Technical Bulletin: ICAR-AICRP (SAS&USW)/2020/02

SURVEY, CHARACTERIZATION AND MAPPING OF GROUNDWATER OF AGRA REGION AND BHARATPUR DISTRICT FOR IRRIGATION PURPOSE

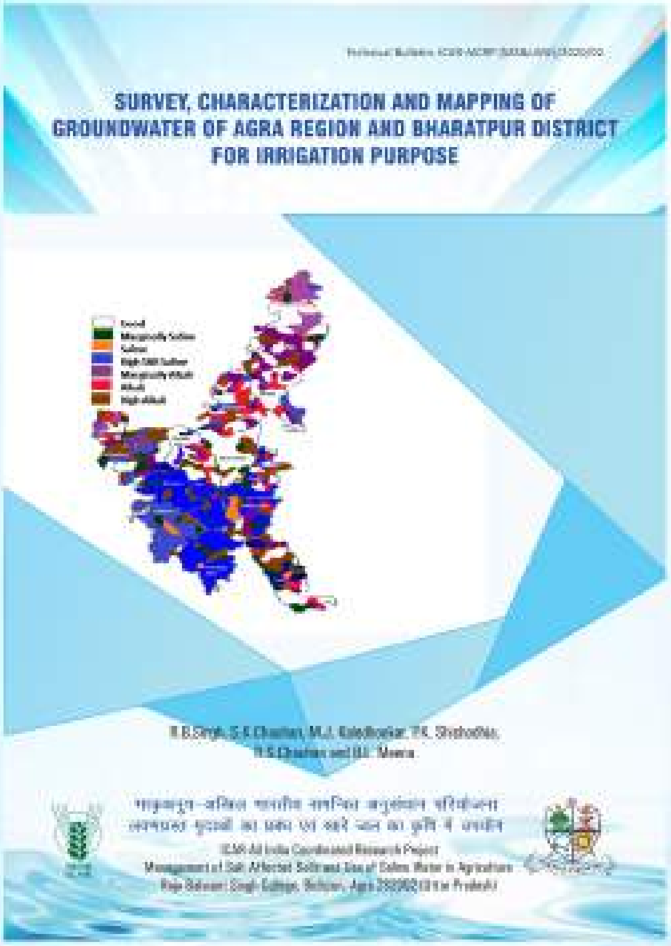
R.B.Singh, S.K.Chauhan, M.J. Kaledhonkar, P.K. Shishodhia,
R.S.Chauhan and B.L. Meena

भाकृअनुप–अखिल भारतीय समन्वित अनुसंधान परियोजना
लवणग्रस्त मृदाओं का प्रबंध एवं खारे जल का कृषि में उपयोग

ICAR-All India Coordinated Research Project
Management of Salt Affected Soils and Use of Saline Water in Agriculture
Raja Balwant Singh College, Bichpuri, Agra-282002 (Uttar Pradesh)

Citation:

Singh R.B., Chauhan S.K., Kaledhonkar M.J., Shishodhia P.K., Chauhan R.S. and Meena B.L. (2020) Survey, Characterization and Mapping of Groundwater of Agra Region and Bharatpur District for Irrigation Purpose. ICAR-AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, R.B.S. College, Bichpuri, Agra. Technical Bulletin: ICAR-AICRP (SAS&USW)/2020/02, 76p.



Cover Photo : Groundwater quality map of Agra district (2017)

Published by:

All India Coordinated Research Project
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Printed By:

Aaron Media
Ground Floor-17, Super Mall
Sector-12, Karnal-132001, Haryana
Email: aaronmedia1@gmail.com

भारतीय कृषि अनुसंधान परिषद
कक्ष क्र. 101, कृषि अनुसंधान भवन–II, पूसा, नई दिल्ली – 110 012, भारत

Indian Council of Agricultural Research
Room No. 101, Krishi Anusandhan Bhavan-II, Pusa, New Delhi - 110 012, INDIA

डॉ. सुरेश कुमार चौधरी / Dr. Suresh Kumar Chaudhari
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Deputy Director General (Natural Resource Management)

15.07.2020

Foreword

Groundwater is the most preferred source of irrigation water and about 89% of total annual groundwater extraction is used for irrigation purpose. However, unplanned and non-scientific development of groundwater resource has resulted in long-term decline of groundwater levels and consequent higher energy consumption for lifting water from deeper aquifers. In recent years, there is growing concern about groundwater contamination and its quality degradation due to geogenic and anthropogenic reasons. With very limited amount of good quality irrigation water in semi and arid regions, farmers are compelled to use poor quality groundwater for irrigation purpose. Indiscriminate use of such waters in long-term deteriorates soil quality, adversely affects crop yields and limits choices of crops. Thus it is imperative to address the key issues such as depleting groundwater storage and quality, suitability of groundwater for irrigation purpose on basis of quality parameters and sustainable management of poor quality groundwater for irrigation in long-term.

The Agra centre of the AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture (SAS&USW), located in RBS College, has conducted a comprehensive survey for mapping of groundwater quality in 8 districts, namely Agra, Mathura, Aligarh, Etah, Firozabad, Mainpuri and Etawah in the state of Uttar Pradesh and Bharatpur in the state of Rajasthan. In general good, saline and alkali ground water in different districts vary from 17 to 78%, 3.6 to 63% and 16 to 60%, respectively. Further, it is observed that good quality groundwater is dominated in Etah, Mainpuri and Etawah district. Alkali groundwater is dominated in Aligarh and Firozabad district while saline ground water is dominated in Agra, Mathura and Bharatpur district. The centre also conducted different experiments on use of saline and alkali groundwater for crop production and identification tolerant crops/crop varieties for saline and alkali environments.

I am very pleased to know that scientists of AICRP on SAS&USW, RBS College, Agra has prepared groundwater quality maps, developed strategies for management of poor quality (saline/ alkali) groundwater and documented information in systematic manner to increase agricultural production in the region despite of constraint of irrigation water quality. I am sure, this publication will be useful for researchers, policy makers and other stakeholders involved in sustainable management of groundwater resources and overall agricultural development.

15/7/20
(S.K. Chaudhari)

Phone : +91-11-2584 8364
Fax : +91-11-2584 8366

E-mail : ddg.nrm@icar.gov.in
Website : www.icar.org.in

ACKNOWLEDGEMENTS

We are indebted to Dr. T. Mahapatra, Secretary, and Department of Agricultural Research & Education and Director General, Indian Council of Agricultural Research (ICAR) and Dr. S. K. Chaudhari, Deputy Director General (Natural Resource Management), ICAR, New Delhi for all necessary support and guidance to AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture (AICRP on SAS&USW), as a whole and centre at RBS College, Agra as specific. It was possible for centre to undertake survey, characterization and mapping of ground water quality for eight districts of Agra region because of constant support and encouragement from the Council. We are also grateful to Dr. Adul Islam, ADG (SWM) for his keen interest in the work.

Dr. P.C. Sharma, Director, ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI), Karnal remained source of inspiration to us and provided valuable guidance during this endeavor. We are grateful to him as he always encouraged us for this compilation. We also express gratitude towards all former Directors (Drs. D.R. Bumbla, J.S.P. Yadav, I.P. Abrol, N.T. Singh, N.K. Tyagi, Gurbachan Singh and D.K. Sharma) of ICAR-CSSRI and former Project Coordinators (Drs. R.K. Gupta, P.S. Minhas, S.K. Gupta and S.K. Ambast) of the scheme who nurtured and pursued dream of salinity and sodicty research at national level. Gratitude is also expressed to Dr Y.V.S.Chauhan, Principal, RBS College, Agra for providing all necessary support and infrastructure for executing voluminous work survey and chemical analysis of groundwater samples.

The authors are very much thankful to all staff of AICRP on SAS&USW, Agra namely Dr C.P.S. Chauhan, Dr. A.K. Singh, Dr A.K. Goyal, Dr R.K. Vishnoi, Dr Bhisam pal and Dr Bijendra singh who were involved in collecting groundwater samples from different districts and all laboratory staff namely Mr Sarnam Singh, Mr Vijendra Singh, Mr N.P. Pachauri, Mr Devi Singh and Mr Kishan Singh who were engaged in analysis of water samples. Thanks for also due to Shri Pradeep, Technician, and Project Coordinating Unit at ICAR-CSSRI for providing all possible help during compilation of manuscript.

Many directly and indirectly helped our efforts of groundwater quality surveys and field experimentation on use of saline and alkali water for irrigation. The progressive farmers willingly came forward for demonstrations of technologies under Operational Research Project. They helped lot in changing overall perception about saline and alkali water use in the region. We thank all contributors who remained our well wishers. Thank are also due to individuals who helped improvement of document through their critical comments.

Authors

CONTENTS

1. GROUNDWATER QUALITY OF AGRA DISTRICT

1.1 Introduction

Agra district is a globally known for Taj Mahal which is one the Seven Wonders of the World. It is important tourist place and several national and international tourists visit Agra every year. The geoghaphical area of Agra district is 4027 km^2. It is located in Indo-Gangetic plain and is part of Agro ecological region 4 (Northern plain, Hot semi-arid eco-region with alluvium derived soils). The district has 15 blocks namely Fatehpur Sikri, Akola, Achhnera, Bichpuri, Jagner, Sainya, Kheragarh, Barauli Ahir, Khandauli, Shamsabad, Bah, Pinahat, Fatehabad, Etmadpur, Jaitpur Kalan. The location map of the district is shown in Fig. 1.1. The district occupies marginal alluvial plain of Yamuna and Chambal Rivers.

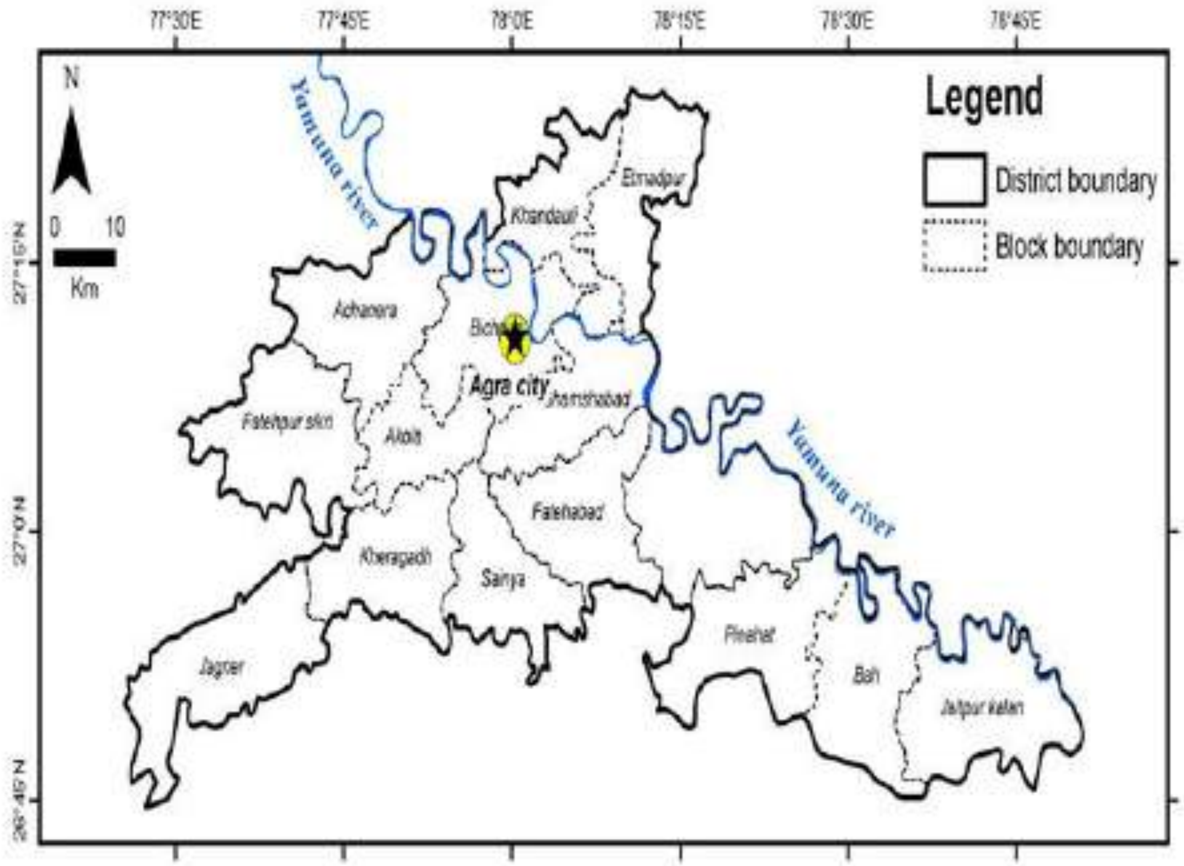

Fig. 1.1: Location of Map of Agra district showing various blocks (Source: Kumar et al. 2017)

The area is more or less flat and gently sloping from northwest to southeast. The altitude of the area generally varies from 120 to 190 m mean sea level. Geomorphologically, the district may be divided into four units' *viz.* alluvial plains, ravines, structural valleys and structural hills. The soils are predominantly alluvial in origin mainly sandy loam, loam and clayey loam. The district has forest cover of 356.91 km^2, net sown area of 2827.91 km^2 and gross sown area of 4246.94 km^2 with cropping intensity of 150 percent. The main sources of irrigation are tubewells/ bore wells, canals and ponds. The net irrigated area is 258700 ha and gross irrigated area is 283645 ha. The irrigation intensity is around 110 percent. The major crops of the district in *kharif* season are bajra (115736 ha with the productivity of 16.68 q/ha), rice (5215 ha with the productivity of 21.59 q/ha), sorghum (4289 ha with the productivity of 7.55q/ha), a*rhar* (827 ha with the productivity of 6.95 q/ha), *urd* (179 ha with the productivity of 6.37 q/ha), *til* (1885 ha with the productivity of 1.98 q/ha). In *rabi,* major crops are wheat (140427 ha with the productivity of 37.03 q/ha), mustard (52639 ha with the productivity of 17.41 q/ha), potato (56303 ha with the productivity of 263.77 q/ha), barley (7058 ha with the productivity of 32.98q/ha), gram (1281 ha with the productivity of 18.57q/ha) and other vegetables. The total consumption of NPK (90.53, 37.34 and 5.09 kg/ha) was 132.95 kg/ha (KVK-Agra, 2015).

The climate wise Agra comes under semi-arid region. It has mild winters, hot and dry summers and a monsoon season. In this tract the rainfall is received from South-West monsoon. The annual normal rainfall of Agra based on 51 years data (1965-2015) of meteorological observatory of ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Agra, Uttar Pradesh is calculated as 671.58 mm. It ranged from 241.4 mm to 1235.1 mm. Similarly, annual rainy days ranged from 15 to 55 with average 38. The monsoon season is from June to September and August is the wettest month. Around 80 percent of the total rainfall is received during monsoon season. The hottest month is June with average mean temperature of 34.85^{0}C followed by May with 34.5^{0}C. The coldest month is January with average mean temperature of 14.8^{0}C followed by December with 16.15^{0}C. Average maximum temperature is 34.85^{0}C while average minimum temperature is 16.2^{0}C. The Annual normal Potential Evapo-transpiration (PET) of the district is 1467.2 mm. The maximum PET occurs in the month of May and June as 208.3 mm and 204.4 mm, respectively.The aquifer system is by and large of two tiers and mainly constituted of sand and gravel up to maximum explored depth of 231 m bgl. In the marginal alluvial plains are present in the south-western part of the district and aquifer system is mainly constituted by the joints, fractures in sandstones/quartzites and overlying alluvium/weathered mantle. Major water bearing formations are sand, gravel, fractured sandstone/ quartzite, weathered mantle. Depth to water table ranges from 2.19 to 45.58 m during pre-monsoon season while it ranges from 1.10 to 46.34 m during post monsoon season. As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Agra district is assessed as 91226.49 ha m. The annual extractable groundwater resource is assessed as 84758.50 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 83464.26 and 7654.20 ha m. Thus existing gross annual ground water draft for all uses is 91118.45 ha m and the stage of groundwater extraction for Agra district is 107.50 per cent. Among different blocks of Agra district, Bah, Jagner and Kheragarh are semi-critical; Achhnera and Akola are critical and Barauli Ahir, Bichpuri, Etmadpur, Fatehabad, Fatehpur Sikri, Khandauli, Saiya and Shamsabad are over-exploited. The Pinahat and Jaitpur Kalan are safe blocks.

The surface water in the form of Yamuna River is also polluted because of major cities such as Delhi and its suburbs exist on upstream side. Groundwater quality in the region varies spatially and it is not suitable for drinking purpose at many places. Groundwater is important source for irrigation. However its quality is not good enough for agriculture also. Therefore, survey, characterization and mapping of groundwater quality of the district is very much essential for better irrigation planning for agriculture purpose.

1.2 Groundwater Quality Survey, Characterization and Mapping

The groundwater quality survey, characterization and mapping for Agra were done during 1975-1979 for first time and groundwater quality map was prepared. Over the years, the district depended on groundwater for irrigation purpose and groundwater extraction has also increased and it has reached to 107.50 per cent. In view of this background, it became important to assess spatial changes in groundwater quality and second survey was conducted during 2012 to 2017. Fifteen blocks of the district viz Fatehpur Sikri, Akola, Achhnera, Bichpuri, Jagner, Sainya, Kheragarh, Barauli Ahir , Khandauli, Shamsabad, Bah, Pinahat, Fatehabad, Etmadpur and Jaitpur Kalan were surveyed and total 951 samples were collected mostly from December to March, when the maximum number of tube wells were operational for irrigation purpose. The samples were analyzed for different water quality parameters such as pH, EC, cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^{2-}, HCO^{-}_3, Cl^{-} and SO_4^{2-}). Other parameters such as SAR and RSC were calculated using basic quality parameters. The classification of water quality was done based on EC, SAR and RSC values as suggested by ICAR-CSSRI (Table 1.1). The ranges of EC, pH, SAR and RSC along with mean values for different blocks of district are presented in Table 1.2.

Table 1.1: Grouping of quality irrigation waters for irrigation in India

Quality of water	EC (dSm^{-1})	SAR (mmol/l)$^{1/2}$	RSC (me/l)
A. Good	<2	<10	<2.5
B. Saline			
i. Maginally saline	2-4	<10	<2.5
ii. Saline	>4	<10	<2.5
iii. High –SAR saline	>4	>10	<2.5
C. Alkali water			
i. .Marginally alkali	<4	<10	2.5-4
ii. Alkali	>4	<10	>4
iii. High alkali	<4>	>10	>4

Table 1.2: Ranges of different water quality parameters and corresponding mean values

Blocks	EC (dSm^{-1})		pH		RSC (meq/l)		SAR (mmol/l)$^{1/2}$	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Fatehpur Sikri	2.1-26.3	7.6	7.9-9.0	8.4	Nil-13.8	6.1	1.40-55.1	16.0
Akola	2.0-19.5	6.2	7.8-8.8	8.3	Nil-28.2	5.5	7.50-38.6	18.2
Achhnera	1.9-25.4	6.4	8.1-9.3	8.6	Nil- 9.4	2.7	5.20-52.4	18.5
Bichpuri	1.7-23.2	7.3	7.5-9.1	8.4	Nil- 8.4	2.8	6.50-37.9	18.2
Jagner	0.7-11.2	2.8	7.5-8.8	8.2	Nil- 8.2	5.0	1.00-39.2	8.70
Sainya	0.6-13.9	4.2	7.4-8.5	8.0	Nil-13.2	4.0	1.60-15.6	9.70
Kheragarh	0.8-12.0	4.0	7.8-8.6	8.5	Nil-12.2	5.2	2.50-31.3	10.3
Barauli Ahir	0.8-7.1	1.8	7.9-9.0	8.5	Nil- 9.0	3.2	1.10-16.7	6.50
Khandauli	0.9-16.7	2.7	7.1-8.9	7.8	Nil-10.0	3.7	1.60-35.2	11.2
Shamsabad	0.7-8.9	2.1	7.3-9.0	8.1	Nil-8.4	2.9	1.30-48.9	9.50
Bah	0.8-2.4	1.2	8.1-9.1	8.6	Nil-11.0	3.5	0.20-15.2	4.20
Pinahat	0.6-5.4	1.4	7.5-10.7	8.3	Nil-7.6	3.2	1.0-15.8	5.30
Fatehabad	0.7-5.9	1.7	7.8-9.5	8.6	Nil-9.8	3.9	1.40-23.0	7.40
Etmadpur	0.8-13.5	3.1	7.6-9.1	8.4	Nil-9.4	3.3	3.00-22.7	11.5
Jaitpur Kalan	0.6-3.3	1.0	8.0-9.1	8.5	Nil-9.0	2.5	1.90-13.8	4.40

**Mean RSC of the positive values*

The maximum EC 26.3 dSm^{-1} was recorded in Fatehpur Sikri followed by 25.4 dSm^{-1} in Achhnera and 23.2 dSm^{-1} in Bichpuri block. The highest RSC value 28.2 me/l was recorded in Akola block followed by 13.8 and 13.2 meq/l in Fatehpur Sikri and Jagner block, respectively. The highest SAR 55.1 (mmol/l)$^{1/2}$ was recorded in Fatehpur Sikri followed by 52.4 and 48.9 (mmol/l)$^{1/2}$ in Achhnera and Shamsabad block, respectively.

The distribution of water samples in different EC, SAR and RSC classes is presented in Table 1.3. According to EC classes, more than 50 per cent samples of Fatehpur Sikri, Akola, Achhnera and Bichpuri blocks were found in classes of more than 5.0 dSm^{-1}. In EC class < 1.5 dSm^{-1}, the maximum samples (i.e. 88.7 per cent) were found in Jaitpur Kalan followed by 84.4 per cent in Bah and 76.0 per cent in Pinahat block. More than 50 per cent samples in most of the blocks were having RSC <2.5 me/l. In category >2.5 me/l RSC more than 30 per cent samples were recorded in all blocks except Fatehpur Sikri, Akola, Achhnera and Bichpuri blocks. In case of SAR classes, the major number of samples were found in 0-10 and 10-20 $(mmol/l)^{1/2}$ classes. More than 85 per cent samples having SAR >10 $(mmol/l)^{1/2}$ were recorded in three blocks i.e. Fatehpur Sikri, Akola and Achhnera blocks.

Table 1.3: Frequency distribution of water samples in different EC, RSC and SAR classes of different blocks of Agra district

Particulars	Fatehpur Sikri (60)	Akola (40)	Achhnera(58)	Bichpuri (45)	Jagner (50)	Sainya (54)	Kheragarh(59)	Barauli Ahir(69)	Khandauli (70)	Shamsabad (68)	Bah (64)	Pinahat (50)	Fatehabad (90)	Etmadpur (73)	Jaitpur Kalan (71)
EC classes (dSm^{-1})															
0- 1.5	0.0	0.0	0.0	0.0	34.0	16.7	11.9	46.4	31.4	48.5	84.4	76.0	62.2	24.7	88.7
1.5- 3.0	3.33	25.0	25.9	24.4	36.0	35.2	37.3	46.4	40.0	30.9	15.6	20.0	30.0	41.1	6.5
3.0- 5.0	30.0	22.5	24.1	22.2	20.0	22.2	27.1	5.8	18.6	17.7	-	2.0	6.7	20.6	2.8
5.0-10.0	46.7	37.5	32.8	26.7	6.0	16.7	15.2	1.4	7.1	2.9	-	2.0	1.1	6.8	-
>10.0	20.0	15.0	17.2	26.7	4.0	9.2	8.5	-	2.9	-	-	-	-	6.8	-
RSC Classes (me/l)															
Absent	80.0	60.0	65.5	75.5	40.0	51.8	55.9	39.1	38.6	39.7	6.2	16.0	18.9	23.3	8.5
0-2.5	5.0	15.0	19.0	13.3	26.0	18.5	10.2	27.6	22.9	27.9	28.1	34.0	27.8	20.5	50.7
2.5- 5.0	3.3	10.0	10.3	6.7	10.0	13.0	11.9	17.4	22.8	22.1	50.0	34.0	30.0	31.5	38.0
5.0-10.0	8.3	10.0	5.2	4.4	14.0	14.8	20.3	15.9	15.7	10.3	14.1	16.0	23.3	24.7	2.8
>10.0	3.3	5.0	-	-	10.0	1.9	1.7	-	-	-	1.6	-	-	-	-
SAR Classes $(mmol/l)^{1/2}$															
0-10	10.0	10.0	13.8	42.2	70.0	42.6	49.1	82.6	45.7	64.7	95.3	88.0	70.0	45.2	93.0
10-20	46.7	60.0	51.7	35.5	24.0	57.4	45.8	17.4	48.6	29.4	4.7	12.0	27.8	49.3	7.00
20-30	23.3	22.5	27.6	20.0	4.0	-	3.40	-	4.30	4.40	-	-	2.20	5.50	-
30-40	18.3	7.5	5.2	2.2	2.0	-	1.70	-	1.40	-	-	-	-	-	-
>40	1.7	-	1.7	-	-	-	-	-	-	1.5	-	-	-	-	-

The cationic order Na>Mg>Ca>K was found in all the blocks whereas anionic order $Cl>SO_4>HCO_3>CO_3$ was also found in all the blocks except in Barauli Ahir block ($SO_4>Cl>HCO_3>CO_3$) as shown in Fig. 1.2 a to Fig. 1.2e.

