SUSTAINABILITY OF SHALLOW AQUIFER BENEATH AN INTENSIVE AGRICULTURAL TRACK-A CASE STUDY FROM WESTERN UTTAR PRADESH, INDIA

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Groundwater is a primary resource for irrigation, domestic and industrial purposes in most of alluvial tracks of famous Indo-Gangetic plane in India. The study area is bounded by river Krishni and Hindon which forms a part of Ganga-Yamuna interfluves. Study shows over-exploitation has created an adverse impact on groundwater regime. The groundwater is being excessively abstracted from shallow aquifer, posing threat to its sustainability. Further, an attempt has been made to calculate various components of groundwater budget and to propose relevant management plans to curb prevailing groundwater situations. The methodology proposed by Groundwater Resource Estimation Committee (GEC 1997), with few additions, was adopted to compute the groundwater budget. Various inflows and outflows to and from the aquifer have been calculated. The recharge due to rainfall and other recharge parameters such as horizontal inflows, irrigation return flow and canal seepage were estimated. Groundwater withdrawals from the aquifer i.e. through direct pumpage and subsurface outflow were calculated. The result shows deficit groundwater budget. Total groundwater recharge is 185.13 million cubic metres (Mm^3), whereas the total groundwater discharge is 253.2 Mm^3. Thus, change in groundwater storage is -68.07 Mm^3 implies an excess utilization of 37% from aquifer in-storage. According to GEC'97, stage of groundwater development is 137% which categories the area into over-exploited category. Future deterioration is expected due to uncontrolled groundwater pumping and lack of surface water irrigation. Due to ease of accessibility and assured supply, groundwater has become backbone of agriculture based economy. Subsequently, groundwater depletion is likely to bring additional economic burden to its user as pumping from deeper levels requires more energy and maintenance. This study recommends introducing strict control on groundwater abstraction in order to manage the groundwater resources in the area.

Keywords: Groundwater budget; Irrigation return-flows; Over-exploitation; Management; Western Uttar Pradesh, India.

Introduction

Management of groundwater resources needs the knowledge of the reaction of groundwater system to outside stresses such as excess of groundwater abstraction. Such cognition is particularly vital in semi-arid regions, where natural recharge and discharge rate are often small; groundwater abstraction can rapidly change the behavior of the system (Elco and Bruggeman 2008).

Groundwater development has played a fundamental role in fuelling agricultural growth in many parts of the developing world (Giordano, 2006). Due to abstraction of large quantities of groundwater through pumping for irrigation and domestic uses, has threatened the sustainability of agriculture development. It has been concluded, therefore, that it is necessary to restrict the exploitation of groundwater to its availability (Marechal et al., 2002).

The sustainability of groundwater exploitation can be evaluated using water balance or groundwater modeling studies. The use of water balance approaches to determine sustainable pumping rates is embedded in groundwater legislation in many countries (Kalf and Woolley 2005).

The development and over-exploitation of groundwater resources in certain parts of the country have raised the concern and need for judicious and scientific resource management and conservation (Kumar, 2003). Overexploitation and mismanagement create adverse impacts on groundwater regime. Therefore, quantitative evaluation of groundwater resources of an area or basin is an essential pre-requisite for its management (Umar et al., 2008). An attempt has been made in the present work to calculate various components of the groundwater budget of Krishni-Hindon interstream region and draw conclusions relevant to groundwater management.

Study Area

Physiography and Climate

The study area lies in the western part of Muzaffarnagar district, bounded on the east by the Hindon river and on the west by the Krishni river. It lies between the latitude 29°05'N and 29°30'N and the longitude 77°20' E and 77°32' E and covers an area of about 650 km^2 (Figure-1). The whole area is fertile. Sugarcane is the principal crop of the area besides, few others crops are also grown. The drainage of the study area is mainly controlled by the two rivers i.e. Krishni and Hindon, flowing from north to south. The Krishni and Hindon rivers are the tributaries of Yamuna and both these rivers are perennial in nature. In general, both the rivers are mature, meandering rivers. The channel of Hindon is fairly deep and well defined. The elevation ranges from 256 to 224 m amsl. In general, higher elevations are

