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GIS based study of Spatio-Temporal changes in groundwater depth and quality in Kaithal district of Haryana, India

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ABSTRACT

The study has analyzed the spatio-temporal changes in groundwater depth and quality from 1992 to 2007 in Kaithal district of Haryana state to understand the hydrological behavior and status of the area. Pre- and post- monsoon depth to water level below ground level (bgl), electrical conductivity (EC) and Landsat remote sensing data were used in the study. Spatial distribution of depth and EC in the study area were mapped and classified into standard zones in GIS environment for 1992, 1997, 2002 and 2007. Change detection maps, seasonal fluctuation maps and groundwater prospects maps were generated using cross and difference operations in Integrated Land and Water Information System (ILWIS 3.6) to identify critical as well as potential groundwater zones in the district. The study revealed a decline in average groundwater depth from 9 m bgl in 1992 to 16 m bgl in 2007. Average EC of groundwater in the district was also found to degrade from 1722 μS/cm to 2267 μS/cm in the corresponding period. The changes in depth and quality were more prominent in two-third part of the district (upland plains) under Gulha, Siwan, Kaithal and Pundri blocks. In the remaining low lying part in southern region, depth and EC were almost stable in 3-10m and 2500-9000 μS/cm range respectively. Due to high EC (>4000 μS/cm), the groundwater in a part of Rajaund block was found unsuitable for irrigation. Also, it had low public acceptability for drinking. Entire Pundri block along with a part of the adjoining Kaithal block (about 32% of total area) was identified as the zone of good groundwater prospects. Western part in Siwan block (about 8% of total area) was found critical due to fast depleting groundwater levels. The depletion of levels and worsening of groundwater quality in general, can be attributed to over-exploitation of groundwater and excessive use of agrochemicals in addition to natural factors. High EC (2500-9000 μS/cm) and a nearly shallow water table observed in Rajaund and Kalayat blocks can be understood to be a combined effect of inadequate groundwater withdrawal, poor drainage conditions, effect of leaching, and geohydrological setting of the area.

INTRODUCTION

In arid and semi-arid regions, irrigation is the lifeline of agriculture and has assumed greater importance with induction of modern technology particularly after the introduction of high yielding varieties of seeds, chemical fertilizers, pesticides, insecticides etc. With the advent of green revolution, the groundwater use in agriculture has increased by a greater proportion as compared to surface water. As a result, levels have declined significantly in north-western region of the country. The lowering of groundwater levels has resulted in reduction in individual well yield, growth in well population, failure of bore wells, drying up of dug wells and increase in power consumption (Imtiyaz & Rao 2008). Moreover, over-exploitation, excessive agriculture, untreated effluents and wastes have caused deterioration in groundwater quality. Whereas paucity of clean drinking water can affect the general health and life expectancy of people (Nash & McCall 1995), the use of poor quality water in irrigation can degrade the soils due to contamination (Palaniswami & Ramulu 1994; Datta et al., 2000; Patel et al., 2004; Marechal et al., 2006). Thus, the issue of availability and sustainability of safe groundwater is of great importance and calls for a scientific action plan to ensure water security in the region.

Groundwater is often developed without proper understanding of its occurrence in time and space and is, therefore, threatened by over-exploitation and contamination. For that reason, groundwater management is the key to combat the emerging problem of water security. Knowledge of water table depth is a crucial element in many hydrological investigations, including agricultural salinity management, landfill characterization, chemical seepage movement, and water supply studies (Buchanan &Triantafilis 2009). Due to increasing use of groundwater, growing importance of contamination as a result of anthropogenic activities, and quality constraints, it has become necessary to assess and analyze the groundwater depth and quality for monitoring and planning sustainable management of the resource.

Electrical conductivity (EC) of groundwater is a measure of degree of mineralization and is dependent on rock-water interaction and thereby residence time of water in rocks (Eaton 1950). However, improper water management and addition of salts to the soil by inorganic fertilizers may also increase its value. This parameter is widely used for classification of groundwater quality in terms of salinity by comparing with BIS, WHO and USSL standards (Subbarao et al., 1997; Gopinath & Seralathan 2006). Several studies on groundwater depth and quality have been reported (Ballukraya 2005; Masoudi, Patwardhan & Gore 2007). Such studies require handling of large amount of spatial and attribute data making the analysis cumbersome. This problem can be efficiently solved by using geographical information system (GIS), which can be a powerful tool for assessing water

