CHAPTER 7

GROUNDWATER BUDGET
GROUNDWATER BUDGET

7.1 GENERAL

The basic objective of groundwater resource evaluation is to estimate the total quantity of groundwater resources available, and their future supply potential to predict possible conflict between supply and demand and to provide a scientific database for rational water resources utilization (Earth Summit, 1992). Quantification of the available groundwater resources of an area is important for evolving a sustainable development strategy.

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 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. The management of aquifers raises a variety of difficult issues when these are being intensively used (Llamas and Custodio, 2003; Puri and El Naser, 2003). Consequently, judicious management implies increasingly more comprehensive management over a wider spatial extent (Howard and Gelo, 2003). 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.

Groundwater resource Estimation Committee 1997 (GEC 97) methodology with few additions is being utilized to estimate groundwater resources of inter-stream area.
7.2 COMPONENTS OF GROUNDWATER BALANCE

The groundwater resources in unconfined aquifers can be classified as static and dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage and influent seepage (Kumar, 2003).

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 (groundwater discharge to the rivers and springs), 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. The water level fluctuation method is based on the application of groundwater balance equation, which is stated in general terms as follows for any specified period

\[ I - O = \pm \Delta S \]  \hspace{1cm} (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.

Flows are of two types, inflows and outflows (Figure 7.1). The inflows are positive and contribute to the recharge of aquifer. The outflows correspond to water leaving the aquifer and thus relate to the discharge of aquifer. A simplified presentation of various inflow and outflow components is listed below.

7.2.1 Items of supply to groundwater reservoir

1. Precipitation infiltration to the water table
2. Canal seepages
3. Recharge from irrigation return flow
4. Ground water inflow into the area under consideration

\[ \text{THERESIS} \]
5. Recharge from surface water application
6. Recharge from tanks, ponds and groundwater recharge structures

7.2.2 Items of disposal from groundwater reservoir
1. Evaporation from capillary fringe in areas of shallow water table, and transpiration by phreatophytes and other plants / vegetation
2. Natural discharge by seepage to streams
3. Ground water outflow
4. Artificial discharge by pumping

Figure- 7.1 Simplified presentation of various inflow and outflow component

The heavy demand of groundwater sometime leads to excessive withdrawals and indiscriminate utilization which is often reflected in serious imbalance of hydrogeological situations at later date. It is, therefore, imperative to identify various recharges and discharge components of groundwater regime and their effect on its variation with time.

7.3 ESTIMATION OF GROUNDWATER RECHARGE
The evaluation of groundwater recharge parameters forms an important aspect of groundwater resources evaluation. It takes into account hydrometeorological and hydrological processes taking place on the surface and also involves sub-surface lithological characteristics (Baweja and Karanth, 1980). Various estimation of groundwater recharge in the country has been made (Rao 1970, Raghava Rao et al., 1969 and Pathak, 1982).
The techniques used for estimating groundwater recharge rates can be divided into physical and chemical methods (Allison 1988 and Foster 1988). The physical methods of the budget includes the:

(i) calculation of soil water balance by processing the hydro meteorological data and the soil crop data,
(ii) interpretation of hydrologic data including analysis of piezometric fluctuations and differential stream flow analysis and
(iii) soil physics measurement

The chemical method of groundwater recharge estimation comprises chemical and isotopic analysis of pore fluids from the saturated and unsaturated zones. The chloride mass balance method with certain conditions and assumptions has been found to provide reasonable estimates of groundwater recharge in semi-arid areas comparable to those obtained by physical methods (Woods and Sanford, 1995).

Tritium, a radioactive isotope of hydrogen is commonly used as a tracer in hydrological studies. The tritium injection method (Zimmermann et al., 1967; Munnich, 1968) assumes a piston flow model for movement of water infiltrating the vadose zone. It means that the soil moisture moves downwards in discrete layers. Several studies using tritium tracer were conducted in the alluvial aquifers of Indo-Gangetic Plain of Western Uttar Pradesh (Gupta et al., 1985; Goel, 1975; Rangarajan, 2006). The average estimated value for the rainfall recharge is 20.5% of the total rainfall.

The water table fluctuation method is a physical method of groundwater budget estimation and this method is most promising and attractive owing to its accuracy, ease of use and cost effectiveness for assessing groundwater balance in semi-arid areas (Beekman and Xu, 2003). Water table fluctuation method is applied to calculate recharge since this method takes into account the response of groundwater levels to groundwater input and output components.