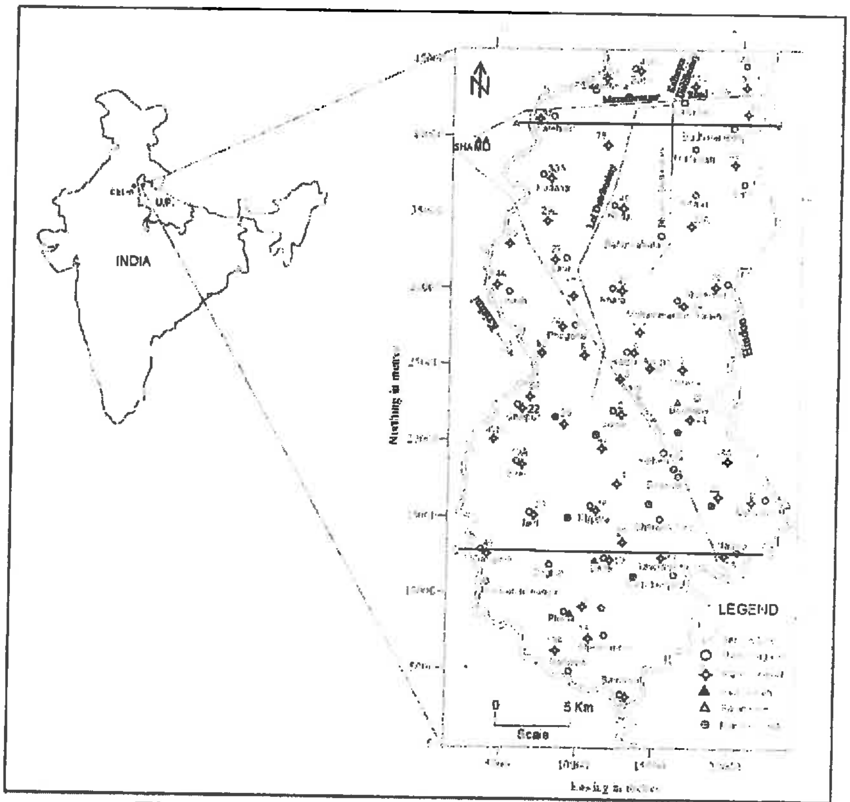

Figure 1 : Location map of the study area

towards the north, while lower elevations are encountered in the southern parts of the study area and along the Krishni and Hindon rivers, which form the boundaries.

The area savors a subtropical climate with very hot summer and fairly cold winters. The highest temperature, reaching up to 45^{0}C, is recorded during the month of June, whereas the lowest temperature of 4^{0}C is recorded during the month of January. The average mean daily temperature of the area ranges from 20°C to 32°C. Winds are generally light and only a little stronger in the summer and monsoon seasons. The area, on an average receives an annual rainfall of 588 mm and 697 mm at two raingauge stations. Rainfall is the main source for the recharge of the groundwater system.

Hydrogeological setting

The study area is a part of the Central Ganga Plain. The Delhi Supergroups forms its basement (Kumar 2005). The Delhi Quartzite, in turn, is overlain by Quaternary alluvium. The thickness of the alluvium is approximately more than 1 Kilometers. The alluvial deposits can be subdivided into older and younger alluvium. The latter is confined to river channels and the vicinity of the lowland areas. It is generally inundated by floods during the monsoon. The alluvium in the Krishni-Hindon interfluve region consists of alternate beds of sand and clay with occasional interbeds of calcareous concretions, locally known as *kankar*. Four distinct permeable granular zones occur within a depth of 450 m bgl (i.e. below ground level), separated by three distinct impermeable horizons. The granular zones lie in depth ranges of 1-185 m, 115-235 m, 235-329 m and 355-488 m bgl (Bhatnagar et al., 1982).

In the present investigation the first group of aquifer was studied in detail. Two hydrogeoloical cross sections were prepared on the basis of bore holes data drilled to a depth of 117 m. The section AB (Figure 2.2a) is an E- W section in the upper part of the study area showing a monostratum aquifer system. The top clay layer is persistent through out, though it varies in thickness from 29.5 m in the west to 33 m in the east. Underlying this clay bed is a granular zone which is approximately 65 m thick. In this granular zone, a number of clay lenses were encountered at variable depth. These clay lenses pinch out laterally, and therefore, the granular zone behaves as a single aquifer. Section CD, (Figure 2.2b) the southern most section in the area of study, shows the presence of many lensoidal bodies of sand within the thick clay layer occurring on the top of the section. These lensoidal bodies, evidently, have potential for being aquifers. The thickness of clay layer varies from 25 m in the west to 56.5 m in the east. As deciphered from the section (Figure 2.2b), this clay layer shows an irregular and some what zig- zag contact with the underlying granular zone showing the effects of palaeo-topography/differential weathering.

