

# Management of water resources for sustainable agriculture in an irrigated semi-arid region of India

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## Abstract

Large-scale introduction of canal irrigation in arid and semi-arid areas has increased crop production; on the other hand it also intensified the process of secondary salinisation, which is causing universal concern because of its implication on food security and environment. The problem, however, is amenable to solution through implementation of suitable irrigation and groundwater management policies. The present study focuses on hydrological analysis and the estimation of seasonal net groundwater recharge for the study area, which is located in a semi-arid region of Haryana, India. The analysis showed that the rainfall in the area is quite variable particularly in the monsoon season and that the mean monthly reference evapotranspiration estimated for the study area showed a high inter-annual variation with values between 2.45 and 8.47 mm/d in the month of December and May, respectively. Groundwater recharge analysis revealed that rainfall is the main recharge component in monsoon season (65% of total recharge). Net recharge in the monsoon season is 129.2 million m<sup>3</sup>, whereas it is negative (-38.4 million m<sup>3</sup>) during winter season because groundwater abstraction by tubewell pumping is higher than the recharge. Thus, the study area has been receiving a groundwater surplus of 90.8 million m<sup>3</sup> during two crop seasons under the present cropping system. The increase in net recharge resulted in an annual groundwater table rise of 0.10 m in the study area over the study period of 13 years. Since water table in the area has been rising continuously, suitable water management strategies has to be suggested to bring the water table down to a safe limit and to prevent further water table rise to ensure sustainable agricultural production. Increase in groundwater abstraction by installing more tubewells and encouraging farmers to use saline groundwater in conjunction with fresh canal water could be one of the management options.

*Key Words:* Water management; Groundwater recharge; Waterlogging; Water balance

## Introduction

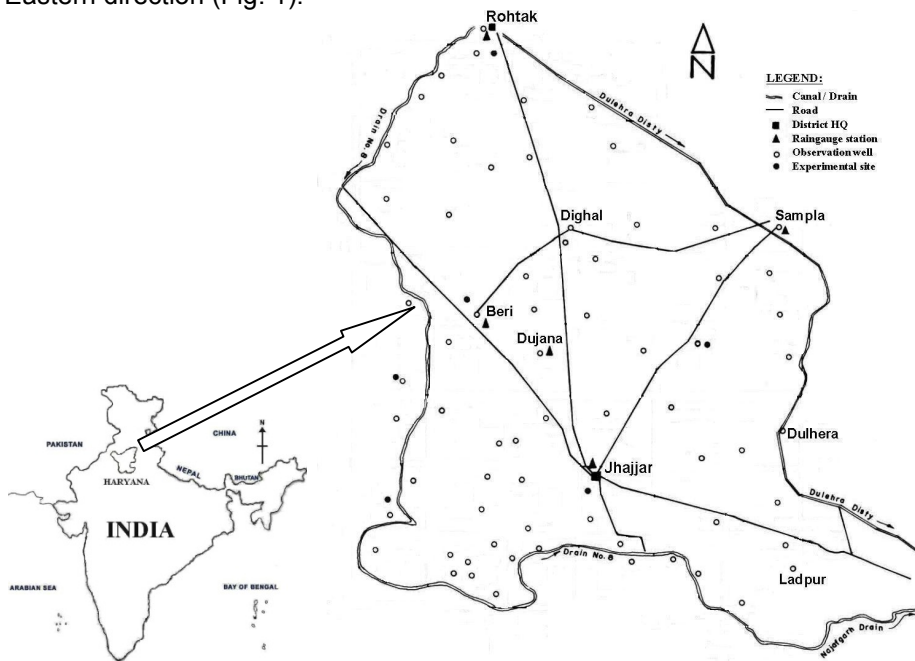
During the last few decades, the threat of soil and groundwater salinisation induced by irrigation has become a major issue in hydrology, agronomy, soil, and irrigation sciences (Tyagi, 1993; Kaledhonkar and Keshari, 2006). Because of its importance for food security and environmental conservation, water and salt balance studies have been receiving due attention at various research institutions worldwide (Kitamura et al., 2006; Rejani et al., 2008). More than 50% of the world's irrigated lands are affected by secondary salinization, sodicity, and/or water logging. In India, alone, 8.4 million ha are affected by soil salinity and alkalinity, of which about 5.5 million ha are, also waterlogged (Ritzema et al., 2008). Due to the 'Green Revolution' in India during 1970s, a continuous expansion of farmland (Abrol, 1999; Singh, 1999; Jhorar et al., 2009), and dual cropping on existing farm land occurred in north-west parts of the country, particularly in Haryana and Punjab (Abrol, 1999). This generated the need for more canal water use for irrigation as rainfall in the area is not sufficient to fulfil the crop water demand. Here the water table started rising and caused waterlogging and soil salinisation in western and central parts of Haryana State including Rohtak and Jhajjar districts where underground water is of poor quality (Boumans, 1988; Singh, 1999; Jhorar et al., 2009). It is estimated that about 500,000 ha of Haryana are waterlogged. In addition, the problem is spreading in more canal-