Nitrate: The nitrate was detected in only Fatehpur Sikri and Barauli Ahir block in 15.0 and 4.3 per cent samples, respectively. Out of those samples, fifty per cent samples, respectively, were found in both 0-2.5 class and 2.5-5.0 me/l class in Fatehpur Sikri block whereas all samples (100 per cent) in Barauli Ahir block were found in 0-2.5 class. In remaining blocks no sample with nitrate presence was found (Table 1.4).

Fluoride: Most of the samples (>85 percent) in all surveyed blocks were under in 0-2.5 ppm fluoride class, whereas in Bichpuri, Sainya, Kheragarh and Bah blocks, 100 per cent samples were found in 0-2.5 ppm fluoride class. Only three blocks have more than 10 per cent samples in 2.5- 5.0 ppm fluoride class. (Table 1.5). The distribution of water samples in different water quality classes as given in Table 1.6.

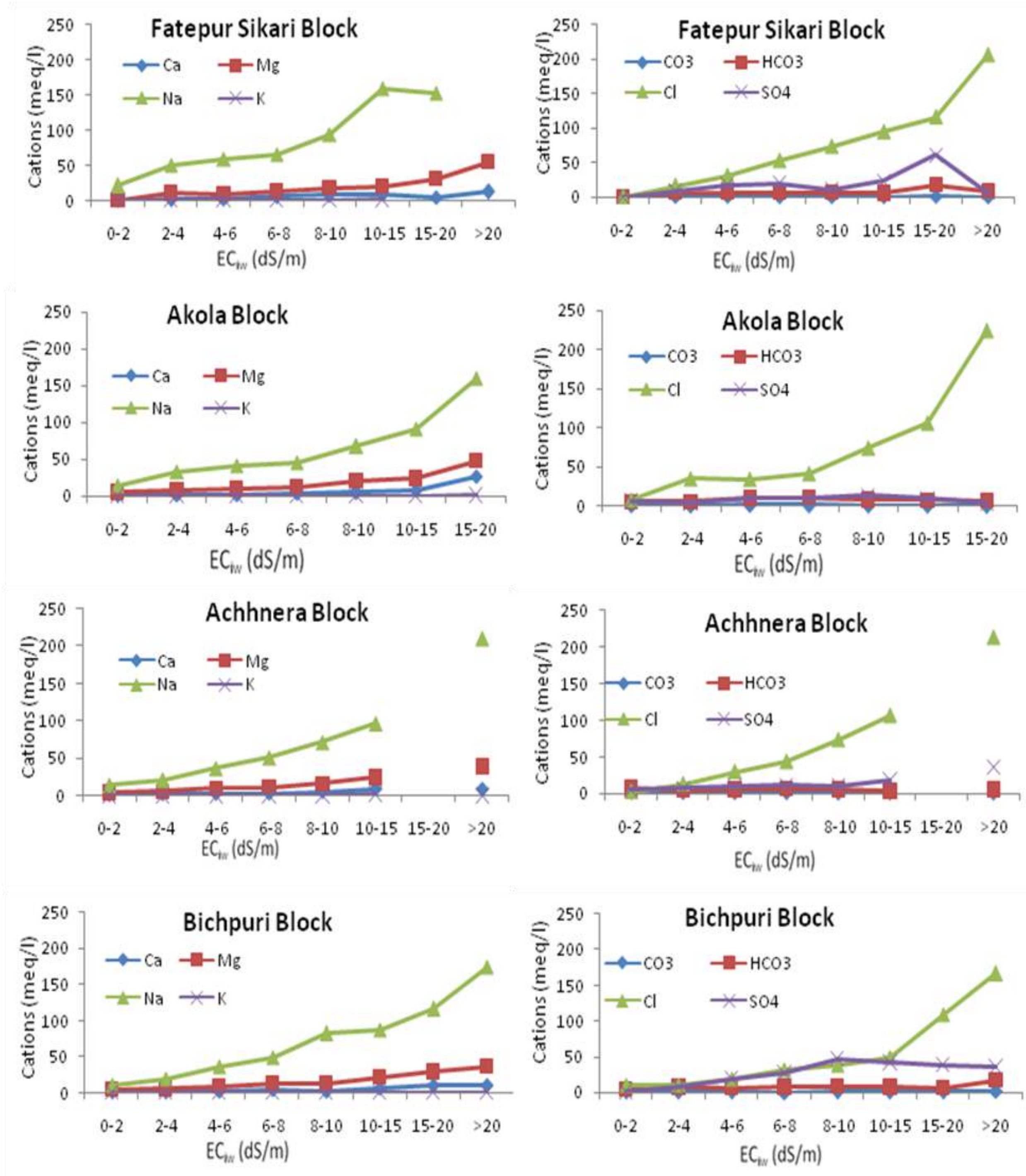

Fig. 1.2a: Cationic and anionic composition with respect to EC classes of Fatehpur Sikri, Akola, Achhnera and Bichpuri blocks of Agra district

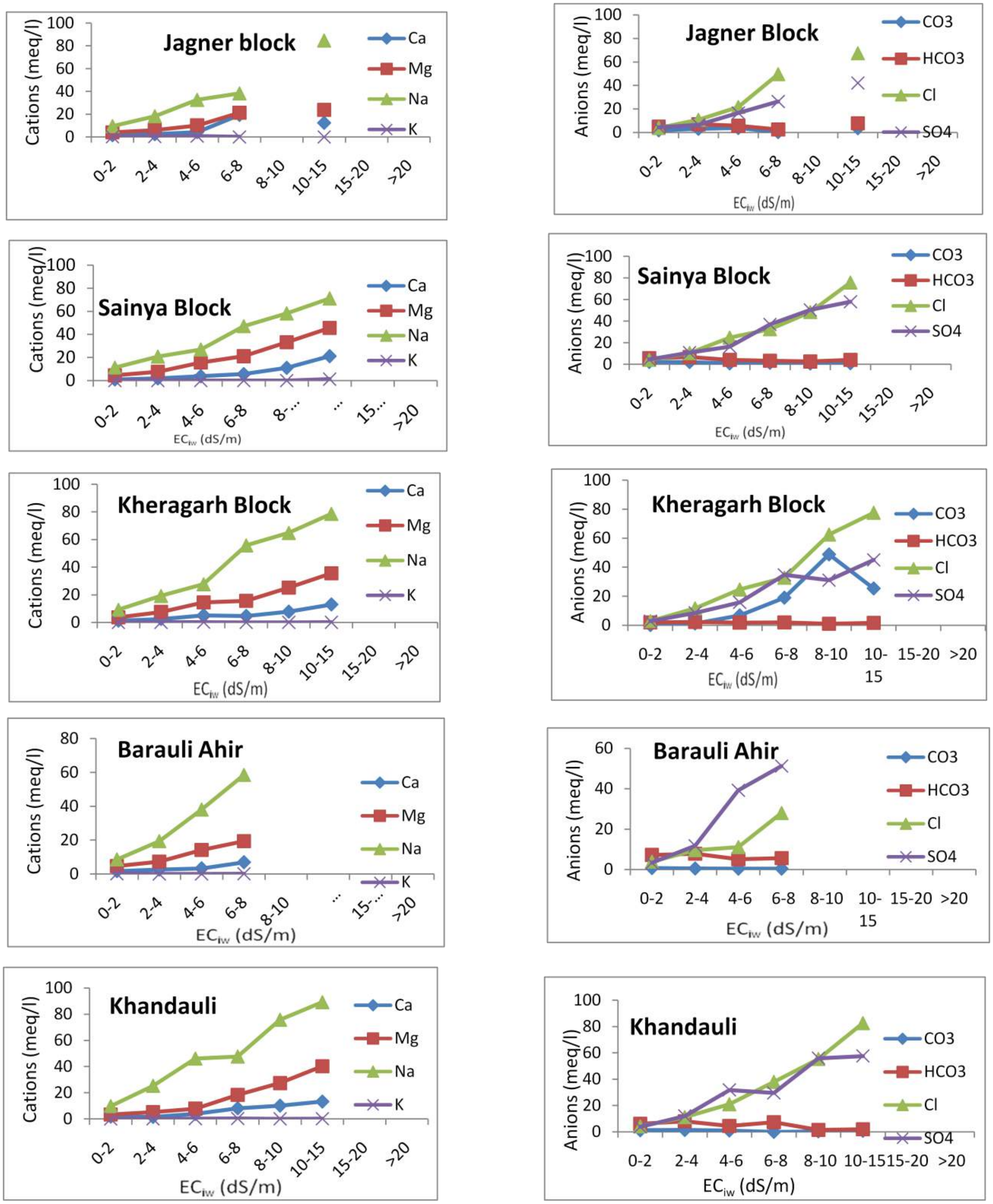

Fig. 1.2b: Cationic and anionic composition with respect to EC classes of Jagner, Sainya, Kheragarh, Barauli Ahir and Khandauli blocks of Agra district

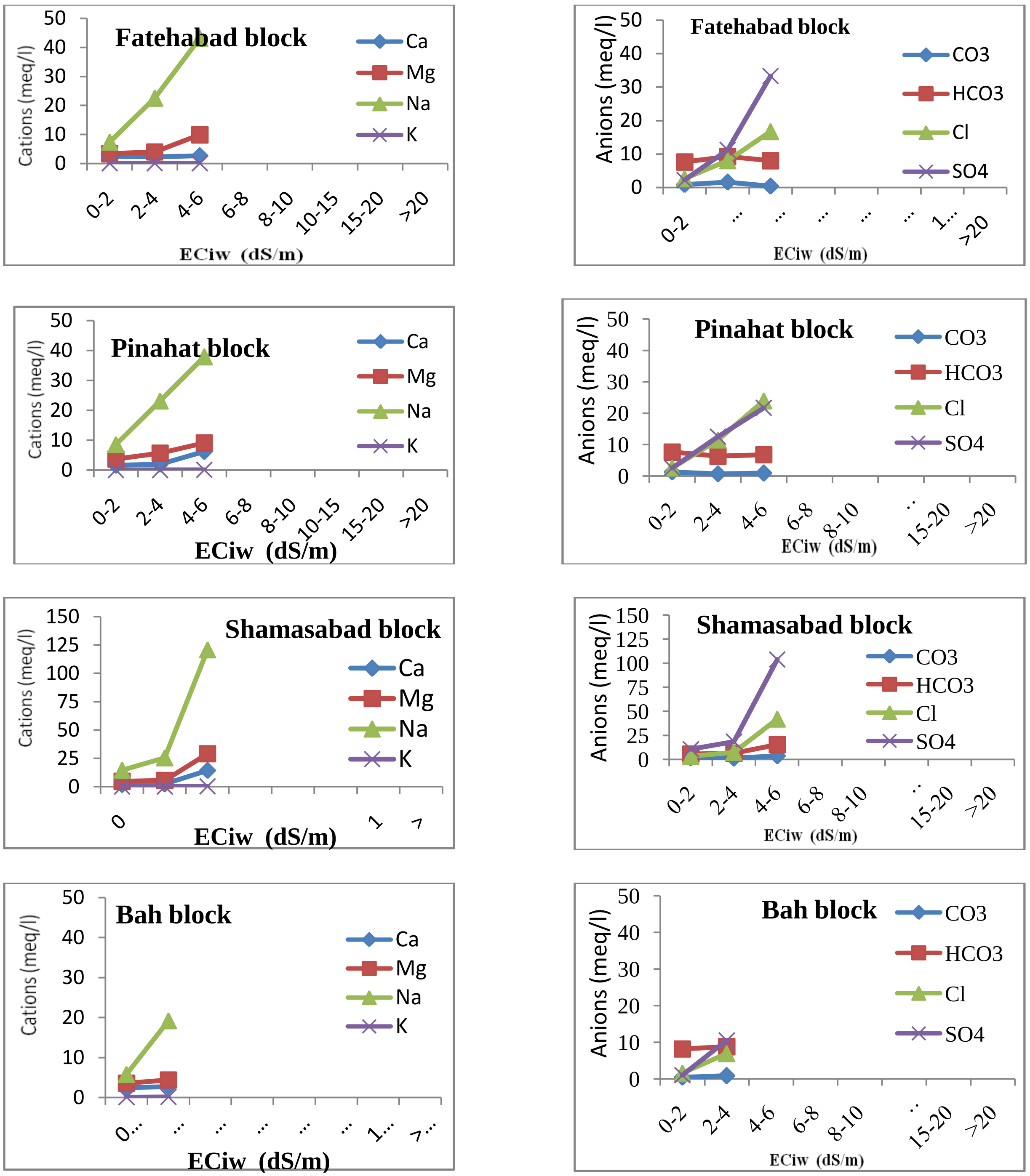

Fig. 1.2c: Cationic and anionic composition with respect to EC classes of Fatehabad, Pinahat, Shamsabad and Bah blocks of Agra district

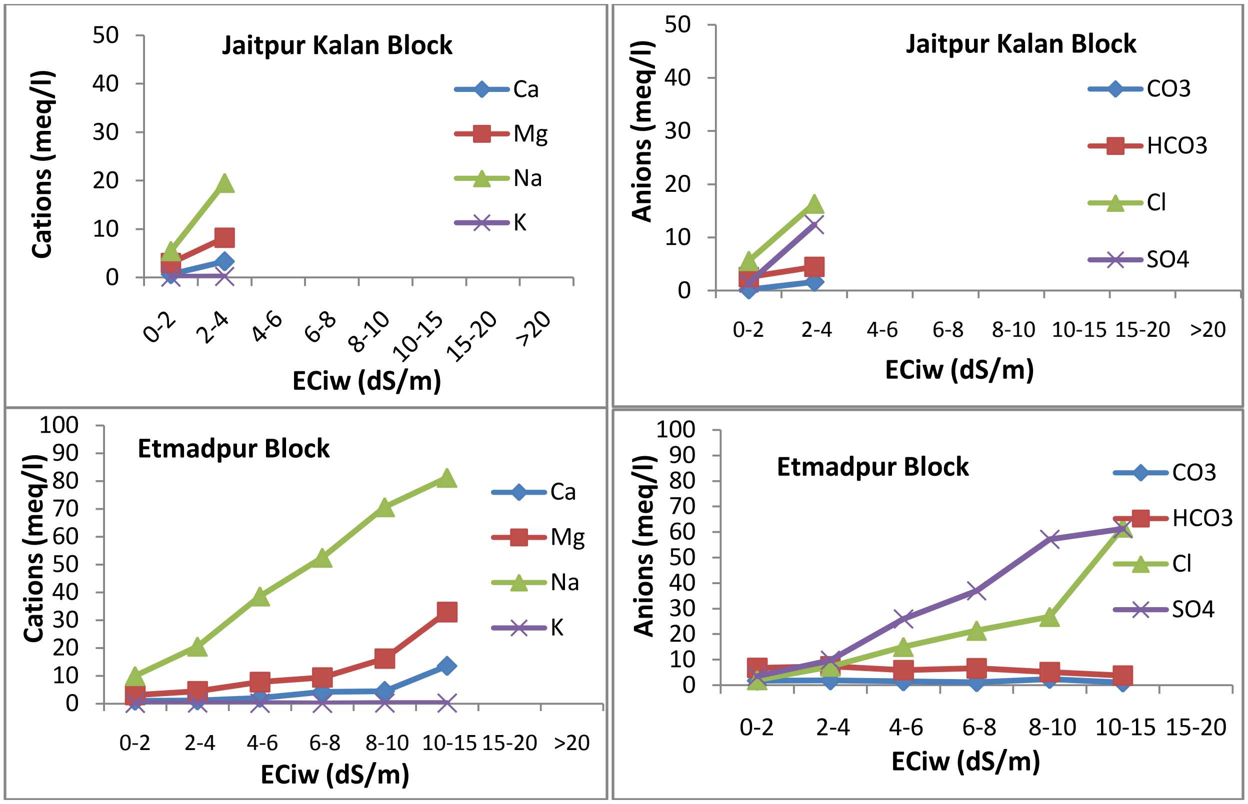

Fig. 1.2d: Cationic and anionic composition with respect to EC classes of Jaitpur Kalan and Etmadpur blocks of Agra district

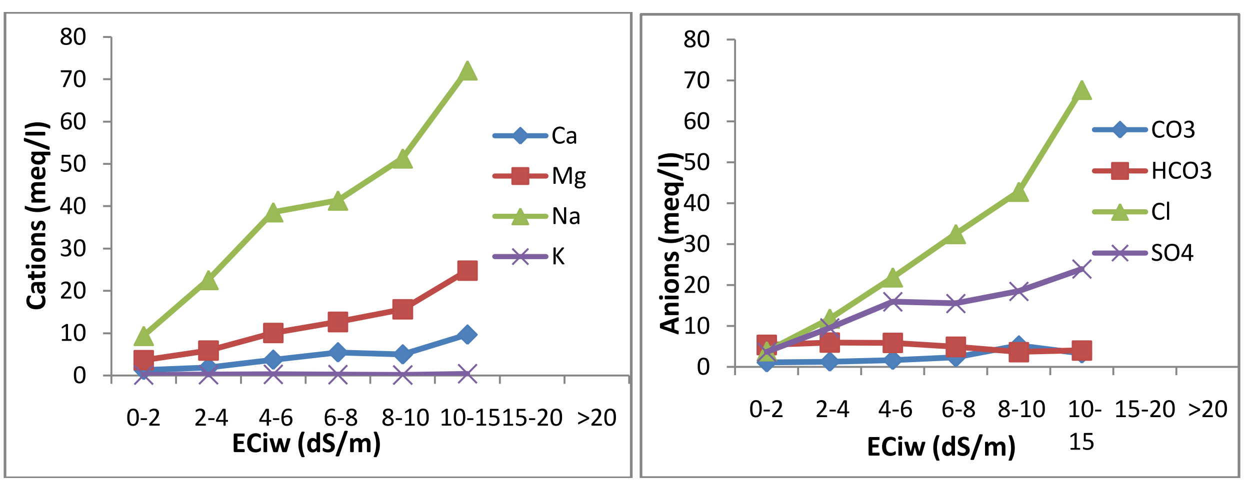

Fig. 1.2e: Average cationic and anionic composition with respect to EC classes of Agra district

Table 1.4: Nitrate in different blocks of Agra district

Particulars	Fatehpur Sikri (60)	Barauli Ahir (69)
Nitrate (meq/l)		
*Nitrate having samples (percent)	15.0	4.3
** Per cent among Nitrate having samples		
0 - 2.5	50.0	100.0
2.5 - 5.0	50.0	-
5.0 – 7.5	-	-

*Per cent of collected samples in respective blocks; ** Per cent of nitrate having samples only

Table 1.5: Percent of samples in different Fluoride classes in blocks of Agra district (2012-17)

Name of Block (2012-14)	Fluoride class (ppm)		Blocks 2014-16	Fluoride class (ppm)		Block (2016-17)	Fluoride class (ppm)	
	0-2.5	2.5-5.0		0-2.5	2.5-5.0		0-2.5	2.5-5.0
Fatehpur Sikri	95.0	5.0	Barauli Ahir	98.5	1.5	Etmadpur	89.0	11.0
Akola	90.0	10.0	Khandauli	98.6	1.4	Jaitpur Kalan	98.6	1.4
Achhnera	94.8	5.2	Shamsabad	97.1	2.9	-	-	-
Bichpuri	100.0	-	Bah	100.0	-	-	-	-
Jagner	87.7	12.3	Pinahat	100.0	-	-	-	-
Sainya	100.0	-	Fatehabad	85.6	14.4	-	-	-
Kheragarh	100.0	-	-	-	-	-	-	-

Table 1.6 revealed that no sample of good quality ground water was found in Fatehpur Sikri, Akola and Achhnera blocks. The maximum (53.6 percent) good quality water was in Barauli Ahir block followed by 50.7 per cent in Jaitpur Kalan and 44.0 per cent in Pinahat block. The most of poor quality water samples were of high SAR saline followed by Alkali type waters (i.e. Marginally Alkali, Alkali and High Alkali) and Marginally Saline. In Agra district, 23.9 per cent water samples were of good quality, whereas 45.6 per cent samples were of Saline type waters (i.e. Marginally Saline, Saline and High SAR Saline) and rest 30.5 per cent samples were of Alkali type waters (i.e. Marginally Alkali, Alkali & High Alkali). The spatial distribution water quality classes for Agra district is shown in Fig. 1.3.

1.3 Comaparison of Results of Two Groundwater Quality Surveys

The water quality distribution of Agra district based on recent survey (2012-17) as in Table 1.6, Fig. 1.3 and 1.4) was compared with earlier survey conducted during 1975-1979 (Table 1.7 and Fig. 1.4), almost 35 years ago. On the basis of recent survey, it was observed that the good quality groundwater samples in the surveyed blocks reduced sharply except Jagner, Sainya, Barauli Ahir, Khandauli and Kheragarh blocks. The major numbers of samples were in high SAR saline water quality class in both the surveyed periods except the Jagner, Sainya, Barauli, Ahir and Kheragarh blocks. The samples under High SAR Saline water quality class increased in seven blocks (Table 1.7). The saline water quality samples (marginally saline and saline) decreased in Fatehpur Sikri, Bichpuri Jagner, Sainya,Kheragarh, Barauli Ahir, Shamsabad, Bah while slightly increasing trend was observed in Alkali water samples. In general water samples under different classes in three blocks namely, Jagner, Sainya and Kheragarh remained unchanged even after three decades of time interval.

Table 1.6: Distribution of water samples in different water quality ratings (surevey period 2012 to 2017)

Name of block	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
		……………………………..Percentage of samples……………………………………………….						
2012-14								
Fatehpur Sikri	60	-	6.7	3.4	80.0	-	-	10.0
Akola	40	-	5.0	-	80.0	-	2.5	12.5
Achhnera	58	-	10.3	1.7	79.3	-	-	8.60
Bichpuri	45	4.4	8.9	-	80.0	-	-	6.70
Jagner	50	38.0	10.0	4.0	14.0	6.0	12.0	16.0
Sainya	54	18.5	11.1	3.7	38.9	1.9	11.1	14.8
Kheragarh	59	5.1	11.9	10.2	39.0	15.2	-	18.6
2014-16								
Barauli Ahir	69	53.6	7.3	-	8.7	7.3	15.9	7.20
Khandauli	70	32.9	20.0	-	17.1	14.3	-	15.7
Shamsabad	68	39.7	10.3	-	-	20.6	4.4	25.0
Bah	64	28.1	4.7	-	-	45.3	-	21.9
Pinahat	50	44.0	10.0	26.0	18.0	2.0	-	-
Fatehabad	90	32.2	2.2	1.1	15.6	15.6	22.2	11.1
2016-17								
Etmadpur	73	11.0	2.7	-	32.9	16.4	16.4	20.5
Jaitpur Kalan	71	50.7	4.2	-	2.8	32.4	7.10	2.80
Agra District	**951**	**23.9**	**8.4**	**3.4**	**33.8**	**11.9**	**6.20**	**12.4**

Table 1.7: Distribution of water samples in different water quality ratings (1975-1979)

Block	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
		……………………………..Percentage of samples……………………………………………….						
Fatehpur Sikri	86	4.65	4.65	8.14	80.23	1.16	-	1.16
Akola	29	-	6.9	17.24	58.62	-	3.45	13.79
Achhnera	77	1.30	6.49	20.78	64.94	-	-	6.49
Bichpuri	38	15.79	23.68	15.79	26.32	-	7.89	10.53
Jagner	40	5.0	20.0	15.0	40.0	5.0	5.0	10.0
Sainya	52	7.7	7.7	25.0	40.4	3.8	7.7	7.7
Kheragarh	55	0.0	1.8	20.2	63.6	3.7	0.0	10.9
Barauli Ahir	53	32.1	9.4	1.9	7.5	9.4	24.5	15.1
Khandauli	40	20	12.5	2.5	10.0	5.0	22.5	27.5
Shamsabad	68	62.3	-	-	3.5	10.4	10.4	13.4
Bah	64	67.5	-	-	-	20.9	9.3	2.3
Pinahat	50	70.4	-	-	3.7	14.8	11.1	-
Fatehabad	90	64.0	4.2	-	4.2	17.2	10.4	-
Etmadpur	49	22.4	14.3	4.1	10.2	8.2	18.4	22.4
Jaitpur Kalan	38	76.3	-	-	5.3	10.5	7.9	-
Agra district	**829**	**29.96**	**7.44**	**8.70**	**27.90**	**7.34**	**9.24**	**9.42**

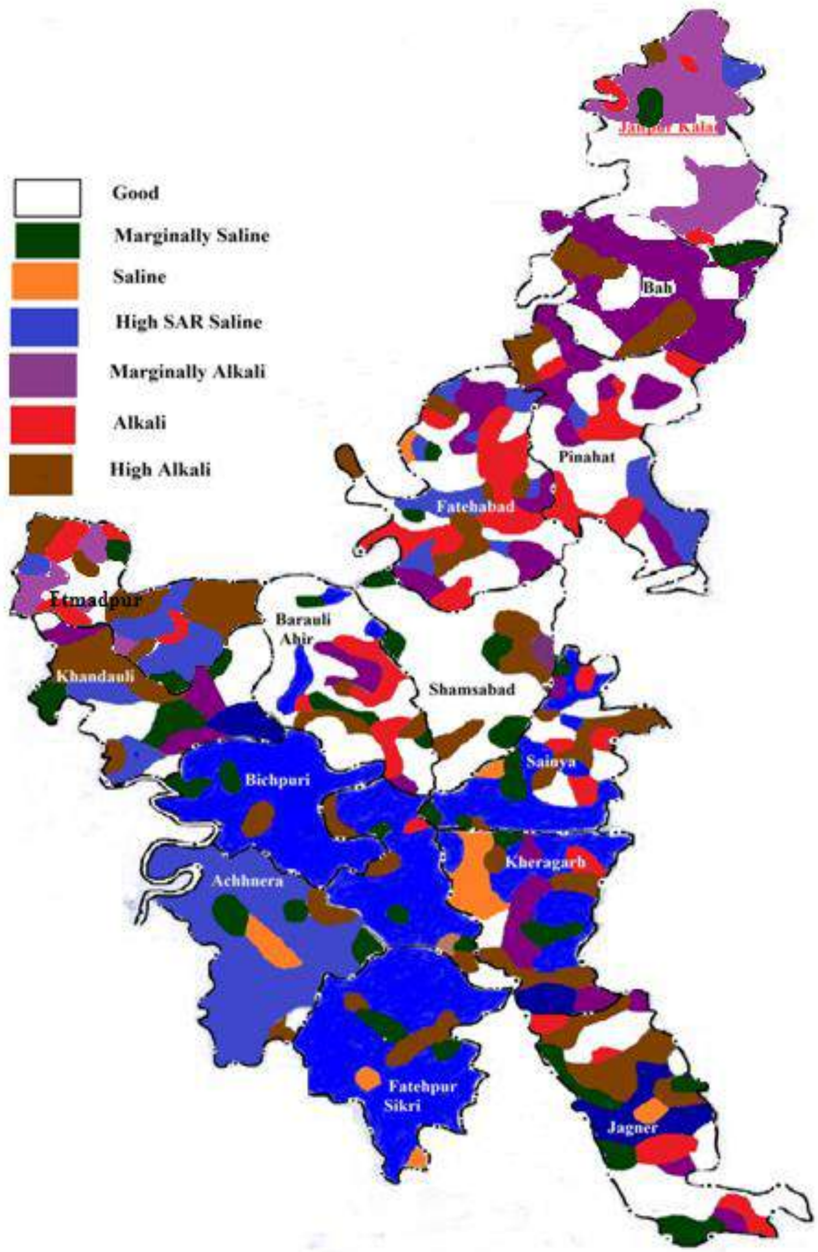

Fig. 1.3: Water quality map of Agra district (2017)

The spatial distribution of groundwater quality as per survey during 2012-2017 is shown in Fig. 1.4.

