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GROUNDWATER VARIABILITY IN HARYANA: A SPATIO-TEMPORAL ANALYSIS

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Abstract

Groundwater resources play a major role in ensuring food and livelihood security across the world, especially in countries that depend on agriculture. The state of Haryana in India has witnessed tremendous increase in agricultural production since the spread of Green Revolution and increased use of water resources. The increased demand of water for irrigation has resulted in intensive exploitation of groundwater resources in the state. Therefore, groundwater table in the state has reached at a critical level of depth. The average annual decline in groundwater table depth was observed to be above 56.3 cm. The average depth of groundwater table in the state has increased from 12.5 m to 17.2 m during 2004-13. Further, the area under critical depth of groundwater table (more than 10 m) has increased from 52 per cent in 2004 to 62 per cent in 2013. Depletion of groundwater resources at such an alarming rate will threaten the long term sustainability of tube-well irrigated agriculture in Haryana. In this study, therefore, an attempt has been made to assess the spatial and temporal groundwater table variability in Haryana during recent times (2004-2013) to highlight the over-exploitation of groundwater resources.

Introduction

Groundwater, an important component of the global freshwater resource, is the primary source of irrigation, industrial and drinking water requirements in many parts of the world (Singh and Sharma, 2010). Globally, groundwater provides about 50 per cent of current potable water supplies, 40 per cent of the demand of industrial water supply and 20 per cent of water use in irrigation (Villholth, 2006). Compared to surface water, groundwater use often brings large economic benefits per unit volume, because of ready local availability, drought reliability and good quality requiring minimal treatment (Villholth, 2006). It is a renewable resource and has the remarkable distinction of being a highly dependable and safe source of water supply (Singh and Singh, 2002). Groundwater constitutes the most important source of assured irrigation and plays a major role in ensuring livelihood and food security across the world, especially in economies that depend on agriculture (Mukherji and Shah, 2005). India, Pakistan, Bangladesh and China account for the bulk of the world's groundwater use in agriculture (Kaur et al., 2011). Shah et al. (2003) estimated that 55-60 per cent of the Indian population is dependent, directly or indirectly, on groundwater for its livelihood. The importance of the groundwater resource in India can be realized from the fact that nearly

two fifth of the agriculture is dependent on irrigation from groundwater resources (CWC, 2013) and about 60 per cent of the irrigated food production depends on irrigation from groundwater wells. In addition, about 56 per cent of the rural households get drinking water supply from hand pumps or tube-wells, 14 per cent from open wells and 25 per cent from piped water systems in India (Shankar et al., 2011).

Due to excessive utilization of groundwater, many parts of the country are experiencing extreme over-exploitation of the groundwater resources. The most dramatic change in the utilization of groundwater resources in India is that the share of tube-wells in irrigated areas has increased from a merely 1 per cent in 1960-61 to 40 per cent in 2006-07. Three states such as Punjab, Uttar Pradesh and Haryana account for about 60 per cent of tube-wells in India. On an average, there are 27 tube-wells per 100 hectares of net sown area in Punjab, 21.5 in Uttar Pradesh and 14.1 in Haryana in 2001 (Shah et al., 2001). The stage of groundwater exploitation in Punjab (145 per cent), Rajasthan (125 per cent) and Haryana (109 per cent) have reached unsustainable level and the number of unsafe districts in terms of groundwater usage has increased from 33 in 1995 to 178 in 2004 (Shankar et al., 2011). Nearly, all districts in Punjab, Rajasthan and Haryana are in unsafe category forcing farmers to replace their centrifugal pumps with submersible pumps (Chawla et al., 2010).

Haryana state with only 1.4 per cent of the total geographical area of the country is contributing about 7 per cent of the India's food production. Soon after its inception in 1966, the highest priority was accorded to agriculture, as a result of this the cropped area increased from 4.6 to 6.5 M ha during 1966-2012. In addition, the state recorded a growth of 240.7 (three fold) and 549.5 (six fold) per cent in area under wheat and rice cultivation, respectively during 1966-67 and 2011-12. Moreover, the net irrigated area expanded two fold (1.3 to 3.0 M ha), resulting in the increased food production from 2.6 to 18.3 million tones during 1966-2012 (Anonymous, 2012). The number of tube-wells in the state has increased from 0.02 million in 1966 to 0.73 million in 2012, indicating a thirty times rise in their number. Similarly, the share of tube-well irrigated area to the total irrigated area increased from 38.9 per cent in 1975-76 to 61.2 per cent in 2011-12. This impressive growth of agriculture sector during the last four decades has caused adverse impacts on groundwater resources of the state. The net water available in the state is about 8.62 billion cubic meters (BCM) against the annual demand of 9.45 BCM. Thus, leaving a deficit of 0.83 BCM of water that is being met by over-exploitation of groundwater resources (http://www.india-wris.nrse.gov.in/wrpinfo/?tittle=Ground_water_resources). Therefore, there is an urgent need to study the spatio-temporal variability of groundwater table depth in Haryana to highlight its judicious utilization for ensuring long term sustainability of agriculture leading to food security of the country in general and of the state in particular.

Objectives of the Study

Keeping in view of the above research reviews, the major objectives of the present study are:

- to assess the spatio-temporal variability of groundwater in the state of Haryana during 2004-13 and
- to delineate the over-exploited and under-utilized zones of groundwater resources in the state.

Hypotheses

To achieve above objectives, following hypotheses are formulated for testing:

- Higher the area under tube-well irrigation more is the depth of groundwater table.
- More the number of tube-wells deeper is the depth of groundwater table.
- Depth of ground water table and area under rice cultivation are positively related.
- Area under canal irrigation and depth of groundwater table are inversely related.
- More the amount of rainfall lesser will be the fall in groundwater table.

