation period, and is calculated from the saturated thickness and hydraulic conductivity specified for the layer (McDonald and Harbaugh 1988) [14].

Boundary Conditions

Boundary conditions were selected based upon the requirement to simulate the conceptual model outlined previously and upon the results of preliminary modeling efforts.

Specified Head Boundaries

The eastern boundary i.e Yamuna river and a part of the western boundary (Aravali hills) of the active portion of the model consists of constant head cells. In the western boundary the head at these nodes was specified as 222 and 210 mamsl which was considered to be a realistic value for this location. This constant head boundary served two purposes: i) firstly, it provided a source or sink of water flowing into or out of the model domain from the western boundary of the study area, and ii) it satisfied the requirement that head be specified as constant for at least one node in order to give the model a reference from which to calculate heads (Anderson and Woessner. 1992) [1]. Based upon topography and surface water drainage patterns, the location of this constant head boundary likely approximates the general area of a groundwater divide.

The Yamuna river has been considered as constant boundary and it was linearly averaged from 194 to 189 m amsl between upper reaches to lower reaches.

Specified Flow Boundaries

North and South Boundaries

The north model boundary and a portion of the west model boundary consisted of no-flow boundaries located at distances which were determined to be sufficiently remote from the study area to minimize any boundary effects during transient (stressed) simulations (based upon preliminary modeling).

Top and Bottom Boundaries

The upper boundary of the model is defined by the upper surface of the till/bedrock unit and was represented as a specified flux boundary using MODFLOW's recharge package. In this way, recharge to the aquifer via downward flux from the overlying silts and clays was represented. It was recognized that this boundary would not simulate a leaky response under stressed conditions (due to possible leakage from the overlying silt/clay). However, allowing for such leakage in the model was not considered necessary since it would likely not have a large effect on the overall response of the aquifer. Furthermore, sufficient data was not available to support the simulation of this overlying layer (which would also result in an unjustified increase in the complexity, and associated uncertainty, of the model).

The lower boundary of the model was represented as a specified flux (no-flow) boundary.

Discretization of Time

The present groundwater flow model was run in steady state with a time period of 365 days.

Input Parameters

Model input parameters were selected based upon the following considerations: known or estimated aquifer properties alone (top and bottom elevations), trial and error calibration alone (riverbed conductivity), or parameter values were varied within a known range or a range believed to be reasonable and set at the value which yielded the best calibration (hydraulic conductivity, and recharge).

Hydraulic Conductivity

For 3D modeling, hydraulic conductivity is the most important hydraulic properties. Aquifer hydraulic conductivity was inferred from transmissivity values calculated from pumping test data. The transmissivity values were interpolated and divided by the aquifer thickness to arrive at the average horizontal hydraulic conductivity in each cell. The two zones for hydraulic conductivity were identified based on hydrogeology. Kx and Ky is assigned as 17 and 1 m/d for alluvium and quartzite, respectively.

No estimates of vertical hydraulic conductivity were available from either the aquifer pumping test analyses or available regional documentation. However, it was assumed that the ratio of horizontal to vertical hydraulic conductivity was at least 10:1 based on the presence of interlayer silty sands and clays noted in the boring logs.

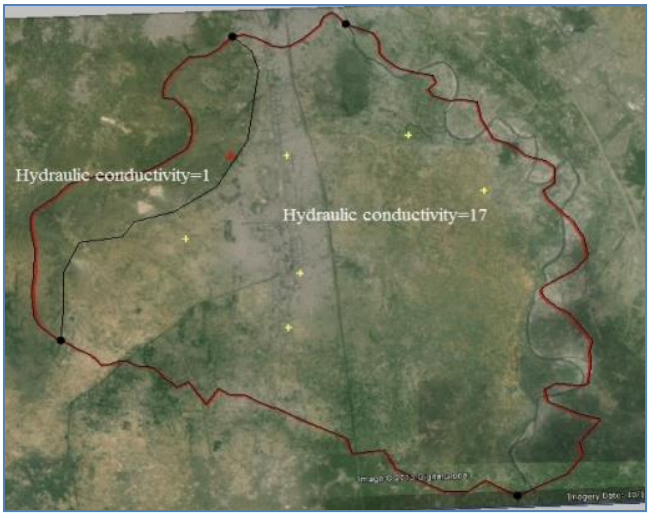


Fig-14 Hydraulic conductivity zones

Top and Bottom Elevations

The available data concerning aquifer top elevations (i.e. the top of the alluvial aquifer unit) was contoured in order to provide a representation of the top surface of the aquifer. The output from the contouring software was input directly to the MODFLOW pre-processor to define the layer top elevations array.

