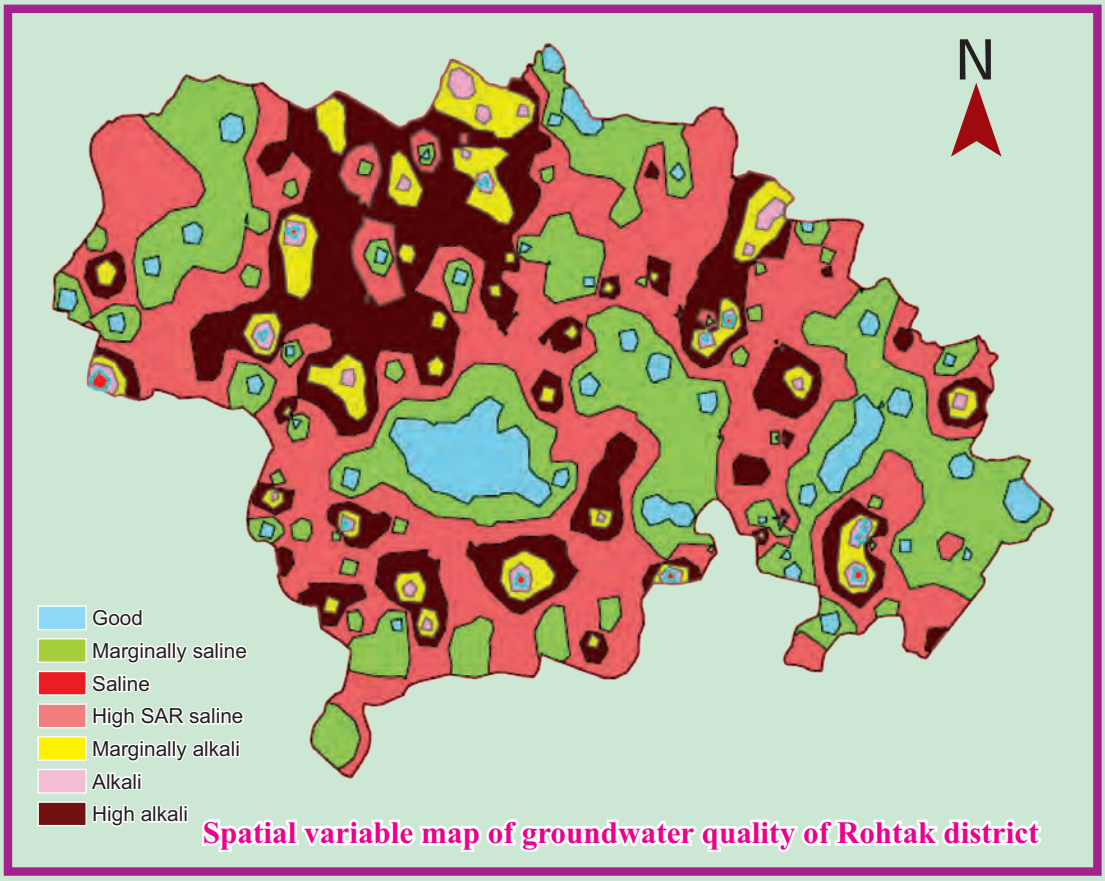
GIS MAPPING OF GROUNDWATER QUALITY OF ROHTAK DISTRICT, HARYANA



Spatial variable map of groundwater quality of Rohtak district

• Sanjay Kumar • S.K. Sharma • Ramprakash • Rajpaul Yadav
• Satyavan • R.S. Antil • S.K. Ambast

2013

DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
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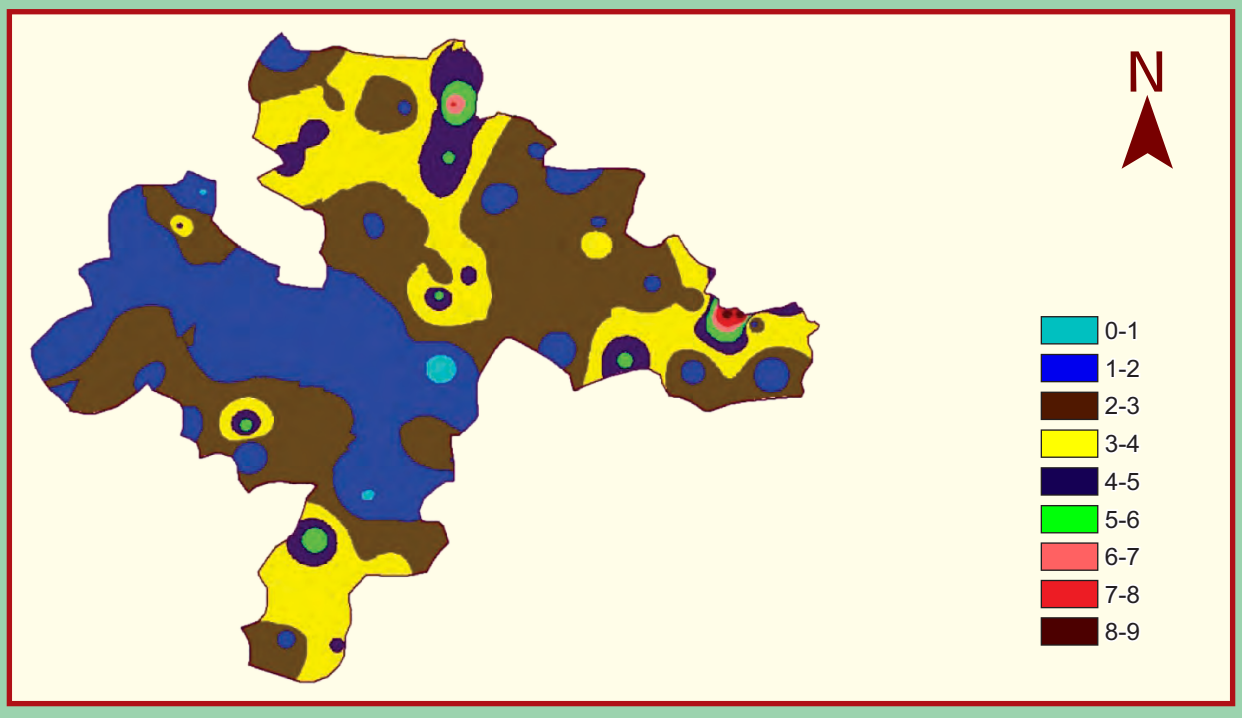

Spatial variable map of EC of groundwater in Rohtak block

Spatial variable map of EC of groundwater in Sampla block

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AICRP on Management of Soil Affected Soils and Use of Saline Water in Agriculture

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CONTENTS

FOREWORD

India is endowed with a rich and vast diversity of natural resources, water being one of them. Its development and management plays a vital role for existence of life by producing food and sustainable socio-economic development. The present trends of population dynamics and shrinking land holding call for harnessing the available poor quality groundwater by evolving suitable technology and proper management practices. But continuous use of poor quality for growing crops is bound to increase salinity and sodicity problems in otherwise productive good lands. Moreover, the depleting water resources owing to over exploitation of groundwater in Haryana state poses major threat for sustainable crop production.

The total annual replenishable groundwater resources of the country have been estimated as 433 billion cubic meter (BCM). Out of this, the net annual groundwater availability for the entire country is 399 BCM. The annual groundwater draft is 231 BCM which indicates that only 58 per cent of the available groundwater is being used by the country. Whereas, in Haryana state, the total annual replenishable groundwater resources have been estimated to 9.31 BCM and out of this about 8.63 BCM is the net annual available groundwater. The annual groundwater draft is 9.45 BCM which indicates that 110 per cent of the available groundwater is being used by the state. The groundwater of central part of Haryana especially Rohtak district is generally marginally saline to marginally alkali and rising at a rate of 6.9 cm annually. In order to plan management strategies in this area, there has been requirement of detailed survey of groundwater quality. Hence the present bulletin on "GIS Mapping of Groundwater Quality for Rohtak District, Haryana" is very timely and would prove to be a stepping stone for enhancing the crop production and management of poor quality water in the district.

I complement the authors for bringing out this compilation of survey work with beautiful spatial graphical portrait relevant to groundwater depth and its characteristics. I am confident that this publication will prove useful to students, teachers, researchers and farmers for enhancing the crop production through judicious use of available poor quality waters and to the planners for providing technical guidelines regarding the formulation of spatial (location specific) strategies for efficient management of the water resources in the district.

Dr. K.S. Khokhar
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June 2013
Hisar

PREFACE

Introduction of canal irrigation in the arid and semi arid regions of Haryana in the early sixties helped to increase crop production. However, losses from the irrigation systems, particularly in areas underlain with poor quality groundwater, have endangered considerable area with the problem of poor quality groundwater and waterlogging. As a consequence, groundwater depth is rising and its quality is deteriorating at a alarming rate in many parts of the state, particularly in Rohtak district. Canal water is the major source for irrigation due to good canal network in the district. The overall depth of water table in the district has been increased from 5.34 m (in year 1981) to 3.27 m (in year 2011) which shows a rising trend with an average of 6.9 cm per year. Moreover, with the advancement in modern technologies and irrigation system, there is a tremendous pressure on groundwater quantity and quality.

One of the basic steps for preparing the plan for the management of groundwater quality is to assess the severity, extent and distribution of the problem through reconnaissance survey. Keeping all this in view and to combat these problems, this bulletin is prepared in comprehensive form with spatial coverage regarding the fluctuation and quality of groundwater being used by the farmers for irrigation purpose in the Rohtak district. The purpose of this bulletin is to update the relevant information so that the latest synthesized knowledge becomes easily accessible to research workers, teachers, students, planners and policy makers as well as farmers who can utilize it profitably with the better management and development of water resources for enhancing crop production.

We are extremely grateful to Dr. K.S. Khokhar, the hon'ble Vice-Chancellor, CCS Haryana Agricultural University, Hisar for encouraging and appreciating the work.

The authors are highly thankful to Indian Council of Agricultural Research for providing financial help and technical guidance for the preparation of this bulletin.

The words are nor eloquent enough to express our special feelings for our family members for their moral support, deep affections and encouragement during preparation of this bulletin.

We wish to record the gratitude to our field staff, office staff and all who rendered their support and services in various capacities throughout the preparation of this document.

Authors

ROHTAK DISTRICT AT A GLANCE

Sr. No.	Items	Statistics	
1.	General information		
	Geographical area	1668 sq. km.	
	Number of blocks and their names	five, Kalanaur, Lakhan Majra, Meham, Rohtak, Sampla	
	Number of villages	147	
2.	Average Annual Rainfall (mm)	592 mm	
	Highest rainfall (between 1989 to 2011)	1004 mm in 1995	
	Lowest rainfall (between 1989 to 2011)	231 mm in 1999	
3.	Major soil types	sand to loam	
4.	Net area sown	126268 ha	
	Area sown more than once	89518 ha	
5.	Area under various crops and average yield		
	Major crops	**Area (ha)**	**Av. Yield (q/ha)**
	Paddy	20000	18.33
	Bajra	17000	21.10
	Arhar	11000	11.76
	Cotton	9000	4.79
	Sugar cane	13000	64.43
	Sorghum	23500	225.00
	Wheat	95000	39.58
	Raya	19000	14.38
	Barley	1100	25.70
	Gram	1700	8.80
	Horticultural crops		
	Ber	265	112.00
	Guava	285	71.00
	Marigold	110	22.50
	Vegetable crops		
	Cucurbits	251	74.00
	Onion	500	120.00

	Potato	250	155.00
	Carrot	200	220.00
6.	Irrigation sources by different sources		
	Well/Tubewells	31000 ha	
	Canals	66900 ha	
7.	Tubewell/pumping Set (2005-2006)	20000	
8.	Rivers and canals in the districts	Jawahar Lal Nehru feeder, Bhalaout and Bhiwani sub branch, and Kalanaur distributaries	
9.	Goundwater quality in the district		
	Good	25.2 per cent	
	Marginally saline	24.0 per cent	
	Saline	5.1 per cent	
	High SAR saline	17.2 per cent	
	Marginally alkali	10.1 per cent	
	Alkali	7.1 per cent	
	High alkali	11.3 per cent	
10.	Water table fluctuation (from 1981 to 2011)	2.07 m rise	
11.	Blockwise annual water table fluctuation (from 1981 to 2011)		
	Kalanaur	2.84 m rise	
	Lakhan Majra	0.73 m rise	
	Meham	7.00 m rise	
	Rohtak	0.30 m rise	
	Sampla	-0.53 m decline	
12.	Major groundwater problems and issues	• Rise in water table (6.9 cm/year) • Poor groundwater quality	
13.	Remedial measures	• Introduction of salt tolerant crops and varieties. • Plantation of highly transpiring trees. • Adoption of modern methods of irrigation.	

1. INTRODUCTION

1.1 LOCATION

Rohtak district occupies the central part of Haryana state, bounded by Jind and Sonipat districts in the north and east side, by Jhajjar district in the south, and by Bhiwani and Hisar districts in the west. It lies between 28° 40/ 58//N and 29° 06/ 13//N latitude and between 76° 12/ 47// E and 76° 51/ 43// E longitude. It has a geographical area of 1668 sq km with the greatest length and breadth of the district are 62.5 and 44.0 km, respectively. The average elevation of the plains in the district above mean sea level is 220 m. There is a gentle slope from north to south i.e.19 cm per km upto Jhajjar town in the northern part of the district and there is considerable slope west to east. The district has five blocks viz. Kalanaur, Lakhan Majra, Meham, Rohtak and Sampla (Fig.1.1).

Fig.1.1: Location map of Rohtak district

The district area falls in Yamuna sub-basin of Ganga basin and is mainly drained by the artificial drain no. 8 which flows from north to south.

1.2 RAINFALL AND CLIMATE

The climate of the Rohtak district is sub-tropical, semi-arid, continental and monsoon type. It has hot summers, cool winters and small rainy season. The maximum temperature reaches up to 45°C in summer and it falls up to 3°C in the month of January. The mean seasonal temperatures during kharif and rabi season are 29°C to 31°C and 16°C to 18°C with relative humidity of 70% and 55%, respectively. The normal annual rainfall in the district is about 592 mm spread over 23 days. The south west monsoon sets in the last week of June and withdraws towards the end of September and contributes about 84% of the annual rainfall. The average annual rainfall of the district from year 1989 to 2011 is represented in Fig.1.2. The highest rainfall (1004 mm) in the district was held during the year 1995 and the lowest (231 mm) was during 1999.

Fig.1.2: Average annual rainfall of Rohtak district

1.3 MAJOR CROPS AND LAND USE PATTERN

In Rohtak district, the predominating existing farming system is Agriculture + Animal Husbandry followed by Agriculture + Animal Husbandry + Horticulture. The major cropping system under the existing farming systems is primarily rice-wheat cropping with buffalo. In the district, bajra, guar, paddy and cotton are the major crops in kharif season, whereas, wheat, mustard and sugarcane are in rabi season. The main fodder crop is jowar and cluster bean. Apart from this, kharif vegetables, onions, turmeric, cucumber etc. are grown as minor crops. The net sown area of the district is 126268 ha and total crop area is 215786 ha with cropping intensity of 171%. The forest lies approximately on 4475 ha area. Total operational land holdings in the district are 165441,

out of which 52% holding are occupied by marginal and small farmers (up to 1 ha). Average size of landholdings in the district is 1.81 ha.

1.4 GEOMORPHOLOGY AND SOILS

With the exception of a few small out liers of Alwar quartzite, there is no sign of hard rock exposures in Rohtak district, which is almost concealed by the wide expanse of alluvium. The district can be broadly divided into two major geomorphic units as Older Alluvial Plain and Recent Sahibi Flood Plain. These are the sediments derived mostly from the Himalayan rivers, as a part of the Indo-Gangetic alluvium, having a heterogeneous composition with frequent calcium carbonate concretion layers at shallower depths. River Sahibi is of seasonal nature and its termination into an aerial delta, leaves behind a vast flood plain. The soils are tropical arid brown to arid brown with alluvial origin, calcareous in nature, sandy to loam with pH 7.02 to 8.5, low to medium in organic carbon, low in available nitrogen, low to high in available phosphorous and medium to high in potash availability. The thickness of column is more than 150 cm and the structure varies from massive to angular blocky. The available moisture capacity is good with imperfectly drained and moderate permeability.

1.5 FARM MECHANIZATION

Farm mechanization is a very important tool for improving productivity of different crops, time saving, reducing drudgery, timely farm operations, resource conservation and protection from natural calamities. In the district, the timely sowing of wheat due to zero tillage seed cum fertilizer drills has improved the productivity of wheat during recent years which is remarkable achievement in wheat production. Placement of fertilizers by drill, during sowing, results in higher nutrient use efficiency and likewise higher irrigation efficiency under bed planting and laser levelling technologies. Use of crop harvesting machines ensures early completion of harvesting and threshing works which escapes the untimely rainfall and storms hazards particularly in wheat, rice and potato crops. At present, there are 12344 tractors, 164 zero till seed cum fertilizer drills, 7508 threshers, 291 rotavators, 57 straw reapers, 18 post hole diggers, 4 potato diggers, and 5 power tiller in the district. There is need to create more awareness among farmers for proper use of farm machineries for higher efficiency, saving human and energy resources etc.

1.6 IRRIGATION STATUS

Out of the total geographical area (166847 ha) of Rohtak district, 141877 ha was cultivated during the year 2009-10. The elements of basin hydrological system like groundwater infiltration, seepage, surface storage etc. are activated only by precipitation. Depth of water table in most of the area (approx. 98 %) of district is reported within 10 metres from the ground surface and overall it is showing rising trend. Out of total irrigated area (97900 ha) of the district, 66900 ha is irrigated by canals and 31000 ha is irrigated by tube-wells. Jawahar Lal Nehru feeder and Bhalaut sub-branch are the two main canals which are spreading a network of sub-branches, minors and distributaries. Besides this, Bhiwani sub-branch and Kalanaur distributaries feeds some area of Kalanaur, Meham and Lakhan Majra blocks.

2. GROUNDWATER SCENARIO OF ROHTAK DISTRICT

The total annual replenishable groundwater resources of the country have been estimated as 433 billion cubic meter (BCM). Out of this, the net annual groundwater availability for the entire country is 399 BCM. The annual groundwater draft is 231 BCM which indicates that only 58 per cent of the available groundwater is being utilized by the country. This reflects that the available resources of groundwater in the country as a whole is under exploited. Whereas, in Haryana state, the total annual replenishable groundwater resources have been estimated as 9.31 BCM and out of this about, 8.63 BCM is the net annual available groundwater. The annual groundwater draft is 9.45 BCM which indicates that 110 per cent of the available groundwater is being used by the state, means over exploited. The flow of groundwater in the state is generally towards southwest.

2.1 GROUNDWATER RESOURCES OF THE DISTRICT

In Rohtak district, according to assessment of Central Ground Water Board in year 2002, out of five blocks, four blocks (Lakhan Majra, Kalanaur, Meham and Rohtak) were under white category (groundwater development < 65%) and only one block (Sampla) was under gray category (groundwater development between 65-85%). The water availability and future scope of groundwater for irrigation purpose was safe in 4 blocks of the district, whereas, Sampla block was over exploited. At present, the total replenishable groundwater resource in the district is 253.13 million cubic meter (MCM), while the existing groundwater draft is 167.90 MCM. Blockwise stage of groundwater development is 47, 52, 65, 66 and 101 per cent in Lakhan Majra, Meham, Kalanaur, Rohtak and Sampla block, respectively. The overall stage of groundwater development in the district is 66.2%. More groundwater availability for future irrigation development is 85.23 MCM which reveals no scarcity of groundwater potential in the district. Out of five blocks, two blocks (Lakhan Majra and Meham) are under white category, two blocks (Kalanaur and Rohtak) are under gray category and one block (Sampla) is under over-exploited category (groundwater development >100%).

