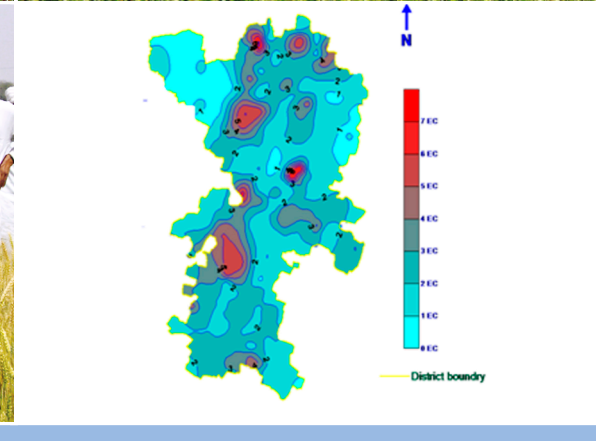
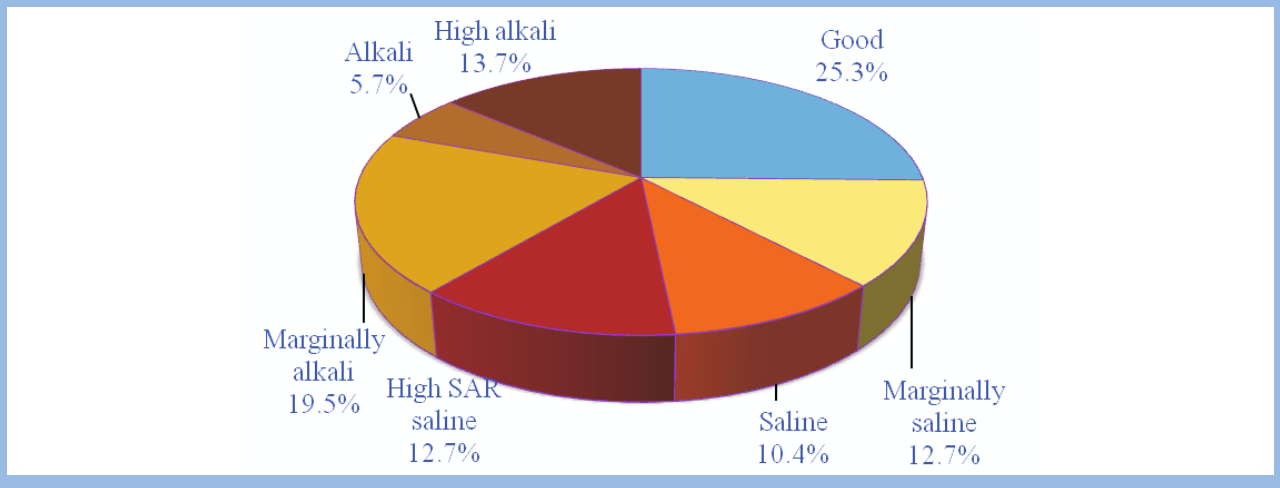
ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION OF MAHENDRAGARH DISTRICT, HARYANA



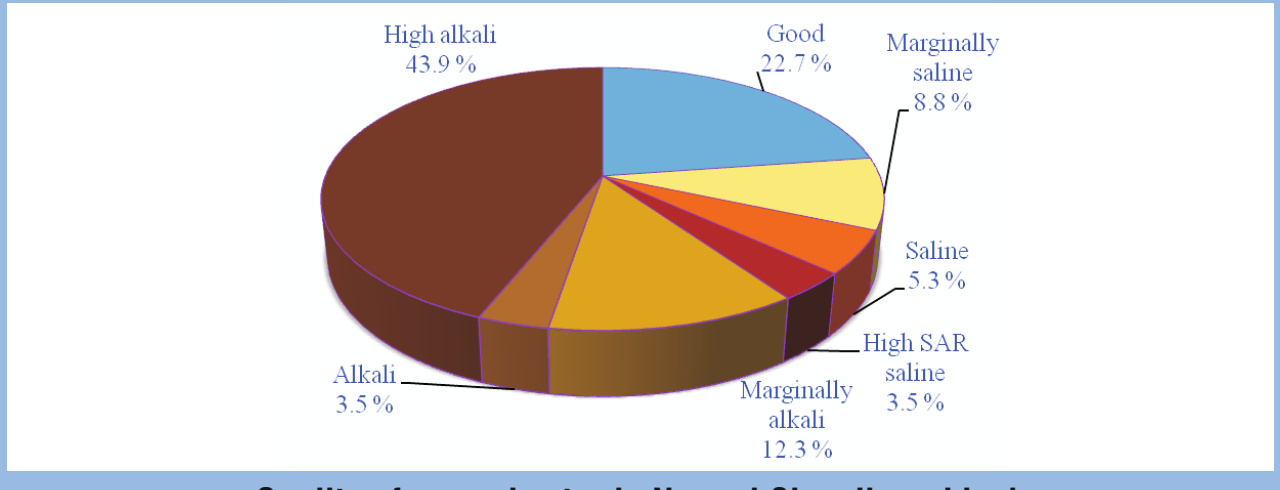
• Sanjay Kumar • S.K. Sharma • Vinod Phogat • Satyavan
• R.P. Mor • J.P. Singh • R.P. Narwal • S.K. Gupta

2011

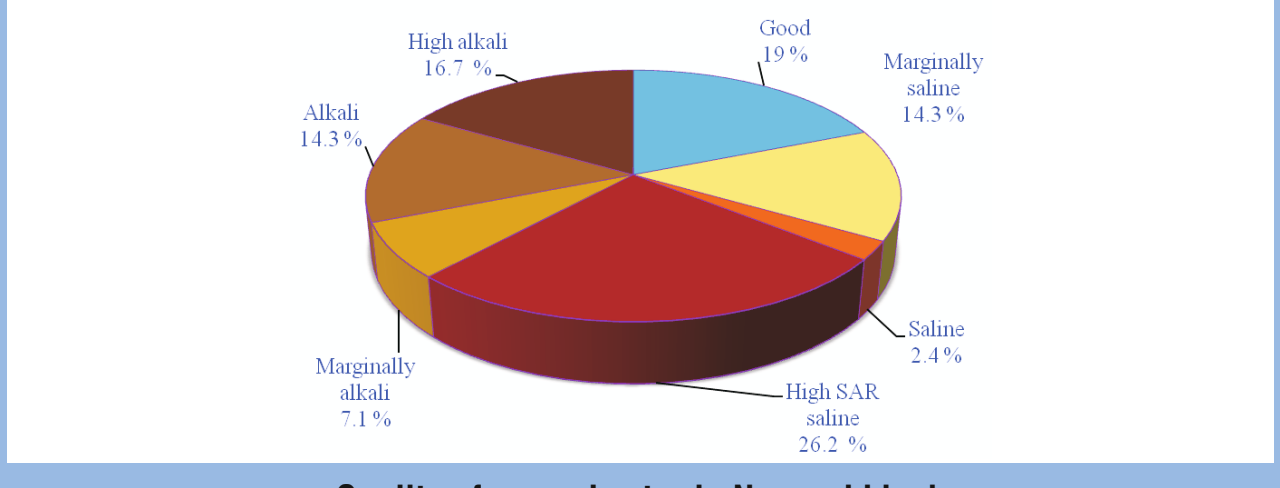
DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR-125 004 (HARYANA)



Quality of groundwater in Mahendragarh block



Quality of groundwater in Nangal Chaudhary block



Quality of groundwater in Narnaul block

ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION OF MAHENDRAGARH DISTRICT, HARYANA

Sanjay Kumar
S.K. Sharma
Vinod Phogat
Satyavan
R.P. Mor
J.P. Singh
Department of Soil Science
CCS Haryana Agricultural University, Hisar-125 004

R.P. NARWAL
Director of Research
CCS Haryana Agricultural University, Hisar-125 004

S.K. GUPTA
Project Co-ordinator
AICRP on Management of Soil Affected Soils and Use of Saline Water in Agriculture
Central Soil Salinity Research Institute, Karnal-132 001

2011

DEPARTMENT OF SOIL SCIENCE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR-125 004 (HARYANA)

The Authors:

Sanjay Kumar, Scientist (SWE)
Department of Soil Science, CCS HAU, Hisar

S.K. Sharma, Senior Soil Scientist
Department of Soil Science, CCS HAU, Hisar

Vinod Phogat, Scientist
Department of Soil Science, CCS HAU, Hisar

Satyavan, Agronomist
Department of Soil Science, CCS HAU, Hisar

R.P. Mor, Senior Soil Scientist
Department of Soil Science, CCS HAU, Hisar

J.P. Singh, Prof. and Head
Department of Soil Science, CCS HAU, Hisar

R.P. Narwal, Director of Research
CCS HAU, Hisar

S.K. Gupta, Project Co-ordinator
Central Soil Salinity Research Institute, Karnal

Correct Citation: Kumar, Sanjay; Sharma, S.K.; Phogat, Vinod; Satyavan; Mor, R.P.; Singh, J.P.; Narwal, R.P. and Gupta, S.K. 2011. Assessment of Groundwater Quality for Irrigation of Mahendragarh District, Haryana. Research Bulletin. pp 43. Department of Soil Science, CCS Haryana Agricultural University, Hisar.

CONTENTS

FOREWORD

Water is the most important natural input not only for producing food and sustainable socio-economic development but important for existence of life as well. 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. Moreover, the depleting water resources owing to over exploitation of ground water in Haryana state poses major threat for sustainable crop production. In the state, groundwater accounts for 50 per cent of the irrigated area and more than half of these waters (55 per cent) are of poor quality.

The total annual replenishable ground water resources of the country have been estimated as 433 billion cubic meter (BCM). Out of this, the net annual ground water availability for the entire country is 399 BCM. The annual ground water 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 ground water 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 southern part of Haryana especially Mahendragarh district is generally brackish and declining at a rate of 164 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 "Assessment of Groundwater Quality for Irrigation of Mahendragarh 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 hope this publication will prove useful to students, teachers, researchers and farmers for enhancing the crop production through judicious use of available poor quality waters. This bulletin will also provide technical guidelines to formulate spatial strategies for efficient management of the water resources in the district.

Dr. K.S. Khokhar
Vice-Chancellor
CCS HAU, Hisar

April 2011
Hisar

PREFACE

Water is vital for realizing the full potential of the agricultural sector and country's development. One of the major obstacles to increase food production in arid and semi-arid regions is the lack of fresh water resources. With the advancement in modern technologies and irrigation system, there is a tremendous pressure on groundwater quantity and quality. As a consequence, groundwater depth and quality are deteriorating at a alarming rate in many parts of the state, particularly in Mahendragarh district. The district is under semi-arid climate with a long dry hot weather, having an average annual rainfall of 407 mm. Due to very limited canal network, rainfall is the only source for recharge of groundwater. The over exploitation of groundwater in the district has been increased from 119 per cent (in year 1978) to 136 per cent (in year 2010).

Keeping all this in view and to combat these problems, this bulletin is prepared in comprehensive form which contains considerable information regarding the fluctuation and quality of groundwater being used by the farmers for irrigation purpose in the Mahendragarh 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 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

MAHENDRAGARH DISTRICT AT A GLANCE

Sr. No.	Items	Statistics
1.	General information	
	Geographical area (sq. km.)	1899 sq. Km.
	Number of blocks and their names	five, Ateli, Kanina, Mahendragarh, Nangal Chaudhary, Narnaul
	Number of villages	404
2.	Average Annual Rainfall (mm)	407 mm
	Highest rainfall (between 1993 to 2009)	890 mm in 1996
	Lowest rainfall (between 1993 to 2009)	129.4 mm in 2002
3.	Major soil types	sand to loamy sand
4.	Net area sown	140000 ha
	Area sown more than once	128000 ha
5.	Area under major crops	
	Wheat	41000 ha
	Oil seeds	94000 ha
	Cotton	13100 ha
	Barley	1000 ha
6.	Crop production	
	Total Cereals	491 ton
	Total Pulses	2 ton
	Total Food Grains	493 ton
	Total Oil Seeds	145 ton
7.	Irrigation sources by different sources	
	Well/Tubewells	77000 ha
	Canals	8000 ha
	Other sources	nil

8.	Tubewell/pumping Set (2007-2008)	25093
9.	Rivers and canals in the districts	Mahendragarh distributary only
10.	Goundwater quality in the district	Alkali in nature
	Good	20.7 per cent
	Marginally saline	12.7 per cent
	Saline	6.0 per cent
	High SAR saline	12.0 per cent
	Marginally alkali	12.4 per cent
	Alkali	5.0 per cent
	High alkali	31.2 per cent
11.	Water table fluctuation (from 2000 to 2010)	-16.44 m
12.	Blockwise annual water table fluctuation	
	Ateli	-229 cm
	Kanina	-93 cm
	Mahendragarh	-118 cm
	Narnaul	-122 cm
	Nangal Chaudhary	-260 cm
13.	Major groundwater problems and issues	Very fast decline in water table (164 cm annually) due to exploitation
14.	Remedial measures	Apply gypsum in the soil and adopting modern methods of irrigation

1. INTRODUCTION

1.1 LOCATION

Mahendragarh district occupies the southern extremity of the state. It lies between 27° 47/ 50// N and 28° 28/ 15// N, latitude and between 75° 53/ 40// E and 76° 22/ 10// E longitude. Narnaul town is the administrative headquarters of this district. It is surrounded by Bhiwani and Rohtak districts of Haryana in the north, by Rewari district of Haryana and Alwar district of Rajasthan in the east, by Alwar, Jaipur and Sikar districts of Rajasthan in the south and by Sikar and Jhunjhunu districts of Rajasthan in the west. It has a geographical area of 1899 square kilometers. The district has five blocks viz, Mahendragarh, Kanina, Ateli, Narnaul and Nangal Chaudhary (Fig.1.1) The elevations of the plains above the mean-sea level range from 270.6 to 294.6 m in south, 217.1 to 267.0 m in north, 252.9 to 294.6 m in west and from 218.6 to 270.6 m in east.

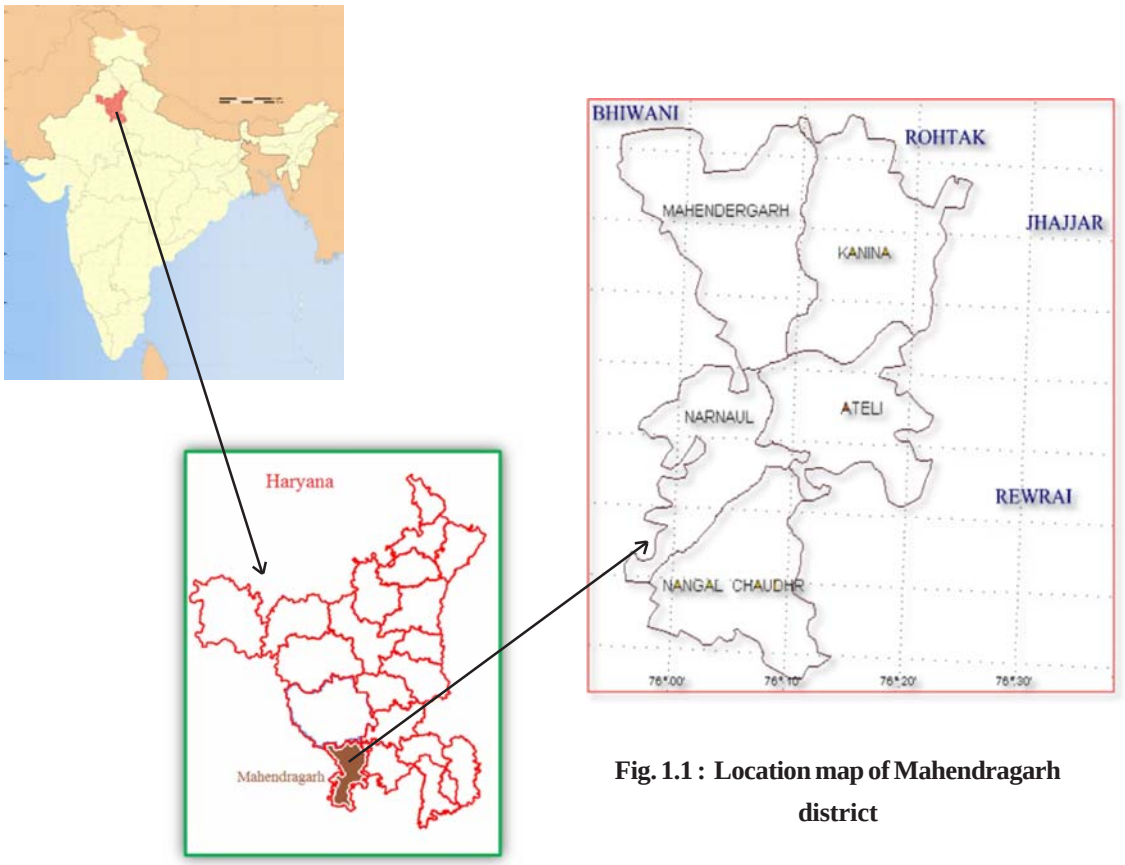


Fig. 1.1 : Location map of Mahendragarh district

1.2 RAINFALL AND CLIMATE

Mahendragarh district is a semi-arid with a long dry hot weather period lying in the south-western part of Haryana state. Hot, dust raising winds are common in April, May and June. From March onward the day temperature starts rising and in the month of May and June, it becomes very hot. By the end of June, the monsoon clouds appear. The average annual rainfall in the district is 407 mm and about 90 per cent of the normal annual rainfall in the district is received during June to September, whereas, July and August being the rainiest months. The blockwise details of average annual rainfall from year 1993 to 2009 is given in Table 1.1. Among this period, the highest rainfall (890 mm) in the district was occurred during the year 1996 and the lowest (129.4 mm) was during 2002 (Fig.1.2). The occurrence, origin, quality and availability of groundwater in the district are related to the recent and sub-recent formations. These geological formations of the area do not contain groundwater in substantial quantity. Due to very limited canal network, rainfall is the only source of groundwater.