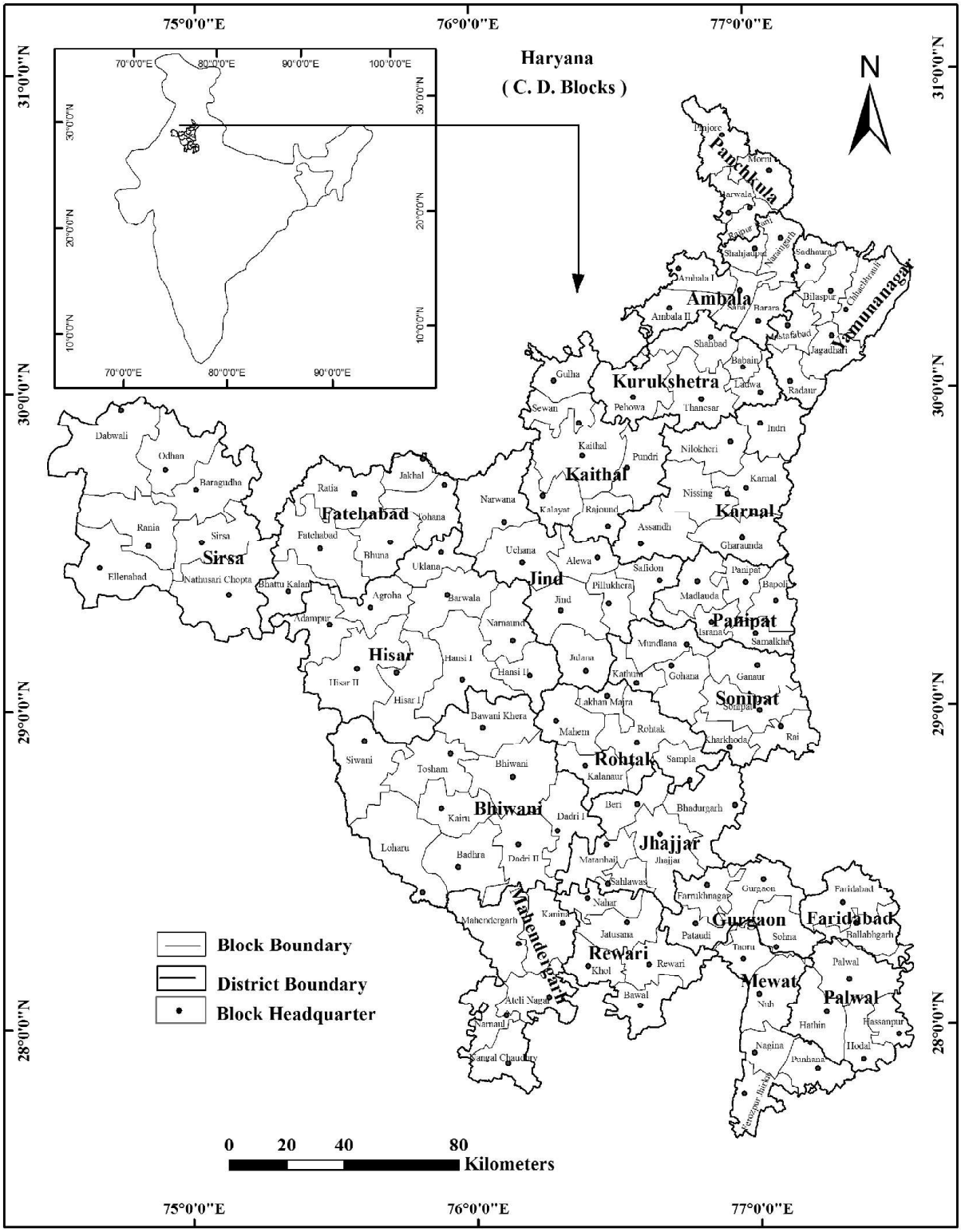
Study Area

Haryana state extends between latitudes 27° 39' and 30° 55' N and longitudes 74° 28' and 77° 36' E (Fig. 1). It covers a geographical area of about 44212 km^2 accounting about 1.4 per cent of the total area of the country. Administratively, it comprises of 21 districts and 118 community development (CD) blocks. The state has a variety of landscapes varying from hills in the northern region to almost level alluvial plains in the central parts and sand dunes in south-western parts. The geological formation of the state ranges from Precambrian to recent times. Physically, the state falls into three broad divisions, namely the sub-Himalayan tract, Indo-Gangetic plain and outliers of Aravali Hills. In the Indo-Gangetic plain, unconsolidated clay, silt, sand and gravels compose the alluvium deposited layer-after-layer by river Yamuna. River Ghaggar, which is not perennial, touches northern parts of the state. The general slope of the ground is from north to south but the slopes become reverse further south and south-west due to presence of subdued ranges of the Aravalis. The soil texture of the state comprised of 55 per cent sandy loam, 30 per cent loamy sand, 10 per cent loamy and 5 per cent sandy, which are generally favourable for a variety of crops. In addition, the state has a good canal network for irrigation such as, western Yamuna canal, Bhakra canal, Gurgaon canal, Agra canal, Jui canal and Jawahar Lal Nehru canal.

Hot summer and cold winters are the characteristics of climate. May and June are the hottest and December and January are the coldest months of the year. The maximum temperature rises to 45°C in the month of June while average minimum temperature drops to below 5°C in the month of January. Dust storms are common during summers. Normal annual rainfall ranges between 300 mm in the south-west to 1200 mm in the north-east; 80 per cent of this is received during monsoon period (July-September). The remaining rainfall comes in the winter period from December till February. The co-efficient of variation of rainfall is more than 45 per cent in western districts, whereas it ranges between 25 to 45 per cent in eastern districts. More than 65 per cent area of the state lies in arid to semi-arid belt having scanty to highly erratic rainfall both in quantity and distribution. Even during the monsoon period, dry spells of more than three weeks are common. The maximum rainfall for a ten years return period varied in the state from 65 to 135 mm per day, 125 to 190 mm in two consecutive days and from 135 to 215 mm in four consecutive days (Agarwal and Roest, 1996). The relative humidity is generally high during rainy months and also during winter, which ranges from 70 to 80 per cent. The aridity index in the state is larger than 0.66 and potential evapotranspiration ranges from 1250 to 1650 mm.

Database and Methodology

The present study is primarily based on


Haryana
(C. D. Blocks)
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31°0'0"N
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Jind
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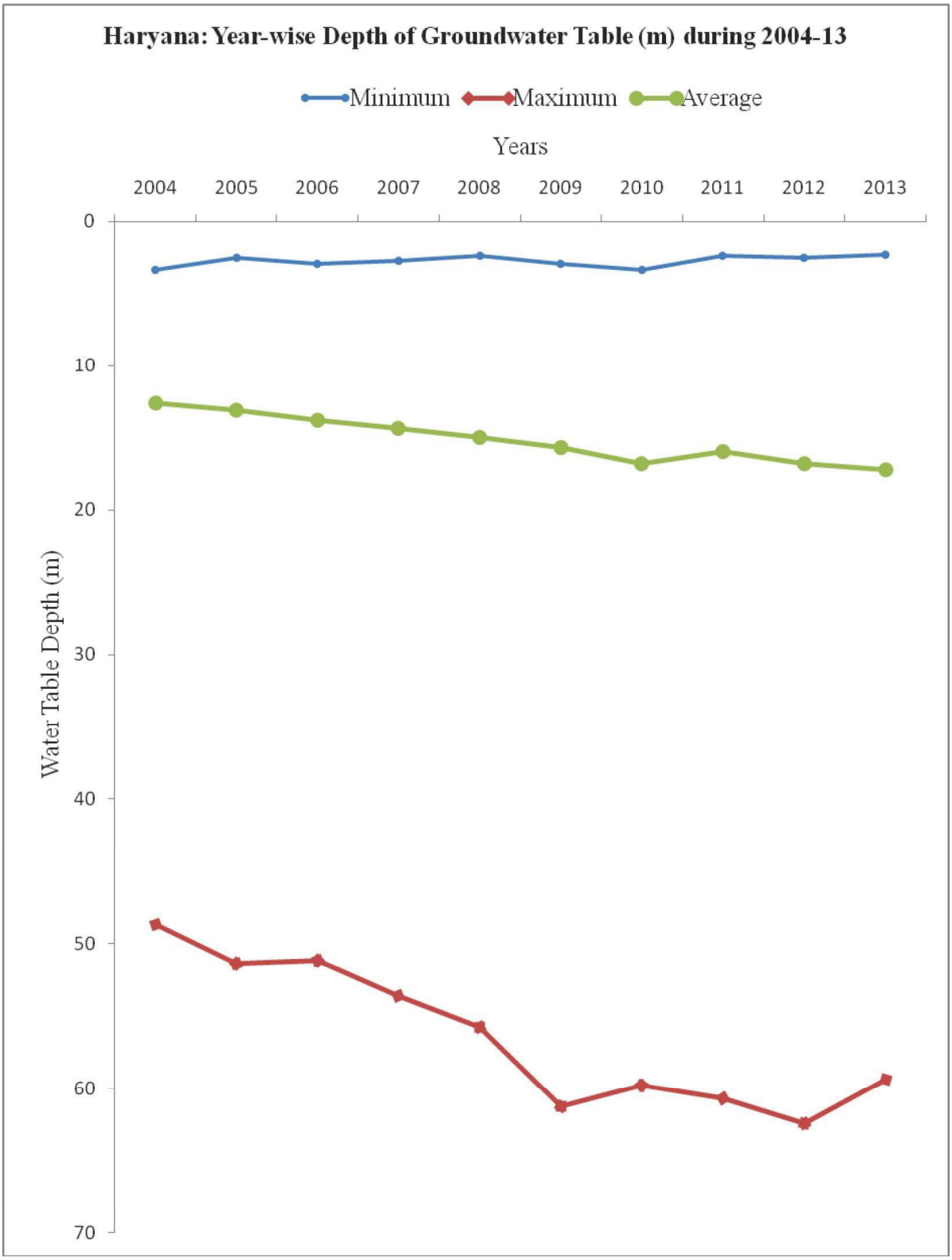
0 20 40 80
Kilometers

Fig.1



Source: Table 1

Fig. 2

secondary data collected for the period 2004-2013 from the unpublished records of Groundwater Cell, Department of Agriculture, Haryana, Panchkula. This unpublished groundwater table fluctuations data are the only reliable and official source pertaining to the state of Haryana. The recording of depth of groundwater table in meters below ground level is carried out twice in a year during the months of June (pre-monsoon) and October (post-monsoon). For the present study, pre-monsoon (June) groundwater table fluctuation data of 118 points (blocks) have been procured, carefully examined for discrepancies, missing values, other errors etc. and are finally analysed and interpreted. The spatial and temporal variations in groundwater table behaviour have been exhibited with the help of tables and graphs using Microsoft Office based spread sheet and maps using Arc GIS 9.3 package. The water table data of these observation wells have been used to create groundwater surface maps at 0.0–3.0, 3.1–10.0, 10.1–20.0 and more than 20.0 m depth for the period 2004 and 2013. This classification was based on the premise that areas with water table depth between 0.0–3.0 m are either water logged or prone to water logging. The water table depth between 3.1–10.0 m was classified as safe limit for the present study, as it is ideally suitable for installation of centrifugal pumps for groundwater extraction. The groundwater table depth beyond 10.0 m was classified as critical limit for shifting from centrifugal pump to submersible pump. Beyond 20.0 m groundwater table depth is considered deep (over-exploitation) and not fit for pump installation. Finally, rise and fall of the groundwater table were calculated at CD block-wise and district-wise to interpret the results and draw the conclusions. Maps are also prepared to highlight the spatial variations in the depth of groundwater table. In addition, ancillary data pertaining to the factors affecting the variability of groundwater table (tube-well irrigated area, number of tube-wells, area under rice cultivation, canal irrigated area and amount of rainfall) have been collected for the same period from Statistical Abstract, Haryana.