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 northern part of the country receives 80% of rainfall in monsoon season. For purpose of recharge assessment using water level fluctuation method, the monsoon season may be taken as May/June to October/November for all areas. This
recommendation means that an additional period of one month after recession of monsoon is taken to account for the base flow which occurs immediately following the monsoon period but may not be utilized for groundwater development based on present practice. The rate of recession of water level is relatively rapid in the beginning, for a period of one and half months, after which the water level starts rising and reaches to maximum. It is therefore, recommended that the groundwater recharge may be estimated for monsoon period utilizing water level fluctuations.

The non-monsoon season, i.e. November/December to April/May would correspond to Rabi cultivation. Zaid period of cultivation is along with that of Rabi but for a smaller time period, i.e. from January to April. 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.

7.3.1 Estimation of groundwater recharge for the monsoon season in non command area

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

\[ RG - DG - B + IS + I = S \] (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

\[ R = S + DG + B - IS - I \] (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,
\[ R = h \times S_y \times A + D + B - I_s - I \]  

Where

- \( h \) = rise in water level in the monsoon season
- \( S_y \) = specific yield
- \( A \) = area for computation of recharge

\[ R = 0.43 \times 0.15 \times 647.12 + 105.7 + 0 - 4.2 - 2.29 \]

\[ R = 140.95 \text{ million cubic meter (Mcum)} \]

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,

\[ R_{rf} = R - R_{gw} - R_{wc} - R_{t} \]  

where

- \( R_{rf} \) = recharge from rainfall
- \( R_{gw} \) = recharge from groundwater irrigation in the area
- \( R_{wc} \) = recharge from water conservation structures
- \( R_{t} \) = Recharge from tank and ponds

\[ R_{rf} = 140.95 - 69.86 \]

\[ R_{rf} = 71.09 \text{ Mcum} \]

\( R_{wc} \) and \( R_{t} \) 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

\[ R = R_{rf} + R_{gw} + I_s + I \]

\[ R = 71.09 + 69.86 + 4.2 + 2.29 \]

\[ R = 147.44 \text{ Mcum} \]
7.3.2 Estimation of recharge during non-monsoon season

Almost 80-85% of the rainfall occurs in the monsoon period. However, some showers occur in the months of December to March too. The non-monsoon rainfall is scanty and low in magnitude but is of much importance for the Rabi crops. Though it imparts feeble effect on groundwater budget but needs to be considered.

7.3.2.1 Recharge from rainfall

The recharge from rainfall during the non-monsoon season may be estimated based on the rainfall infiltration factor provided the normal rainfall in the non-monsoon season is greater than 10% of the normal annual rainfall. If the rainfall is less than this threshold value, the recharge due to rainfall in the non-monsoon season may be taken as zero (GEC 97). The non-monsoon rainfall recharge is calculated by applying infiltration factor to the rainfall i.e. geographical area x non-monsoonal rainfall x infiltration factor, where infiltration factor is 0.22 (GEC 97) and 0.08144 is the non-monsoon rainfall in m for the year 2007.

Rainfall recharge in the non-monsoon season may be estimated based on the rainfall infiltration factors in Table 7.1.

<table>
<thead>
<tr>
<th>Non-monsoon Rainfall (m)</th>
<th>Infiltration factor</th>
<th>Total area (km²)</th>
<th>Rainfall recharge (Mcum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08144</td>
<td>0.22</td>
<td>647.12</td>
<td>11.59</td>
</tr>
</tbody>
</table>

7.4 RECHARGE THROUGH IRRIGATION RETURNS

The area is agriculture dominated and most of the crops grown require 4 to 5 flood irrigation. Therefore, it is important to account for the water that returns back to the aquifer system.

The groundwater is the major source of irrigation in the study area. The volume of pumped water, which rejoins the water table, constitutes the irrigation return flow. For example, rice cultivation requires large volume of water since it requires a few cm of standing water in the field and this results in a high return flow. Instances of more than 50% return flow have been reported (Jalota et al., 2002). The infiltration factor is dependent upon several factors including soil types and texture, depth to water table, types of crop and method of application of water. Although,
different crops and irrigation system give rise to different percentage as return flow but 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). Kharif crop would pertain to monsoon season. However rabi and zaid are sown in the non-monsoon season. Crop wise irrigation return seepage in the area has been calculated which is given in Table 7.2.

Table 7.2: Seasonal crop wise irrigation return in the area

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Area irrigated (km²)</th>
<th>Average wetted depth (m)</th>
<th>Irrigation water applied (Mcum)</th>
<th>Seepage factor (%)</th>
<th>Seepage (Mcum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kharif</td>
<td>499</td>
<td>0.4</td>
<td>199.6</td>
<td>35</td>
<td>69.86</td>
</tr>
<tr>
<td>Non Monsoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rabi</td>
<td>254</td>
<td>0.4</td>
<td>101.6</td>
<td>15</td>
<td>17.22</td>
</tr>
<tr>
<td>Zaid</td>
<td>33</td>
<td>0.4</td>
<td>13.2</td>
<td>15</td>
<td>1.98</td>
</tr>
</tbody>
</table>

The total quantum of the irrigation return flow is thus computed to be 89.06 Mcum.