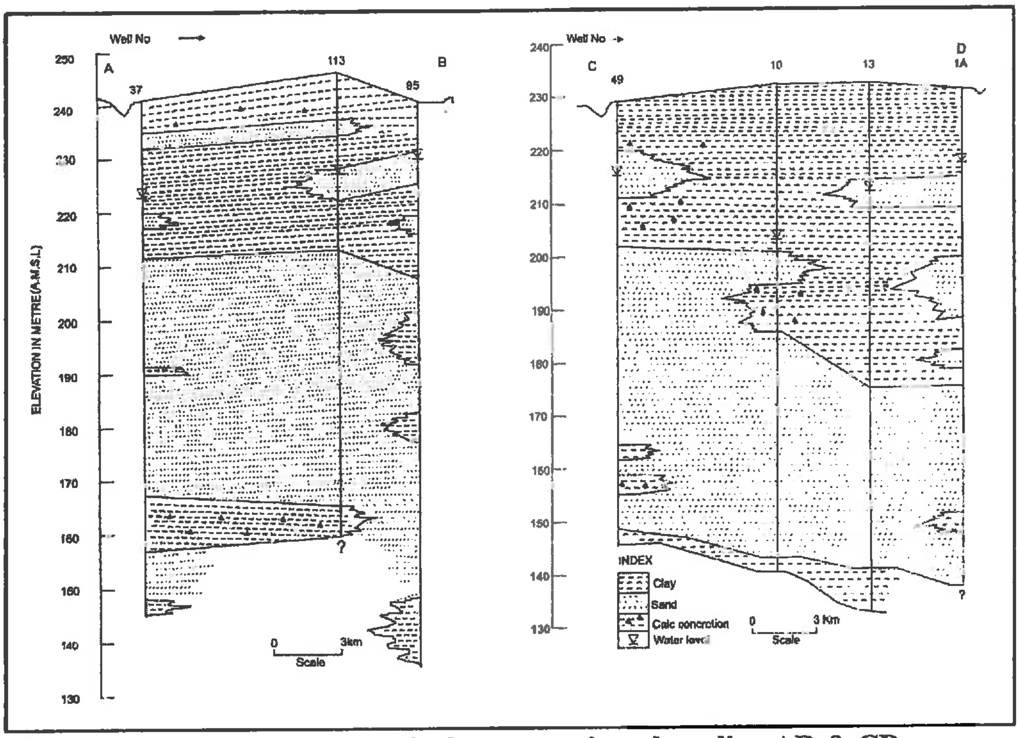

Figure 2 Hydrogeological cross section along line AB & CD

Underlying this clay bed is a single potential granular zone which extends to a depth of 54 m in the west and 38 m in the east. Minor clay lenses are present within the granular zone. There is small clay layer below the granular zone and which is thicker towards east.

Depths to water table during pre- and post-monsoon in 2006 range between 9.87 to 27.78 m bgl and 8.9 to 27.46 m bgl, respectively. Water table contour maps have revealed that the movement of groundwater is, in general, from north to south (Fig.3). Two significant groundwater troughs have been observed in the middle of the area at location Mohammadpur Raising and Lank. Evidently, these are persistent features and could have developed as a result of excessive and indiscriminate pumping.

Hydraulic gradient during pre- and post-monsoon periods has been estimated at 0.82 – 3.3 and 0.75 – 4.2 m/km, respectively. At places the gradient is rather steep. For example, it is 2.4 to 3.3 between Mohammadpur Raising and Barnawa. This seems to be related to excessive pumping.

