

THE RELATIVE CONTRIBUTION OF PARAMETERS OF WATER BALANCE EQUATION TO RISING WATER TABLE PHENOMENON IN INLAND ALLUVIUM BASIN OF HARYANA, INDIA

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Abstract

Haryana state is located in the north-western part of India. By sub-dividing the state into eight ground water basins, Inland Alluvium basin (22.4% area of the state) is the largest ground water basin in the state. It covers the middle east, central and south-western saucer shaped depression of the state. This area is underlain by saline and brackish ground waters. It lacks adequate natural surface drainage outlet and its geo-hydrological conditions do not permit natural subsurface drainage.

Inland Alluvium basin is experiencing seasonal water logging, flooding after rainfall and secondary soil salinization problems. In view of these intricate problems, this study was aimed at identifying the most important factor to which the phenomenon of rising water table can be attributed.

In the present study, only irrigation (Irr), precipitation (Pr) and net lateral subsurface flow (Q_{ln}) were considered to be relatively independent parameters in water balance equation. The relative contribution of each of these parameters was evaluated from their functional relationship with average change in water table. In the study, the variance of Δh was accounted for more by precipitation (Pr) than other variables. That is, the relative contribution of precipitation to rising water table condition is higher than that of irrigation and net lateral subsurface inflow.

Keywords: Haryana state, Inland Alluvium basin, ground water basins, relative contribution, precipitation, net lateral subsurface flow, water balance, rising water table.

1 Introduction

Haryana state is located in north-western part of India between latitudes 24°35' and 31°55' north and longitude 74°23' and 77°36' east, covering an area of 44,212 sq. km. The middle east, central and south-western parts of the state (about 67% area of the state) is underlain by brackish and saline ground waters and lie in arid and semi-arid belts. The primary source of irrigation in the state is canal water as brackish ground waters inhibit their direct use for irrigation in most parts (Agarwal and Khanna, 1983).

Haryana state receives irrigation water from two distinct sources: the Bhakra Canal system and the Western Yamuna Canal system. These two main command systems supply water by gravity for about 88% of the irrigated area in the state. About 12% irrigated area is supplied water by lift irrigation schemes (Agarwal and Roest, 1996).

Canal irrigation in the state has boosted the crop production on one hand. On the other hand it disturbed the hydrodynamic equilibrium of the most parts, resulting in seasonal water logging and secondary salinization problems.

By sub-dividing the state into eight ground water basins, Inland Alluvium basin (22.4% area of the state) is the largest ground water basin in the state. It covers the middle east, central and south-western saucer shaped depression of the state. It lacks adequate natural surface and subsurface drainage outlet.

The canal irrigation in this basin has resulted in rising of water table leading to seasonal water logging, flooding and secondary soil salinization problems. These problems have resulted in reduction of crop yield and rendered a considerable area unfit for cultivation.

Therefore, in order to combat these serious problems for sustainable agriculture, an appropriate strategy based on integrated approach is needed. Keeping in view the above intricate problems, the present study was undertaken for a part of Inland Alluvium basin of Haryana state. The areas of two districts (Rohtak and Jhajjar) were comprised to know relative contribution of precipitation, irrigation and lateral subsurface flow to the fluctuation of ground water level.

2 Review of Literature

Literatures pertinent to this study have been cited under the headings of subsurface inflow and outflow analysis, water table fluctuation and geohydrological features of the study area.

2.1 Subsurface Inflow and Outflow analysis

The subsurface flow into or out of region is mainly governed by the hydraulic gradient and the transmissivity of the aquifer at its boundaries. It is generally worked out by making use of flow net technique.

Singh and Kumar (1982a) estimated subsurface inflow and outflow for the Government Farm at Hansi (Haryana) using average water table contour map and flow net technique. Singh and Kumar (1982b) conducted a study in the vicinity of flood plains of Sahibi river (Haryana) over an area of 73 ha from December 1976 through December 1979. They employed flow net technique to estimate the rate of subsurface inflow and outflow through the boundaries of the area.