irrigated areas and creating hydrologic imbalances. Water losses from irrigation systems and non-exploitation of saline ground water are the major factors contributing to this phenomenon.

In this paper, we analyse the hydro-geological conditions of an area in Rohtak-Jhajjar districts of Haryana State, to provide an overview of the process dynamics that lead to imbalance of the system.

### Description of the study area

The study area lies in Haryana State of India between 28°30' N to 28°54' N latitude and 76°27' E to 76°54' E longitude and covers an area of about 92,000 ha. Administratively, the study area is distributed in two districts of Rohtak (24,783 ha) and Jhajjar (67,217 ha). The area is bounded by the Diversion Drain No. 8 flowing from North to South, which continued as Najafgarh Drain in South-Eastern direction and the Dulehera Distributary bounding the area in Eastern direction (Fig. 1).



**Figure 1.** Location map of study area with rain gauge stations and observation points.

The study area features semi-arid climatic conditions with a mean annual rainfall of 566 mm, about 75% of which is received from the south-west monsoon during July-September. A typical year features 36-40 rainy days. The mean temperature shows a wide range of fluctuation throughout the year with a maximum temperature around 46°C in summer (May-June) and a minimum temperature around 3°C, sometimes accompanied by frost during winter (December-January). The mean monthly weather parameters of the region are shown in Fig. 2.

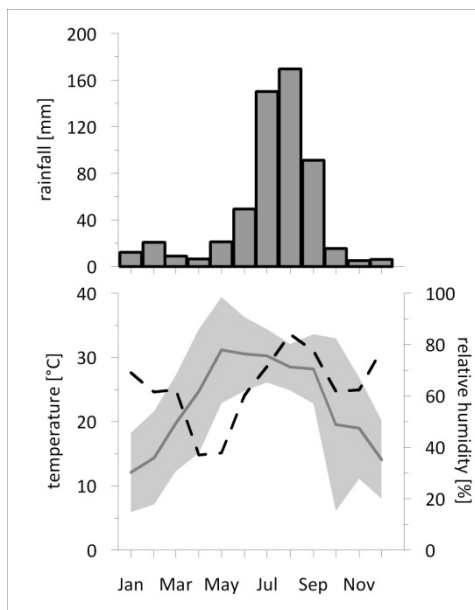
The soil type is mainly of sandy loam to fine loam. The hydraulic conductivity of the aquifer material ranges between 4.7 and 11.2 m/day. Specific yield varies from 0.09 to 0.17 (Rao et al., 1994) and soil porosity varies between 43.7 and 53.2%. Traditionally the year is divided into two principal crop seasons, *kharif* (monsoon, July-October) and *rabi* (winter, November-March). Wheat is the major crop in winter and covers about 81% in the season. Rice is the second major crop, which is grown in the *monsoon* season. Millets, sorghum, sugarcane, cotton, barley, mustard, pulses, vegetables, and fruits are also cultivated in the area. Cropping intensity in the area is estimated at 169%.