Table 1.1 : Block wise details of average annual rainfall (mm) of Mahendragarh district

Year	Narnaul block	Mahendragarh block	Ateli block	Kanina block	Nangal Chaudhary block	Mahendragarh district
1993	690.6	548.4	1104.6	171.0	258.8	554.7
1994	484.3	435.1	587.8	177.2	361.1	409.1
1995	939.6	797.1	948.8	711.0	497.5	778.8
1996	1288.5	669.8	975.0	771.0	745.5	890.0
1997	837.8	503.0	707.4	396.0	468.6	582.6
1998	516.8	296.0	379.8	334.0	310.0	367.3
1999	286.1	182.0	206.0	178.2	187.2	207.9
2000	352.4	219.4	206.0	202.8	181.2	232.4
2001	628.1	370.8	373.0	270.2	344.0	397.2
2002	209.3	91.9	97.5	82.0	166.2	129.4
2003	427.8	381.0	341.5	371.0	461.0	396.5
2004	304.7	199.6	351.0	174.0	249.5	255.8
2005	894.2	409.2	502.5	351.2	628.0	557.0
2006	432.7	196.4	197.0	127.5	460.2	282.8
2007	547.3	321.4	380.9	233.5	642.5	425.1
2008	1219.9	593.5	847.0	532.5	583.0	755.2
2009	591.5	195.5	371.0	268.0	243.5	333.9

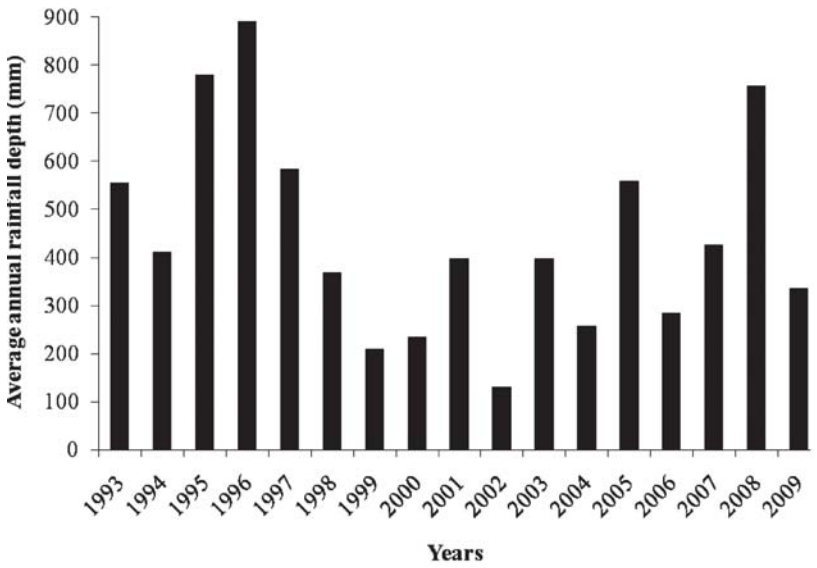


Fig.1.2 : Average annual rainfall of Mahendragarh district

1.3 MAJOR CROPS

Nearly 86.5 per cent of population of the district lives in villages and their main occupation is agriculture. Due to hot and dry area with limited rainfall duration, the crop grown in the district are pearl-millet and cotton in kharif season, whereas, wheat and mustard in rabi season. The main fodder crop is jowar and cluster bean. Apart from this, kharif vegetables, onions, turmeric, cucumber, etc. are also grown as minor crops.

1.4 GEOMORPHOLOGY AND SOILS

The district shows full sequence of the exposures of Delhi and Aravali ranges of Pre-cambrianage, which are composed of quartzite, shales, phylites, schists, etc., with different igneous intrusives. It consists of fairly leveled to gently undulating alluvial and sandy plains, interspersed by sand dunes, isolated hillocks and ridges. The soils are mostly sand to loamy sand throughout the profile. They are excessively drained and have a problem of shifting sand dunes. According to 7th approximation they are non-calcareous, Typic Torripsamments. However, the soils in Narnaul and Nangal Chaudhry blocks are sandy loam at the surface and loam in the sub-surface and are well drained. The hill ranges are a marked feature of the district. They are a part of great Aravali chain. They provide natural meadows for animals and also contain a number of rich minerals. The Dhosi hill touches a height of about 700 metres above sea level. Alkaline earths occur as efflorescence on the surface of earth and contain predominantly carbonate and bicarbonate of sodium. Their presence on the surface makes the land infertile, but on the other hand these can be economical source for sodium carbonate when the concentration of such salts reaches high. Alkaline efflorescence are quite extensive around Gohoro (Golwa) and Nangal Durgo in the area.

2. GROUNDWATER SCENARIO

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. 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 Mahendragarh district, according to assessment of groundwater potential approved by NABARD in year 1978, the total useable recharge was 379.70 million cubic metre (MCM) and out of it 451.78 MCM was being utilized which indicates that 119 per cent of the available groundwater was being used. Now in year 2010, according to Central Ground Water Board, utilizable groundwater resources in the district is 193 MCM and net groundwater draft is 262 which indicates that 136 per cent of the available groundwater was being used. This means over exploitation of groundwater has been increased by 17 per cent in the last 32 years. In the district, shallow aquifers occur in the alluvial deposit down to a depth of 60 m to 100 m. Wells in these areas yield 30 to 50 m^3/hr for moderate drawdown. In some parts of the district, aquifers in the weathered/fractured quartzites and cavernous limestone have yield potential of 5 to 50 m^3/hr for moderate to high drawdown.

2.2 GROUNDWATER FLUCTUATION STUDY OF THE DISTRICT

The groundwater data reveal that the level of water table in whole district is beyond the critical level of 10 metres. In the year 2000, the highest water table was 3.0 m in Chhitroli village of Kanina block due to Mahendragarh distributory passes very near to this village. But the average water table for this block was 17.98 m (Table 2.1). The lowest water table in this year was 83.45 m in Nithalawas village of Mahendragarh block. But the average water table of this block was 41.66 m. Whereas, the average water table in Ateli, Narnaul and Nangal Chaudhary blocks were 29.76, 26.05 and 37.24 m, respectively. During the year 2010, the highest (7.45 m) and the lowest water table (100.0 m) were remained in same villages Chhitroli and Nithalawas, respectively. Whereas, the average water table in Ateli, Kanina, Mahendragarh, Nangal Chaudhary and Narnaul

blocks were 52.63, 27.28, 53.51, 38.24 and 63.23 m, respectively (Table 2.1). The average annual water table declining rate for the district is 164 cm. The blockwise average groundwater levels during the different years are shown in the Figure 2.1. It is observed from the figure that the declining trend is very steep in the Narnaul block, particularly in the last two years.

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

Block	Average water table (m)		Water table fluctuation (m)	Average annual water table fluctuation (cm)
	2000	2010		
Ateli	29.76	52.63	-22.87	-229
Kanina	17.98	27.28	-9.29	-93
Mahendragarh	41.66	53.51	-11.85	-118
Narnual	26.05	38.24	-12.19	-122
Nangal Chaudhary	37.24	63.23	-25.99	-260
Mahendragarh district	30.54	46.98	-16.44	-164

The groundwater contour maps of the district are constructed for the year 2000 and 2010 to study the temporal behaviour in the groundwater level, as shown in Figures 2.2 and 2.3. In year 2000, groundwater levels were deeper in the central part of the district (Fig.2.2), ranging from 40 to 60 m (Mahendragarh block). Position of groundwater in the northern and southern part of the district was better, ranging from 10-30 m. It can be observed from the contour map that the groundwater level in Kanina block was better than other blocks (Fig.2.2) In year 2010, groundwater levels were also deeper in the central part of the district (Fig.23), ranging from 60 to 80 m (Mahendragarh and Narnaul blocks). Position of groundwater level in the northern part of the district is still better than

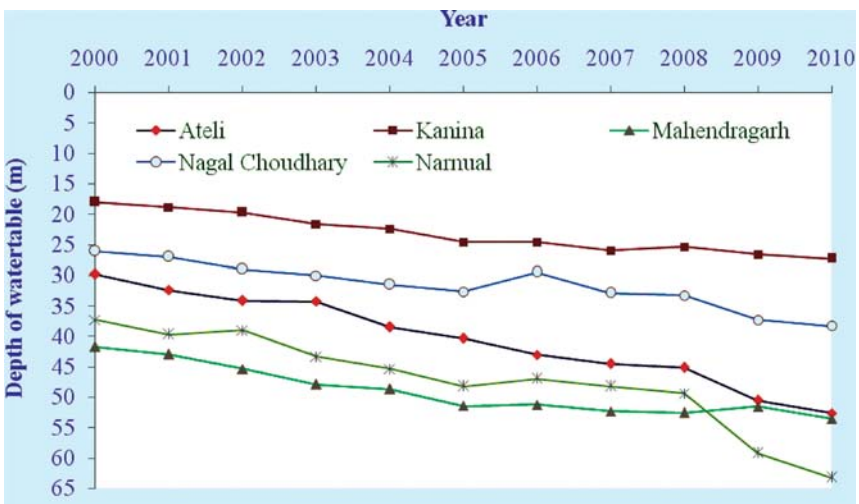


Fig.2.1: Periodical behaviour of waterable in different blocks of Mahendragarh district

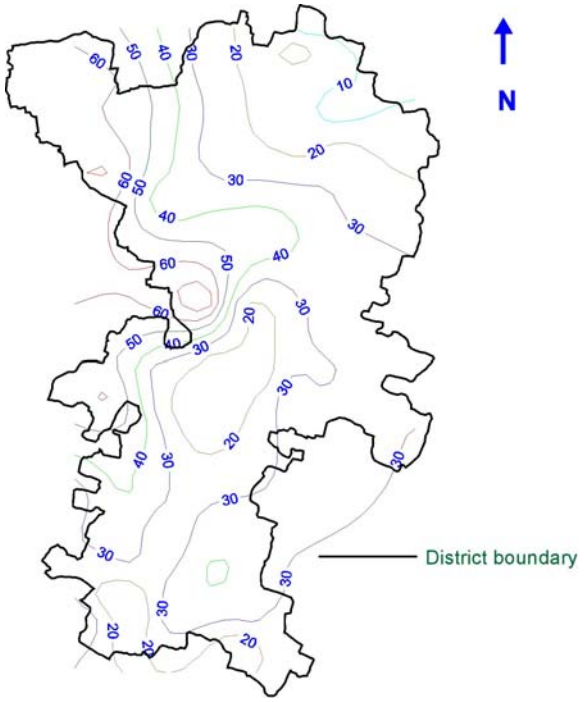


Fig.2.2: Contour map of groundwater level in Mahendragarh district during year 2000

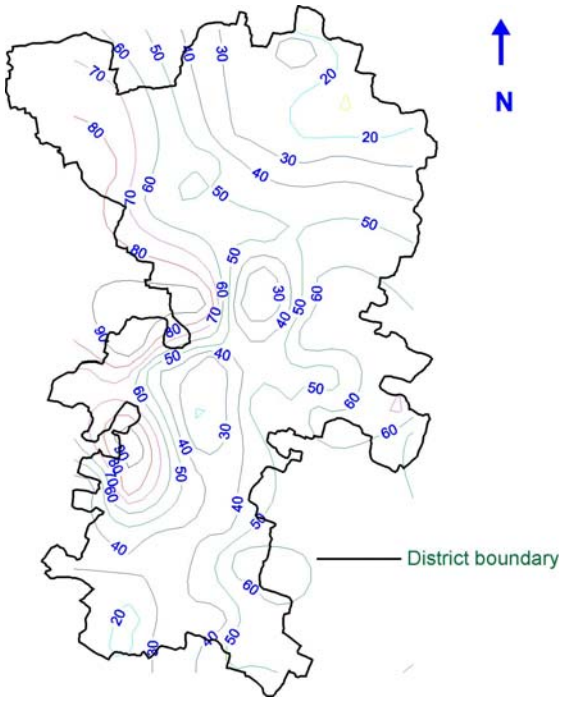


Fig.2.3: Contour map of groundwater level in Mahendragarh district during year 2010

other parts of the district, ranging from 20-40 m (Fig.2.3). From the contour map of year 2010, it is observed that groundwater level in southern part changed drastically in ten years (from 2000). Earlier in year 2000, it was ranging from 20-30 m but now in 2010, it is from 20-60 m. From the contour maps, it can be predicted that overall position of groundwater level in the district is very vulnerable as the range of groundwater level of the district has been changed from 10-60 m to 20-80 m from year 2000 to 2010. This may occur due to the deficit in rainfall in recent years and over exploitation of groundwater. According to a report of Central Ground Water Board, all the blocks in the district are over-exploited for groundwater and water table is going down at very high rate.

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. The elevation, longitude and latitude angles of the sampling points were recorded by GPS system at each location. All the 299 groundwater samples (59 from Ateli, 54 from Kanina, 87 from Mahendragarh, 57 from Nangal Chaudhary and 42 from Narnaul) were analyzed for various chemical parameters, viz. EC, pH, cations (Na^+, Ca^{+2} and Mg^{+2}) and anions (CO_3^{-2}, HCO_3^- and Cl^-). Subsequently, SAR and RSC were calculated for these samples. The range and mean of different water quality parameters of these blocks are presented in various tables. 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 Saline Water Use in Agriculture". Blockwise average chemical composition and the extent of their distribution are discussed below.

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 ATELI BLOCK

Ateli block lies between 28º00'20" to 28º13'20" N latitude and 76º05' 30" to 76º21' 40" E longitude. It is surrounded by Khol block of Rewari in east, by Kanina, Mahendragarh and Narnaul blocks of Mahendragarh district in north and west. It is surrounded by Rajasthan state on south and some part of east side. The block is having 81 villages.

In the block, EC ranged from 0.84 to 5.30 dS/m with a mean of 2.09 dS/m (Table 3.2). The lowest electrical conductivity of 0.84 dS/m in water samples was observed in village Ateli. The study revealed that 62.7 per cent of the samples showed EC values less than 2 dS/m and the maximum value of EC was found as 5.30 dS/m in village Ateli Mandi. Spatial variability in the

samples is observed from the Fig.3.1 where a graph is drawn between the sample points and their EC values. It is observed from the contour map (Fig.3.2a) that the EC of groundwater is high in the middle part of the Ateli block where red colour contour lines are shown. In the map, increase in the intensity of red from green colour indicates the increase in EC of groundwater. In the block, groundwater in surrounding areas is of low EC compared to the central part of the block. The pH ranged from 7.39 to 8.98 with an average of 8.23 (Table 3.2). The lowest pH 7.39 in water samples was observed in village Tigra and the highest value 8.98 was recorded in village Nangal Sirohi. It is observed from the contour map (Fig.3.2b) that in western boundary of the block, value of pH is higher than other parts of the block. More than 8.5 value of pH represent the alkali nature of water. The SAR ranged from 3.18 to 26.02 (m mol/l)^{½} (Table 3.2) with an average value of 10.44 (m mol/l)^{½}, the lowest SAR value being recorded in village Rithal Garhi and the highest value being recorded in Bajar village. The variations in values of SAR of this block are shown by contour map (Fig.3.2c). In the central part of the block, the value of SAR is lower than the outer parts of the block. Increasing SAR values reflects increase in sodicity of groundwater. Highest SAR is observed in the eastern part of the block. The RSC varied from nil to 8.00 (me/l) (Table 3.2) with an average of 2.68 (me/l) and maximum value of RSC 8.00 (me/l) was found in the village Sihma. It was observed that in 25.42 per cent water samples, RSC was nil. RSC is responsible for increase in alkaline nature of groundwater .The overall RSC of this block is lower in comparison to other blocks of the district. Only western part of the block has higher RSC than other parts of the block. In the central part of the block, it is almost absent/nil (Fig.3.2d).