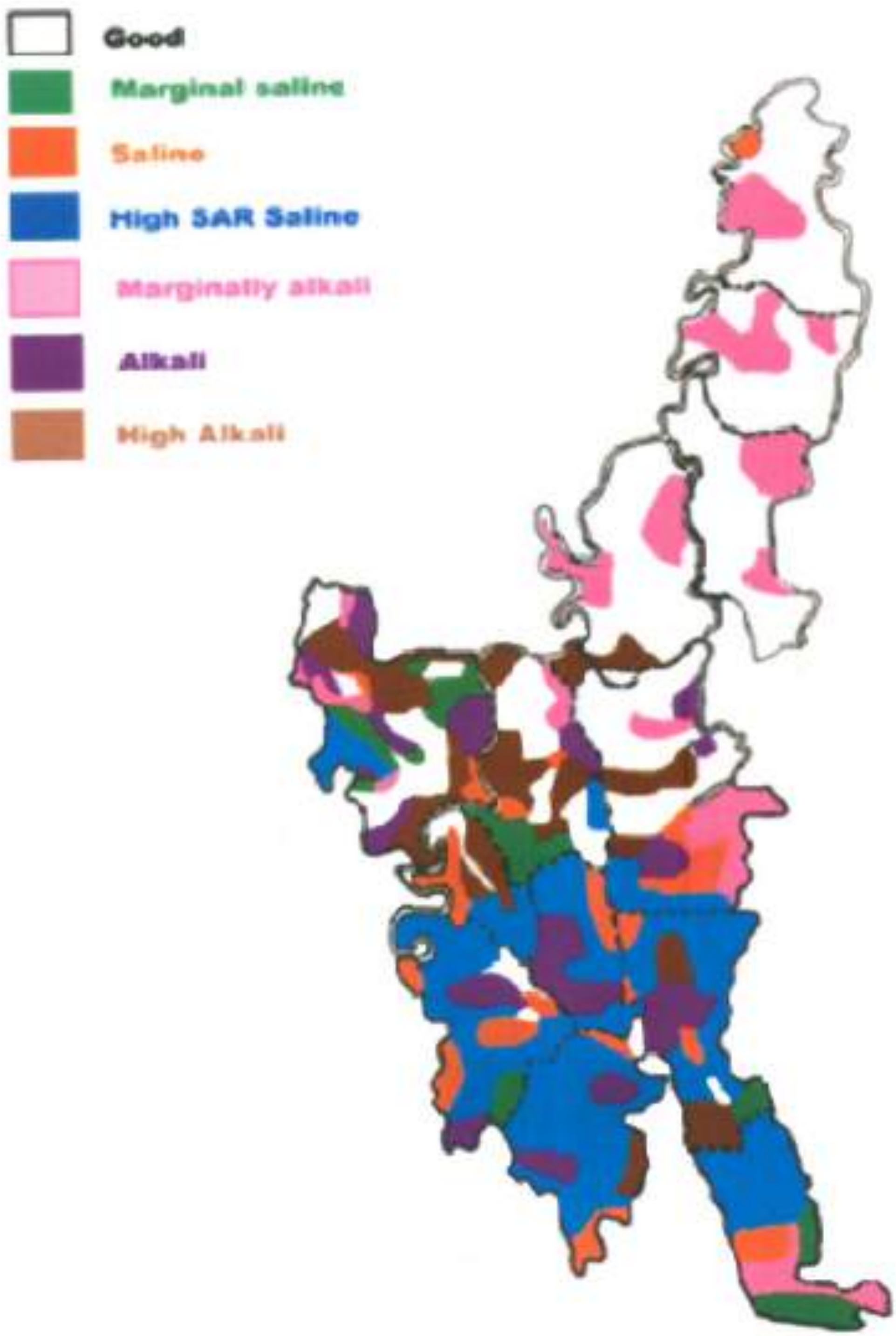

Fig.1.4: Water quality map of Agra district prepared 1980

2. GROUNDWATER QUALITY OF MATHURA DISTRICT

2.1. Introduction

Mathura is an important holy city in the state of Uttar Pradesh. In Hinduism, Mathura is believed to be the birthplace of Krishna, which is located at the Krishna Janmasthan Temple Complex. It is located approximately 55 km north of Agra, and 145 km south-east of Delhi. Mathura is bounded on the northeast by Aligarh District, on the southeast by Hathras District, on the south by Agra district, and on the west by Rajasthan and northwest by Haryana state. The district lies between latitudes 27°13' and 27°57' N and longitudes 77°15' and 77°58'east. Total geographical area of the district is 3303 km^2 (3.32 Mha). The location of the district is shown in Fig. 2.1. It is situated in Agro ecological region 4 (Northern plain, Hot semi-arid eco-region with alluvium derived soils). There are three numbers of tehsils namely Chhata, Mathura and Mat. There are twelve numbers of blocks in the district.

Fig.2.1 Location map of Mathura district (Source: www.maps of india.com)

Physiographically district occupies a part of Yamuna sub- basin, in which Yamuna river traverses through the Geophysical control of the district in the direction from north to south and divides it into two physical units – the eastern or trans Yamuna and the western or cis- Yamuna tract except few scattered low hills, occurring near the Bharatpur border. Tthe entire area is fairly flat, generally sloping towards south. Total geographical area of the district is 332000 ha, total cultivated land is 328000 ha and total

Irrigated land is 311000 mha (KVK Mathura). The length of canal in the district is 1309 km by which 106408 ha area is irrigated. Net sown area is 269178 ha and net irrigated area is 261445 ha. Net irrigated area to net sown area is 97.13 per cent. The groundwater irrigated area of the district is around 60.26 percent. The major crops during kharif district are paddy, bajra, til, arhar, maize, cotton and Sorghum. Crops during winter are wheat, barley, mustard, gram and pea. Moong, urd and vegetables are grown during summer season.

The average annual rainfall of the district is 620 mm. The climate is sub-tropical humid and it is characterised by a hot dry summer and a pleasant cold season. About 88 percent of rainfall takes place from June to September. During the monsoon, surplus water is available for deep percolation to ground water. January is the coldest month with the mean daily minimum temperature at about 7 ^{0}C and May is the hottest month with mean daily maximum temperature 42 ^{0}C. With the onset of the monsoon, day temperature decreases appreciably. The potential evapo-transpiration is 1467.20 mm

The area is part of the western fringe of Ganga alluvial plain and slopes gently towards east and along the drainage lines. The main three geomorphic units such as i) Younger Alluvium Plain, ii) Older Alluvium Plain and iii) Relict Mountains, Hills and Ridges are noticed in the district. The major soil textual classes found in the district are silty soil, sandy soil and loamy soil. The clay, kankar (calcareous concretion) and Reh (saline efflorescence) are also predominating in the blocks of Chhata, Nandgaon, Goverdhan, Mathura and Farah. The area is underlain by unconsolidated sediments which are deposited uncomfortably over the Pre-Cambrian basement Delhi System. The shallow aquifer group occur down to depth of 50.0 mbgl where as deep aquifers group exist between 135 - 185 mbgl. The aquifer material is generally composed of fine to medium grained sand. Kankars are invariably associated with sand and clay in older alluvium plain. Ground water occurs under unconfined to semi-confined conditions in the shallow aquifer group and semi-confined to confined condition in the deep aquifer group. The pre-monsoon depth to water level was found in the range of 2.65 to 14.34 mbgl while depth to water level in post-monsoon period was found in the range of 1.33 to 14.00 mbgl. Seasonal water level fluctuation varies from -0.15 to 3.85 m. As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Mathura district is assessed as 111724.97 ha m. The annual extractable groundwater resource is assessed as 105152.63 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 75651.09 and 5911.71 ha m. Thus existing gross annual ground water draft for all uses is 81562.80 ha m and the stage of groundwater extraction for Mathura district is 77.57 per cent. Among different blocks of Mathura district, Farah is semi-critical and Baldeo, Nohjhil and Raya are over exploited. Remaining blocks such as Sadabad, Sahpau, Goverdhan, Mathura, Mant, Chaumuha, Chhata and Nandgaon are under safe category.

The district has sizable canal irrigated area (261445 ha) but around 60.26 percent area is dependent on groundwater irrigation. Groundwater quality in the region varies spatially and it is not suitable for drinking purpose at many places and adversely affects crop yield. Therefore, survey, characterization and mapping of groundwater quality of the district was undertaken for better agriculture planning.

2.2 Groundwater quality survey, characterization and mapping

Groundwater samples (1078 No.) from different locations in Mathura district were collected during rabi season as almost all tubewells remain operational during this period. The samples were analysed for EC, SAR and RSC. The EC values of samples ranged from 03 to 33.0 dS/m, SAR ranged from 6.4 to 63

$(mmole/l)^{1/2}$ and RSC ranged from nil to 17.5 me/l with mean as 3.7 dS/m, 8.2 $(mmole/l)^{1/2}$ and 0.2 respectively (Table 2.1).

Table 2.1: Range and mean chemical composition of underground irrigation water of Mathura district

Blocks	EC	pH	Cations (meq/l)				Anions (meq/l)				RSC (meq/l)	SAR $(mmol/l)^{1/2}$
			Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4		
Min.	0.32	7.0	0.2	0.1	0.3	-	-	-	0.2	0.2	Nil	0.4
Max.	33.0	10.4	43.2	90.6	176.0	28.1	13.0	17.7	172.0	220.0	17.5	63.2
Av.	3.7	8.0	4.5	10.1	21.6	0.5	0.9	7.1	17.0	12.1	0.2	8.2

The frequency distribution of data showed that 60 percent water samples were having EC below 3 dS/m; 19 per cent samples were in the range of 3-5 dS/m and 21 percent above 5 dS/m. The RSC values of around 98 per cent samples were less than 10 meq/l; around 13 per cent samples were having RSC in the range of 5-10 me/l while 14 per cent samples were with RSC in the range of 2.5 to 5.0 meq/l. Around 72 per cent samples were having RSC below 2.5 me/l and can treated as good quality for irrigation purpose. The SAR values were less than 10 in 70 per cent water sample and 27 per cent samples were having SAR between 10-20 $(mmole/l)^{1/2}$. Around 3 per cent samples were having SAR above 20 $(mmole/l)^{1/2}$. On an average, the cationic and anionic types were Na-Mg-Ca and Cl-SO_4-HCO_3, respectively. Groundwater samples were classified into different subgroups of EC, RSC and SAR as given in Table 2.2.

Table 2.2: Frequency distribution of EC, RSC and SAR classes of Mathura district

Classes	No. of Samples	Percentage	Classes	No. of Samples	Percentage	Classes	No. of Samples	Percentage
EC (dS/m)			RSC (meq/l)			SAR $(mmole/l)^{1/2}$		
<1.5	300	27.83	-ve	577	53.53	0-10	746	69.20
1.5-3.0	339	31.45	0-2.5	186	17.25	10-20	291	26.99
3.0-5.0	207	19.20	2.5-5.0	150	13.91	20-30	35	3.25
5.0-10.0	167	15.49	5.0-10.0	144	13.36	30-40	4	0.37
>10.0	65	6.03	>10.0	21	1.95	>40	2	0.19

Further groundwater samples were classified into irrigation water quality subgroups as per criteria given in Table 2.2. It was observed that maximum number of samples (21 per cent) in Mathura district fall under good category. High SAR saline, marginally saline and saline samples were 17.4 per cent, 17.2 per cent and 10.7 per cent, respectively. Under alkali type, marginal alkali, alkali and high alkali samples were 16.2, 9.0 and 8.5 per cent, respectively. The distribution of different irrigation water quality categories in different blocks is given in Table 2.3.

The good quality groundwater samples in Sadabad, Baldeo, Sahpau, Farah, Goverdhan, Mathura, Raya, Mant, Naujheel, Chaumuha, Chhata, Nandgaon block were 18.6, 19.7, 24.7, 9.3, 20.2, 28.7, 17.5, 39.3, 14.8, 15.3, 24.2 and 20.1 per cent with average for Mathura district as 21 per cent. The all types of saline categories (Marginally Saline, Saline and High SAR Saline) samples in respective blocks were 52.9, 56.3, 6.2, 60.8, 66.3, 52.1, 49.4, 41.7, 56.9, 43.4, 24.3 and 33.3 percent with average for Mathura district as 45.3 percent. Also all types of alkali categories in those blocks were 28.5, 24, 69.1, 29.9, 13.5, 19.2, 33.1, 19, 28.3, 41.3, 51.5 and 46.6 percent with average for Mathura district as 33.67 percent. This indicated that saline water types of waters were dominating compared to good and alkali type of waters in the Mathura district. The variations in individual irrigation water category in different blocks can be understood from the Table 2.3.

Table 2.3: Distribution of water samples in different water quality ratings of Mathura district

S.No.	Blocks	No. Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Sadabad	72	18.6	33.5	11.1	8.3	12.5	6.3	9.7
2	Baldeo	76	19.7	25.0	7.9	23.4	7.9	13.5	2.6
3	Sahpau	84	24.7	2.5	-	3.7	25.9	35.8	7.4
4	Farah	97	9.3	10.3	15.5	35.0	11.3	5.1	13.5
5	Goverdhan	104	20.2	20.2	19.2	26.9	9.6	3.0	0.9
6	Mathura	94	28.7	20.2	17.0	14.9	6.4	5.4	7.4
7	Raya	97	17.5	13.4	11.3	24.7	16.5	7.3	9.3
8.	Mant	86	39.3	22.6	3.6	15.5	9.5	5.9	3.6
9.	Naujheel	125	14.8	19.9	16.4	20.6	7.8	8.0	12.5
10.	Chaumuha	85	15.3	15.3	11.8	16.3	29.4	-	11.9
11.	Chhata	95	24.2	13.7	5.3	5.3	33.7	6.2	11.6
12.	Nandgaon	63	20.1	9.5	9.5	14.3	23.8	11.7	11.1
	Mathura district	**1078**	**21.0**	**17.2**	**10.7**	**17.4**	**16.2**	**9.0**	**8.5**

The spatial distribution of the water quality classes in Mathura district are also depicted on the map Fig. 2.3. It observed from the map that every block have patches of each water quality class. However, alkali patches are small ones while good quality water class, high SAR, Saline, Saline patches are larger in sizes indicating their dominance.

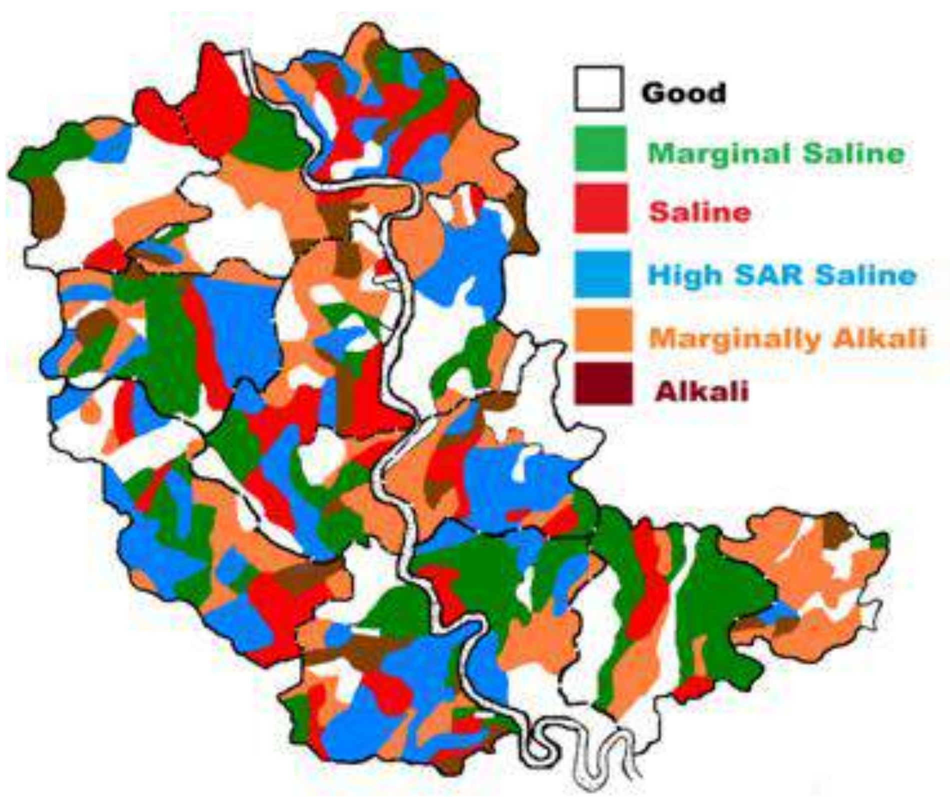

Fig. 2.2: Water quality map of Mathura district

3.1 Introduction

Aligarh district is situated on the western part of Uttar Pradesh occupying a small part of Ganga – Yamuna doab. It lies between latitude $27^0$35' and $28^0$10'N and longitudes $77^0$29'00" and $78^0$36'00"E. The district is bounded by major rivers Ganga and Yamuna, from north east and North West sides, respectively. This district is surrounded by Palwal district of Haryana from north west, Badaun from north east, Bulandshahr in north, Mathura in west to south-east, Hathars in south and Etah in east and south-east. The total geographical area of the district is 3691.50 km^2. It has been divided into five tehsils and 17 development blocks such as Mursan, Hathras, Sasani, Sikandrarao, Akbarabad, Hasayan, Iglas, Gonda, Lotha, Dhanipur, Java Sinkanpur, Khair, Chandos, Tappal, Chharra, Bijouli and Atrauli as shown Fig 3.1. The forest area and net sown area of the district are 2577 and 303954 ha, respectively. The net irrigated area is 301987 ha out of which 29791 ha is canal irrigated while remaining is groundwater irrigated. The gross irrigated area of district is around 445824 ha.

Fig. 3.1 Location map of Aligarh district

(Source: http://aligarhdirectory.com/wp-content/themes/skdirectory/thumbs/aligarh-map.jpg)

Aligarh district situated in Central Ganga Plain lies in the interfluvial tract of Ganga and Yamuna. Major physiographic units of the district are i) Recent Flood Plain ii) Terrace Zone iii) Older Alluvial Plain. Hydro-geological data indicates that the area is underlain by moderately thick pile of quaternary sediments, which comprises of sand of various grades, clays and kankar. Alluvial sediments overlies Vindhyan group of rocks in an unconformable way. There are numerous rivers and revulets but the more important are Ganga and Yamuna. Few rivers like Karban, Rutba and Kali which pass through the district and remain almost dry except in the rainy season. The mean annual rainfall of the district is 800 mm, relative humidity 65 percent, Lang's factor 25.6 mm per °C and Mayer's (NS) quotient 76. Thus, the climate of the district Aligarh is semi arid (KVK-Aligarh, 2015). The rainfall occurs during the monsoon period which is from June to September and July is the wettest month. Aligarh experiences the tropical monsoon type of climate. The summer and winter are severe. Maximum temperature shoots upto 45^0C during May and minimum temperature remains around 18^0C. Average maximum temperature remains around 42^0C during May. In the winter season, the maximum temperature rests around 21^0C and minimum temperature remains around 10^0C. Rainy season commences in the middle of June and continues till September **(KVK- Aligarh, 2015**).

In general the entire area is an alluvial plain, with a gentle slope from north-west to south-east. There are several natural depressions apart from those formed by the river valleys and drainage lines. Elevated sand ridges are also found especially in the west of the district, mostly in Khair and Iglas Tehsils. District Aligarh is narrower in the north but gets wider in south and eventually passes into the adjoining district of Etah. This tract is characterized by the soil, which apparently looks clayey with imperfect natural drainage and in consequence the landscape is dotted with lakes and is disfigured by salt affected soil patches. Soils are mostly represented by vast expanse of the alluvial developed from the river Ganga and its major tributaries. However, the soils of the Central Plateau are coarse loamy, sandy, red (Raker and Parwa) and black (Kaber and Mar). Wheat, barley, rice, maize, sugarcane, gram, pigeon pea, lentil, soybean, potato, mustard and vegetables are the main crops of this locality.

As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Aligarh district is assessed as 95421.14 ha m. The annual extractable groundwater resource is assessed as 89024.52 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 51082.36 and 10220.91 ha m. Thus existing gross annual ground water draft for all uses is 61303.27 ha m and the stage of groundwater extraction for Aligarh district is 68.86 per cent. Among different blocks of Aligarh district Chandaus, Gangiri, Jawan, Khair and Lodha are semi-critical; Iglas is critical. Remaining blocks such as Mursan, Hathras, Sasani, Sikandrarao, Akbarabad, Hasayan, Gonda, Dhanipur, Tappal, Chharra, Bijouli and Atrauli are safe.

3.2 Groundwater Quality Survey, Characterization and Mapping

The total 1849 ground water samples from different blocks of Aligarh district were collected. The survey was under taken during December/January to March every year when most of the tube wells were under use. The main criteria of characterizing the water qualities were EC, SAR and RSC values of water. In Aligarh district EC ranged from 0.3 to 19.5 dS/m, SAR from 0.6 to 45.6 $(mmole/l)^{1/2}$ and RSC from nil to 20.2 meq/l, respectively with respective average value on 5.0 dS/m, 6.4 (mmole/l)1/2 4.0 meq/l (Table 3.1). Further the average cationic and anionic pattern showed that water were dominated by Na ion over divalent and amongst divalent Mg^{++} ion over Ca^{++} ion and among anions HCO_3^- CO_3^{2-} dominated over $Cl^-$and SO_4^{2-} ions. Over all dominance of sodium bicarbonate indicated alkali problem in groundwater.