## Materials and methods

The general water balance of any area over certain time period can be written as:

$$(I + R + Q_{in}) - (ET + RO + IP + Q_{out}) - Q_w = \pm \Delta S \quad (1)$$

where I and R are the applied water on the ground surface through irrigation, and rainfall, respectively;  $Q_{in}$  and  $Q_{out}$  are lateral water fluxes into and out of a hydrologic system along a boundary; ET represents evapotranspiration losses in surface and subsurface waters, including the unsaturated and saturated zones; RO is surface water runoff; IP is intercepted rainfall by vegetation;  $Q_w$  is groundwater withdrawal through tubewells; and  $\Delta S$  is the change in saturated groundwater storage. Eq. 1 does not include unsaturated storage changes, because of its insensitivity to the mechanism by which water moves through the unsaturated zone (Healy and Cook, 2002). The units for all components in the water balance equation are in volume ( $m^3$ ) per time period. Difference of total and effective rainfall was taken as combined water loss through RO and IP (Gupta, 1983).  $\Delta S$  were calculated with the *net recharge*, as groundwater table and specific yield data were available. Due to the geological and topographical conditions, which form a natural depression in the centre, groundwater outflows are unlikely to occur. Therefore,  $Q_{out}$  was considered non-significant in this study, however, due to the same reason  $Q_{in}$  was considered significant. The groundwater inflows from the adjacent areas,  $Q_{in}$ , were estimated using Eq. 1. The data on weather, crops, soils, aquifer, canal, and tubewells were available from various State government departments and district administrations located in and around the study area. Different water balance components were estimated as follows.



**Figure 2.** Distribution of mean monthly values of minimum, maximum, and average air temperature (grey area and grey line), relative humidity (dotted line) and rainfall

### Rainfall data

Daily rainfall data for 34 years (January, 1975-December, 2008) at five raingauge stations located in the study area (Fig.1) were collected and analysed in terms of completeness and homogeneity. For every raingauge stations a weight was calculated with the Thiessen Polygon BALWOIS 2010 – Ohrid, Republic of Macedonia – 25, 29 May 2010

method.

The monsoon and annual rainfall data were statistically analysed. The relative departure was worked out as relative anomalies ( $A_i$ ), i.e. deviation from the long-term mean ( $\bar{R}$ ), of monsoon and annual rainfall ( $R_i$ ). These anomalies were calculated as:

$$A_i = \frac{R_i - \bar{R}}{\bar{R}} \cdot 100 \quad (2)$$

This analysis of the relative anomalies was carried out for monsoon and annual rainfall to test the uniformity of rainfall. Additionally, normal statistical parameters like variability or dispersion, standard deviation, and the coefficient of variation of the annual rainfall were computed.

### Groundwater data

Groundwater is abstracted through a number of both shallow and deep tubewells. In the present study, the water table data were obtained from the office of the Hydrologist. The groundwater levels were monitored through a network of 68 observation wells, distributed all over the study area (Fig. 1). The water table at the observation wells were monitored from 1989 to 2008 twice a year (June and October). The period of measurements coincided with the general trend of deepest (June – before rainy season) and shallowest (October – end of monsoon) water levels. The observations showed that the quality of groundwater is saline causing the tubewell waters to have an electrical conductivity (EC, a measure of the ionic capacity of a fluid) in the range of 2.0 to 20.74 dS/m. The average water table fluctuates from a depth of 1.02 m during monsoon to 3.98 m in summer season.

### Irrigation data

The study area is characterised by an extensive canal network, used for irrigation purposes. It is estimated that large parts of the cropped area in Rohtak (82%) and Jhajjar districts (49%) are irrigated by canal water. The distribution of the available canal water is regulated by the *warabandi* irrigation system which allows the owner of a certain plot to use the entire watercourse or field channel flow for a fixed duration of time proportional to the plot size (Kamra et al., 2002; Kumar and Singh, 2003). The discharges through all the major and minor canals that enter and leave the area were monitored twice a day (morning and evening) through stage measurements by the Irrigation Department during the course of the study. The average daily discharges through minor and major canals were recorded between 0.40 and 15.0 m<sup>3</sup> per second, while the canals run between 38- 69 days in each seasons during the study period. Information on private tubewells were collected village-wise and analysed on seasonal level for the entire study period. Local agronomic practices were followed for irrigation water requirement of each crop during both seasons.