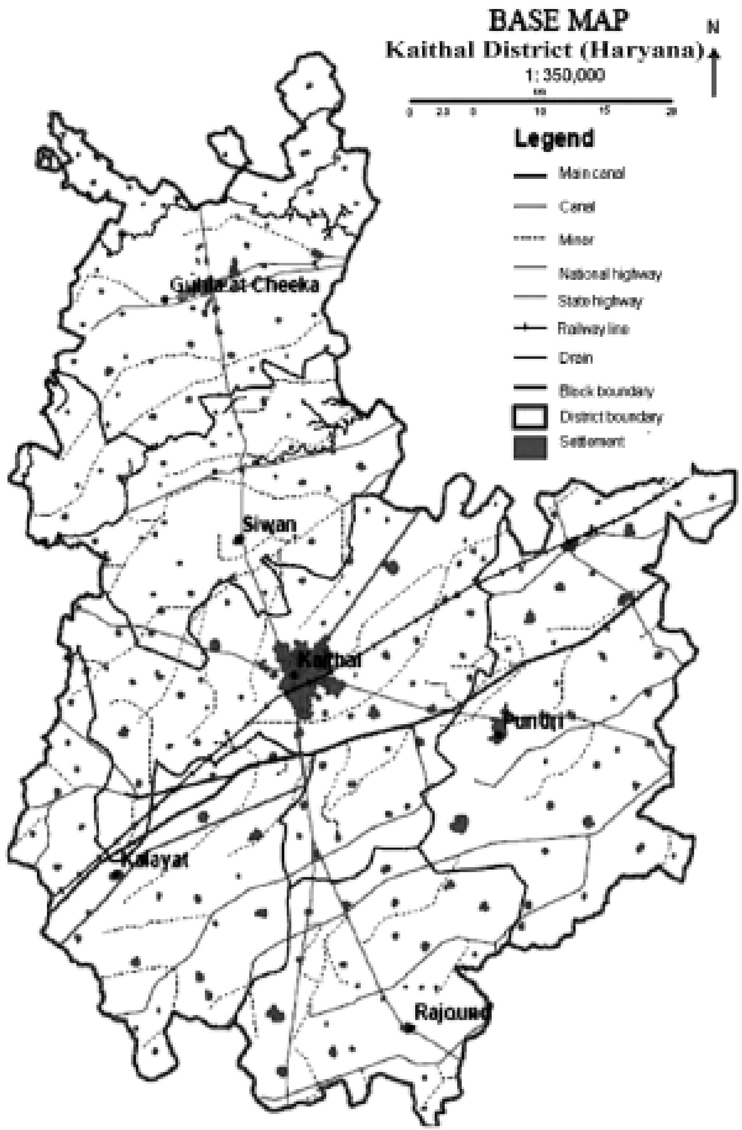

Figure 1. Base map of Kaithal district with drainage and canal network. Source: Haryana Space Application Centre (HARSAC), Hisar

quality and developing solutions for water resources related problems (Tjandra, , Kondhoh & Aslam 2003).

The Kaithal district (Fig.1) in Haryana state of India has agriculture based economy. Hence, availability of groundwater in good quality and quantity is of utmost importance for the area. Because of natural physiography, high population density, and intense agricultural activity, the groundwater levels and quality in the district is under high risk. Therefore, the present study was undertaken with an objective to analyze the long term changes in groundwater depth and quality with regards to natural and anthropogenic conditions prevailing in the area.

MATERIALS AND METHODS

Data Used

The study has used topographical sheets (53 B/4, B/ 8, C/1, C2, C/5, C/6, C/9 and C/10) on 1:50,000 scales, obtained from Survey of India, Dehradun. Depth to water level and EC data from 79 locations distributed all over the district, was obtained from Groundwater Cell, Department of Agriculture, Government of Haryana. The Landsat 5 TM data of September, 24 1995 and other related data collected from various agencies and publications were also used in the study.

Methodology

Boundary map of Kaithal district was demarcated in GIS environment using ILWIS 3.6 software with the help of SOI topographical sheets. Locations of sampling stations were digitized to prepare well location map. EC and depth to water level values at these locations were attached with well location map in form of attribute table. Spatial distribution maps for these key parameters were generated by carrying out point interpolations using moving average (inverse distance) method. The spatial variation of groundwater depth was classified into 0-3, 3-10, 10-20, 20-30 and 30-45 m ranges. Similarly, the EC distribution was also sliced into zones of excellent, good, moderate, doubtful and unsuitable quality for EC in < 250, 250 – 750, 750 – 2250, 2250 – 4000 and > 4000 range respectively as per standards adopted by the United State Environment Protection Agency (USEPA). Area under each depth and quality zone was determined from histograms generated by the software for these maps. To obtain the seasonal fluctuation map for groundwater depth, difference operation was performed on corresponding pre- and post-monsoon maps for the years 1992 and 2007 in MAPCALCULATE.

Further, intersections of various thematic maps were performed by overlaying one over the other through cross operation of two raster maps, keeping track of all the combinations that occurred between the values or classes in both maps. An output cross map and cross table containing items which were combinations of the class names of the input maps (depth and EC maps) were obtained. 1992 and 2007 cross maps for groundwater depth and EC were also prepared to analyze the extent of changes during the period under study. To classify the district into different zones of overall groundwater prospects in the year 2007, the corresponding maps of depth and EC were also crossed.

The Landsat 5 TM imagery (post floods image) was geo-referenced and draped with geographical map of the state. Visual interpretation of the image was carried out to understand the topography by identifying the low lying areas in the district from the signatures of stagnant flood water in the region (Fig. 2).

