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RESEARCH ARTICLE

Variability Analysis of Groundwater Levels – A GIS-Based Case Study

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Abstract The present study has analyzed the variability in depth to water level below ground level (bgl) vis-à-vis groundwater development and rainfall from 1987 to 2007 in agriculture dominated Kaithal district of Haryana state in India. Spatial distribution of groundwater depth was mapped and classified into different zones using ILWIS 3.6 GIS tools. Change detection maps were prepared for 1987-1997 and 1997-2007. Groundwater depletion rates during successive decades were compared and critical areas with substantial fall in groundwater levels were identified. Further, block wise trends of change in groundwater levels were also analyzed. The water table in fresh belt areas of the district (Gulha, Pundri and Kaithal blocks) was observed to decline by a magnitude ranging from 10 m to 23 m. In Kalayat and Rajaund blocks, the levels were found fluctuating in a relatively narrow range of 4-9 m. During 1997-2007, the depletion has been faster compared to the preceding decade. Excessive groundwater depletion in major part of the district may be attributed to indiscriminate abstraction for irrigation and decrease in rainfall experienced since 1998. Changes in cropping pattern and irrigation methods are needed in the study area for sustainable management of the resource.

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Introduction

Groundwater may be defined as water occupying all the voids within a geologic stratum (Todd and Mays, 2005). The groundwater levels respond slowly to changes in weather and can take months or years to replenish once pumped for irrigation or other uses. Abstraction of groundwater exceeding natural replenishment generates stress in the aquifers causing depletion of water table, changes in the direction and velocity of groundwater flow, increased cost of abstraction and ecological damage. The environmental effects may include deterioration of water quality, loss of vegetation, land subsidence, inland ingress of saline water in coastal regions, reduction of porosity, etc. (Biswas, 2003). The formation of regional depressions of potentiometric levels in several aquifer systems have been observed due to excessive groundwater use. Therefore, the risks related to groundwater levels are a cause of serious concern in water resource management (Custodio, 2002). Surface water and groundwater are important components of the hydrological cycle and are interdependent. The management of these resources plays a key role in conserving the sustainable conditions, particularly in arid and semi-arid regions.

Over the years, demand for freshwater has increased many folds. Greater domestic water needs, changes in cropping pattern, use of hybrid seeds and chemical fertilizers, increase in area under irrigation, rapid industrialization and climate change have contributed to this increase. The rise in groundwater use along with increase in intensity of surface water supply has helped in bringing green revolution in the north western region of India. Simultaneously, this has also resulted in a trend of falling groundwater levels which are dynamic and fluctuate due to both short-and-long term trends and stresses such as pumping and climatic conditions. Depth to water level (bgl) provides critical hydrological information about discharge, recharge and storage within an aquifer. Long-term groundwater level data are essential to develop groundwater models and to design, implement and monitor the effectiveness of groundwater monitoring programs (Taylor and Alley, 2001). Precise estimation of ground water levels, their variability, climatic conditions and groundwater development are vital for scientific planning and sustainable management of the resource. This requires handling of large quantity of spatial and non-spatial data. Geographical information system (GIS) is a useful tool and is being used widely in such cases where spatial data are involved (Chaudhary *et al.,* 1996).

Kaithal district of Haryana is an agriculture dominated area which has been facing the problems of depleting levels in its fresh groundwater quality belt. At the same time, rising water table and salinity conditions are prevailing in certain pockets in southern parts of the district. In 2001-02, net irrigated area in the district was 1,852 km^2, out of which, 521 km^2 (40%) was irrigated by surface water and 1,331 km^2 (60%) with groundwater (Statistical Abstract, 2009). Due to heavy dependence on groundwater to meet its huge irrigation needs, the sustainability of the resource is a major concern in the district. Hence, there is a need for a systematic and detailed study of groundwater levels and the factors (both anthropogenic and natural) affecting its dynamics and resulting in negative effects to the environment. Therefore, the objective of the present study has been to analyze long-term variability in groundwater levels, its relation with rainfall, groundwater development, and possible consequences in the Kaithal district.