### Effective rainfall

To obtain a good estimate of the effective rainfall for water balance calculation, the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) method (Dastane, 1977) was used, according to this method the effective rainfall ( $R_{eff}$ ) for rice and non rice crops were estimated from daily rainfall ( $R$ ) as:

$$R_{eff}(t) = 0.7 R(t), \text{ for non-rice crops} \quad (3)$$

$$R_{eff}(t) = 0.8 R(t), \text{ for rice} \quad (4)$$

### Crop evapotranspiration

In this study based on data availability, Hargreaves and Samani method (Hargreaves and Samani, 1985) was used for the estimation of reference evapotranspiration. This method

computes daily mean  $ET_0$  from extraterrestrial solar radiation and mean maximum and minimum air temperature as:

$$ET_0 = 0.0023 \cdot R_a \cdot (T_{avg} + 17.8) \cdot \sqrt{T_{max} - T_{min}} \quad (5)$$

where  $R_a$  is the extraterrestrial solar radiation (mm/d),  $T_{avg}$ ,  $T_{max}$  and  $T_{min}$  are daily mean, maximum, and minimum air temperatures ( $^{\circ}C$ ), and  $ET_0$  is the reference crop evapotranspiration (mm/d).

Using Eq. 5, daily  $ET_0$  were calculated, which showed a range between 2.45 (December) and 8.47 (May) mm/d. From the  $ET_0$  values, actual crop evapotranspiration ( $ET_c$ ) was estimated with crop coefficients ( $K_c$ ) using the following relationship:

$$ET_c = ET_0 \cdot K_c \quad (6)$$

Suitable  $K_c$  values for each selected crop were taken from the literature (Tyagi et al. 2000a, 2000b, 2000c; Allen et al., 1998 and Doorenbos and Pruitt, 1977).

### Net groundwater recharge

The seasonal net groundwater recharges were estimated using the norms (Gupta, 1983; Singh et al., 1984; Singh and Kumar, 1994), to estimate groundwater fluxes for the study area. This net recharge constitutes various recharges and discharge components, such as rainfall; seepage from main canals, distributaries, minors, and water courses; field irrigation losses; and pumping from tubewells. The net recharge determines to a large extent the water table tendency in the area and is the basis for the waterlogging/salinity and falling water table problems. Rainfall is the major source of groundwater recharge during the monsoon season, apart from rice-field percolation as nearly 60% of the total water applied on rice fields, percolates down (Tyagi et al., 2000a, 2000c). During the drier winter season with only little rainfall, seepage from canal networks is the main source of groundwater recharge. Canal seepage depends on canal length, wetted perimeter, and lining of the canal bed.

The net recharge in each season was calculated as the sum of the three recharge components and one discharge component. Watertable depths were calculated with seasonal net recharge. The calculated water table depths were compared with observed ones and plotted graphically for the entire study period. Further, in order to evaluate the methodology, statistical measures can be used to quantify the differences in the calculated and observed state variables i.e., groundwater tables. In this study, mean error (ME) (Ting et al., 1998; Rejani et al., 2008) and root mean square error (RMSE) (Fang et al., 2009) were used.

$$ME = \frac{1}{N} \sum_{i=1}^N (O_i - P_i) \quad (7)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (O_i - P_i)^2} \quad (8)$$

where  $N$  is the total number of the observations,  $O_i$  is the observed groundwater table of the  $i$ th observation and  $P_i$  is the calculated groundwater table of the  $i$ th observation ( $i = 1$  to  $N$ ). Additionally, a case is presented to study the exact effect of rice field percolation on watertable depth with change in rice area with existing canal water supply.