2.2 GROUNDWATER FLUCTUATION STUDY OF THE DISTRICT

The groundwater data reveals that the level of water table in whole district is having upward trend. In the year 1981, average water table in the district was 5.34 m which raised to 3.27 m in 2011 (Table 2.1). All blocks of the district also have same trend expect Sampla block. In Kalanaur block, it raised from 5.70 to 2.86 m from year 1981 to 2011 with an average annual increase of 9.5 cm per year. In Lakhan Majra block, it raised from 4.23 to 3.50 m from year 1981 to 2011 with an average annual increase of 2.4 cm per year. In Meham block, it raised from 11.11 to 4.11 m from year 1981 to 2011 with an average annual increase of 23.3 cm per year. In Rohtak block, it raised from 3.15 to 2.85 m from year 1981 to 2011 with an average annual increase of 1.0 cm per year. In Sampla block, it declined from 2.52 to 3.05 m from year 1981 to 2011 with an

average annual decline of 1.8 cm per year. Sharp rise in the water table was observed in Meham block from year 1981 to 2001 and after 2001 pace of rise of water table was very less. In Kalanaur block, the pace of rising water was 9.5 cm per year and it was at reached to a level of 2.84 m in year 2011. In this block, the situation is going to become very critical in the coming year and even some area in this block is under water logging problem at present. The overall situation of water table in the district showed a rise trend with an average of 6.9 cm per year from the year 1981 to 2011.

Table 2.1: Blockwise average water table depth and fluctuation in Rohtak district

Block	Average water table (m)				From 1981 to 2011	
	1981	1991	2001	2011	Water table fluctuation (m)	Average annual fluctuation (cm/year)
Kalanaur	5.70	5.90	4.59	2.86	2.84	9.5
Lakhan Majra	4.23	4.92	5.01	3.50	0.73	2.4
Meham	11.11	8.42	4.98	4.11	7.00	23.3
Rohtak	3.15	3.74	3.89	2.85	0.30	1.0
Sampla	2.52	4.56	4.53	3.05	-0.53*	-1.8*
Rohtak district	5.34	5.51	4.60	3.27	2.07	6.9

* -ve sign reflects decline in water table

The blockwise average groundwater levels during the different years is shown in the Figure 2.1. It is observed from the figure that the rising trend was very steep in Meham block from year 1981 to 1996. Stage of groundwater development in Sampla block is more than 100 per cent even than it is not much affecting the water table since the water table is ranging from 2.52 to

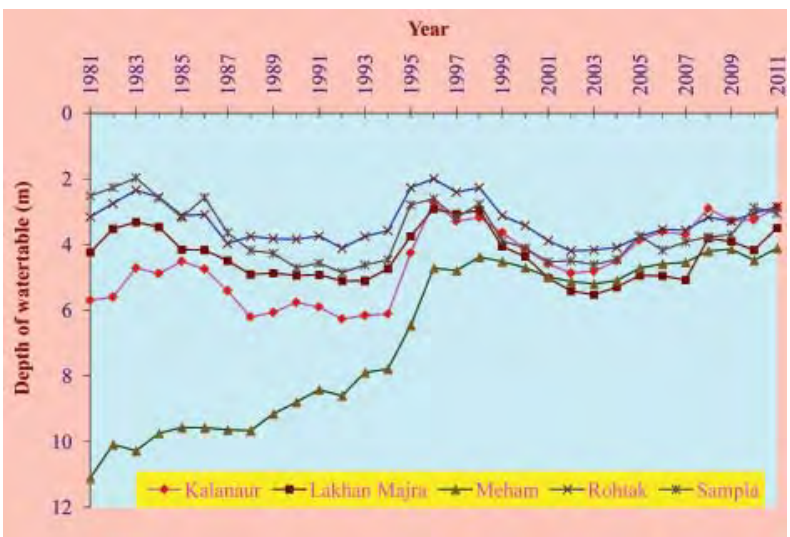


Fig. 2.1: Periodical behaviour of water table in different blocks of Rohtak district

3.05m from year 1981 to 2011 (Fig. 2.1). By observing the present position of table water in all block, there is need to exploit more and more groundwater from the district.

To study the spatial and temporal behaviour of the groundwater level of the district, various maps are prepared through GIS for June 1981, June 1991, June 2001, June 2011 and October 2011, as shown in Figures 2.2, 2.3, 2.4, 2.5 and 2.6, respectively.

During June 1981, the water table was ranging from 0 to 28 m in the district. To study the spatial variability of water table, this range was divided into seven categories at an interval of 4 m and represented by different colours in Figure 2.2. Water table was the highest in south-eastern region of the district and its depth increased as going towards north-western region of the district. The maximum area of the district was under the range of 4-8 m by covering parts of Kalanaur, Rohtak, Lakhan Majra and Meham blocks. Water table in whole Sampla block and some part of Rohtak block was under the range of 0-4 m.

During June 1991, the water table was ranging from 0 to 20 m in the district. This range was divided into five categories at an interval of 4 m and represented by different colours in Figure 2.3. On the basis of temporal behaviour, it can be concluded that the range of water table depth was squeezed from 0-28 m to 0-20 m in the span of ten years (from 1981 to 1991). Spatial behaviour of the water table was having similar trend as in June 1981 that the highest in south-eastern region of the district and its depth increased as going towards north-western region. On comparing these two maps, a change in water table depth is clearly observed which indicates that the water table went lower in Sampla block (south-eastern part), whereas, in Meham block (north-western part) went higher. The maximum area of the district was under the range of 4-8 m by covering completely Kalanaur and Sampla blocks, and partly Rohtak and Lakhan Majra blocks. In Meham block it was ranging from 8 to 16 m.

During June 2001, the range of water table depth was reduced drastically to 0 to 10 m. This range was divided into five categories at an interval of 2 m and represented by different colours in Figure 2.4. Spatial behaviour of the water table reflects that till 2001, the north-western part of the district containing mostly Meham block of the district, was much safer than the rest part of the district. The maximum area of the district was under the range of 4-6 m by covering all the blocks except Meham block in which 6-8 m range was more dominating.

During June 2011, the water table was ranging from 0 to 14 m in the district. This range was divided into seven categories at an interval of 2 m and represented by different colours in Figure 2.5. The upper range 12-14 m was located only at one site in Lakhan Majra block of the district. Maximum area of the district was under 2-4 m depth of water table by covering the area of Rohtak, Sampla and Kalanaur blocks. Maximum area of Meham and Lakhan Majra blocks was having water table greater than 4m. On the basis of temporal behaviour, it can be concluded from these spatial variable maps of water table that area under the range of 0-2 m depth of water table had been increased significantly from 1981 to 2011 and requires serious attention for its management. To see the effect of rainfall on the water table, a spatial variable map for water table depth for the

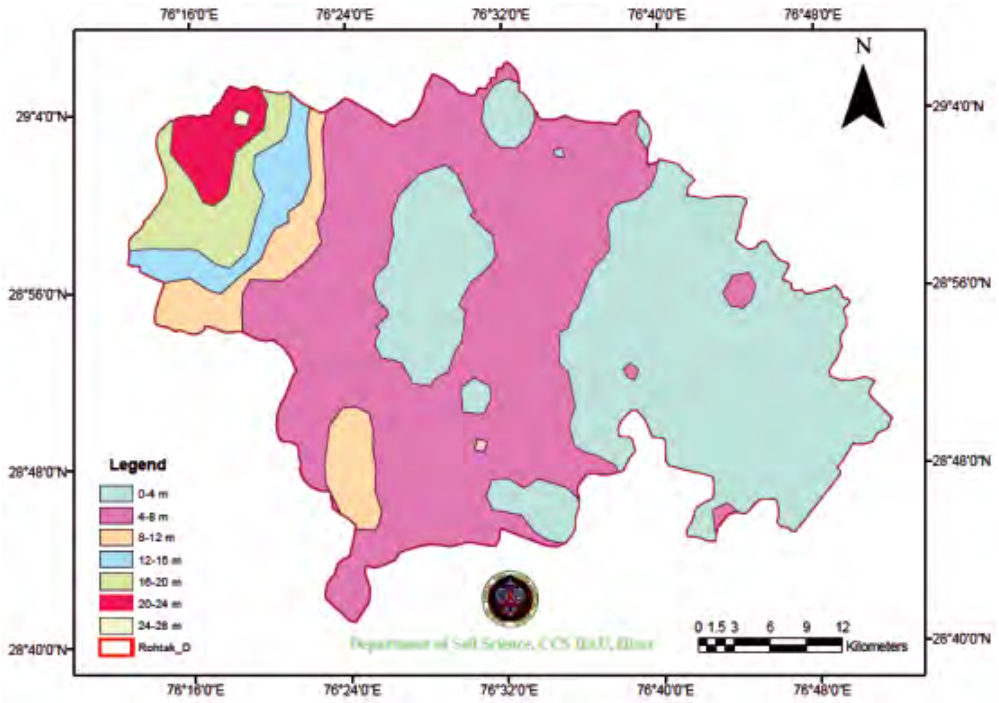


Fig.2.2: Spatial variable map of groundwater level in Rohtak district during year June, 1981

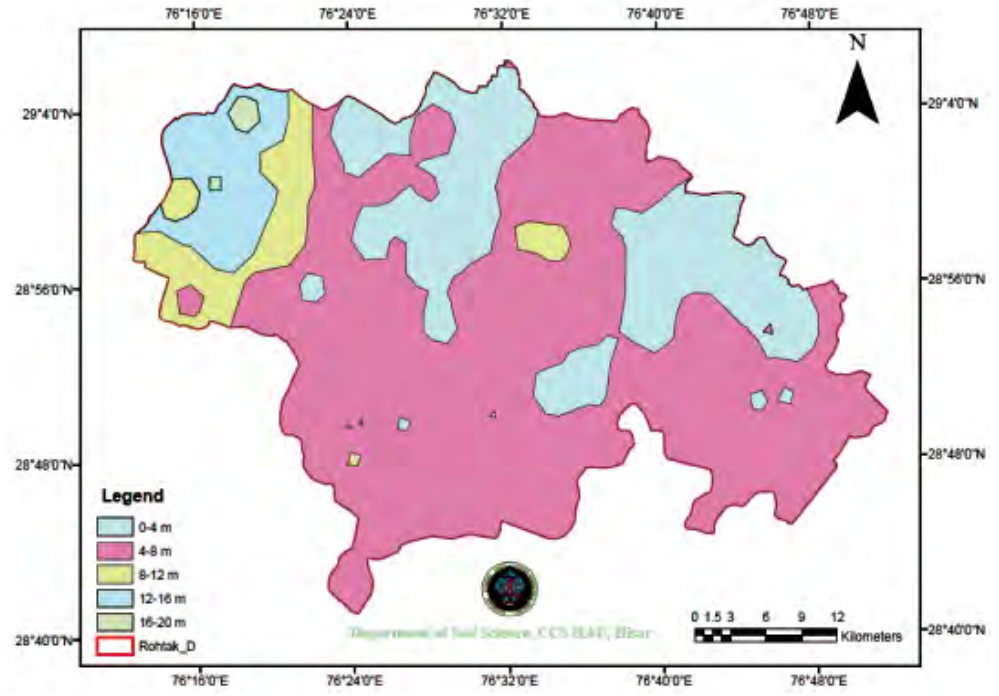


Fig.2.3: Spatial variable map of groundwater level in Rohtak district during year June, 1991

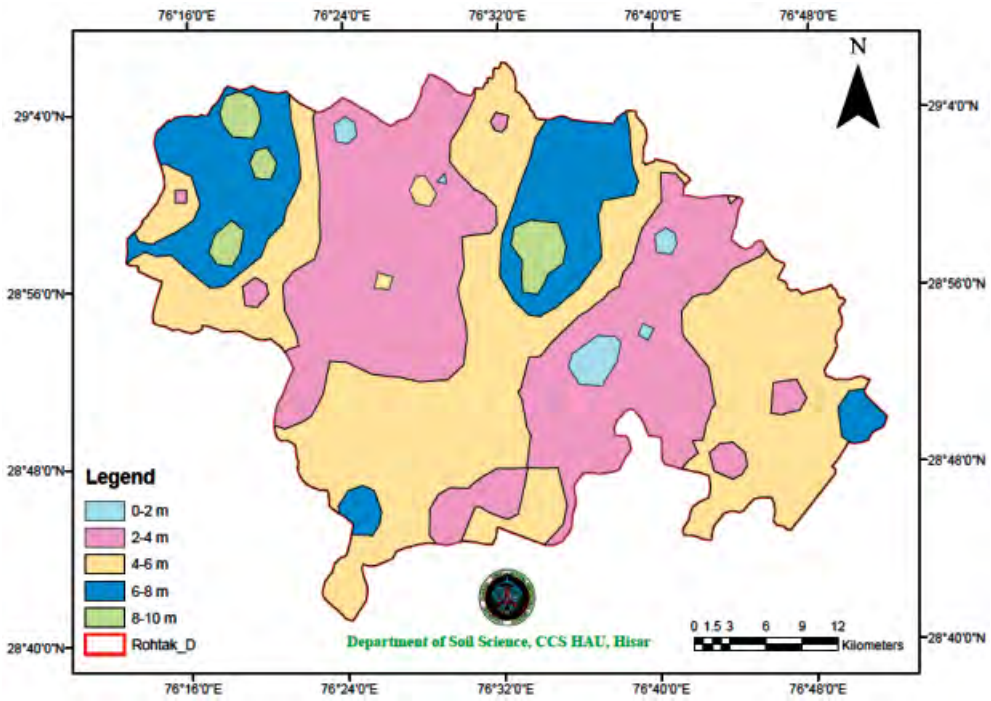


Fig.2.4: Spatial variable map of groundwater level in Rohtak district during year June, 2001

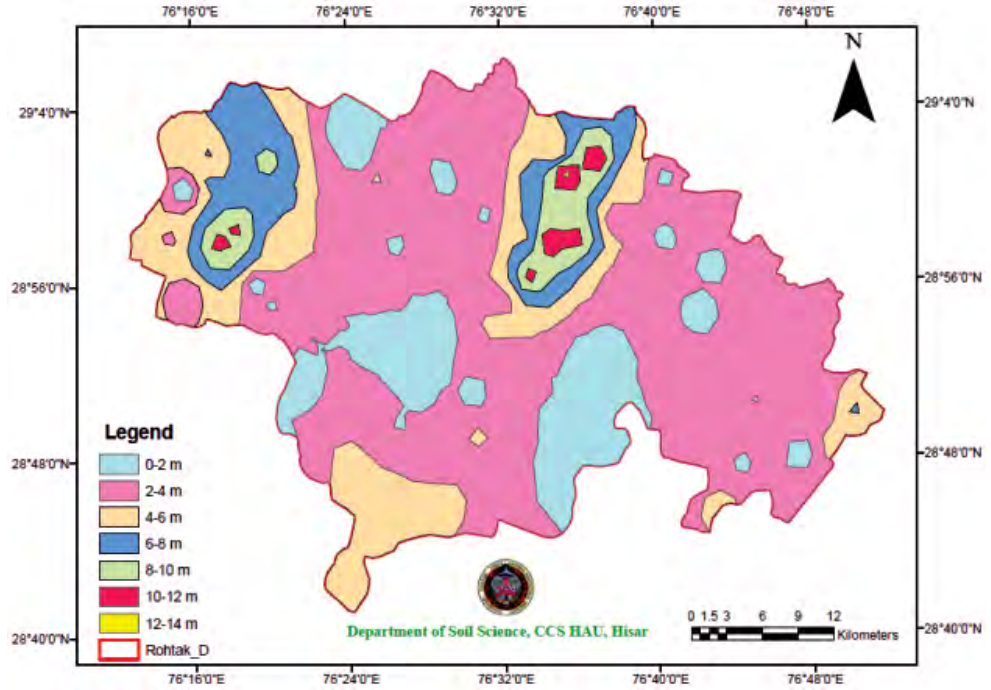


Fig.2.5: Spatial variable map of groundwater level in Rohtak district during year June, 2011

period Oct, 2011 was prepared (Fig.2.6). In this figure, the water table was ranging from 0 to 12 m in the district. This range was divided into six categories at an interval of 2 m. Most of the area of the district comes under 2-4 m depth of water table. On comparing the maps of June and October, it can be cleared observed that the area under 0-2 m depth of water table has been increased drastically from June to October in Rohtak, Kalanaur and Sampla blocks.

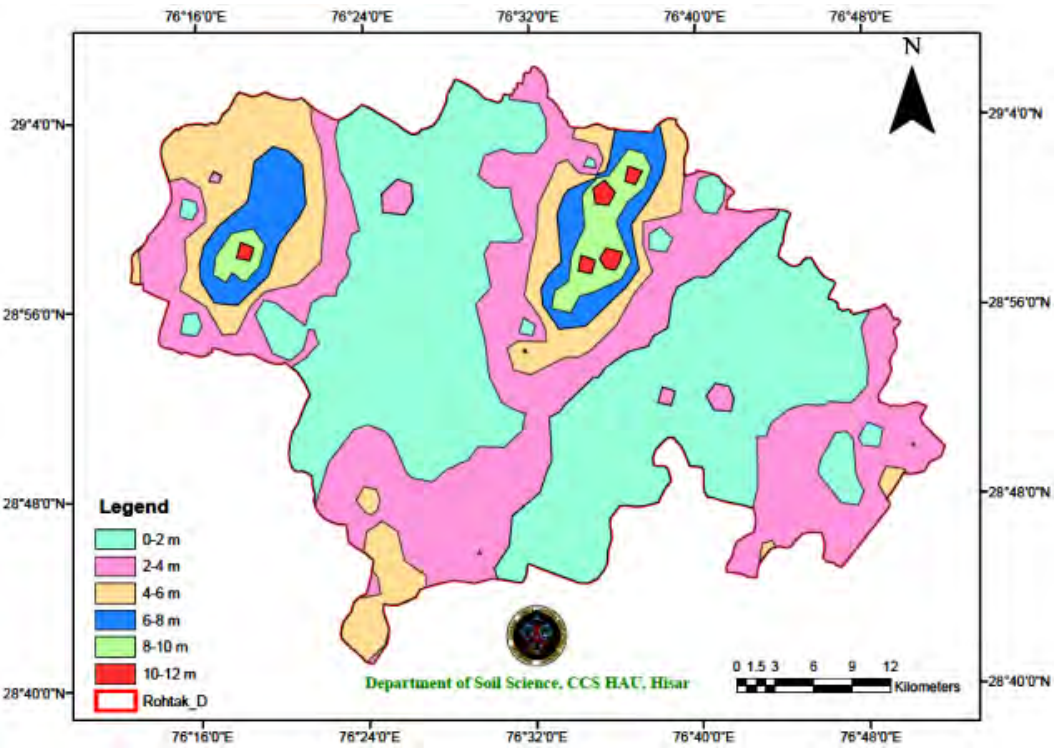


Fig.2.6: Spatial variable map of groundwater level in Rohtak district during year Oct., 2011

3. BLOCKWISE CHEMICAL COMPOSITION OF GROUNDWATER

Water samples were collected at an interval of three to four kilometers on the kachcha, link and main roads by covering approximately all the villages of Rohtak district. The elevation, longitude and latitude angles of the sampling points were recorded by GPS system at each location. All the 238 ground water samples (41 from Kalanaur, 33 from Lakhan Majra, 48 from Meham, 72 from Rohtak and 44 from Sampla) were analyzed for various chemical parameters viz. pH, EC cations (Na^+, Ca^{+2}, Mg^{+2} and K^+) and anions (, HCO_3^-, Cl^- and SO_4^{-2}). Subsequently, SAR and RSC were calculated for these samples by using the following formulae.

$$RSC\ (me/l) = (CO_3 + HCO_3) - (Ca + Mg) \quad \text{... (i)}$$

$$SAR\ (m\ mol/l)^{½} = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{1/2}} \quad \text{… (ii)}$$

Blockwise range and mean of different water quality parameters and their spatial extent are presented in impending sections of this chapter of the bulletin. Then the samples were classified into seven categories as per the criteria (Table 3.1) formulated by All India Coordinate Research Project on "Management of Salt Affected Soils and Use of Saline Water in Agriculture".