Results and Discussion

Temporal Variation in Groundwater Table Depths

The groundwater table depth in the state ranged between 2.4 to 62.4 m from the ground level during the study period 2004-2013 (Fig. 2). The minimum groundwater table depth during the study period varies from 2.4 to 3.4 m,

Table 1
Haryana: Year-wise Depth of Groundwater Table (m) during 2004-13

Year	Minimum (m)	Maximum (m)	Average (m)
2004	3.4	48.6	12.5
2005	2.6	51.4	13.1
2006	3.0	51.2	13.7
2007	2.8	53.6	14.3
2008	2.5	55.7	14.9
2009	3.0	61.2	15.7
2010	3.3	59.8	16.7
2011	2.4	60.7	15.9
2012	2.6	62.4	16.7
2013	2.4	59.4	17.2

Source: Compiled by Authors

Table 2
Haryana: District-wise Average Annual Fall/Rise (cm) in Groundwater Table Depths during 2004-2013

Districts	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	Average (2004-2013
Ambala	-112.0	-60.0	-20.0	-34.0	-61.0	-69.0	98.0	-89.0	-18.0	-40.6
Bhiwani	133.0	-150.0	-271.0	-119.0	20.0	-36.0	70.0	-98.0	166.0	-31.7
Faridabad	-96.0	-79.0	-35.0	-41.0	-58.0	-46.0	-7.0	-101.0	-161.0	-69.3
Fatehabad	50.0	-369.0	288.0	-461.0	-155.0	-310.0	-34.0	-128.0	-84.0	-133.7
Gurgaon	-45.0	-183.0	-167.0	-96.0	-106.0	-129.0	43.0	109.0	-258.0	-92.4
Hisar	-26.0	54.0	12.0	-81.0	22.0	-86.0	52.0	-11.0	46.0	-2.0
Jind	-21.0	-50.0	-19.0	-50.0	-14.0	-210.0	162.0	-109.0	-78.0	-43.2
Jhajjar	-19.0	37.0	22.0	-3.0	7.0	-29.0	121.0	-39.0	10.0	11.9
Kaithal	-61.0	-69.0	-287.0	-130.0	-82.0	-108.0	-44.0	-120.0	-119.0	-113.3
Karnal	-70.0	-98.0	-99.0	-97.0	-106.0	-73.0	81.0	-102.0	-43.0	-67.4
Kurukshetra	-141.0	-189.0	-142.0	-101.0	-87.0	-17.0	65.0	-232.0	-174.0	-113.1
Mahendragarh	-319.0	57.0	-157.0	-49.0	-294.0	-268.0	302.0	-78.0	-122.0	-103.1
Mewat	9.0	-38.0	-86.0	-2.0	-33.0	-35.0	-1.0	48.0	-10.0	-16.4
Palwal	-70.0	-37.0	-90.0	-11.0	3.0	-16.0	-599.0	-206.0	60.0	-107.3
Panipat	-24.0	-53.0	-61.0	-21.0	-72.0	-85.0	-91.0	-147.0	- 21.0	- 63.9
Panchkula	-76.0	-94.0	-5.0	170.0	-190.0	-183.0	63.0	-147.0	-21.0	-53.7
Rohtak	24.0	47.0	-4.0	25.0	1.0	-16.0	72.0	-38.0	30.0	15.7
Rewari	-219.0	-40.0	-50.0	-51.0	30.0	-117.0	205.0	-86.0	-107.0	-48.3
Sonipat	27.0	-1.0	-26.0	14.0	-12.0	-66.0	49.0	-2.0	-65.0	-9.1
Sirsa	-11.0	-71.0	7.0	-202.0	-138.0	-176.0	-6.0	-50.0	50.0	-66.3
Yamunanagar	-47.0	-10.0	-40.0	83.0	-239.0	-119.0	194.0	-135.0	6.0	-34.1
Haryana	-53.0	-66.0	-59.0	-60.0	-74.0	-105.0	12.5	-88.9	-46.7	-56.3

Source: Compiled by Authors

whereas maximum depth ranges between 48.6 to 62.4 m (Table 1). However, groundwater table behaviour reveals that it has fallen in the entire state from 12.5 m in 2004 to 17.2 m in 2013. A maximum fall of 105.0 cm was observed in the year 2009-10, while a rise of 12.5 cm was observed in 2010-11. The rise in groundwater table depth during 2010-11 is attributed to good monsoon rainfall and subsequent flooding in the state. However, at district level, maximum decline (-599.0 cm) was experienced by Palwal district in 2010-11, while a maximum rise (302.0 cm) was found in Mahendragarh district during the same year (Table 2). In addition, area under different groundwater table depths was also computed and has been presented in Table 3. A perusal of the table indicates that during the study period, area under safe category (0.0-10.0 m) has reduced from 2110 thousand ha (47.7 per cent) in the year 2004 to 1703 thousand ha (38.6 per cent) during 2013. However, area under critical and over-exploited groundwater table depth category (more than 10.0 m) has increased from 2311 thousand ha (52.2 per cent) in the year 2004 to 2718 thousand ha (61.5 per cent) during 2013. It is worth noting that the area vulnerable to waterlogging or waterlogged conditions has increased from nil in 2004 to 51 thousand ha (1.2 per cent) during 2013 (Table 3). Taking number of blocks into account it has been found that the number of blocks with safe limit of

Table 3
Haryana: Year-wise Area (000 ha) under Different Groundwater Table Depths (m) during 2004-2013

Years	0-3.0 m	3.1-10.0 m	10.1-20.0 m	>20.0 m
2004	-	2109.8 (58)	1576.0 (40)	735.3 (20)
2005	28.1 (1)	1941.2 (53)	1819.6 (46)	632.1 (18)
2006	-	1966.4 (54)	1647.7 (42)	806.9 (22)
2007	28.1 (1)	1899.8 (50)	1678.3 (40)	814.8 (27)
2008	31.8 (1)	1685.9 (47)	1749.8 (43)	953.8 (27)
2009	-	1796.3 (46)	1671.2 (44)	953.8 (28)
2010	-	1458.9 (38)	1752.1 (47)	1210.0 (33)
2011	31.8 (1)	1586.7 (44)	1496.4 (42)	1306.1 (31)
2012	31.8 (1)	1581.6 (46)	1424.3 (39)	1383.3 (32)
2013	51.1 (2)	1651.5 (41)	1464.3 (41)	1254.1 (34)

Source: Compiled by Authors
(Figures in parenthesis indicate the number of blocks)

Table 4
Haryana: Number of CD Blocks and Area under Different Depth of Groundwater Table during 2004-2013

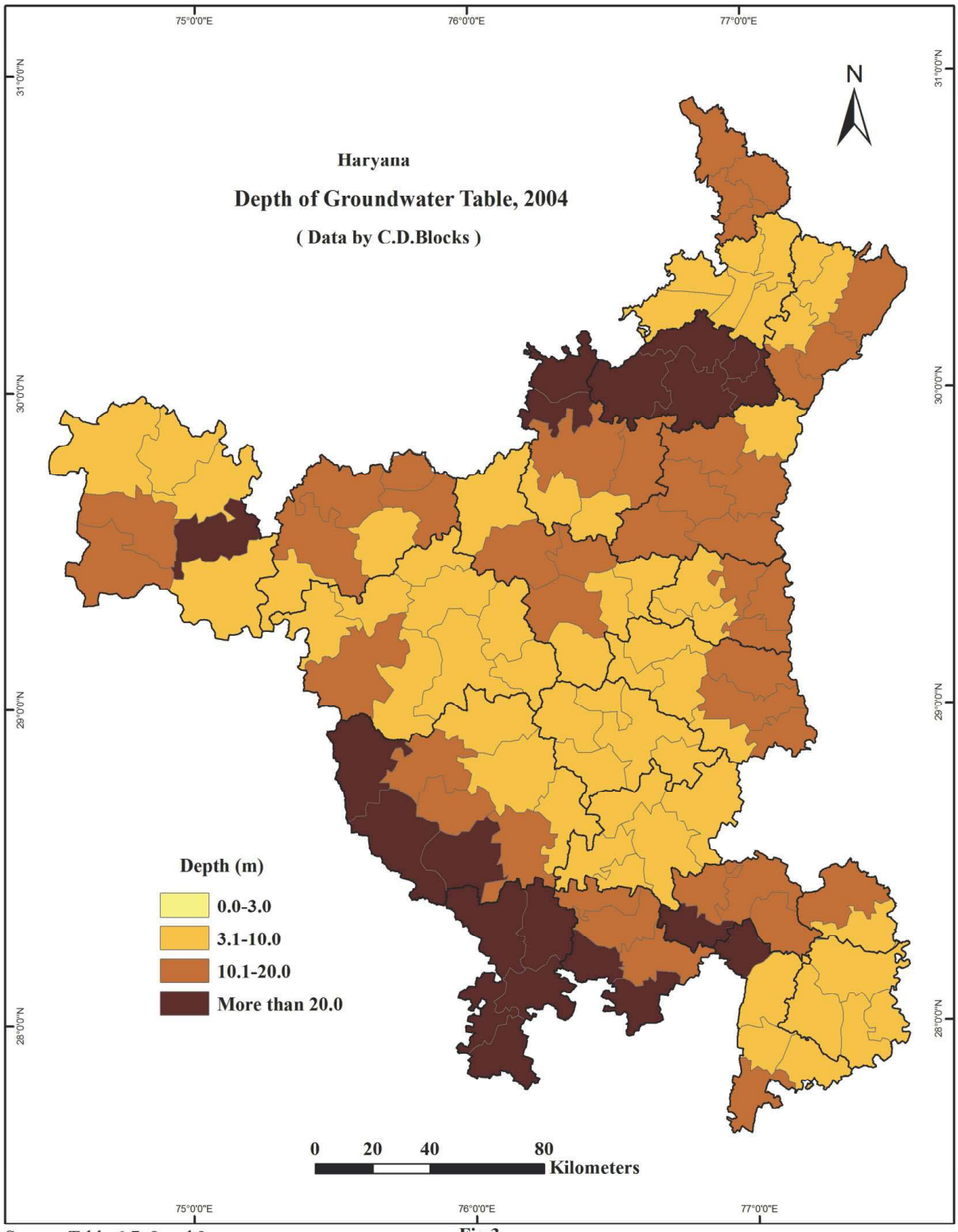
Depth of Groundwater Table (m)	No. of CD Blocks		Blocks (%)		Area (000 ha)		Area (%)	
	2004	2013	2004	2013	2004	2013	2004	2014
3.0 and less	-	2	-	1.6	-	51.1	-	1.2
3.1 to 10.0	58	41	49.2	34.7	2109.8	1651.5	47.7	37.4
10.1 to 20.0	40	41	33.8	34.7	1576.0	1464.3	35.6	33.1
More than 20.0	20	34	16.9	28.9	735.3	1254.1	16.6	28.4