2.2 Water Table Fluctuation

Studying the water table fluctuation of an area is an essential step to understand the relative causes of drainage problems and its surrounding.

In Haryana, in the fresh ground water areas (north eastern and south eastern parts) water table is declining constantly while in saline or brackish ground water areas (middle east, central and south western parts) water table is rising at an alarming rate (Agarwal and Khanna, 1983).

Gupta (1985) reported that water table in Rohtak district had been rising at the annual rate of 0.6 m in deep water table areas. It had been rising of 0.08 m in shallow water table areas following the introduction of canal irrigation. He pointed as years of rise and fall of water table in these areas were related with high and low rainfalls, respectively.

Singh (1985) studied water table fluctuation for Government Farm at Hansi (Haryana) which is adjacent to the study area. In his study it was found that the water level had reached to the surface during three to four months period depending on the rainfall during monsoon.

Agarwal and Kumar (1998) reported that nearly 50 per cent of the area of Haryana state was afflicted with serious problems of rise in water table, mostly the area falling in the districts of Rohtak, Jhajjar, Jind, Bhiwani, Hisar, Sirsa and Sonapat.

2.3 Geohydrological Features of the Study Area

Haryana is mainly a part of the alluvial Indo-Gangatic plain. The alluvial areas in the state form unified, highly transmissive aquifers in which ground water occurs, for the most, under water table condition (Garalapuri and Duggal, 1974). In Haryana state, ground water predominantly flows from north-east to south-west. In the

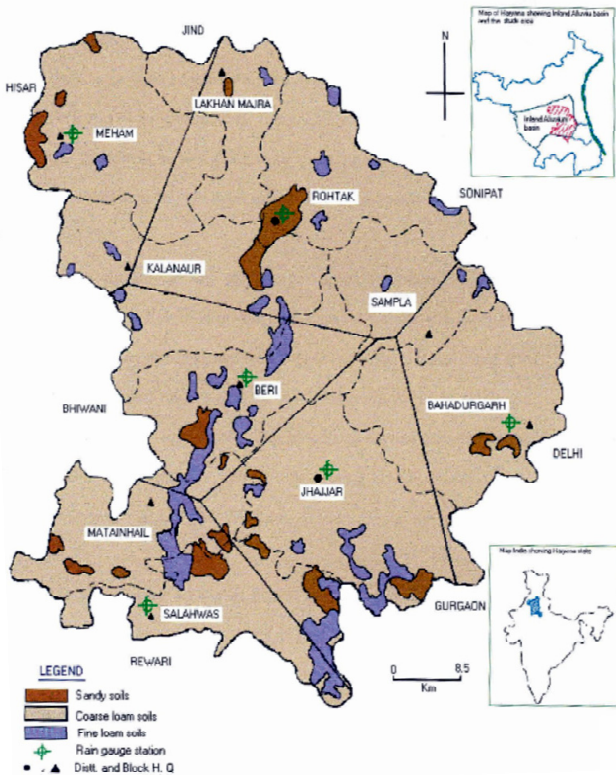
further south-west the flow is from south to north-west indicating the convergence of ground water flow in the Inland alluvium basin (Singh, 1998).

3. Materials and Methods

3.1 Description of the Study Area

Inland Alluvium basin covers the central east, central and south-eastern saucer shaped depression of Haryana state. A part of Inland Alluvium basin, located between 28°23' and 29°6' N latitude and 76°13' and 76°58' E longitude with an area of 3469 sq. km was selected for the study. The selected area comprises the entire area of Rohtak and Jhajjar districts.

The dominant soil type in the study area is coarse loam (85.42%), followed by fine loam (9.51%) and sandy (5.07%) soils (Goyal *et al.* 1996). Fig.1 shows the map of major soil types in the study area.



Figur 1 Map of major soil types along with Theison polygons fitted for the influence areas of gauge stations in the study area (after Goyal *et al.* 1996).