Table 3.1: Criteria for water quality classification (AICRP, 1989)

Quality	Class	EC (dS/m)	SAR $(mmol/l)^{½}$	RSC (me/l)
Good	A	<2	<10	<2.5
Marginally saline	B_1	2-4	<10	<2.5
Saline	B_2	>4	<10	<2.5
High SAR saline	B_3	>4	>10	<2.5
Marginally alkali	C_1	<2	<10	2.5-4.0
Alkali	C_2	<2	<10	>4.0
High alkali	C_3	Variable	>10	>4.0

3.1 KALANAUR BLOCK

Kalanaur block constitutes part of Rohtak district of Haryana state, having 28 villages. It lies between 28º40′58″ to 28º54′19″ N latitude and 76º20′16″ to 76º34′38″ E longitude. It is surrounded by Meham and Rohtak blocks of Rohtak district in north and east directions, respectively, by Beri

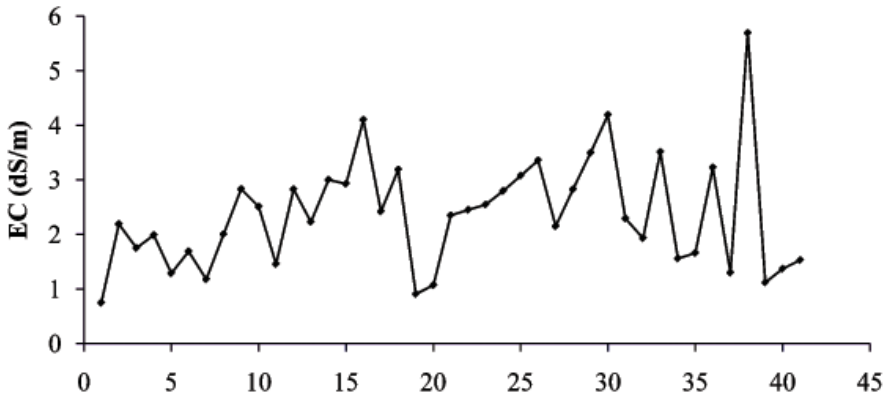
Khas block of Jhajjar district in the south-east direction, by Dadri-I and Bhiwani blocks of Bhiwani district in south-west and west directions, respectively.

In the block, electrical conductivity (EC) ranged from 0.80 to 5.70 dS/m with a mean of 2.36 dS/m (Table 3.2). The lowest EC of 0.80 dS/m in water samples was observed in village Lahli and the highest EC of 5.70 dS/m was found in south side of village Gharnawati. The study revealed that 92.7 % of the samples showed EC less than 4 dS/m. Variability of EC in groundwater samples can be observed from the Figure 3.1where a graph is drawn between the sample points vs their EC values and location specific variability of EC in the block is shown by spatial variable map (Fig.3.2a). In the spatial variable map of EC, the EC values are divided into 6 classes and reflected by different colours. EC of groundwater is very scatter but EC of southern part is higher than northern part of the block. The most dominating range of EC in the block is 1 to 3 dS/m. The highest EC range (5-6 dS/m) was observed at one spot in the block. No particular trend in the variation of EC is present in the block.

Table 3.2: Range and average of different water quality parameters in Kalanaur block

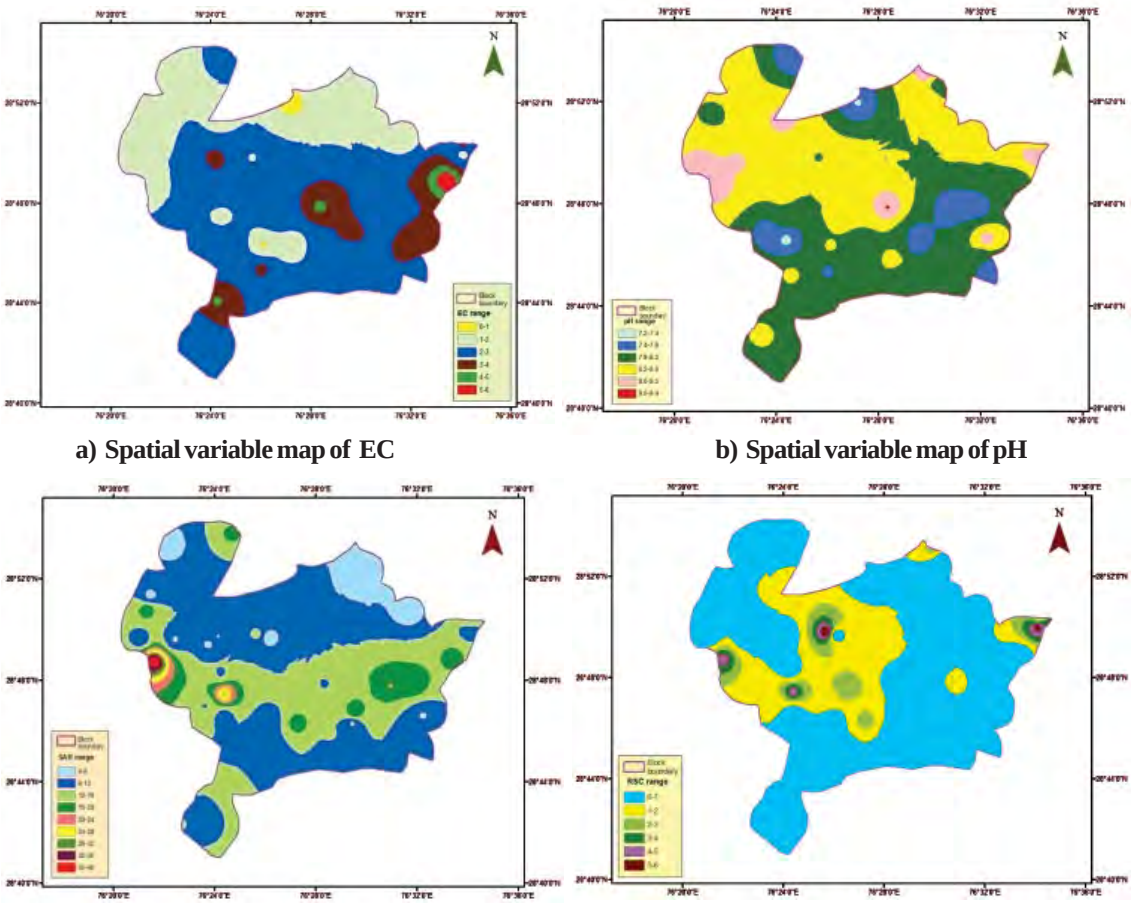
Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.80-5.70	2.36
2	pH	7.08-8.81	7.99
3	CO_3^{-2} (me/l)	0.00-4.40	0.40
4	HCO_3^{-} (me/l)	2.00-11.20	5.39
5	Cl^{-} (me/l)	2.20-42.00	16.65
6	SO_4^{-2} (me/l)	0.00-19.20	2.26
7	Ca^{+2} (me/l)	0.17-3.80	1.82
8	Mg^{+2} (me/l)	0.30-12.00	5.05
9	Na^{+} (me/l)	6.58-48.91	19.49
10	K^{+} (me/l)	0.02-4.25	0.74
11	RSC (me/l)	0.00-6.00	0.92
12	SAR (m mol/l)^{½}	4.77-38.04	12.04

The pH ranged from 7.08 to 8.81 with an average of 7.99. The lowest pH 7.08 in water samples was observed in village Kateshra and the highest value 8.55 was recorded in village Garhi. In the spatial variable map of pH, the pH values are divided into 6 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.2b) that the pH of groundwater is ranging from 7.8 to 8.6 in most part of the block. The highest pH range (9.0-9.4) was observed at one spot in the block. More than 8.5 value of pH represent the alkali nature of water, thus, the more than fifty percent area of the block has non-alkali water.



Samples collected spatially in the block

Fig.3.1: Variability of EC in groundwater samples collected in Kalanaur block



a) Spatial variable map of EC

b) Spatial variable map of pH

c) Spatial variable map of SAR

d) Spatial variable map of RSC

Fig.3.2: Spatial variable map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Kalanaur block of Rohtak district

The sodium adsorption ratio (SAR) ranged from 4.77 to 38.04 (m mol/l)^{½} with an average value of 12.04 (m mol/l)^{½} (Table 3.2), the lowest SAR value was recorded in south-eastern side of village Bhali and the highest value recorded in Kherari village. The variations in the values of SAR of this block is shown by spatial variable map (Fig.3.2c). In the map, the SAR values are divided into 9 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.2c) that the SAR of groundwater is ranging from 8.0-16.0 in most part of the block and this range is sprinkled in many parts of block. The highest SAR range (32-40) was observed at one spot in the block.

The residual sodium carbonate (RSC) ranged from nil to 6.0 me/l with an average value of 0.92 me/l and the highest value was recorded in Jindsan village. The variations in values of RSC of this block is shown by spatial variable map (Fig.3.2d). In the map, the RSC values are divided into 6 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.2d) that the RSC of groundwater is ranging from 0 to1 in most part of the block. The highest RSC range (5-6) was observed at two spots in the block.

The average chemical composition and related quality parameters in different EC classes for Kalanaur block are given in Table 3.3. The distribution of samples in different EC classes is shown in Fig.3.3. It showed that per cent samples in EC classes increased with increase in the EC of groundwater upto 3 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of groundwater. The maximum number of 16 samples were concentrated in EC class of 2-3 and followed by 14 samples in EC class of 1-2 dS/m. It is seen that 78.1 per cent samples were found upto EC of 3 dS/m, whereas, there is no sample after EC class of 5-6 dS/m.

Table 3.3: Chemical composition of groundwater samples of Kalanaur block in different EC classes

EC classes (dS/m)	No. of samples	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
			(me/l)									(m mol/l)^{½}
0-1	2	5.0	0.00	3.40	5.10	0.10	0.53	1.47	8.62	0.21	0.30	9.19
1-2	14	34.1	0.16	5.44	8.56	1.60	1.05	2.54	12.26	0.87	2.09	12.80
2-3	16	39.0	0.14	5.62	18.89	1.98	2.07	5.72	21.32	0.89	0.33	11.36
3-4	6	14.5	1.25	5.28	23.00	4.40	2.81	8.61	27.49	0.31	0.33	11.83
4-5	2	5.0	2.20	6.50	35.20	0.46	2.80	8.25	30.38	0.49	0.35	12.99
5-6	1	2.4	0.00	3.60	42.00	11.00	3.20	9.00	43.28	0.60	0.00	17.52

In case of anions, chloride was the dominant anion with maximum value of 42.00 me/l, observed in the north side of village Gharnawati and minimum value of 2.20 me/l was recorded in village Garnawati. Bicarbonate (HCO_3^-) ranged from 2.00 to 11.20 me/l, the maximum value was observed in the water samples of village Khanur and minimum value was found in village Sampala. The average values for CO_3^{-2}, HCO_3^-, Cl^- and SO_4^{-2} were found to be 0.40, 5.39, 16.65 and 2.26

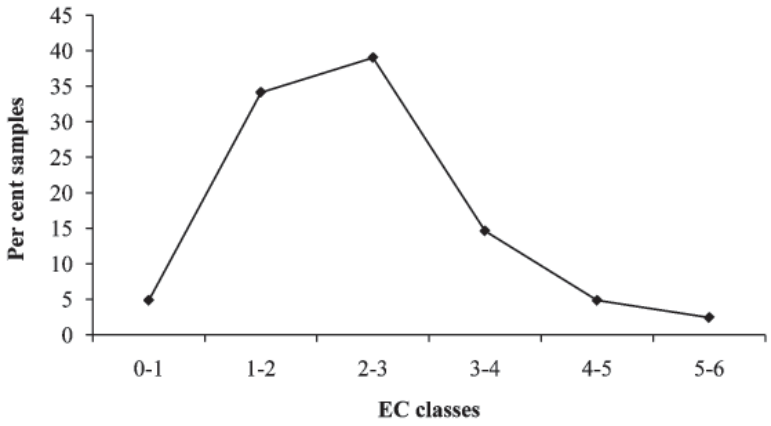


Fig. 3.3: Per cent samples in different EC classes of Kalanaur block

me/l, respectively and the anions were in order of $Cl^{-} > HCO_3^{-} > SO_4^{-2} > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Fig.3.4.

In cations, sodium concentration varied widely from 6.58 to 48.91 me/l, minimum value was observed in village Nond and maximum value was observed in Kasrenti followed by magnesium (0.30 to12.00 me/l) and calcium (0.17 to 3.80 me/l). Average values for Na^{+}, Mg^{+2}, Ca^{+2} and K^{+} were 19.49, 5.05, 1.82 and 0.74 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.5. It was observed that cations in groundwaters followed the order $Na^{+} > Mg^{+2} > Ca^{+2} > K^{+}$.

According to AICRP classification, the maximum samples were found in marginally saline (36.6 %) category followed by good (22.0%) (Fig.3.6). The per cent samples in saline classes i.e. marginally saline, saline and high SAR saline classes were 36.6, 4.9 and 9.8, respectively. Marginally alkali, alkali, and high alkali categories were recorded as 7.3, 9.8 and 9.8 % samples. The lowest percentage of samples (4.9 %) was observed in saline category.

3.2 LAKHAN MAJARA BLOCK

Lakhan Majara block constitutes part of Rohtak district of Haryana state, having 13 villages. It lies between 28º56′16″ to 29º06′13″ N latitude and 76º22′37″ to 76º34′55″ E longitude. It is surrounded by Julana and Kathurah blocks of Jind and Sonipat districts, respectively, in north direction, by Rohtak block of Rohtak district in east and south directions, and by Meham block of Rohtak district in west direction.

In the block, EC ranged from 0.79 to 9.38 dS/m with a mean of 2.36 dS/m (Table 3.4). The lowest EC of 0.79 dS/m in water samples was observed in village Gugaheri and the highest EC of 9.38 dS/ was found in village Lakhan Majra. The study revealed that 84.8 % of the samples showed EC less than 4 dS/m. Variability of EC in groundwater samples can be observed from the Figure 3.7 where a graph is drawn between the sample points vs their EC values and location specific variability of EC in the block is shown by spatial variable map (Fig.3.8a). In the spatial

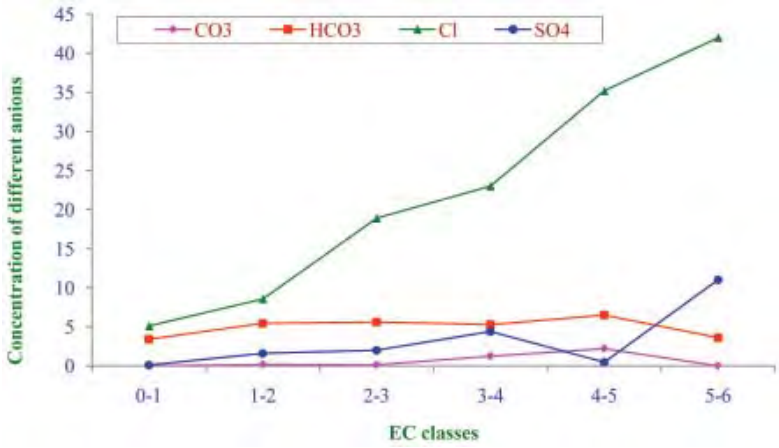


Fig. 3.4: Anions (CO_3, HCO_3, Cl, SO_4) concentration (me/l) in different EC classes of Kalanaur block

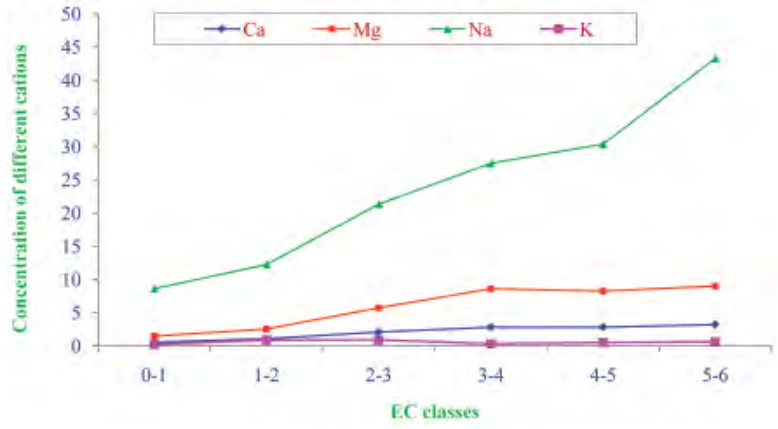


Fig. 3.5: Cations (Na, Ca, Mg, K) concentration (me/l) in different EC classes of Kalanaur block

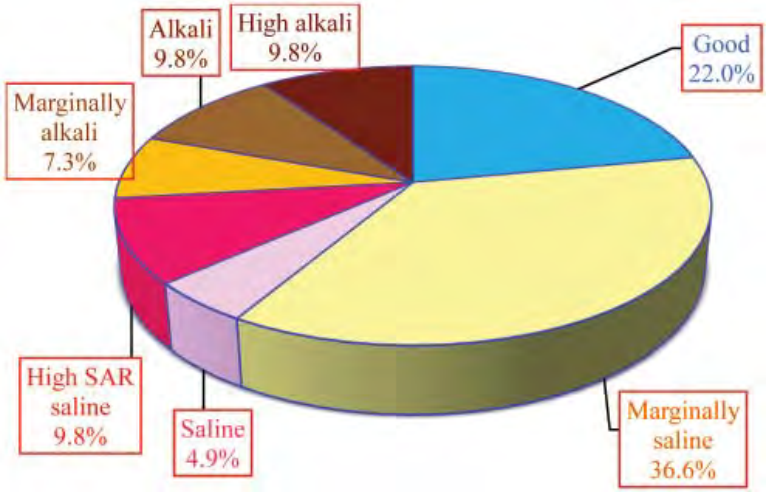


Fig.3.6: Quality of groundwater (per cent) in Kalanaur block of Rohtak district

variable map of EC, the EC values are divided into 9 classes and reflected by different colours. EC of groundwater is very scatter in the block and no particular trend in the variation of EC is present in the block. The most dominating range of EC in the block is 1 to 3 dS/m. The highest EC range (7-9 dS/m) was observed at one spot in the block.