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

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.84 – 5.3	2.09
2	pH	7.39 – 8.98	8.23
3	Na^{+} (me/l)	5.69 – 34.12	16.57
4	Ca^{+2} (me/l)	0.2 – 11.1	2.47
5	Mg^{+2} (me/l)	0.3 – 8.8	3.72
6	Cl^{-} (me/l)	3.5 – 47.0	13.05
7	CO_3^{-2} (me/l)	0.0 – 3.0	0.79
8	HCO_3^{-} (me/l)	3.6 – 11.2	6.52
9	SAR (m mol/l)^{½}	3.18 – 26.02	10.44
10	RSC (me/l)	0.0 – 8.00	2.68

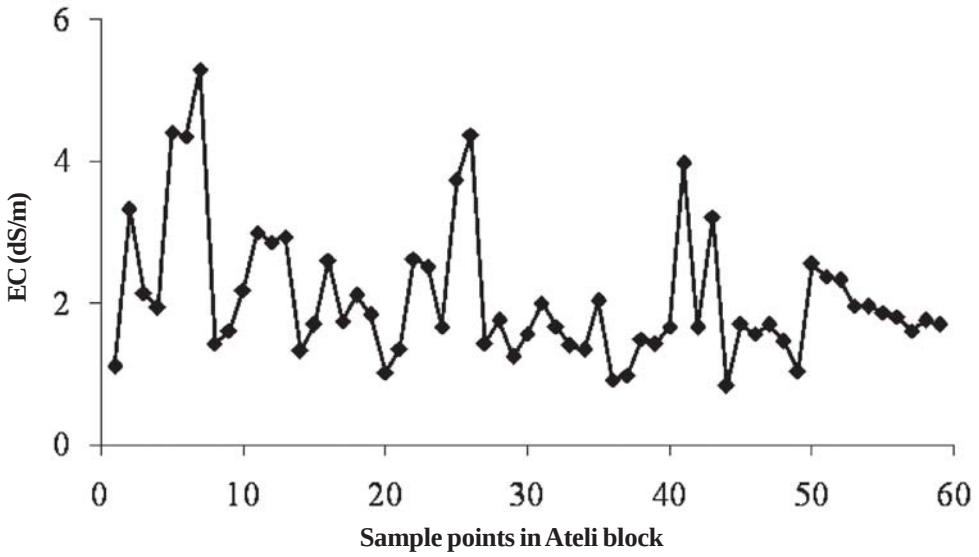
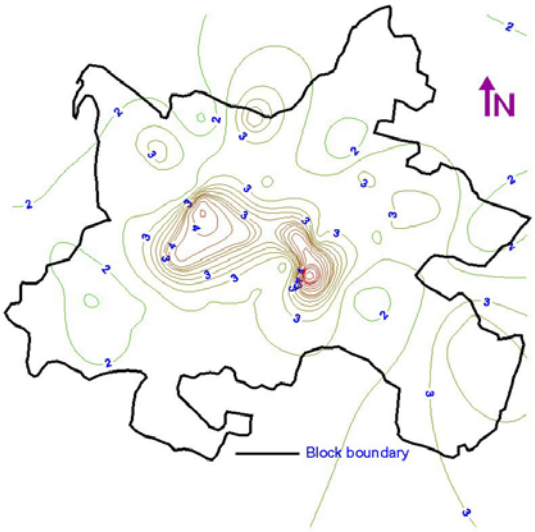


Fig.3.1: Spatial variability in EC of the collected samples

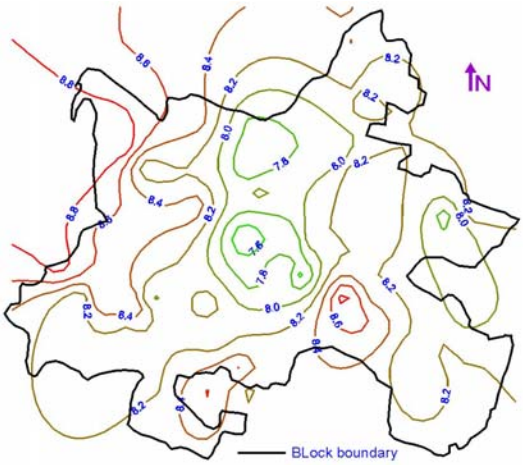
The average chemical composition and related quality parameters in different EC ranges for Ateli block are given in Table 3.3. The distribution of salts in the groundwater was varying as depicted in Fig.3.3. It showed that per cent in EC classes increased with increase in the EC of groundwater upto 2 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of irrigation water. The maximum number of 34 samples were concentrated in EC class of 1-2 and followed by 14 samples in EC class of 2-3 dS/m. It is seen that 86.44 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample above EC of 6 dS/m.

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

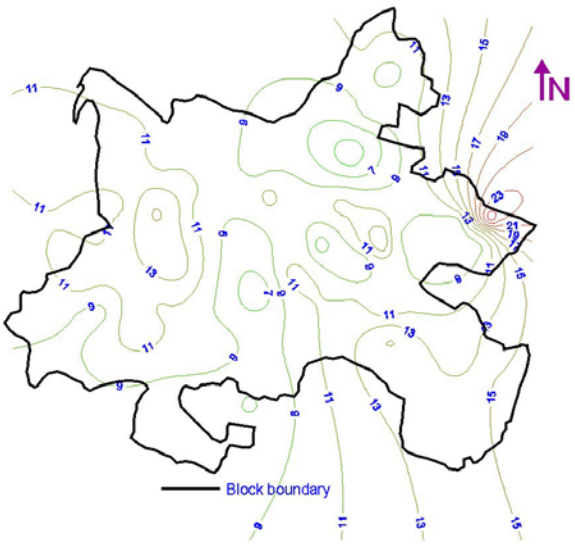
EC classes (dS/m)	No. of samples	% of samples	Na	Ca	Mg	CO_3 (me/l)	HCO_3	Cl	RSC	SAR (m mol/l)^{½}
0-1	3	5.08	9.90	0.97	1.33	1.07	6.07	5.27	4.83	9.28
1-2	34	57.63	14.32	1.54	2.79	0.86	6.73	8.85	3.38	10.81
2-3	14	23.73	18.13	2.43	4.77	0.71	6.26	14.61	1.55	9.97
3-4	4	6.78	23.11	5.93	5.95	0.95	8.10	22.60	1.73	10.01
4-5	3	5.08	26.94	7.47	7.57	0.13	4.40	37.13	0.00	9.82
5-6	1	1.69	34.12	10.60	7.40	0.00	4.60	47.00	0.00	11.37



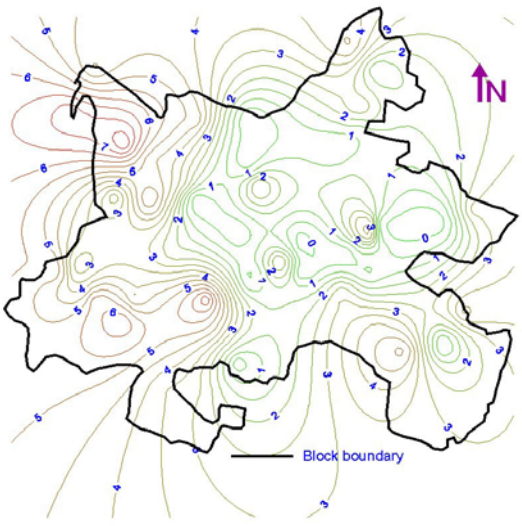
a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater



d) Contour map of RSC of groundwater

Fig.3.2: Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Ateli block of Mahendragarh district

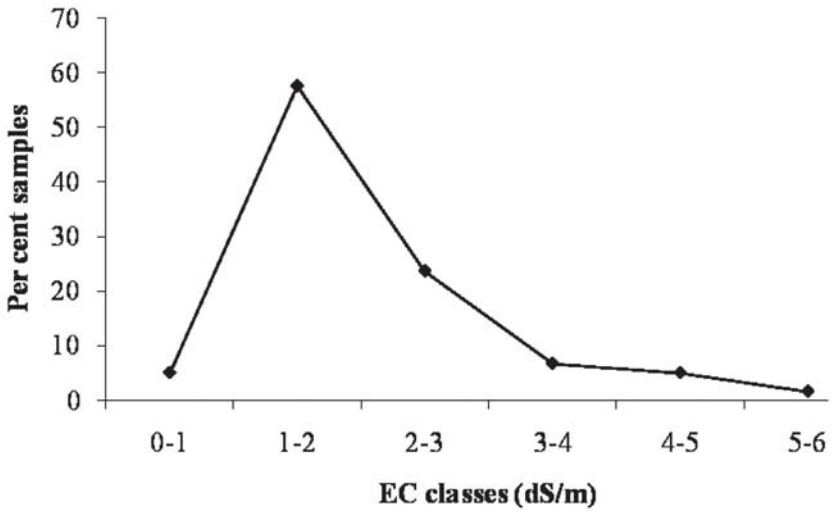


Fig.3.3: Per cent samples in different EC classes

In case of anions, chloride was the dominant anion with maximum value of 47.0 me/l, observed in village Ateli Mandi and minimum 3.5 me/l was recorded in village Nangal Sirohi. Bicarbonate (HCO_3^-) ranged from 3.6 to 11.2 me/l, the maximum value was observed in the water samples of village Sihma and minimum value was found in village Bajar. The average values for CO_3^{-2}, HCO_3^- and Cl^- were found to be 0.79, 6.52, 13.05 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Fig.3.4.

In cations, sodium concentration varied widely from 5.69 to 34.12 me/l, minimum value was observed in village Rithal Garhi and maximum value was observed in Ateli Mandi followed by magnesium (0.3 to 8.8 me/l) and calcium (0.2 to 11.1 me/l). Average values for Na^+, Mg^{+2} and Ca^{+2} were 16.57, 3.72 and 2.47 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.5. It is observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2}$.

According to AICRP classification, the maximum samples were found in high alkali quality (42.4 per cent) category followed by marginally saline (22.0 per cent) (Fig. 3.6). The per cent samples in good, marginally alkali, saline and high SAR saline classes were 16.9, 10.2, 6.8 and 1.7 per cent, respectively. The highest number of samples (25) was found in high alkali class followed by 13 and 10 in marginally saline and good classes, respectively. However, no sample was found in alkali class.

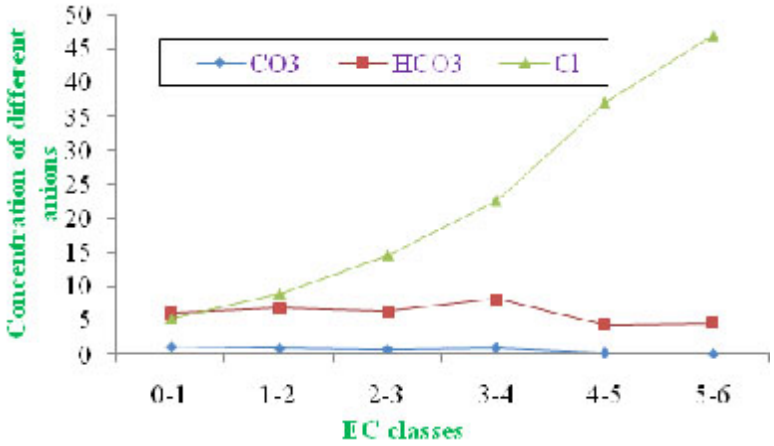


Fig. 3.4: Anions (CO_3, HCO_3, Cl) concentration in different EC classes of Ateli block

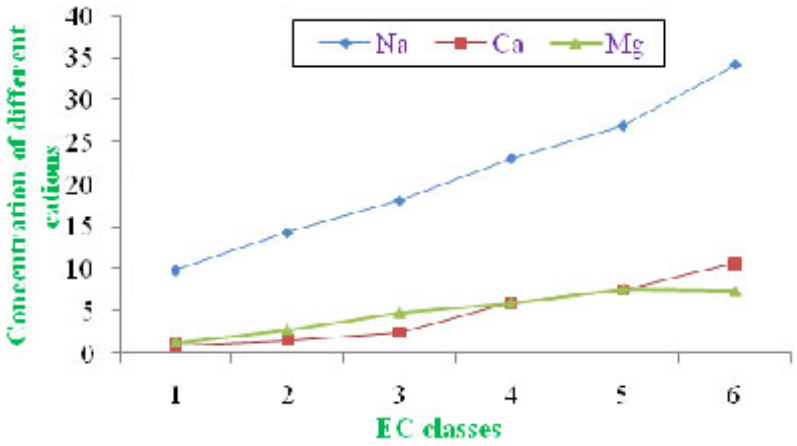


Fig. 3.5: Cations (Na, Ca, Mg) concentration in different EC classes of Ateli block

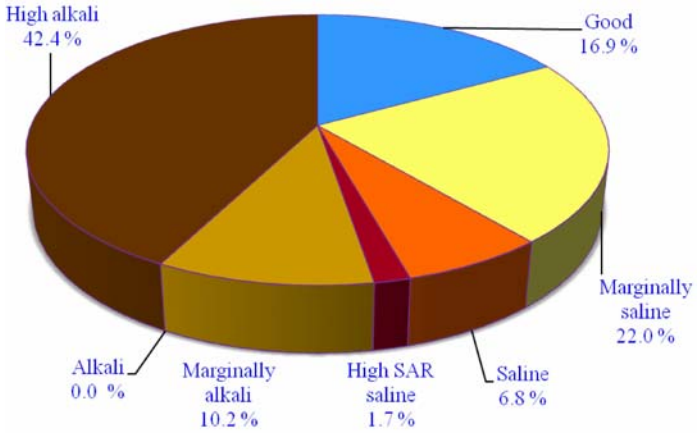


Fig.3.6: Quality of groundwater (per cent) in Ateli block of Mahendragarh district

3.2 KANINA BLOCK

Kanina block lies between 28º10′20″ to 28º28′15″ N latitude and 76º09′45″ to 76º22′00″ E longitude. It is surrounded by Nahar, Jatusana and Khol blocks of Rewari district on north-east side, by Dadri block of Bhiwani district in north, by Mahendragarh and Ateli blocks of Mahendragarh district in west and south sides respectively. The block is having 63 villages.

In the block, EC ranged from 0.35 to 9.29 dS/m with a mean of 2.37 dS/m (Table 3.4). The lowest electrical conductivity of 0.35 dS/m in water samples was observed in village Kakrala. The study revealed that 85.2 per cent of the samples showed EC less than 4 dS/m and the maximum EC was found as 9.29 dS/m in village Dongra Ahir. Spatial variability in the samples is observed from the Fig.3.7 where a graph is drawn between the sample points and their EC values. It is observed from the contour map (Fig.3.8a) that the EC of groundwater is high in the northern and southern parts of the block where red colour contour lines are shown. In the block, EC of groundwater in the central as well as eastern and western parts of the block is very low which reflects that groundwater of the most part of the block is having EC less than or equal two. The pH ranged from 7.53 to 9.37 with an average of 8.51. The lowest pH (7.53) in water samples was observed in village Pota and the highest pH (9.37) was recorded in village Kharana. It is observed from the contour map (Fig.3.8b) that in central and southern parts of the block, pH is higher than other parts of the block. The value of pH in the whole block is more than 8.5 except some patches. The SAR ranged from 3.98 to 25.04 (m mol/l)^{½} with an average value of 12.36 (m mol/l)^{½}, the lowest SAR value was recorded in village Unhani and the highest value recorded in Chhitroli village. The variations in values of SAR of this block are shown by contour map (Fig.3.8c). In the central part of the block, the value of SAR is lower than the outer parts of the block. The RSC varied from nil to 13.0 (me/l) with an average of 3.10 (me/l) and maximum value of RSC 13.0 (me/

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

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.35 – 9.29	2.37
2	pH	7.53 – 9.37	8.51
3	Na^{+} (me/l)	3.4 – 63.63	20.04
4	Ca^{+2} (me/l)	0.5 – 12.2	2.4
5	Mg^{+2} (me/l)	1.4 – 81.4	14.79
6	Cl^{-} (me/l)	2.1 – 93.6	17.18
7	CO_3^{-2} (me/l)	0.0 – 4.0	1.08
8	HCO_3^{-} (me/l)	2.0 – 11.2	5.98
9	SAR (m mol/l)^{½}	3.98 – 25.04	12.36
10	RSC (me/l)	0.0 – 13.0	3.10

l) was found in the village Kanina. It was observed that in 24.07 per cent water samples, RSC was nil. There are three main patches of higher RSC in the block on eastern, southern and northern boundaries. In the central part of the block, it is almost absent/nil (Fig.3.8d).

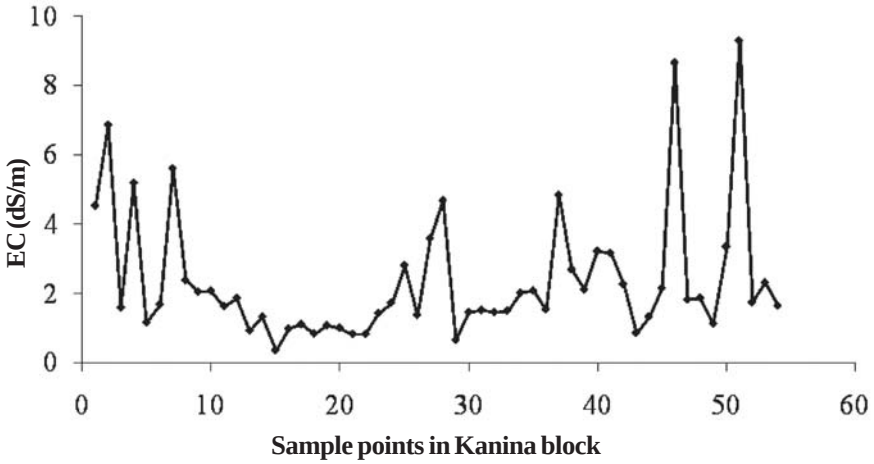
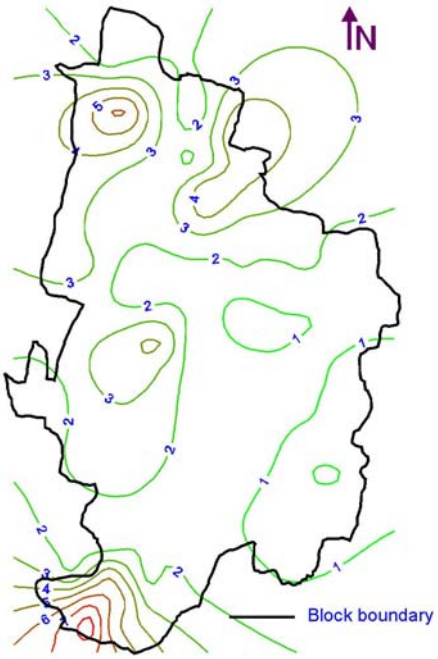


Fig.3.7: Spatial variability in EC of the collected samples

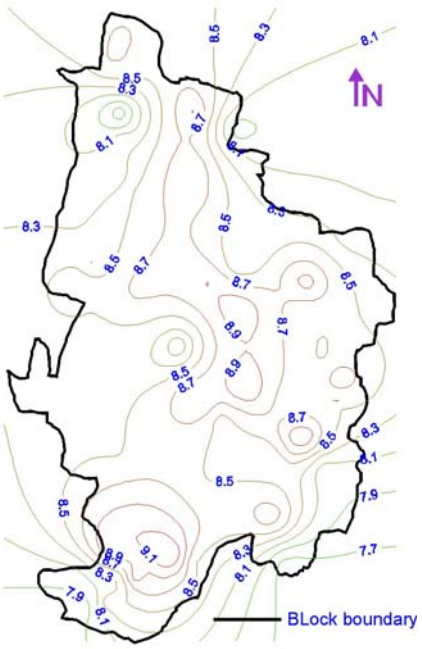
The average chemical composition and related quality parameters in different EC ranges for Kanina block are presented in Table 3.5. The distribution of salts in the groundwaters was varying as depicted in Fig.3.9. It showed that per cent in EC classes increased with increase in the EC of groundwater upto 2 dS/m and afterwards, percentage of samples started decreasing gradually with further increase in EC of irrigation water. The maximum number of 22 samples was concentrated in EC class of 1-2 and followed by 11 samples in EC class of 2-3 dS/m. It is seen that 77.78 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample found in the EC class of 7-8 dS/m.