The northern parts of the study area slopes towards south-west up to the low land that stretch from north-west to south-east through centre of the area. However, there are slightly undulating surfaces at the south-western part from the low lands. But from farthest south-west the surface slopes towards north-east and the eastern

parts of the study area slope towards south-east. The study area is, thus, a closed basin with flow converging towards the center except from the eastern and east-southern parts.

The climate of the study area is of sub-tropical, semi-arid, continental and monsoon type with prolonged hot period from March to October. The south-western monsoon brings rain from July to September, contributing 71 to 78 per cent of total annual rainfall over the area. From October to mid April, except for a few light showers due to western depressions, the weather remains dry and cold (Goyal *et al.*, 1996). The average annual rainfall over the study area in the last 25 years (1976-2000) ranged from 356.23 mm to 639.24 mm.

The study area and its surrounding form unified aquifers in which ground water exists under water table condition (Garalapuri and Duggal, 1974) and it has no open water course which crosses or borders except the irrigation canals.

3.2 Data Collection

For an area facing land-drainage problems collection of relevant data at an appropriate level of detail and subsequent analysis and interpretation of these data need to be attempted before formulating possible alternative strategies to combat the problems. For the present study, the geohydrological, rainfall and irrigation input data of the area were collected from various state- and central-agencies involved in recording and exploration of the details.

3.3 Data Analysis and Interpretation

3.3.1 Water Balance

The general form of water balance equation which is basically a statement of conservation of mass which is expressed as:

$$I - O = \Delta S \quad \dots\dots\dots 1$$

where, I = Inflow to the system
 O = Outflow from the system
 Δ S = Change in storage

was used. Considering various inflow and outflow component of unsaturated and saturated zones of the soil systems in the study area, the following more informative forms of water balance equations were used.

For unsaturated zone:

$$(Pr + Irr - R.off) - ET_a - (Perc - Cap) = \Delta S_{sm} \quad \dots\dots\dots 2$$

For saturated zone:

$$(Perc - Cap) + (Q_{inf} - Q_{dr}) + (Q_{up} - Q_{do}) + (Q_{lsi} - Q_{lso}) = \Delta S_{gw} \quad \dots\dots\dots 3$$

where,
 Perc = Percolation of water towards the water table
 Cap = Capillary rise from the ground water table into
 Pr = Precipitation
 Irr = Irrigation water supplied to the area
 R. off = Runoff from the study area
 ET_a = Actual evapotranspiration
 Q_{inf} = Seepage from surface water bodies
 Q_{dr} = Outflow of ground water into surface water bodies
 Q_{up} = Upward vertical flow of ground water entering the unconfined aquifer
 Q_{do} = Downward vertical flow of ground water leaving the unconfined aquifer
 Q_{lsi} = Lateral subsurface inflow from adjacent areas
 Q_{lso} = Lateral subsurface outflow to adjacent area
 Δ S_{sm} = Change in soil moisture storage
 Δ S_{gw} = Change in ground water storage

Under present investigation, parameters of water balance equation were estimated considering the time interval to be from June 1st to May 30th with the following assumptions.

Assumptions

Overland inflow from the surroundings to the study area is negligible.
 Change in soil moisture content over a period from June 1st to May 30th is negligible.
 With the above assumptions and prevailing conditions of the study area, the following components of water balance equations will vanish.

$$\begin{aligned} (Q_{inf} - Q_{dr}) &= 0 \\ (Q_{up} - Q_{do}) &= 0 \\ \Delta S_{sm} &= 0 \end{aligned}$$

Then equations 2 and 3 will reduce to:

$$(Pr + Irr - R.off) - ET_a - (Perc - Cap) = 0 \dots\dots\dots 4$$

and

$$(Perc - Cap) + (Q_{lsi} - Q_{iso}) = \Delta S_{gw} \dots\dots\dots 5$$

By solving for (Perc - Cap) from equation 4 and substituting it in equation 5 we get

$$(Pr + Irr - R.off) - ET_a + (Q_{lsi} - Q_{iso}) = \Delta S_{gw} \dots\dots\dots 6$$

3.3.4 Subsurface Inflow and Outflow

Subsurface inflow and outflow from the area were worked out by making use of flow net technique. The average water table contour maps for the period from June to May were drawn by using the computer program (SURFER).