Table 3.4: Range and average of different water quality parameters in Lakhan Majra block

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.79-9.38	2.36
2	pH	6.82-8.56	7.81
3	CO_3^{-2} (me/l)	0.00-4.00	0.83
4	HCO_3^{-} (me/l)	1.10-12.40	6.24
5	Cl^{-} (me/l)	6.00-84.60	17.87
6	SO_4^{-2} (me/l)	0.10-6.23	1.21
7	Ca^{+2} (me/l)	0.32-5.67	1.70
8	Mg^{+2} (me/l)	1.05-17.73	5.05
9	Na^{+} (me/l)	8.55-69.32	21.00
10	K^{+} (me/l)	0.01-1.50	0.56
11	RSC (me/l)	0.00-8.50	2.62
12	SAR (m mol/l)^{½}	8.09-21.57	11.89

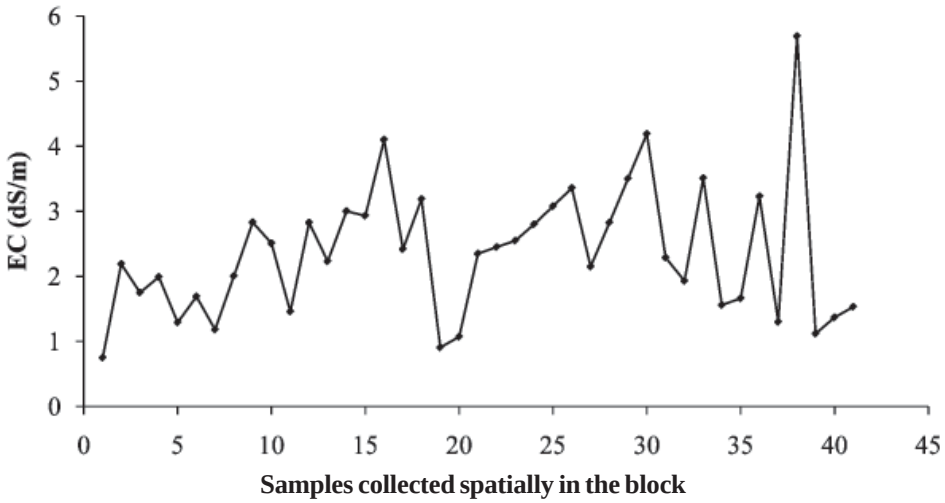


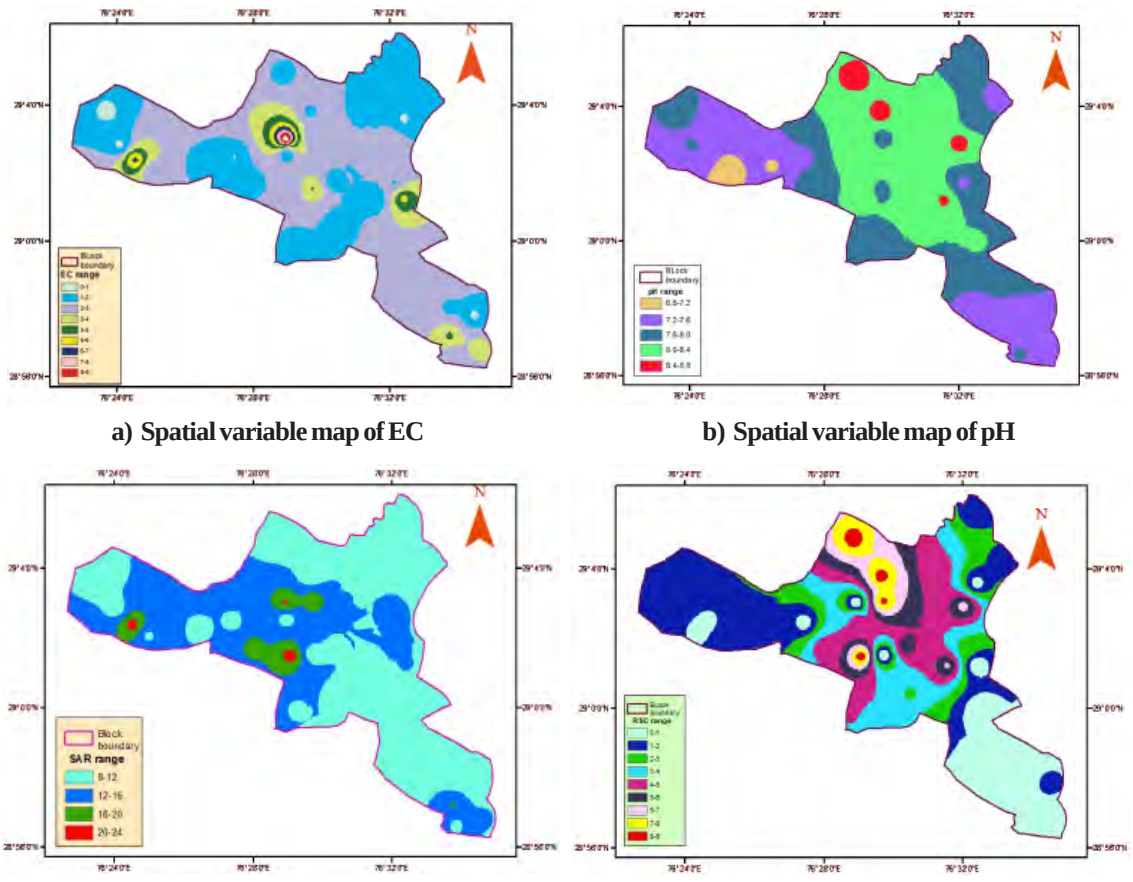
Fig.3.7: Variability of EC in groundwater samples collected in Lakhan Majra block

The pH ranged from 6.82 to 8.56 with an average of 7.81 (Table 3.4). The lowest pH 6.82 in water samples was observed in village Bansi and the highest value 8.56 was recorded in village Chiri. In the spatial variable map of pH, the pH values are divided into 5 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.8b) that the pH of groundwater

is ranging from 8.0 to 8.4 in most part of the block. The highest pH range (8.4-8.8) was observed at four spots in the block. More than 8.5 value of pH represent the alkali nature of water, thus, very less area of the block has alkali water.

The SAR ranged from 8.09 to 21.57 (m mol/l)^{½} with an average value of 11.89 (m mol/l)^{½} (Table 3.4), the lowest SAR value was recorded in village Lakhan Majra and the highest value was recorded in Kharanti village. The variations in values of SAR of this block is shown by spatial variable map (Fig.3.8c). In the map, the SAR values are divided into 4 classes and reflected by different colours. It was observed from the spatial variable map that the SAR of groundwater is ranging from 8.0-16.0 in most part of the block and this range is sprinkled in many parts of block. The highest SAR range (20-24) was observed at three spots in the block.

The RSC ranged from nil to 8.50 me/l with an average value of 2.62 me/l and the highest value was recorded in Kharanti village. The variations in values of RSC of this block is shown by



a) Spatial variable map of EC **b) Spatial variable map of pH**

c) Spatial variable map of SAR **d) Spatial variable map of RSC**

Fig. 3.8: Spatial variable map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Lakhan Majra block of Rohtak district

spatial variable map (Fig.3.8d). In the map, the RSC values are divided into 9 classes and reflected by different colours. It was observed from the spatial variable map that the RSC of 0 to 1 is dominating range in the block and particularly in southern part of the block. The highest RSC range (8-9) was observed at four spots in the block.

The average chemical composition and related quality parameters in different EC classes for Lakhan Majra block are given in Table 3.5. The distribution of salts in different EC classes is shown in Fig.3.9. It showed that per cent in EC classes increased with increase in the EC of groundwater upto 2 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of groundwater. The maximum number of 14 samples were concentrated in EC class of 1-2 and followed by 8 samples in EC class of 2-3 dS/m. It is seen that 81.8 per cent samples were found upto EC of 3 dS/m, whereas, there is no sample in EC classes of 7-8 and 8-9 dS/m.

Table 3.5: Chemical composition of groundwater samples of Lakhan Majra block in different EC classes

EC classes (dS/m)	No. of samples	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
			(me/l)									$(m\ mol/l)^{½}$
0-1	5	15.2	0.48	2.88	7.16	0.58	0.55	1.55	9.87	0.33	1.26	9.84
1-2	14	42.5	1.15	6.95	8.49	0.79	1.17	2.99	14.45	0.54	3.96	10.40
2-3	8	24.2	0.75	7.91	18.08	1.65	1.92	5.46	23.15	0.53	3.13	13.20
3-4	1	3.0	0.00	6.00	25.00	2.10	2.40	5.60	24.31	0.71	0.00	12.16
4-5	2	6.1	0.40	6.40	35.80	1.15	3.18	11.17	33.73	0.72	0.00	13.18
5-6	1	3.0	0.80	6.00	49.20	1.20	3.70	17.40	39.31	1.00	0.00	12.10
6-7	1	3.0	0.00	4.40	60.00	0.90	3.50	10.30	55.71	0.70	0.00	21.21
7-8	0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-9	0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9-10	1	3.0	1.20	1.80	84.60	6.23	5.67	17.73	69.32	1.30	0.00	20.27

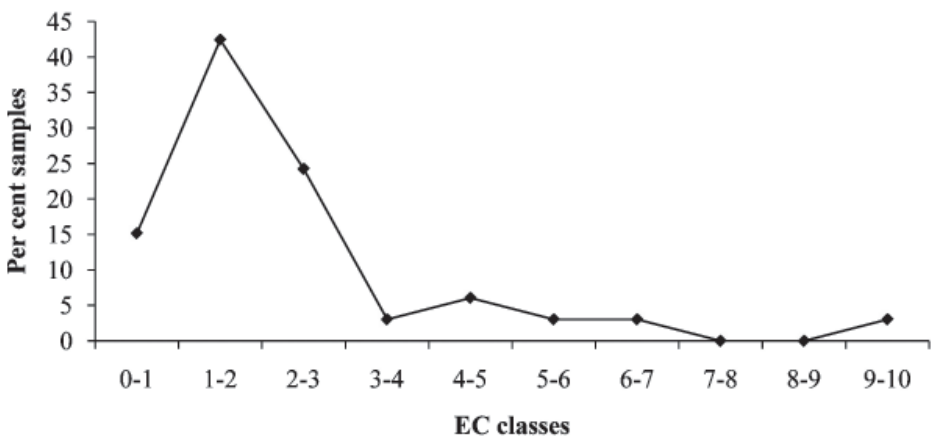


Fig.3.9: Per cent samples in different EC classes

In case of anions, chloride was the dominant anion with maximum value of 84.60 me/l, observed in south-west corner of the village Lakhan Majra and minimum value of 6.00 me/l was recorded in north-east corner of the village Lakhan Majra. The average values for CO_3^{-2}, HCO^-_3, Cl^- and SO_4^{-2} were found to be 0.83, 6.24, 17.87 and 1.21 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Figure 3.10.

In cations, sodium concentration varied widely from 8.55 to 69.32 me/l, minimum value was observed in village Gugaheri and maximum value was observed in Lakhan Majra followed by magnesium (1.05 to17.33 me/l) and calcium (0.32 to 5.67 me/l). Average values for Na^+, Mg^{+2}, Ca^{+2} and K^+ were 21.00, 5.05, 1.70 and 0.56 me/l, respectively. The concentration of the cations in different classes of EC is given by Figure 3.11. It was observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2} > K^+$.

According to AICRP classification, the maximum samples were found in marginally saline (21.2%) and high alkali (21.2%) categories followed by good (15.2%) and marginally alkali (15.2%) (Fig.3.12). The per cent samples in saline classes i.e. marginally saline, saline and high SAR saline classes were 21.2, 3.0 and 12.1, respectively. Marginally alkali, alkali, and high alkali categories were recorded as 15.2, 12.1 and 21.2% samples. The lowest percentage of samples (3.0 %) was observed in saline category.

3.3 MEHAM BLOCK

Meham block constitutes part of Rohtak district of Haryana state, having 25 villages. It lies between 28º51′22″ to 29º05′14″ N latitude and 76º12′47″ to 76º28′56″ E longitude. It is surrounded by Lakhan Majra, Rohtak and Kalanaur blocks of Rohtak district in north-east, east and south-east directions, respectively, by Bhiwani block of Bhiwani district in south-west, by Hansi-II block of Hisar district in west and by Julana block of Jind district in north direction.

In the block, EC ranged from 0.51 to 7.34 dS/m with a mean of 2.54 dS/m (Table 3.6).The lowest EC of 0.79 dS/m in water samples was observed in village Basana and the highest EC of 7.34 dS/ was found in village Sisar. The study revealed that 75.9 % of the samples showed EC values less than 3 dS/m. Variability of EC in groundwater samples can be observed from the Figure 3.13 where a graph is drawn between the sample points vs their EC values and location specific variability of EC in the block is shown by spatial variable map (Fig.3.14a). In the spatial variable map of EC, the EC values are divided into 8 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.14a) that the EC of groundwater is ranging from 1-3 dS/m in most part of the block. The highest EC range (6-8 dS/m) was observed at two spots in the block. No particular trend in the variation of EC was present in the block. In the block, groundwater of south-eastern part has lower EC as compared to the other parts of the block.

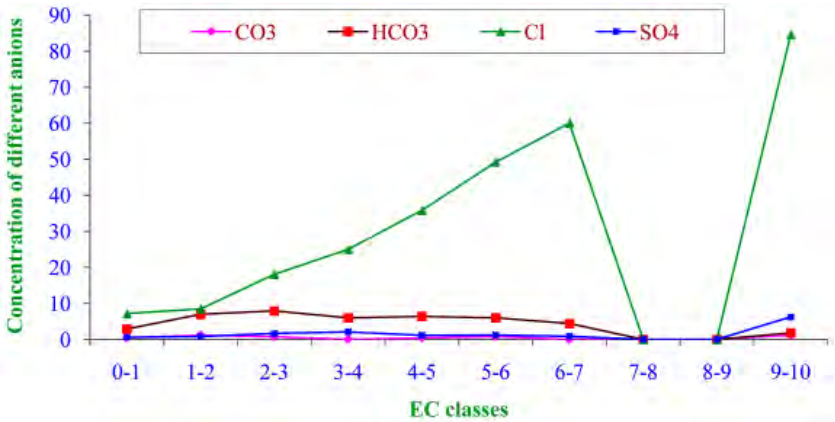


Fig. 3.10: Anions (CO_3, HCO_3, Cl, SO_4) concentration (me/l) in different EC classes of Lakhan Majra block

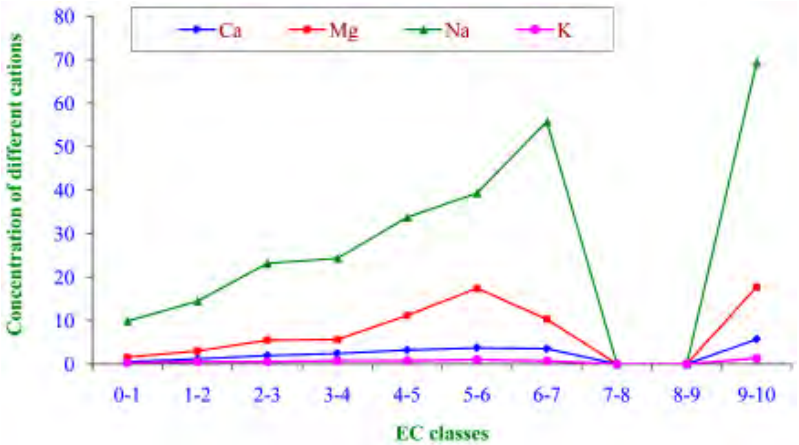


Fig. 3.11: Cations (Na, Ca, Mg, K) concentration (me/l) in different EC classes of Lakhan Majra block

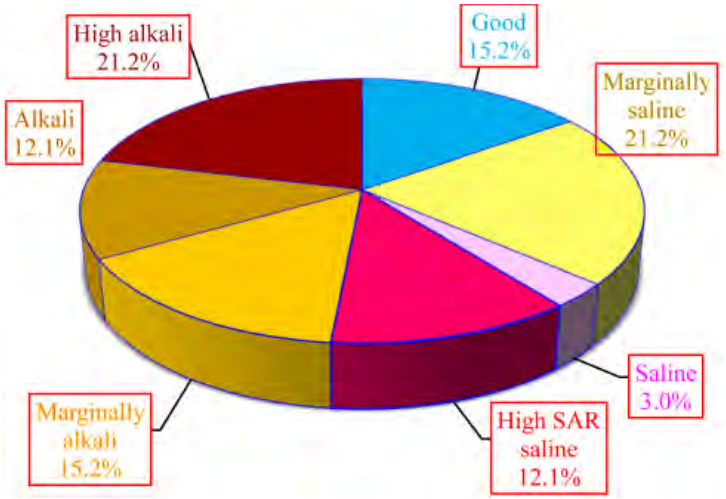


Fig. 3.12: Quality of groundwater (per cent) in Lakhan Majra block of Rohtak district

Table 3.6: Range and average of different water quality parameters in Meham block

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.51-7.34	2.54
2	pH	6.34-8.83	7.51
3	CO_3^{-2} (me/l)	0.00-4.40	0.71
4	HCO_3^- (me/l)	0.80-11.20	5.15
5	Cl^- (me/l)	3.00-58.00	18.07
6	SO_4^{-2} (me/l)	0.00-23.50	2.16
7	Ca^{+2} (me/l)	0.20-6.38	1.82
8	Mg^{+2} (me/l)	0.30-17.62	4.97
9	Na^+ (me/l)	5.77-57.56	20.61
10	K^+ (me/l)	0.01-2.20	0.23
11	RSC (me/l)	0.00-6.30	0.87
12	SAR (m mol/l)^{½}	5.18-30.76	12.75

The pH ranged from 6.34 to 8.83 with an average of 7.51 (Table 3.6). The lowest pH of 6.34 in water samples was observed in village Bhani Chanderpal and the highest pH (8.83) was recorded in village Meham. In the spatial variable map of pH, the pH values are divided into 8 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.14b) that the pH of groundwater is ranging from 7.6-8.0 in most part of the block and this range is dominating mostly in the eastern parts of block. The highest pH range (8.4-9.2) was observed at one spot in the block.

The SAR ranged from 5.18 to 30.76 (m mol/l)^{½} with an average value of 12.75 (m mol/l)^{½} (Table 3.6), the lowest SAR value was recorded in village Kheri Meham and the highest was recorded in Meham. The variations in values of SAR of this block is shown by spatial variable map (Fig.3.14c). In the map, the SAR values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.14c) that the SAR of groundwater is ranging from 8.0-16.0 in most part of the block and this range is dominating in the central and eastern parts of block. The highest SAR range (20-32) was observed at two spots in the block.

The RSC varied from nil to 6.30 (me/l) with an average of 0.87 (me/l) (Table 3.6) and the highest value of RSC (6.30 me/l) was recorded in the village Barhan. The variations in values of RSC of this block is shown by spatial variable map (Fig.3.14d). In the map, the RSC values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.14d) that the RSC of groundwater is ranging from 0-1 in most part of the block and this range is dominating mostly in the western part of the block. It was observed that in 67% water samples, RSC was nil. The highest RSC range (5-7) was observed at one spot in the block.