In case of anions, chloride was the dominant anion with maximum value of 93.6 me/l was observed in village Dongra Ahir and minimum 2.1 me/l was recorded in village Kakrala. Bicarbonate (HCO_3^-) ranged from 2.0 to 11.2 me/l, the maximum value was observed in the water samples of village Kanina and the minimum value was found in village Kakrala. The average values for CO_3^{-2}, HCO_3^- and Cl^- were found to be 1.08, 5.98, 17.18 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Fig.3.10.

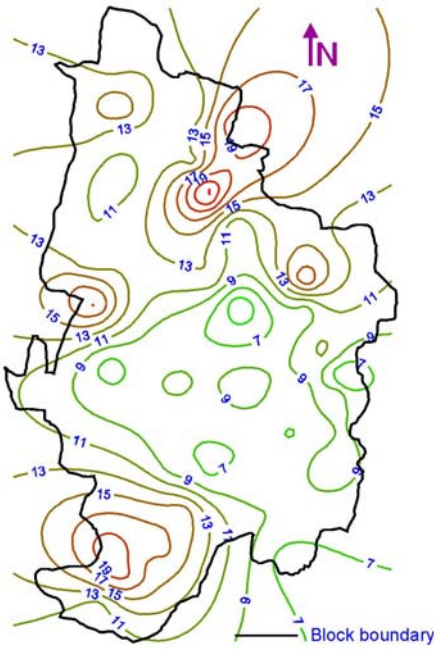
In cations, sodium concentration varied widely from 3.4 to 63.63 me/l, minimum value was observed in village Kakrala and maximum value was observed in Dongra Jat followed by magnesium (1.4 to 81.4 me/l) and calcium (0.5 to 12.2 me/l). Average values for Na^+, Mg^{+2} and Ca^{+2} were



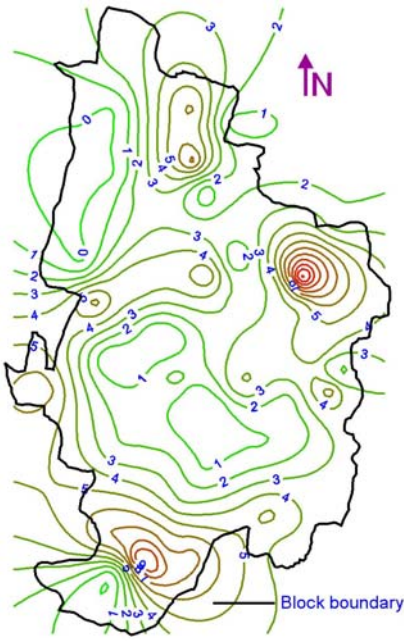
a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater



d) Contour map of RSC of groundwater

Fig.3.8: Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Kanina block of Mahendragarh district

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

EC classes (dS/m)	No. of samples	% of samples	Na	Ca	Mg	CO_3 (me/l)	HCO_3	Cl	RSC	SAR (m mol/l)^{½}
0-1	9	16.67	8.24	0.88	1.47	0.71	4.93	3.78	3.30	7.88
1-2	22	40.74	15.45	1.26	2.18	1.26	6.57	8.71	4.39	12.42
2-3	11	20.37	19.38	2.21	3.10	1.27	6.88	14.64	3.64	13.34
3-4	4	7.41	23.01	4.08	5.40	0.70	5.10	25.30	0.08	11.50
4-5	3	5.56	32.51	5.47	9.67	0.33	4.13	42.80	0.00	12.00
5-6	2	3.70	49.60	3.95	5.30	2.60	6.30	40.50	0.30	23.16
6-7	1	1.85	53.67	6.80	11.70	1.00	5.60	54.00	0.00	17.65
7-8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-9	1	1.85	63.63	10.00	10.50	0.00	5.00	83.20	0.00	19.87
9-10	1	1.85	48.92	12.20	29.30	0.00	2.40	93.60	0.00	10.74

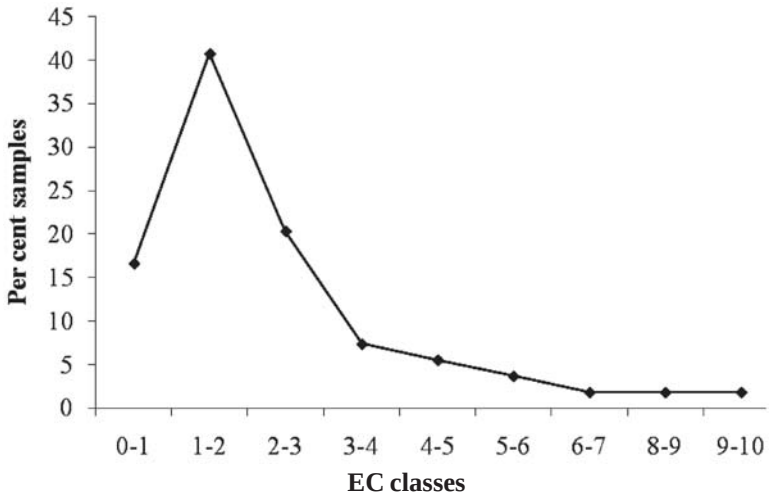


Fig.3.9: Per cent samples in different EC classes

20.04, 14.79 and 2.4 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.11. It is observed that cations in groundwaters followed the order $Na^{+} > Mg^{+2} > Ca^{+2}$.

According to AICRP classification, the maximum samples were found in high alkali quality (44.4 per cent) category followed by high SAR saline (20.4 per cent) (Fig.3.12). The per cent samples in good, marginally alkali, marginally saline, alkali and saline classes were 16.6, 7.4, 5.6, 3.7 and 1.9 per cent, respectively. The highest number of samples (24) were found in high alkali class followed by 11 and 9 in high SAR saline and good classes, respectively. However, the least number of samples (1) was found in saline class.

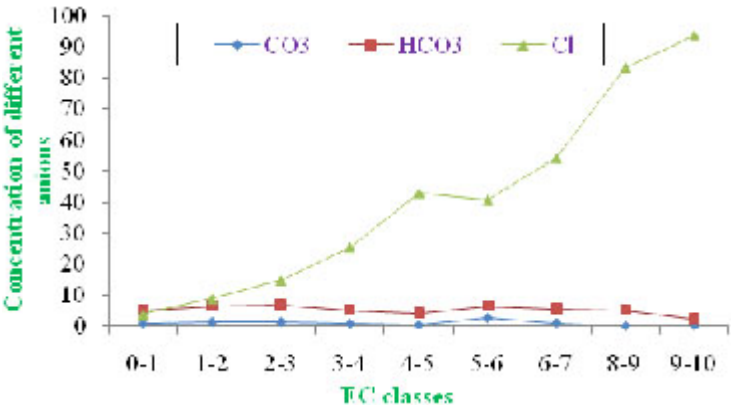


Fig.3.10: Anions (CO_3, HCO_3, Cl) concentration (me/l) in different EC classes of Kanina block

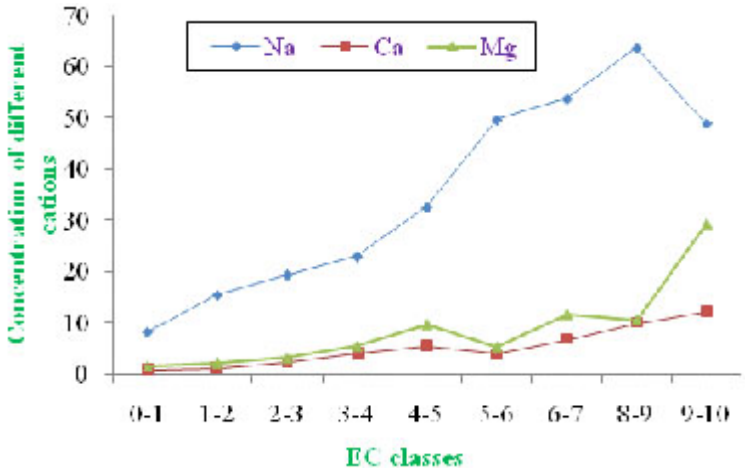


Fig.3.11: Cations (Na, Ca, Mg) concentration (me/l)in different EC classes of Kanina block

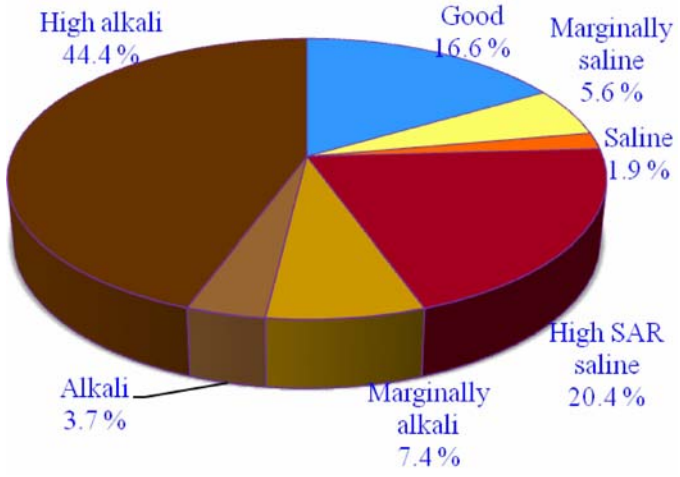


Fig.3.12: Quality of groundwater (per cent) in Kanina block of Mahendragarh district

3.3 MAHENDRAGARH BLOCK

Mahendragarh block lies between 28º09′30″ to 28º27′50″ N latitude and 75º53′40″ to 76º12′30″ E longitude. It is surrounded by Kanina block of Mahendragarh district in the east, by Dadri and Loharu blocks of Bhiwani district in the north-west directions and by Narnaul block in south side. On west-south side, it is surrounded by Rajasthan state. The block is having 99 villages.

In the block, electrical conductivity (EC) ranged from 0.5 to 9.65 dS/m with a mean of 2.16 dS/m (Table 3.6). The lowest EC of 0.50 dS/m in water samples was observed in village Gadharwas. The study revealed that 85.06 per cent of the samples showed EC values less than 4 dS/m. The maximum EC (9.65 dS/m) was found as in village Khudana near the main road. Spatial variability in the samples is observed from the Fig.3.13 where a graph is drawn between the sample points and their EC values. It is observed from the contour map (Fig.3.14a) that the EC of groundwater is high in the middle and upper (northern) part of the block where red colour contour lines are shown. No particular trend in the variation of EC is present in the block. In Mahendragarh block, groundwater in surrounding areas is of low EC compared to the central part of the block. The pH ranged from 7.00 to 10.12 with an average of 8.30 (Table 3.6). The lowest pH of 7.00 in water samples was observed in village Khatod and the highest pH (10.12) was recorded in village Khudana. It is observed from the contour map (Fig. 3.14b) that eastern parts of block have higher pH than the western parts of the block. Contour map reflects that the value of pH is highly spatially variable and the lowest value 7.4 is represented in the centre of the block. The SAR ranged from 0.54 to 17.32 (m mol/l)^{½} with an average value of 8.77 (m mol/l)^{½} (Table 3.6), the lowest SAR value recorded in village Palri and the highest recorded in Gahri Khudana village. The variations in values of SAR of this block are shown by contour map (Fig.3.14c). In the central part of the block, the value of SAR is higher than the outer parts of the block. In most parts of the block, SAR is ranging from 6-10 (m mol/l)$^{1/2}$. The RSC varied from nil to 14.72 (me/l) with an average of 2.14 (me/l) (Table 3.6) and maximum value of RSC (14.72 me/l) was found in the village Bhurjat. It was observed that in 42.53 per cent water samples, RSC was nil. In the north-eastern corner of the block, RSC is higher and in the central part of the block, it is almost absent/nil (Fig.3.14d). In most part of block, RSC is ranging from 0-2 me/l.

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

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.5 – 9.65	2.16
2	pH	7.00 – 10.12	8.30
3	Na^{+} (me/l)	1.01 – 58.2	15.04
4	Ca^{+2} (me/l)	0.3 – 19.5	2.77
5	Mg^{+2} (me/l)	0.19 – 26.3	4.59
6	Cl^{-} (me/l)	1.3 – 88.0	14.35
7	CO_3^{-2} (me/l)	Nil – 4.8	0.63
8	HCO_3^{-} (me/l)	0.6 – 16.96	5.36
9	SAR (m mol/l)^{½}	0.54 – 17.32	8.77
10	RSC (me/l)	Nil – 14.72	2.14

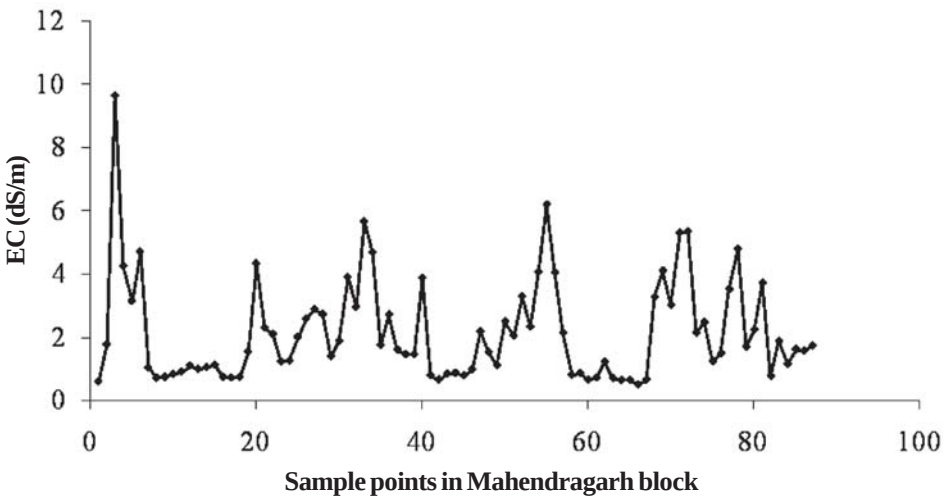
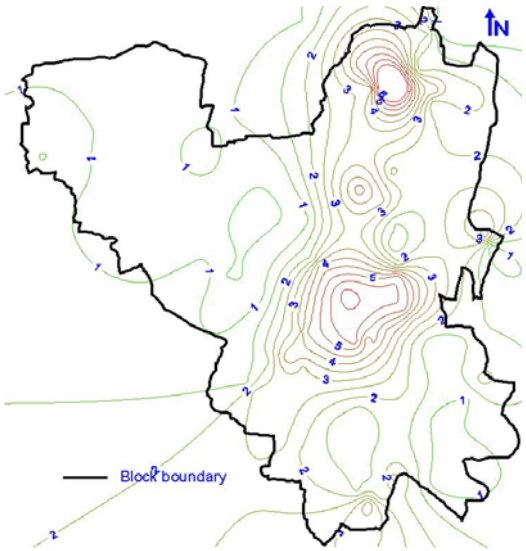
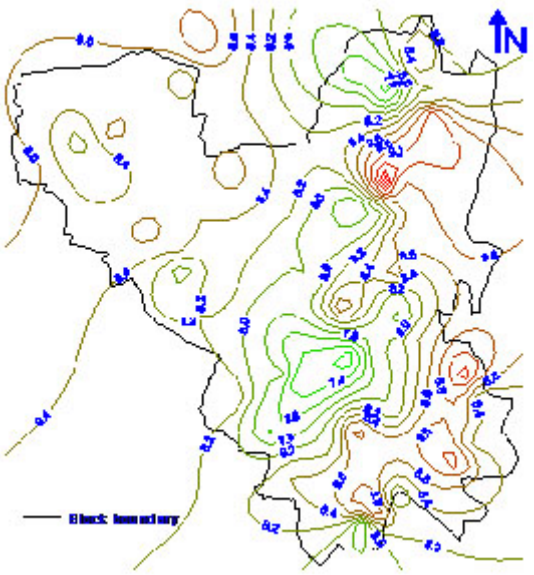


Fig.3.13: Spatial variability in EC of the collected samples

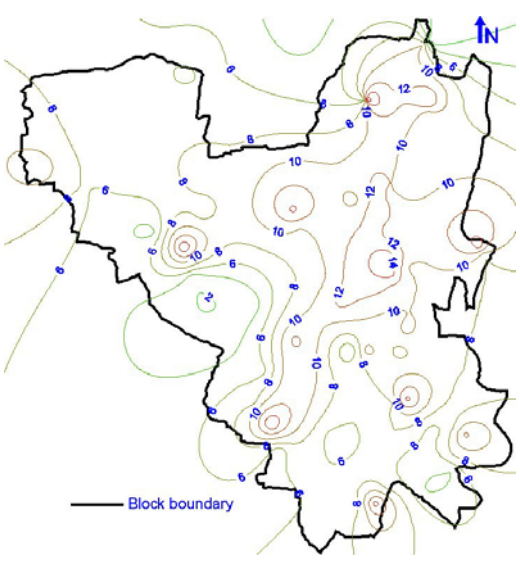
The average chemical composition and related quality parameters in different EC ranges for Mahendragarh block are given in Table 3.7. The distribution of salts in the groundwaters was varying as shown in Fig.3.15. It showed that per cent samples in EC classes 0-1 and 1–2 dS/m is same and afterwards, percentage of samples started decreasing gradually with further increase in EC of irrigation water. The maximum number of 25 samples was concentrated in each EC class of 0-1 and 1-2 dS/m. It is seen that 57.48 per cent samples were found upto EC of 2 dS/m, whereas,



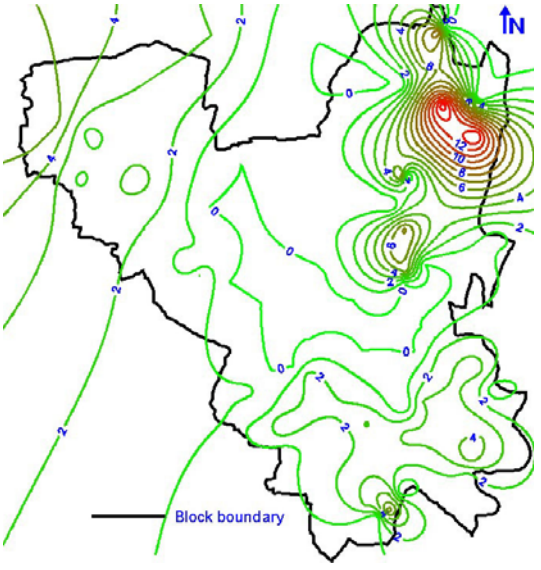
a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater



d) Contour map of RSC of groundwater

Fig.3.14: Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Mahendragarh block of Mahendragarh district

there was no sample found in the EC class of 7-8 dS/m. Average RSC of the EC class 1-2 was the highest (4.25) and its value was obtained nil after EC class 3-4.