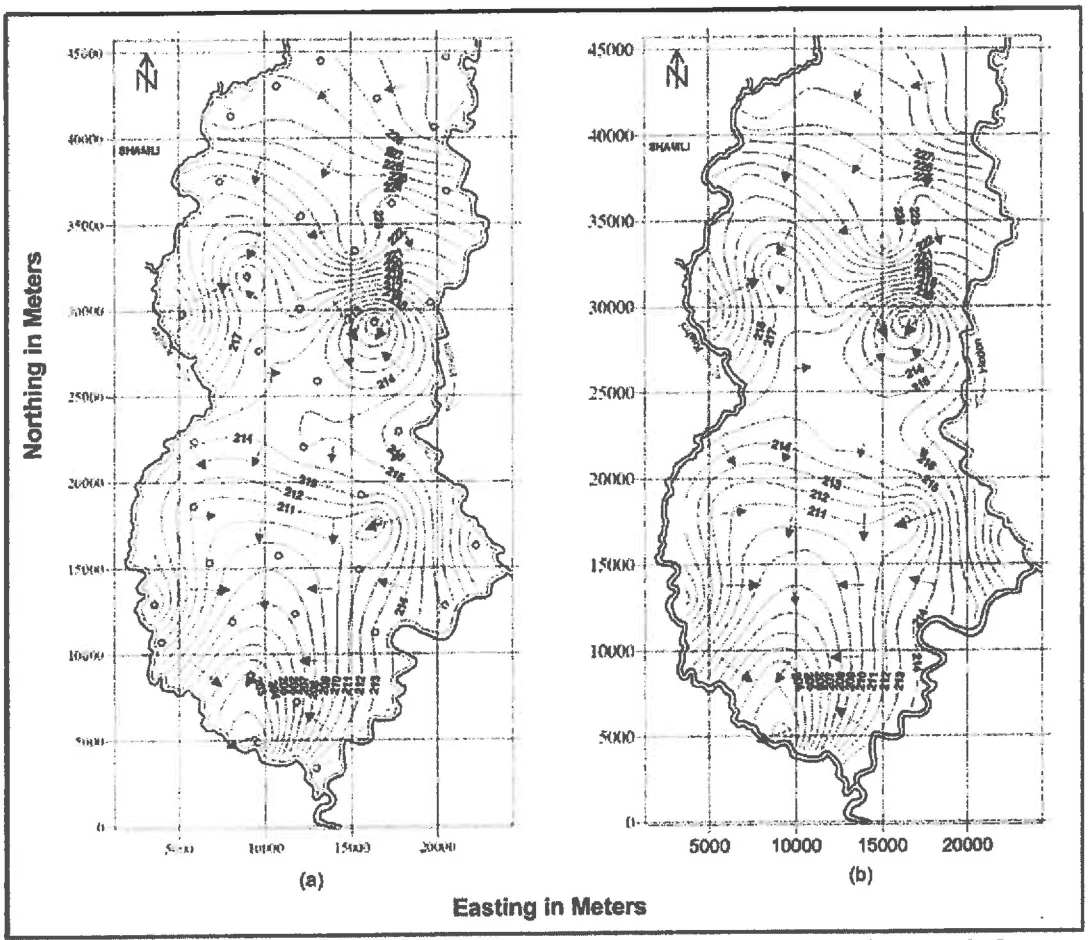

Figure 3 Water table contour maps of pre & post monsoon time period

Methodology and data collection

A systematic hydrogeological investigation was carried out in the study area. A network of uniformly spaced 39 monitoring wells was established for water level monitoring. The location of observation wells were marked with the help of GPS. Repeat measurements of water level were carried out during June and November 2006. The depth of the wells ranged from 20- 90 m. Water level in the study area has attained a declining trend (Fig.4).