The average chemical composition and related quality parameters in different EC classes for Meham block are given in Table 3.7. The distribution of salts in different EC classes is shown in Fig.3.15. It showed that per cent in EC classes increased with increase in the EC of groundwater

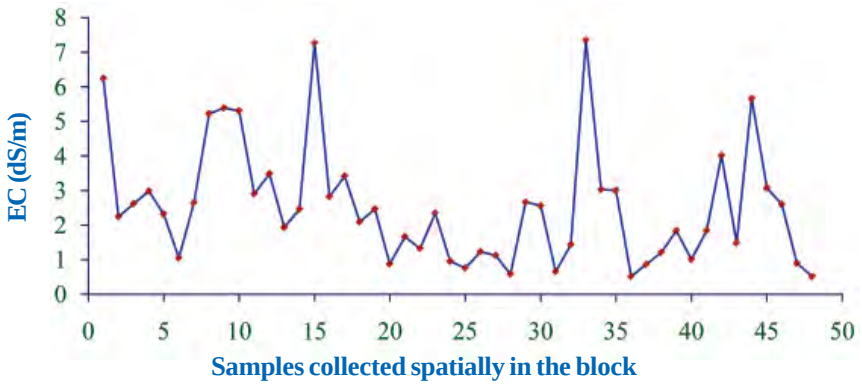
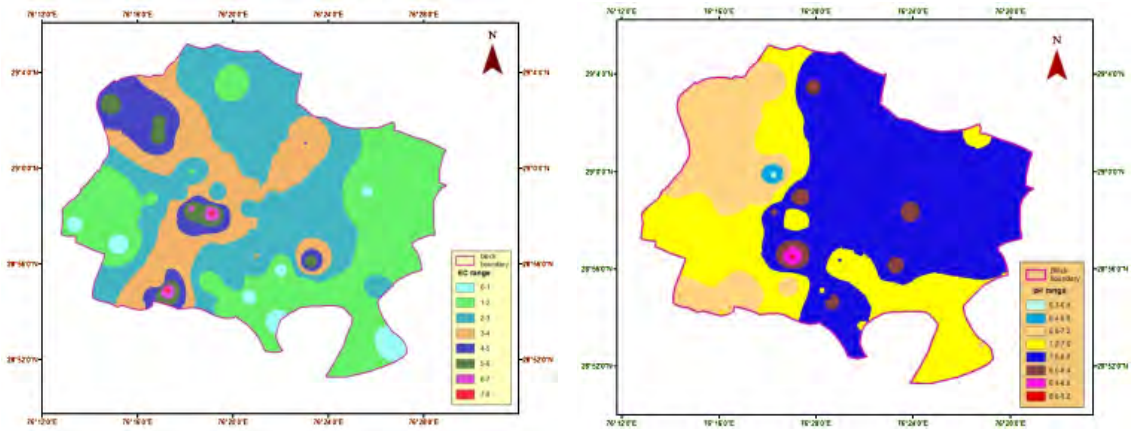
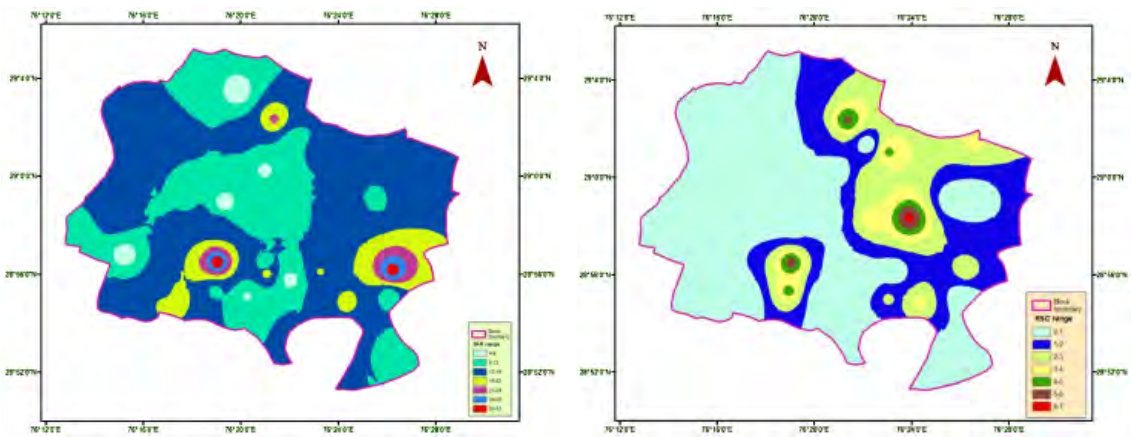


Fig. 3.13: Variability of EC in groundwater samples collected in Meham block



a) Spatial variable map of EC **b) Spatial variable map of pH**



c) Spatial variable map of SAR **d) Spatial variable map of RSC**

Fig. 3.14: Spatial variable map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Meham block of Rohtak district

upto 3 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of groundwater except 5-6 class. The maximum number of 15 samples was concentrated in EC class of 2-3. It is seen that 75 per cent samples were found upto EC of 3 dS/m, whereas, two samples were found in the EC class of 7-8 dS/m. Average RSC of the EC class 4-5 was the highest (4.20) and after this class, RSC was found absent.

Table 3.7: Chemical composition of groundwater samples of Meham block in different EC classes

EC classes (dS/m)	No. of samples	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
			(me/l)									$(m\ mol/l)^{½}$
0-1	10	20.8	0.00	2.86	4.75	0.11	0.47	1.12	7.99	0.07	0.09	9.75
1-2	11	22.9	0.45	4.64	9.64	0.61	0.75	1.96	13.63	0.30	1.61	13.93
2-3	15	31.3	1.43	5.47	18.31	1.79	1.91	5.23	20.79	0.16	1.52	12.89
3-4	4	8.3	1.23	8.05	23.05	1.10	2.67	7.78	27.80	0.30	0.30	12.39
4-5	1	2.1	3.00	11.20	30.00	0.00	2.50	7.50	30.24	0.40	4.20	13.52
5-6	4	8.3	0.00	6.05	40.30	7.53	4.09	10.34	38.98	0.66	0.00	14.57
6-7	1	2.1	0.00	6.40	51.60	4.40	4.80	15.20	46.20	0.14	0.00	14.61
7-8	2	4.2	0.00	5.80	52.20	15.00	5.68	16.12	52.04	0.20	0.00	15.91

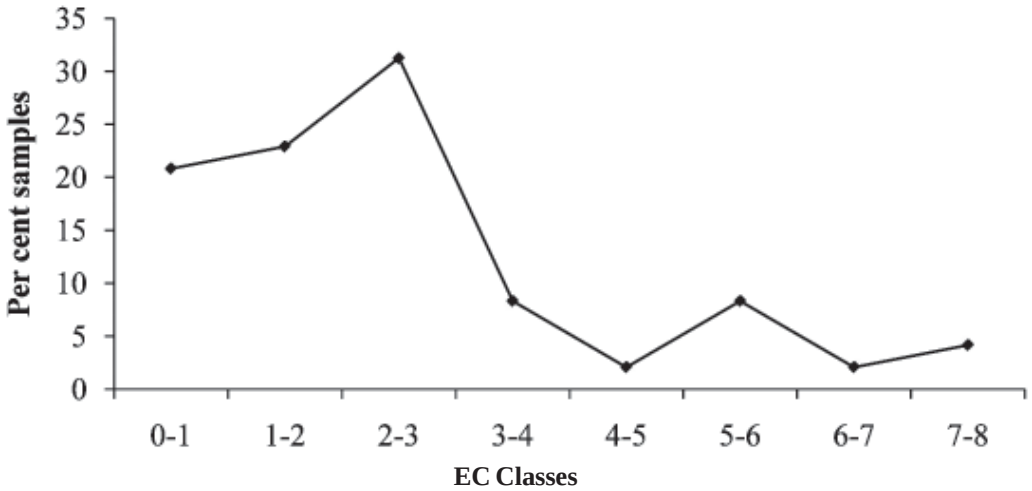


Fig. 3.15: Per cent samples in different EC (dS/m) classes of Meham block

In case of anions, chloride was the dominant anion with maximum value of 58.00 me/l (Table 3.6), observed in village Sisar and minimum value of 3.00 me/l was recorded in village Bhani Bhairon. Bicarbonate (HCO_3^-) ranged from 0.80 to 11.20 me/l, the maximum value was observed in the water sample of village Nindana and minimum value was found in village Basana. The average values for CO_3^{-2}, HCO_3^-, Cl^- and SO_4^{-2} were found to be 0.71, 5.15, 18.07 and 2.16 me/l, respectively (Table 3.6) and the anions were in order of $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^{-2}$. The concentration of the anions in different classes of EC is depicted in Figure 3.16.

In cations, sodium concentration varied widely from 5.77 to 57.56 me/l (Table 3.6), minimum value was observed in village Basana and maximum value was observed in Sisar, followed by magnesium (0.30 to 17.62 me/l) and calcium (0.20 to 6.38 me/l). Average values for Na^{+}, Mg^{+2}, Ca^{+2} and K^{+} were 20.61, 4.97, 1.82 and 0.23 me/l, respectively (Table 3.6). The concentration of the cations in different classes of EC is given by Figure 3.17. It was observed that cations in groundwaters followed the order $Na^{+} > Mg^{+2} > Ca^{+2} > K^{+}$.

According to AICRP classification, the maximum samples were found in good quality (22.9 %) category followed by marginally saline (20.8 %) (Fig.3.18). The per cent samples in saline classes i.e. marginally saline, saline and high SAR saline classes were 20.8, 6.3 and 18.7, respectively. The per cent samples in saline classes were 20.8, 6.3 and 18.7 % in marginally saline, saline and high SAR saline classes, respectively. High alkali and marginally alkali categories were recorded as 12.5 % samples each. The lowest percentage of samples (6.3 %) was observed in alkali class as well as saline categories.

3.4 ROHTAK BLOCK

Rohtak block constitutes part of Rohtak district of Haryana state, having 57 villages. It lies between 28º44′22″ to 29º03′55″ N latitude and 76º26′01″ to 76º49′45″ E longitude. This block all most lies in the centre of Rohtak district and the biggest among all the five blocks. It is surrounded by Kathura, Gohana and Kharkhoda blocks of Sonipat district in north, north-east and east directions, respectively, by Sampla, Kalanaur, Meham and Lakhan Majra blocks of Rohtak district in south-east, south-west, west and north-west directions, respectively, and by Beri Khas block of Jhajjar district in south direction.

In the block, EC ranged from 0.55 to 8.60 dS/m with a mean of 2.70 dS/m (Table 3.8). The lowest EC of 0.55 dS/m in water samples was observed in village Bohar and the highest EC of 8.60 dS/ was found in village Mungan. The study revealed that 80.62 % of the samples showed EC less than 4 dS/m. Variability in the EC of groundwater was observed from the Figure 3.19 where a graph is drawn between the sample points vs their EC values and location specific variability of EC in the block is shown by spatial variable map (Fig.3.20a). In the spatial variable map of EC, the EC values are divided into 9 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.20a) that the EC of groundwater is ranging from 2-3 dS/m in most part of the block. The highest EC range (7-9 dS/m) was observed at two spots in the block. No particular trend in the variation of EC was present in the block but EC of northern part of block is more than southern part.

The pH ranged from 6.80 to 8.90 with an average of 7.90 (Table 3.8). The lowest pH (6.80) in water samples was observed in village Bhagwatipur and the highest pH (8.90) was recorded in village Sunaria Kalan. In the spatial variable map of pH, the pH values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.20b) that the pH of groundwater is ranging from 7.6-8.4 in most part of the block. The highest pH range (8.4-9.2) was observed at two spots in the block.

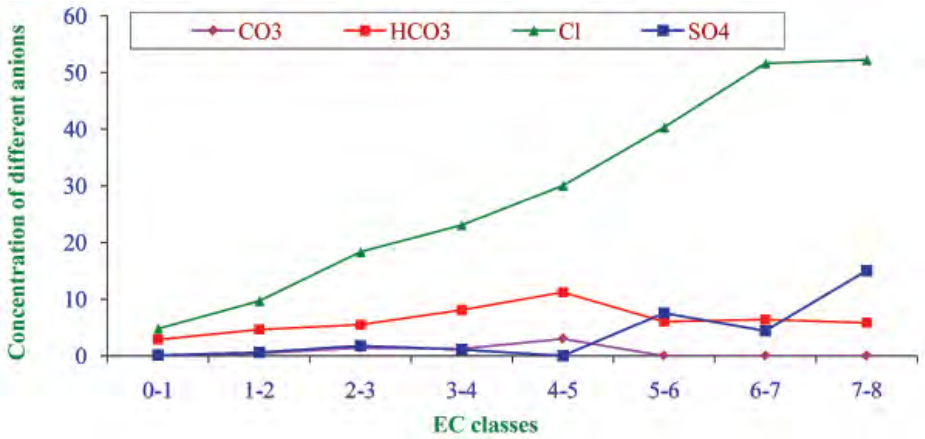


Fig. 3.16: Anions (CO_3, HCO_3, Cl, SO_4) concentration (me/l) in different EC (dS/m) classes of Meham block

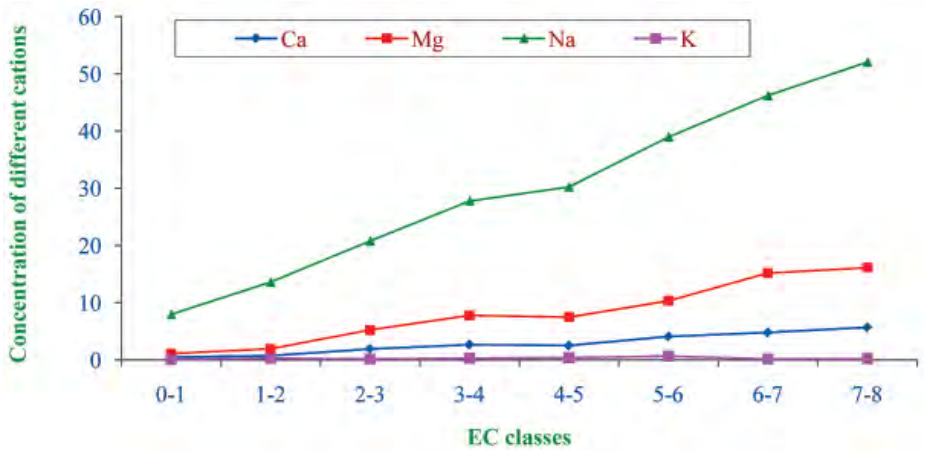


Fig. 3.17: Cations (Na, Ca, Mg, K) concentration (me/l) in different EC (dS/m) classes of Meham block

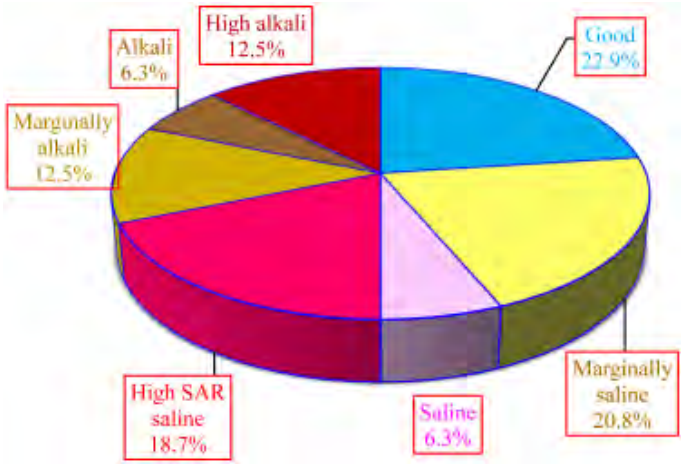


Fig. 3.18: Quality of groundwater (per cent) in Meham block of Rohtak district

Table 3.8: Range and average of different water quality parameters in Rohtak block

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.55-8.60	2.70
2	pH	6.80-8.90	7.90
3	CO_3^{-2} (me/l)	0.00-3.20	0.78
4	HCO_3^- (me/l)	1.20-10.40	5.55
5	Cl^- (me/l)	3.00-68.00	18.62
6	SO_4^- (me/l)	0.10-23.00	3.03
7	Ca^{+2} (me/l)	0.00-7.50	2.06
8	Mg^{+2} (me/l)	0.65-22.70	5.69
9	Na^+ (me/l)	4.76-60.21	19.92
10	K^+ (me/l)	0.02-11.20	1.13
11	RSC (me/l)	0.00-8.70	1.24
12	SAR (m mol/l)^{½}	3.85-24.45	10.57

The SAR ranged from 3.85 to 24.45 (m mol/l)^{½} with an average value of 10.57 (m mol/l)^{½} (Table 3.8), the lowest SAR value was recorded in village Ladhadot and the highest value was recorded in Brahmanwas village. The variations in values of SAR of this block is shown by spatial variable map (Fig.3.20c). In the map, the SAR values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.20c) that the SAR of groundwater is ranging from 9.0-12.0 in most part of the block and this range is sprinkled in all parts of block. The highest SAR range (21-24) was observed at one spot in the block.

The RSC ranged from nil to 8.70 me/l with an average value of 1.24 me/l (Table 3.8) and the highest value was recorded in Kansala village. The variations in values of RSC of this block is shown by spatial variable map (Fig.3.20d). In the map, the RSC values are divided into 9 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.20d) that the RSC of groundwater is ranging from 0 to 2 in most part of the block and this range is sprinkled in all parts of block. The highest RSC range (7-9) is observed at two spots in the block.

The average chemical composition and related quality parameters in different EC classes for Rohtak block are presented in Table 3.9. The distribution of salts in different EC classes is shown in Figure 3.21. It showed that per cent in EC classes increased with increase in the EC of groundwater upto 2 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of groundwater. The maximum number of 28 samples was concentrated in EC class of 1-2 and followed by 18 samples in EC class of 2-3 dS/m. It is seen that 69.4 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample found in the EC class of 6-7 dS/m.

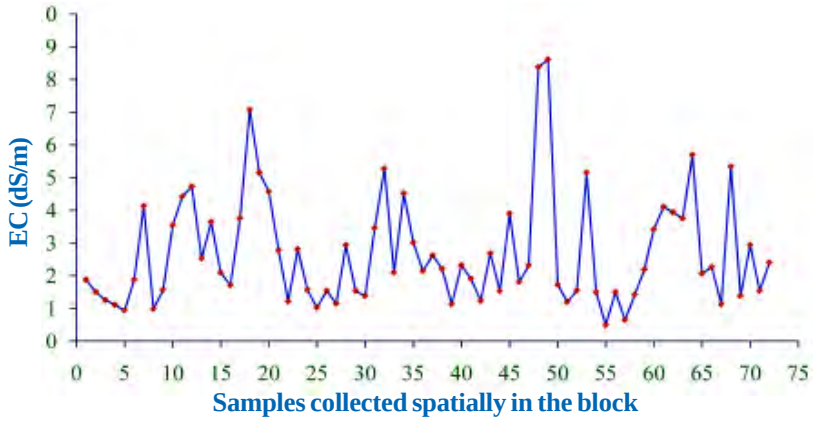
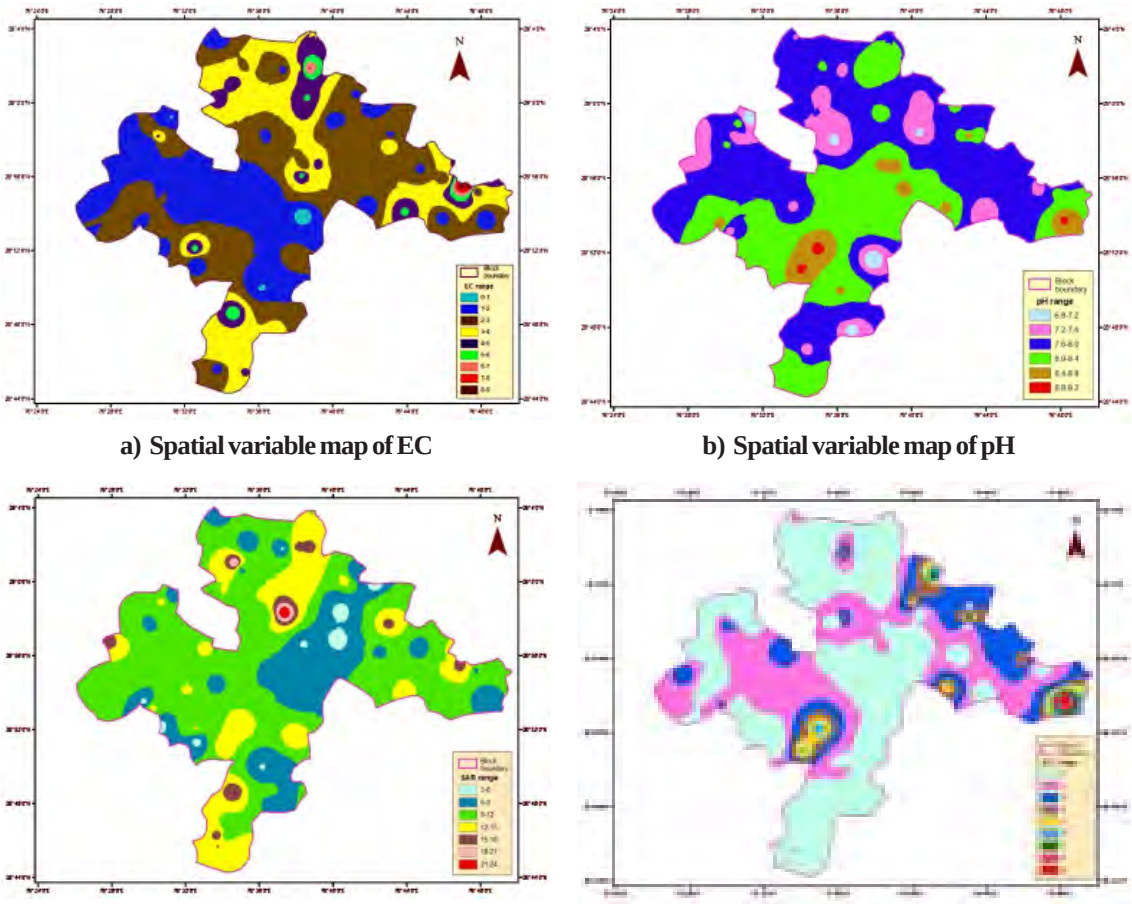