Similarly, the contour map of the underlying impervious layer of the aquifer in the study area was prepared based on the geophysical information of exploratory bore holes.

Flow lines, approximately perpendicular to the average water table contour lines, forming nearly squares, were constructed by free hand along the boundary of the study area (Figs. 2).

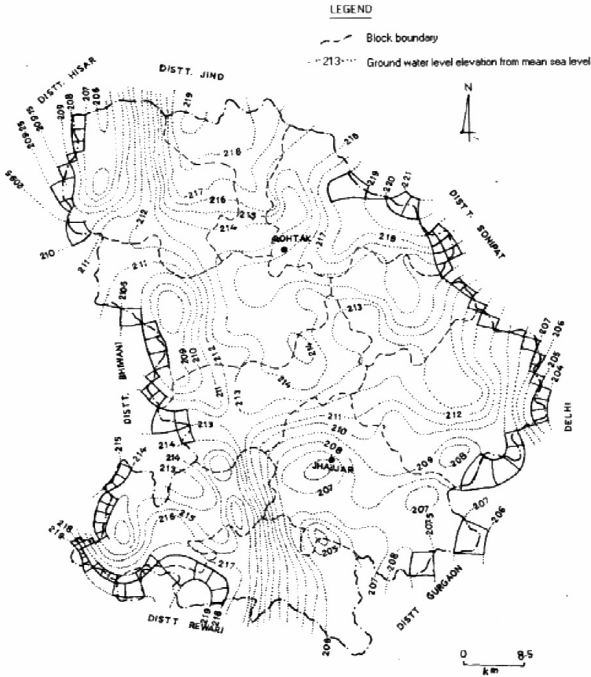


Figure 2 Average water table contour map of June 1994 to May 1995 with flow net constructed along the boundary.

The rate of subsurface inflow or outflow from the study area through each square was calculated by the following relation.

$$Q_{lsf} = \Delta h.K.D \tag{7}$$

where, Δh = drop in hydraulic head between equipotential lines, m,
 K = hydraulic conductivity of the aquifer, m/day and
 D = Saturated thickness of the aquifer, m

The average saturated thickness of each square of the flow nets was determined by superimposing the average water table contour map over the contour map of the impervious layer of the area. Afterwards the reduced level of impervious layer were deducted from that of water table.

The K-value of the saturated thickness of the aquifer at each flow net square along the boundary of the study area was determined by working out the weighted average of the K-values of different soil layers (stratification) based on the lithology of the exploratory bore holes near the boundaries. The average daily subsurface inflow and outflow from the study area were worked out by the following relations.

$$Q_{lsik} = \left(\sum_{i=1}^n \Delta h_i K_i D_i \right)_{in} \tag{8}$$

$$Q_{lsok} = \left(\sum \Delta h_j K_j D_j \right)_{out} \quad 9$$

where, Σ = Summation

$i = 1, 2, 3, \dots, n$

n = number of squares through which subsurface inflow occurs

$j = 1, 2, 3, \dots, m$

m = number of squares through which subsurface outflow occurs

Subscripts 'in' and 'out' are to indicate inflow and outflow, respectively.

Finally the net subsurface flow (Q_{lsn}) during the period considered was computed as:

$$Q_{lsn} = \sum_{k=1}^{12} Q_{lsik} = \sum_{k=1}^{12} Q_{lsok} \quad 10$$

In this way lateral subsurface flow was analyzed for six consecutive years (1994-2000)

3.3.5 Change in Ground Water Storage

Water table fluctuation maps over a period of 12 months (June-May) were drawn for the periods considered with the help of the computer program explained earlier.