Materials and methods

Study area

Haryana state, located in north-west of India is one of the smallest states in India constituting 1.3% of country‘s total geographical area. Yet, its share in country‘s total food production has been more than 6%. The state is chronically deficient in water resources. The present requirement of water for irrigation in the state is much more than the available surface and subsurface resources. Kaithal district, carved out by reorganization of the state in 1989, is located between 29^o 32’ to 30^o 12’N latitude and 76^o 08’ to 76^o 45’ E longitude in north-western part of the state. The district comprised of five blocks-Gulha, Kaithal, Pundri, Kalayat and Rajaund (Fig. 1). In 2001, it had a population of 946,131 which had observed a growth of 21% during 1991-2001. Out of total area of 2,284 km^2, the net sown area in 2006-07 was 2,020 km^2

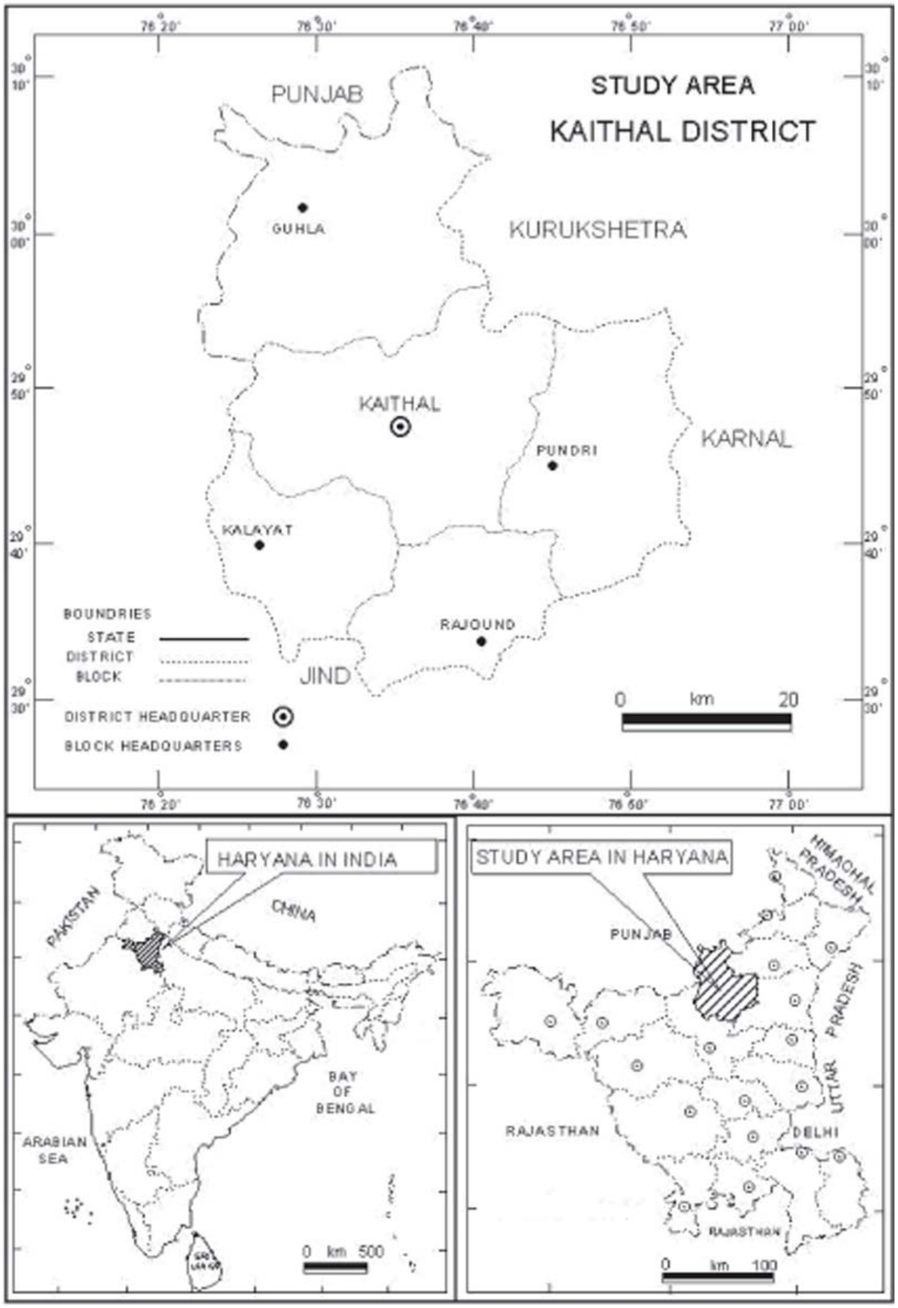

Fig. 1 Location map of study area

(88.4%), which accounted for around 15% of rice and 8% of total wheat production of the state (Statistical Abstract, 2009).

Physiography, soil and climate

The entire region is covered by alluvial deposits of quaternary to recent age, consisting of clay and sand. Kankar, gravel, cemented and unconsolidated sand are also found in the beds. The elevation varies from 217 to 252 m from mean sea level showing a gentle slope from north-east to south-west. Physiographically, the district may be divided into two units – the upland plain (Gulha, Kaithal and Pundri blocks) and the low lying area (Kalayat and Rajaund blocks). The low lying area lies on the topographical depression existing in the state with axis passing though Delhi – Rohtak – Hisar and Sirsa. In upland areas, the soil texture varies from sandy loam to loam on the surface and from loam to clay loam/silty clay loam in the subsurface. In the low lying areas, the soils are poorly drained and soil texture varies from loam to clay loam or silty clay.

The climate is sub-tropical monsoon type with seasonal rhythm, hot summer and cold winter. The temperature starts rising from March and continues till June end. May and June are hottest months with daily maximum temperature at about 40^0C. Temperature sometimes may rise to 45^0C. During winter, the temperature starts decreasing by mid November. January is the coldest month. Average annual rainfall in the district is 528 mm.