Fig. 3.19: Variability of EC in groundwater samples collected in Rohtak block



a) Spatial variable map of EC

b) Spatial variable map of pH

c) Spatial variable map of SAR

d) Spatial variable map of RSC

Fig. 3.20: Spatial variable map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Rohtak block of Rohtak district

Table 3.9: Chemical composition of groundwater samples of Rohtak block in different EC classes

EC classes (dS/m)	No. of samples	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
			(me/l)									$(m\ mol/l)^{½}$
0-1	4	5.6	0.20	3.15	5.80	0.43	0.58	1.73	6.86	0.24	1.30	6.50
1-2	28	38.9	0.85	5.14	8.52	1.02	1.13	2.53	11.48	0.98	2.05	9.10
2-3	18	25.0	0.95	6.36	16.08	2.69	1.91	4.89	18.77	1.14	1.43	10.83
3-4	8	11.1	0.60	5.40	25.90	4.70	3.00	8.10	26.00	1.10	0.00	11.70
4-5	6	8.3	0.56	7.56	32.86	4.11	3.02	10.17	32.84	1.10	0.12	13.30
5-6	5	6.9	0.64	5.20	39.68	10.01	4.28	13.76	37.35	0.77	0.00	12.84
6-7	0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-8	1	1.4	0.00	7.40	53.60	6.54	2.98	9.02	38.91	11.2	0.00	15.88
8-9	2	2.8	1.30	3.50	66.60	10.20	6.85	20.25	58.52	0.93	0.00	16.00

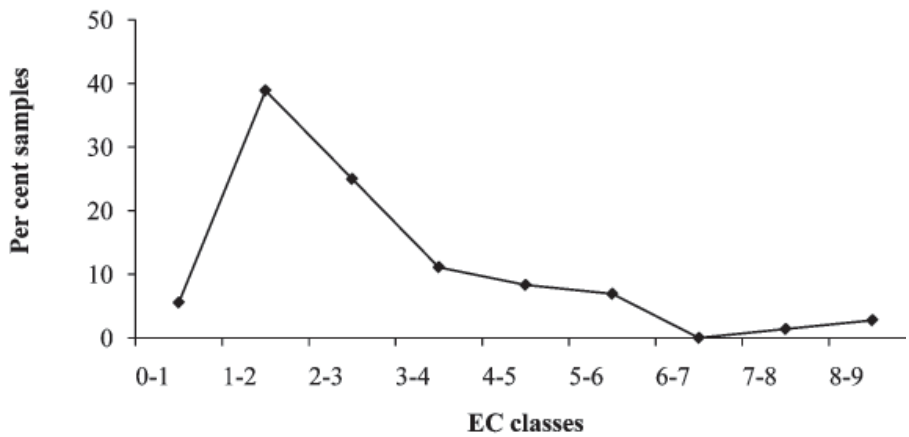


Fig. 3.21: Per cent samples in different EC (dS/m) classes of Rohtak block

In case of anions, chloride was the dominant anion with maximum value of 68.00 me/l (Table 3.8), observed in village Mungan and minimum 3.00 me/l was recorded in village Maina. Bicarbonate (HCO_3^-) ranged from 1.20 to 10.40 me/l, the maximum value was observed in the water sample of village Samar Gopal Kalan and the minimum value was found in village Bohar. The average values for CO_3^{-2}, HCO_3^-, Cl^- and SO_4^{-2} were found to be 0.78, 5.55, 18.62 and 3.03 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^{-2}$. The concentration of the anions in different classes of EC is depicted in Figure 3.22.

In cations, sodium concentration varied widely from 4.76 to 60.21 me/l (Table 3.8), minimum value was observed in village Maina and maximum value was observed in Mungan followed by magnesium (0.65 to 22.70 me/l) and calcium (0.00 to 7.50 me/l). Average values for Na^+, Mg^{+2}, Ca^{+2} and K^+ were 19.92, 5.69, 2.06 and 1.13 me/l, respectively. The concentration of the cations in different classes of EC is given by Figure 3.23. It was observed that cations in ground waters followed the order $Na^+ > Mg^{+2} > Ca^{+2} > K^+$.

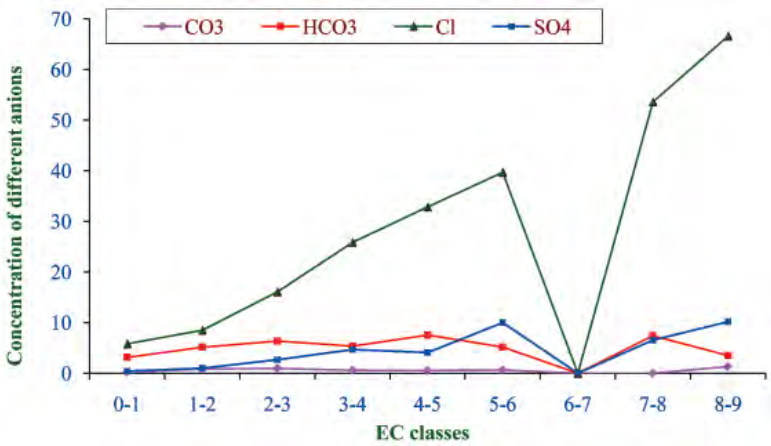


Fig. 3.22: Anions (CO_3, HCO_3, Cl, SO_4) concentration (me/l) in different EC (dS/m) classes of Rohtak block

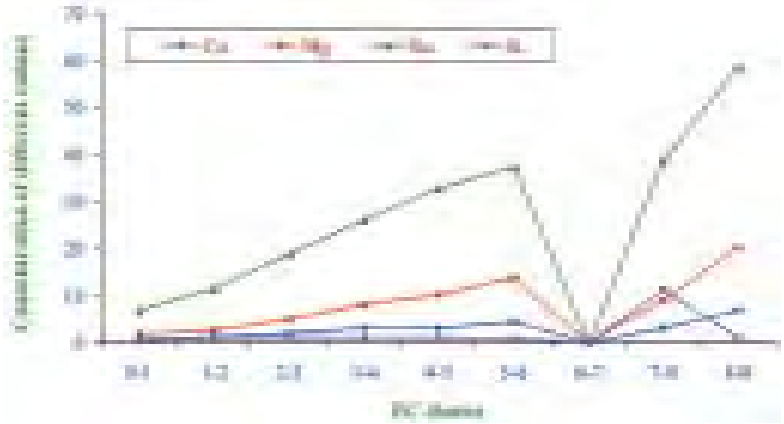


Fig. 3.23: Cations (Na, Ca, Mg, K) concentration (me/l) in different EC (dS/m) classes of Rohtak block

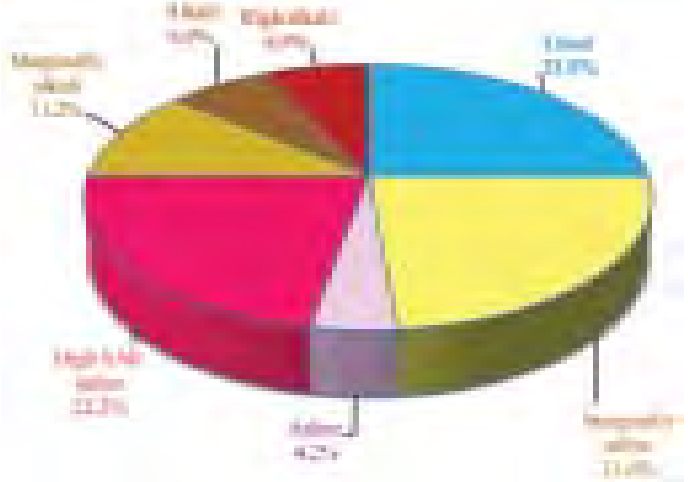


Fig. 3.24: Quality of groundwater (per cent) in Rohtak block of Rohtak district

According to AICRP classification, the maximum samples were found in good quality (25.0 %) category followed by marginally saline (23.6 %) (Fig.3.24). The per cent samples in saline classes i.e. marginally saline, saline and high SAR saline classes were 23.6, 4.2 and 22.2, respectively. Marginally alkali, alkali, and high alkali categories were recorded as 11.2, 6.9 and 6.9 % samples. The lowest percentage of samples (4.2 %) was observed in saline category.

3.5 SAMPLA BLOCK

Sampla block constitutes part of Rohtak district of Haryana state, having 24 villages. It lies between 28º44′31″ to 28º54′53″ N latitude and 76º38′41″ to 76º51′43″ E longitude. It is surrounded by Rohtak block of Rohtak district in north and east directions, by Kharkhoda block of Sonipat district in north-east direction, and by Bahadurgarh and Beri Khas blocks of Jhajjar district in south and south-west directions, respectively.

In the block, EC ranged from 0.40 to 7.54 dS/m with a mean of 2.45 dS/m (Table 3.10). The lowest EC of 0.40 dS/m in water samples was observed in village Bhalout and the highest EC was found as 7.54 dS/m in village Kasrenti. The study revealed that 84.09 % of the samples showed EC less than 4 dS/m. Variability in the EC of groundwater was observed from the Figure 3.25 where a graph is drawn between the sample points vs their EC values and location specific variability of EC in the block is shown by spatial variable map (Fig.3.26a). In the spatial variable map of EC, the EC values are divided into 8 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.26a) that the EC of groundwater is ranging from 1-2 dS/m in most part of the block. The highest EC range (7-8 dS/m) was observed at one spot in the block. No particular trend in the variation of EC is present in the block but EC of western part is lower than eastern part of the block.

Table 3.10: Range and average of different water quality parameters in Sampla block

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.40-7.54	2.45
2	pH	6.30-8.55	7.17
3	CO_3^{-2} (me/l)	0.00-2.00	0.40
4	HCO_3^{-} (me/l)	0.50-10.40	5.55
5	Cl^{-} (me/l)	2.00-71.00	15.95
6	SO_4^{-2} (me/l)	0.00-18.10	3.15
7	Ca^{+2} (me/l)	0.25-7.50	2.00
8	Mg^{+2} (me/l)	0.75-21.60	5.12
9	Na^{+} (me/l)	4.27-54.10	17.52
10	K^{+} (me/l)	0.10-7.20	0.76
11	RSC (me/l)	0.00-7.00	1.21
12	SAR (m mol/l)^{½}	3.82-20.80	9.30

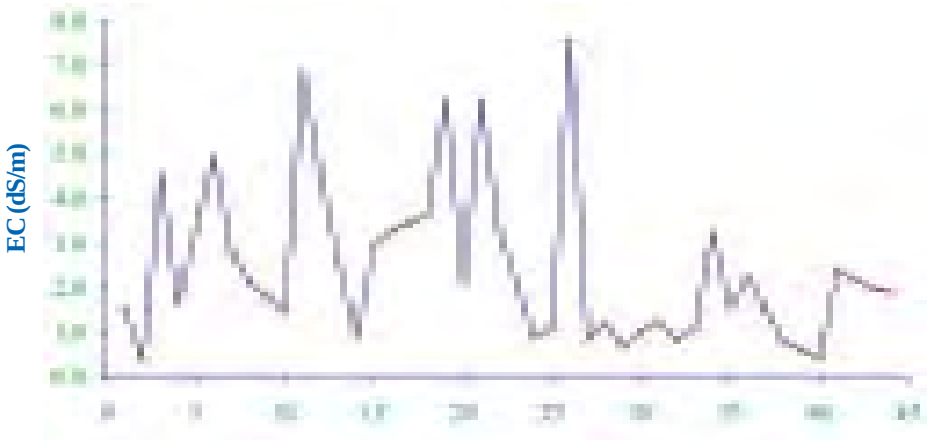
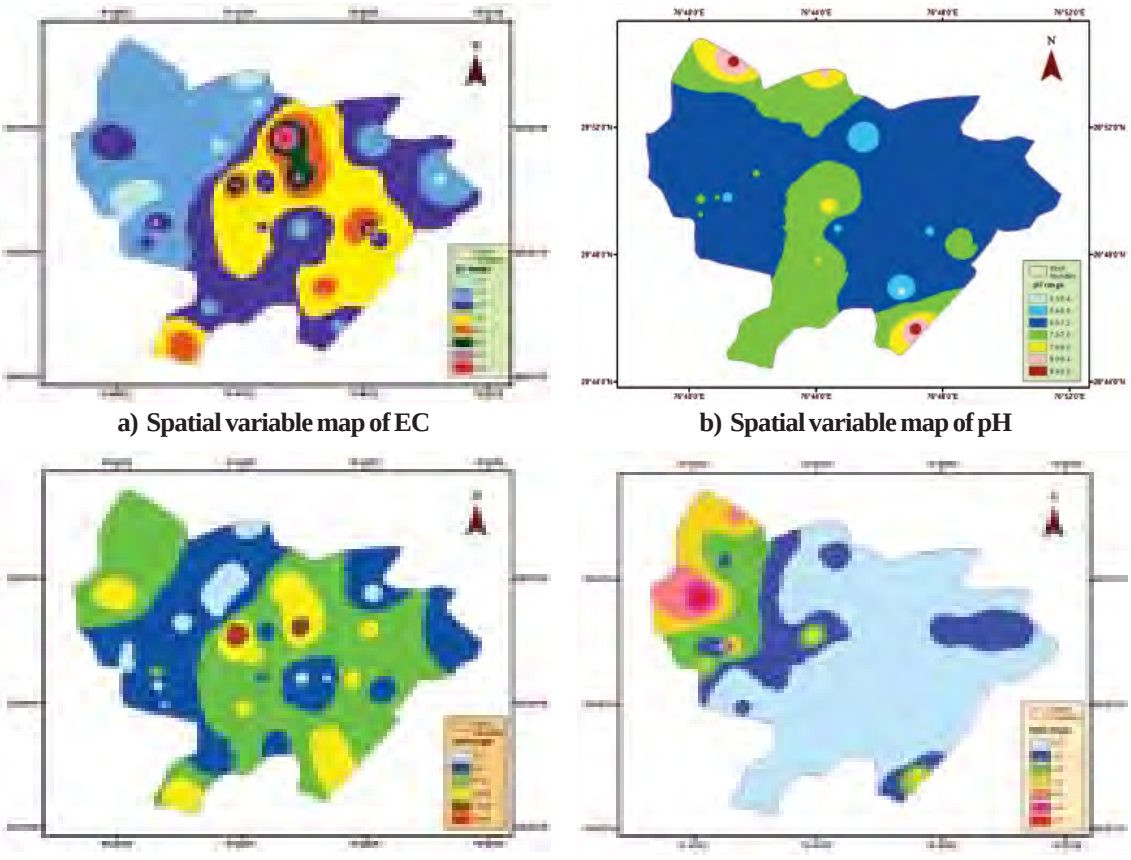


Fig. 3.25: Variability of EC in groundwater samples collected in Sampla block



a) Spatial variable map of EC

b) Spatial variable map of pH

c) Spatial variable map of SAR

d) Spatial variable map of RSC

Fig. 3.26: Spatial variable map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Sampla block of Rohtak district

The pH ranged from 6.30 to 8.55 with an average of 7.17 (Table 3.10). The lowest pH 6.30 in water samples was observed in the northern side of Sampla village and the highest value 8.55 was recorded in the southern side of Sampla village. In the spatial variable map of pH, the pH values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig.3.26b) that the pH of groundwater is ranging from 6.8-7.2 in most part of the block. The highest pH range (8.4-8.8) is observed at two spots in the block. More than 8.5 value of pH represent the alkali nature of water, thus, the whole block has non-alkali water except some boundary area.

The SAR ranged from 3.82 to 20.80 (m mol/l)^{½} with an average value of 9.30 (m mol/l)^{½} (Table 3.10), the lowest SAR value was recorded in village Nond and the highest value was recorded in Gandhra village. The variations in values of SAR of this block is shown by spatial variable map (Fig.3.26c). In the map, the SAR values are divided into 6 classes and reflected by different colours. It was observed from the spatial variable map that the SAR of groundwater is ranging from 9.0-12.0 in most part of the block and this range is sprinkled in many parts of block. The highest SAR range (18-21) was observed at one spot in the block.

The RSC ranged from nil to 7.00 me/l with an average value of 1.21 me/l (Table 3.10) and the highest value was recorded in Khrisad village. The variations in values of RSC of this block is shown by spatial variable map (Fig.3.26d). In the map, the RSC values are divided into 7 classes and reflected by different colours. It was observed from the spatial variable map (Fig. 3.26d) that the RSC of groundwater is ranging from 0 to 1 in most part of the block and particularly eastern part of the block. The highest RSC range (6-7) was observed at two spots in the block.

The average chemical composition and related quality parameters in different EC classes for Sampla block are given in Table 3.11. The distribution of salts in different EC classes is shown in Figure 3.27. It showed that per cent in EC classes increased with increase in the EC of groundwater upto 2 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of groundwater. The maximum number of 13 samples were concentrated in EC class of 1-2 and followed by 9 samples in EC class of 0-1 as well as 2-3 dS/m. It is seen that 70.45 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample in EC class of 5-6 dS/m.

In case of anions, chloride was the dominant anion with maximum value of 71.00 me/l (Table 3.10), observed in village Kasrenti and minimum 2.00 me/l was recorded in village Khararwar. Bicarbonate (HCO_3^-) ranged from 0.50 to 10.40 me/l, the maximum value was observed in the water sample of village Gandhra and minimum value was found in village Karor. The average values for CO_3^{-2}, HCO_3^-, Cl^- and SO_4^{-2} were found to be 0.40, 5.55, 15.95 and 3.15 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^{-2}$. The concentration of the anions in different classes of EC is depicted by Figure 3.28.

Table 3.11: Chemical composition of groundwater samples of Sampla block in different EC classes

EC classes (dS/m)	No. of samples	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
			(me/l)									(m mol/l)^{½}
0-1	9	20.4	0.04	3.32	4.63	0.31	0.47	1.39	5.23	0.57	1.57	5.62
1-2	13	29.6	0.34	5.31	8.95	0.55	1.31	3.37	10.65	0.52	1.38	7.43
2-3	9	20.5	0.52	7.32	14.30	2.76	2.72	5.22	16.77	0.53	1.70	9.20
3-4	6	13.6	0.62	6.75	16.68	9.03	2.34	6.06	25.26	0.69	0.30	12.39
4-5	3	6.8	0.65	5.83	34.20	5.57	3.13	9.28	34.93	0.40	0.00	14.03
5-6	0	0.0	—	—	—	—	—	—	—	—	—	—
6-7	3	6.8	0.73	6.47	47.07	10.41	4.10	12.67	41.28	3.58	1.30	15.96
7-8	1	2.3	0.40	2.00	71.00	1.80	6.63	19.89	54.10	0.56	0.00	14.86

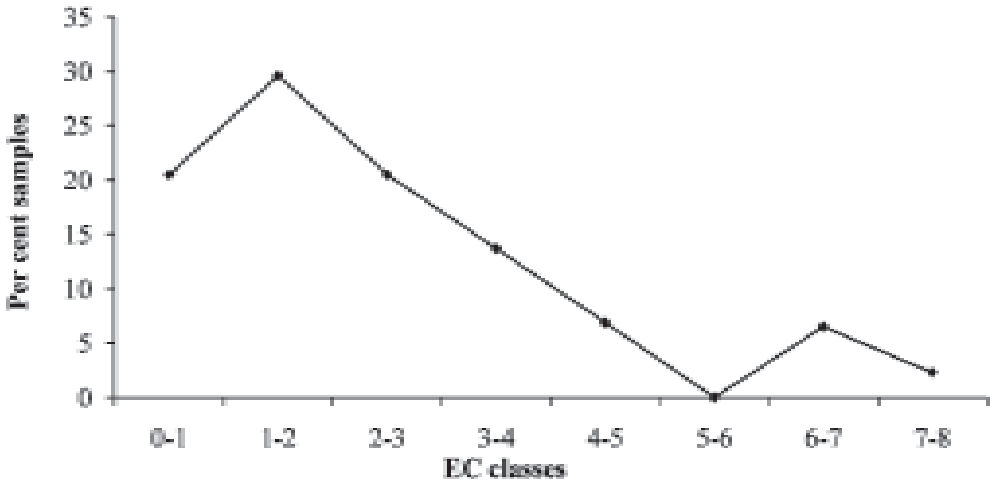


Fig. 3.27: Per cent samples in different EC classes of Sampla block

In cations, sodium concentration varied widely from 4.27 to 54.10 me/l (Table 3.10), minimum value was observed in village Nond and maximum value was observed in Kasrenti followed by magnesium (0.75 to 21.60 me/l) and calcium (0.25 to 7.50 me/l). Average values for Na^+, Mg^{+2}, Ca^{+2} and K^+ were 17.52, 5.12, 2.00 and 0.76 me/l, respectively. The concentration of the cations in different classes of EC is given by Figure 3.29. It was observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2} > K^+$.