## Results and discussion

### Rainfall analysis

Based on the analysis of 34 years of daily rainfall data, the weighted average monsoon and annual rainfall were found to be 422 mm and 566 mm, respectively. The mean winter-rainfall was recorded to be only 61 mm. The analysis showed that rainfall conditions in the region are variable both in time and space. The comparison of the driest and wettest year out of 34 year BALWOIS 2010 – Ohrid, Republic of Macedonia – 25, 29 May 2010

long period showed a minimum annual rainfall amount of 236 mm in 1987 and a maximum of 1,001 mm in 1995. The largest positive relative departure of 77% from the long term mean annual rainfall occurred in 1995, whereas, year 1987 showed the largest negative relative departure of -58%. The standard deviation and the coefficient of variation (CV) of the annual rainfall were calculated at 184 mm and 0.33, respectively, while during the monsoon season the corresponding values were 178 mm and 0.42. The higher CV value in monsoon season indicates the larger variability of rainfall in this time of the year. Among the five raingauge stations, Jhajjar receives the largest mean annual rainfall of 688 mm, while Beri recorded the lowest (468 mm).

### Crop evapotranspiration

During the monsoon season, ET<sub>c</sub> values were estimated at 92.53 and 48.06 million m<sup>3</sup> for rice and sorghum, respectively, while for millet and cotton values were 36.12 and 35.19 million m<sup>3</sup>, respectively. The ET<sub>c</sub> for wheat and mustard was estimated at 194.66 and 8.81 million m<sup>3</sup>, respectively, in winter. Sugarcane is an annual crop; its ET<sub>c</sub> was estimated at 20.90 and 17.21 million m<sup>3</sup> during the monsoon and winter seasons, respectively. Based on above results, the total ET<sub>c</sub> was estimated at 234.86 for monsoon and 235.61 million m<sup>3</sup> for winter season.

### Net groundwater recharge

The analysis of different groundwater recharge components (Table 1) showed that deep percolation through irrigated fields is the major recharge component during monsoon season; it contributed 57% of the mean seasonal total recharge. The contributions of rainfall and canal seepage were estimated to be 33 and 10%, respectively. During winter season, canal seepage is the main recharge component with an average contribution of 55% in the total recharge of 42.2 million m<sup>3</sup> (Table 2). The average tubewell draft of 93.5 million m<sup>3</sup> resulted in a negative net recharge of -51.3 million m<sup>3</sup>. The net recharges in winter season were always negative due to higher tubewell draft in the season. However, the annual net recharges were always positive because of higher monsoon recharges which were not fully compensated by the higher tubewell drafts during winter. The analysis also revealed that the number of tubewells has an increasing trend during the study period. That can be seen from Tables 1 and 2, which show a steady rise in tubewell draft; however this draft is not enough to fully compensate the recharge accrued by other sources. Moreover the rice area, which is the major contributor in net recharge, has also been increasing

**Table 1** Net recharge components in monsoon season (million m<sup>3</sup>).

Year	Rainfall	Canal seepage	Deep percolation	Total Recharge	Tubewell draft	Net recharge
1989-90	38.8	19.8	87.5	146.1	38.6	107.5
1990-91	82.6	20.0	88.3	190.9	41.0	149.9
1991-92	66.6	18.8	89.1	174.5	43.6	131.0
1992-93	66.7	28.3	91.1	186.1	46.1	140.0
1993-94	96.5	20.6	101.3	218.4	48.6	169.9
1994-95	84.0	26.4	109.0	219.4	51.1	168.3
1995-96	159.3	18.9	115.9	294.1	53.6	240.5
1996-97	120.5	20.1	121.1	261.8	56.0	205.7
1997-98	55.3	23.3	125.6	204.2	58.6	145.6
1998-99	57.4	27.1	132.2	216.7	61.2	155.5
1999-2000	49.9	19.0	135.2	204.0	63.6	140.4
2000-2001	56.9	24.7	140.8	222.4	64.6	157.8
2001-2002	58.7	20.8	142.2	221.7	65.7	156.0
2002-2003	64.2	19.5	142.8	226.6	66.1	160.5
2003-2004	78.6	17.5	137.9	234.0	68.2	165.8