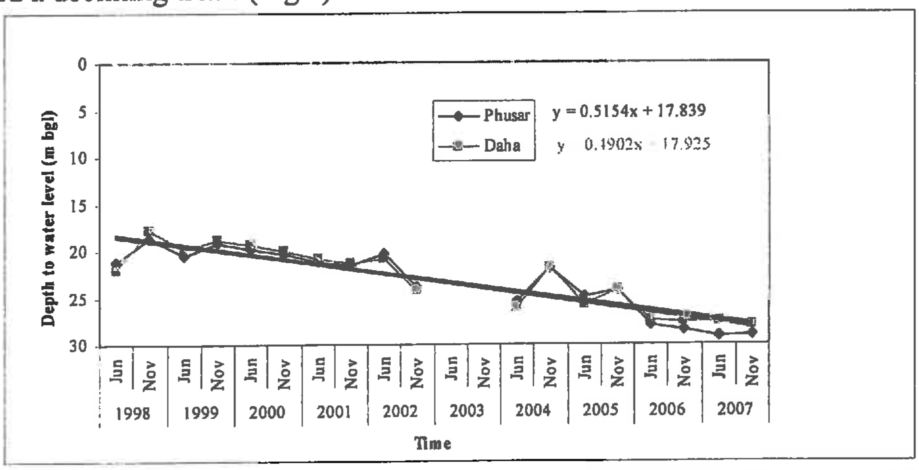

Figure 4 Hydrograph showing significant declining trend at Phusar and Daha

The Groundwater Estimation Committee 1997 (GEC 97) methodology is being adopted to compute the groundwater resources of the country in volumetric terms. The same methodology with few additions is utilized in the present study. Horizontal inflows and river aquifer interaction are included in groundwater budget in order to arrive at accurate results.

Components of groundwater balance

Groundwater recharge is important hydrogeologic parameter to be cautiously evaluated and applied for optimum groundwater development. The groundwater budget of an area focuses on the underground flows. Changes in subsurface water storage can be attributed to the recharge, irrigation return flow and groundwater inflow to the basin minus the base flow, evapotranspiration, pumping and groundwater outflow from the basin (Schicht and Walton, 1961).

The groundwater balance may be expressed in the form of equation which requires quantification of the components of inflow to, and outflow from a groundwater reservoir, as well as changes in storage therein and it is follows.

Input – Output = Change in Storage or

$$I - O = \pm\Delta S \qquad (1)$$

In the above equation, the terms input and output are used in the general sense, referring to all components of groundwater balance, which are either input to the unit i.e. recharge or output from the unit i.e. groundwater discharge.

The groundwater level fluctuation method is used for recharge assessment in the monsoon season. For non-command area, recharge in the non-monsoon season is a small component and may be estimated empirically. The monsoon season is taken as May/June to October/ November while the non-monsoon season, i.e. November/December to April/May. In the present study, the hydrological year has been defined as the beginning of June 2006 to the end of May 2007, which includes a monsoon and a non-monsoon period.

Estimation of groundwater recharge for the monsoon season

The water level fluctuation method is applied for the monsoon season to estimate the recharge. The groundwater balance equation for the monsoon season in non-command area is given by

$$RG-DG-B+IS+I=S \qquad (2)$$

Where,

RG = gross recharge due to rainfall and other sources including recycled water

DG = gross groundwater draft

B = base flow into streams from the area

IS = recharge from streams into groundwater body

I = net groundwater inflow into the area across the boundary (inflow-outflow)

S = groundwater storage increase

All quantities in Eqn.2 refer to the monsoon season only.

To signify the total recharge (RG) Eqn.2 can be rewritten as

$$R = S + DG + B - IS - I \qquad (3)$$

Where

R = possible recharge, which is gross recharge minus the natural discharge in the area in the monsoon season.

Substituting the expression for storage increase S in terms of water level fluctuation and specific yield, Eqn.3 becomes,

$$R = h \times Sy \times A + DG + B - Is - I \qquad (4)$$

Where

h = rise in water level in the monsoon season

Sy = specific yield

A = area for computation of recharge

R = 0.43x 0.15x 647.12+ 105.7+0- 4.2- 2.29

R = 140.95 million cubic meter (Mcum)

The specific yield value was taken from the pumping test carried out (Gupta et al., 1985) and it is assumed to be uniform in the entire study area. Here the base flow is zero, and the recharge from canal seepage is minimal, so it is added in the stream recharge in the above equation.

The recharge calculated from Eqn.4 gives the available recharge from rainfall and other sources for the particular monsoon season. For non-command areas, the recharge from other sources may be recharge from recycled water from groundwater irrigation, recharge from tanks and ponds and recharge from water conservation structures, if any.

The rainfall recharge is given by,

$$Rrf = R - Rgw - Rwc - Rt \qquad (5)$$

where

Rrf = recharge from rainfall

Rgw = recharge from groundwater irrigation in the area

Rwc = recharge from water conservation structures

Rt = Recharge from tank and ponds

Rrf = 140.95- 69.86

Rrf = 71.09 Mcum

Rwc and Rt are not applicable in the present study area.