Irrigation

The district represents a prosperous agricultural area irrigated by canals and wells. Due to dominance of paddy and wheat in the cropping pattern, there is severe stress on these sources. Ghaggar - a seasonal river, flows through the northern part of the district. Sirsa branch of Western Jamuna Canal (WJC) forms the canal drainage pattern with a network of distributaries and minors supplying surface water in the district. However, dependence has been more on groundwater. Though, the total number of tube wells remained almost unchanged (57,120 in 2007 against 57,405 in 1990), there has been immense increase in overall abstraction due to increased average discharge with the replacement of the shallow centrifugal pumps by deep, heavy duty submersible systems.

Data used and methodology

Data used

Survey of India topographical sheets on 1:50,000 scale were used to prepare the base map. Historical rainfall data was obtained from District Revenue Officer, Kaithal. The groundwater level data from 1987 to 2007 for June (pre-monsoon) has been derived from routine monitoring of 79 observation wells by Groundwater Cell, Department of Agriculture, and Government of Haryana. Collateral data pertaining to agricultural practices and irrigation was also collected from the published literature.

Methodology

Boundary map of Kaithal district was digitized in ILWIS 3.6 GIS environment. Locations of observation wells were digitized to prepare the well location map. Depth to water level (bgl) data was attached in the form of the attribute table to the well location point map. Point interpolations were carried out using moving average method (inverse distance) to obtain spatial distribution maps for groundwater depth in the study area. Slicing of the maps was performed in 0-3, 3-10, 10-30 and 30-45 m depth zones. Histograms for each thematic map were generated to calculate the area under each depth zone. Difference maps and cross maps were generated using MAPCALCULATE in ILWIS 3.6 to analyze depletion rate and to delineate overexploited and critical areas. Further, graphs were prepared to show the relationship between rainfall and groundwater levels changes.