According to AICRP classification, the maximum samples were found in good quality (38.6 %) category followed by marginally saline (18.2 %) and high SAR saline (18.2%) (Fig.3.30). The per cent samples in saline classes were 18.2, 6.8 and 18.2 % in marginally saline, saline and high SAR saline classes, respectively. Marginally alkali, alkali, and high alkali categories were recorded as 4.5, 2.3 and 11.4 % samples. The lowest percentage of samples (2.3 %) was observed in alkali category.

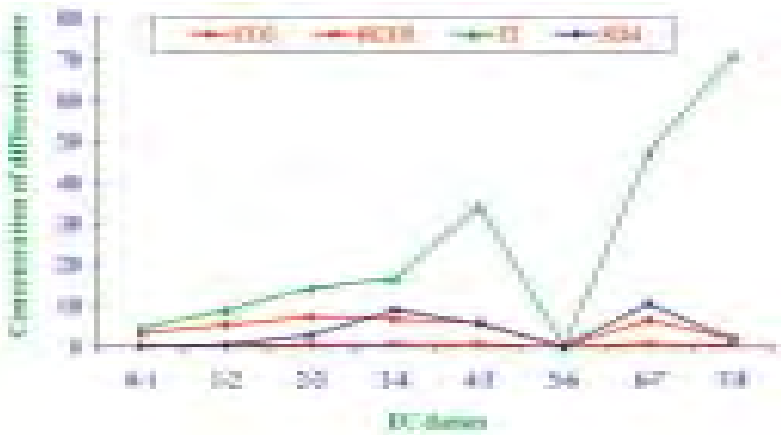


Fig. 3.28: Anions (CO_3, HCO_3, Cl, SO_4) concentration (me/l) in different EC classes of Sampla block

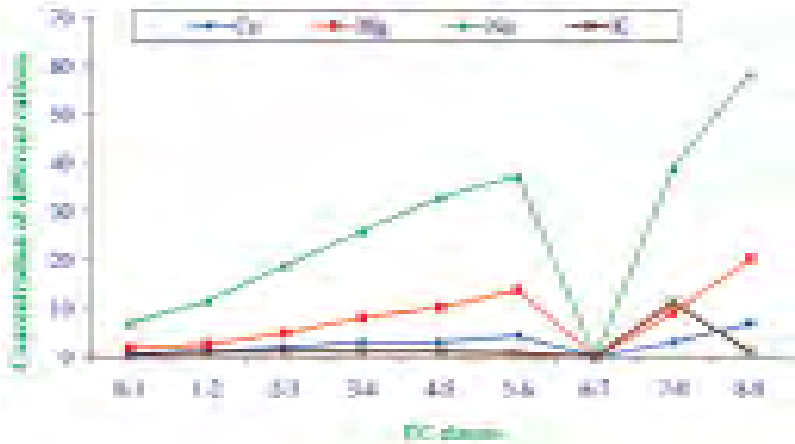


Fig. 3.29: Cations (Na, Ca, Mg, K) concentration (me/l) in different EC classes of Sampla block

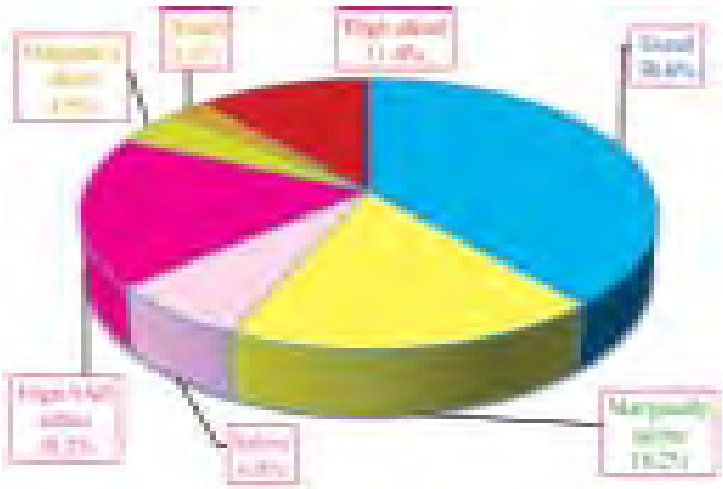


Fig.3.30: Quality of groundwater (per cent) in Sampla block of Rohtak district

4. GROUNDWATER QUALITY OF ROHTAK DISTRICT

4.1 SAMPLING POINTS IN THE DISTRICT

Total 238 water samples were collected with the spatial points through GPS for all the blocks of Rohtak district and a location map for these sampling points was prepared (Fig.4.1). Each sample was a representative of the discrete sampling point within the sampling network. Sampling frequency and the location of discrete sampling points was considered carefully to resolve spatial distributions of groundwater quality and to minimize the random error. The samples were collected uniformly throughout the whole Rohtak district except some parts of Kalanaur block due to water logging problem in that area.

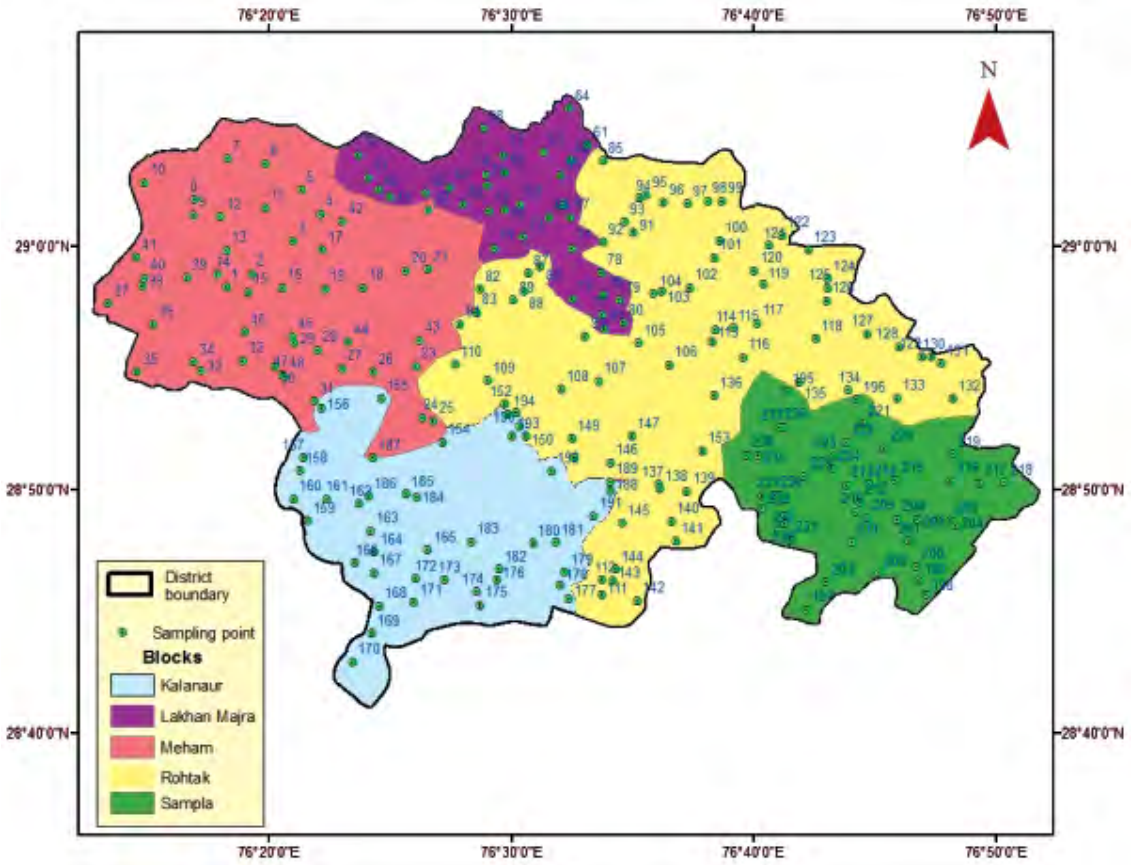


Fig.4.1: Location map of the sampling points in Rohtak district

4.2 ELECTRICAL CONDUCTIVITY (EC) OF GROUNDWATER

In Rohtak district, EC ranged from 0.40 to 9.38 dS/m with a mean of 2.52 dS/m. The lowest EC of 0.40 dS/m in water samples was observed in village Bhalout of Sampla block, whereas, the highest EC of 9.38 dS/m was found in village Lakhan Majra of Lakhan Majra block. The study revealed that 84.45 % of the samples showed EC values less than 4 dS/m. It was observed from the spatial variable map (Fig.4.2) that the EC of groundwater is highly scattered and no particular trend is present. In the map, the EC values are divided into 10 classes and reflected by different colours. Dominance of yellow colour in the map indicates that EC of groundwater is mostly ranging between 2-3 dS/m. Next dominating colour in the map is green which shows the EC range of 1-2 ds/m. The highest EC range of 9-10 dS/m can be seen at one spot in Lakhan Majra block of the district.

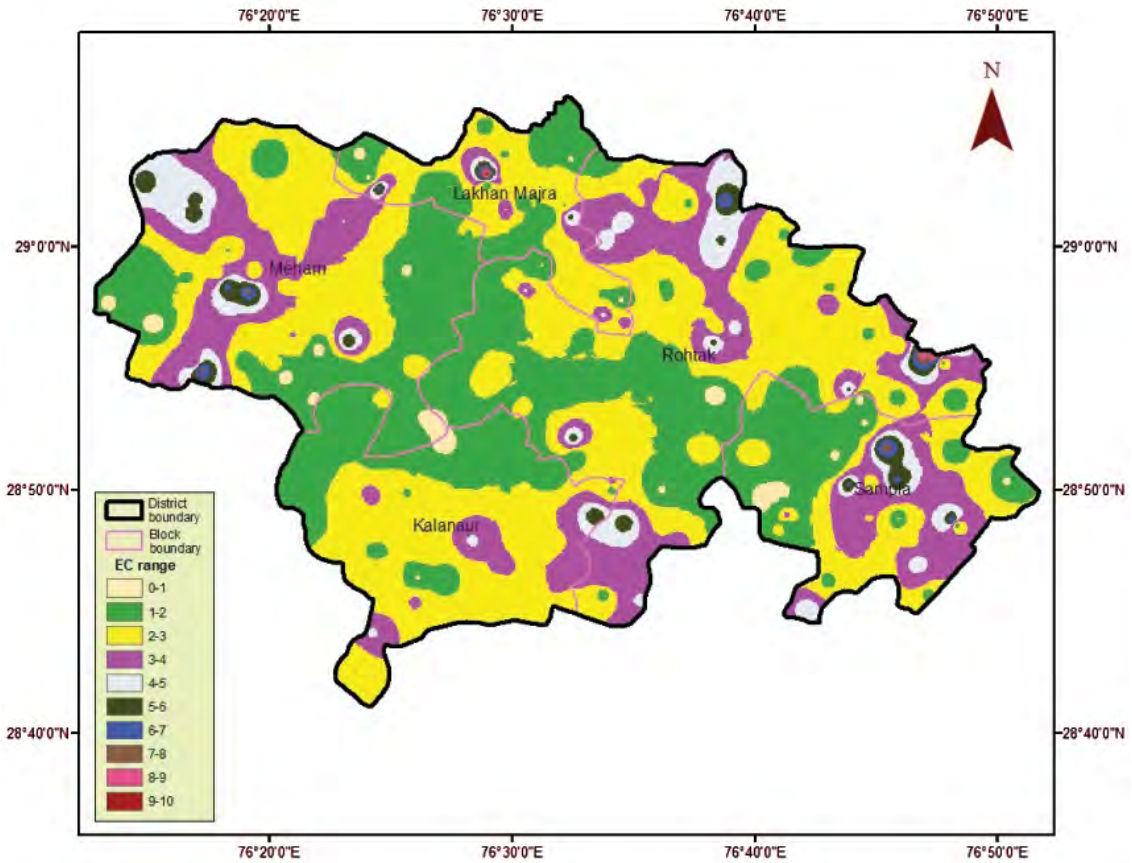


Fig. 4.2: Spatial variable map of EC of groundwater in Rohtak district

4.3 SODIUM ADSORPTION RATIO (SAR) OF GROUNDWATER

In Rohtak district, SAR ranged from 3.82 to 34.04 (m mol/l)$^{1/2}$ with a mean of 11.21 (m

mol/l)$^{1/2}$. The lowest SAR of 3.82 (m mol/l)$^{1/2}$ in water samples was observed in village Nond of Sampla block and its maximum value 34.04 (m mol/l)$^{1/2}$ was found in village Kherari of Kalanaur block. In the spatial variable map, the SAR values are divided into 10 classes and reflected by different colours (Fig.4.3). Dominance of blue colour in the map indicates that SAR of groundwater is mostly ranging between 8-12 (m mol/l)$^{1/2}$. Next dominating colour in the map is yellow which shows the SAR range of 12-16 (m mol/l)$^{1/2}$. The highest SAR range of 36 to 40 (m mol/l)$^{1/2}$ was observed at one spot in Kalanaur block of the district.

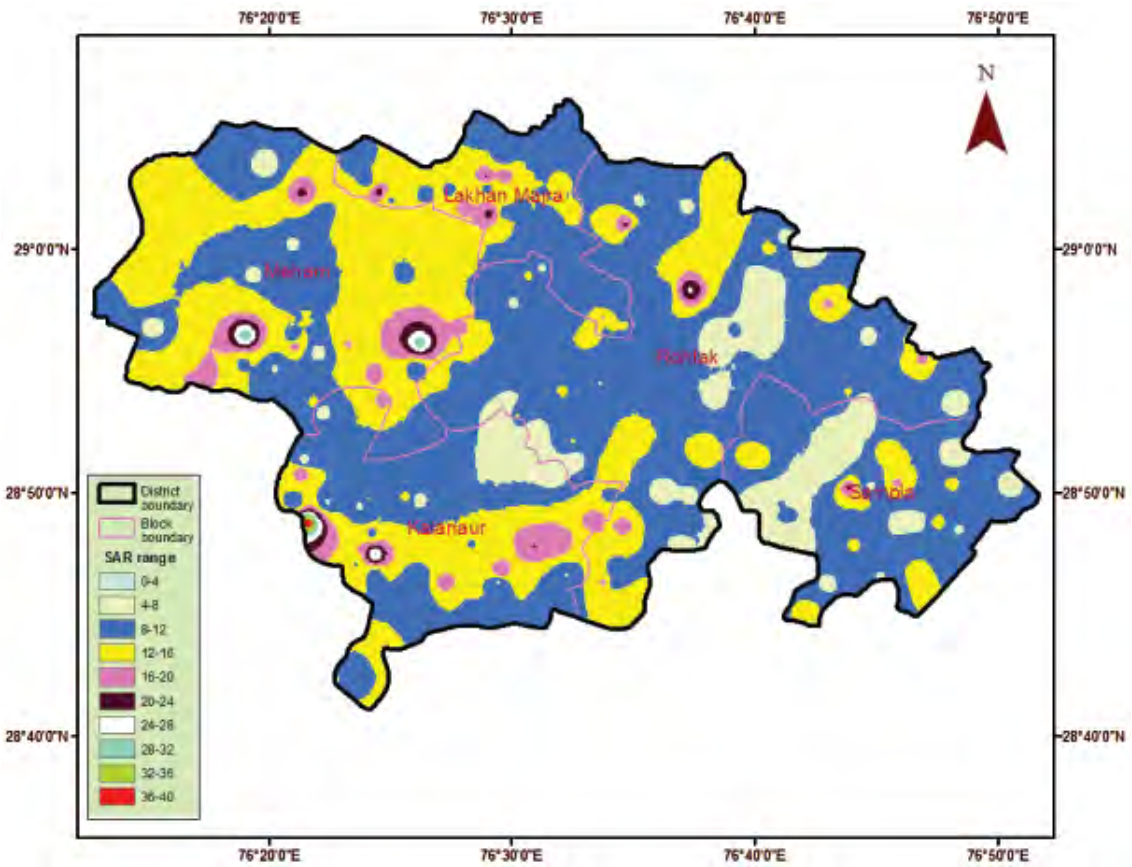


Fig.4.3: Spatial variable map of SAR of groundwater of Rohtak district

4.4 RESIDUAL SODIUM CARBONATE (RSC) OF GROUNDWATER

In Rohtakh district, RSC ranged from nil to 8.7 me/l with a mean of 1.32 me/l. The highest RSC of 8.7 me/l in water samples was observed in Kansala village of Rohtak block. In the spatial variable map, the RSC values are divided into 9 classes and reflected by different colours (Fig.4.4). Dominance of sky colour in the map indicates that RSC of groundwater is mostly ranging between 0-1 me/l. Next dominating colour in the map is green which shows the RSC range of 1-2 me/l. The

highest RSC range of 8 to 9 me/l was observed at different spots in Lakhan Majra block of the district.

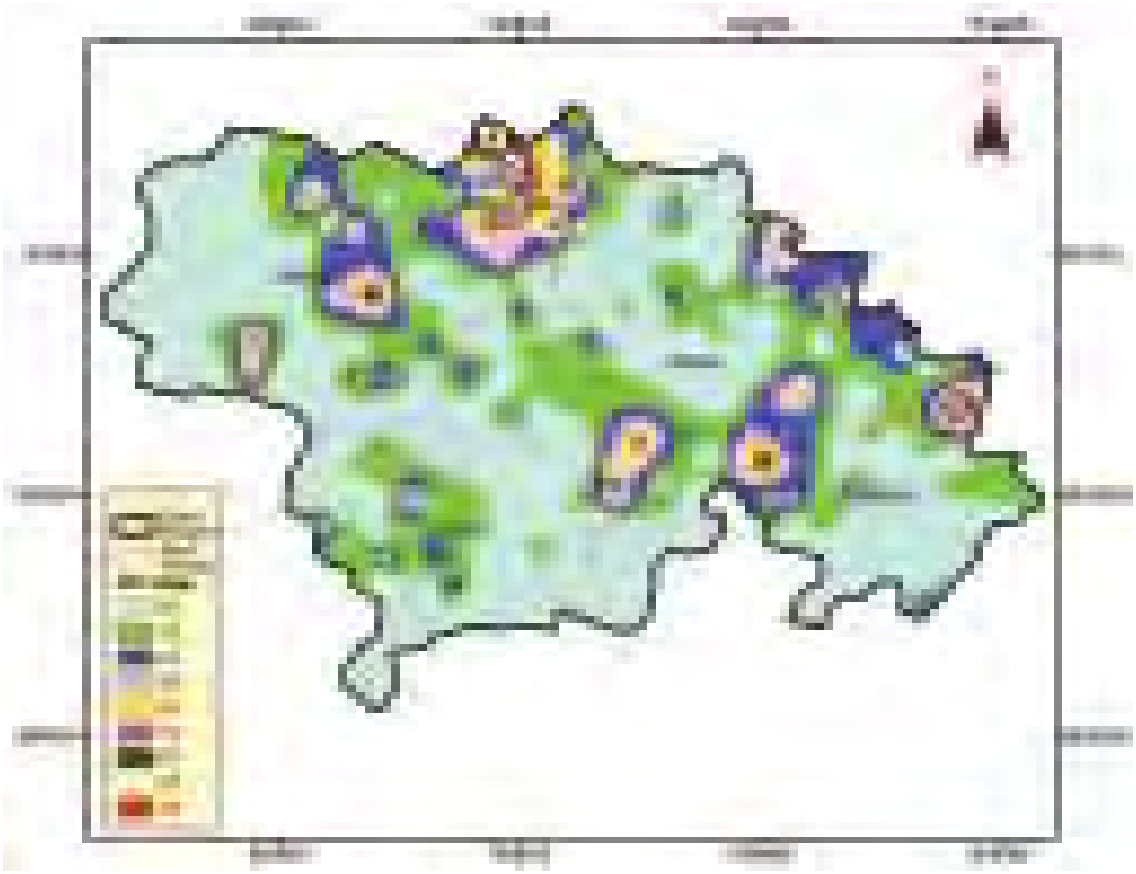


Fig. 4.4: Spatial variable map of RSC of groundwater quality in Rohtak district

4.5 CLASSIFICATION OF GROUNDWATER

Overall in Rohtak district, 60, 57, 41, 27, 24, 17 and 12 samples were found in good, marginally saline, high SAR saline, high alkali, marginally alkali, alkali and saline, respectively (Table 4.1). The highest percentage (25.2) of the groundwater in the district is under the good category and the lowest percentage (5.1) is under saline category. Decreasing trend of the water quality under different categories is shown in Fig. 4.5. Percent samples in saline classes i.e. marginally saline, saline and high SAR saline classes were 24.0, 5.1 and 17.2, respectively. Percent samples in alkali classes i.e. marginally alkali, alkali and high alkali classes were 10.1, 7.1 and 11.3, respectively.