The recharge from rainfall estimated as per Equation 5 is for particular monsoon season. Therefore, the total monsoonal recharge is added up all the monsoon components

R= Rrf + Rgw + IS +I

R= 71.09+ 69.86 + 4.2 + 2.29

R= 147.44 Mcum

Similarly rainfall recharge in the non-monsoon season may be estimated based on the rainfall infiltration factor which is given in Table 1.

Table 1: Non-monsoon rainfall recharge

Non-monsoon Rainfall (m)	Infiltration factor	Total area (km^2)	Rainfall recharge (Mcum)
0.08144	0.22	647.12	11.59

Inflow from irrigation returns

To evaluate the recharge from irrigation return flow to groundwater, the irrigated area and volume of water applied for irrigation are taken into consideration for working out the total volume of water applied. A large volume returns back to the aquifer by direct infiltration in the irrigated land. Seepage factor is based on the major cropping pattern it varies widely from 15 to 35% for the three major crops, i.e. Rabi, kharif and Zaid (GEC 97). Crop wise irrigation return seepage is calculated with the help of seepage factor for the crop in particular season (Table 2). The total quantum of the irrigation return flow is thus computed to be 89.0 million m^3.

Table 2: Seasonal crop wise irrigation return in the area

Crop type	Area irrigated (km^2)	Average wetted depth (m)	Irrigation water applied (Mcum)	Seepage factor (%)	Seepage (Mcum)
Monsoon					
Kharif	499	0.4	199.6	35	69.86
Non Monsoon					
Rabi	254	0.4	101.6	15	17.22
Zaid	33	0.4	13.2	15	1.98

Inflow from canal seepage

Recharge through percolation from canals depends on the infiltration capacity of the canal sub-surface lithology, extent of wetted perimeter, length of canal (Karanth, 1987). The wetted perimeter and total length of different canals were determined.

Canal seepage = length × wetted perimeter × total running days x specific loss.
The total canal seepage comes out 3.55 million m^3 (Table 3).

Table 3: Recharge due to canal seepage in the study area

Type of canal	Total length of canal (km)	Average wetted peri-meter (m)	Average running days		Seepage (Mcum)	
			Non monsoon	Monsoon	Non monsoon [Col. 2 x col. 3 x col. 4 x $20x10^{-2}$]	Monsoon [Col. 2 x col. 3 x col. 5 x $20x10^{-2}$]
1	2	3	4	5	6	7
Distributary	37.27	4.7	29	58	1.02	2.03
Minor	13.0	3.2	16	43	0.14	0.36

Estimation of Horizontal inflows across the boundaries

The Krishni and Hindon rivers may be regarded as hydraulically connected with the aquifer. To estimate boundary flows, the study area is divided into 21 grids such that the length and breadth of each grid is 5x1 km. The western and eastern part constitute river Krishni and Hindon, respectively. The horizontal inflow and seepage from streams was calculated with the help of grid pattern (Figures 3a and 3b). These flows are dependent on horizontal permeability, thickness of the saturated zone and local hydraulic gradient.

$$Q_{inf} = \sum_{i=1}^{n} Q_i = \sum_{i=1}^{n} T_i \times \frac{\Delta h_i}{\Delta l} \times \Delta w = \frac{\Delta w}{\Delta l} \sum_{i=1}^{n} T_i \times \Delta h_i$$

Where, Q_{INF} is the total inflow from north and stream recharge towards the study area, T is the transmissivity (m^2/day), $\Delta h/\Delta l$ is the hydraulic gradient, and Δw is the width of the grid (m). The trasmissivity values ranges from 720- 1820 m^2/day (Gupta et al., 1985). The specific value of "T" was used for individual grids depending upon the closeness of data point.

Applying and solving the above equation for each grid of uniform length and breadth. Where, $T_{i=1-n}$ = 720-1820 m^2/day and Δh_i refers to the change in hydraulic head at each grid.

$$Q_{Total} = \sum_{i=1}^{19} Q_{Is} + \sum_{i=20}^{21} Q_{inf}$$

here, Q_{Is} and Q_{inf} are stream recharge and horizontal inflow from north

$$= 11901.3+15056.25$$

$$Q_{Total} = 26957.55\ m^3/\ day$$

After solving the above equation for each grid of uniform length and breadth, the Q_{Total} can be obtained and given in table 4.