Recharge

The magnitude of indirect recharge to the aquifer through downward flux from the overlying alluvium was not known. A reasonable range for recharge values has been estimated using rainfall data from IMD data at 0.2 m/year. Consequently, recharge levels across the model domain were established through trial and error calibration of parameter values within this range.

Groundwater Draft

The aquifer in the district is stressed by groundwater abstraction through shallow tube wells (depth ranging from 20-40 m) and deep tube wells (depth >40 m). The groundwater draft is another source of uncertainty as in India groundwater draft by public is not monitored and poorly regulated. Draft data is available only for tube wells operated by MCF .Therefore, Groundwater draft data estimates have been taken from Ground Water Resource Estimation of Faridabad, 2009 due to non-availability data. Total discharge estimated from the shallow and deep tube wells is 125.69 MCM (unit draft 700 m^3/d). The draft from the shallow tube wells is distributed almost uniformly over the study area.

Model Calibration and Verification

For a groundwater model with reliable input parameters and stresses, the response is generally close to the observed field data. The disagreement in the model results may be due to either unreliable input data or wrong conceptualization or uncertainty in the stress periods. For example, hydraulic conductivity is determined by pumping tests and is point value. This may vary in space depending on the heterogeneity of the aquifer media. Therefore, calibration of the model parameters is thus necessary.

Traditionally, models are calibrated by trial-and error processes in which model parameters are adjusted within reasonable limits from one simulation to the next to achieve the best model fit. Model fit is commonly evaluated by visual comparison of simulated and measured heads and flows or by comparing root mean square (RMS) errors of heads and flows between simulations (Yaouti et al 2008) [7]. Models can also be calibrated using inverse methods, in which the optimal parameter values for a given parameter structure are determined using a mathematical technique, such as nonlinear regression (Cooley and Naff 1990) [3]. This technique is sometimes referred to as parameter estimation. Several parameter estimation codes existed at the time of calibration (Harbaugh et al., 2000; Hill et al., 2000; [9] Poeter and Hill, 1998[17]).

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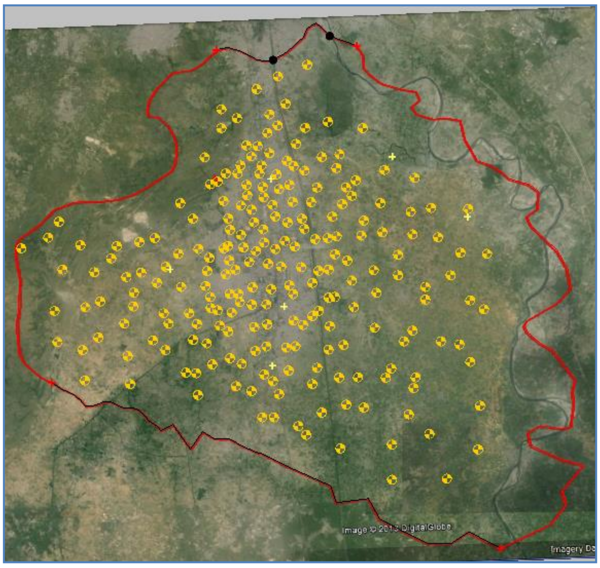

Fig-15 Distribution of pumping wells

Steady State Conditions

Calibration Values

Steady state simulations were calibrated to observed head values as measured on May 2013 [Fig-17]. Therefore, simulated heads beyond the main study area were for the most part calibrated on a qualitative basis only, based upon factors such as the observed trend in the local groundwater gradient and surface elevations.

The main source of error associated with these calibration values is considered to result from the fact that the data points used consist of wells with differing screen lengths completed at different elevations within the aquifer. It was estimated that this variation would translate to point of measurement elevation differences of approximately 10 metres. Therefore, the point of measurement uncertainty would account for an error in the hydraulic head calibration values.

Final Parameter Values

Calibration proceeded by trial and error using the parameter values or ranges of values described previously. Calibration followed an iterative process wherein steady state conditions was simulated. Since the pumping test did not produce sufficient draw downs at the monitoring locations to permit a quantitative evaluation of the model calibration, these stressed simulations were used as a qualitative check only. In this way, parameter values that produced a very significant difference between the calculated and observed responses could be modified, and the steady state simulation recalibrated.

Sensitivity analysis

To quantify the uncertainty of the calibrated model, a sensitivity analysis was performed. Hydraulic conductivity and recharge was object of the sensitivity analysis. For the sensitivity analysis, the values of the object parameters were increased/decreased sequentially within plausible ranges, and the effect on travel times and infiltration rates was examined. Sensitivity analysis was performed with changing the values of calibrated parameters (e.g., hydraulic conductivity and recharge). The results [Table-4] indicated that is more recharge sensitive than hydraulic conductivity in the present case. However, the model has been run using the calibrated parameters as it produced good results.