The frequency distribution patterns of water samples amongst different EC, SAR and RSC classes are presented in Table 3.2. About 93.3 per cent of water samples showed EC below 3 dS/m and 4.2 per cent samples were having EC between 3.0 -5.0 dS/m and 2.5 percent samples were with EC > 5 dS/m. As RSC classes, around 10 per cent of samples did not pose the RSC problem. About 30 per cent water samples were found in each RSC class namely 0-2.5 meq/l and 2.5-5.0 meq/l. Further around 31 per cent water samples were having RSC above 5.0 meq/l and out of which around 5 per cent samples were with RSC above 10 me/l. Amongst SAR classes the majority of water samples (81.3 per cent) were having SAR in between 0-10 $(mmole/l)^{1/2}$. Around 16.5 per cent samples were found with SAR in between 10-20 while 2.2 per cent samples were having SAR above 20 $(mmole/l)^{1/2}$.

Table 3.1: Range and mean of different quality parameters of ground water for Aligarh district

Blocks	EC	pH	Cations (meq/l)			Anions (meq/l)				RSC	SAR
			Ca^{2+}+Mg^{2+}	Na+	K+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}		
Min.	0.29	7.0	0.30	0.10	0.01	-	0.30	0.20	-	Nil	0.65
Max.	19.5	9.4	40.9	152.0	10.6	8.8	19.3	73.6	106.5	20.2	45.6
Average	1.5	8.3	4.8	9.8	0.30	1.5	6.4	3.6	3.4	4.1	6.4

Table 3.2: Frequency distribution of EC, RSC and SAR classes of Aligarh district

Classes	No. of Samples	Percentage	Classes	No. of Samples	Percentage	Classes	No. of Samples	Percentage
EC (dS/m)			RSC (meq/l)			SAR $(mmole/l)^{1/2}$		
<1.5	1333	72.4	-ve	185	10.1	0-10	1503	81.3
1.5-3.0	385	20.9	0-2.5	549	29.8	10-20	305	16.5
3.0-5.0	78	4.2	2.5-5.0	532	28.9	20-30	27	1.5
5.0-10.0	44	2.0	5.0-10.0	481	26.1	30-40	8	0.4
>10.0	9	0.5	>10.0	102	5.5	>40	6	0.3

The cationic and anionic distribution of groundwater samples showed that Na^+ dominates over Ca^{++} and Mg^{++} and Mg^{++} over Ca^{++}. It was also observed that with increase in EC, the portion of Na increased at faster rate compared to other divalent cations (i.e. Mg^{++} and Ca^{++}). In case of anions, the Cl^- and SO_4^{2-} increased progressively with increase in EC. However, concentration of CO_3 and HCO_3 did not vary much with EC and remained almost same irrespective of EC class in groundwater samples.

Seven water quality classes were observed on the basis of EC, SAR and RSC (Table 3.3). The classes were good, marginally saline, saline, high SAR saline, marginally alkali, alkali and high alkali. Distribution of water samples under different classes in case of Aligarh district is given in Table 3.3. Out of the total, 32 per cent waters were of good quality. Only 8 per cent water samples fall in all sort of salinity problem classes. Majority of groundwater samples i.e. 60 per cent were found under alkali type and out of which 15.4, 30.8 and 14.4 per cent groundwater samples belonged to marginally alkali, alkali and high alkali class. The Java Sinkanpur, Chharra, Bijouli, Atrauli and Dhanipur blocks have more than 50 per cent groundwater samples under good quality class. The range of good quality samples varied from 52.0 per cent in Dhanipur to 82.1 per cent in Java Sinkanpur. The Sikandrarao was having good quality water samples of 38 per cent. In case of remaining blocks, good quality samples were below 30 per cent ranging from 0 per cent in Mursan to 29.3 per cent in Chandos. It was also observed that the blocks namely Mursan, Hathras, Gonda, Iglas, Hasayan, Sasani, Akbarabad, Lotha, Tappal, Khair and Chandos mainly had samples with alkali type of waters (i.e. marginally alkali, alkali and high alkali). The percentage of alkali type waters in these blocks remained as 94.9, 90.3, 71.6, 81.9, 84.0, 83.5, 73.0, 77.9, 48.7, 66.1 and 61.6, respectively. Thus, main groundwater quality problem of the district is alkali water and management options related to alkali water such as frequent application of gypsum or use of pressmud, distillery spent wash, farm yard manure or green manuring are needed to reduce adverse effects of alkali water use for irrigation.

Table 3.3: Distribution of water samples in different water quality ratings of Aligarh district

S.No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Mursan	86	-	-	-	5.1	4.2	48.8	41.9
2	Hathras	93	5.3	-	1.1	3.2	7.5	64.5	18.3
3	Sasani	109	12.8	-	-	3.7	12.8	40.4	30.3
4	Sikandrarao	100	38.0	2.0	2.0	20.0	33.0	2.0	3.0
5	Akbarabad	93	27.0	-	-	-	23.6	38.7	10.7
6	Hasayan	84	9.5	4.1	-	2.4	27.4	44.7	11.9
7	Iglas	122	7.4	3.3	-	7.4	3.3	44.1	34.5
8.	Gonda	95	6.3	-	-	22.1	15.8	15.8	40.0
9.	Lotha	127	19.7	2.4	-	-	21.3	51.0	5.6
10.	Dhanipur	117	52.0	-	-	-	19.7	27.4	0.9
11.	Java Sinkanpur	151	82.1	-	-	-	13.2	4.0	0.7
12.	Khair	121	23.1	6.6	2.5	1.7	0.8	38.0	27.3
13.	Chandos	99	29.3	5.1	-	4.0	28.3	28.3	5.0
14.	Tappal	42	20.4	20.4	2.8	7.7	9.9	24.7	14.1
15.	Chharra	100	78.0	-	-	-	2.0	20.0	-
16.	Bijouli	150	71.0	-	-	-	11.0	17.0	1.0
17.	Atrauli	160	57.8	-	-	-	28.4	13.7	-
	Aligarh district	**1849**	**31.7**	**2.6**	**0.5**	**4.5**	**15.4**	**30.8**	**14.4**

Spatial distribution of ground water samples in different irrigation water quality classes for Aligarh district is shown in Fig. 3.2.

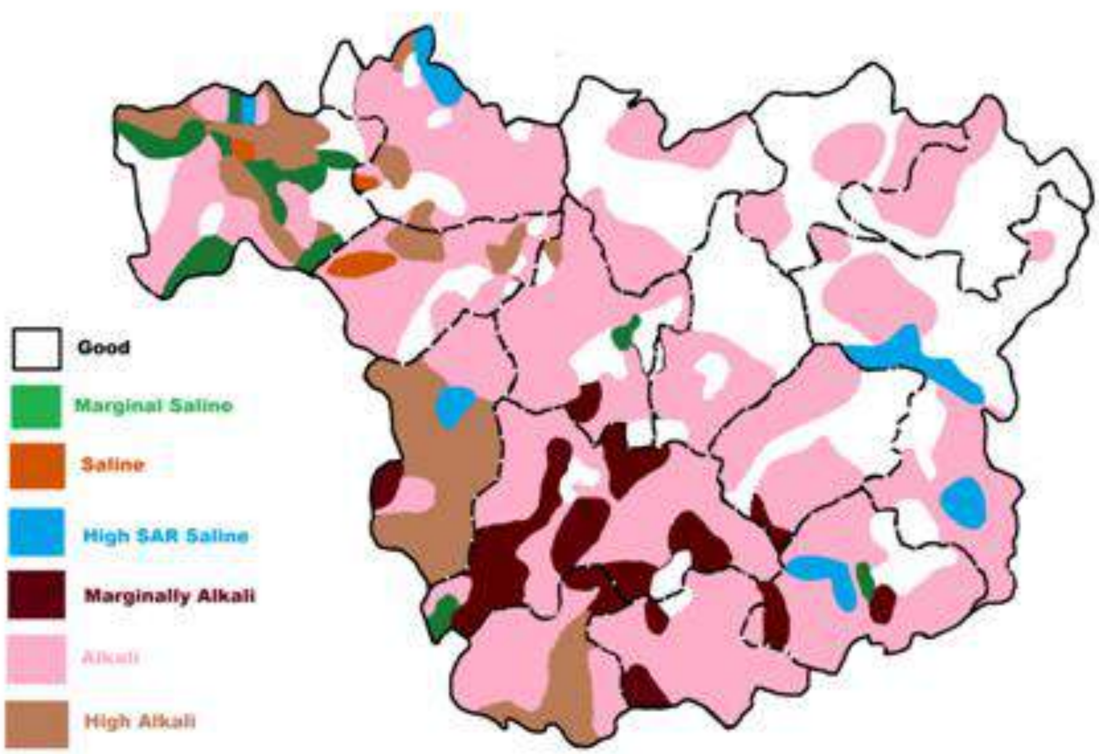

Fig. 3.2: Water quality map of Aligarh district

4.1 Introduction

The Etah district is situated in the western part of the state. It lies in the central portion of the Ganga and Yamuna doab and is bounded on the north-east side by the river Ganga, which separates it from the Budaun district. In general the district exhibits a flat topography with a few gentle undulations. Geographical area of the district is 2452.92 km^2. Gross sown area is 292000 ha while net sown area is 186000 ha. Total forest area is 1000 ha. Geomorphologically the area is not fully matured. The district may be divided into important geomorphic units such as Flood Plain, Younger Alluvial Plain and Older Alluvial Plain. Predominant geological formations in the district are alluvium (alluvial sediments of quaternary age). Major water bearing formation is sand of various grades, clay, silt and kankar. The drainage system of the district is controlled by the tributaries of river Ganga, namely Kali Nadi, Isan, Arind and Bargash. The Kali Nadi forms the border of district from northern side. It is perennial and remaining tributaries are ephemeral. The primary occupation of the people of the district is agriculture. The district has divided into three tehsils namely Etah, Jalesar, Aliganj and these tehsils are further divided into thirteen blocks (Fig. 4.1) namely Marhara, Nidhauli Kalan, Sakeet, Awagarh, Jalesar, Sheetalpur, Jethra, Aliganj, Kasganj, Soron, Sirhpura, Amanpur and Sahawar.

Fig. 4.1: Location map of Etah district

The surface water irrigation is mainly through the network of the Lower Ganga Canal and Upper Ganga Canal. Gross irrigated area is 282000 ha and net irrigated area is 186000 ha. The area is situated between Ganga and Yamuna (Doaab) which is highly fertile (Alluvial soil). The soils in the district can be grouped into loam, clay and sandy clay loam. The farmers are harvesting three crops in a year. The water for irrigation is available throughout the year. Major agricultural crops are rice, wheat, barley, jowar, bajra, maize; the soil is suitable for the cultivation of tobacco. The average annual rainfall is 722.4 mm. The climate is sub-humid and it is characterized by a pleasant cold season and a hot day summer.

About 88 per cent of rainfall takes place from June to September. During monsoon surplus water is available for deep percolation to ground water. There is a meteorological observatory at Mainpuri, the records of which may be taken as representative meteorological conditions. After February there is continuous increase in the temperature. May is generally the hottest month of the year. The mean daily maximum temperature in May is about 41^0C, mean daily minimum temperature is about 27^0C and maximum temperature reaches up to over 46^0C. With the onset of the monsoon, there is a rapid decrease in the day temperature. January is the coldest month with the mean daily maximum temperature is about 22^0C and mean daily minimum temperature is 8^0C. The mean monthly maximum temperature is 32.8 ^{0}C and mean monthly minimum temperature is 16.5^0C. The potential evapo-transpiration is 1431.7 mm. The ground water occurs in the pore spaces of unconsolidated alluvial sediments in the zone of sedimentation. The top silty / sandy clay beds mixed with kankar support the dug wells where ground water occurs under water table conditions. The ground water in the deeper aquifers occurs in semi confined to confined conditions. As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Etah district is assessed as 60714.87 ha m. The annual extractable groundwater resource is assessed as 57189.46 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 41770.55 and 4283.97 ha m. Thus existing gross annual ground water draft for all uses is 46054.52 ha m and the stage of groundwater extraction for Etah district is 80.53 per cent. Among different blocks of Etah district; Aliganj, Awagarh, Jaithara, Nidholi Kalan and Sheetalpur are semi-critical; Jalesar are critical. Remaining blocks such as Marhara, Sakeet, Kasganj, Sirhpura, Soron, Sahawar and Amanpur are safe.

4.2 Groundwater Quality Survey, Characterization and Mapping

The ground water survey of Etah district was completed in 1998-99. The 1474 groundwater samples were collected from different locations of the districts and were analysed for cations and anions. The water quality parameters of samples were used for characterization and classification of samples. The range and mean values of different water constituents viz. EC, pH, Ca^{++}+Mg^{++}, Na^+, K^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, RSC and SAR are presented in Table 4.1. The maximum EC value was recorded in Jalesar block i.e. 19.3 dS/m and minimum in Sahawar i.e. 0.29 dS/m. Similarly, the highest average was recorded in Jalesar (4.0 dS/m) block while lowest average was recorded in Sirhpura (0.65 dS/m) block. Highest RSC value of 24.0 (meq/l) was observed in Awagarh while minimum value of 0.8 meq/l was observed in Sahawar. The highest average RSC of 4.2 meq/l was observed in Sakeet and lowest average value of 0.01 meq/l was found in Sahawar block. The maximum SAR of 44.3 $(mmol/l)^{1/2}$ was found in Jalesar block while minimum SAR of 4.13 $(mmole/l)^{1/2}$ was found in Sahawar block. The average maximum SAR of 10.2 $mmol/l)^{1/2}$ was observed in Jalesar block and average lowest SAR of 0.64 $(mmol.l)^{1/2}$ was observed in Sahawar block.

The frequency distributions of ground water samples under different classes of EC, RSC and SAR are presented in Table 4.2. The data revealed that in case of Kasganj, 100 per cent samples were having EC less than 1.5 dS/m. Further, more than 90 per cent samples in Marhara, Sheetalpur, Jethra, Aliganj, Sirhpura, Amanpur, Soron and Sahawar blocks were having EC less than 1.5 dS/m and could be considered as good quality waters for irrigation.

Table 4.1: Range and mean of different quality parameters of ground water of Etah district

Blocks	EC	pH	Cations (meq/l)			Anions (meq/l)				RSC (meq/l)	SAR (mmol/l)1/2
			$Ca^{++}+Mg^{++}$	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}		
Marhara											
Min.	0.3	8.0	1.2	0.3	0.07	Nil	0.8	0.2	-	Nil	0.3
Max.	1.5	9.0	6.4	11.7	1.89	2.0	9.4	3.8	4.0	8.6	10.0
Av.	0.7	8.6	3.8	3.7	0.23	0.69	4.9	1.0	1.1	1.8	2.8
Nidhauli kalan											
Min.	0.4	8.2	2.0	0.5	0.05	Nil	2.0	0.4	-	Nil	0.4
Max.	6.1	9.2	25.0	40.0	4.7	2.4	9.8	33.2	32.9	7.0	20.9
Av.	1.2	8.7	4.4	7.2	0.44	0.8	4.7	2.7	3.8	1.7	4.5
Sakeet											
Min.	0.3	7.6	0.8	1.3	0.06	Nil	1.2	0.4	Nil	Nil	0.9
Max.	7.6	9.2	29.0	48.5	6.78	2.8	10.4	29.8	38.5	11.8	13.5
Av.	1.3	8.1	5.7	7.7	0.28	0.80	5.0	3.4	4.7	4.2	1.5
Awagarh											
Min.	0.5	-	2.0	1.1	0.02	Nil	1.8	0.4	Nil	Nil	0.7
Max.	12.5	-	49.6	160.0	2.5	5.2	20.8	3.6	160.6	24.0	25.2
Av.	1.8	-	6.7	13.4	0.3	0.4	8.1	2.6	9.2	2.9	6.7
Jalesar											
Min.	0.6	-	2.0	1.6	0.3	NIL	1.2	0.4	Nil	Nil	0.4
Max.	19.3	-	89.4	181.2	6.8	2.0	17.0	92.4	156.0	13.2	44.3
Av.	4.0	-	19.6	30.6	0.5	0.5	7.9	11.5	22.7	2.1	10.2
Sheetalpur											
Min.	0.4	7.3	1.6	1.2	-	Nil	2.0	0.4	Nil	Nil	0.8
Max.	9.7	9.4	43.6	76.0	-	3.6	11.0	44.6	67.7	13.0	16.0
Av.	1.2	8.3	5.0	8.5	-	0.9	4.6	2.6	4.1	1.3	4.6
Jethra											
Min.	0.3	7.5	1.8	1.6	-	Nil	1.2	0.4	0.7	Nil	0.8
Max.	3.8	9.0	16.2	29.6	-	1.6	7.4	13.6	28.0	4.2	10.6
Av.	0.7	8.2	4.3	4.0	-	0.5	3.3	0.9	3.6	0.2	2.7
Aliganj											
Min.	0.4	7.7	1.2	2.2	-	Nil	1.4	0.4	1.3	Nil	1.7
Max.	4.9	9.2	16.2	42.2	-	2.0	15.0	18.2	36.0	12.4	18.6
Av.	1.0	8.2	3.5	8.0	-	0.8	4.1	1.4	5.3	1.7	6.0
Kasganj											
Min.	0.3	7.7	2.4	Nil	0.06	Nil	2.2	0.6	Nil	Nil	Nil
Max.	1.4	8.8	8.2	10.7	0.55	2.4	6.0	3.0	9.0	2.4	6.2
Av.	0.7	7.2	5.1	2.0	0.15	0.4	3.7	1.1	2.1	0.1	1.3
Soron											
Min.	0.3	8.2	1.4	0.2	0.06	Nil	1.0	0.4	0.6	Nil	0.1
Max.	6.6	8.9	36.6	17.8	5.5	2.4	4.4	18.6	38.6	3.6	6.8
Av.	0.7	8.7	5.6	1.6	0.4	0.5	2.7	1.3	3.2	0.1	1.0
Sirhpura											
Min.	0.3	8.3	1.2	Nil	0.05	Nil	2.2	0.4	0.2	Nil	Nil
Max.	2.2	9.2	8.2	19.9	1.7	3.6	9.2	3.0	6.8	11.1	20.9
Av.	0.7	8.6	4.8	1.2	0.2	0.1	3.7	1.0	1.7	0.3	1.0
Amanpur											
Min.	0.3	7.9	1.2	Nil	0.02	Nil	2.0	0.4	Nil	Nil	Nil
Max.	1.7	9.1	9.8	14.0	1.3	1.6	6.8	7.0	14.1	3.6	12.8
Av.	0.7	8.2	4.7	2.2	0.1	0.1	3.8	1.1	2.3	0.2	1.4
Sahawar											
Min.	0.3	8.5	2.2	Nil	0.01	0.4	1.4	0.6	Nil	Nil	Nil
Max.	1.9	8.9	12.0	5.6	3.5	1.6	4.0	7.6	8.5	0.8	4.1
Av.	1.0	8.7	5.0	1.1	0.3	0.8	2.2	1.7	1.8	0.01	0.6

Table 4.2: Frequency distribution of irrigation water of Etah district with respect of EC, RSC and SAR classes

Blocks	Particulars														
	EC classes (dS/m)					RSC classes (meq/l)					SAR classes (mmol/l)1/2				
	0-1.5	1.5-3.0	3.0-5.0	5.0-10.0	>10.0	Absent	0-2.5	2.5-5.0	5.0-10.0	>10	0-10	10-20	20-30	30-40	>40
Marhara															
No. of samples	101	1	-	-	-	9	66	21	6	-	101	1	-	-	-
percent	99.2	0.8	-	-	-	8.8	64.7	20.6	5.9	-	99.2	0.8	-	-	-
Nidhauli Kalan															
No. of samples	108	20	6	3	-	27	79	24	7	-	125	11	1	-	-
percent	78.8	14.6	4.4	2.3	-	19.7	57.8	15.5	5.1	-	91.2	8.0	0.7	-	-
Sakeet															
No. of samples	23	15	8	8	-	40	91	17	3	3	140	13	1	-	-
percent	79.9	9.7	5.2	5.2	-	26.0	59.2	11.0	1.9	1.9	90.9	8.4	0.6	-	-
Awagarh															
No. of samples	73	32	6	3	2	16	62	26	11	1	95	16	2	3	-
percent	62.9	27.6	5.2	2.6	1.7	13.8	53.4	22.4	9.5	0.9	81.9	13.8	1.7	2.6	-
Jalesar															
No. of samples	45	42	15	21	14	64	17	25	15	6	85	38	8	4	2
percent	32.8	30.6	10.9	15.3	10.2	16.7	19.7	18.2	10.0	4.4	62.0	27.7	5.8	3.0	1.5
Sheetalpur															
No. of samples	124	5	1	6	-	38	72	22	3	1	129	7	-	-	-
percent	91.2	3.7	0.7	4.4	-	27.9	52.9	16.2	2.2	0.7	94.8	5.2	-	-	-
Jethra															
No. of samples	121	2	-	-	-	90	32	1	-	-	122	1	-	-	-
percent	98.4	1.6	-	-	-	73.2	26.0	0.8	-	-	99.2	0.8	-	-	-
Aliganj															
No. of samples	105	7	3	-	-	16	70	21	7	1	102	13	-	-	-
percent	91.3	6.1	2.6	-	-	13.9	60.9	18.3	6.0	0.9	88.7	11.3	-	-	-
Kasganj															
No. of samples	105	-	-	-	-	92	13	-	-	-	105	-	-	-	-
percenttage	100.0	-	-	-	-	87.6	12.4	-	-	-	100.0	-	-	-	-
Soron															
No. of samples	93	1	-	2	-	87	6	3	-	-	96	-	-	-	-
percent	96.9	1.0	-	2.1	-	90.6	6.3	3.1	-	-	100.0	-	-	-	-
Sirhpura															
No. of samples	79	1	-	-	-	70	6	3	-	1	79	-	1	-	-
percent	98.8	1.2	-	-	-	87.5	7.5	3.7	-	1.2	98.8	-	1.2	-	-
Amanpur															
No. of samples	98	4	-	-	-	89	13	-	-	-	101	1	-	-	-
percent	96.1	3.9	-	-	-	87.3	12.7	-	-	-	99.0	1.0	-	-	-
Sahawar															
No. of samples	70	1	-	-	-	69	2	-	-	-	71	-	-	-	-
percent	98.6	1.4	-	-	-	97.2	2.8	-	-	-	100.0	-	-	-	-

In case of remaining blocks, namely, Sakeet, Nidhauli Kalan, Awagarh and Jalesar, groundwater samples having EC between 0-1.5 dS/m were 79.9, 78.8, 62.9 and 32.8 per cent. The 25.5 per cent of ground water samples in Jalesar block were having EC above 5 dS/m while in Nidhauli Kalan, Sakeet, Awagarh and Sheetalpur blocks such samples were less than 5 per cent. Only in Jalesar and Awagarh block 10.2 and 1.7 per cent samples were having EC above 10 dS/m.

Regarding RSC value, it was found that in 73.2 per cent samples in Jethra and more than 87 per cent samples in Kasganj, Sirhpura, Amanpur, Soron and Sahawar blocks do not have any RSC value. In case of Marhara, Nidhauli Kalan, Sakeet, Awagarh, Jalesar, Sheetalpur, Jethra, Aliganj, Soron and Sirhpura blocks, percentage of ground water samples with RSC in between 2.5 to 10 meq/l was 26.5, 20.6, 12.9, 31.9, 28.2, 18.4, 0.8, 24.1, 3.1 and 3.2, respectively (Table 4.2). In case of these waters, use of gypsum/ green manuring for management of sodicity is required. The SAR data (Table 4.2) showed that high SAR was not a common feature in most of the blocks. In majority blocks, about 90 per cent and more have SAR below 10 $(mmol/l)^{1/2}$. Only in Awagarh and Jalesar blocks, less than 6 per cent samples had SAR above 30 $(mmo/l)^{1/2}$.

The mean of different cations and anions in relation to different EC_{iw} classes were studied. Among the cations, the Ca^{++}+Mg^{++} and Na^+ increased with EC_{iw} within different EC_{iw} classes whereas the K^+ ion did not show any relation with EC_{iw} classes. Further the Ca^{++}+Mg^{++} and Na^+ ions increased proportionately up to ECiw 10 dS/m but beyond it, mainly Na^+ contributed to EC_{iw} increase. Amongst the anions, SO_4^{2-} and Cl^- were dominant in all the EC_{iw} classes. The rate of increase of SO_4^{2-} and Cl^- was proportionate for EC_{iw} classes having EC_{iw} below 10 dS/m; beyond it, SO_4^{2-} increased sharply compared to Cl^-. The CO_3^{2-} and HCO_3^- anions did not show any relation with EC_{iw} and remained almost same for all EC_{iw} classes. The cationic and anionic types in different blocks were also studied. Except Marhara and Jethra blocks, all other blocks have Na^+ dominated water. Regarding anionic type, it was observed that ground water samples of district were SO_4^{2-} dominated rather than Cl^- dominated.

Distribution of water samples in different water quality classes for Etah district is given in Table 4.3. Around 78 per cent samples of Etah district were under good quality. Around 6.5 per cent were found saline type. Out of which, marginally saline, saline and high SAR saline were 2.0, 0.6 and 3.9 per cent, respectively. Around 16 per cent samples were found under alkali water categories such as marginally alkali, alkali and high alkali with per cent of samples as 5.0, 7.1 and 2.3 per cent, respectivey.