Results and discussion

Spatial variability

Spatial variations of groundwater levels at intervals of five years from 1987 to 2007 have been shown in

(Fig. 2). The area under different depth zones has been determined from these maps (Table 1). Comparison of 1992, 1997, 2002 and 2007 maps revealed a spatially non-uniform groundwater level decline. Whereas a regular decline was seen in more than 70% of the area (maximum in north-western region), the levels were found fluctuating in a rather narrow and shallow range

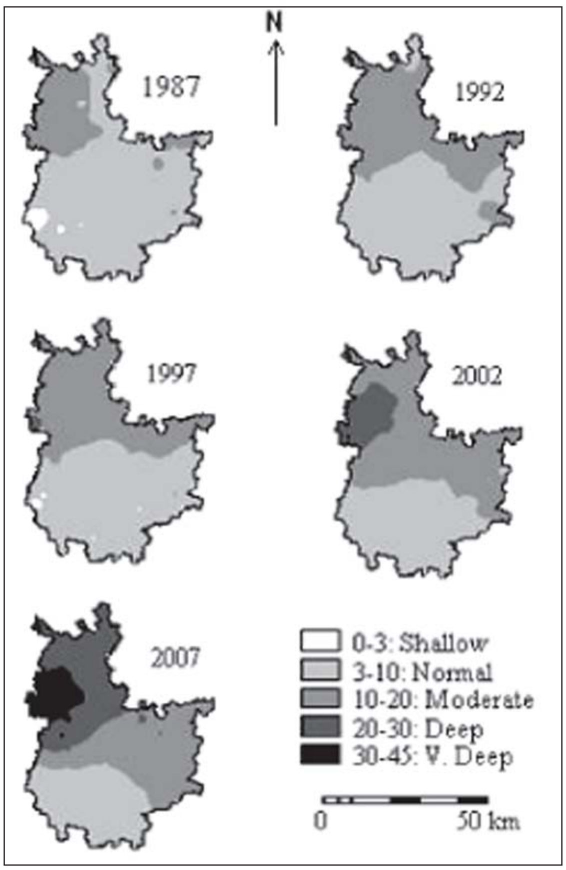

Fig. 2 Spatial variation of groundwater depth in Kaithal district from 1987 to 2007

of 4-9 m in the remaining part (southern region of the district). The observed hydrological anisotropy may be attributed to physiographic variations in the district.

To analyze the block wise-trends, the average pre-monsoon depth to water level (bgl) for each block has been plotted from 1987 to 2007 (Fig. 3). In Gulha block, the rate of decline in levels was found to be maximum (0.81m/year) followed by Kaithal and Pundri blocks (0.51 and 0.38 m/year respectively). However, in Kalayat and Rajaund blocks, the groundwater levels were almost stable. The overall district average of depth to water level (bgl) declined from 7.46 m in 1987 to 14.93 m in 2007 (0.37 m/year). This observation is consistent with a recent study based on Gravity Recovery and Climate Experiment (GRACE), which has reported an average decline of 0.3 m in groundwater levels in northern India (Rodell *et al.,* 2009).

The groundwater depletion in each block at successive intervals of five years is given in Table 2. During 198-1992, the decline in groundwater levels in all the blocks was observed to be small (district average: 1.38 m). In the next five years (1992-1997), a net rise was observed in groundwater levels, possibly due to increased recharge caused by the floods in

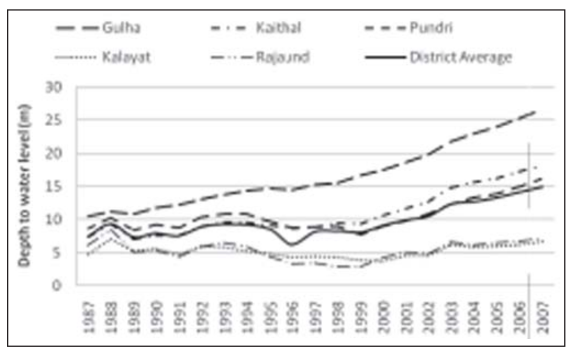

Fig. 3 Block wise trend of average depth to water level (bgl)

1995. In successive spans of 1997-2002 and 2002-2007, the levels have shown decline at regularly increasing rates. Less rainfall during this period seemed to have contributed to this decline.