Table-4 *Sensitivity analysis- steady state simulation*

Parameter	Parameter Variation (+/- change)	Mean Error		Root Mean Squared Error		Mean Absolute Error		Effect
		(m)	(change)	(m)	(change)	(m)	(change)	
Hydraulic Conductivity (K)	+20%	0.73	725%	0.84	3%	0.89	25%	Small
	+50%	1.41	425%	0.93	7%	1.48	108%	Moderate
	+70%	1.74	250%	1.0	15%	1.78	151%	Moderate
Recharge (r)	+20%	-0.73	925%	1.01	16%	1.07	51%	Moderate
	-20%	0.82	950%	0.86	1%	0.95	34%	Small
	+50%	-1.89	825%	1.37	57%	2.01	183%	Large
	-50%	1.98	850%	1.09	25%	2	182%	Large

Model Validation

To check the validity of the model, computed water table heads are compared with field observed heads and a good match is found during pre-monsoon giving correlation coefficient (R^2) of 0.872.

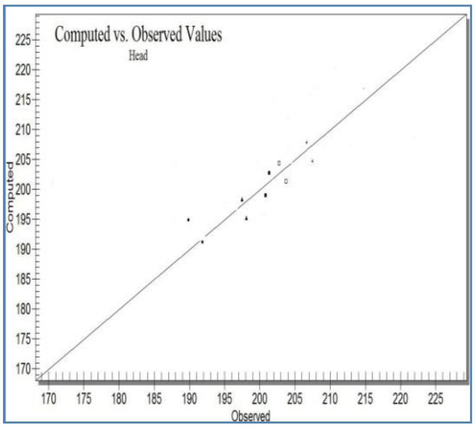

Fig-16 Observed versus calculated head

The computed groundwater table for 2013 after calibration revels that groundwater flow is west to east from Aravalis to towards Yamuna river. This map shows all the areas are having groundwater in aquifers. The groundwater depression is noticeable in Faridabad city due to heavy groundwater withdrawal. The villages like Pali, Mangar, Gothdamohbtabad and Bhankri shows diverging flow indicating it as recharge areas.

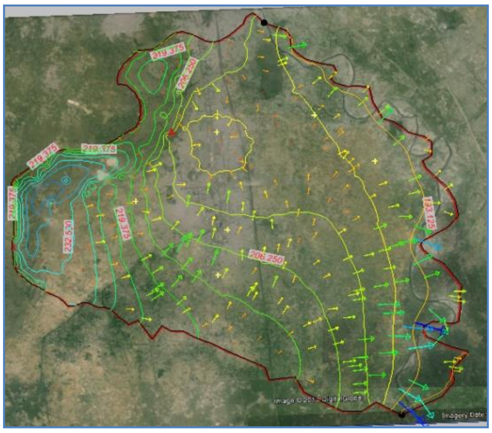

Fig-17 Computed water table (2013) after calibration and Groundwater Flow Direction

Water Level Prediction

Assuming that everything remains constant like rainfall, recharge rate and other hydrologic fluxes over the time except groundwater draft. Groundwater draft has been increased on the assumption that urbanization, increase in population and industrialization will result into increased groundwater draft. Accordingly, groundwater draft has been increased for 2025 and 2050. Model output for the same is shown in [Fig-18].

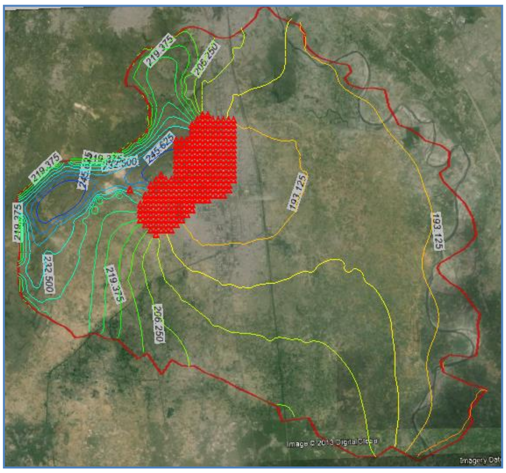

Fig-18 Groundwater table during 2025 (Red colour shows dry area)

The groundwater table map of 2025 [Fig-19] shows that Bhankri, Bajri, Ghazipur and Nagla Gujran will go dry and will be left without groundwater. These areas are marked by red colour (dry cells). In other areas the water table will keep declining but will be having groundwater.

Similarly, in 2050 the areas without any groundwater will include Faridabad, Sirohi, Fatehpur, Sarurpur, Tikri, Dhoj, Paota, Alwalpur, Alampur, and Zakopur.