2004-2005	44.2	16.5	138.4	199.1	68.9	130.2
2005-2006	78.9	18.2	140.4	237.6	70.2	167.4
2006-2007	58.5	15.8	142.6	216.9	71.3	145.6
2007-2008	83.0	15.2	143.6	241.8	72.5	169.3
<b>Mean</b>	<b>73.7</b>	<b>20.6</b>	<b>122.4</b>	<b>216.6</b>	<b>58.4</b>	<b>158.2</b>

**Table 2** Net recharge components in winter season (million m<sup>3</sup>).

Year	Rainfall	Canal seepage	Deep percolation	Total Recharge	Tubewell draft	Net recharge
1989-90	13.8	22.6	11.5	47.8	58.7	-10.9
1990-91	17.6	24.3	8.2	50.2	62.9	-12.8
1991-92	6.4	25.6	4.2	36.2	67.3	-31.1
1992-93	7.0	20.8	3.7	31.5	71.6	-40.1
1993-94	9.8	23.7	4.9	38.4	75.8	-37.5
1994-95	11.8	26.4	7.8	46.0	80.2	-34.2
1995-96	2.2	25.3	3.0	30.5	84.5	-54.0
1996-97	17.6	23.0	9.0	49.6	88.7	-39.1
1997-98	18.3	20.1	13.0	51.5	93.0	-41.5
1998-99	19.8	18.8	10.5	49.1	97.4	-48.3
1999-2000	19.0	25.9	10.6	55.5	101.8	-46.3
2000-2001	3.9	27.5	11.2	42.6	103.0	-60.4
2001-2002	5.4	26.5	9.9	41.8	104.5	-62.7
2002-2003	9.8	23.2	11.2	44.2	107.6	-63.4
2003-2004	4.2	18.9	12.5	35.6	111.4	-75.8
2004-2005	7.5	19.8	11.5	38.8	113.6	-74.8
2005-2006	6.2	18.5	13.5	38.2	114.5	-76.3
2006-2007	5.4	19.1	10.9	35.4	116.3	-81.0
2007-2008	8.6	17.4	12.5	38.5	123.3	-84.8
<b>Mean</b>	<b>10.2</b>	<b>22.5</b>	<b>9.5</b>	<b>42.2</b>	<b>93.5</b>	<b>-51.3</b>

#### Groundwater table rise

The analysis of the groundwater balance showed that the study area is receiving a mean net recharge of 158.2 million m<sup>3</sup> during monsoon season, which resulted in an average groundwater table rise of 0.172 m in this period, whereas the negative average net recharge of 51.3 million m<sup>3</sup> during the winter season could bring down the water table by 0.056 m. Thus, in a year, it resulted to a net groundwater table rise of 0.116 m. Further, the rise in water table is partially contributed by specific hydro-geological and topographical conditions; the mean annual lateral inflows from the adjoining areas were estimated at 19.2 million m<sup>3</sup>, which contributed to a water table rise of 0.021 m taking the mean annual rise in the study area to 0.137 m. Thus, the contribution of groundwater inflows in the study area was at 15% of the total recharge. The entire situation leads to a continuous accumulation of groundwater in the study area, which kept the groundwater table rise. Long term monitoring of groundwater table provided evidence of this situation. Fig. 3 shows time-series of depth to water table in the month of June during 1989-2008. It shows the mean water table depths in 1989 and 2008 were at 4.12 and 1.72 m, respectively, which indicated a rise in water table by 2.40 m in a span of 19 years. However, out of 68 observation wells, the maximum and minimum water table rise was recorded at 4.39 and 0.87 m, respectively in particular wells during the study period. The calculated and observed water table depths were plotted and shown in Fig. 4. This can be seen that the calculated values reasonably match with the observed ones; this is also confirmed

statistically by the high regression coefficient of 0.987 and lower values of ME (0.0425) and RMSE (0.1061).