STUDY AREA

Location and Physiography

Kaithal district is constituted by six administrative blocks (Gulha, Siwan, Kaithal, Pundri, Rajaund and Kalayat) located between 29° 32′ to 30° 12′N latitude and 76° 08′ to 76° 45′ E longitude (Fig.1). It forms a part of the upper Ghaggar basin in the vast Indo-Gangetic plain, covering 2284 km^2 of area and appears monotonous. The region is entirely 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 m to 252 m from mean sea level with a gentle slope from north-east to south-west. Physiographically, the district may be divided in two units: the upland plain and the low lying areas. The upland plain is spread along the north-eastern boundary of the district, while the low lying area covers the southern part of the district.

Climate

The district has a sub-tropical monsoon climate where we find seasonal rhythm, hot summers and cool winters. The temperature starts rising from March and continues till June end. May and June are hottest months with daily maximum temperature at

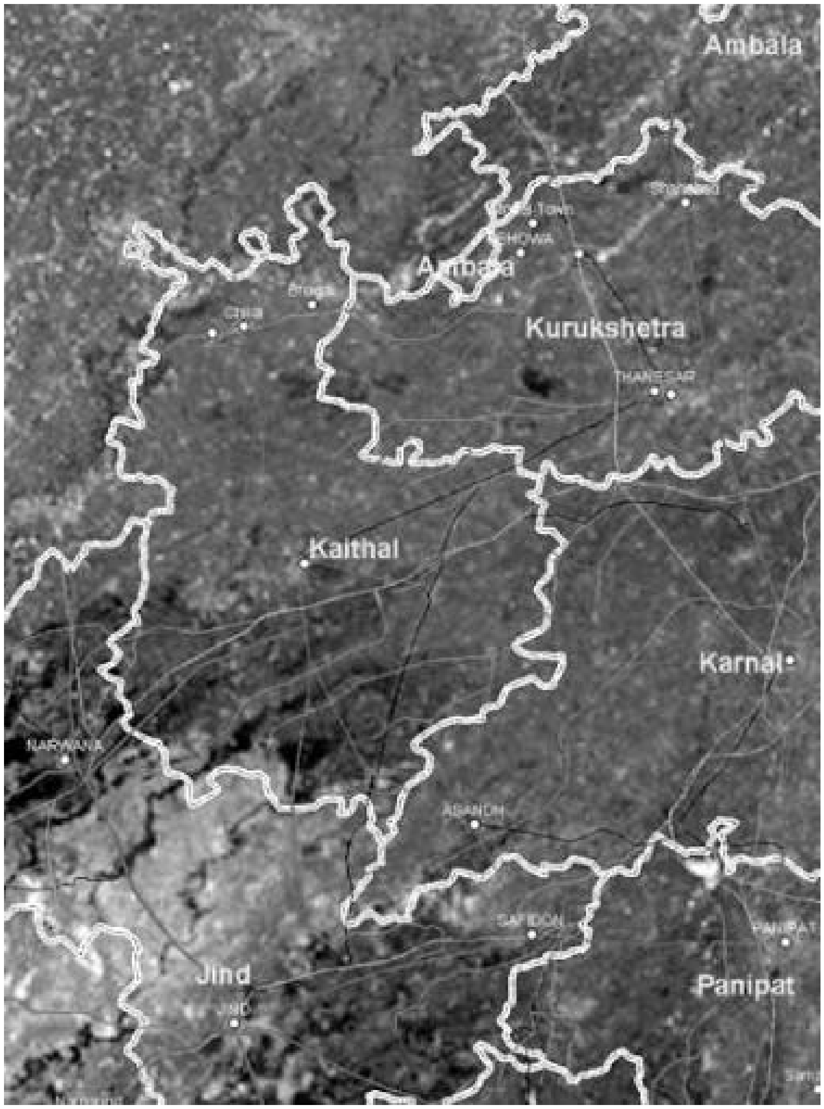

Figure 2. Landsat image of Kaithal and surrounding districts depicting flood affected area. Source: Haryana Space Application Centre (HARSAC), Hisar

about 40^{0}C, which may sometimes rise to 45^{0}C. During winters, the temperature starts decreasing by the middle of November. January is the coldest month. About 80 percent of the annual rainfall is received during June to September months. Total rainfall in the district in the year 1992 and 2007 was 467 and 446 mm respectively whereas the average annual rainfall during the period under study was 610 mm.

Land use

Out of the total cultivable area in the district, net area sown, area sown more than once and gross cropped area in 2007-08 were 88.6%, 76.8% and 165.4 % respectively (Statistical Abstract, 2009). Rice and wheat are the main crops with the district accounting for 8% and 14% of the total production of the state respectively. In late eighties, the practice of taking additional short duration crop called as Saathi or summer paddy started in the region due to decreasing landholding and increasing pressure on the available fertile agricultural land. As Saathi paddy is grown during summer period from April to July, it puts great stress on groundwater (and energy) during the critical summer months. The ban imposed by the government has checked the problem to a great extent. According to a study based upon the analysis of satellite data (Yadav et al, 2008), 5017 ha area in Gulha, Siwan, and Kaithal and Pundri blocks was under Saathi in 2003, which reduced to only 312 ha (266 ha in Gulha block) in 2008.