Identification of different depth zones

The resultant map (Fig. 4) was obtained by carrying out cross operation in ILWIS on spatial variability maps of 1987 and 2007. This map shows the classification of the district into zones of different categories of change in groundwater depth. The

Table 1 Area under different depth zones (1987-2007)

Year	0-3 m		3-10 m		10-20 m		20-30 m		30-40 m	
	(km^2)	%	(km^2)	%	(km^2)	%	(km^2)	%	(km^2)	%
1987	37.5	1.64	1735	75.96	511	22.37	0	0	0	0
1992	0	0	1242	54.38	1042	45.62	0	0	0	0
1997	10	0.44	1278	55.95	983	43.04	13	0	0	0
2002	0	0	909	39.8	1138	49.82	234	10.25	1	0.04
2007	0	0	657	28.76	808	35.38	627	27.45	191	8.36

Table 2 Block-wise average depth to water level and groundwater depletion

Blocks	Average pre-monsoon depth (m)					Decline in successive five years (m)				Decline 87-07 (m)	Av. annual decline (m)
	1987	1992	1997	2002	2007	87-92	92-97	97-02	02-07		
Gulha	10.5	13.1	15.25	19.76	26.71	2.6	2.15	4.51	6.95	16.2	0.81
Kaithal	7.32	8.94	8.9	12.64	18.12	1.62	-0.4	3.74	5.48	10.8	0.54
Kalayat	4.79	5.92	4.42	4.55	6.58	1.13	-0.5	0.13	2.03	1.8	0.09
Pundri	8.6	10.36	8.83	10.88	16.13	1.76	-1.53	2.05	5.25	7.6	0.38
Rajaund	6.08	5.89	3.4	4.81	7.12	-0.19	-2.49	1.41	2.31	1	0.05
District Average	7.46	8.84	8.16	10.53	14.93	1.38	-0.68	2.37	4.4	7.47	0.37

corresponding areas and per cent areas have been given in Table 3. About 27% of the total district area falling under Kalayat and Rajaund blocks depicted no change in groundwater levels. Pundri block, parts of Kaithal and Gulha blocks constituting about 45% of total area showed a moderate change. Large change in depth was observed in about 16% of the district area falling in Gulha and Kaithal blocks. A pocket (about 8% of district area) was identified to be in critical condition in western part of Gulha block touching the Punjab boundary with decline in groundwater levels from 10-20 m range in 1987 to 30-45 m range in 2007. The depletion in this part has exceeded 20 m in a period of 20 years. Fig. 5 shows the temporal variation of groundwater levels in four representative observation wells in 'critical' area. The decline had been so fast that if this trend were not

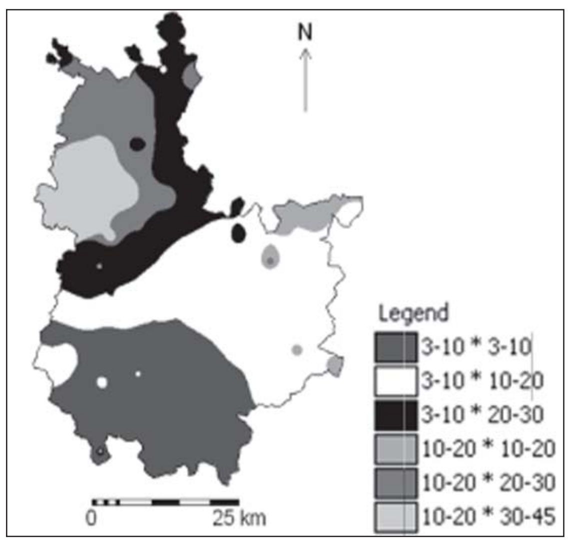

Fig. 4 Zones of different extent of decline in groundwater depth

Table 3 Blocks lying in different categories of groundwater level change

S. No.	Range of depth (m)		Change class	Blocks	Area (%)	Area (km^2)
	1987	2007				
1	3-10	3-10	No change	Kalayat, Rajaund	27.07	618
	10-20	10-20		Pundri	2.98	68
2	0-3	3-10	Moderate	Kalayat	1.64	37
	3-10	10-20		Kaithal, Pundri	32.41	740
	10-20	20-30		Gulha	11	251
3	3-10	20-30	Large	Gulha, Kaithal	16.46	375
4	10-20	30-45	Critical	Gulha	8.35	190

checked, consequences may include collapse of agricultural output and severe shortage of potable water in the area. The general depletion of water table in the district may be due to increased cultivation of paddy (which requires a lot of water). The area under cultivation of rice has increased from 109,000 ha in 1989-90 to 151,000 ha in 2006-07. Besides, cultivation of two paddy crops in the Kharif season practiced during the last decade aggravated the problem in certain areas. As the transplantation timing of early variety (summer paddy or Saathi) is from last week of April to mid of May (before the onset of monsoon), the dependence on groundwater has resulted in increased decline of groundwater levels. Despite