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

EC classes (dS/m)	No. of samples	% of samples	Na	Ca	Mg	CO_3 (me/l)	HCO_3	Cl	RSC	SAR (m mol/l)^{½}
0-1	25	28.74	6.40	0.86	1.40	0.34	3.34	3.54	1.79	7.04
1-2	25	28.74	11.11	1.42	2.30	0.82	6.98	6.19	4.25	8.71
2-3	16	18.39	17.35	3.13	6.04	0.86	5.94	14.87	1.63	9.14
3-4	8	9.20	24.32	3.77	6.28	1.00	5.93	24.90	1.11	11.34
4-5	8	9.20	27.22	6.36	8.84	0.30	5.45	34.95	0.00	10.33
5-6	3	3.45	27.36	9.00	16.10	0.00	5.20	48.83	0.00	8.42
6-7	1	1.15	40.84	6.80	14.20	0.80	4.80	54.00	0.00	12.60
7-8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-9	1	1.15	58.20	19.50	26.30	0.40	2.40	88.00	0.00	12.16

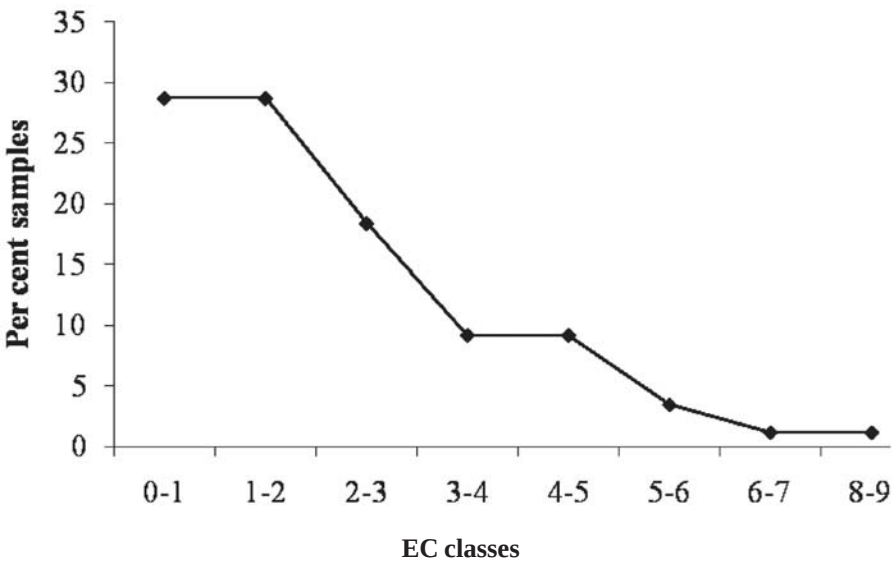


Fig.3.15: Per cent samples in different EC classes

In case of anions, chloride was the dominant anion with maximum value of 88 me/l (Table 3.6) was observed in village Khudana and minimum 1.3 me/l was recorded in village Kadma. Bicarbonate (HCO_3^-) ranged from 0.6 to 16.96 me/l, the maximum value was observed in the

water samples of village Bhurjat and minimum value was founded in village Digrota. The average values for CO_3^{-2}, HCO_3^- and Cl^- were found to be 0.63, 5.36, 14.35 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > CO_3^{-2}$. The concentration of the anions in different classes of EC is depicted in Fig.3.16.

In cations, sodium concentration varied widely from 1.01 to 58.2 me/l (Table 3.6), minimum value was observed in village Palri and maximum value was observed in Khudana followed by magnesium (0.19 to 26.3 me/l) and calcium (0.3 to 19.5 me/l). Average values for Na^+, Mg^{+2} and Ca^{+2} were 15.04, 4.59 and 2.77 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.17. It is observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2}$.

According to AICRP classification, the maximum samples were found in good quality (25.3 per cent) category followed by marginally alkali (19.5 per cent) (Fig.3.18). The per cent samples in high alkali, marginally saline, high SAR saline, saline, and alkali classes were 13.7, 12.7, 12.7, 10.4 and 5.74 per cent, respectively. The highest number of samples (22) were found in good quality class followed by 17 and 12 in marginally alkali and high alkali classes, respectively. However, the minimum number of sample (5) were found in alkali class.

3.4 NANGAL CHAUDHARY BLOCK

Nangal Chaudhary lies between 27º47′30″ to 28º20′00″ N latitude and 75º58′20″ to 76º13′40″ E longitude. Most part of this block is surrounded by Rajasthan state except some parts in north and west side which is surrounded by Narnaul block of Mahendragarh district. The block is having 90 villages.

In Nangal Chaudhary block, EC ranged from 0.71 to 5.25 dS/m with a mean of 1.87 dS/m (Table 3.8). The lowest electrical conductivity of 0.71 dS/m in water samples was observed in village Rai Malikpur and the maximum EC of 5.25 dS/m was found Nangal Nuniya. The study revealed that 89.47 per cent of the samples showed EC values less than 3 dS/m. Spatial variability in the samples is observed from the Fig.3.19 where a graph is drawn between the sample points and their EC values. It is observed from the contour map (Fig.3.20a) that the EC of groundwater is high in the sorthern part of the block. In this block, overall EC of groundwater is low as compared to other blocks. Most of the area of the block is having EC less 2 dS/m. Contour map is showing only one contour of 5 dS/m EC at the boundary of the southern part of the block (Fig.3.20a). The pH ranged from 7.45 to 9.37 with an average of 8.52. The lowest pH of 7.45 in water samples was observed in village Nilaja and the highest value 9.37 was recorded in village Poshwali Dhani. It is observed from the contour map (Fig.3.20b) that eastern part of block has higher pH than the

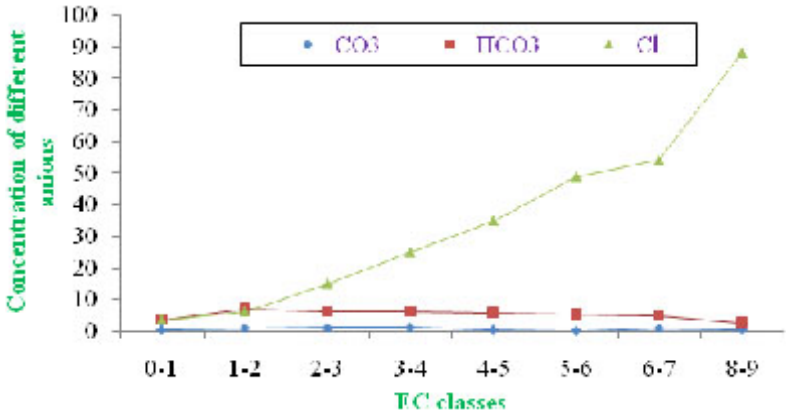


Fig.3.16: Anions (CO_3, HCO_3, Cl) concentration (me/l) in different EC classes of Mahendragarh block

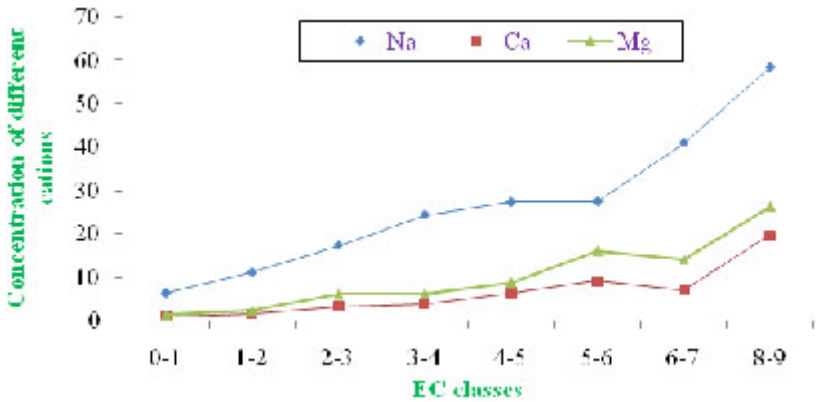


Fig.3.17: Cations (Na, Ca, Mg) concentration (me/l) in different EC classes of Mahendragarh block

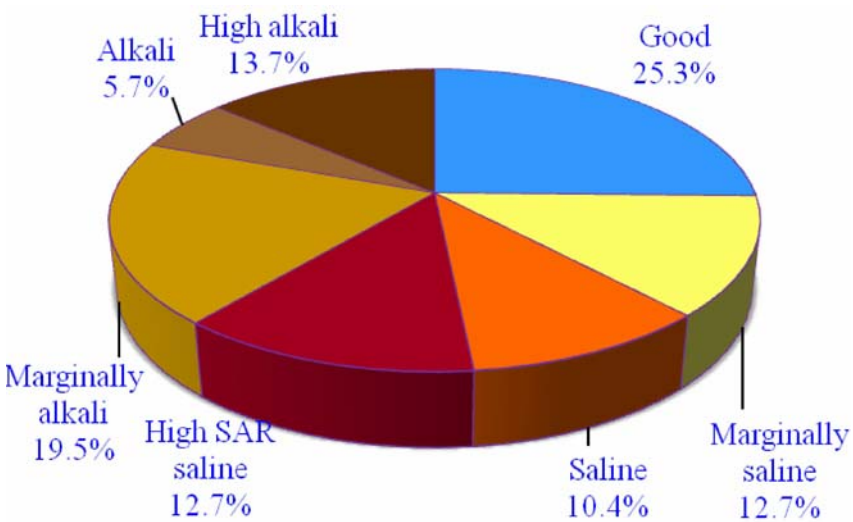


Fig.3.18: Quality of groundwater (per cent) in Mahendragarh block of Mahendragarh district

western part of the block. The SAR ranged from 4.48 to 19.10 (m mol/l)^{½} with an average value of 10.64 (m mol/l)^{½}, the lowest SAR value being recorded in village Gotri and the highest value being recorded in Amarpura village. The variations in values of SAR of this block are shown by contour map (Fig.3.20c). In the eastern and southern part of the block, the value of SAR is higher than the other parts of the block. The most of the groundwater has higher SAR in the block. The RSC varied from nil to 12.0 (me/l) with an average of 3.32 (me/l) and maximum value of RSC 12.0 (me/l) was found in the village Akbarpur Sirohi. It was observed that in 28.07 per cent water samples, RSC was nil. In the eastern and southern part of the block, the value of RSC is higher than the other parts of the block (Fig.3.20d). Overall RSC of the groundwater samples is low.

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

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.71-5.25	1.87
2	pH	7.45-9.37	8.52
3	Na^{+} (me/l)	5.90-36.23	15.74
4	Ca^{+2} (me/l)	0.5-10.0	2.14
5	Mg^{+2} (me/l)	1.06-10.3	3.05
6	Cl^{-} (me/l)	3.80-38.0	11.99
7	CO_3^{-2} (me/l)	nil-3.60	0.93
8	HCO_3^{-} (me/l)	3.0-12.0	6.38
9	SAR (m mol/l)^{½}	4.48-19.10	10.64
10	RSC (me/l)	nil-12.0	3.32

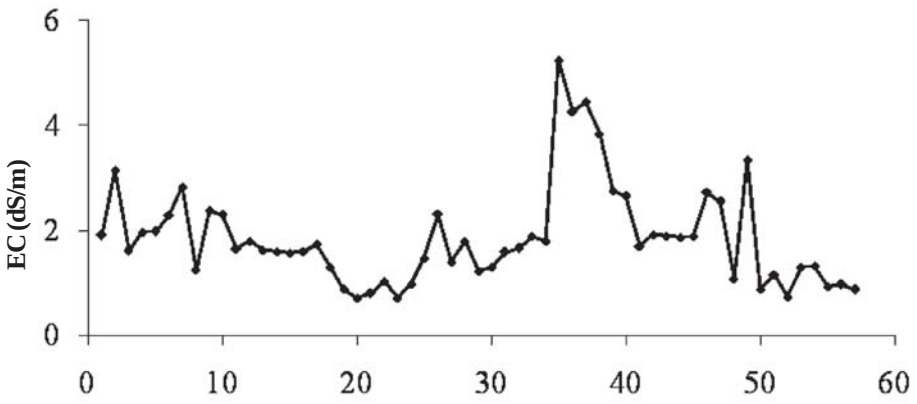
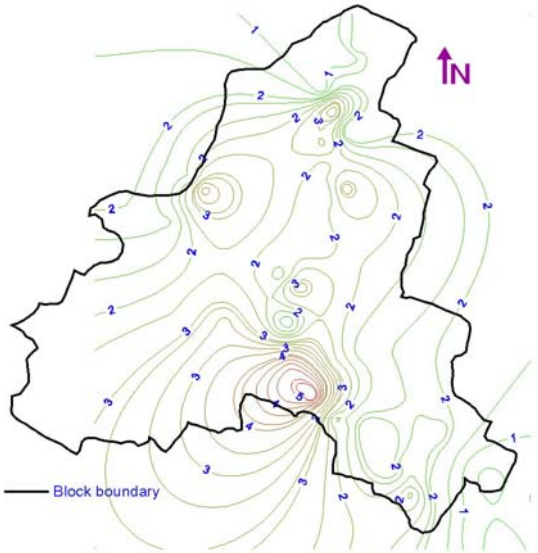
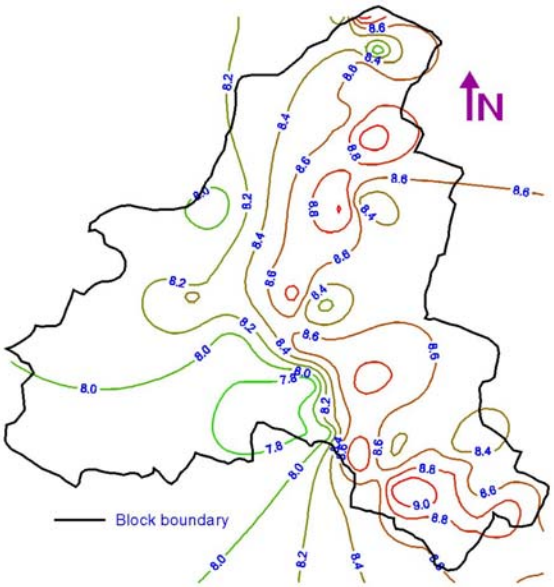


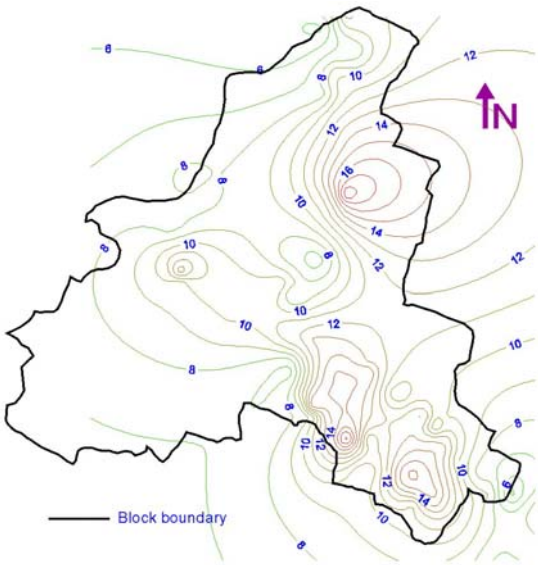
Fig.3.19: Spatial variability in EC of the collected samples



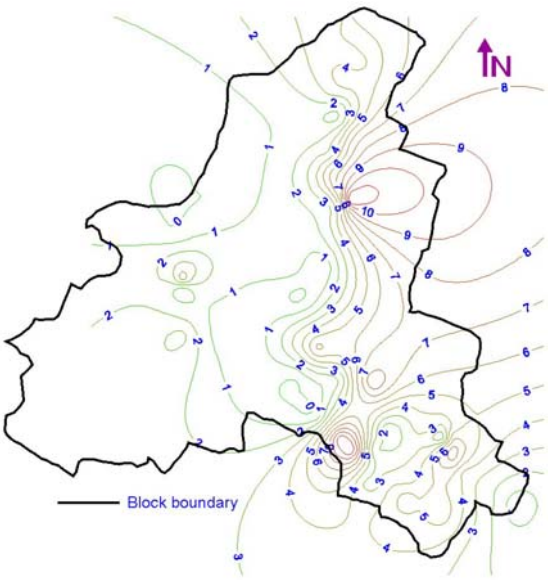
a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater



d) Contour map of RSC of groundwater

Fig.3.20: Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Nangal Chaudhary block of Mahendragarh district

The average chemical composition and related quality parameters in different EC ranges for Nangal Chaudhary block are given in Table 3.9. The distribution of salts in the groundwaters was varying as shown in Fig.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 irrigation water. The maximum number of 32 samples was concentrated in EC class of 1-2 and followed by 10 samples in EC class of 0-1 dS/m. It is seen that 89.47 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample above EC of 6 dS/m.