Table 4.3: Distribution of water samples in different water quality classes for Etah district

S.No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Awagarh	116	42.2	2.6	-	6.0	1.7	37.9	9.5
2	Jalesar	137	22.6	13.9	1.5	27.6	2.4	24.8	8.0
3	Nidhauli Kalan	137	17.1	3.6	-	3.6	13.9	5.8	2.9
4	Marhara	102	74.5	-	-	-	16.7	8.8	-
5	Sakeet	154	70.8	4.5	3.2	5.8	8.4	5.2	1.9
6	Sheetalpur	136	74.3	0.7	1.5	4.4	13.2	5.9	-
7	Jethra	123	98.4	-	-	0.8	-	0.8	-
8.	Aliganj	115	69.6	0.9	-	2.6	17.4	3.5	6.1
9.	Kasganj	105	100.0	-	-	-	-	-	-
10.	Sirhpura	80	93.7	-	-	-	5.0	-	1.3
11.	Soron	96	94.8	-	2.1	-	3.1	-	-
12.	Sahawar	71	100.0	-	-	-	-	-	-
13.	Amanpur	102	96.1	-	-	-	2.9	-	-
	Etah district	**1474**	**77.6**	**2.0**	**0.6**	**3.9**	**6.5**	**7.1**	**2.3**

The spatial distribution of different types of irrigation waters in Etah district is shown in Fig. 4.2.

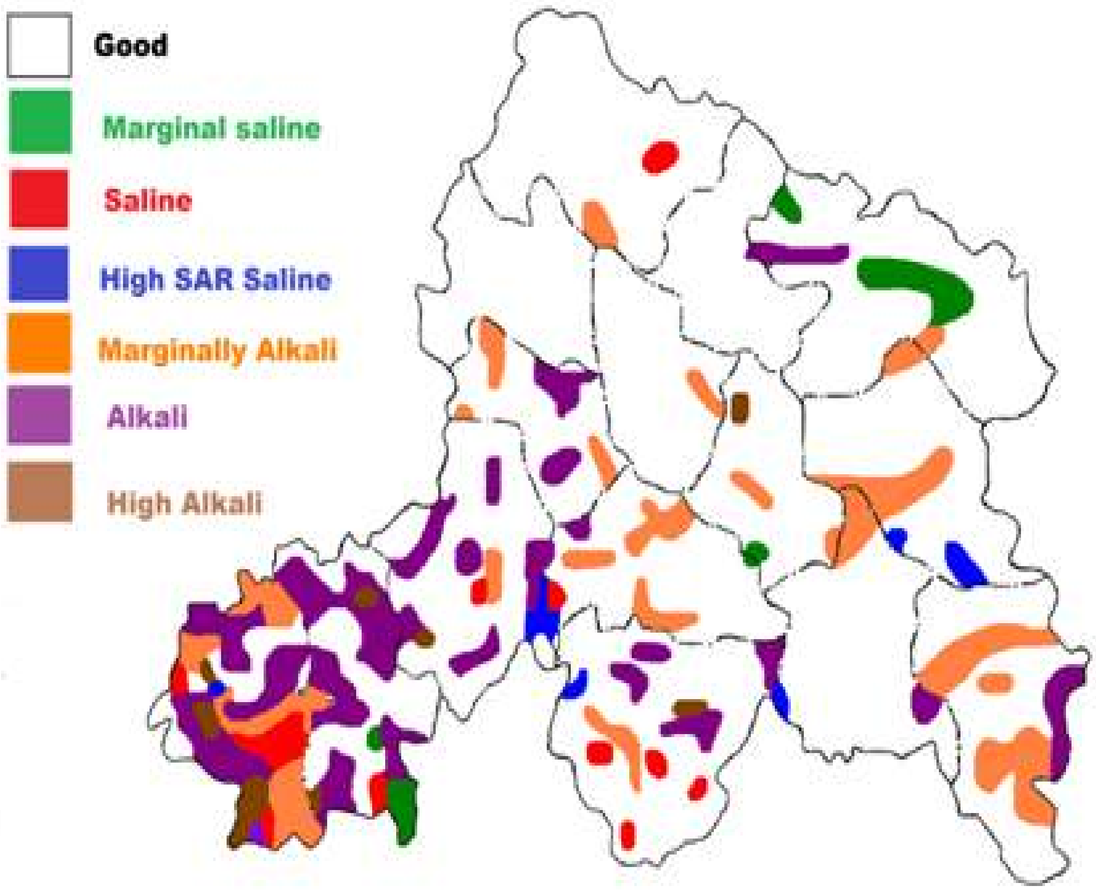

Fig. 4.2 Water quality map of Etah district

The highest 100 per cent waters of Kasganj and Sahawar blocks are of good quality. In rest of the blocks such water ranged between 70 to 90 per cent. In Jalesar block, good quality ground water was only 22.6 per cent. The Jalesar had 27.6 per cent of ground water samples under saline categories. The saline category waters in remaining blocks were either absent or less than 6 percent. The alkali type waters (Marginally Alkali, Alkali and high alkali) was a common feature in all the blocks and they ranged from nil to 50 per cent. The marginal alkali water was highest i.e. in 17.4 per cent samples in Aliganj block while alkali water class recorded highest (37.9 per cent) in Awagarh block. The high alkali water was highest in Awagarh block (9.5 per cent) (Table 4.3).

Fluoride:

The Fluoride content in water was also determined and presented in Table 4.4. Except Awagarh and Jalesar blocks, more than 90 per cent samples had Fluoride less than 2.5 ppm. Twenty per cent in Jalesar and 12 per cent in Awagarh block have Fluoride between 2.5 to 5.0 ppm range while in rest of the blocks less than 7 per cent sample had Fluoride in this class. In Awagarh block, only 4.3 per cent samples were with Flouride above 5 ppm.

Table 4.4: Frequency distribution (percent) of irrigation water of different blocks and range of Fluoride (ppm) in Etah district

Blocks	Flouride classes (ppm)					Min.	Max.	Average
	0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	>10.0			
Awagarh (116)	83.6	12.1	3.4	0.9	-	Nil	7.6	1.6
Jalesar (137)	80.3	19.7	-	-	-	Nil	3.7	1.4
Nidhauli Kalan (137)	94.9	4.4	0.7	-	-	Nil	7.0	1.0
Marhara (102)	99.0	1.0	-	-	-	Nil	2.6	0.3
Sakeet (154)	98.0	2.0	-	-	-	Nil	3.0	0.7
Sheetalpur (136)	93.4	6.6	-	-	-	0.6	3.5	1.6
Jethra (123)	99.2	0.8	-	-	-	Nil	2.6	1.0
Aliganj (115)	94.8	5.2	-	-	-	0.8	3.4	1.6
Kasganj (105)	94.3	5.7	-	-	-	Nil	2.9	1.2
Sirhpura (80)	96.2	3.8	-	-	-	Nil	3.0	1.4
Soron (96)	98.9	1.1	-	-	-	Nil	3.0	0.7
Sahawar (71)	97.2	2.8	-	-	-	0.2	3.0	1.5
Amanpur (102)	95.1	4.9	-	-	-	Nil	2.9	1.4
Average (1474)	93.9	5.7	0.3	0.1	-	0.12	7.6	1.2

Nitrate:

Presence of Nitrate was also recorded and it was found that hardly 1 per cent had nitrate. In these samples the Nitrate ranges from 0.1 to 3.0 meq/l.

5. GROUNDWATER QUALITY OF FIROZABAD DISTRICT

5.1 Introduction

Firozabad is located in north central India, in western Uttar Pradesh state, 40 km away from Agra and around 240 km away from Delhi, at the northern edge of the Deccan Plateau, at 27°09’N 78°24’E / 27.15°N 78.4°E / 27.15; 78.4. The location map of the district is shown in Fig. 5.1. The geographical area of the district is 2362 km^2. The height above sea level is 164 m (540 ft). The boundaries of Firozabad district touch Etah district in north and Mainpuri and Etawah districts in the east. The Yamuna River makes its southern boundary. There are four (4) sub-divisions/tehsils namely Firozabad, Shikohabad, Tundla and Jasrana with nine (9) development blocks namely Narkhi, Firozabad, Tundla, Eka, Khairgarh, Jasrana, Shikohabad, Araon and Madanpur. Approximately 73.6 percent of the population lives in rural area. More than half of the workforce is engaged in manufacturing activities. The district is mostly flat and its slope is from North West to south. Geomorphologically, the area is not fully matured. However, based on existing features the district is divided into five units such as Flood Plain, Younger Plain, Older Alluvial Plain, Salt Encrustation and Ravines. The net sown area of the district is about 180954 ha. The main sources of irrigation are tubewells/ bore wells and canals. The Gross irrigated area is 2111400 ha and net irrigated area is 171752 ha.

Fig. 5.1: Location map of Firozabad district

Soils of Firozabad are typical of those in the Ganga alluvial plain. The diversity is mainly due to the influence of various rivulets, canals and partially due to the presence of Yamuna River. The soils are loam, sandy loam, loamy sand, silty clay loam, ravines and waste land. The fertility status of soils is poor to very poor. The average annual rainfall of the district is 665.40 mm. The climate is sub-humid. About 90 per cent of a rainfall takes places from June to September. During monsoon surplus water is available for deep percolation to ground water. Temperature varies from 4^0C (during December-January) to 48^0C (during May-June). The district has 237 state tube-wells and 32295 private tube-wells which contributes assured irrigation to almost 80.49 per cent of the cultivable area. Upper Ganga canal and lower Ganga canal are two major canals of the district.

The major cropping patterns followed in the district are bajra, paddy, *arhar, til, urd, moong* in *kharif* and wheat, mustard, barley, potato, garlic etc. in *rabi*. The major crops of the district are Bajra (70411 ha with the productivity of 23.65q/ha), wheat (99553ha, with the productivity of 41.27 q/ha), potato (38832 ha with the productivity of 255 q/ha), paddy (21599 ha with the productivity of 27.48q/ha), *urd* (476 ha with the productivity of 6.64 q/ha), *til* (1034 ha with the productivity of 1.08 q/ha) (KVK-Firozabad, 2015). About 70 per cent of the cultivated area is covered under bajra and wheat crops and the rest of the area under potato, vegetables, fodder, oilseeds, pulses and other crops. Firozabad is the known for area under potato cultivation. Besides others, there is lot of scope for marketing of horticultural crops keeping in view the district is near with National Capital Region (NCR). There is one state garden nursery at Firozabad which takes care of saplings of some horticultural plants like-guava and seed production of aonla, potato and vegetables.

Water bearing formations of alluvial tract of Firozabad district are comprised of sands of various grades, gravels, silt and clay. The results of exploratory drillings by CGWB indicated that in the south-western parts of the district, where Vindhyan sandstone has been encountered at different depths as basement, the alluvium sediments attain the minimum thickness. The thickness of sediments gradually increases toward central and north-eastern part of the district. Ground water occurs under unconfined to semi-confined conditions depending upon the nature and occurrence of the number of local/semi-regional clay beds.

As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Firozabad district is assessed as 75664.29 ha m. The annual extractable groundwater resource is assessed as 70630.98 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 72524.096 and 6154.17 ha m. Thus existing gross annual ground water draft for all uses is 78679.13 ha m and the stage of groundwater extraction for Firozabad district is 111.39 per cent. Among different blocks of Firozabad district, Madanpur are semi-critical; Araon are critical and Firozabad, Khairgarh, (Hathwant), Narkhi, Shikohabad and Tundla are over-exploited. Remaining blocks, Jasrana and Eka are safe.

Hence, these blocks do not have good scope for further ground water development and groundwater recharge is priority for these blocks. Shallow and moderately deep tube wells are recommended only in safe category block. Simultaneously ground water regime monitoring is essential to noticing any adverse effect. In canal command area strategy of conjunctive use of surface and ground water needs to be adopted for future ground water development. The moderately deep tube wells may upto 100 m and tapping 20 to 35 m of granular zone are recommended. Pre-monsoon depth to water level ranges from 1.21 to 25.10 mbgl and post monsoon depth to water level ranges from 1.06 to 25.25 mbgl (Prasad, 2013).

5.2 Groundwater Quality Survey, Characterization and Mapping

The 1180 groundwater samples were collected from different locations of the districts and were analysed for cations and anions during 1998. The water quality parameters of samples were used for characterization of samples into different irrigation water classes and mapping at spatial scale. The ranges and mean values of different water constituents/ parameters are presented in Table 5.1.

Table 5.1: Range and mean chemical composition of underground irrigation water of Firozabad district

Blocks	EC	pH	Cations (meq/l)			Anions (meq/l)				RSC	SAR
			Ca+Mg	Na	K	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^-		
Araon											
Min.	0.4	-	0.6	0.3	-	Nil	2.6	0.4	-	Nil	0.4
Max.	3.5	-	9.8	10.5	-	4.0	16.8	9.6	-	12.8	15.0
Av.	1.1	-	5.0	3.0	-	1.5	7.2	1.7	-	3.7	3.9
Shikohabad											
Min.	0.4	-	2.2	0.3	-	1.6	Nil	0.4	-	Nil	0.5
Max.	2.2	-	14.6	12.0	-	3.2	14.8	9.4	-	10.2	9.8
Av.	0.6	-	5.3	3.5	-	1.3	4.2	1.7	-	2.9	3.6
Firozabad											
Min.	0.6	7.6	1.8	1.2	-	Nil	0.8	0.4	-	Nil	0.8
Max.	2.7	9.5	8.4	24.0	-	4.4	12.8	6.6	15.8	9.0	15.6
Av.	1.2	8.9	4.2	8.4	-	1.0	5.8	1.5	4.4	2.7	6.1
Tundla											
Min.	0.7	7.8	1.8	1.6	-	Nil	1.4	0.4	1.4	Nil	0.1
Max.	12.5	10.0	60.2	89.8	-	7.2	20.8	52.4	133.0	14.6	34.4
Av.	2.1	8.8	6.7	16.4	-	2.3	6.2	4.1	11.1	3.6	9.2
Madanpur											
Min.	0.3	7.4	1.8	0.2	-	NIL	1.4	0.6	Nil	Nil	Nil
Max.	2.5	9.2	10.0	24.0	-	3.6	12.4	6.0	20.4	9.0	12.8
Av.	1.1	8.5	4.6	6.6	-	1.1	5.3	1.3	3.5	2.0	4.4
Narkhi											
Min.	0.6	8.0	2.0	1.8	-	Nil	2.4	0.6	Nil	Nil	1.0
Max.	8.6	9.2	38.4	62.5	1.7	3.2	14.0	51.2	71.6	11.0	18.3
Av.	1.8	8.5	7.1	13.1	0.7	1.1	6.3	5.3	5.5	2.7	6.7
Jasrana											
Min.	0.6	8.0	1.2	0.5	-	Nil	3.0	0.6	Nil	Nil	0.2
Max.	12.4	9.5	40.0	107.5	2.5	3.6	13.8	52.6	100.4	11.6	32.6
Av.	1.7	8.6	6.2	13.9	0.2	1.5	7.2	4.5	6.6	3.7	7.4
Hathwant											
Min.	0.5	7.3	1.2	2.0	0.1	Nil	2.0	0.6	Nil	Nil	1.2
Max.	15.5	9.5	74.2	135.0	8.4	3.6	11.8	107.0	152.2	10.2	30.0
Av.	2.6	8.8	9.0	22.9	0.3	1.3	7.1	10.7	12.1	3.2	9.5
Eka											
Min.	0.2	7.0	1.6	0.2	-	Nil	1.4	0.2	Nil	Nil	0.1
Max.	4.2	8.5	23.2	37.5	6.2	2.0	14.4	24.0	22.7	12.0	27.9
Av.	1.2	8.0	4.2	9.6	0.5	0.5	6.4	2.9	4.8	3.3	6.4

The highest EC value of 15.5 dS/m was recorded in Hathwant block followed by 12.5 dS/m in Tundla and 12.4 dS/m in Jasrana block. The minimum EC value ranged between 0.3-0.7 dS/m in different blocks. The average EC ranged from 0.6 to 2.6 dS/m only. In case of RSC highest value (i.e.14.6 meq/l) was found in Tundla block followed by Aroun block (i.e.12.8 meq/l). The average RSC value ranged between 2.0 to 3.7 meq/l. The highest SAR value (34.4 mmol/l) $^{1/2}$ was also found in Tundla block. In rest of the blocks, it did not exceed 15 $(mmol/l)^{1/2}$. The average SAR value ranged from 3.9 to 9.5 $(mmol/l)^{1/2}$ in different blocks. The cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) were assessed in different EC_{iw} classes and found that Na^{+} and Mg^{++} increased with increase in EC_{iw} and rate of increase of Na^{+} was higher at higher EC_{iw} value. The Ca^{++} also increased but in narrow range i.e. from 0.7 to 9.7 meq/l up to EC_{iw} class more than 10.0 meq/l whereas the Mg^{++} and Na^{+} in this EC_{iw} class, increased up to 40 and 115 meq/l. The cationic order of groundwater was $Na^{+} > Mg^{++} > Ca^{++}$. The K^{+} ion do not have any link with EC_{iw}. The CO_3^{2-} and HCO_3^{-} anions remain almost constant throughout ECiw classes from <1 to >10 dS/m. However, the Cl^{-} and SO_4^{--} anions increased with EC_{iw} classes almost in similar proportion. The SO_4^{--} remained dominant over Cl^{-} in all the EC_{iw} classes in all blocks except Araon and Shikohabad. Thus, ground waters of the district are SO_4^{--} dominated except Araon and Shikohabad.

The frequency distribution of water samples in different EC, RSC and SAR classes are presented in Table 5.2. The data revealed that 50 per cent of samples of all blocks except Tundla block had EC below 1.5 dS/m. In Aroun, Shikohabad and Firozabad blocks such samples (with EC < 1.5 dS/m) were around 90 per cent. Maximum numbers of samples in EC_{iw} 1.5-3.0 class were in Tundla block (50 per cent) while ground samples in this class ranged between 20-23.5 per cent in Narkhi, Hathwant and Jasrana blocks. The groundwater samples in EC_{iw} 3 to 10 dS/m class were found as 5.6, 13.4, 14.4, 12.5 and 22.2 per cent in Eka, Tundla, Narkhi, Jasrana and Hathwant block, respectively.

RSC problem is common in all the blocks with varying magnitude. Around 18 to 24 per cent ground water samples in Tundla, Madanpur, Narkhi, Jasrana and Hathwant blocks were without RSC problem. Groundwater samples without RSC varied in range of 3- 6 per cent of total samples in remaining blocks (i.e. Aroun and Firozabad). In RSC class 0-2.5 meq/l, groundwater samples in the blocks ranged from 14.1 to 52.1 per cent where maximum was in Madanpur and minimum was in Jasrana block. In case of RSC class (2.5 to 5.0 meq/l), groundwater samples in different blocks varied from 22.1 per cent (Madanpur) to 42.6 percent (Eka). The RSC class (i.e. 5-10 meq/l) samples in different blocks ranged from 8 -32.6 per cent with maximum 32 per cent in Jasarana block and minimum 8 per cent in Madanpur block.

The groundwater samples under SAR class having value less than 10 $(mmol/l)^{1/2}$ varied from 63.5 to 100 per cent with minimum in Hathwant block and maximum in Shikohabd. The class (10-20) samples varied from 4 to 38.1 per cent with minimum in Aroun block and maximum in Tundla block. The samples under SAR Class (20-30 $(mmol/l)^{1/2}$) varied from 3.3 to 9.5 meq/l with minimum in Eka block and maximum in Hathwant block. Many blocks did not have samples in this category as given in Table 5.2.

The irrigation water samples were divided into different irrigation water classes considering EC, RSC and SAR and block wise distribution of samples in different classes is provided in Table 5.3. The spatial distribution of these classes in different blocks is shown in Fig. 5.2.

Table 5.2: Frequency distribution of irrigation water of Firozabad district with respect of EC, RSC and SAR classes

Blocks	Particulars														
	EC class (dS/m)					RSC class (meq/l)					SAR class $(mmol/l)^{1/2}$				
	0-1.5	1.5-3.0	3.0-5.0	5.0-10.0	>10.0	Absent	0-2.5	2.5-5.0	5.0-10.0	>10	0-10	10-20	20-30	30-40	>40
Aroun															
No. of samples	114	9	2	-	-	7	34	54	27	3	120	5	-	-	-
percent	91.2	7.2	1.6	-	-	5.6	30.4	40.0	21.6	2.4	96.0	4.0	-	-	-
Shikohabd															
No. of samples	109	9	-	-	-	17	42	34	23	2	118	-	-	-	-
percent	92.4	7.6	-	-	-	14.4	35.6	28.8	19.5	1.7	100.0	-	-	-	-
Firozabad															
No. of samples	136	19	-	-	-	6	75	58	16	-	137	18	-	-	-
percent	87.7	12.3	-	-	-	3.9	48.4	37.4	10.3	-	88.4	11.6	-	-	-
Tundla															
No. of samples	49	67	11	5	2	32	26	34	36	6	77	51	5	1	-
percent	36.6	50.0	8.2	3.7	1.5	23.9	19.4	25.4	26.9	4.5	57.5	38.1	3.7	0.7	-
Madanpur															
No. of samples	115	25	-	-	-	25	73	31	11	-	132	8	-	-	-
percent	82.1	17.9	-	-	-	17.9	52.1	22.1	7.9	-	94.3	5.7	-	-	-
Narkhi															
No. of samples	85	28	10	9	-	32	36	44	19	1	107	25	-	-	-
percent	64.4	21.2	7.6	6.8	-	24.2	27.3	33.3	14.4	0.8	81.1	18.9	-	-	-
Jasrana															
No. of samples	82	30	11	4	1	24	18	43	41	2	109	13	5	1	-
percent	64.1	23.4	8.6	3.1	0.8	18.7	14.1	33.6	32.0	1.6	85.2	10.1	3.9	0.8	-
Hathwant															
No. of samples	72	26	11	11	6	28	26	41	30	1	80	34	12	-	-
percent	57.2	20.6	8.7	8.7	4.8	22.2	20.6	32.6	23.8	0.8	63.5	27.0	9.5	-	-
Eka															
No. of samples	97	18	7	-	-	7	39	52	22	2	103	15	4	-	-
percent	79.5	14.8	5.7	-	-	5.7	32.0	42.6	18.0	1.6	84.4	12.3	3.3	-	-
Average of district															
No. of samples	859	231	52	29	9	178	369	391	225	17	983	169	26	2	-
percent	72.8	19.6	4.4	2.5	0.8	15.1	31.3	33.1	19.1	1.4	83.3	14.2	2.4	0.2	-

Table 5.3: Distribution of water samples in different irrigation water quality classes in Firozabad district

S. No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Aroun	125	33.6	0.8	-	-	33.6	29.6	2.4
2	Shikohabad	118	45.7	5.1	-	-	18.6	30.5	-
3	Firozabad	155	50.3	-	-	-	24.5	17.4	7.8
4	Tundla	134	30.6	3.3	0.8	7.5	10.4	17.2	29.8
5	Madanpur	140	65.0	2.9	-	-	17.1	10.7	4.3
6	Narkhiu	132	31.8	5.3	2.3	12.9	21.2	20.5	6.0
7	Jasrana	128	18.7	8.6	1.6	4.7	26.6	32.0	7.8
8.	Hathwant	126	19.9	2.4	0.8	21.4	22.2	22.2	11.1
9.	Eka	122	32.8	1.6	-	4.1	32.8	18.9	9.8
Firozabad district		**1180**	**36.5**	**3.3**	**0.6**	**5.6**	**23.0**	**22.1**	**8.8**

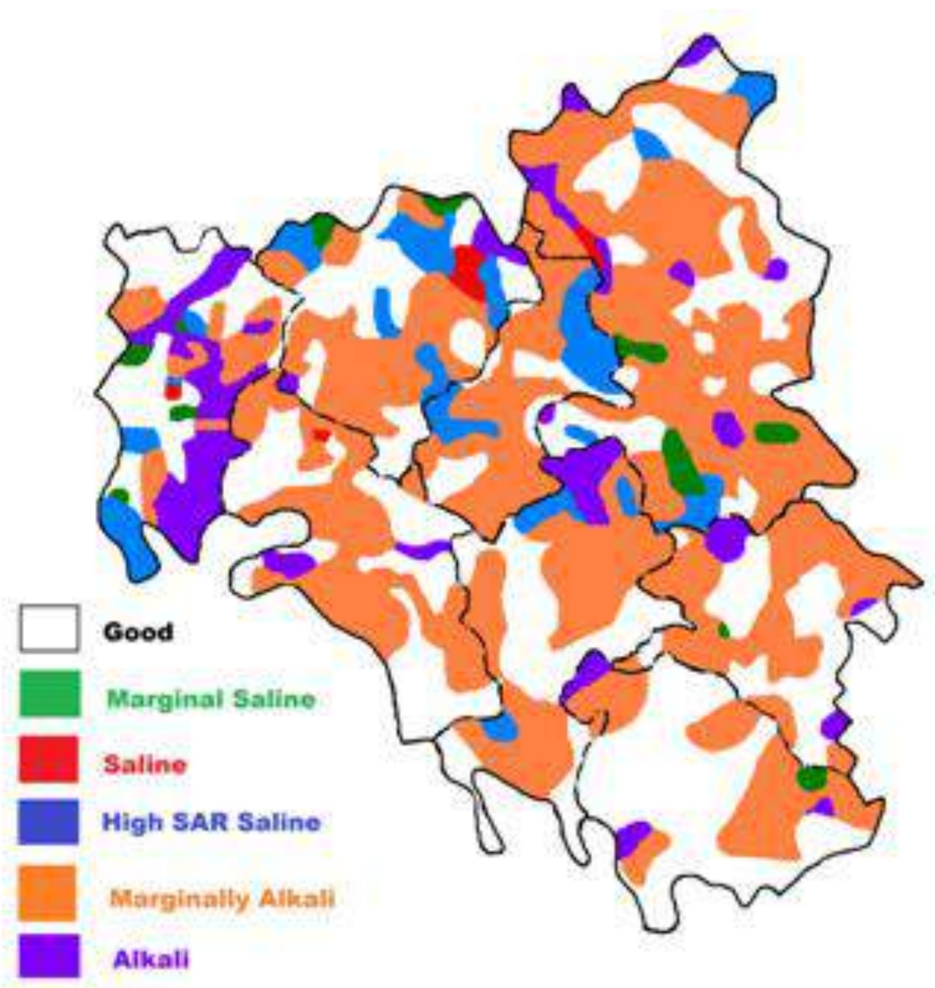

Fig. 5.2: Water quality map of Firozabad district

Out of total groundwater samples, 36.5 per cent samples were of good quality, 9.5 per cent samples were saline and 53.9 per cent samples were alkali. Within saline type of groundwater, 3.3, 0.6 and 5.6 per cent samples beloned to marginally saline, saline and high SAR saline class, respectively. Within alkali type of groundwater, 23.0, 22.1 and 8.8 per cent samples belonged to alkali, marginally alkali and high alkali, class, respectively. It indiacted that the problem of alkali water is much higher compared to saline type of waters in the district.