Source: Compiled by Authors

Table 5
Haryana: District-wise Number of CD Blocks and Area under Different Groundwater Table Depths (m) during 2004-2013

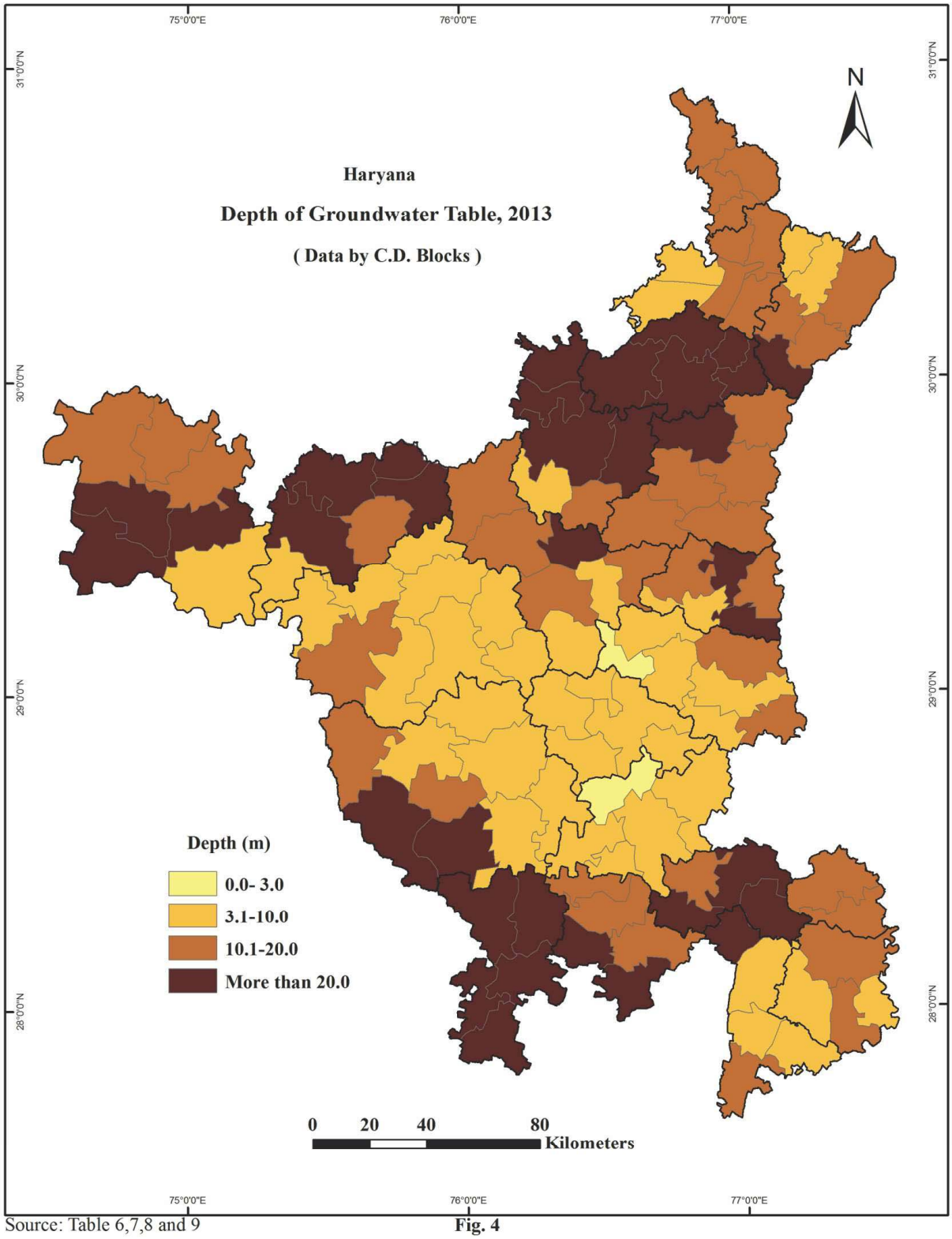
Districts	Depth of Ground-water Table(m)	2004				2013			
		No. of CD Blocks	CD Blocks (%)	Area (000ha)	Area (%)	No. of CD Blocks	CD Blocks (%)	Area (000ha)	Area (%)
Ambala	3.1-10.0	6	100	157.4	100.0	2	33.3	64.6	41.1
	10.1-20.0	-	-	-	-	4	66.6	92.7	58.9
Bhiwani	3.0-10.0	3	33.3	163.4	34.2	5	55.5	261.0	54.6
	10.1-20.0	3	33.3	134.1	28.1	2	22.2	93.8	19.7
	>20.0	3	33.3	180.2	37.7	2	22.2	122.2	25.5
Faridabad	3.0-10.0	1	50.0	29.4	39.7	-	-	-	-
	10.1-20.0	1	50.0	44.6	60.2	2	100.0	74.1	100.0
Fatehabad	3.0-10.0	3	50.0	100.5	39.6	1	16.6	35.3	13.9
	10.1-20.0	3	50.0	153.2	60.3	1	16.6	45.3	17.9
	>20.0	-	-	-	-	4	66.6	173.0	68.2
Gurgaon	10.1-20.0	3	75.0	99.7	79.3	1	25.0	27.9	22.2
	>20.0	1	25.0	26.0	20.6	3	75.0	97.8	77.7
Hisar	0.0-3.0	-	-	-	-	-	-	-	-
	3.1-10.0	9	100.0	398.2	100.0	8	88.8	332.8	83.5
	10.1-20.0	-	-	-	-	1	11.1	65.4	16.4
Jind	3.1-10.0	4	57.1	147.8	54.7	2	28.5	61.0	22.6
	10.1-20.0	3	42.8	122.3	45.2	4	57.1	182.0	66.7
	>20.0	-	-	-	-	1	14.2	27.0	10.1
Jhajjar	0.0-3.0	-	-	-	-	1	25.0	31.8	17.3
	3.1-10.0	5	100.0	183.4	100.0	4	75.0	151.5	82.6
Kaithal	3.1-10.0	2	33.3	60.4	26.1	1	16.6	33.8	14.6
	10.1-20.0	2	33.3	114.2	49.3	1	16.6	26.5	11.4
	>20.0	2	33.3	57.0	24.6	4	66.6	171.2	73.9
Karnal	3.1-10.0	1	16.6	38.3	15.2	-	-	-	-
	10.1-20.0	5	83.3	213.6	84.4	5	83.3	210.9	83.7
	>20.0	-	-	-	-	1	16.6	41.0	16.2
Kurukshetra	>20.0	5	100.0	153.0	100.0	5	100.0	153.0	100.0
M.garh	>20.0	5	100.0	189.9	100.0	5	100.0	189.9	100.0
Mewat	3.1-10.0	3	60.0	98.4	65.3	3	60.0	98.4	65.3
	10.1-20.0	1	20.0	29.1	19.3	1	20.0	29.1	19.3
	>20.0	1	20.0	23.0	15.3	1	20.0	23.0	15.3
Palwal	3.1-10.0	4	100.0	135.9	100.0	-	-	-	-
	10.1-20.0	-	-	-	-	4	100.0	135.9	100.0
Panipat	3.1-10.0	2	40.0	58.7	46.3	2	40.0	46.3	36.5
	10.1-20.0	3	60.0	68.0	53.6	2	40.0	58.7	46.3
	>20.0	-	-	-	-	1	20.0	21.6	17.1
Panchkula	3.1-10.0	-	-	-	-	1	25.0	32.2	35.9
	10.1-20.0	4	100.0	89.8	100.0	2	50.0	42.0	46.7
	>20.0	-	-	-	-	1	25.0	15.5	17.2
Rewari	10.1-20.0	3	60.0	97.7	61.2	3	60.0	97.7	61.2
	>20.0	2	40.0	61.9	38.8	2	40.0	61.9	38.8
Rohtak	3.1-10.0	5	100.0	174.5	100.0	5	100.0	174.5	100.0
Sonipat	0.0-3.0	-	-	-	-	1	14.2	19.2	9.08
	3.1-10.0	4	57.1	110.6	52.1	4	57.1	128.2	60.4
	10.1-20.0	3	42.8	101.5	47.8	2	28.5	64.6	30.4
Sirsa	3.1-10.0	4	57.1	266.8	62.3	1	14.2	82.5	19.2
	10.1-20.0	2	28.5	115.7	27.1	3	42.8	184.2	43.1
	>20.0	1	14.2	45.1	10.5	3	42.8	160.8	37.6
Yamuna-nagar	3.1-10.0	3	50.0	70.8	40.1	2	33.3	48.3	27.3
	10.1-20.0	3	50.0	105.9	59.9	3	50.0	103.9	58.8
	>20.0	-	-	-	-	1	16.6	24.4	13.8