The ratio of area between consecutive contour lines of equal change in water table was determined by using digital planimeter. Then the average value of two consecutive contour lines of equal change in water table was taken for average change of water table in the area between. The weighted average rise or fall were worked out independently for the areas experienced rising or falling, respectively. Finally, average change in water table was determined and change in ground water storage was computed by the following equation.

$$\Delta S_{gw} = \mu \Delta h \quad 11$$

where, μ = Specific yield of the aquifer, ..

Δh = Overall average change in water table from June to May, and

ΔS_{gw} = Change in ground water storage

On the basis of the pumping tests at shallow tube wells conducted in the study area by HSMITC and Ground Water Cell, an average value of 8 per cent specific yield was used.

3.4 The Functional Relationship of Parameters of Water Balance Equation with the Water Table fluctuation

As it was described earlier, the inflow and outflow components of water balance equation for the study area included precipitation (Pr), irrigation (Irr), surface runoff (R.off), actual evapotranspiration (ET_a), lateral subsurface inflow (Q_{lsi}) and lateral subsurface outflow (Q_{lso}) (equation 6).

It is obvious that annual water losses from an area through evapotranspiration and surface runoff are highly dependent on the annual depth of irrigation and/or rainfall. But it is difficult and more complicated to study the relative contribution of the parameters that depend on each other to other parameter that depends on them.

Therefore, in the present study, only irrigation (Irr), precipitation (Pr) and net lateral subsurface flow (Q_{lsn}) were considered to be relatively independent. The relative contribution each of these independent parameters

was evaluated from functional relationship of the average change in water table from June to May (Δh) with inputs from irrigation (Irr), rainfall (Pr) and net lateral subsurface flow (Q_{lsn}).

The functional relationships considered were:

$$\Delta h = f(\text{Irr}, \text{Pr}, Q_{lsn})$$

$$\Delta h = f(\text{Irr})$$

$$\Delta h = f(\text{Pr})$$

$$\Delta h = f(Q_{lsn})$$

$$\Delta h = f(\text{Irr}, \text{Pr})$$

$$\Delta h = f(\text{Irr}, Q_{lsn})$$

$$\Delta h = f(\text{Pr}, Q_{lsn})$$

where Δh = Average change in water table from June to May in the area (cm)

Irr = Total irrigation water input to the study area from June to May (mm)

Pr = Total rainfall depth received from June to May in the study area (mm)

Q_{lsn} = Net lateral subsurface flow into the study area from June to May (mm)

Prediction equations in multiple regression analysis for the above functions were expressed as:

Full model

$$\Delta h = a + b_1 \text{Irr} + b_2 \text{Pr} + b_3 Q_{lsn}$$

Restricted model I

$$\Delta h = a + b \text{Irr}$$

Restricted model II

$$\Delta h = a + b \text{Pr}$$

Restricted model III

$$\Delta h = a + b Q_{lsn}$$

Restricted model IV

$$\Delta h = a + b_1 \text{Irr} + b_2 \text{Pr}$$

Restricted model V

$$\Delta h = a + b_1 \text{Irr} + b_2 Q_{lsn}$$

Restricted model VI

$$\Delta h = a + b_1 \text{Pr} + b_2 Q_{lsn}$$

where

a 's = Empirical constants

b 's, b_1 's, b_2 's and b_3 = Empirical coefficients.

Here the term 'restricted model' is used to refer to the prediction models for the regression of dependent variable (Δh) on independent variables. This is considered in the full model but with lesser number of independent variables than that of full model at least by one.