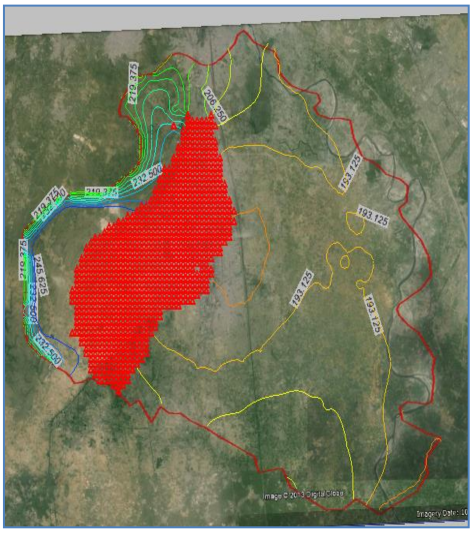

Fig-19 Groundwater table during 2050 (Red colour shows dry area)

Summary

Analysis of hydrograph of ground water monitoring wells shows significant decline of water level in last two decades. The continues decline in the groundwater levels from 1991-2012 is quite perceptible. It has been observed that there is significant continuous decline in the groundwater levels in most part of the district except a small patch at Kabulpur near Yamuna river area.The maximum decline of 12 meters in the last twenty years at the rate of have been observed in the Faridabad urban areas. It is to be noted that the area showing maximum decline rate is also the areas having maximum depth to pre monsoon water levels. Moving from the Yamuna Riverto west direction the rate of decline increases in the direction of the increase in elevation of the surface topography.

Hydrograph interpretation of groundwater monitoring wells in the alluvium has demonstrated that the alluvial aquifer in the District of Faridabad is subject to large variations in groundwater levels, which can be directly correlated to recharge and indirectly correlated to irrigation use. Water levels in monitoring wells adjacent to the Yamuna River respond to small amounts of rainfall and these wells also display a rapid response to a flood event. Analysis of hydrograph of urban and rural areas shows distinct pattern. Monitoring wells falling in urban area shows declining trend and response to rainfall recharge is delayed whereas in rural areas water level bounces back due to open uncovered land and return flow from irrigation. Fall in water level in rural areas is not as sharp as in urban areas.

The results from numerical groundwater modelling shows that the rate of increase if ground water draft will adversely affect availability of groundwater resources. The western part of the district comprising Bhankri, Bajri, Ghazipur, Nagla Gujran Faridabad, Sirohi, Fatehpur, Sarurpur, Tikri, Dhoj, Paota, Alwalpur, Alampur, and Zakopur, will face severe water shortage in 2025 and 2050.

Conclusion

Faridabad district is highly industrialized and urbanized. The groundwater is the only source to meet the drinking water requirement. Due to these groundwater resources of the study area is under stress and leading to decline in groundwater levels. Decline in groundwater level is more pronounced in urban area due to heavy withdrawal of groundwater. This is reflected in hydrograph analysis of long term historical water level data.The western part of the Yamuna River have major cone of depression around Faridabad urban area (Sector-21, 30 and 45) area. Groundwater flows into this zone from the surrounding areas. The presence of depressions near Sector-21, 30 and 45 area attracts groundwater flow in to these depressions. The another cone of depression in Badshapur area developed on account of heavy discharge due to change in land use pattern from agriculture to urbanization activity, attracts groundwater flow from all directions towards it. The elevated ridge in the western area near Khot, Mangar, Bhankri and Gazipur has emerged out as major areas of recharge with ground water flowing in the East and North East directions from it.

The future scenario of groundwater resources was evaluated using numerical groundwater modelling. The groundwater table map of 2025 [Fig-19] shows that Bhankri, Bajri, Ghazipur and Nagla Gujran will go dry and will be left without ground water. These areas are marked by red colour (dry cells). In other areas the water table will keep declining but will be having groundwater.

Similarly, in 2050 the areas without any groundwater will include Faridabad, Sirohi, Fatehpur, Sarurpur, Tikri, Dhoj, Paota, Alwalpur, Alampur, and Zakopur.

To arrest the declining groundwater resources it is necessary to replenish the groundwater resources. In order to assess the aquifer volume available for recharge GIS based analysis was carried out. Post Monsoon water level is used to estimate unsaturated thickness of aquifer, which is available for recharge. Water level more than 3 meter has been considered as maximum water level for recharge above this it will create water logging condition. The spatial analysis reveals that a total of 2561 MCM of volume is available for recharge during Pre Monsoon. During Post Monsoon, the volume is available for recharge is about 1839 MCM of. Thus, the total volume of natural recharge in the district is 722 MCM annually. About 978 MCM volume of unsaturated aquifer storage is available for recharge in rural area.

The rapid urbanization of the study area will aggravate dwindling groundwater resources and its sustainability. The future of the district vis-a vis fresh ground water availability is bleak. The need of the hour is sustainable and eco-friendly management of the fresh ground water resources available.

Conflict of Interest: None declared

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