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

EC classes (dS/m)	No. of samples	% of samples	Na	Ca	Mg	CO_3 (me/l)	HCO_3	Cl	RSC	SAR (m mol/l)^{½}
0-1	10	17.54	8.62	1.03	1.77	0.32	4.98	5.24	2.66	7.56
1-2	32	56.14	15.28	1.63	2.29	1.08	6.70	9.15	4.11	11.55
2-3	9	15.79	20.14	3.33	3.62	1.60	7.13	16.31	3.47	11.67
3-4	3	5.26	20.74	5.83	8.07	0.00	4.20	28.67	0.00	8.25
4-5	2	3.51	21.19	4.20	9.10	0.20	5.80	33.60	0.00	8.24
5-6	1	1.75	36.23	3.6	7.9	0.4	10.8	38	0	15.11

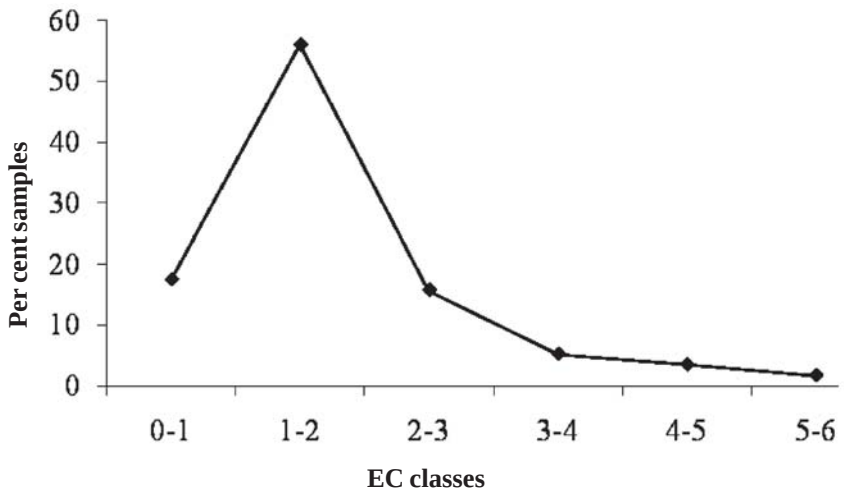


Fig.3.21: Per cent samples in different EC classes of Nangal Chaudhary

In case of anions, chloride was the dominant anion with maximum value of 38.0 me/l was observed in village Nangal Nuniya and minimum 3.8 me/l was recorded in village Dhani Kodinja. Bicarbonate (HCO_3^-) ranged from 3.0 to 12.0 me/l, the maximum value was observed in the water

samples of village Akabarpur Sirohi and minimum value was founded in village Kalba. The average values for CO_3^{-2}, HCO_3^- and Cl^- were found to be 0.93, 6.38, 11.99 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Fig.3.22.

In cations, sodium concentration varied widely from 5.9 to 36.23 me/l, minimum value was observed in village Dhani Kodinja and maximum value was observed in Nangal Nuniya, followed by magnesium (1.06 to 10.3 me/l) and calcium (0.5 to 10.0 me/l). Average values for Na^+, Mg^{+2} and Ca^{+2} were 15.74, 3.05 and 2.14 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.23. It is observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2}$.

According to AICRP classification, the maximum samples were found in high alkali quality (43.9 per ecnt) category followed by good quality (22.7 per cent) (Fig.3.24). The per cent samples in marginally alkali, marginally saline, saline, alkali, and high SAR saline were 12.3, 8.8, 5.3, 3.5 and 3.5 per cent, respectively. The maximum number of samples (25) was found in high alkali class followed by 13 and 7 in good and marginally alkali classes, respectively. However, the minimum number (2) of sample was found in alkali and high SAR saline classes each.

3.5 NARNUAL BLOCK

Narnaul block lies between 27º54′10″ to 28º11′00″ N latitude and 75º55′50″ to 76º09′50″ E longitude. Most part of this block is surrounded by Rajasthan state except some parts on east side which is surrounded by Mahendragarh and Ateli blocks of Mahendragarh district. The block is having 71 villages. Rainfall (Table 1.1) from the period 1993 to 2009 indicates that this block received maximum rainfall than other blocks in most of the years.

In Narnual block, EC ranged from 0.44 to 8.15 dS/m with a mean of 2.85 dS/m (Table 3.10). The lowest electrical conductivity of 0.44 dS/m in water samples was observed in village Kuksi. The study revealed that 88.09 per cent of the samples showed EC values less than 5 dS/m and the maximum value of EC was found as 8.15 dS/m in village Golawala in the north-eastern corner of the block. Spatial variability in the samples is observed from the Fig.3.25 where a graph is drawn between the sample points and their EC values. It is observed from the contour map (Fig.3.26a) that the EC of groundwater is high in the middle and upper (northern) part of the block. In this block, groundwater in surrounding areas is of low EC compared to the central part of the block. The pH ranged from 7.20 to 9.14 with an average of 8.29. The lowest pH (7.20) in water samples was observed in village Nizampur and the highest value 9.14 was recorded in village Lahroda. It is observed from the contour map (Fig.3.26b) that higher pH value exists in the patches in the east, north and central parts of the block. In most parts of the block, irrigating groundwater

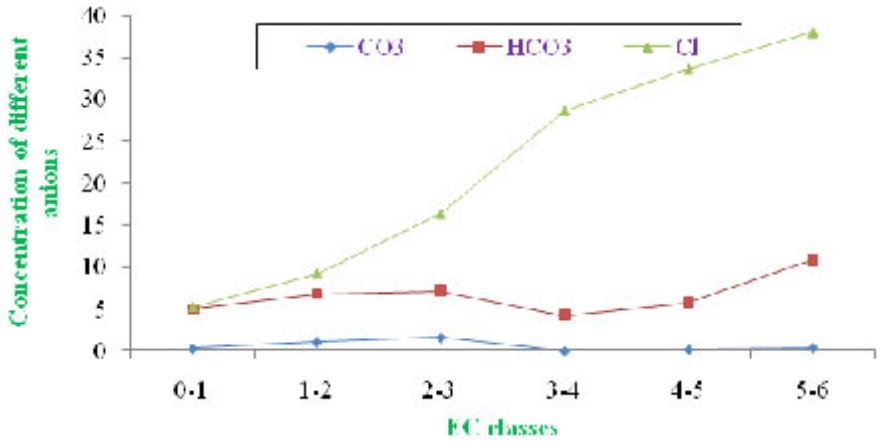


Fig.3.22: Anions (CO_3, HCO_3, Cl) concentration in different EC classes of block

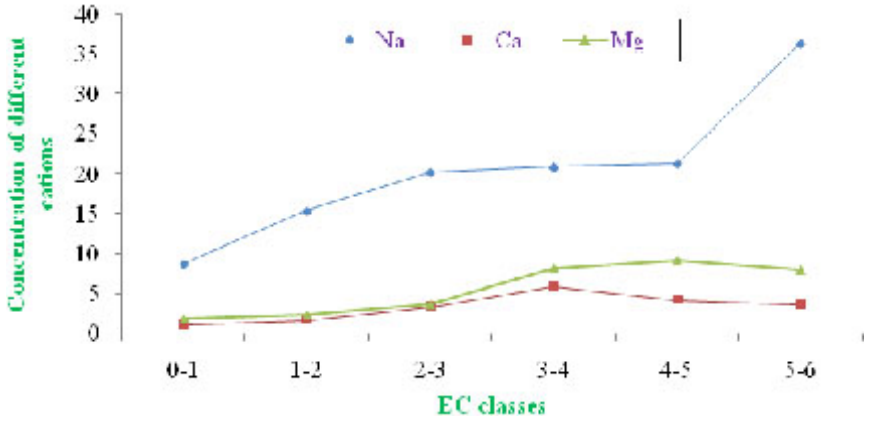


Fig.3.23: Cations (Na, Ca, Mg) concentration in different EC classes of block

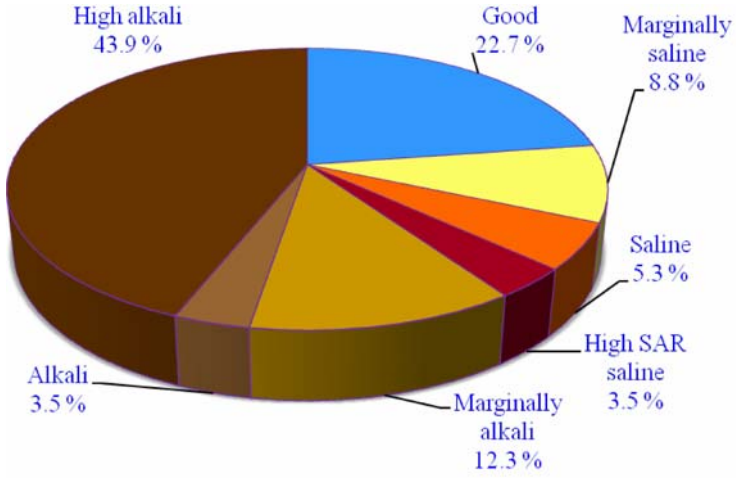


Fig.3.24: Quality of groundwater (per cent) in Nangal Chaudhary block of Mahendragarh district

is normal in relation to alkalinity. The SAR ranged from 3.28 to 18.03 (m mol/l)^{½} with an average value of 10.98 (m mol/l)^{½}, the lowest SAR value was recorded in village Kuksi and the highest value was recorded in Golawala village. The variations in values of SAR of this block are shown by contour map (Fig.3.26c). In the central and Northern part of the block, the value of SAR is higher than the other parts of the block. Increasing SAR values reflects increase in sodicity of groundwater. Red clour is dominating more than green colour, reflects that the most of the groundwater has higher SAR in the block. The RSC varied from nil to 13.6 (me/l) with an average of 2.36 (me/l) and maximum value of RSC 13.6 (me/l) was found in the village Karoli. It was observed that in 50 per cent water samples, RSC was nil. The variations in values of RSC of this block are shown by contour map (Fig.3.26d). Central and north-eastern parts of the block has higher RSC than other parts of the block. In the western part of the block, it is almost absent/nil.

Table 3.10 : Range and average of different water quality parameters in Narnual block of Mahendragarh district

Sr. No.	Parameters	Range	Average
1	EC (dS/m)	0.44 – 8.15	2.85
2	pH	7.2 – 9.14	8.29
3	Na^{+} (me/l)	3.95 – 53.17	21.36
4	Ca^{+2} (me/l)	0.6 – 10.9	3.22
5	Mg^{+2} (me/l)	0.9 – 16.1	4.85
6	Cl^{-} (me/l)	0.0 – 4.8	0.67
7	CO_3^{-2} (me/l)	1.8 – 14.0	6.64
8	HCO_3^{-} (me/l)	2.6 – 74.0	21.33
9	SAR (m mol/l)^{½}	0.0 – 13.6	2.36
10	RSC (me/l)	3.28 – 18.03	10.98

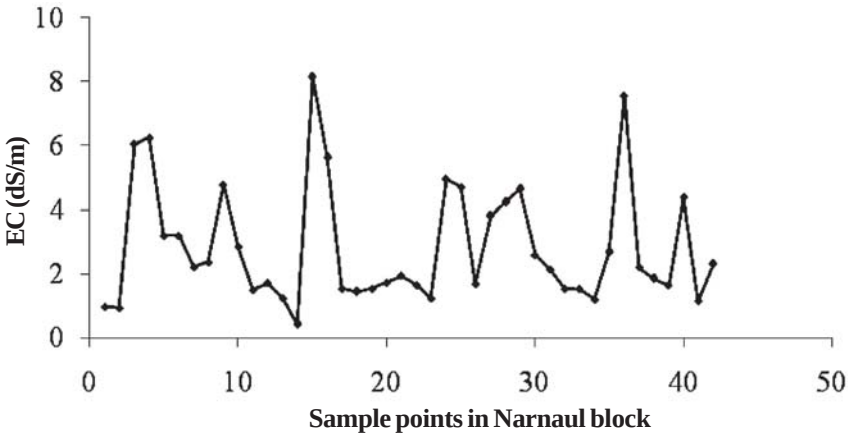
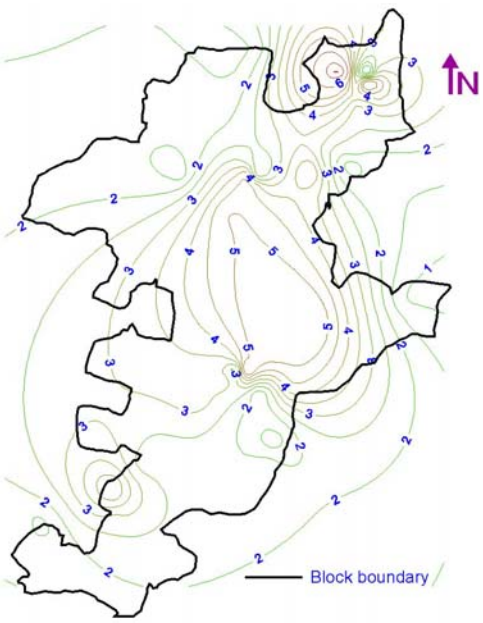
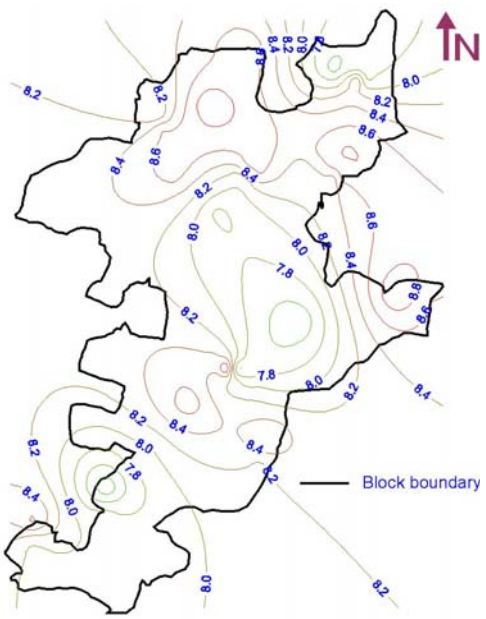


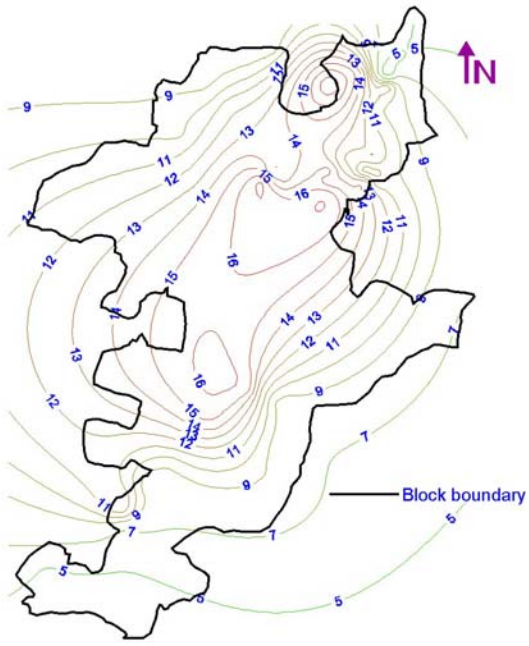
Fig.3.25: Spatial variability in EC of the collected samples



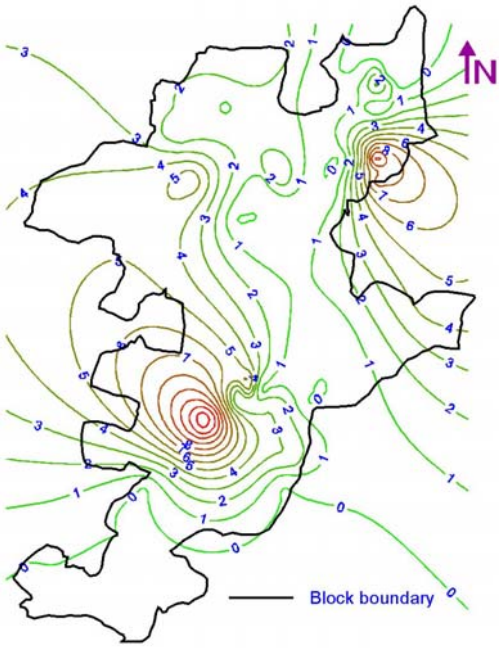
a) Contour map of EC of groundwater



b) Contour map of pH of groundwater



c) Contour map of SAR of groundwater



d) Contour map of RSC of groundwater

Fig.3.26: Contour map of water quality parameters (EC, pH, SAR, RSC) of groundwater in Narnual block of Mahendragarh district

The average chemical composition and related quality parameters in different EC ranges for Narnual block are given in Table 3.11. The distribution of salts in the groundwaters was varying as shown in Fig.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 irrigation water except in the range 4-5 dS/m. The maximum number of 32 samples was concentrated in EC class of 1-2 and followed by 10 samples in EC class of 0-1 dS/m. It is seen that 89.47 per cent samples were found upto EC of 3 dS/m, whereas, there was no sample above EC of 6 dS/m.