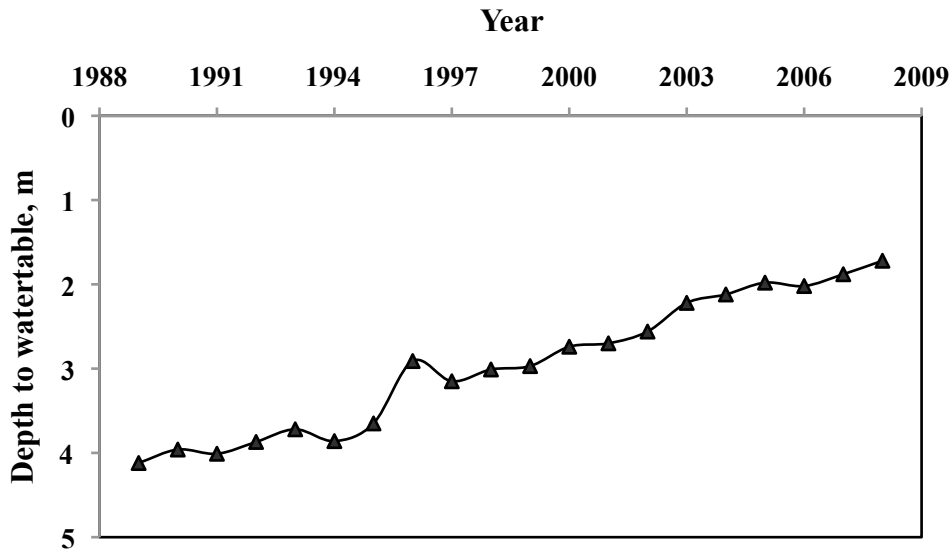


Fig. 3. Development of groundwater table in the study area from 1989 to 2008

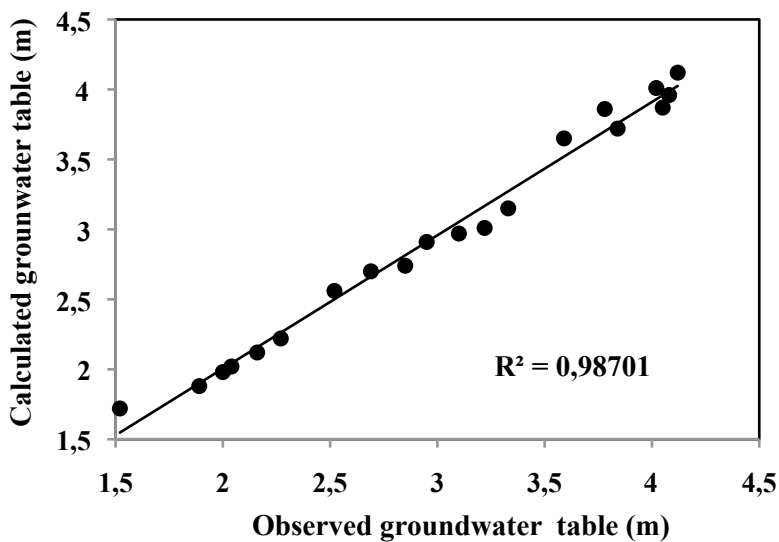


Fig. 4. Comparison between observed and calculated groundwater tables during the study period (1989-2008).