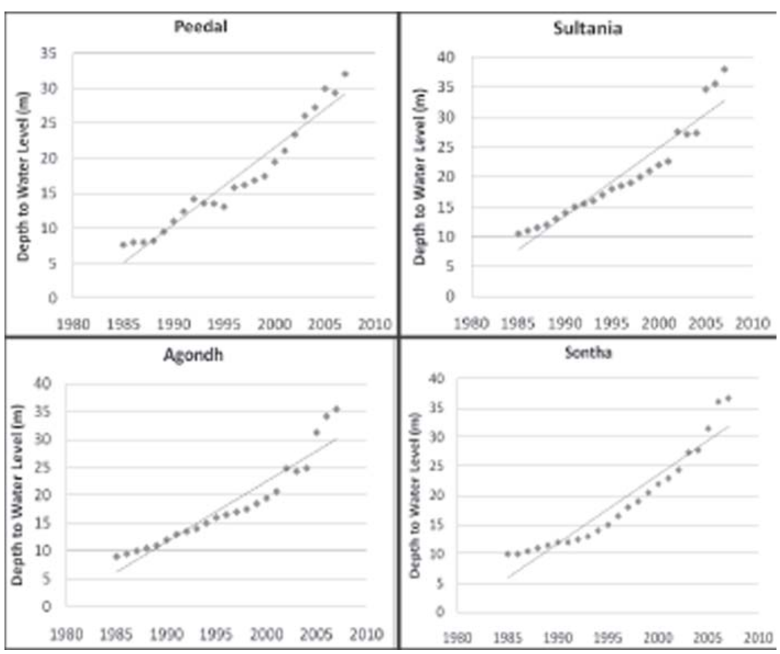

Fig. 5 Temporal variation of groundwater levels in some villages from critical area of Gulha block

imposition of ban on Saathi, its cultivation in certain remote areas goes on unchecked (Yadav *et al*., 2008). The alarming depletion observed in north-western part of the district could be attributed to this reason.

Groundwater levels and annual rainfall

As the annual replenishment of the aquifer primarily depends on rainfall, thus the groundwater level changes might be correlated with the variations in precipitation amounts. Therefore, groundwater depth (pre-monsoon) and annual rainfall have been plotted versus year for the considered period (Fig. 6). The effect of heavy rain falls in 1988, 1990, 1994, 1995 and 1997, on the depth to water level (bgl) after slight time lag (recharge time) is quite visible. The best fit regression lines were drawn to depict the trends of rainfall and groundwater levels. The slopes of these lines appear to suggest that the decreasing trend of rainfall over the last 20 years has contributed significantly to the observed increasing trend in groundwater depletion besides other factors.

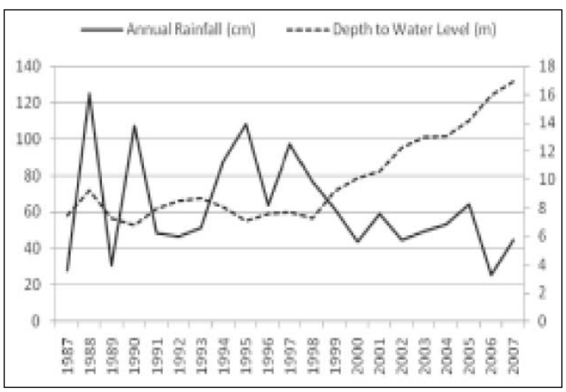

Fig. 6 Trend of average depth to water level (bgl) vis-a-vis annual rainfall in Kaithal district

Groundwater depletion rate

The amount of groundwater depletion occurred in two successive decades has been compared in 1997-1987 and 2007-1997 (Fig. 7). It was observed that the decline during the earlier decade was from small (up to 3 m) to moderate (3-10 m). On an average, the depletion of water table in the district was found fluctuating between 7–9 m. The decline in the next decade was large (10-15 m) to critical (>15 m).