Source: Compiled by Authors



Source: Table 6,7, 8 and 9

Fig.3



Source: Table 6,7,8 and 9

Fig. 4

groundwater table has declined from 58 to 43 while those recording groundwater tables beyond critical depth has increased from 60 to 75 during the study period (Table 4).

Spatial Variations in Depth of Groundwater Table, 2004

District-wise number of CD blocks and area under different groundwater table depths during 2004 in the state of Haryana has been shown in Table 5. It was revealed form the analysis that Kurukshetra and Mahendragarh districts have been completely over-exploited (more than 20.0 m), whereas blocks of Gurgaon and Rewari districts were in critical to over-exploited (10.1 to more than 20.0 m) category. On the other hand, blocks of Bhiwani, Kaithal, Mewat and Sirsa districts were observed in safe to over-exploited category (3.1 to more than 20.0 m). While, all the 4 blocks of Panchkula district witnessed a critical groundwater table depth (10.1 to 20.0 m). Safe to critical category (3.1 to 20.0 m) of groundwater table depth was observed in all the blocks of Faridabad, Fatehabad, Jind, Karnal, Panipat, Sonipat and Yamunanagar districts during the year. Conversely, Ambala, Hisar, Rohtak, Jhajjar and Palwal districts were found completely in safe category (3.1 to 10.0 m). Interestingly, none of the districts in state suffered from the problem of waterlogging (0.0 to 3.0 m) during the year 2004 (Table 5; Fig. 3).

Spatial Variations in Depth of Groundwater Table, 2013

Spatial variations in groundwater table depths during the year 2013 have been exhibited in Fig. 4. Kurukshetra and Mahendragarh districts remained in the over-exploited category (more than 20.0 m), while Rewari district was found in between critical to over-exploited category (10.1 to more than 20.0 m). Similarly, Fatehabad, Gurgaon, Jind, Kaithal, Mewat, Panipat, Panchkula, Sirsa and Yamunanagar districts were found in safe to over-exploited category (3.1 to more than 20.0 m). Faridabad and Palwal districts were observed under critical category (10.1 to 20.0 m), whereas Ambala, Bhiwani and Hisar districts were found to be in safe to critical category (3.1 to 20.0 m). Meanwhile, during the year 2013 Rohtak district was found under safe category (3.1 to 10.0 m), while, Jhajjar and Sonipat districts witnessed waterlogged to safe (0.0 to 10.0 m) conditions (Table 5). Such a situation in these districts may be attributed to seepage from canals, heavy rainfall compounded by high discharges and inadequate drainage outlets. To sum up, except seven districts viz. Ambala, Karnal, Jhajjar, Sonipat, Rohtak, Faridabad and Palwal, all other districts were found in critical to over-exploited category of groundwater table depth (more than 10.0 m) during the year 2013.

For in-depth study of groundwater variability during 2013, data have been calculated on C.D. block level and depicted in Tables 6, 7, 8 and 9, while spatial variations are presented in Fig.4. On the basis of depth of groundwater table three types of areas have been identified:

i) Over-exploited Areas of Groundwater Table

Out of the total 118 blocks, 34 blocks comprising 28.8 per cent of the total blocks and 28.4 per cent of total area of the state, witnessed over-exploitation of ground water resources during 2013. All the five blocks of Kurukshetra and Mahendragarh districts, four blocks each of Fatehabad and Kaithal districts, three blocks each of Gurgaon and Sirsa districts; two blocks each of Rewari and Bhiwani districts and one block each of the Jind, Karnal, Mewat, Panipat, Yamunanagar and Panchakula districts

Table 6

Haryana: CD Blocks with Over-exploited Depth (More than 20.0 m) of Groundwater Table with Rise and Fall during 2004-13.

Name of Block	District	Depth of Groundwater Table 2013 (m)	Depth of Groundwater Table 2004 (m)	Rise 2004-13 (m)	Fall 2004-13 (m)
Badhra	Bhiwani	59.4	37.1	-	- 22.3
Loharu		58.0	44.1	-	- 13.9
Fatehabad	Fatehabad	29.5	12.7	-	- 16.8
Tohana		24.2	10.9	-	- 13.3
Ratia		31.9	18.9	-	- 13.0
Jakhal		29.9	10.9	-	- 19.0
Pataudi	Gurgaon	30.4	22.7	-	- 7.7
Gurgaon		33.2	19.1	-	- 14.1
Sohna		22.8	15.2	-	- 7.6
Alewa	Jind	24.7	15.3	-	- 9.4
Thanesar	Kurukshetra	32.2	20.9	-	- 11.3
Shahbad		39.2	26.5	-	- 12.7
Pehowa		30.9	20.9	-	- 10.0
Ladwa		28.5	21.7	-	- 6.8
Babain		35.6	25.6	-	- 10.0
Guhla	Kaithal	31.4	23.0	-	- 8.4
Kaithal		25.7	16.1	-	- 9.6
Pundri		22.0	13.5	-	- 8.5
Siwan		39.2	23.0	-	- 16.2
Nilokheri	Karnal	20.4	11.7	-	- 8.7
Ateli	Mahendragarh	63.6	35.4	-	- 28.2
Kanina		26.8	22.4	-	- 4.4
Mahendragarh		45.4	48.6	3.2	-
N. Chaudhary		41.0	30.4	-	- 10.6
Narnaul		57.2	45.2	-	-12.0
Taoru	Mewat	23.2	20.2	-	- 3.0
Panipat	Panipat	25.7	18.8	-	- 6.9
Barwala	Panchkula	22.9	11.4	-	- 11.5
Bawal	Rewari	23.1	20.1	-	- 3.0
Khol		50.6	11.6	-	- 39.0
Ellenabad	Sirsa	20.7	11.7	-	- 9.0
Sirsa		36.6	21.1	-	- 15.5
Rania		22.3	13.9	-	- 8.4
Radour	Yamunanagar	20.7	14.7	-	- 6.0

Source: Compiled by Authors

Table 7
Haryana: CD Blocks with Critical Depth (10.1 to 20.0 m) of Groundwater Table with Rise and Fall during 2004-13

Name of Block	District	Depth of Groundwater Table 2013 (m)	Depth of Groundwater Table 2004 (m)	Rise 2004-13 (m)	Fall 2004-13 (m)
Shahzadpur	Ambala	10.5	6.4	-	- 4.1
Barara		15.2	7.0	-	- 8.2
Naraingarh		14.8	9.9	-	- 4.9
Saha		13.6	9.9	-	- 3.7
Siwani	Bhiwani	18.0	20.4	2.4	-
Kairu		19.7	19.2	-	- 0.5
Faridabad	Faridabad	18.5	11.7	-	- 6.8
Ballabhgarh		14.1	8.4	-	- 5.7
Bhuna	Fatehabad	16.3	7.4	-	- 8.9
Farukh Nagar	Gurgaon	17.7	13.9	-	- 3.8
Hisar-II	Hisar	10.8	11.5	0.7	-
Narwana	Jind	12.5	8.3	-	- 4.2
Safidon		11.9	8.2	-	- 3.7
Uchana		14.4	10.6	-	- 3.8
Jind		16.0	11.5	-	- 4.5
Rajound	Kaithal	12.2	6.1	-	- 6.1
Karnal	Karnal	14.8	11.7	-	- 3.1
Indri		12.0	8.4	-	- 3.6
Gharaunda		19.7	14.0	-	- 5.7
Assandh		19.1	11.4	-	- 7.7
Nissing		19.9	12.1	-	- 7.8
F. Zirkha	Mewat	13.9	11.1	-	- 2.8
Israna	Panipat	10.6	6.8	-	- 3.8
Madlauda		11.8	8.7	-	- 3.1
Palwal	Palwal	18.1	7.0	-	- 11.1
Hassanpur		16.6	7.3	-	- 9.3
Hodel		14.5	6.7	-	- 7.8
Hathin		16.4	6.0	-	- 10.4
Raipur Rani	Panchkula	11.5	10.1	-	- 1.4
Morni		16.1	15.0	-	- 1.1
Jatusana	Rewari	12.2	13.2	1.0	-
Rewari		15.1	15.4	0.3	-
Nahar		13.8	13.7	-	- 0.1
Rai	Sonipat	13.4	12.5	-	- 0.9
Ganaur		18.6	11.1	-	- 7.5
Odhan	Sirsa	12.2	9.9	-	- 2.3
Dabwali		11.0	9.7	-	- 1.3
Baragudha		10.2	5.2	-	- 5.0
Jagadhari	Yamunanagar	15.8	11.2	-	- 4.6
Chhachhrauli		10.3	10.8	0.5	-
Mustafabad		13.1	8.7	-	- 4.4