The values of empirical constant and coefficients in equations in all prediction models were determined by multiple linear regression analysis using SPSS. Then the relative contribution of each independent variable to the variance of the dependent variable in the full prediction regression model was evaluated based on:

1. The variance of dependent variable accounted for each independent variable in the full model without partial effects of other independent variables. For this purpose, the squared multiple correlation coefficient values of restricted prediction models I to III were used.
2. The variance of dependent variable accounted for each independent variable in the full model after the effects of other independent variables in the model were partialled. For this purpose, the squared multiple partial correlation coefficient values for the regression of dependent variable (Δh) on each independent variable in full model was computed by using the following relations.

$$R^2_{hb_1(b_2b_3)} = \frac{R^2_{hb_1b_2b_3} - R^2_{hb_2b_3}}{1 - R^2_{hb_2b_3}} \quad 12$$

$$R^2_{hb_2(b_1b_3)} = \frac{R^2_{hb_1b_2b_3} - R^2_{hb_1b_3}}{1 - R^2_{hb_1b_3}} \quad 13$$

$$R^2_{hb_3(b_1b_2)} = \frac{R^2_{hb_1b_2b_3} - R^2_{hb_1b_2}}{1 - R^2_{hb_1b_2}} \quad 14$$

where

$R^2_{h.b_1(b_2b_3)}$ = The squared multiple partial correlation coefficient for regression of Δh on independent variable associated with the empirical coefficient b_1 after the effects of other independent variables associated with the empirical coefficients b_2 and b_3 were partialled (in full model).

$R^2_{h.b_2(b_1b_3)}$ = The squared multiple partial correlation coefficient for regression of Δh on independent variable associated with the empirical coefficient b_2 after the effects of other independent variables associated with the empirical coefficients b_1 and b_3 were partialled (in full model).

$R^2_{h.b_3(b_1b_2)}$ = The squared multiple partial correlation coefficient for regression of Δh on independent variable associated with the empirical coefficient b_3 after the effects of other independent variables associated with the empirical coefficients b_1 and b_2 were partialled (in full model).

$R^2_{h.b_1b_2b_3}$ = The squared multiple correlation coefficient for regression of Δh on the independent variables associated with the empirical coefficients b_1 , b_2 and b_3 in full model.

$R^2_{h.b_2b_3}$ = The squared multiple correlation coefficient for regression of Δh on independent variables associated with empirical coefficients b_2 and b_3 in full model.

$R^2_{h.b_1b_3}$ = The squared multiple correlation coefficient for regression of Δh on independent variables associated with empirical coefficients b_1 and b_3 in full model.

$R^2_{h.b_1b_2}$ = The squared multiple correlation coefficient for regression of Δh on independent variables associated with empirical coefficients b_1 and b_2 in full model.

4 Results and Discussion

The squared multiple correlation coefficient value for regression of Δh on Irr, Pr and Q_{lsn} (full model) was quite high. It indicated that about 98.9% of variance of Δh was due to the variation in inflows of Irr, Pr and Q_{lsn} (Table 1).

The squared correlation coefficient values of restricted models I to III indicated that about 13.6%, 83.5% and 0.9% of variance of Δh was due to the variations in Irr, Pr and Q_{lsn} , respectively (Table 2). The squared multiple partial correlation coefficient values (Table 3) indicate that controlling any two of the three independent variables resulted in an increase in the proportion of the variance that the remaining independent variable account for in average change in the water table (Δh). This may be due to some correlation among the independent variables themselves.

However, the squared multiple partial correlation coefficient of Δh with Pr with controlled effects of Irr and Q_{lsn} was the highest. About 98.73% of the variance of Δh would have been accounted for Pr if the effects of the variations in Irr and Q_{lsn} could be controlled. This and the higher squared multiple correlation coefficient values of the restricted models, in which Pr was included as independent variable, indicate that the variance of Δh was accounted for more by Pr than other variables.