Among the different blocks good quality groundwater samples ranged from 18.7 per cent in Jasrana and 65 per cent in Madanpur. Also in case of saline type of waters, per cent of samples ranged from 0 (i.e. in Firozabad block) to 24.6 per cent (i.e. Hathwant block). Alkali types of water samples were lowest (i.e. 32.1 per cent) in Madanpur block while highest in Jasrana block (i.e. 66.4 per cent). Surprisingly, five blocks (namely, Aroun, Tundla, Jasrana, Hathwant and Eka) were having more 50 per cent alkali waters. Three blocks namely, Shikohabad, Firozabad and Narkhiu were having alkali water samples close to 50 per cent; ranging from 47.7 to 49.7 per cent.

Fluoride:

The Fluoride in groundwater was also determined in presented in Table 5.4. Except Tundla and Hathwant block more than 90 per cent samples were having Fluoride less than 2.5 ppm. Around 26 per cent ground waters in Tundla and 16 per cent in Hatwant had Fluoride between 2.5-5.0 ppm, whereas in rest of the blocks less than 10 per cent samples belonged to this class. In Shikohabad 3.6 per cent samples and in Hathwant 4.8 per cent water contained Fluoride between 5.0-7.5 ppm class. In Hathwant block 2.4 per cent samples had Fluoride between 7.5 -10.0 ppm. The highest average values i.e. 1.61 and 1.87 ppm was recorded in Tundla and Hathwant block, respectively.

Table 5.4: Frequency distribution of irrigation water of different blocks and range of Fluoride (ppm) in Firozabad district

F Classes (ppm)	Shikohad	Firozabad	Tundla	Madan-pur	Narkhi	Jasrana	Hathwant	Eka
0-2.5	92.9	98.1	74.1	90.7	96.2	90.6	77.0	94.3
2.5-5.0	3.6	1.9	26.0	9.3	3.8	8.6	15.9	5.7
5.0-7.5	3.6	-	-	-	-	0.8	4.8	-
7.5-10.0	-	-	-	-	-	-	2.4	-
>10.0	-	-	-	-	-	-	-	-
Min.	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Max.	7.0	2.2	3.45	3.45	3.5	5.12	8.37	4.37
Ave.	1.12	0.89	1.61	1.49	1.07	1.25	1.87	1.25

Nitrate:

Nitrate in groundwater samples was also analysed and it was found that only 1 per cent samples had nitrate. In these samples, nitrate ranged from 0.1 to 3.0 meq/l.

6. GROUNDWATER QUALITY OF MAINPURI DISTRICT

6.1 Introduction

The Mainpuri is the district of Agra division of Uttar Pradesh. It is bounded on the North by Etah District, on the East by District Farrukhabad and Kannauj, on the South by District Etawah and on West by the District Firozabad and Etah. The location map of the district is shown in Fig. 6.1. It lies between North Latitude 26^0 53' to 27^0 31' and East Longitude 78^0 27' to $79^0$26'. The geographical area of district is 2745 km^2. Major Physiographic units of the district are Central Ganga alluvial plain which is sub divided in Older and Newer alluvial plain. The terrain has gentle slope from north-west to south-east with a gradient of 0.2 m/km. The district has has three Tehsils i.e. Mainpuri, Karhal and Bhogaon. It is further divided into nine developmental blocks for better developmental activities. The Mainpuri tehsil contains three blocks i.e Ghiror, Kurawali and Mainpuri, the Karhal tehsil includes two blocks i.e. Barnahal and Karhal whereas the Bhogaon tehsil have four blocks as Elau, Bhogaon, Bewar and Kishani.

Fig. 6.1: Location of Mainpuri district

The Mainpuri district is part of Ganga basin and forms a part of Ganga Yamuna Doab, covering the parts of Kali, Isan, Arind and Sengar watersheds. The area is drained by Kali, Arind, Sengar and Isan rivers and their tributaries which flow from North West to south east direction. These streams generally follow a meandering course through narrow flood plains. Both Kali and Isan rivers are the tributaries of Ganga

River, where as Arind and Sengar rivers are the tributaries of Yamuna River. The gross cultivable area and net sown area of the district is 201620 and 194866 ha, respectively. The forest area is 1745 ha. The net irrigated area is 192144 ha and gross irrigated area is 339274 ha. Both surface and ground water being used for irrigation in the area. Approximately 70 per cent (192144 ha) land of the total area is covered by various irrigation methods, out of which 26 per cent area is irrigated by surface water and remaining 74 per cent by ground water. Three main branches of Lower Ganga Canal System namely Bewar Branch, Kanpur Branch and Etawah Branch pass through district and substantial length (1014 km) of canal network contributes to irrigate in all the three tehsils of the district. The normal rainfall in Mainpuri district is 732.3 mm (1901-1970 records) of which 88 percent is contributed from monsoon season (June to September) and remaining 12 per cent rainfall occur during non-monsoon period. The climate of the district is sub-humid and characterized by hot summer and bracing cold season. After February, there is continuous increase in temperature till May which is generally the hottest month. The mean daily maximum temperature in May is 42.2 ^{0}C and the mean daily minimum is 26.2 ^{0}C. Maximum temperature rises up to over 46 ^{0}C. With arrival of the monsoon in June, there is an appreciable drop in the day temperature. The minimum temperature during December-January is as low as 7.4^{0}C. The potential evapo-transpiration is 1437.7 mm.

The alluvial soils in district are originated from Ganges and its tributaries. Textural classes vary from Sandy-loam to Silty –clay-loam. The *Kharif* crops like paddy, bajara, maize and groundnut are cultivated on 89318, 14879, 56329 and 209 ha with productivity as 25.07, 19.23, 23.75 and 7.35 q/ha. The rabi crops such as wheat, barley, gram, field pea, mustard /toria and potato are cultivated on 143712, 2415, 954, 1313, 9683 and 16402 ha with productivity as 33.52, 30.52, 9.99, 12.03, 16.47 and 196.43 q/ha. The summer crops such as groundnut, *moong*, *urd*, Onion and spring maize are cultivated on 36000, 2899, 1300, 350 and 9750 ha with productivity as 26.15, 8.62, 8.97, 225.00 and 44.50 kg/ha (KVK-Mainpuri, 2015). The shallow water level conditions along the lower Ganga canal system at places led to formation of *usar* (*Reh*) as is evident in Karhal tehsil and at some villages in Mainpuri and Bhogaon tehsils. The mainpuri tehsil, in particular is highily infested with alkalinity.

As mentioned earlier, the entire area is underlain by Quaternary alluvium comprising mainly clay, Kankar, sand and gravel over the basement of Pre- Cambrian Vindhyan formation. Different grades of sand and gravel form the multi-aquifer system in the area. Ground water occurs under water table condition in phreatic zones and under semi-confined to confined condition in deeper zones. In canal command area, falling in Kurawali, Sultanganj, Bewar, Mainpuri and some parts of Karhal block, the depth to water level rests between 2.0 and 4.0 m bgl during pre-monsoon period due to seepage from the various distributaries of lower Ganga canal system. Some parts of Ghiror, Kurawali, Sultanganj, Bewar and Karhal blocks are prone to water logging during post monsoon period also. The shallow water level conditions along the lower Ganga canal system at places led to formation of usar (Reh) as is evident in Karhal tehsil and at some villages in Mainpuri and Bhogaon tehsils. The mainpuri tehsil, in particular is highly infested with alkalinity.

The district is underlain by Quaternary alluvium comprising mainly clay, Kankar, sand and gravel over the basement of Pre- Cambrian Vindhyan formation. Different grades of sand and gravel form the multi-aquifer system in the area. Ground water occurs under water table condition in phreatic zones and under semi-confined to confined condition in deeper zones. An approximately 70 m thick aquifer zone lies at a depth range of 30 m bgl which is regionally extensive. This zone bifurcates towards NW-NE directions, giving rise to a multiple sand layer in Mainpuri and Bhogaon area at different depths levels. Two to three sand beds are inter layered with clay and Kankar beds in discrete manner (Joshi, 2013).

As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Mainpuri district is assessed as 90795.09 ha m. The annual extractable groundwater resource is assessed as 86255.34 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 55983.23 and 4191.23 ha m. Thus existing gross annual ground water draft for all uses is 60174.46 ha m and the stage of groundwater extraction for Mainpuri district is 69.76 per cent. Among different blocks of Mainpuri district, Jageer and Mainpuri are semi-critical and Baranahal are over exploited. Remaining blocks such as Kurawali, Ghiror, Karhal, Elau, Bhogaon, Bewar and Kishani are safe. Pre-monsoon and post-monsoon water level data are collected by CGWB during May and November month, respectively. Fairly a large area has shallow to moderate depth of water table. Depth to water level generally varies between 1.27 to 9.00 mbgl in the area. However, exceptionally very deep depth to water table was recorded at Barnahal well where it was about 24.50 m bgl during Pre-monsoon and 24.15 m bgl during post monsoon period of 2012.

6.2 Groundwater Quality Survey, Characterization and Mapping

The 1014 groundwater samples were collected from different locations in nine blocks viz. Kurawali, Ghiror, Mainpuri, Barnahal, Karhal, Elau, Bhogaon, Bewar and Kishani of the district and were analyzed for cations and anions during 2003. The water quality parameters of samples were used for characterization of samples into different irrigation water classes and mapping at spatial scale. The mean quantum of different cations and anions in relation to different EC classes were determined and presented in Fig. 6.2. Amongst the cations, the Ca+Mg and Na increased with EC class where as K did not show any relation with EC. The Na dominated in all EC classes and increased with EC class. However, Ca+Mg increased proportionately in low proportion after EC classes 6-7 dS/m. Similar to cations, the Cl and SO_4 also increased with EC class. Contrarily, the CO_3 and HCO_3 anions did not have any relation with EC class. However, upto EC 2 dS/m the HCO_3 dominated. Later on Cl and SO_4 were dominant. Further it was observed that upto EC 7 dS/m, the SO_4 dominated and beyond EC 9 dS/m the Cl dominated.

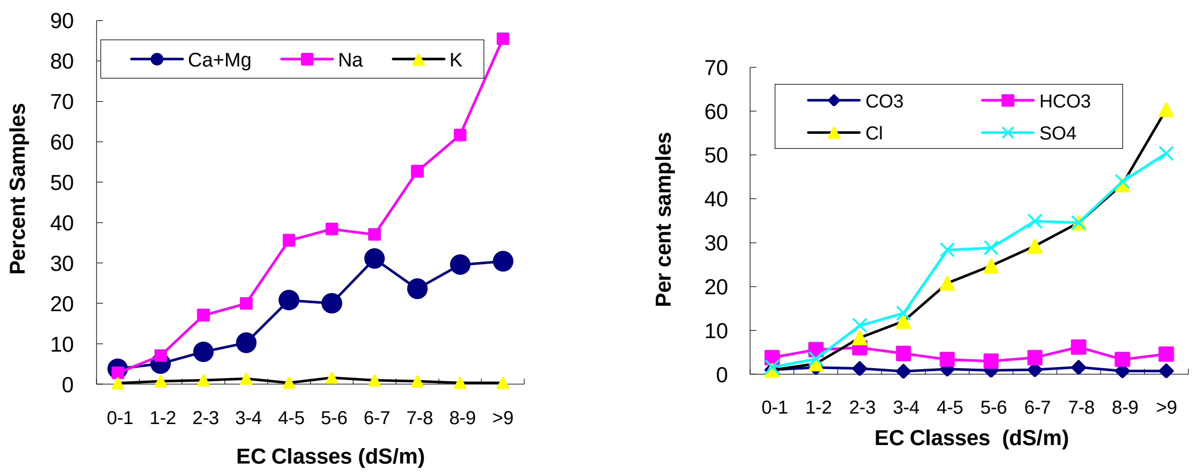

Fig. 6.2: Average cationic and anionic composition with respect to EC classes of Mainpuri district

The ranges and mean values of different water parameters viz. EC, pH, RSC and SAR are presented in Table 6.1. The maximum EC value was recorded in Elau block i.e. 10.7 dS/m and minimum EC value was < 1 dS/m in all the blocks. Similarly the highest and lowest average value was recorded in Elau (1.50

dS/m) and Bewar (0.75 dS/m), respectively. Regarding RSC value, it was observed that highest RSC 11.7 me/l was found in Kurawali. The highest average RSC value of 2.6 meq/l was recorded in Elau and Kishani block and lowest of 1.0 me/l was observed in Bewar block. The maximum value of SAR ranged from 46.6 in Elau block to 4.1 $(mmol/l)^{1/2}$ in Bewar and lowest SAR value was below 1.2 $(mmol/l)^{1/2}$ in all the blocks.

Table 6.1: Range and mean of quality parameters of groundwater of different blocks of Mainpuri district

Blocks	EC (dS/m)	pH	RSC(me/l)	SAR $(mmol/l)^{1/2}$
Kurawali				
Min.	0.34	8.1	Nil	0.1
Max.	5.07	9.6	11.7	29.1
Average	0.93	8.7	1.5	3.7
Ghiror				
Min.	0.47	8.1	Nil	0.5
Max.	2.46	9.0	5.1	9.1
Average	0.84	8.4	1.2	3.3
Mainpuri				
Min.	0.38	7.8	Nil	0.1
Max.	3.08	9.1	3.8	12.8
Average	0.94	8.2	1.4	3.0
Barnahal				
Min.	0.44	7.6	Nil	1.2
Max.	6.60	8.7	6.2	7.8
Average	1.01	8.2	1.8	3.1
Karhal				
Min.	0.27	7.6	Nil	0.2
Max.	2.50	9.0	7.8	12.3
Average	0.80	8.4	2.2	2.7
Elau				
Min.	0.35	7.6	Nil	0.3
Max.	10.70	9.4	6.6	46.6
Average	1.50	8.4	2.6	5.4
Bhogaon				
Min.	0.21	7.6	Nil	0.1
Max.	2.50	8.7	9.0	12.6
Average	0.80	8.1	2.1	3.9
Bewar				
Min.	0.47	7.0	NIL	0.9
Max.	1.35	8.4	4.2	4.1
Average	0.75	7.64	1.0	1.58
Kishani				
Min.	0.63	7.5	NIL	1.1
Max.	3.60	8.5	7.2	12.5
Average	1.16	8.0	2.6	3.26

The frequency distribution of groundwater samples is presented in Table 6.2. The data revealed that more than 90 per cent samples in Ghiror, Mainpuri, Barnahal, Karhal, Bhogaon, whereas 100 per cent in Bewar block were with EC below 1.5 dS/m. However in Elau Block only 78.1 percent samples were in this class while 86.7 per cent samples of Kishani block were below 1.5 dS/m. The percent of groundwater samples in 1.5-3.0 dS/m in different blocks varied from 1.8 to 11.5 per cent with minimum in Barnahal while maximum in Kurawali block. The water samples in 3.0 -5.0 dS/m class were not present in all blocks. This class was observed in Kurawali, Elau and Kishani block with per cent of samples as 1.9, 2.7 and 3.3, respectively. The water samples having EC in between 5-10 dS/m were recorded as 1.8 per cent in Barnahal and 6.8 per cent in Elau block. Only Elau block, 1.3 per cent ground water samples had EC above EC 10 dS/m. Regarding RSC value, it was found that 15-25 per cent samples in Kurawali, Ghiror, Barnahal, Elau, Bhogaon blocks did not have any RSC value and in Karhal block such samples were only 2.3 per cent. However, 45.9 and 36.9 per cent samples of Mainpuri and Bewar, respectively, were without RSC. The RSC class with 0-2.5 meq/l, percent samples in different blocks varied from 45.9 to 65.7 per cent with minimum in Mainpuri and Ghiror block, respectively. The RSC class with 2.5-5.0 meq/l, per cent samples in different blocks varied from 2.3 to 30 per cent with minimum and maximum in Bewar and Karhal block, respectively. The RSC Class 5.0-10.0 meq/l was absent in Mainpuri and Bewar. In remaining blocks, percent of samples varied from 0.9 to 10.0 with minimum in Ghiror and maximum in Kishani, respectively. Only 1.9 per cent samples of Kurawali block were having RSC > 10.0 meq/l and other blocks were not having such type of samples. The SAR data showed that high SAR was not common feature in most of the blocks. In majority blocks, about 90 per cent and more samples had SAR below 10 $(mmol/l)^{1/2}$. In Kurawali, Karhal, Bhogaon, Elau and Kishani blocks, only less than 8.2 per cent samples which had SAR between10-30 $(mmol/l)^{1/2}$. Only Elau block had 2.8 percent samples with SAR above 30 $(mmol/l)^{½}$.

Table 6.2: Frequency distribution of irrigation water of different blocks of Mainpuri District with respect of EC, SAR and RSC classes

Particulars	Kurawali (104)	Ghiror (108)	Mainpuri (135)	Barnahal (110)	Karhal (130)	Elau (73)	Bhogaon (104)	Bewar (130)	Kishani (120)
EC Classes (dS/m)									
0-1.5	86.5	95.4	90.4	96.4	96.9	78.1	93.3	100	86.7
1.5-3.0	11.5	4.6	9.6	1.8	3.1	11.0	6.7	-	10.0
3.0-5.0	1.9	-	-	-	-	2.7	-	-	3.3
5.0-10.0	-	-	-	1.8	-	6.8	-	-	-
>10.0	-	-	-	-	-	1.3	-	-	-
RSC Classes (me/l):									
Absent	25.0	20.4	45.9	20.0	2.3	20.5	16.4	36.9	10.0
0-2.5	55.8	65.7	45.9	61.8	62.3	49.3	60.6	60.8	51.7
2.5-5.0	13.5	12.9	8.2	14.5	30.0	21.9	19.2	2.3	28.3
5.0-10.0	3.9	0.9	-	3.7	5.4	8.2	3.8	-	10.0
>10.0	1.9	-	-	-	-	-	-	-	-
SAR Classes $(mmol/l)^{1/2}$:									
0-10	93.2	100	98.5	100.0	97.7	89.0	94.2	100	97.5
10-20	3.9	-	1.5	-	2.3	6.8	5.8	-	2.5
20-30	2.9	-	-	-	-	1.4	-	-	-
30-40	-	-	-	-	-	1.4	-	-	-
>40	-	-	-	-	-	1.4	-	-	-

Fluoride: As given in Table 6.3, except Elau block more than 90 per cent samples had F less than 2.5 ppm. About 14 per cent in Elau block have F between 2.5-5.0 ppm, while in rest of the blocks less than 5 per cent samples were having F in this class. In Bhogaon block only 1 per cent samples had F above 5 ppm.

Lithium: As given in Table 6.3, in all the blocks of the district more than 90 per cent samples had Lithium below 2.5 ppm, 9.5 per cent in Ghiror and 8.2 per cent in Elau had Lithium between 2.5 –5.0 ppm while in rest of the blocks less than 5 per cent samples came in this class. Less than 3 per cent samples in most of the blocks had Lithium 5-7.5 ppm. In Mainpuri and Karhal blocks 1 per cent and 2.3 per cent samples were found in above 10 ppm class.

Table 6.3: Frequency distribution of Fluoride and Lithium in groundwater of Mainpuri District

Particulars	Kurawali (104)	Ghiror (108)	Mainpuri (135)	Barnahal (110)	Karhal (130)	Elau (73)	Bhogaon (104)	Bewar (130)	Kishani (120)
Fluoride (ppm)									
0-2.5	96.1	97.2	100.0	99.1	100.0	86.3	94.2	100.0	96.7
2.5-5.0	3.9	2.8	-	0.9	-	13.7	4.8	-	3.3
5.0-7.5	-	-	-	-	-	-	-	-	-
7.5-10.0	-	-	-	-	-	-	1.0	-	-
>10.0	-	-	-	-	-	-	-	-	-
Lithium (ppm)									
0-2.5	95.2	91.7	99.2	96.4	90.0	91.8	92.3	-	-
2.5-5.0	1.9	9.5	-	0.9	4.6	8.2	4.8	-	-
5.0-7.5	2.9	1.8	-	2.7	0.8	-	1.9	-	-
7.5-10.0	-	-	-	-	2.3	-	1.0	-	-
>10.0	-	-	0.8	-	2.3	-	-	-	-

() Number indicates samples

The groundwater samples of different blocks were divided into different water quality classes and data are presented in Table 6.4. The distribution of different water quality classes in Mainpuri district revealed that 78.2 percent samples were of good quality. In salinity category, 2.1 per cent are marginally saline, 0.20 per cent saline and 1.30 per cent high-SAR saline. Further, in alkali classes, 11 percent are marginally alkali, 5.5 per cent alkali and only 1.4 per cent samples were of high alkali. The spatial distribution of these classes in different blocks is shown in Fig. 6.3.

Table 6.4: Distribution of water samples in different water quality ratings of Mainpuri district

S.No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Kurawali	104	83.6	-	-	1.9	4.8	2.9	6.7
2	Ghiror	108	97.2	1.9	-	-	-	0.9	-
3	Mainpuri	135	85.9	4.4	-	1.5	7.4	0.7	-
4	Barnahal	110	82.7	-	1.8	-	15.4	-	-
5	Karhal	130	63.8	0.8	-	-	20.8	14.6	-
6	Elau	73	57.5	6.8	-	5.5	16.4	8.2	5.5
7	Bhogaon	104	74.0	-	-	3.9	15.4	5.8	1.0
8.	Bewar	130	98.4	-	-	-	0.8	0.8	-
9.	Kishani	120	58.3	4.2	-	-	19.2	15.8	2.5
Mainpuri district		**1014**	**78.2**	**2.1**	**0.2**	**1.3**	**11.0**	**5.5**	**1.4**

The data showed that majority ground water samples (84-98.4 percent) were in good quality except Karhal had 64 per cent, Elau 57.5 per cent and Bhogaon 74 per cent samples under good quality. The salinity problem was not of much magnitude in different blocks. The Elau block only had 6.8 percent samples under marginally saline and 5.5 per cent samples under high SAR saline. The alkali problem was variable in general and also with respect to classes in different blocks. The marginal alkali water ranged from 0.8 to 20.8 percent with minimum in Bewar block while maximum in Karhal block. In alkali class, the highest water samples i.e. 15 percent were recorded in Karhal followed by 8 percent in Elau and 6 percent in Bhogaon block. The waters having high alkali problem were observed in Kurawali with 6.7 percent and Elau with 5.5 percent. In general, the water samples of Mainpuri district is infested with alkali problem.