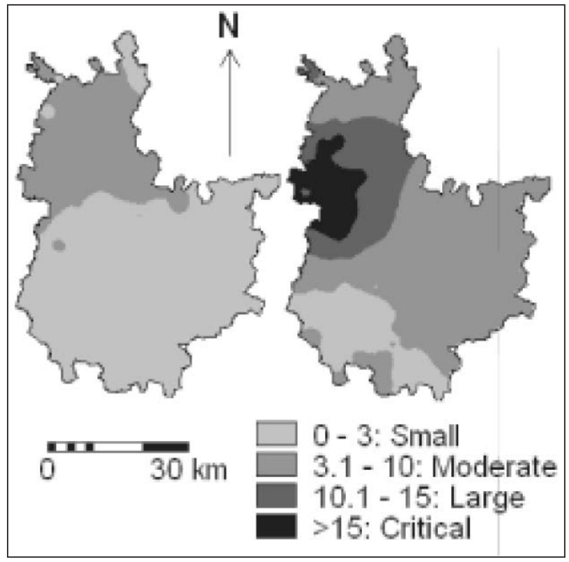

Fig. 7 Comparison of groundwater depletion during 1987-97 and 1997-2007

The regular decline of groundwater levels was conspicuous since 1999, with decrease in precipitation after 1999 supporting the decline (Fig. 6). Therefore, definite relationships between atmospheric precipitation and temporal and spatial variations of groundwater level existed which can be further investigated for in future research. .

Groundwater balance and scope

The net availability of water for recharge from all sources, net draft, groundwater balance and development in the study area for 1991 and 2004 are given in Table 4. It is evident that during 1991, Gulha and Pundri blocks had negative water balance whereas, it was positive in other blocks of the district. There had been increase in net draft in the district form 63,094 ha m in 1991 to 100,584 ha m in 2004 whereas, net availability had decreased from 89,768 ha m to 56,312 ha m in the corresponding period. As a result, the water balance in 2004 was found to be negative. The groundwater development of the district

Table 4 Groundwater development in Kaithal district (1991-2004)

Block	Net availability (ha m)		Net draft (ha m)		Groundwater balance (ha m)		Groundwater development (%)	
	1991	2004	1991	2004	1991	2004	1991	2004
Gulha	10730	13590	13029	26479	-2299	-12889	121	194
Kaithal	27778	13618	23714	23404	+4063	-9786	85	174
Kalayat	25009	5819	5544	8141	+19464	-2322	22	140
Pundri	15156	15489	19756	27306	-4600	-11817	130	176
Rajaund	11093	7796	1049	15254	+10044	-7458	9	195
District	89768	56312	63094	100584	+26673	-4427	70	179

Source: Groundwater Cell, Govt. of Haryana, Kurukshetra

is around 180% meaning thereby that entire district was overexploited during 2004. The situation has further aggravated since then. On account of over exploitation of dynamic resource potential of shallow aquifer, there is no potential available for further development in the district.

Conclusions

Groundwater depletion is a key issue related to its use. Results obtained from the analysis revealed that the district is suffering from the acute problem of groundwater depletion. A part of the Gulha block along Punjab border was found to be critically affected. The depletion rate accelerated during the last decade due to increased stress on irrigation and a decreased rainfall. Similar trends if continued may result in severe shortage of fresh water, thereby causing reduced agricultural productivity, extensive socio-economic stresses, conflicts and sufferings in the region. Critical areas need judicious management for using the current water resources efficiently. Change in the cropping pattern, establishment of water harvesting systems is urgently required in order to improve the water balance. Moreover, application of modern irrigation techniques like drip irrigation system and sprinkler irrigation system, are needed to be encouraged. Special attention is required on the southern and south-western part of the district for evolving strategy where the groundwater is saline and rising at many places due to inadequate withdrawal of water.

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