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

EC classes (dS/m)	No. of samples	% of samples	Na	Ca	Mg	CO_3 (me/l)	HCO_3	Cl	RSC	SAR (m mol/l)^{½}
0-1	10	17.54	8.62	1.03	1.77	0.32	4.98	5.24	2.66	7.56
1-2	32	56.14	15.28	1.63	2.29	1.08	6.70	9.15	4.11	11.55
2-3	9	15.79	20.14	3.33	3.62	1.60	7.13	16.31	3.47	11.67
3-4	3	5.26	20.74	5.83	8.07	0.00	4.20	28.67	0.00	8.25
4-5	2	3.51	21.19	4.20	9.10	0.20	5.80	33.60	0.00	8.24
5-6	1	1.75	36.23	3.6	7.9	0.4	10.8	38	0	15.11

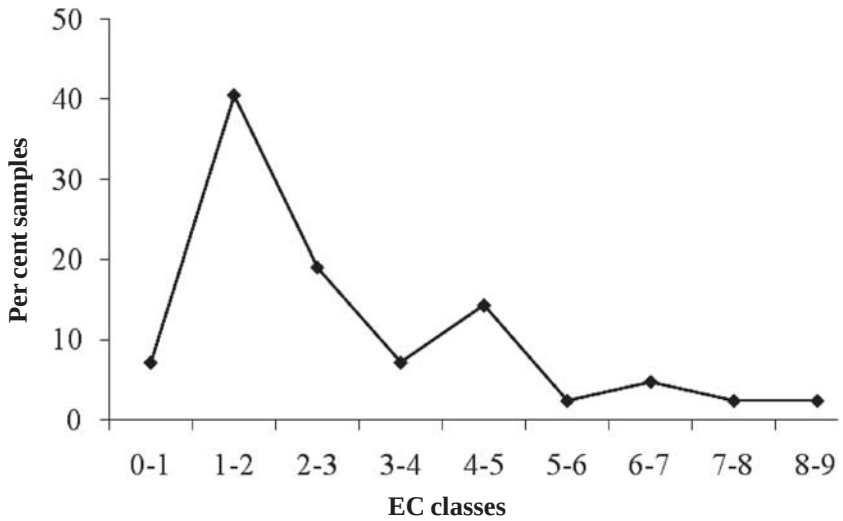


Fig.3.27: Per cent samples in different EC classes

In case of anions, chloride was the dominant anion with maximum value of 74.0 me/l was observed in village Golawala and minimum 2.6 me/l was recorded in village Kuksi. Bicarbonate

(HCO_3^-) ranged from 1.8 to 14.0 me/l, the maximum value was observed in the water samples of village Kakroli and minimum value was found in village Kuksi. The average values for CO_3^{-2}, HCO_3^- and Cl^- were found to be 0.67, 6.64, 21.33 me/l, respectively and the anions were in order of $Cl^- > HCO_3^- > CO_3^{-2}$. The concentration of the anions in different classes of EC is given by Fig.3.28.

In cations, sodium concentration varied widely from 3.95 to 53.14 me/l, minimum value was observed in village Kuksi and maximum value was observed in Golawala followed by magnesium (0.6 to 16.1 me/l) and calcium (0.6 to 10.9 me/l). Average values for Na^+, Mg^{+2} and Ca^{+2} were 21.36, 4.85 and 3.22 me/l, respectively. The concentration of the cations in different classes of EC is given by Fig.3.29. It is observed that cations in groundwaters followed the order $Na^+ > Mg^{+2} > Ca^{+2}$.

According to AICRP classification, the maximum samples were found in high SAR saline quality (26.2 per cent) category followed by good quality (19.0 per cent) (Fig.3.30). The per cent samples in high alkali, marginally saline, alkali, marginally alkali and saline classes were 16.7, 14.3, 14.3, 7.1 and 2.4 per cent, respectively. The highest number of samples (11) were found in high SAR saline class followed by 8 and 7 in good and high alkali classes, respectively. However, the minimum number (1) of sample was found in saline class.

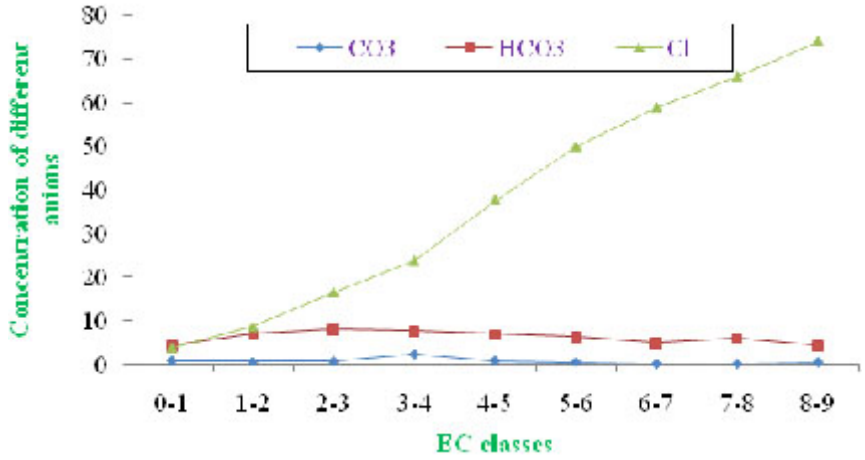


Fig.3.28: Anions (CO_3, HCO_3, Cl) concentration in different EC classes of Narnual block

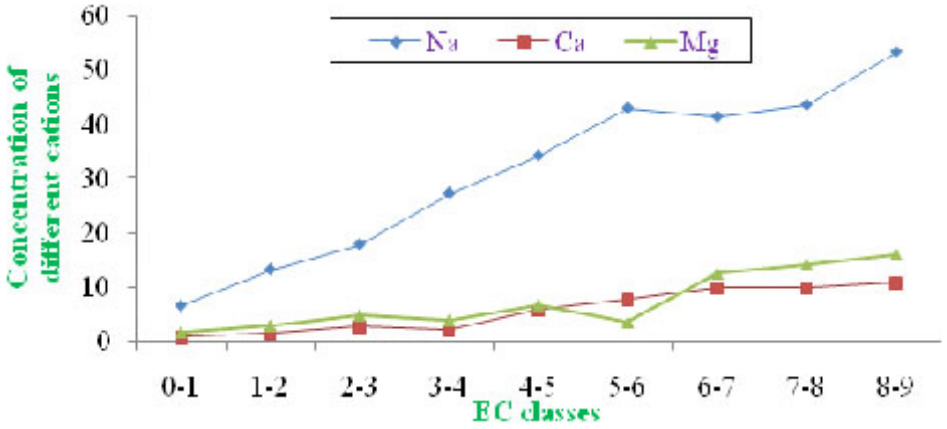


Fig.3.29: Cations (Na, Ca, Mg) concentration in different EC classes of Narnual block

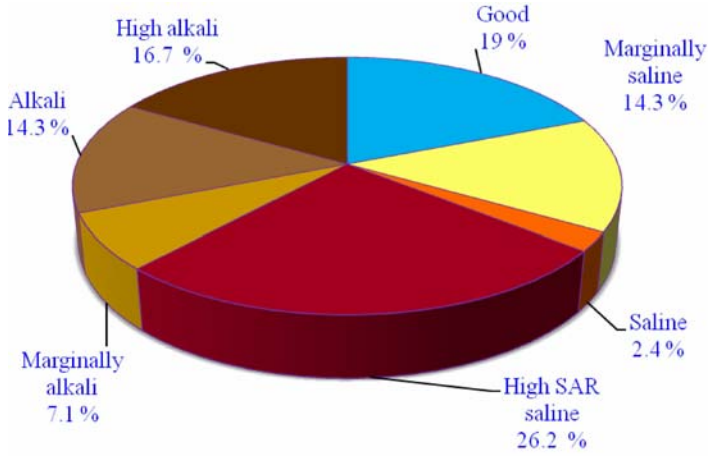


Fig.3.30: Quality of groundwater (per cent) in Narnaul block of Mahendragarh district

4. GROUNDWATER QUALITY OF MAHENDRAGARH DISTRICT

4.1 SAMPLING POINTS IN THE DISTRICT

Total 299 water samples have been collected with the spatial points through GPS for all the blocks of Mahendragarh district and a location map for the these sampling points is 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 through all the blocks except some parts of Nangal Chaudhary and Narnual blocks due to presence of small hills in that area.

4.2 ELECTRICAL CONDUCTIVITY (EC)

In Mahendragarh district, EC ranged from 0.44 to 8.15 dS/m with a mean of 2.85 dS/m. The lowest electrical conductivity of 0.44 dS/m in water samples was observed in village Kuksi. The study revealed that 88.09 per cent of the samples showed EC values less than 5 dS/m and the maximum value of EC was found as 8.15 dS/m in village Golawala in the north-east corner of the block. It is observed from the contour map (Fig.4.2) that the EC of groundwater is high in the middle and upper (Northern) part of the block where red colour contour are shown. In the most part of the district, EC of groundwater remained in the range of 2-3 dS/m.

4.3 SODIUM ADSORPTION RATIO (SAR)

In Mahendragarh district, SAR ranged from 0.54 to 26.02 (m mol/l)$^{1/2}$ with a mean of 10.41 (m mol/l)$^{1/2}$. The lowest SAR of 0.54 (m mol/l)$^{1/2}$ in water samples was observed in village Palri in Mahendragarh block and the maximum value of SAR was found as 26.02 (m mol/l)$^{1/2}$ in village Bajar in Ateli block. It is observed from the contour map (Fig.4.3) that the SAR of groundwater is highly variable and higher values of SAR is observed in the patches through red colour in the contour map. In the most part of the district, SAR of groundwater remained in the range of 9-11 (m mol/l)$^{1/2}$.

4.4 RESIDUAL SODIUM CARBONATE (RSC)

In Mahendragarh district, RSC ranged from nil to 14.72 me/l with a mean of 2.67 me/l. The highest RSC of 14.72 me/l in water samples was observed in village Bhurjat of Mahendragarh block. It is observed from the contour map (Fig.4.4) that the RSC of groundwater is high in the different patches though out the district where red colour contour are shown. In most parts of the

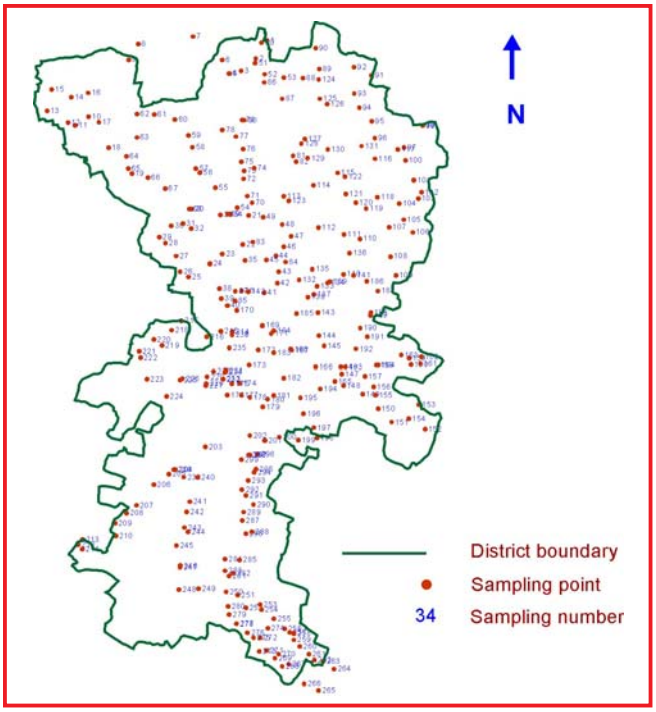


Fig.4.1: Location map of the sampling points in Mahendragarh district

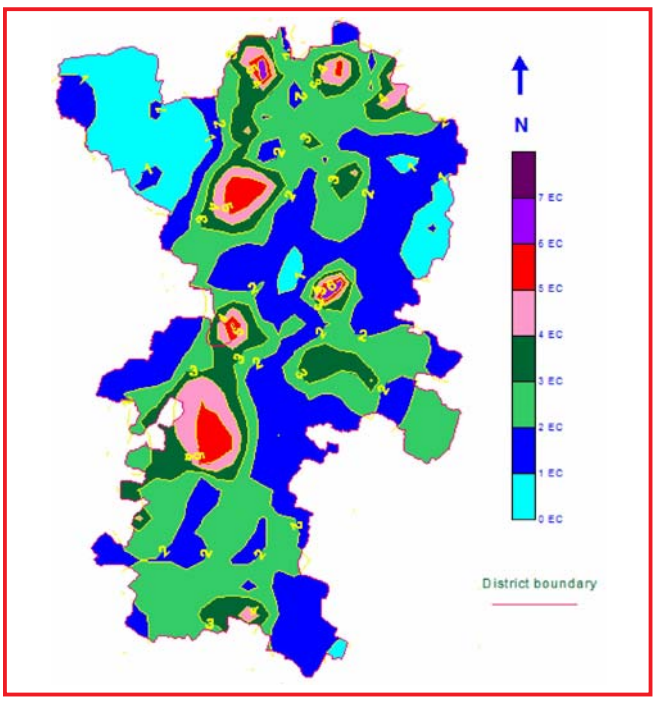


Fig.4.2: Contour map of EC of groundwater in Mahendragarh district

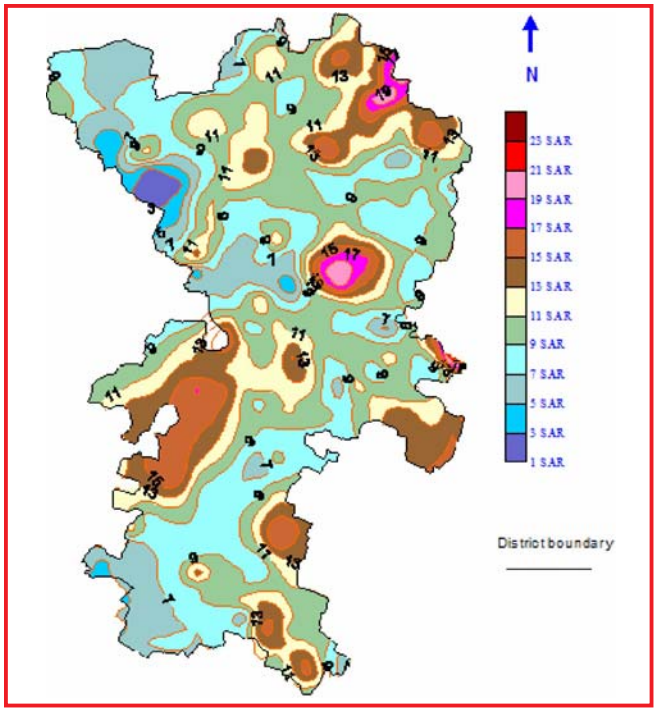


Fig.4.3: Contour map of SAR of groundwater of Mahendragarh district

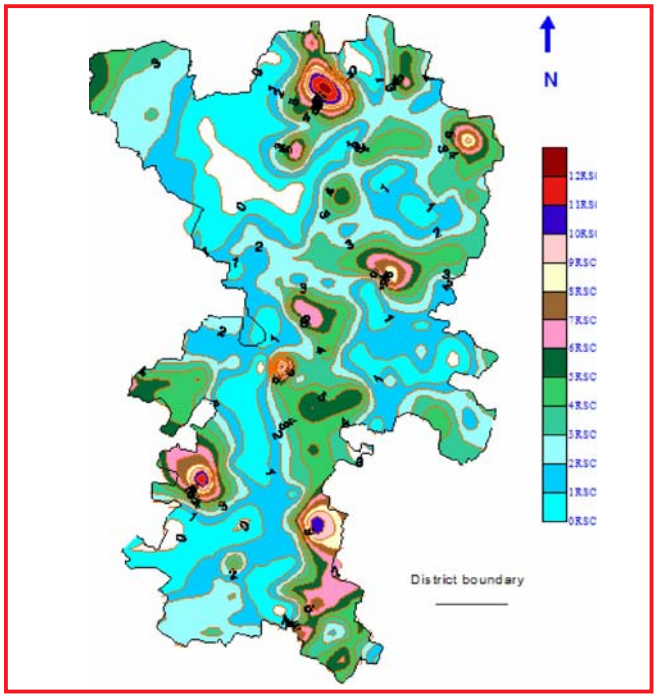


Fig.4.4: Contour map of RSC of groundwater quality in Mahendragarh district

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

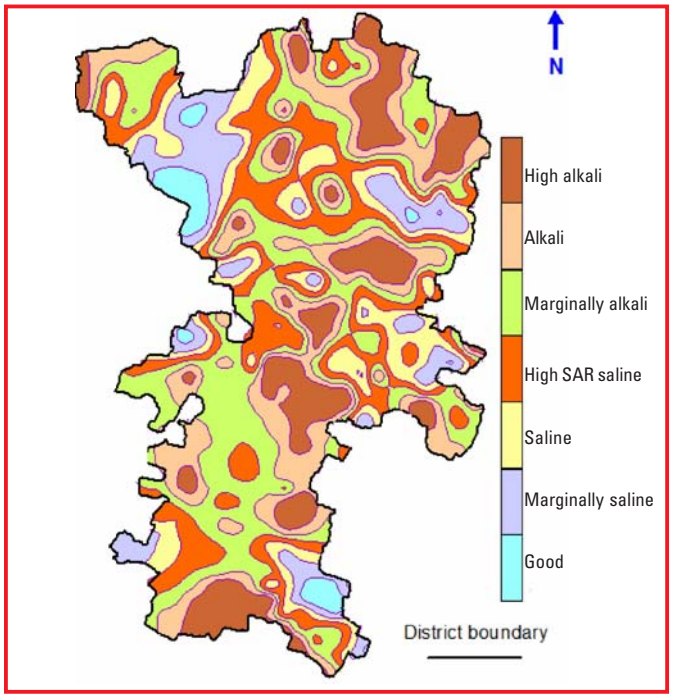


Fig. 4.6 : Contour map of groundwater quality of Mahendragarh district

district, RSC of groundwater remained in the range of 2-3 me/l.