Irrigation

Ghaggar - a seasonal river, flows in the district through the northern part (Fig.1). Sirsa Branch of Western Jamuna Canal (WJC) with a network of distributaries and minors provides surface water in the district. The canal distribution is concentrated more in southern part as compared to northern parts. Net irrigated area in the district in 2001-02 was 1331 km^2, out of which, 521 km^2 (40%) was irrigated by surface water and 1852 km^2 (60%) with groundwater. In 2001-02, average density of shallow tube wells was 22 per km^2. The district was also affected by the floods that swept the state in first week of September 1995.

RESULTS AND DISCUSSION

Depth to Water Level

Variation in depth to water level is an indicator of net recharge or draft from the aquifer. The average groundwater depth was found to decline from 9 m bgl in 1992 to 16 m bgl in 2007, indicating over-exploitation of the resource in the district. Spatial distributions of depth to water levels (bgl) at intervals of five years during the period under study are depicted in Fig.3. The areas calculated in various depth zones from these maps are presented in Table 1. In the base year, 54% area in north of the district was found in normal and rest of 46% area was in moderate groundwater depth range. The comparison of the 1992, 1997, 2002 and 2007 maps revealed a general decline in groundwater levels except in southern areas. Relatively small decline during the period 1992-1997 can be attributed to the replenishing effect of the September 1995 floods in the region. The 2007 map indicated that, in 27% of the total area in northern and 8% area in north-western parts of the district were in deep and very deep range respectively while Southern parts (29% of total area), were found in 3-10m range.

The resultant cross map (Fig.4) obtained from depth spatial variability maps of 1992 and 2007 classified the district into zones of changes in groundwater depth during the study period. The area under each zone is presented in Table 2. Zone 6 with 8% of the total district area (lying in Siwan block) demonstrated maximum depletion from 10-20m range in 1992 to 30-45m range in 2007. Such a fast depletion can be attributed to the prevalence of Saathi (summer paddy) cultivation in this area (Yadav et al, 2008). In about 24% of the total district area falling in Gulha and Siwan blocks, the levels declined from moderate to deep class. In Pundri and Kaithal blocks, levels declined from normal to moderate class. However, water levels in Kalayat and Rajaund blocks located in south (29% of the total area) of the district showed almost no change.

In general, the observed groundwater depletion in the district during the study period was indicative of increasing net groundwater withdrawal for irrigation without any improvement in recharge. Further, the observed spatial non-uniformity in depletion may be attributed to diverse land use and inherent physiographic variations in the district. Areas experiencing greater decline were part of the upland plains where intensive cultivation of paddy have caused stress on the groundwater sources. On the other hand, areas showing negligible decline were a part of the physiographic depression existing in south of the district. This was corroborated by the interpretation of post flood Landsat image, where the areal extent of dark patches which represented the water logged areas (Fig.2), matched with the zone of negligible groundwater decline delineated in the maps prepared in the analysis.

In alluvial plains, direct precipitation on intake areas and downward percolation of stream runoff are major sources of recharge to aquifers. The recharge depends upon the character and thickness of soil and other deposits below and above the water table, topography, land use/land cover, depth to water table, intensity, duration and seasonal distribution of rainfall etc. The depth to water level fluctuation between post- and pre-monsoon seasons, therefore, gives information about these parameters at a given place. The maps (Fig.5) depicted a groundwater fluctuation varying from -2.2m to 0.8m and - 2.0m to 5.8m for the years 1992 and 2007 respectively. The negative fluctuation demonstrated areas of net recharge while positive fluctuation depicted areas of net decline. Dominance of negative fluctuation areas over the positive ones in 1992 showed that groundwater withdrawals (during the period intervening two successive monsoons) were effectively replenished by the monsoon in most parts of the district, particularly in south of the main canal passing through the middle, and in the plains along the Ghaggar River near northern boundary of the district. However, certain patches located in intensive paddy growing area in the central to northern parts of the district demonstrated slight decline in levels. This can be attributed to high withdrawals driven by the irrigation demands of paddy. Further, the 2007 fluctuation map

Table 1. Area under different depth zones (1992 and 2007).

Groundwater depth range (m bgl)	Depth class	1992		1997		2002		2007	
		(km^2)	%	(km^2)	%	(km^2)	%	(km^2)	%
0-3	Shallow	0	0	10	0.4	0	0	0	0
3-10	Normal	1242	54	1278	56	909	40	657	29
10-20	Moderate	1042	46	983	43	1138	50	808	35
20-30	Deep	0	0	13	0.4	234	10	627	27
30-45	Very deep	0	0	0	0	1	.04	191	8