Table 4: Subsurface horizontal flows and stream recharge during monsoon and non-monsoon season

Inflows (Mcum)		Stream recharge (Mcum)	
Monsoon	Non-monsoon	Monsoon	Non-monsoon
2.29	3.21	1.81	2.53

Total annual recharge

The total annual recharge is obtained as the sum of recharge in the monsoon season and recharge in the non-monsoon season which is given in the table 5.

Table 5: Annual groundwater recharge in the study area (Mcum)

Area type	Rainfall recharge	Irrigation returns	Canal seepage	HIF	Recharge from stream	Total recharge
Non Command	82.68	89.06	3.55	5.5	4.34	185.13

Groundwater draft estimation

Groundwater draft is a key input in groundwater resource estimation. Groundwater discharge through pumpage is the major negative components (i.e., outflows) in the area. Evaporation from the water table and subsurface horizontal outflows are negligible and are not taken into consideration in this study.

In the present study, there are 124 state tube wells, 5886 private tube wells (electric) and 1574 private pump sets (diesel) in the area. The unit yearly draft for the above groundwater structures has been fixed by GEC 1997. The annual unit draft for state tube well, private tube wells (electric) and private pump sets (diesel) is 0.2, 0.037 and 0.0075 million m^3/y (Mcum/year), respectively.

The groundwater draft has been worked out by multiplying the total numbers of wells by unit draft for different season. Season-wise draft through pumpage for monsoon period (152 days) and non-monsoon period (213 days) is calculated separately and given in Table 6.

Table 6: Unit drafts for different Water extraction machine (Mcum)

Season	State Tube wells	Private tube wells (Electric)	Private pumpset (Diesel)	Total Draft
Monsoon	10.3	90.6	4.8	105.7
Non-monsoon	14.3	126.5	6.7	147.5

Groundwater Budget

The quantitative changes due to the difference between total inflows and total out flows from the aquifer may be expressed in a water balance equation based on law of conservation of mass (Karanth 1987).

The groundwater balance may be expressed in the form of the equation

$$I - O = \pm\Delta S$$

Where I is inflow that includes all recharge parameters and O is outflow which includes all discharge parameters. The term $\pm\Delta S$ is change in storage.

Substituting the values derived in the study in the groundwater balance equation give the following:

$$\Delta S = 185.13 - 253.2$$
$$\Delta S = -68.07 \;\; Mcum$$

This indicates that the study area has a negative groundwater balance for the period from June, 2006 to May, 2007, of the order of 68 *Mcum*. In other words, the system has been depleted by this much amount during the given period.

Conclusion and recommendation

The results of groundwater budget show that change in groundwater storage in area is -68.07 Mcum. The deficit balance implies that groundwater in the area is excessively pumped. The stage of groundwater development is 137%. Thus, it has reached to its maximum and area is categorized under critical/dark category. As rainfall serves as a major recharge component, irregularity or delay in the monsoon may lead to the scarcity of groundwater in the area. Further, continuous deepening of water levels is expected to have socio-economic impacts as more energy (say money) is needed to extract groundwater from deeper levels. Any perturbation in meeting water demand may lead to serious consequences on prevailing crop pattern and water buyer's community (basically poor or small land owners) may refrain from cultivating water intensive yet profitable crop.

It is clear that the situation has reached an alarming stage which is likely to deteriorate further in the coming years. Future deterioration can be expected due to yearly increase of groundwater abstraction and uncontrolled pumping. It is therefore clear that strict control on groundwater abstraction needs to be introduced in order to manage the groundwater resources in the area. The following remedial measures are suggested.

1 *Further groundwater developments*: The water balance results shows that the present rate of pumping may not be sustainable. Therefore no further groundwater exploitation should be allowed.

2 *Controlled abstractions:* In order to reduce total abstraction even the present rate of pumping has to be carefully controlled. It is recommended that a constant watch be kept on water levels in order to check the over drafting.
3 *Augmentation of water resources:* Suitable, measures for augmentation of groundwater resources may be adopted e.g. artificial recharge and rain water harvesting may ease the situation.
4 *Construction of recharge structure:* Percolation ponds and community tanks are the potential techniques for recharging the groundwater aquifer.
5 *Proper well spacing:* should be done to prevent the decline of water level and excess of withdrawal.

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