7.5 RECHARGE THROUGH CANAL SEEPAGES

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. Data of total numbers of running days were collected from the District Irrigation Department.

Canal seepage = length × wetted perimeter × total running days

The seepage from various canals and distributaries are given in Table 7.3

Table 7.3: Recharge due to canal seepage in the study area

<table>
<thead>
<tr>
<th>Type of canal</th>
<th>Total length of canal (km)</th>
<th>Average wetted perimeter (m)</th>
<th>Average running days</th>
<th>Seepage (Mcum)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non monsoon</td>
<td>Monsoon</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Non monsoon [Col. 2 x col. 3 x col. 4 x 20x10⁻³]</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Distributary</td>
<td>37.27</td>
<td>4.7</td>
<td>29</td>
<td>58</td>
</tr>
<tr>
<td>Minor</td>
<td>13.0</td>
<td>3.2</td>
<td>16</td>
<td>43</td>
</tr>
</tbody>
</table>

Total recharge due to canal seepage is thus estimated at 3.55 Mcum.
7.6 ESTIMATION OF HORIZONTAL INFLOWS AND OUTFLOWS

Horizontal inflows (HIN) and outflows (HOUT) take place at the boundaries of the watersheds. Krishni and Hindon rivers may be regarded as hydraulically connected with the aquifer. Groundwater discharge in the form of horizontal outflow is the function of hydraulic gradient, but in this case it is negligible. Horizontal inflows and recharge from stream are, however, to be included in groundwater budget. In an alluvial area, the subsurface inflows are possible from every possible direction.

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 7.2a and 7.2b). These flows are dependent on horizontal permeability, thickness of the saturated zone and local hydraulic gradient.

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

where, $Q_{\text{INF}}$ 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 $\Delta w$ 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, $T_{\text{north}} = 720-1820$ m$^2$/day and $\Delta h_i$ refers to the change in hydraulic head at each grid.

$$Q_{\text{Total}} = \sum_{i=1}^{19} Q_i + \sum_{i=20}^{21} Q_{\text{INF}}$$

here, $Q_i$ and $Q_{\text{INF}}$ are stream recharge and horizontal inflow from north

$$= 11901.3 + 15056.25$$

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

110
Figure- 7.2a Horizontal inflows and seepage from stream (June 2006)
Figure- 7.2b Horizontal inflows and seepage from stream (November 2006)
After solving the above equation for each grid of uniform length and breadth, the $Q_{\text{Total}}$ can be obtained which serves as a component in groundwater budget estimation. The estimates of boundary flows are given in the Table 7.4.

Table 7.4: Subsurface horizontal flows and stream recharge during monsoon and non-monsoon season

<table>
<thead>
<tr>
<th>Inflows (Mcum)</th>
<th>Stream recharge (Mcum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsoon</td>
<td>Non-monsoon</td>
</tr>
<tr>
<td>2.29</td>
<td>1.81</td>
</tr>
<tr>
<td>3.21</td>
<td>2.53</td>
</tr>
</tbody>
</table>

7.7 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, where in each season, the recharge comprises of recharge from rainfall and recharge from other sources (Table 7.5).

Table 7.5: Annual groundwater recharge in the study area (Mcum)

<table>
<thead>
<tr>
<th>Area type</th>
<th>Rainfall recharge</th>
<th>Irrigation returns</th>
<th>Canal seepage</th>
<th>HIF</th>
<th>Recharge from stream</th>
<th>Total recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Command</td>
<td>82.68</td>
<td>89.06</td>
<td>3.55</td>
<td>5.5</td>
<td>4.34</td>
<td>185.13</td>
</tr>
</tbody>
</table>

7.8 GROUNDWATER DRAFT ESTIMATION
Groundwater draft refers to the quantity of groundwater that is being withdrawn from the aquifer. Groundwater draft is a key input in groundwater resource estimation. Groundwater discharge through pumpage is the major negative components (i.e., outflows) in the irrigated land. Evaporation from the water table and subsurface horizontal outflows are negligible and are not taken into consideration in this study. Discharge mainly takes place through pumpage by various groundwater structures.

Data of boreholes present in the basin was collected from District Statistical Report. Three types of bore wells were categorized on the basis of their yield. The State Tube Wells have a discharge rate of 1500 l/m. Private (electric) tube well
and private pump sets (diesel) have discharge rate of the order of 250 l/m and 60 l/m, respectively. In total, 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 Mcum, respectively.