**Sustainability of rice-wheat cropping system**

Introduction of high yielding rice-wheat dual cropping system under Green Revolution in India is not suitable for the natural hydro-geological and topographical condition of the study region. Percolation through rice fields has increased recharge rate considerably during monsoon season. In winter season, parts of groundwater are used for irrigation with shallow groundwater pumping system. At present rice is grown in about 33% of the net cropped area in monsoon season; however, the contribution of rice crop in total field percolation is about 70%, i.e. out of

average percolation of 122.4 million m<sup>3</sup> (Table 2), 85.68 million m<sup>3</sup> was contributed by rice field, which leads to a water table rise of 0.09 m in study area during monsoon season. Thus, out of total annual water table rise of 0.137 m, more than two-thirds is contributed by rice field percolation alone. Fig. 5 shows that what is likely to happen with water table if rice area is doubled (+100%), halved (-50%), and if there is no rice crop (-100%) in the study area. This can be seen that the water table could have come at ground surface against the existing 1.72 m with +100% increase in rice area, on the contrary, a fall in the water table could be noticed with decreased rice area. The analysis revealed that if no rice crop were grown in the study area, the water table could have increased by only 0.69 m during the study period of 19 years against a rise of 2.4 m under existing cropping pattern. This comparative small rise of 0.69 m in water table can be fully compensated by installing more tubewells in study area.

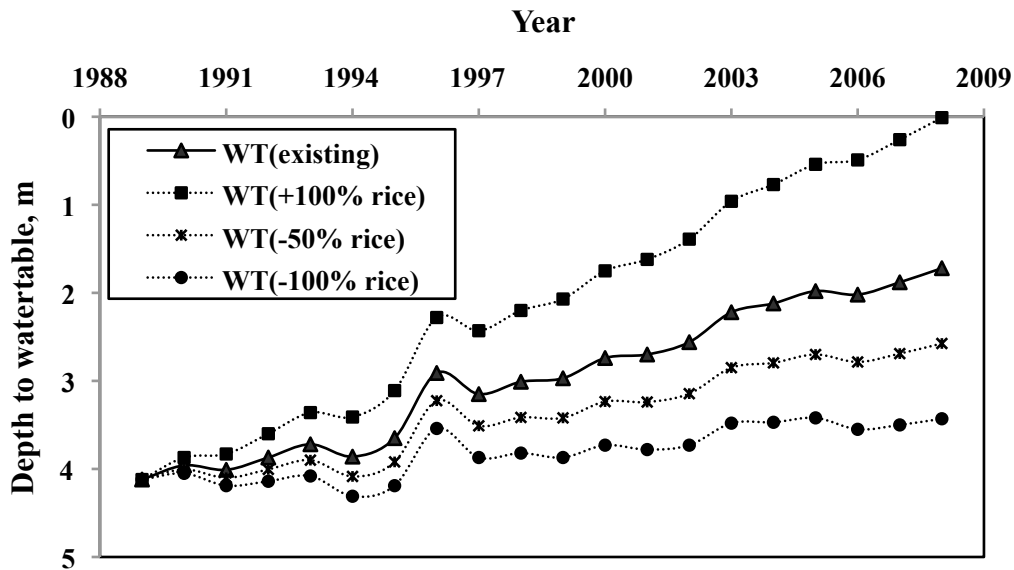


Fig. 5. Groundwater table behavior with change in rice area

### Conclusions and recommendations

Assessment of groundwater balance in the study area located in the Haryana State of India revealed that groundwater level is rising continuously, and high agricultural production potential cannot be sustained with the existing rice-wheat cropping system. Thus, a reduction in rice area against other crops is suggested, as it could reduce the percolation rates considerably. Moreover, a reduction of canal water release into the non-rice areas could also reduce net recharge to the aquifer.

Groundwater abstraction should be increased by installing more tubewells at new locations and encouraging farmers to use groundwater in conjunction with good quality canal water. More tubewell draft can compensate the groundwater inflows, particularly, if installed along the boundary areas. Salt tolerant varieties of crops should be introduced, as salt tolerant crops may be irrigated with poor quality groundwater thereby avoiding the undesirable effects of saline water on salt sensitive crops.

Water distribution and management strategies could be reconsidered. At present, canal water release pattern is governed by cultivable area rather than on water requirements of irrigated crops. Distribution of canal water based on spatially distributed crop water requirements could result in significant saving in groundwater recharge due to reduction in water losses in conveyance system.

The policymakers are suggested to implement the policies in such a way that it achieves long-term social goals rather than short-term economic returns.

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