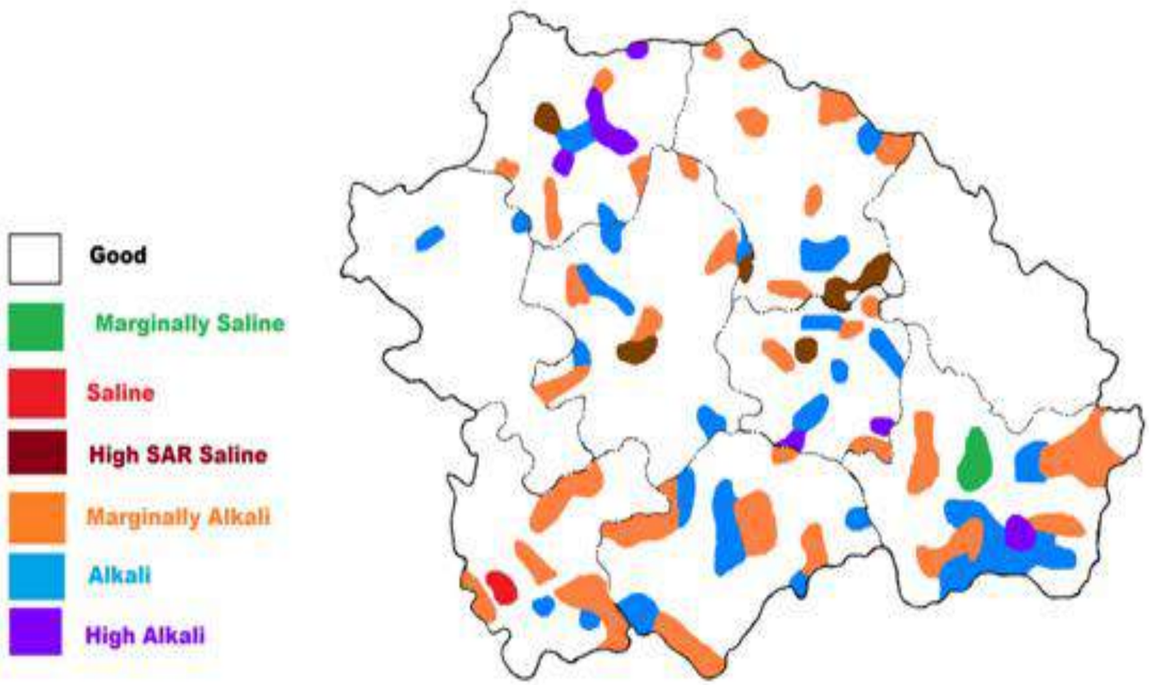

Fig. 6.3: Water quality map of Mainpuri district

7. GROUNDWATER QUALITY OF ETAWAH DISTRICT

7.1 Introduction

Etawah district is located in the western portion of Uttar Pradesh. It lies between North latitude $26^0$21’ to 27^0 01’ and 78° 45’ to $79^0$45’ at an average elevation of 197 m (456 ft). It is a parallelogram in shape with 70 km north-south and 66 km east-west on one side and 24 km on the other side (Fig. 7.1). Etawah is bounded by Farrukhabad and Mainpuri districts on north, to small extent Agra district on west. The district of Auraiya is on the eastern side and Jalaun and Gwalior district in south, the division line being, except for a short distance, the rivers of Chambal and Yamuna. The total area of the district is 2434 km^2. It has 8 blocks namely Saifai, Jaswant Nagar, Badhpura, Basrehar, Bharthana, Takha, Mahew and Chakarnagar. Major Physiographic units of the district are a) Upland doab region; b) Slightly undulating region; and c) Ravines. The area is drained by Yamuna and Chambal rivers. The district, a part of doab region of rivers Ganga and Yamuna, is generally plain area with minor undulation which slopes gently towards south-easterly direction. The gross cultivable area and net sown area of the district are 2414.38 and 147078 ha, respectively. The forest area is 30140 ha. The net irrigated area is 122252 ha and gross irrigated area is 182026 ha. Both surface and ground water being used for irrigation in the area. Approximately 50 per cent (122252 ha) land of the total area is covered by various irrigation methods. Out of which 50 per cent area is irrigated by surface water and remaining 50 per cent by ground water.

Fig.7.1: Location of the Etawah district in Uttar Pradesh

The climate of Etawah district is sub-humid and is characterized by a pleasant cold season and a hot dry summer. The average annual rainfall in the district is 792 mm. About 90 per cent of the annual normal rainfall is received by south-west monsoon during June to September. The August is wettest month and surplus water is available for deep percolation to ground water aquifers. In Etawah district, May is the hottest month with mean daily maximum temperature is 42.2^{0}C whereas the mean daily minimum temperature is 26.2^{0}C. There is steady increase in temperature after February and temperature reaches sometimes 46^{0}C or more in the month of May. Day and night temperatures decrease rapidly from November to January, which is usually the coldest month with the mean daily maximum temperature of 23^{0}C and the mean daily minimum temperature of 8^{0}C. The potential evapo-transpiration is 1431.7 mm. Soil types of the area are generally the same as occur in Ganga alluvial plain. Textural classes vary from Sandy to clay loam.

The principal *kharif* crops in the district are sorghum, paddy and maize. These are sown either alone or in combination with pigeon pea. The Kharif crops like pearl millet paddy, maize and pigeonpea are cultivated on 36586, 50571, and 4171 ha with productivity as 20.06, 27.09, 19.57 and 16.25 q/ha. The *rabi* crops such as wheat, mustard, gram, field pea and potato are cultivated on 94132, 11434, 3650, 1651 and 8676 ha with productivity as 37.62, 11.72, 17.71, 21.20, 16.47 and 254.25 q/ha. The summer crops such as groundnut, moong, and spring maize are cultivated on 17568, 20343, and 1496 ha with productivity as 17.23, 6.43, and 19.40 q/ha (KVK- Etawah, 2015).

The district occupies a part of Gangetic plain and is underlain by quaternary sediments consisting clay, silt, kankar and sand of different grade. These sediments are argillaceous in nature and relatively compact. The clays predominate over sandy horizon in older alluvium. The configuration of geological horizon controls the occurrence and movement of groundwater. The major granular zones (sand mixed with kankar and gravel) have been found at depth between 30 to 326 mbgl (m below ground level) in Etawah District (Kudesia, 2009). The entire area has a capping of clay/sandy clay beds with varying thickness. At some places sand lenses do occur within this clay bed. By and large a three tier aquifer system exists in the area. The first (main) aquifer exists over the entire southern part of the district at the depth ranging between 60-160 m below ground level. The thickness of this aquifer varies from 50 to 75 m. In the central parts of the district near Bharthana, this aquifer lies at the depth of 100 m below ground level. The second aquifer which is separated with overlying first aquifer by a prominent clay beds is encountered at a depth between 160-217 m below ground level. The quality of groundwater in this aquifer is better than first aquifer. Finally the third and deepest aquifer is met at around 218 mbgl and continues till the bedrock. The quality of groundwater in this aquifer is very poor.

The top silty/sandy clay bed mixed with kankar constitute the water table shallow aquifer generally caters the groundwater to the dug wells and the groundwater in this aquifer occurs under unconfined conditions. The first aquifer is extensively exploited through state and private tube wells. The groundwater in this aquifer occurs under semi-confined to confined conditions. The aquifer material is composed of sands of different grades with occasional clay lenses. In the second (middle) and third (deep) aquifers, the groundwater occur under confined conditions

During pre-monsoon period the depth to water table varies from 2.80 mbgl (in Bahadurpur) to 37.90 mbgl (in Barecha) in the district. In the post monsoon period the depth to water table varies from 2.22 mbgl (in Bahadurpur) to 37.75 mbgl (in Barechha) in the district. The fluctuation of water table ranges from 0.15 m to 0.58 m in the entire district (Source, Kudesia, 2009). As per dynamic groundwater resources assessment of India by (CGWB, 2017), total groundwater recharge from all sources for Etawah district is assessed as 87867.70 ha m. The annual extractable groundwater resource is assessed as 79080.93 ha m. The prevalent groundwater extraction for irrigation and domestic as well as industrial purpose are assessed as 27552.56 and 3215.51 ha m. Thus existing gross annual ground water draft for all uses is 30768.07 ha m and the stage of groundwater extraction for Etawah district is 38.91 per cent. All blocks of district are safe.

7.2 Groundwater Quality Survey, Characterization and Mapping

Total 730 groundwater samples were collected from different locations eight blocks in Saifai, Jaswant Nagar, Badhpura, Basrehar, Bharthana, Takha, Mahewa, Chakarnagar of the district were analyzed for cations and anions during 2011-12. The samples were collected mostly from December to March, when the maximum numbers of tube wells were under use for irrigation purpose. The ranges of irrigation water quality parameters such as EC, pH, SAR and RSC are presented in Table 7.1. The EC, pH, RSC and SAR ranged from 0.46 to 7.59 (dSm^{-1}), 8.9 to 9.5, Nil to 25.7 (meq/l) and 0.31 to 13.9 $(mmol/l)^{1/2}$ in Saifai block; 0.54 to 2.65 (dSm^{-1}), 7.7 to 8.5, Nil to 8.8 (meq/l) and 0.6 to 15.3 $(mmol/l)^{1/2}$ in Jaswant Nagar block; 0.8 to 6.65 (dSm^{-1}), 8.2 to 9.2, Nil to 11.0 (meq/l) and 0.9 to 41.7 $(mmol/l)^{1/2}$ in Badhpura block; 0.6 to 5.6 (dSm^{-1}), 8.0 to 9.2, Nil to 8.8 (meq/l) and 1.4 to 42.2 $(mmol/l)^{1/2}$ in Basrehar; 0.53 to 5.23 (dSm^{-1}), 7.4 to 9.0, Nil to 14.0 (meq/l) and 0.4 to 26.6 $(mmol/l)^{1/2}$ in Bharthana; 0.7 to 10.0 (dSm^{-1}), 7.6 to 9.1, Nil to 11.8 (meq/l) and 2.3 to 31.3 $(mmol/l)^{1/2}$ in Takha, 0.9 to 4.2 (dSm^{-1}), 7.7 to 9.1, Nil to 13.8 (meq/l) and 3.3 to 26.4 $(mmol/l)^{1/2}$ in Mahewa and 0.99 to 7.1 (dSm^{-1}), 8.0 to 9.3, Nil to 6.8 (meq/l) and 1.3 to 9.5 $(mmol/l)^{1/2}$ in Chakar Nagar block of Etawah district.

Table 7.1: Minimum and maximum values of different water constituents

Tehsils	EC (dSm^{-1})		pH		RSC (meq/l)		SAR $(mmol/l)^{1/2}$	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Saifai	0.46-7.59	1.15	8.9-9.5	8.9	Nil-25.7	2.9	0.31-13.9	3.05
Jaswant Nagar	0.54-2.65	1.0	7.7-8.5	8.3	Nil-8.8	3.6	0.6- 15.3	3.22
Badhpura	0.8-6.65	2.0	8.2-9.2	8.8	Nil-11.0	3.5	0.9- 41.7	11.8
Basrehar	0.6- 5.6	1.4	8.0-9.2	8.6	Nil- 8.8	2.3	1.4- 42.2	6.9
Bharthana	0.53-5.23	1.5	7.4-9.0	8.4	Nil-14.0	2.9	0.4-26.6	6.5
Takha	0.7-10.0	2.1	7.6-9.1	8.3	Nil-11.8	3.4	2.3-31.3	10.9
Mahewa	0.9-4.2	1.5	7.7-9.1	8.3	Nil-13.8	2.9	3.3-26.4	7.8
Chakarnagar	0.99-7.1	2.1	8.0-9.3	8.6	Nil-6.8	2.3	1.3-9.5	3.9

The distribution of water samples in different EC, SAR and RSC classes are presented in Table 7.2. The water samples having EC<1.5 dSm^{-1} were found 94 per cent in Saifai block and 96 per cent in Jaswant Nagar, 52.7 per cent in Badhpura, 74.5 per cent in Basrehar, 68.8 per cent in Bharthana , 42.3 per cent in Takha 60 per cent in Mahewa and 42.4 per cent in Chakar Nagar block. Further, the water samples having ECiw between 1.5-3.0 dSm^{-1} were 3.6 per cent in Saifai, 4 per cent in Jaswant Nagar, 30 per cent in Badhpura, 23.4 per cent in Basrehar, 24 per cent in Bharthana, 44.9 per cent in Takha, 36.8 per cent in Mahewa and 41.4 per cent in Chakar Nagar block. In EC_{iw} 3.0 to 5.0 dS/m class, per cent of ground water samples varied from 1.1 to 12.9 with minimum in Basrehar and maximum in Badhpura. The Saifai and Jaswant Nagar block did not have any sample in this class. In EC_{iw} 5.0-10.0 dS/m class, percent of ground water samples varied from 1.0 to 5.3 with minimum in Bharthana and maximum in Chakarnagar. The Mahewa and Jaswant Nagar block did not have any sample in this class. In case of class having EC_{iw} > 10 dS/m, only Takha block had 1.3 per cent samples.

Regarding RSC values, it was observed that only 4.8 per cent in Saifai, 1.0 per cent samples in Jaswant Nagar, 30.1 per cent in Badhpura, 14.9 per cent samples in Basrehar, 15.6 per cent in Bharthana, 19.2 per cent in Takha, 2.1 per cent in Mahewa and 14.1 per cent in Chakar Nagar block were found in absent category and the major category of RSC waters were found in 0-2.5 and 2.5-5.0 meq/l categories. In Saifai 54.2 per cent, Jaswant Nagar 33.3 per cent, Badhpura 34.4 per cent, Basrehar 41.5 per cent, Bharthana 33.3 per cent, Takha 38.5 per cent, Mahewa 56.8 per cent and in Chakar Nagar 52.2 per cent water samples having RSC up to 2.5 meq/l and 26.5 per cent in Saifai, 42.4 per cent in Jaswant Nagar, 15.1 per cent in Badhpura, 30.8 per cent in Basrehar, 25 per cent in Bharthana, 24.4 per cent samples in Takha, 28.4 per cent in Mahewa and 28.3 per cent in Chakar Nagar block came under 2.5-5.0 meq/l category. The high RSC (above 5.0 meq/l) waters were recorded in Saifai block with 14.5 per cent, Jaswant Nagar with 23.2 per cent, Badhpura with 20.4 per cent, Basrehar with 12.8 per cent, Bharthana with 26.1 per cent, Takha with 17.9 per cent, Mahewa with 12.7 per cent and Chakar Nagar with 5.4 per cent samples.

The SAR value was also determined and found that majority water samples; 96.4 per cent in Saifai, 99 per cent in Jaswant Nagar, 62.4 per cent in Badhpura, 86.2 per cent in Basrehar, 87.5 per cent in Bharthana, 61.5 per cent samples in Takha, 81.1 per cent samples in Mahewa and 100 per cent samples in Chakar Nagar block had SAR <10$(mmol/l)^{1/2}$ and 3.6 per cent in Saifai, 1.0 per cent in Jaswant Nagar, 20.4 per cent in Badhpura, 11.7 per cent in Basrehar, 8.3 per cent in Bharthana, 29.5 per cent samples in Takha and 16.8 per cent samples in Mahewa block came under category having SAR 10-20 $(mmol/l)^{1/2}$. Only 17.2 per cent samples in Badhpura, 2.2 per cent in Basrehar, 4.1 per cent samples in Bharthana, 8.4 per cent in Takha and 2.1 per cent samples in Mahewa block came under high SAR_{iw} 20 and above.

Table 7.2: Frequency distribution of water samples in different EC, RSC and SAR classes for different blocks of Etawah district

Particulars	Saifai (83)	J.Nagar (99)	Badhpura (93)	Basrehar (94)	Bharthana (96)	Takha (78)	Mahewa (95)	Chakarnagar (92)	Av. of Etawah
EC Classes (dS/m)									
0-1.5	94.0	96.0	52.7	74.5	68.8	42.3	60.0	42.4	66.3
1.5-3.0	3.6	4.0	30.1	23.4	24.0	44.9	36.8	41.4	26.0
3.0-5.0	-	-	12.9	1.1	6.1	10.2	3.2	10.9	5.6
5.0-10.0	2.4	-	4.3	1.1	1.0	1.3	-	5.3	1.9
>10.0	-	-	-	-	-	1.3	-	-	0.2
RSC Classes (me/l)									
Absent	4.8	1.0	30.1	14.9	15.6	19.2	2.1	14.1	12.7
0-2.5	54.2	33.3	34.4	41.5	33.3	38.5	56.8	52.2	43.0
2.5-5.0	26.5	42.4	15.1	30.8	25.0	24.3	28.4	28.3	27.6
5.0-10.0	13.3	23.2	18.3	12.8	19.8	14.1	10.6	5.4	14.7
>10.0	1.2	-	2.1	-	6.3	3.8	2.1	-	1.9
SAR Classes (mmol/1/2									
0-10	96.4	99.0	62.4	86.2	87.5	61.5	81.1	100	84.3
10-20	3.6	1.0	20.4	11.7	8.3	29.5	16.8	-	11.4
20-30	-	-	10.7	1.1	4.1	7.1	2.1	-	3.2
30-40	-	-	5.4	-	-	1.3	-	-	0.8
>40	-	-	1.1	1.1	-	-	-	-	0.3

The mean quantum of different cations and anions in relation to different EC_{iw} classes are determined and presented in Table 7.3 and Fig. 7.3.

Table 7.3: Cations and anions with respect to EC classes in different blocks of Etawah district

Blocks	EC (dS/m)	Cations				Anions			
		Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
Saifai	0-2	1.0	2.7	4.4	0.1	5.6	5.6	1.0	0.1
	2-4	0.9	2.4	3.1	0.1	1.5	4.5	1.0	0.2
	4-6	-	-	-	-	-	-	-	-
Jaswant	0-2	1.0	2.3	4.0	0.1	1.9	5.5	1.0	0.2
Nagar	2-4	1.2	2.8	15.6	0.2	2.4	6.5	4.7	5.5
	4-6	-	-	-	-	-	-	-	-
Badhpura	0-2	0.9	2.7	10.2	0.05	2.05	4.4	1.2	6.3
	2-4	1.3	3.5	26.6	0.07	2.62	4.9	4.3	19.7
	4-6	1.9	4.3	46.2	0.09	1.72	6.2	17.3	27.5
	6-8	5.4	9.0	65.3	1.0	0.4	1.4	25.0	53.0
	8-10	-	-	-	-	-	-	-	-
Basrehar	0-2	1.2	3.1	7.9	.1	1.7	5.0	1.2	4.5
	2-4	1.8	4.2	22.1	0.2	2.0	7.2	3.7	15.3
	4-6	2.0	7.3	50.6	0.1	1.6	3.1	18.6	36.7
	6-8	-	-	-	-	-	-	-	-
Bharthana	0-2	0.9	3.1	6.9	0.11	1.7	5.3	1.3	2.7
	2-4	1.1	4.0	12.5	0.4	2.3	6.5	4.4	5.4
	4-6	1.4	6.8	31.3	0.9	3.0	8.5	7.6	20.1
	6-8	-	-	-	-	-	-	-	-
	8-10	-	-	-	-	-	-	-	-
	10-15	-	-	-	-	-	-	-	-
Takha	0-2	1.2	3.0	11.2	0.4	1.3	4.7	1.3	8.4
	2-4	1.1	3.6	24.1	1.0	2.1	6.7	3.4	17.5
	4-6	1.4	7.0	42.9	0.4	4.0	7.4	8.4	31.9
	6-8	-	-	-	-	-	-	-	-
	8-10	11.8	23.0	62.6	0.5	0.4	1.6	41.2	54.7
	10-15	15.4	27.2	70.2	0.5	0.4	1.6	52.2	59.1
Mahewa	0-2	0.9	3.6	11.4	0.2	0.6	6.8	1.0	7.4
	2-4	0.8	4.3	24.4	0.5	1.1	9.8	2.2	16.9
	4-6	1.8	8.8	34.7	0.9	0.4	12.0	9.2	24.6
	6-8	-	-	-	-	-	-	-	-
Chakarnagar	0-2	0.49	3.9	4.3	0.1	1.28	5.5	1.4	0.6
	2-4	0.99	4.6	8.7	0.1	1.54	5.4	6.3	1.2
	4-6	2.46	8.0	14.2	0.1	0.9	4.1	14.3	5.6
	6-8	4.6	12.4	20.9	0.2	0.8	3.6	21.8	11.9
	8-10	-	-	-	-	-	-	-	-
	10-15	-	-	-	-	-	-	-	-
Average of Etawah district									
	0-2	0.95	3.1	7.5	0.14	2.0	5.4	1.1	3.8
	2-4	1.15	3.7	17.1	0.32	1.9	6.4	3.8	10.2
	4-6	1.83	7.0	36.7	0.42	1.9	6.9	12.6	24.4
	6-8	5.00	10.7	43.1	0.59	0.6	2.5	23.4	32.4
	8-10	11.8	23.0	62.6	0.5	0.4	1.6	41.2	54.7
	10-15	15.4	27.2	70.2	0.5	0.4	1.6	52.2	59.1
	15-20	-	-	-	-	-	-	-	-

Amongst the cations, the Ca, Mg and Na increased with increase in EC_{iw} classes, whereas the K ion did not show any relation with EC_{iw} classes. Further the Ca, Mg and Na ions increased proportionately up to EC_{iw} 8 dS/m but beyond this the Na cation increased in high proportion. Similar to cations, the anions (Cl and SO_4) also increased with ECiw classes. Contrarily, the CO_3 and HCO_3 anions do not have any relation with EC_{iw} and remained almost same from <1 to 15 EC_{iw} classes.

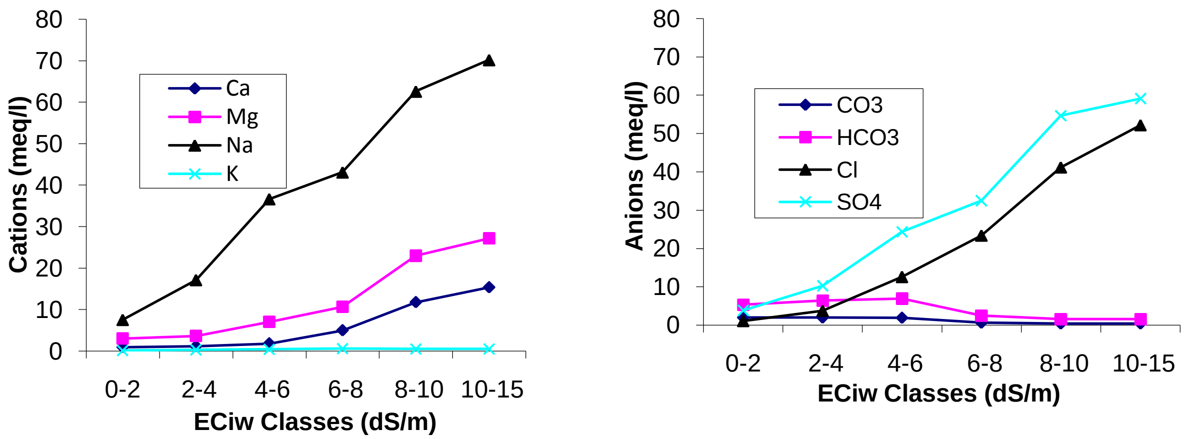

Fig. 7.3: Cations and anions with respect to EC classes in Etawah district

Cationic and anionic preferential order revealed that the cationic orders were same in all the blocks i.e. Na>Mg>Ca>K, while in case of anionic order was differerent in different blocks e.g. HCO_3>CO_3>Cl>SO4 in Safai and Jaswant Nagar blocks, SO_4>HCO_3>Cl>CO_3 in Badhpura and Basrehar blocks, HCO_3>SO_4>Cl>CO_3 in Bharthana and Takha, SO_4>Cl>HCO_3>CO_3 in only Mahewa block and HCO_3>Cl>SO_4> CO_3 in Chakarnagar block (Table 7.4).

Table 7.4: Cationic and anionic pattern in different blocks

Block	Cationic Order	Anionic Order
Saifai	Na>Mg>Ca>K	HCO_3 > CO_3 >Cl>SO_4
Jaswant Nagar	Na>Mg>Ca>K	HCO_3 > CO_3> Cl >SO_4
Badhpura	Na>Mg>Ca>K	SO_4 >HCO_3>Cl>CO_3
Basrehar	Na>Mg>Ca>K	SO_4 >HCO_3>Cl>CO_3
Bharthana	Na>Mg>Ca>K	HCO_3 > SO_4> Cl >CO_3
Takha	Na>Mg>Ca>K	HCO_3 > SO_4> Cl >CO_3
Mahewa	Na>Mg>Ca>K	SO_4>Cl>HCO_3>CO_3
Chakar Nagar	Na>Mg>Ca>K	HCO_3 > Cl >SO_4>CO_3

Fluoride and Nitrate:

The groundwater samples in Fluoride concentration (ppm) in 0.2.5 ppm class varied 88.9 percent in J.Nagar to 100.0 percent in Mahewa. In 2.5- 5.00 ppm class, groundwater samples varied from 1.1 per cent in Chakarnagar to 11.1 per cent in Jaswant Nagar. The nitrate was present in about 9.6 per cent samples of Saifai, 4 per cent in Jaswant Nagar, 4.2 per cent in Bharthana 2.5 per cent in Takha and 5.3 per cent in Mahewa block only. Among them, 75 percent samples were recorded in category <2.5 meq/l and only 25 per cent samples were recorded under category of high nitrate (>10 meq/l) in Saifai block while in case of Mahewa it was 80 per cent and 20 per cent, respectively (Table 7.5). While all the samples of Jaswant Nagar, Badhpura, Bharthana and Takha blocks having nitrate were in category 0-2.5 meq/l.