The groundwater draft has been computed 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 estimated separately and given in Table 7.6.

Table 7.6: Groundwater draft through pumpage (Mcum)

<table>
<thead>
<tr>
<th>Season</th>
<th>State Tube wells</th>
<th>Private tube wells (Electric)</th>
<th>Private pumpset (Diesel)</th>
<th>Total Draft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsoon Season</td>
<td>10.3</td>
<td>90.6</td>
<td>4.8</td>
<td>105.7</td>
</tr>
<tr>
<td>Non-monsoon Season</td>
<td>14.3</td>
<td>126.5</td>
<td>6.7</td>
<td>147.5</td>
</tr>
</tbody>
</table>

7.9 TOTAL DRAFT

The value of total draft is calculated by summing up draft through pumpage from wells of all types, losses via evaporation and horizontal subsurface outflows. The estimates of groundwater draft are given in Table 7.7.

Table 7.7: Total draft in the study area (Mcum)

<table>
<thead>
<tr>
<th>Draft through pumpage</th>
<th>Evap</th>
<th>Outflow</th>
<th>Total discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>253.2</td>
<td>Nil</td>
<td>Nil</td>
<td>253.2</td>
</tr>
</tbody>
</table>

7.10 NET ANNUAL AVAILABILITY AND GROSS GROUNDWATER DRAFT

The total annual groundwater potential obtained for the unit refers to the available annual recharge after allowing for natural discharge in the monsoon season in terms
of base flow and subsurface inflow and outflow. This annual groundwater potential includes the existing groundwater withdrawal, natural discharge due to base flow and subsurface inflow and outflow in the non-monsoon season and availability for future development.

The existing gross groundwater draft for all uses refers to the total of existing gross groundwater draft for irrigation and all other purposes (GEC 97).

7.11 GROUNDWATER BUDGET

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:

\[ \Delta S = 185.13 - 253.2 \]
\[ \Delta S = -68.07 \text{ Mcum} \]

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.

7.12 STAGE OF GROUNDWATER DEVELOPMENT IN THE STUDY AREA

The stage of groundwater development in the study area is given in Table 7.8.

<table>
<thead>
<tr>
<th>Type of Area</th>
<th>Gross Groundwater Draft (Mcum)</th>
<th>Net Annual Groundwater Availability (Mcum)</th>
<th>Change in Groundwater Storage ± ( \Delta S ) (Mcum)</th>
<th>Stage of Groundwater Development (%)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-command area</td>
<td>253.2</td>
<td>185.13</td>
<td>-68.07</td>
<td>137%</td>
<td>Over-exploited</td>
</tr>
</tbody>
</table>
The results of groundwater budget show that change in groundwater storage in area is -68.07 Mm³. The deficit balance implies that groundwater in the area is excessively pumped. The stage of groundwater development is 137%. Thus, stage of groundwater development has reached to its maximum and area is categorized under critical/dark category. This, in turn, implies that or the decline of further groundwater development in the area should be executed with care, caution and restraint. The unplanned and massive groundwater exploitation, as observed today, is creating multifarious problems in the study area. The high concentration of shallow tubewells used by farmers is mainly responsible for the decline of water table in the area. Excessive and indiscriminate pumping has resulted in generating two troughs in western and eastern parts. The water level is going deep and deeper and most of the dugwells have dried.

As rainfall serves as a major recharge component, irregularity or delay in the monsoon also lead to the scarcity of groundwater in the area. It is recommended that a constant watch be kept on water levels in the dugwells and tube wells to check the overdrafting.

The stage of groundwater development is considered as the index of balance between groundwater available and utilization. As the stage of development is more than 100%, it indicates that potential for future development is meager. However, the assessment based on the stage of groundwater development has inherent uncertainties. The uncertainties lie with the estimations of groundwater draft and gross groundwater recharge. Moreover, there are limitations in the assessment methodology and always some uncertainties in the data.

### 7.13 LONG TERM WATER LEVEL TREND

The long term groundwater level trend of the area must be correlated with the water balance results. The long term water level behavior of the groundwater regime has been studied for two permanent hydrograph stations i.e. Phusar and Daha. A perusal of Figure 7.3 shows long term declining trend in the study area which is in accordance with water balance results.
7.14 INFEERENCE

The groundwater budget of the area shows that the total recharge is 185.13 Mcum and total discharge is 253.2 Mcum. Thus, the area is characterized by a change in groundwater storage by about -68 Mcum. The stage of groundwater development works out to be 137%, which put the area into over-exploited category.

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.