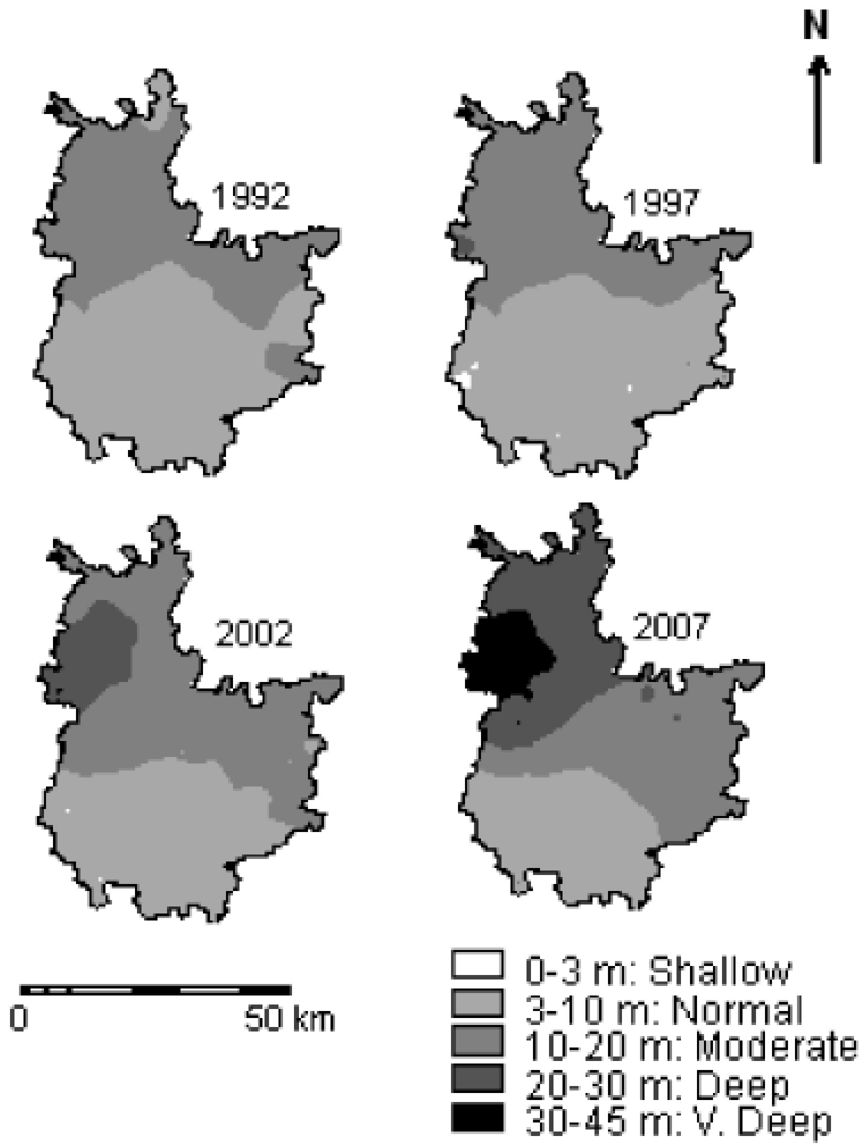

Figure 3. Spatio-temporal variation of groundwater depth in Kaithal district from 1992 to 2007.

Table 2. Change detection in depth of groundwater levels from 1992 to 2007.

Zone	Area		Status of groundwater depth in		Constituting blocks
	% of total	(km^2)	1992	2007	
1	29	657	Normal	Normal	Kaithal, Kalayat, Rajaund
2	22	498	Normal	Moderate	Kaithal, Pundri
3	4	87	Normal	Deep	Gulha, Kaithal
4	13.6	310	Moderate	Moderate	Kaithal, Pundri
5	23.6	540	Moderate	Deep	Gulha, Siwan
6	8	191	Moderate	V. Deep	Gulha, Siwan

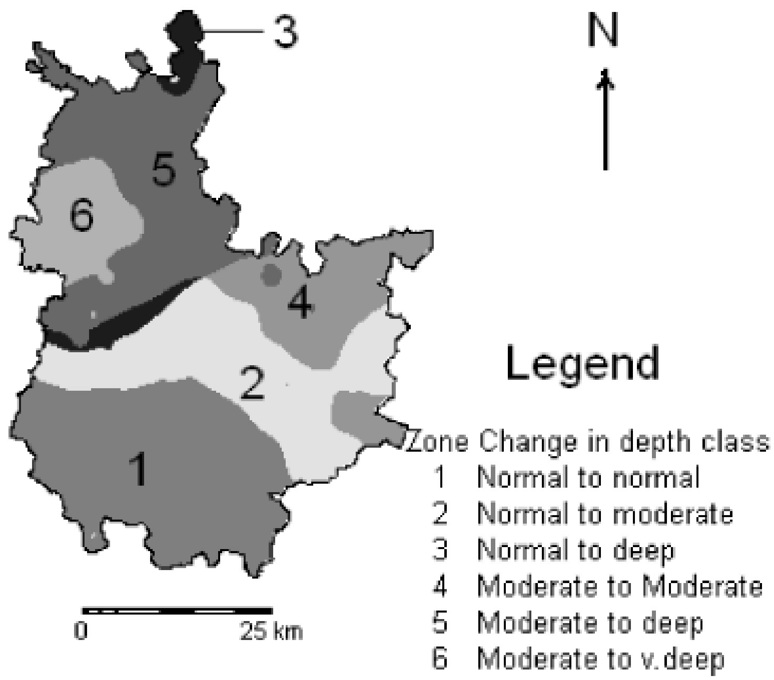

Figure 4. Map showing zones of changes in depth class during 1992-2007

(Fig.5) depicted a significant increase in area as well as extent of net groundwater decline during the study period. This showed that over the fifteen years, the over-exploitation increased to such an extent that rainfall during the monsoon season could no longer replenish the levels. Thus there was a great need for artificial recharge in such parts of the district.