Table 2 Estimated values of the empirical constant and coefficients in full and restricted prediction regression models

Sr. No.	6	Prediction regression equations	Values of empirical constant and coefficients				R ²
			a	b ₁	b ₂	b ₃	
1.	Full model	$\Delta h =$		-0.087	0.04133	-27.764	0.989
		$a+b_1Irr+b_2$	9.115	(-2.956)	(8.884)	(-2.881)	
		$Pr+b_3Q_{lsn}$		(0.208)	(0.071)	(0.213)	
2.	Restricted model I	$\Delta h =$	22.727	-0.101			0.136
		$a+bIrr$		(-0.687)			
				(0.542)			
3.	Restricted model II	$\Delta h = a+bPr$	-16.387	0.03803			0.835
				(3.897)			
				(0.030)			
4.	Restricted model III	$\Delta h =$	0.519	7.937			0.009
		$a+bQ_{lsn}$		(0.162)			
				(0.881)			
5.	Restricted model IV	$\Delta h =$	-2.384	-0.0704	0.03666		0.899
		$a+b_1Irr+b_2$		(-1.132)	(3.897)		
		Pr		(0.375)	(0.060)		
6.	Restricted model V	$\Delta h =$	22.26	-0.101	0.891		0.136
		$a+b_1Irr+b_2$		(-0.543)	(0.016)		
		Q_{lsn}		(0.642)	(0.989)		
7.	Restricted model VI	$\Delta h =$	-9.821	0.04185	-22.207		0.895
		$a+b_1Pr+b_2$		(4.103)	(-1.065)		
		Q_{lsn}		(0.055)	(0.398)		

The values in 1st and 2nd parentheses are t-value and its statistically significant level (α) in each model, respectively the smaller values of the significant levels associated with the empirical coefficients of Pr in each prediction equation, where Pr was included as independent variable, indicate that the empirical coefficients associated with Pr are more confidentially different from zero than that of other variables. This may also confirm the relative importance of Pr as compared to others.

During 1997-98 and 1998-99, there was negative overall average water table fluctuation in spite of relatively more amounts of irrigation water supply. On the other hand, irrigation water supply to the area was less in 1995-96 and 1996-97. But there was water table rise in larger area due to high rainfall amounts in these years.

In spite of less irrigation water supply, the total water inflow to the study area was more and there was positive average water table fluctuation during these years. Due to these conditions the empirical coefficients associated with irrigation (Irr) in prediction models that included Irr as an independent variable were negative, as Δh in the models represented over the entire study area average water table fluctuation from June to May.

This indicated that to draw a realistic conclusion for only the impact of irrigation water supply on the water table fluctuation in the study area. A study is needed to be conducted for smaller areas by discretizing the entire study area into smaller ones based on the water table condition, climatic condition and irrigation water supply.

Table 2 Values of squared multiple partial correlation coefficient for regression of Δh on each of independent variables considered in full model

$R^2_{h-b1(b2b3)}$	$R^2_{h-b2(b1b3)}$	$R^2_{h-b3(b1b2)}$
0.8952	0.9873	0.8911

However, as the present study was concerned, the results obtained were sufficiently satisfactory to draw conclusion for the relative contribution of the water balance parameters considered to the average water table change in the study area. This was also demonstrated by studying the extents of water logged areas before and after rainy seasons (fig. 3&4)