4.5 CLASSIFICATION OF GROUNDWATER

Overall in Mahendragarh district, 93, 62, 38, 37, 36, 18 and 15 samples were found in highly alkali, good, marginally alkali, marginally saline, high SAR saline, saline and alkali, respectively

(Table 4.1). Most of the groundwater in the district was under the category of high alkali (31.2 per cent). Decreasing trend of the water quality under different categories is shown in Fig.4.5. For the plot of water quality contour in the Mahendragarh district, the different quality of groundwater has given different colours, as shown in the Fig.4.6. From the figure, it is observed that high alkali quality groundwater is expanded over a lagre portion of the district. Saline water is very limited, can be seen in small patches of yellow colour.

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

AICRP Classification	Number of samples	Per cent sample
Good	62	20.7
Marginally saline	38	12.7
Saline	18	6.0
High SAR saline	36	12.0
Marginally alkali	37	12.4
Alkali	15	5.0
High alkali	93	31.2
Total	299	

5. GROUNDWATER MANAGEMENT STRATEGY

5.1 STRATEGIES FOR GROUNDWATER MANAGEMENT

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 Mahendragarh 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.
- Reduction in canal water supply by about 25 percent between mid July to mid September and December to February in the districts having sufficient water or waterlogged area. The canal water, thus saved, should be diverted to water deficit areas and lift canal system like Mahendragarh district.
- Adoption of recommended cropping practices in flood affected areas under existing situation during the post-monsoon period.
- Forming water users' associations/societies for effective and efficient management of available water resources.
- Lining of remaining canals and water courses and their periodic maintenance for checking seepage losses.
- Constructing storage reservoirs in the foothill areas of the district at appropriate sites.
- 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-horti, agro-forestry plantation and grasses (in wind erosion area) for which adequate subsidy may be provided.
- Introduction of groundwater legislation to regulate the groundwater exploitation as per potential available and to check further growth of tubewells in district.
- Diversification of cropping pattern to effect reduction in water requirement.
- Exploring the possibility of artificial groundwater recharge during monsoon period in the areas facing groundwater decline.

5.2 RECLAMATION OF SODIC SOIL AND SODIC WATER

Technology for reclamation of sodic soil and sodic water by gypsum application has been demonstrated at the famers'field since 2005 in different villages of Mahendragarh district. During the year 2008-09, the crops were irrigated with sodic water having average RSC 10 me/l through sprinkler method, whereas, in year 2009-10, it was irrigated with sodic water of average RSC 13.8 me/l through sprinkler method at village Bhurjat, Maherdragarh district. The yield of wheat crop increased significantly with the addition of increasing levels of gypsum application (Table 5.1). Both the years, wheat crop yield in 100 per cent gypsum neutralization (G_{100}) treatment increased drastically by more than 2 times of the yield obtained in no gypsum (G_0) treatment. Appreciable increase in yields was also obtained in other treatments also.

During 2008-09, as a result of previous year's demonstration, 191 farmers of this village adopted the technology for the reclamation of sodic soils and waters by applying gypsum in their fields. About 200 tons of the gypsum was used by them. Consequently, the average yield of mustard and wheat was increased by 8 to 10 quintals per ha.

During year 2009-10, the mean yield increased by 73.9, 120.5, 141.0 and 187.0 per cent, respectively, in G_{25}, G_{50}, G_{75} and G_{100} treatments as compared to control (Table 5.2) was observed. The variation in yield with respect to gypsum can be expressed by quadratic equation with a coefficient of correlation (R^2) of 0.984 (Fig.5.1). However, increase in yield from G_{50} to G_{75} is insignificant.

Table 5.1: Yields (t/ha) of wheat crop in relation to gypsum application

Treatments	Yield (t/ha)	
	Sh. Tejpal Singh Year 2008-09	Sh. Virender Singh Year 2009-10
No gypsum (G_0)	2.05	1.61
25 per cent gypsum neutralization (G_{25})	3.19	2.80
50 percent gypsum neutralization (G_{50})	3.54	3.55
75 percent gypsum neutralization (G_{75})	3.84	3.88
100 percent gypsum neutralization (G_{100})	4.17	4.62
CD (at 5%)	0.27	0.49

5.3 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

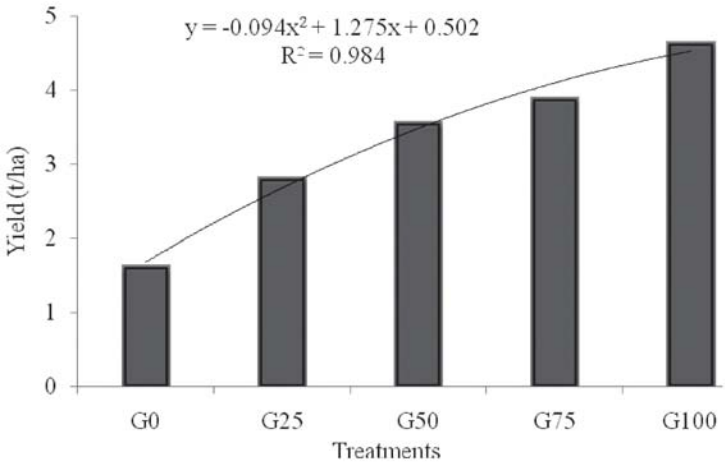


Fig.5.1: Effect of gypsum application on the yield of the wheat during the year 2009-10

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 utilising poor quality waters in 1992 for their wider applicability (Table 5.2). 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.

Table 5.2: Guidelines for using poor quality waters

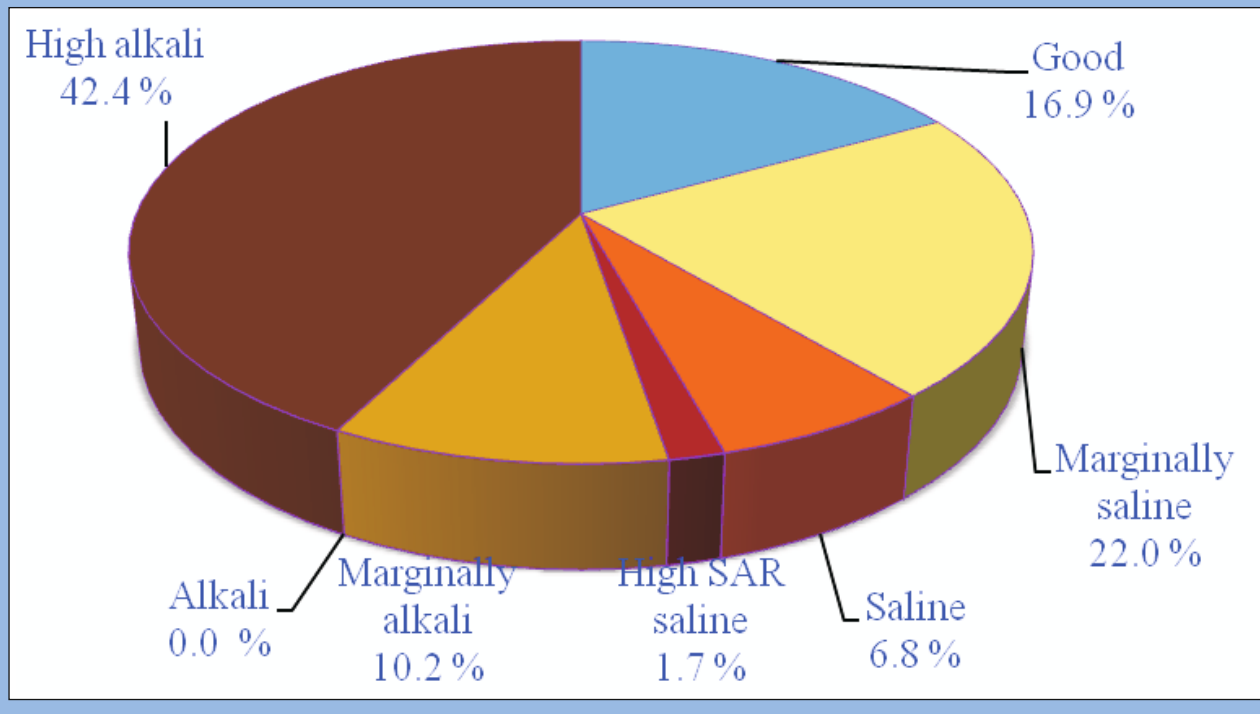
a. Saline waters (RSC < 2.5 me/l)

Soil texture (% clay)	Upper limits of ECiw (dS/m) for crops in rainfall (mm) region								
	Sensitive crops			Semi-tolerant crops			Tolerant crops		
	<350	350-550	550-750	<350	350-550	550-750	<350	350-550	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

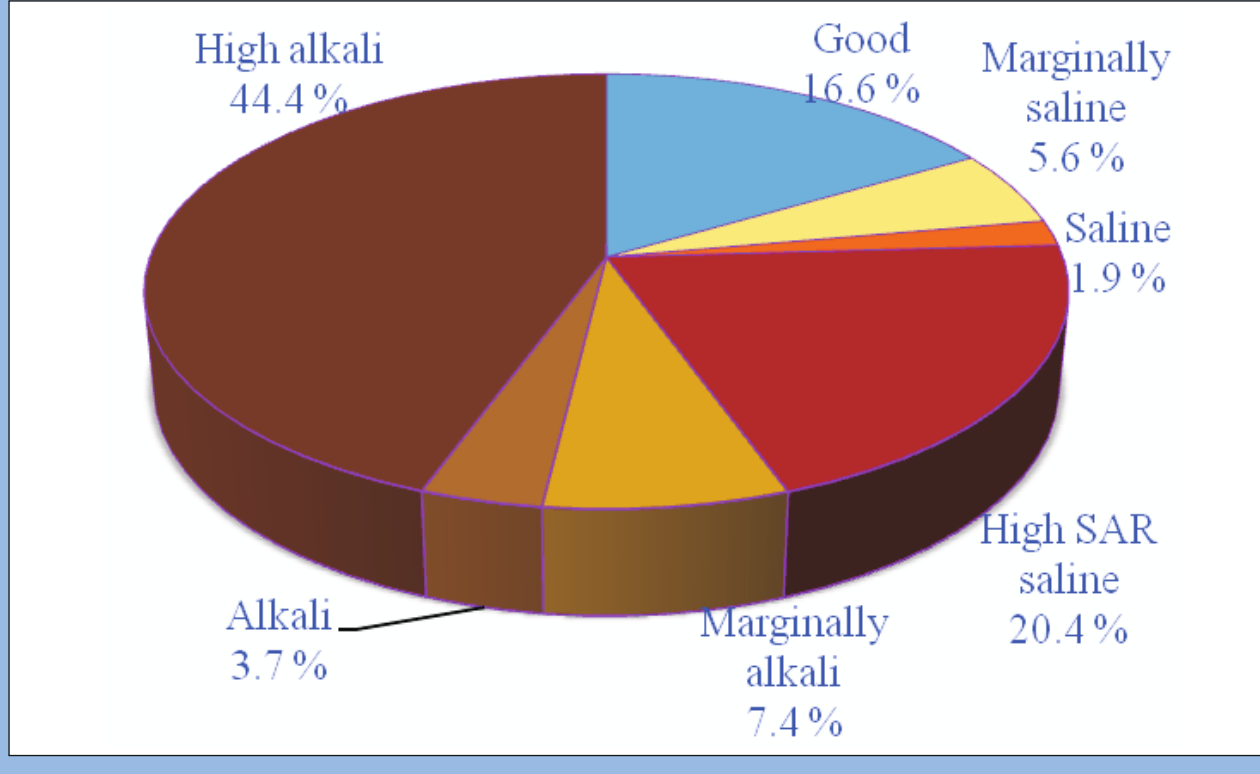
b. Sodic water (RSC > 2.5 me/l and EC_{iw} < 4.0 dS/m)

Soil texture (% clay)	SAR $(mmol/l)^{1/2}$	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	

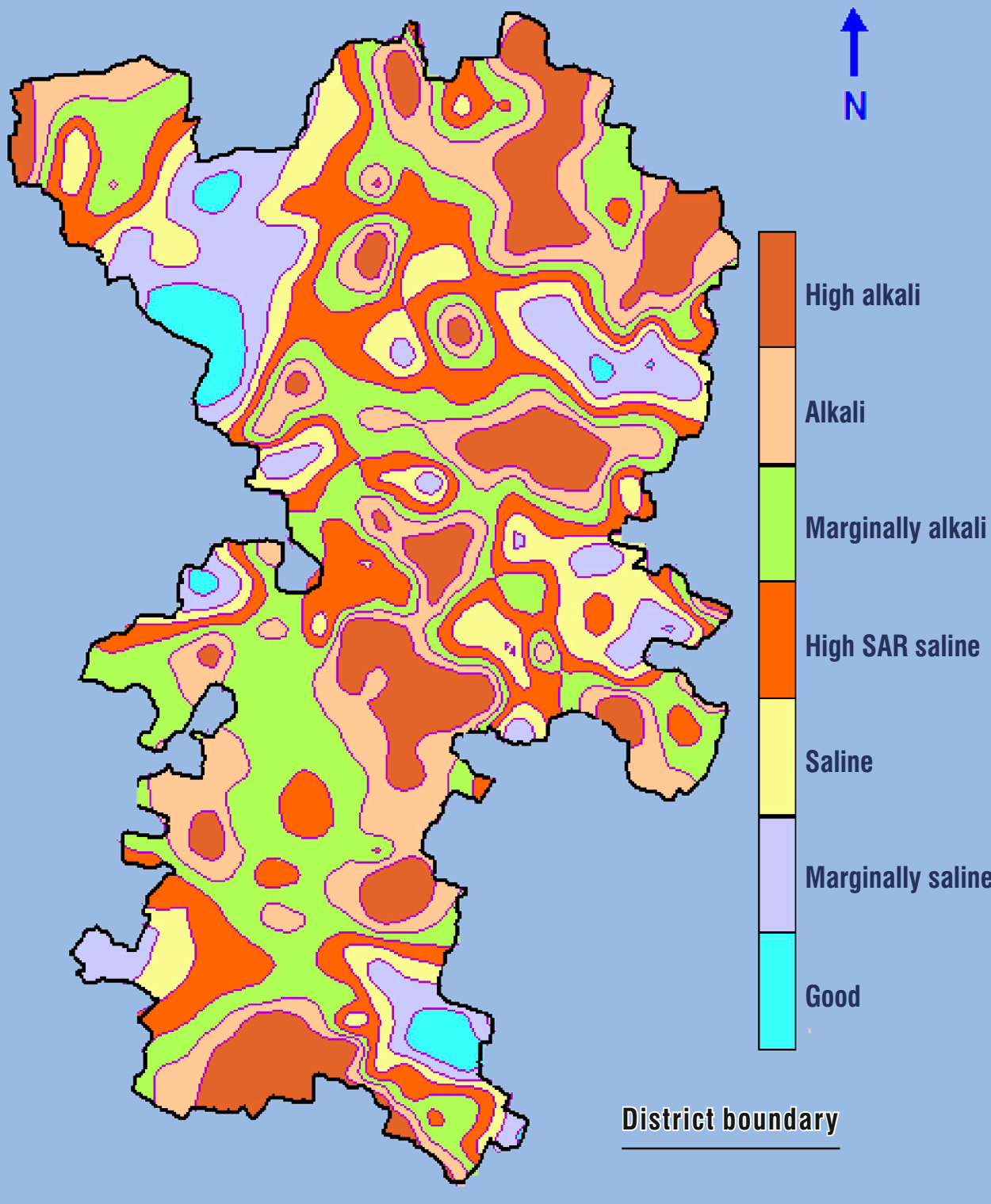
Joint recommendation of HAU, CSSRI and PAU Scientists (1992)



Quality of groundwater in Ateli block



Quality of groundwater in Kanina block



Groundwater quality of Mahendragarh district