The fluctuation maps showed that southern parts of the district were invariably characterized with a net recharge possibly due to poor drainage conditions caused by low lying physiography of the area and the seepage from the canals (including the Sirsa branch) passing through this region.

Electrical Conductivity

As per Bureau of Indian Standards (BIS, 1998) and World Health Organization (WHO, 2004) guidelines, no health based concern is perceived in the use of high EC water. However, suitability of groundwater for irrigation depends on the effects of the mineral constituents of water on the both the plant and the soil (Richards 1954; Wilcox 1955). With increase in EC, plant usable water in the soil solution is decreased because plants can transpire only pure water. As the yield is directly related to amount of water transpired through a crop, therefore, irrigation water with high EC reduces yield potential (Bauder, Waskom & Davis 2006). Moreover, salts may also change the structure, permeability and aeration of the soil, thus deteriorating its quality.

The average electrical conductivity in the district showed an increase from 1722 μS/cm in 1992 to 2267 μS/cm in 2007. Moreover, as per salinity hazard classification adopted, the spatial variations of EC at five year intervals from 1992 to 2007 have been shown (Fig. 6). The areas in different EC zones are presented in Table 3. The distribution maps showed that in 1992, the excellent and good quality zones constituted 2% and 43% of the total area respectively, which were reduced to zero in 2007. This resulted in increase in area of moderate and doubtful zones from 33 and 17 percent to 69 and 27 percent in the corresponding period. Thus, the district demonstrated a general increase in salinity during the period under study.

The cross map (Fig.7) obtained from 1992 and 2007 EC maps divided the district into six main categories of EC change (Table 4). In 67% of the total area of the district (Zone 1 and 2), covering Gulha, Siwan, Pundri and Kaithal blocks, the groundwater quality showed change from good/moderate to moderate category. In remaining one third part (Zone 3, 4, 5 and 6) constituted mainly by Kalayat and Rajaund blocks, the quality was already in doubtful/unsuitable category in 1992 which showed no further change.

The general degradation in groundwater quality, as indicated by the comparison of the EC spatial variation maps, can be attributed mainly to the cumulative effect of chemical fertilizers and pesticides being used in large quantities to increase the agricultural production. The fertilizer (in terms of nutrients) and pesticide consumption in the district in 1995-96 was 56,766 and 432 tonnes respectively

Table 3. Areas under different EC zones (1992 and 2007).

EC (μS/cm)	Quality class	Area (1992) (km^2)	Area (1992) %	Area (1997) (km^2)	Area (1997) %	Area (2002) (km^2)	Area (2002) %	Area (2007) (km^2)	Area (2007) %
< 250	Excellent	50	2	19	1	0	0	0	0
250-750	Good	975	43	1142	50	53	2	0	0
750-2250	Moderate	747	33	968	42	2010	88	1578	69
2250-4000	Doubtful	381	17	154	7	170	4	617	27
>4000	Non-suitable	123	5	0	0	50	2	89	4

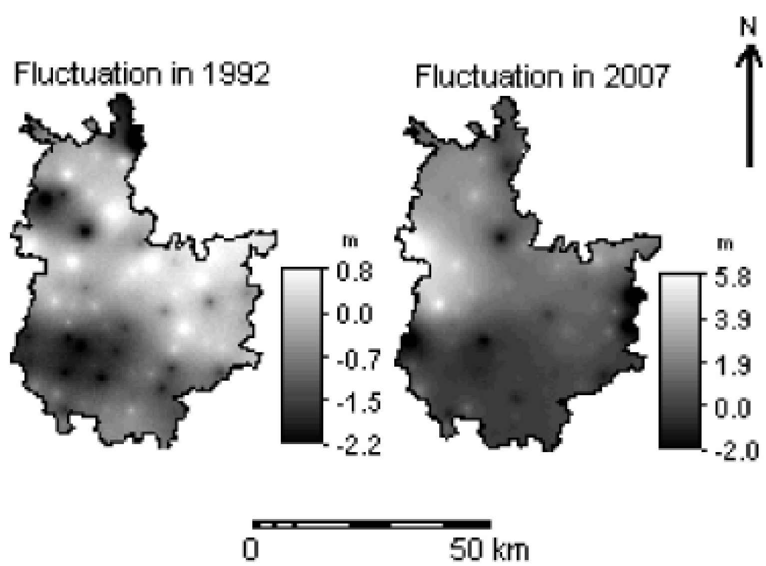

Figure 5. Maps showing seasonal fluctuation of depth to water levels in 1992 and 2007.