Source: Compiled by Authors

Table 8

Haryana: CD Blocks with Safe Depth (3.1 to 10.0 m) of Groundwater Table with Rise and Fall during 2004-13

Name of Block	District	Depth of Groundwater Table 2013 (m)	Depth of Groundwater Table 2004 (m)	Rise 2004-13 (m)	Fall 2004-13 (m)
Ambala-I	Ambala	4.6	4.9	0.3	-
Ambala-II		5.4	4.9	-	-0.5
Dadri-I	Bhiwani	5.2	6.7	1.5	-
Dadri-II		9.9	10.3	0.4	-
Bawani Khera		3.8	6.6	2.8	-
Bhiwani		4.1	6.1	2.0	-
Tosham		8.7	10.6	1.9	-
Bhattu Kalan	Fatehabad	6.6	5.3	-	-1.3
Adampur	Hisar	8.6	7.6	-	-1.0
Barwala		6.9	7.5	0.6	-
Hansi-I		6.0	5.4	-	-0.6
Hansi-II		3.6	3.4	-	-0.2
Hisar-I		6.6	7.8	-	-1.2
Narnaud		9.3	7.0	-	-2.3
Agroha		9.4	7.9	-	-1.5
Uklana		6.8	6.4	-	-0.4
Julana	Jind	5.2	5.2	-	0.00
Pillukhera		5.8	4.5	-	-1.3
Bhadurgarh	Jhajjar	4.4	5.0	0.6	-
Jhajjar		6.5	6.7	0.2	-
Matanhail		6.1	8.4	2.3	-
Sahlawas		3.5	4.7	1.2	-
Kalayat	Kaithal	8.0	5.7	-	-2.3
Nuh	Mewat	5.1	4.2	-	-0.9
Nagina		5.8	6.1	0.3	-
Punhana		8.1	7.0	-	-1.1
Samalkha	Panipat	7.6	17.9	10.3	-
Bapoli		7.5	12.1	4.6	-
Pinjore	Panchkula	8.6	15.0	6.4	-
Rohtak	Rohtak	4.6	5.4	0.8	-
Meham		3.1	5.0	1.9	-
Kalanaur		3.1	5.0	1.9	-
Lakhan Majra		3.9	5.7	1.8	-
Sampla		3.6	5.0	1.4	-
Gohana	Sonipat	5.3	5.9	0.6	-
Kharkauda		4.8	4.2	-	-0.6
Sonipat		9.4	10.5	1.1	-
Mundlana		5.2	5.2	0.0	-
N.S. Chopta	Sirsa	8.5	8.1	-	-0.4
Bilaspur	Yamunanagar	7.9	7.6	-	-0.3
Sadhaura		8.5	4.7	-	-3.8

Source: Compiled by Authors

Table 9

Haryana: Waterlogged CD Blocks with Depth (0.0 to 3.0 m) of Groundwater Table with Rise and Fall during 2004-13

Name of Block	District	Depth of Groundwater Table 2013 (m)	Depth of Groundwater Table 2004 (m)	Rise 2004-13 (m)	Fall 2004-13 (m)
Beri	Jhajjar	3.0	4.4	1.4	-
Kathura	Sonipat	2.4	3.5	1.1	-

Source: Compiled by Authors

recorded over-exploitation of ground water resources during 2013 (Table 6; Fig 4). It is worth mentioning that Kurukshetra and Mahendragarh district remained under over-exploited category of groundwater resource throughout the study period.

ii) Areas under Critical Depth of Groundwater Table

Out of the total 118 blocks, 41 blocks comprising 34.7 per cent of the total blocks and 33.1 per cent of total area of the state recorded critical depth of ground water resources during 2013. Further, the analysis revealed that all blocks of Palwal (four) and Faridabad (two) districts are found under critical depth of groundwater table. Besides, five blocks of Karnal district, four blocks each of Ambala and Jind districts, three blocks each of Yamunanagar, Rewari and Sirsa districts, two blocks each of Sonipat, Panchkula, Panipat and Bhiwani districts and one block each of Mewat, Kaithal, Hisar, Gurgaon and Fatehabad districts witnessed critical depth of groundwater resources during the year 2013 (Table 7; Fig 4).

(iii) Areas with Safe Depth of Groundwater Table

Forty-three blocks accounting 36.3 per cent of the total blocks of the state have recorded 0-10 m depth of groundwater table which is considered safe for tube-well irrigation. It is interesting to note that five blocks each of Rohtak and Jhajjar districts remained in the safe zone throughout the study period. While, eight blocks out of the nine in Hisar district has safe limit of ground water depth. Likewise, five blocks each of Bhiwani and Sonipat districts; three blocks of Mewat district; two blocks each of Ambala, Jind, Panipat and Yamunanagar districts and one block each of Fatehabad, Kaithal, Panchkula and Sirsa districts were found to be in safe zone for tube-well irrigation (Table 8; Fig 4). However, it must be mentioned that Beri block of Jhajjar district and Kathura block of Sonipat district having developed water-logging conditions are included in this category (Table 9; Fig 4).

Further, it is interesting to note that Kurukshetra and Mahendragarh districts remained in over-exploited category throughout the study period, whereas Rohtak and Jhajjar districts were observed in safe category as a result of an increase in area under rising water table. Surprisingly, Ambala, Kaithal, Fatehabad, Hisar, Palwal and Gurgaon are continuously showing an increase in area under over-exploited category since the year 2004. Meanwhile, the worst affected districts pertaining to groundwater table depths were identified as Kurukshetra, Kaithal, Panchkula and Fatehabad as a result of intensive paddy-wheat rotation followed by farmers in these districts. The depletion of groundwater table depths in southern districts such as Mahendragarh, Rewari and Gurgaon can be attributed to steep urbanization and hard rock