On the basis of present analysis, map for spatial distribution of groundwater quality status of Rohtak district was prepared and is presented in Figure 4.6. Different category of the groundwater

samples are presented by different colour in the map. There is the least existence of saline water category which could be seen at five scattered locations in the map with small dots, representing very less area. By analysing the area under different contours of groundwater quality in the district through GIS, it was found that out of three main categories (high SAR saline, marginally saline and high alkali), the maximum area (638.2 sq km) of the district was estimated under high SAR saline category, followed by marginally saline (451.6 sq km) and high alkali (316.76 sq km) category. Dominance of these three categories can be clearly seen in the map. By overlaying the contour maps of EC of groundwater and water table depth, it was found that the tubewells installed near the canals and in shallow water-table (1.5 to 3 m) are of good quality as continuous recharge from the canal is taking place in these areas.

Table 4.1: Number of samples categorized in different classes of water quality for Rohtak district

AICRP Classification	Number of samples	Per cent sample
Good	60	25.2
Marginally saline	57	24.0
Saline	12	5.1
High SAR saline	41	17.2
Marginally alkali	24	10.1
Alkali	17	7.1
High alkali	27	11.3
Total	238	

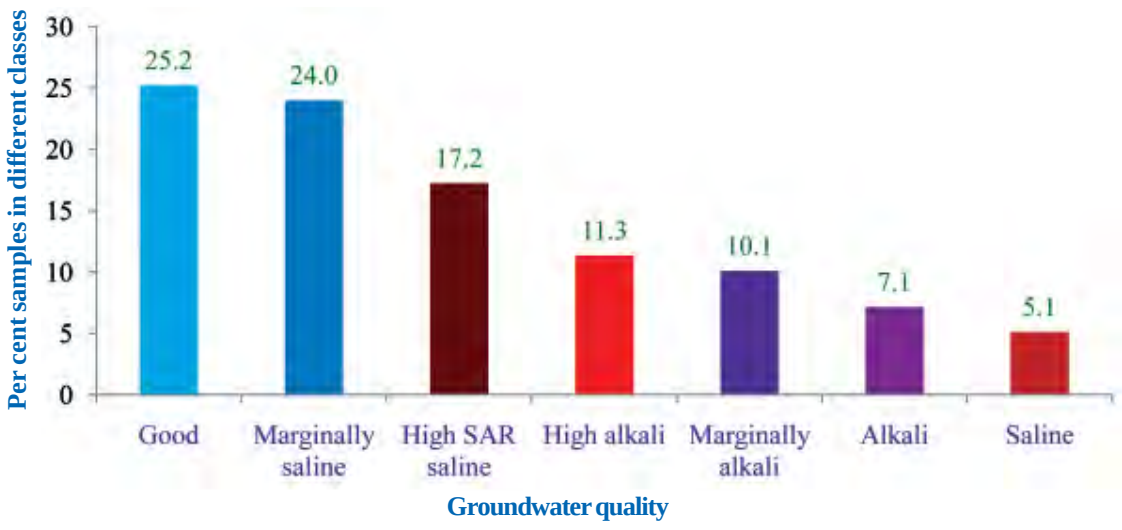


Fig. 4.5: Per cent samples of groundwater in different water quality of Rohtak district

Fig. 4.6: Spatial variable map of groundwater quality of Rohtak district

5. GROUNDWATER MANAGEMENT STRATEGY

5.1 STRATEGIES FOR GROUNDWATER MANAGEMENT

Depending on the quality and depth of groundwater encountered in different regions of the study area, the following practical and feasible strategies need to be adopted for optimal use of available water resources for higher water productivity and correcting emerging hydrological imbalances in Rohtak district.

- Propagating efficient on-farm water management practices including modern methods of irrigation (sprinkler, drip, furrow, etc.) by imparting regular training to farmers and field functionaries.
- Systematic plantation and maintenance of highly water transpiring trees (e.g. eucalyptus) along the roads could be used to partly remove the excess water as there is considerable surface waterlogged area near the roads.
- Reduction in canal water supply by about 25 percent between mid July to mid September and December to February in the areas having sufficient water or waterlogged area which forced the farmer to use groundwater. The canal water, thus saved, should be diverted to water deficit areas of the district/state.
- Formation of water users' associations/societies for effective and efficient management of available water resources.
- Introduction of salt tolerant crops and highly transpiring trees, planned leaching of salts and fish farming with saline water.
- Adoption of recommended cropping practices in flood affected areas under existing situation during the post-monsoon period.
- Lining of remaining canals and water courses and their periodic maintenance for checking seepage losses.
- Constructing storage reservoirs to harvest rainwater as well as together of canal water in the days when there is no demand of water at the field or to run pressurised irrigation system like gun-sprinkler, sprinkler, micro-sprinkler or drip.
- Maximizing conjunctive use of saline water with canal water in the problem area by changing over from the existing 'warabandi' to 'warimetric' so that the farmers are encouraged to use saline groundwater.

- The farmers should also be encouraged to raise agro-horticulture and agro-forestry plantation for which adequate subsidy may be provided.
- Introduction of groundwater legislation to regulate the groundwater exploitation as per potential available. Encourage farmers to install shallow tubewells in high water table areas.
- Exploring the possibility of artificial groundwater recharge during monsoon period in the areas facing groundwater decline.
- Considering the semi arid nature and inland basin conditions in the study area, rain-water harvesting with suitable storage structures at identified locations need to be planned for its subsequent use for agriculture and fish production.
- Considering limited options for the disposal of subsurface drainage effluents, proper management of the water table was identified as one of the option to minimize the harmful effects of subsurface water logging problems.

5.2 GUIDELINES FOR USING SALINE AND ALKALI WATERS

Apart from its composition, assessing the suitability of specific water requires specifications of conditions of its use (soil, climate, crops etc), irrigation methods and other management practices followed. Because of inherent problems in integrating the effects of above factors, it is difficult to develop rigid standards for universal use. Therefore, broad guidelines for assessing suitability of irrigation waters have been suggested from time to time for average use conditions. A committee of consultants from AICRP-Saline Water, CSSRI, Haryana and Punjab Agricultural Universities recommended the guidelines for utilizing poor quality waters in 1992 for their wider applicability (Table 5.1).

Table 5.1: Guidelines for using poor quality waters

(a) Saline waters (RSC < 2.5 me/l)

Soil texture (% clay)	Upper limits of EC_{iw} (dS/m) for crops in rainfall (mm) region								
	Sensitive crops			Semi-tolerant crops			Tolerant crops		
	<350	350-500	550-750	<350	350-500	550-750	<350	350-500	550-750
Fine (>30)	1.0	1.0	1.5	1.5	2.0	3.0	2.0	3.0	4.5
Moderately Fine (20-30)	1.5	2.0	2.5	2.0	3.0	4.5	4.0	6.0	8.0
Moderately Coarse (10-20)	2.0	2.5	3.0	4.0	6.0	8.0	6.0	8.0	10.0
Coarse (<10)		3.0	3.0	6.0	7.5	9.0	8.0	10.0	12.5

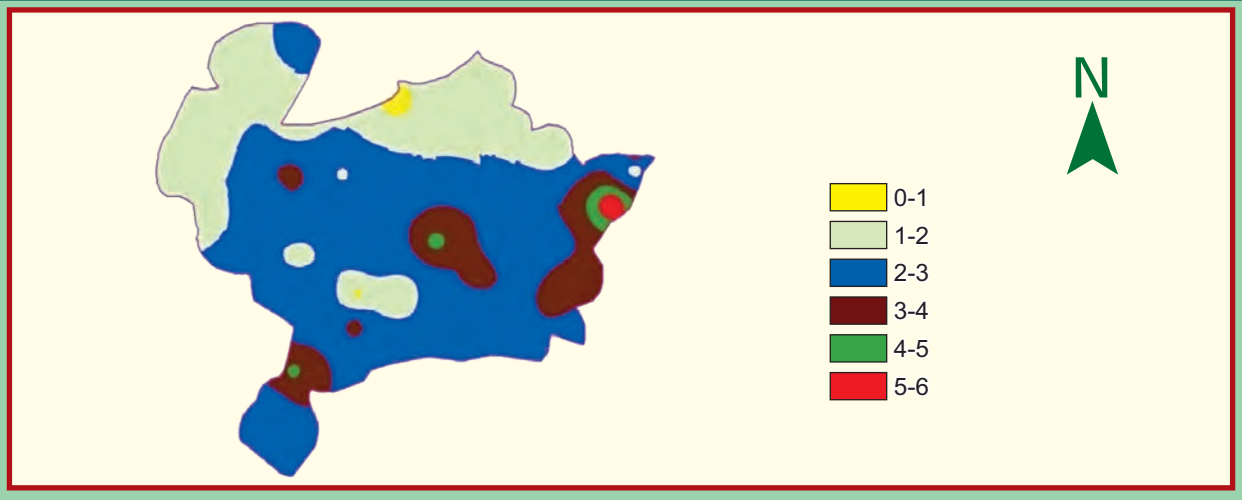
(b) Sodic water (RSC > 2.5 me/l and ECe < 4.0 dS/m)

Soil texture (% clay)	SAR $(mmol/l)^{½}$	Upper limit of RSC (me/l)	Remarks
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallow/rabi crop rotation when annual rainfall is 350-550 mm. When the waters have Na < 75% (Ca + Mg > 25%) or rainfall is > 550 mm, the upper limit of the RSC range 5 becomes safe. For double cropping RSC neutralization with gypsum is essential based on quantity of water used during the rabi season. Grow low water requiring crops during kharif.
Moderately fine (20-30)	10	3.5-5.0	
Moderately Coarse (10-20)	10	5.0-7.5	
Coarse (<10)	10	7.5-10.0	

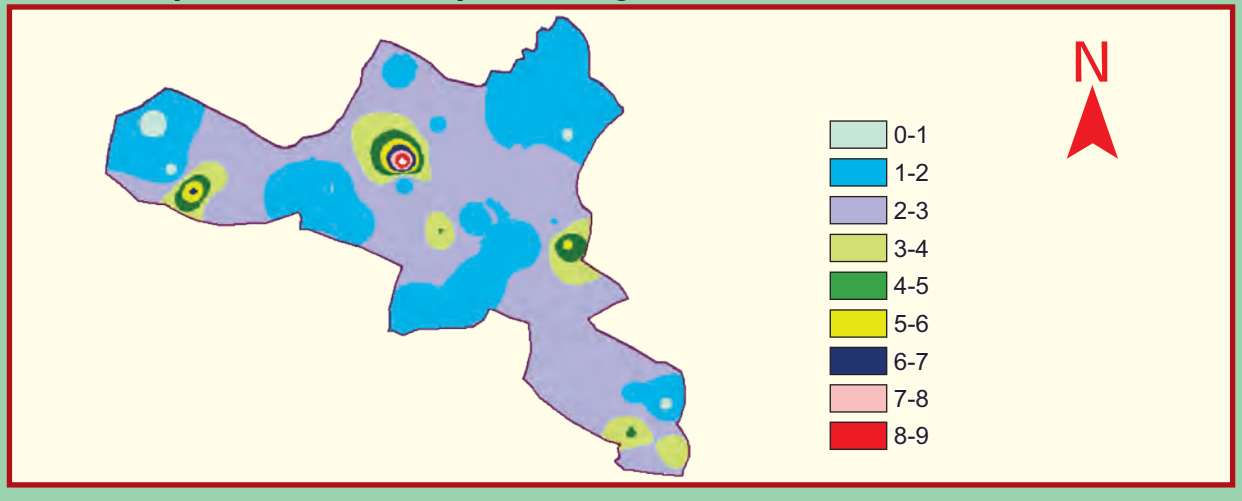
Joint recommendation of HAU, CSSRI and PAU Scientists (1992)

For meeting site specific water quality objectives, factors like water quality parameters, soil texture, crop tolerances and rainfall have been given due considerations. Some of the addendums added to these guidelines include

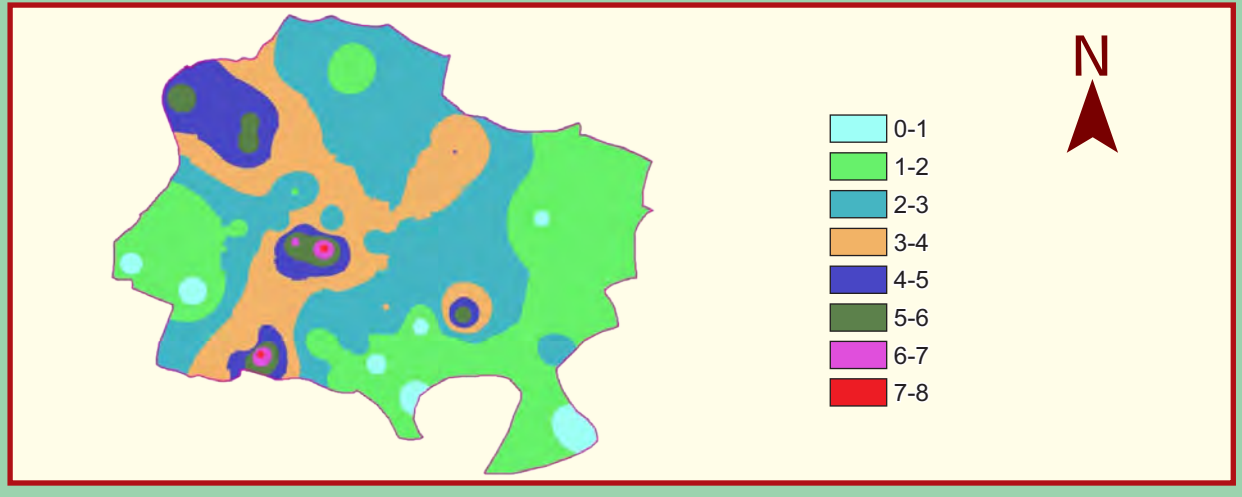
- Use of gypsum for saline water having SAR > 20 and/or Mg : Ca > 3 and rich in silica.
- Fallowing during rainy season is helpful when SAR > 20 and higher salinity waters are used in low rainfall areas.
- Additional phosphorous application is beneficial, especially when $Cl:SO_4$ ratio is > 2.0.
- Use of canal water preferably at early growth stages including pre-sowing irrigation for conjunctive use with saline waters.
- Using 20 per cent extra seed rate and a quick post-sowing irrigation (within 2-3 days) for better germination.
- When $EC_{iw} < EC_e$ (0-45 cm soil at harvest of rabi crops), use saline water for irrigation just before the onset of monsoons will lower soil salinity for higher antecedent soil moisture for greater salt removal by rains.
- Use of organic materials in saline environment.



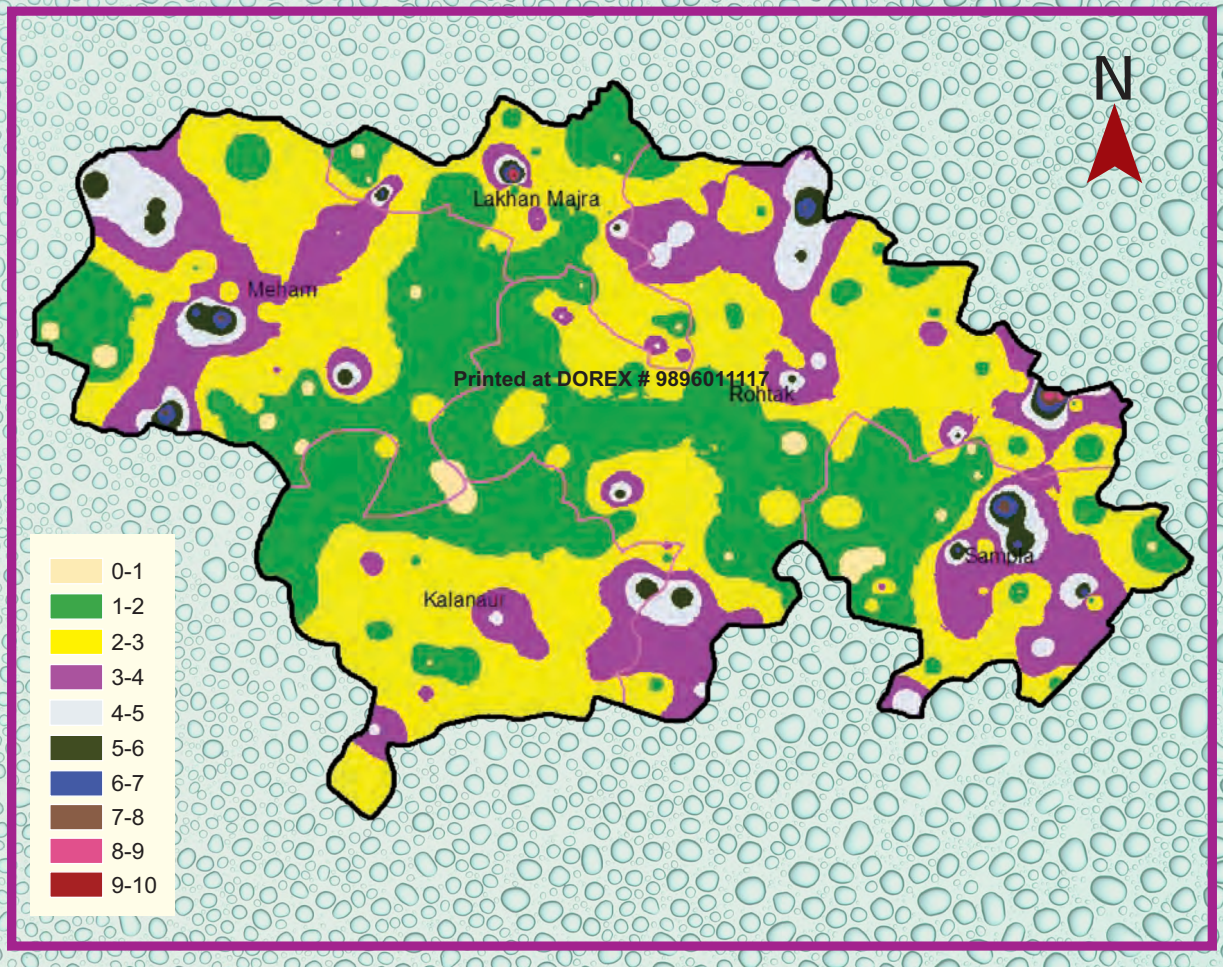
Spatial variable map of EC of groundwater in Kalanaur block



Spatial variable map of EC of groundwater in Lakhan Majra block



Spatial variable map of EC of groundwater in Meham block



Spatial variable map of EC of groundwater in Rohtak district