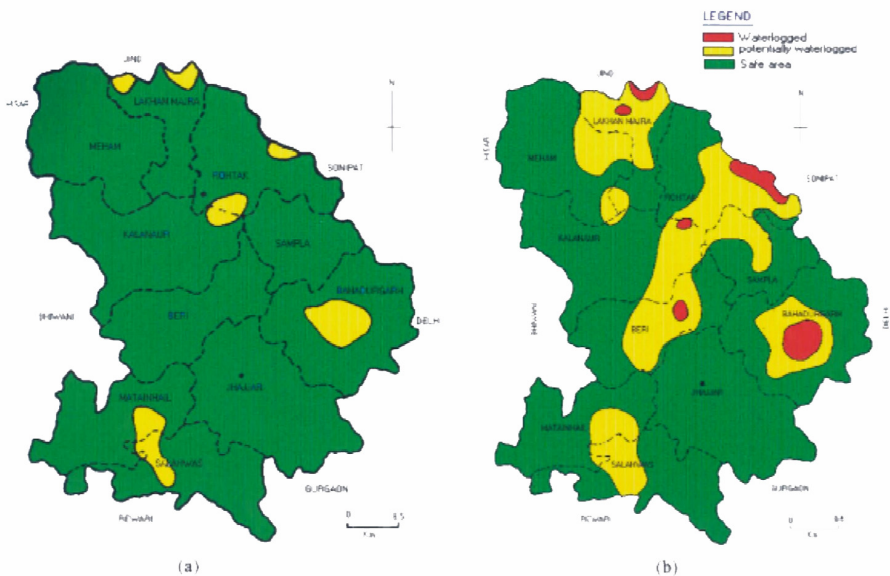
5 Summary and Conclusion

The squared multiple correlation coefficient value for regression of Δh on Irr, Pr and Q_{lsn} (full model) was quite high. It indicated that about 98.9% of variance of Δh was due to the variation in inflows of Irr, Pr and Q_{lsn} and it indicates that the consideration of these parameters to contribute to water table fluctuation was correct.

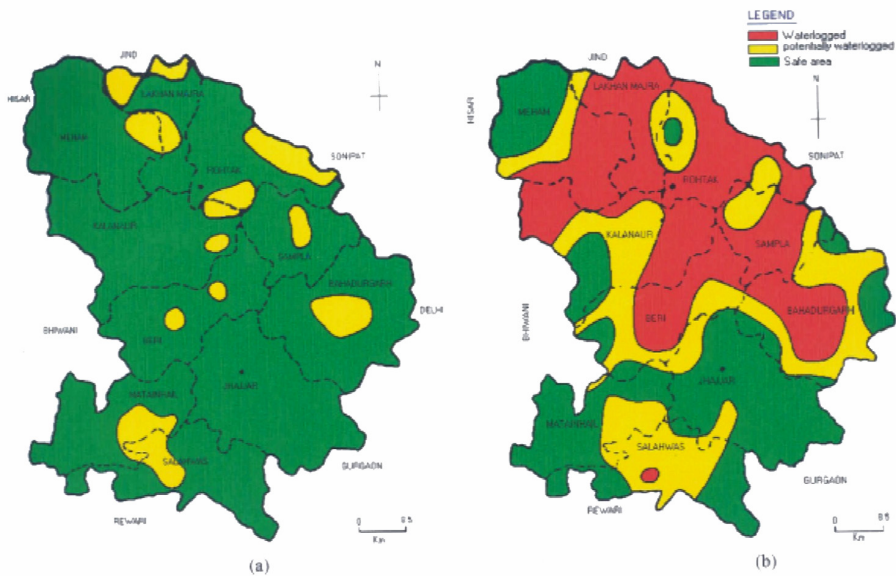
Controlling any two of the three independent variables resulted in an increase in the proportion of the variance that the remaining independent variable accounts for the change in water table (Δh). This may be due to some correlation among the independent variables themselves.

However, the squared multiple partial correlation coefficient of Δh with Pr with controlled effects of Irr and Q_{lsn} was the highest. About 98.73% of the variance of Δh would have been accounted for by Pr if the effects of the variations in Irr and Q_{lsn} could be controlled. This and the higher squared multiple correlation coefficient values of the restricted models, in which Pr was included as independent variable, indicates that the variance of Δh was accounted for more by Pr than other variables.

That is, the contribution of rainfall to water table fluctuation in the area from June to May was relatively higher than that of irrigation and net lateral subsurface flow. Therefore, providing adequate surface drainage system to remove the surplus water during rainy seasons can help to control water table rise besides installing subsurface drainage systems in critical areas



Figur 3 Waterlogged areas in the study area in 1994 (rainfall received during June to Oct. was 572.6mm) (a) June; (b) October



Figur 4 Waterlogged areas in the study area in 1995(rainfall received during June to Oct. was 774.5mm) (c) June; (d) October

6 Literature

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