Table 4. Change detection in quality of groundwater from1992 to 2007.

Zone	Area (%)	Area (km^2)	Groundwater quality in		Constituting Blocks
			1992	2007	
1	43	975	Good	Moderate	Gulha, Siwan, Pundri
2	24	536	Moderate	Moderate	Kaithal, Pundri, Rajaund
3	9	207	Moderate	Doubtful	Kaithal, Kalayat
4	15	342	Doubtful	Doubtful	Kalayat, Rajaund
5	2.4	55	Unsuitable	Unsuitable	Rajaund
6	3	67	Unsuitable	Doubtful	Kalayat, Rajaund

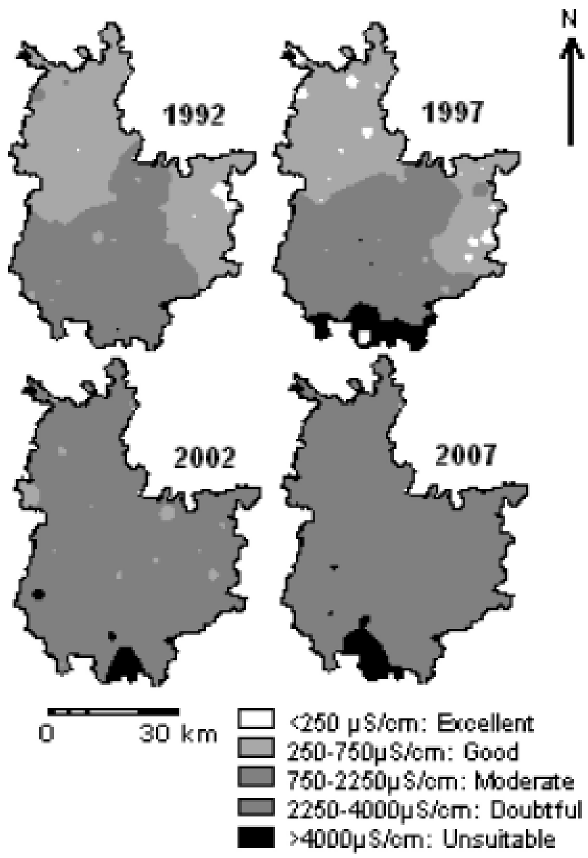

Figure 6. Spatio- temporal variation of EC of groundwater in Kaithal district from 1992 to 2007.

whereas in 2007-08, it was 81,793 and 249 tonnes (Statistical Abstract, 2009). The leaching of salts released in soil by these agrochemicals can result in increase in EC of groundwater. This effect is more pronounced in areas having poor drainage conditions like in Kalayat and Rajaund blocks. The 1995 post floods Landsat image of the area (Fig.2) clearly indicate the poor drainage and water logging conditions in this part. Nearly shallow water table conditions accompanied by capillary action and evaporation might have also contributed to accumulation of salts and hence deterioration in the water quality (Goyal, Sethi & Chaudhary 2006).

Table 5. Zones of different groundwater prospects as regards depth and quality.

Zone	Depth Class	EC Class	Constituting Blocks	Area (%)	Area (km^2)
1	V. Deep	Moderate	Siwan	8.4	191
2	Deep	Moderate	Gulha, Siwan, Kaithal	26.5	606
3	Normal	Doubtful	Kalayat, Rajaund	21.5	490
4	Moderate	Moderate	Pundri, Kaithal	31	702
5	Moderate	Doubtful	Kaithal	4.5	104
6	Normal	Moderate	Pundri, Kaithal	3.5	79
7	Normal	Unsuitable	Rajaund	4	87

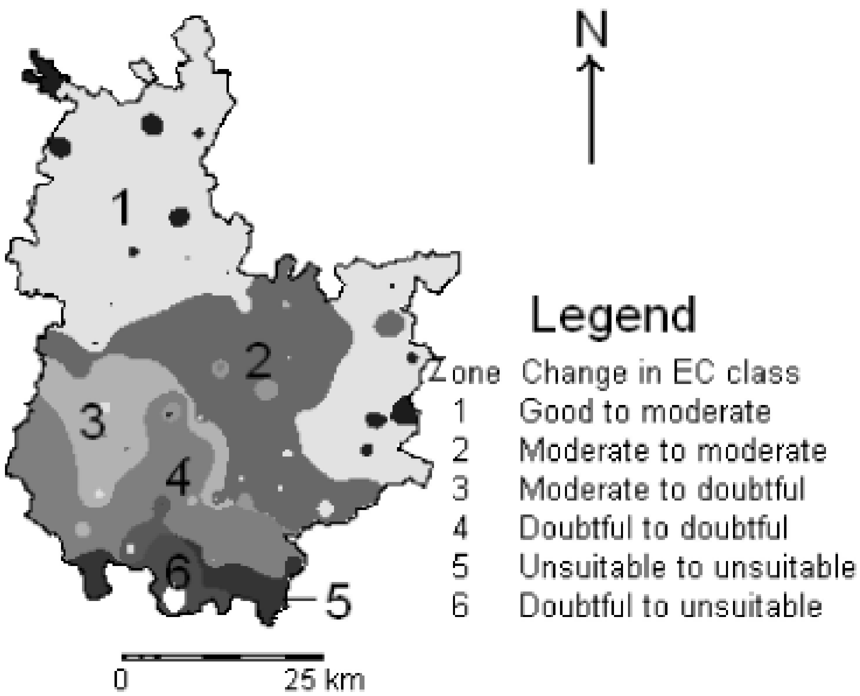

Figure 7. Map showing zones of changes in EC class during 1992 - 2007.