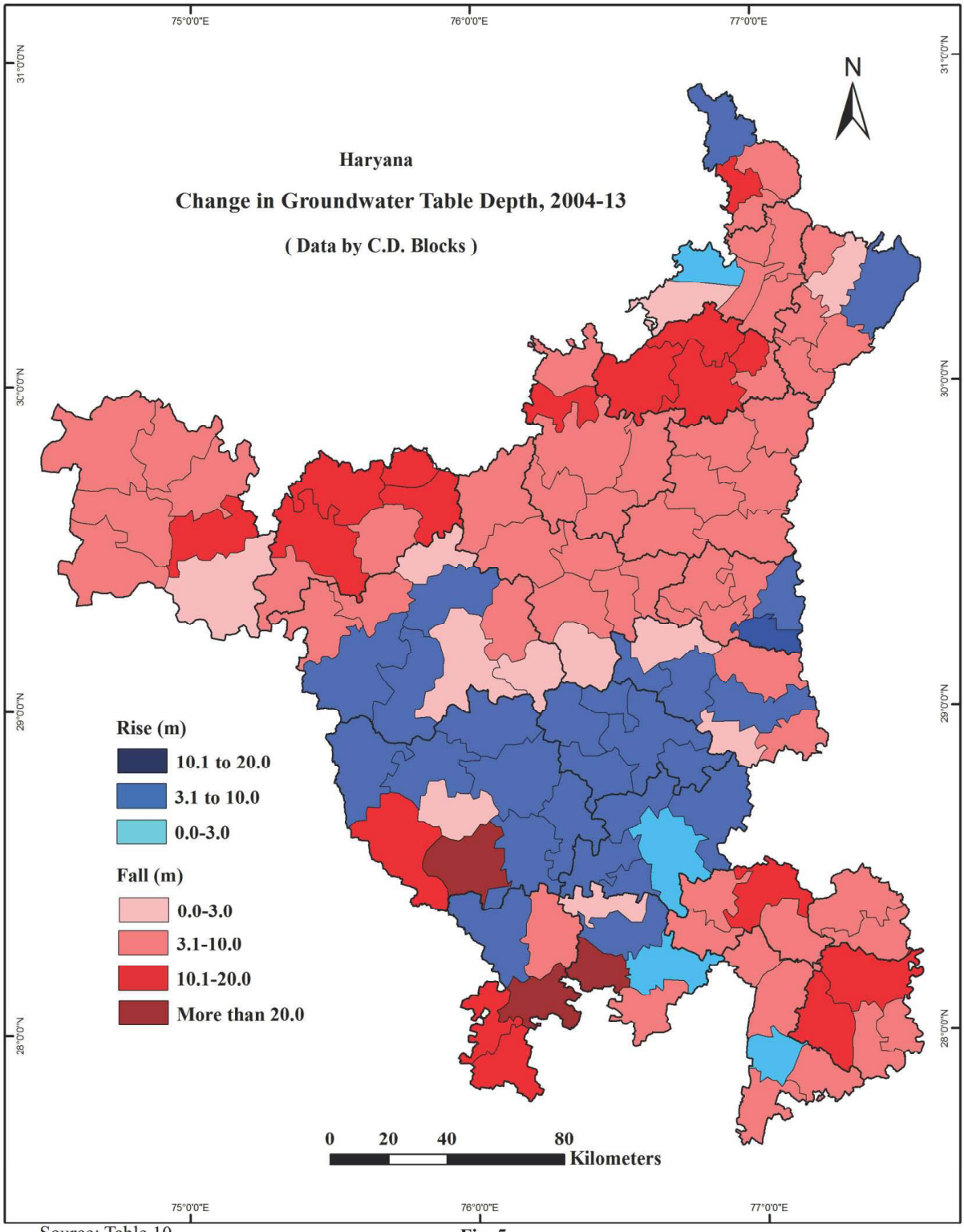
topography which allows less percolation of rainfall. Appreciably, parts of Hisar and Bhiwani districts and central districts such as Jhajjar and Rohtak are showing a rise in groundwater table depth and anomalously it can be attributed to poor quality of groundwater, intensive canal irrigation and bowl shaped topography of these districts encouraging percolation of rainwater.

Spatial Variations in Rise and Fall of Groundwater Table Depths, 2004-13

The average annual decline in groundwater table depth was found to be approximately 56.3 cm during 2004-2013 in the state (Table 2). Meanwhile, ten districts (about 50 % of total districts) of the state viz. Faridabad (69.0 cm), Fatehabad (134.0 cm), Gurgaon (92.0 cm), Kurukshetra (113.0 cm), Kaithal (113.0 cm), Karnal (67.0 cm), Mahendragarh (103.0 cm), Palwal (107.0 cm), Sirsa (66.0 cm) and Panipat (64.0 cm) indicated a fall of more than the state average of 56.3 cm during 2004-2013, whereas Jhajjar and Rohtak districts showed average annual rise in groundwater table depth to the tune of 12 cm and 16 cm, respectively. Besides, Hisar, Sonipat and Bhiwani districts exhibited an erratic trend in groundwater table depths with rising behaviour in 3-5 years out of ten years and falling water table in remaining years (Table 2). It was revealed from the analysis that Hisar district indicated a rise during 2005-06, 2006-07, 2008-09, 2010-11 and 2012-13, while it declined during 2004-05, 2007-08, 2009-10 and 2011-12. Almost similar trends in rise and fall of groundwater table depth were recorded in Bhiwani district during 2004-2013. On the other hand, Sonipat district showed a rise during 2004-05, 2007-08 and 2010-11, whereas a fall has been noticed during 2005-06, 2006-07, 2008-09, 2009-10, 2011-12 and 2012-13 (Table 2).

The area under over-exploited and critical groundwater table depth (more than10.0 m) has increased in almost all the districts with the worst affected being Kurukshetra and Mahendragarh districts having 100 per cent area under over-exploited category, whereas Rohtak district was found in safe category which can be attributed to canal water seepage and poor groundwater quality in the district. Palwal district showed 100 per cent change in groundwater table depth area from safe to critical category. Accordingly, Gurgaon, Rewari, Faridabad and Karnal districts witnessed 100 per cent area under critical to over-exploited category. However, the per cent change in area beyond over-exploited and critical groundwater table depth (more than 10.1 m) was observed as 86, 85, 73, 64 and 59, per cent in the districts of Fatehabad, Kaithal, Yamunanagar Panipat and Ambala, respectively indicating that these districts are facing sharp decline of groundwater resources. Therefore, these districts require urgent attention on behalf of policy makers in the state. The water logged area (0.0 to 3.0 m) had increased by 9.0 per cent in Sonipat district, while Jhajjar district demonstrated an increase of 17.0 per cent during 2004-2013 (Table 5).

For in-depth study, taking into account the depth of groundwater table, CD block-wise average annual rise and fall in groundwater table depth under different categories (over-exploited, critical, safe and waterlogging conditions) has been computed and the obtained results have been presented in Table 10; Fig. 5. It was revealed from the analysis that Khol block in Rewari (39.0 m), Ateli block in Mahendragarh (28.2), Badhra block in Bhiwani (22.3 m) and Jakhal block in Fatehabad district (19.1 m) indicated a maximum fall in groundwater table depth under over-exploited