Overall Groundwater Potential

The information from spatial distributions of groundwater depth and quality for the year 2007 was integrated by carrying out cross operation on the corresponding depth and EC maps. The resultant map (Fig.8) classified the Kaithal district into various zones of overall groundwater prospects (Table 5). The block wise status of groundwater quality and depth is presented in Table 6. It is clearly indicated that Zone 4, constituting about 30% of the total district area, is the best zone as regards groundwater depth and quality Zone 2 (lying in Siwan block) and Zone 7 (lying in Rajaund block) were identified as critical for high depletion rate and high EC indicated in these zones.

Table 6. Block wise status of groundwater depth and quality in 2007

Block	Groundwater Status	
	Depth to water Level	EC
Kaithal	Normal to deep	Moderate to Doubtful
Gulha	Deep	Moderate
Siwan	Deep to very deep	Moderate
Pundri	Normal to Moderate	Moderate
Kalayat	Normal	Doubtful
Rajaund	Normal	Doubtful to unsuitable

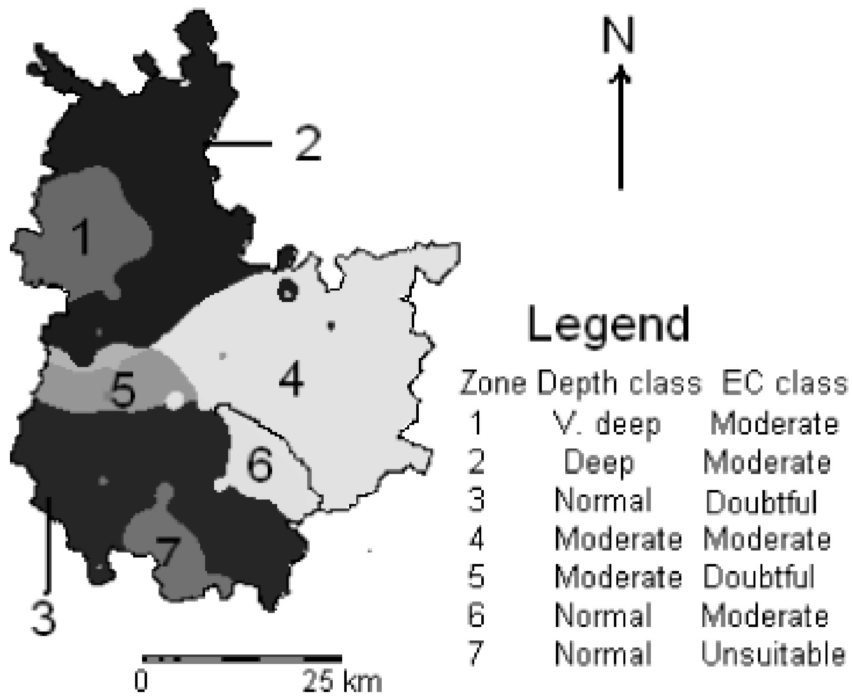

Figure 8. Map showing overall groundwater prospects of Kaithal district.

CONCLUSIONS

In general, groundwater depth and quality in Kaithal district showed a considerable deterioration from 1992 to 2007, possibly due to over-exploitation and excessive use of agrochemicals besides natural factors. The excessive cultivation of paddy (and Saathi, especially in Siwan and Gulha blocks) has caused a great damage to the groundwater resource in the study area.

The groundwater in the Kaithal district was saline in nature and varied from moderate to unsuitable quality for irrigation. Entire Pundri block along with a part of the adjoining Kaithal block (about 32% of total area) was identified as the zone of good groundwater prospects. High EC (2500-9000 μS/cm) and a nearly shallow water table observed in Rajaund and Kalayat blocks depicted a combined effect of inadequate groundwater withdrawal, poor drainage conditions, effect of leaching, and geohydrological setting of the region. Western parts of Siwan block (about 8% of total district area) and a part of Rajaund block (4% of the total district area) were identified as critical due to fast depletion of groundwater levels, and high salinity respectively.

The results of the study provide basic information needed for groundwater management in the study area. To arrest the declining trend of groundwater levels in critical parts of the district, it is necessary to regulate withdrawals and augment the aquifers with artificial recharge. For effective participation of the people, it is essential to educate them on needs and ways for regulation, conservation and augmentation of groundwater resources. The results also emphasize the need to promote awareness among the end users of their water quality, to protect groundwater aquifers and, to implement proper management strategy for sustainability of the resource.

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