Source: Table 10

Fig. 5

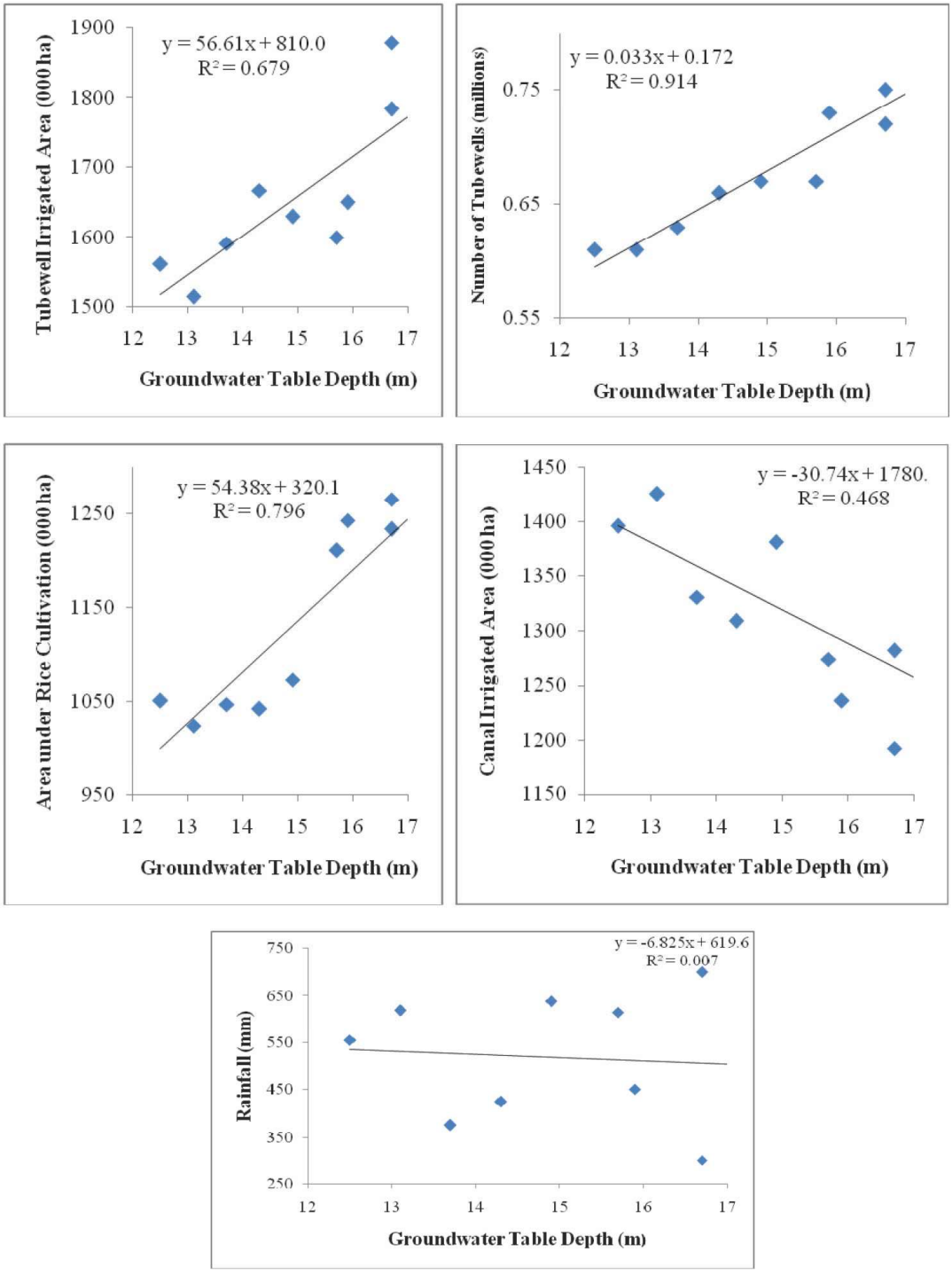
Table 10

Haryana: C D Blocks according to Rise and Fall of Groundwater Table, 2004-13

Rise (m)			Fall (m)			
0.0-3.0	**3.1-10.0**	**10.1-20.0**	**0.0-3.0**	**3.1-10.0**	**10.1-20.0**	**> 20.0**
Siwani	Mahendragarh	Samalkha	Taoru	Pataudi	Loharu	Badhra
Hisar II	Bapoli	-	Bawal	Sohna	Fatehabad	Ateli
Rohtak	Pinjore	-	Kairu	Alewa	Tohana	Khol
Jatusana	-	-	Firozpur	Pehowa	Ratia	-
Rewari	-	-	Raipur Rani	Ladwa	Jakhal	-
Chhachhrauli	-	-	Morni	Babain	Gurgaon	-
Ambala I	-	-	Nahar	Guhla	Thanesar	-
Dadri I	-	-	Rai	Kaithal	Shahbad	-
Dadri II	-	-	Odhan	Pundri	Siwan	-
Bawani	-	-	Dabwali	Nilokheri	N.Chaudhary	-
Bhiwani	-	-	Ambala II	Kanina	Narnaul	-
Tosham	-	-	Bhattu Kalan	Panipat	Barwala	-
Hansi I	-	-	Adampur	Ellenabad	Sirsa	-
Hisar I	-	-	Hansi II	Rania	Palwal	-
Bhadurgarh	-	-	Hisar I	Radour	Hathin	-
Jhajjar	-	-	Narnaund	Shahzadpur	-	-
Matanhail	-	-	Agroha	Barara	-	-
Sahlawas	-	-	Uklana	Naraingarh	-	-
Nagina	-	-	Julana	Saha	-	-
Meham	-	-	Mundlana	Faridabad	-	-
Kalanaur	-	-	Pillukhera	Ballabhgarh	-	-
Lakhanmajra	-	-	Kalayat	Bhuna	-	-
Sampla	-	-	Nuh	Farukh	-	-
Gohana	-	-	Punhana	Narwana	-	-
Sonipat	-	-	Kharkhauda	Safidon	-	-
Beri	-	-	N S Chopta	Uchana	-	-
Kathura	-	-	Bilaspur	Jind	-	-
-	-	-	Sadhaura	Rajound	-	-
-	-	-	-	Karnal	-	-
-	-	-	-	Indri	-	-
-	-	-	-	Gharaunda	-	-
-	-	-	-	Assandh	-	-
-	-	-	-	Nissing	-	-
-	-	-	-	Israna	-	-
-	-	-	-	Madlauda	-	-
-	-	-	-	Hassanpur	-	-
-	-	-	-	Hodel	-	-
-	-	-	-	Ganaur	-	-
-	-	-	-	Baragaudha	-	-
-	-	-	-	Jagadhari	-	-
-	-	-	-	Mustfabad	-	-

Source: Tables 6, 7, 8 and 9

Haryana: Relationship between Depth of Groundwater Table and Tube-well Irrigated Area, Number of Tube-wells, Area under Rice Cultivation, Area under Canal Irrigation and Amount of Rainfall



Source: Compiled by authors **Fig. 6**

Table 11
Haryana: Correlation Matrix between Various Indicators

Parameters	Groundwater Table Depth	Tube-well Irrigated Area	Number of Tube-wells	Area under Rice Cultivation	Canal Irrigated Area	Amount of Rainfall
Groundwater Table Depth	1					
Tube-well Irrigated Area	.824**	1				
Number of Tube-wells	.961**	.840**	1			
Area under Rice Cultivation	.892**	.706*	.850**	1		
Canal Irrigated Area	-.684*	-.705*	-.671*	-.765**	1	
Amount of Rainfall	-.086	-.354	-.235	-.002	.487	1
**. Significant at the 0.1 percent level						
* . Significant at the 0.5 percent level						

Source: Compiled by authors

category blocks in Haryana during the study period. Meanwhile, Palwal (11.1 m), Hathin (10.4 m) and Hasanpur (9.3 m) blocks in Palwal district, Bhuna in Fatheabad (8.9 m) and Barara in Ambala district (8.2 m) recorded the maximum fall in groundwater table depth under critical category of blocks. On the other hand, Samalkha (10.3 m) and Bapoli (4.6 m) blocks in Panipat district and Pinjore (6.3 m) in Panchkula district showed a rise in groundwater table depth under the blocks of safe category, thereby indicating towards the water logging conditions.

Testing of the Hypotheses

In the present study, all the formulated hypotheses stand proved graphically and statistically (Table 11; Fig. 6). Graphically, fall in groundwater table is significantly correlated (positive) with tube-well irrigated area, number of tube-wells and area under rice cultivation (R^2 being 0.66, 0.90 and 0.72, respectively), whereas it is inversely and non-significantly related with area under canal irrigation and the amount of rainfall (R^2 being 0.37 and 0.00, respectively). Statistically also, groundwater table depth has been found positively correlated at 0.1 per cent level of confidence with tube-well irrigated area, number of tube-wells and area under rice cultivation (Table 11). The study also proves that groundwater table depth and canal irrigated area are inversely related (-.684) and found significant at the 0.5 per cent level. Likewise, the assumption higher the amount of rainfall lesser will be the depth of groundwater table also stands proved but could not reach up to any level of significance.

Major Observations

- Groundwater table in the state has fallen at the rate of 56.3 cm/year during the study period of 2004-13.
- The worst affected districts in groundwater depletion have been identified as Kurukshetra, Mahendragarh, Kaithal, Rewari, Gurgaon, Fatehabad, Palwal and Panchkula.

- All the 5 blocks of Kurukshetra and Mahendragarh districts were found to be in over-exploited category throughout the study period. Conversely, all the 5 blocks of Rohtak district remained in the safe category (3.1-10.0 m) during 2004-13.
- All the 4 blocks of Palwal district shifted from the safe category to critical category during the study period.
- Maximum decline in the depth of water table during the study period have been recorded by Fatehabad (134.0 cm), followed by Kaithal and Kurukshetra districts (113.0 cm each) and Palwal (107 cm).
- There was not even a single block in over-exploited category in Fatehabad district during the year 2004, whereas out of 6 blocks, 4 blocks emerged over-exploited during 2013.
- Deepest groundwater table has been observed in Badhra (62.4 m in 2012), while the lowest in Kathura (2.4 m in 2013) blocks of Bhiwani and Sonipat districts, respectively.
- Area under safe category (3.1-10.0 m) has declined from 2110 thousand ha in 2004 to 1652 thousand ha in 2013 recording a growth rate of - 21.6 per cent, while area under over-exploited category (>20.0 m) has increased from 735 thousand ha to 1254 thousand ha during the same period recording a growth rate of 70.5 per cent.
- Similarly, number of blocks in safe category has declined from 58 in 2004 to 43 in 2013, on the other hand, under over-exploited category their number has increased from 20 to 34 during the same period.
- Out of the total 118 blocks 34 blocks were found to be in over-exploited category, while 41 blocks recorded critical depth (10.1-20.0 m) of groundwater table in 2013. In other words, 61.5 per cent of the total blocks recorded critical level of groundwater table depth in 2013.
- Kurukshetra and Mahendragarh districts remained under over-exploited category, whereas Jhajjar and Rohtak districts in central part exhibited an increase in area under rising groundwater table depth during 2004-13.
- Fall in groundwater table is significantly correlated with tube-well irrigated area, number of tube-wells and area under rice cultivation, whereas it is inversely related with area under canal irrigation and the amount of rainfall.

Suggestions

- Khol, Ateli, Badhra and Jakhal blocks indicated a maximum fall of groundwater table depth of 39.0, 28.2, 22.3 and 19.1 m, respectively. These blocks should be treated under SOS (Save our souls) category for groundwater management.
- Palwal, Hathin, Hassanpur, Bhuna and Brara blocks recorded maximum fall under critical category of blocks, registering a groundwater table depth of 11.1, 10.4, 9.3, 8.9 and 8.2 m, respectively; hence, if adequate measures are not taken, these blocks may shift to over-exploited category in near future.
- Samalkha, Bapoli and Pinjore blocks are indicating towards water logging conditions, therefore, these blocks should also be taken care so that these

may not become unfit for agriculture in near future.

- The inverse relationship between area under canal irrigation and depth of groundwater table suggests that areas falling under critical depth of water table need to be brought under the canal irrigation.
- The study suggests that there is a need to reduce area under rice cultivation to check the depletion of groundwater resources; therefore, more stress should be given on crop diversification, particularly in areas falling under critical depth of groundwater table.
- Since each and every block has its own problem related to groundwater behaviour, therefore, groundwater management cells should be created in each block for sustainability of agriculture.

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