Table 7.5: Distribution of Fluoride and NO_3 in different classes and blocks (percent samples)

Particulars	Saifai (83)	J.Nagar (99)	Badhpura (93)	Basrehar (94)	Bharthana (96)	Takha (78)	Mahewa (95)	Chakarnagar (92)	Av. of Etawah
Fluoride (ppm)									
0-2.5	98.8	88.9	96.8	100.0	92.7	94.9	100.0	99.8	96.4
2.5-5.0	1.2	11.1	3.2	-	7.3	5.1	-	1.1	3.6
5.0-7.5	-	-	-	-	-	-	-	-	-
7.5-10.0	-	-	-	-	-	-	-	-	-
>10.0	-	-	-	-	-	-	-	-	-
Nitrate(me/l)									
percent samples of total samples with Nitrate*	9.6	4.0	4.2	-	4.2	2.5	5.3	-	3.7
percent samples from Nitrate samples**									
0-2.5	75.0	100.0	100.0	-	100.0	100.0	80.0	-	92.5
2.5-5.0	-	-	-	-	-	-	20.0	-	3.3
5.0-7.5	-	-	-	-	-	-	-	-	-
7.5-10.0	-	-	-	-	-	-	-	-	-
>10.0	25.0	-	-	-	-	-	-	-	4.2

* Per cent of collected samples in respective blocks. ** Per cent of nitrate having samples only.

The distribution of water samples in different water quality classes (Table 7.6 and Fig. 7.4) revealed that 58 per cent in Saifai, 35 per cent in Jaswant Nagar, 56 per cent in Badhpura, 54 per cent samples of Basrehar, 49 per cent of Bharthana, 42 per cent samples of Takha, 55.8 per cent in Mahewa and 62 per cent samples in Chakar nagar block were of good quality. About 6.4 per cent in Badhpura, 1.1 per cent in Basrehar, 4.2 per cent in Bharthana, 1.3 per cent samples in Takha and 13 per cent samples in Chakar nagar block found in marginal saline category. In high SAR saline category, 1.2 per cent in Saifai, 2.2 per cent in Badhpura, 1.1 per cent in Basrehar, 1 per cent in Bharthana, 19.2 per cent samples in Takha and 3.2 per cent samples in Mahewa block were found. In case of alkaline problem in 19.3, 32.3, 12.9, 26.6, 28.1, 15.4 and 13.0 per cent water samples were found marginally alkali and 21.7, 32.3, 21.5, 12.8, 15.6, 19.2, 12.6 and 2.2 per cent water samples are high alkali problems in Safai, Jaswant Nagar, Badhpura, Basrehar, Bharthana, Takha, Mahewa and Chakarnagar blocks respectively. The spatial distribution of these classes in different blocks is shown in Fig. 7.4.

Table 7.6: Distribution of water samples in different water quality ratings of Etawah district

S.No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Safai	83	57.8	-	-	1.2	19.3	-	21.7
2	J. Nagar	99	35.3	-	-	-	32.3	-	32.3
3	Badhpura	93	55.9	6.4	-	2.2	12.9	1.1	21.5
4	Basrehar	94	54.3	1.1	-	1.1	26.6	4.3	12.8
5	Bharthana	96	49.0	4.2	1.0	1.0	28.1	1.0	15.6
6	Takha	78	42.3	1.3	-	19.2	15.4	2.6	19.2
7	Mahewa	95	55.8	-	-	3.2	20.0	8.4	12.6
8.	Chakarnagar	92	62.0	13.0	9.8	-	13.0	-	2.2
Etawah district		**730**	**51.6**	**3.3**	**1.3**	**3.5**	**20.9**	**2.2**	**17.2**

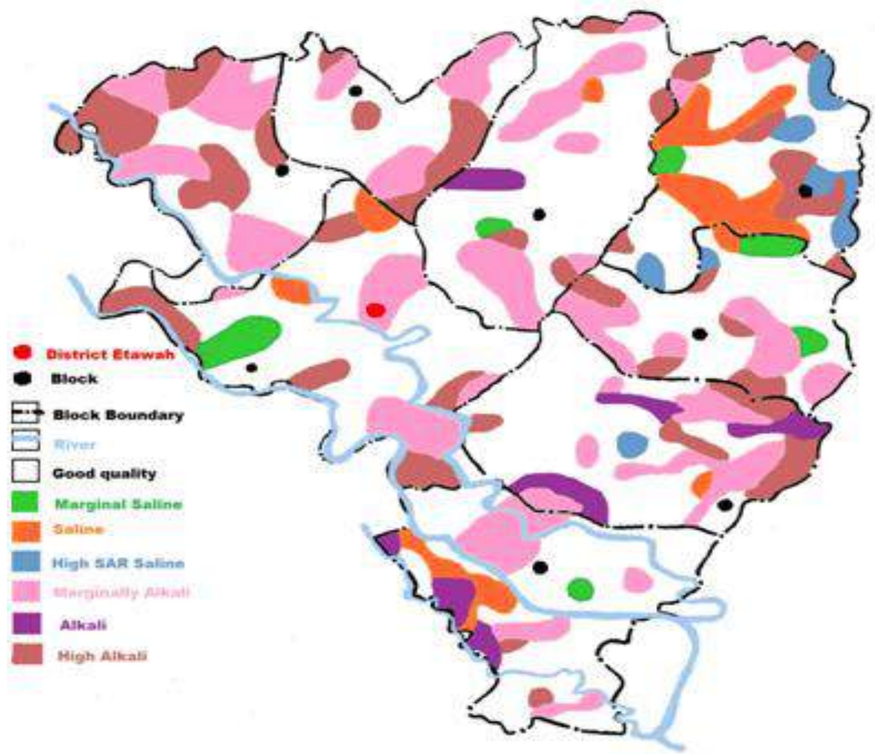

Fig. 7.4: Water quality map of Etawah district

In case of Etawah district, 51.6 per cent ground water samples were in good quality and 48.4 per cent water samples were in poor quality (8.1 percent water samples have saline and 40.3 percent in alkali water). In poor quality classes, marginal alkali was dominant with 20.9 percent of samples and it was followed by high alkali with 17.2 per cent samples. Alkali water samples were only 2.2 per cent. Out of 8.1 per cent samples of saline type, marginally saline, saline and high SR saline waters were 3.3, 1.3 and 3.5, respectively. The major problematic waters were in Jaswant Nagar block i.e. only 35.3 per cent samples were of good quality and rest of 65.6 per cent samples were of alkali water. Thus major water quality issue in the district is alkali water.

8. GROUND WATER QUALITY OF BHARATPUR DISTRICT

8.1 Introduction

The Bharatpur, also known as 'Eastern Gate of Rajasthan', is located in the Braj region 180 km away from Delhi. Geographically, the district is situated between 26° 22′ to 27° 83′ N and 76° 53′ to 78° 17′ E and its average height above sea level is around 183 m. Bharatpur city is the district headquarters and is also known by the name of Lohagarh. Bharatpur touches Gurgaon of Haryana in the north, Mathura in the east, Agra of Uttar Pradesh and Dholpur of Rajasthan in the south and Dausa and Alwar in the west. The main rivers of the district are Rooparel, Gambhir and Ban Ganga which pass through the district. The total area of the district is 5066 km^2. The district is part of Bharatpur Division and is divided into 9 sub-divisions. Administratively, the district is divided into 10 tehsils (Bharatpur, Bayana, Deeg, Kama, Kumher, Nadbai, Nagar, Rupwas, Sewar and Weir) and 9 development blocks (Bayana, Deeg, Kama, Kumher, Nadbai, Nagar, Rupwas, Sewar and Weir). Index map of the district showing block boundaries is presented as **Fig. 8.1**.

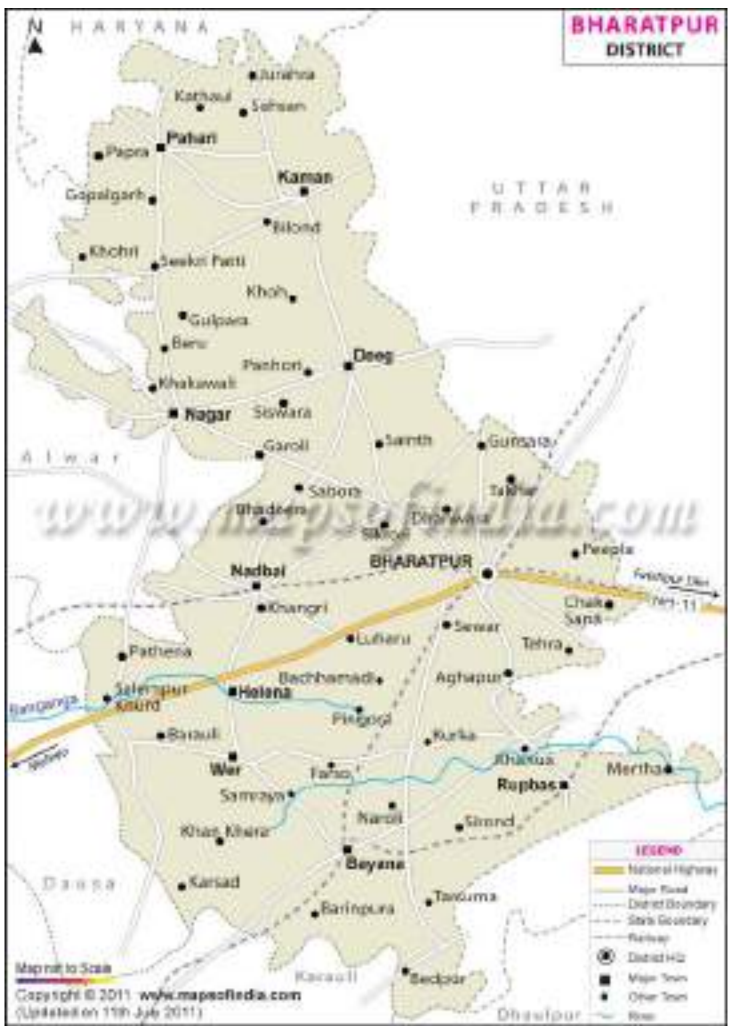

Fig. 8.1: Location map of Bharatpur district

Major Physiographic units (land forms) of the district are Alluvial Plains, Valley hills, Ravines and Flood. Most of the area of the district is occupied by alluvial plains. Alluvial Plain formed due to fluvial activity, consisting of gravels, sand, silt and clay with mainly undulating terrain. Valley fills formed by fluvial activity at lower topographic level. Ravines formed due to small, narrow, deep depression usually carved by running water. Flood Plain is formed at smooth land adjacent to a river channel and it is subjected to periodic flooding. The area of district is drained by Banganga, Gambhiri and Ruparel river basins.

The gross cultivable area and net sown area of the district is 596919 and 396466 ha, respectively. The forest area is 33645 ha. The net irrigated area is 330434 ha and gross irrigated area is 333627 ha. Both surface (canal water) and ground water are used for irrigation in the area. However, very small area is irrigated by canals. Ground water plays an important role for irrigation in the district. Approximately 59 percent (330434 ha) land of the total area is irrigated and out of which 1 per cent area is irrigated by surface water and remaining 99 percent (328000 ha) by ground water.

The normal rainfall in Bharatpur district is 605.3 mm (1971-2011 records). The rainfall has decreased over the years. According to Agro climatic zone, Bharatpur district comes under Flood prone Eastern Plain Zone III b of Rajasthan. The climate of the district being dry, it becomes extremely hot during summer and extremely cold during winter. The cold season is from December to February and is followed by summer from March to June. Period from mid of September to end of November constitute post monsoon season. Maximum temperature rises up to over 49 ^{0}C in May and June. With arrival of the monsoon in June, there is an appreciable drop in the day temperature. The minimum temperature during December-January is as low as 3.5^{0}C. The potential evapotranspiration rates are quite high especially during May and June and annual total is 1780 mm.

The soils of the Bharatpur district are greyish brown and yellowish brown with wide variation in texture from sandy loam to clayey loam. The soils at some places are affected by salinity/ alkalinity. The soils of Bharatpur, Bayana and Deeg subdivisions are fertile. In northeastern part of the district, the soils are compact and have low permeability, which causes water to stagnate on the surface during rainy season. (AICRP-SAS&USW, 2017).

Major crops under irrigation are rai and mustard (203499 ha) and wheat (134777 ha), potato (2835ha), green fodder (2171 ha), barley (2100 ha), cotton (1428ha), vegetables (1349 ha). Ground water occurs both in Quaternary alluvium and consolidated formation belonging to Vindhyan Super Group and Bhilwara and Delhi Super Groups meta-sedimentary rocks. Quaternary alluvium and windblown sand form most wide spread and important aquifer in the district occupying about 85 per cent part of the district.

Groundwater in shallow zones occurs under unconfined conditions and is generally tapped by open wells. The depth to water level varies from 2.10 m bgl (lowest at Kumbher in Kumbher block and Roopwas in Roopwas block) to 52.10 mbgl (deepest at Chokharwara in Weir block) in Post-monsoon. Deeper water level more than 20 m lies in the western part of district covering parts of Weir, Nadbai and small part in Nagar blocks. Major part of the district has water level between 10 and 20 m bgl covering parts of all the nine blocks. Shallow water level less than 10 m lies in parts of Kama, Nagar, Deeg, Kumbher, Sewar, Roopwas and Bayana (CGWB, 2017).

There was large variation in the chemical quality of ground water in the district, both in spatially and depth wise. Both in shallow and deeper aquifers, it varied from fresh to saline. Long term water level data (pre and post monsoon, 2001-12) indicated declining trend in all the blocks ranging from 0.11m/year in Kumbher block to 0.41m/year in Weir block during pre-monsoon period and from 0.02 m/year in Bayana block to 0.54m/year in Nadbai block during post-monsoon period. Annual replenishable ground water resources of district is 495.6775 MCM, net ground water availability is 453.5100 MCM, net annual ground water draft is 508.5642 MCM and projected demand for domestic/ industrial uses up to 2025 is 67.814 MCM. Average stage of ground water development is 112.14 per cent as per March 2009 (GGCB, 2013).

Based on Ground Water Estimation Committee (1997), dynamic groundwater resources of Rajasthan as on 31.03.2013 were reassessed jointly by Central Ground Water Board and Ground Water Department, Govt. of Rajasthan (CGWB, 2017). Net ground water availability is assessed as 457.0051 MCM, net annual ground water draft is 542.8411 MCM. Data indicated that out of 9 blocks, 2 blocks (Deeg and Nagar) are critical and remaining 7 blocks (Bayana, Kama, Kumbher, Nadbai, Roopvas, Sewar and Weir) are over exploited. The stage of ground water development ranges from 97.82 per cent (minimum in Nagar block) to 179.44 per cent (maximum in Nadbai block). It has resulted in decline in water level. Average stage of ground water development is 118.7per cent. The changing scenario of ground water development over the years since 1984 has been presented in Table 8.1 (CGWB, 2017).

Table 8.1: Status of Ground Water Development, Bharatpur District

Year	Net GW availability (mcm)	Gross draft (mcm)	Stage of GW development (percent)
1984	514.0263	179.5381	35
1990	441.3076	323.9381	73.40
1995	493.1348	480.3368	97.40
1998	541.0596	472.4515	87.32
2001	514.2610	479.6573	93.27
2004	453.6358	453.1589	99.89
2009	453.5100	508.56	112.14
2011	449.3600	522.18	116.21
2013	457.0051	542.8411	118.7

(CGWB, 2017)

8.2 Groundwater Quality Survey, Characterization and Mapping

Total of 1332 ground water samples were collected from ten tehsils of Bharatpur district namely Bharatpur, Kumher, Roopvas, Nadvai, Deeg, Nagar, Kama, Pahadi, Bayana and Veir 2004 onwards. The samples were collected mostly from December to March, when the maximum numbers of tube wells were under use for irrigation purpose. The groundwater samples were analyzed for cations and anions. The ranges of irrigation water quality parameters such as EC, pH, SAR and RSC are presented in Table

8.2. The maximum EC value i.e. 36.3 dS/m was recorded in Kumher tehsil followed by 31.7 dS/m in Nagar tehsil and in rest of the tehsils it was around 20 dS/m. The highest RSC value (23.4 meq/l) was recorded in Deeg tehsil followed by 21.8 me/l in Nadvai tehsil. Further, the highest SAR values i.e. 66.7 $(mmol/l)^{1/2}$ was recorded in Nagar tehsils whereas in other tehsils it ranged between 30-40 $(mmol/l)^{1/2}$. The average SAR in different tehsils varied between 7.2 and 16.9 $(mmol/l)^{1/2}$.

Table 8.2: Minimum and maximum values of different water constituents

Tehsils	EC (dS/m)		pH		RSC (meq/l)		SAR $(mmol/l)^{1/2}$	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Bharatpur	0.8-26.1	7.2	7.2-8.8	7.8	Nil-12.8	4.2	1.3-26.5	11.3
Kumher	0.9-36.3	10.0	7.0-9.0	8.1	Nil-13.6	6.1	1.1-37.4	16.1
Roopvas	0.4-18.1	4.2	7.6-9.4	8.7	Nil-15.6	0.8	0.3-44.4	11.5
Nadvai	0.8-19.7	6.1	8.0-9.4	8.9	Nil-21.8	3.5	1.2-39.0	14.9
Deeg	0.6-19.4	7.5	6.7-9.1	8.2	Nil-23.4	1.8	2.6-35.0	12.7
Nagar	0.9-31.7	6.1	7.2-8.9	7.9	Nil-18.0	2.4	1.5-66.7	15.2
Kama	0.8-18.4	5.9	7.3-9.1	8.1	Nil-9.6	1.6	4.0-28.2	12.5
Pahadi	1.2-30.5	8.2	7.1-8.9	8.0	Nil-14.2	5.4	2.7-40.5	16.9
Bayana	0.4-13.8	1.9	7.6-8.9	8.3	Nil-12.4	2.9	1.1-27.3	7.2
Veir	0.5-20.2	3.0	7.4-9.2	8.2	Nil-27.6	5.3	1.0-31.6	10.8

The distribution of water samples in different EC, SAR and RSC classes are presented in Table 8.3. In all the tehsils except Roopvas, Bayana and Veir the ground water samples having EC < 1.5 dS/m were less than 10 per cent. It indicated that groundwater faced the problem of salinity. The percent of samples in this class were 34, 60.8 and 35.0 per cent in Roopvas, Bayana and Veir tehsil, respectively. The water samples having EC values >5 dS/m are 67, 78, 31, 55, 71, 51, 39.8, 61.6, 9.0 and 16.0 per cent, respectively, in Bharatpur, Kumher, Roopvas, Nadvai, Deeg, Nagar, Kama, Pahadi Bayana and Veir tehsils.

Table 8.3: Frequency distribution of water samples in different EC, RSC and SAR classes of Bharatpur

Particulars	Bharatpur (150)	Kumher (123)	Roopvas (156)	Nadvai (125)	Deeg (116)	Nagar (153)	Kama (118)	Pahadi (1129)	Bayana (125)	Veir (137)
EC Classes (dS/m) :										
0-1.5	6.0	3.2	34.0	9.6	8.6	7.2	10.2	5.1	60.8	35.0
1.5-3.0	10.7	8.9	22.4	20.1	12.9	25.5	32.2	15.1	22.4	34.3
3.0-5.0	16.0	9.7	12.2	14.4	16.4	16.3	17.8	18.2	8.0	14.6
5.0-10.0	45.3	30.9	20.5	35.2	32.8	34.6	25.4	24.2	8.0	13.8
>10.0	22.0	47.1	10.9	20.0	29.3	16.3	14.4	37.4	0.8	2.2
RSC Classes (meq/l) :										
Absent	94.7	86.2	64.1	52.2	73.3	59.4	66.1	76.8	48.0	42.3
0-2.5	3.3	1.6	13.5	8.8	12.1	7.8	12.7	6.1	27.2	18.2
2.5-5.0	0.7	3.2	11.5	6.4	3.4	13.1	5.1	5.1	16.0	16.8
5.0-10.0	0.7	7.3	7.7	16.2	4.3	12.4	16.1	9.1	8.0	15.3
>10.0	0.7	1.6	3.2	13.6	6.9	7.2	0.0	3.0	0.8	7.3
SAR classes $(mmol/l)^{1/2}$:										
0-10	48.7	21.9	51.3	32.0	40.5	26.8	44.1	19.2	80.0	51.8
10-20	44.0	49.6	30.8	43.2	44.0	46.4	48.3	47.5	12.8	36.5
20-30	7.3	24.4	15.4	20.8	12.9	20.9	6.8	27.3	7.2	10.9
30-40	--	4.1	1.9	4.0	2.6	4.5	0.8	4.0	0.0	0.7
>40	--	--	0.6	--	--	1.3	0.0	2.0	0.0	0.0

In case of RSC, it was observed that in 42 –95 percent of ground water samples in different tehsils did not have any RSC value. The significant number of water samples having RSC >5 meq/l are as 30 per cent in Nadvai, 23 per cent in Veir and 20 per cent in Nagar tehsils only. The study of SAR classes revealed that 20–50 percent waters have SAR < 10 $(mmol/l)^{1/2}$ in different tehsils. Further the ground water having SAR in the range of 10- 20 $(mmol/l)^{1/2}$ ranged in 30 –50 per cent waters of different tehsils except Bayana having 12.8 per cent. It showed that majority waters in the study area had SAR up to 20 $(mmol/l)^{1/2}$. However, about 28.5 per cent in Kumher, 18 per cent in Roopvas, 25 per cent in Nadvai 15 per cent in Deeg and 27 per cent in Nagar had SAR > 20 $(mmol/l)^{1/2}$.

The cationic and anionic preferential order revealed that in all the eight Tehsils the cationic order are Na>Mg>Ca>K and in anionic terms in all the tehsils the Cl and SO_4 anions dominated over CO_3 and HCO_3 anions. Among Cl and SO_4, Cl dominated over SO_4. The anionic order was Cl> SO_4> HCO_3 > CO_3 in all blocks expect in Roopvas Tehsil where it was SO_4>Cl > HCO_3>CO_3. Further relation among cations and among anions in different EC classes were also assessed and depicted in Fig 8.2 and 8.3.

In all eight Tehsils the Na, Mg and Ca increased with EC classes whereas K status remained almost constant. The proportionate increase of Na ion was higher with EC classes. In Kumher and Bharatpur tehsils the Mg ion increased with higher proportion than Ca for groundwater salinity (EC_{iw}) over 10 dS/m. Amongst the anions in different EC classes, it was found that CO_3 and HCO_3 ions had no relation with EC and attained almost the same value from lower to higher EC classes. The Cl and SO_4 anions increased with EC classes and of these two the Cl ions increased with higher proportion than SO_4 at higher salinity levels except Kama Tehsil.

Fluoride: Fluoride ranged around up to 5 ppm in majority tehsils. In Kumher, Roopvas, Pahadi, Bayana and Vier 3.8, 4.5, 2, 1.6 and 1.5 per cent samples in were above 5 ppm. The Pahadi district highest concentration of 11.5 ppm was observed. The average values of fluoride in different tehsils were in the range 1- 2 ppm. In the tehsils such as Bharatpur, Kumher, Roopvas, Nadvai, Bayana and Veir, 90 per cent groundwater samples had F < 2.5 ppm whereas such class had about 70 per cent in Deeg, Nagar and Kama tehsils. The tehsils, Deeg, Nagar, Kama and Pahadi had water containing F in the range 2.5-5.0 ppm. But on the whole, majority waters had F < 2.5 ppm in all the tehsils (Table 8.4).

Lithium: The Lithium (Li) content was variable in different tehsils. It had high values in Bharatpur, Kumher and Nagar tehsils. The highest maximum value of 53.5 ppm was reported from Nagar tehsil and lowest maximum value of 5.2 ppm was from Nadvai tehsil. Further, groundwater samples with Li above 10 ppm were reported from Bharatpur (7.3 per cent), Kumher (6.5 per cent), Roopvas (3.2 per cent), Nagar (4.6 per cent), and Pahadi (6.1 per cent) and Veir (2.2 per cent) tehsils (Table 8.4).

Nitrate: The nitrate was present in Bharatpur (33 per cent), Kumher (26.1 per cent), Roopvas (9.1 per cent), Nadvai (12 per cent), Deeg (14.1 per cent), Nagar (20 per cent), Kama (32 per cent), Pahadi (34 per cent), Bayana (5 per cent) and Veir (3 per cent) samples. It had vide range and as high as 151 meq/l in Bharatpur and 105 me/l in Kumher tehsils with the lowest value of around 5 me/l in Nadvai, Kama and Nagar tehsils. About 36 per cent water in Bharatpur and 16 per cent in Kumher tehsils only had nitrate more than 10 meq/l (Table 8.4).

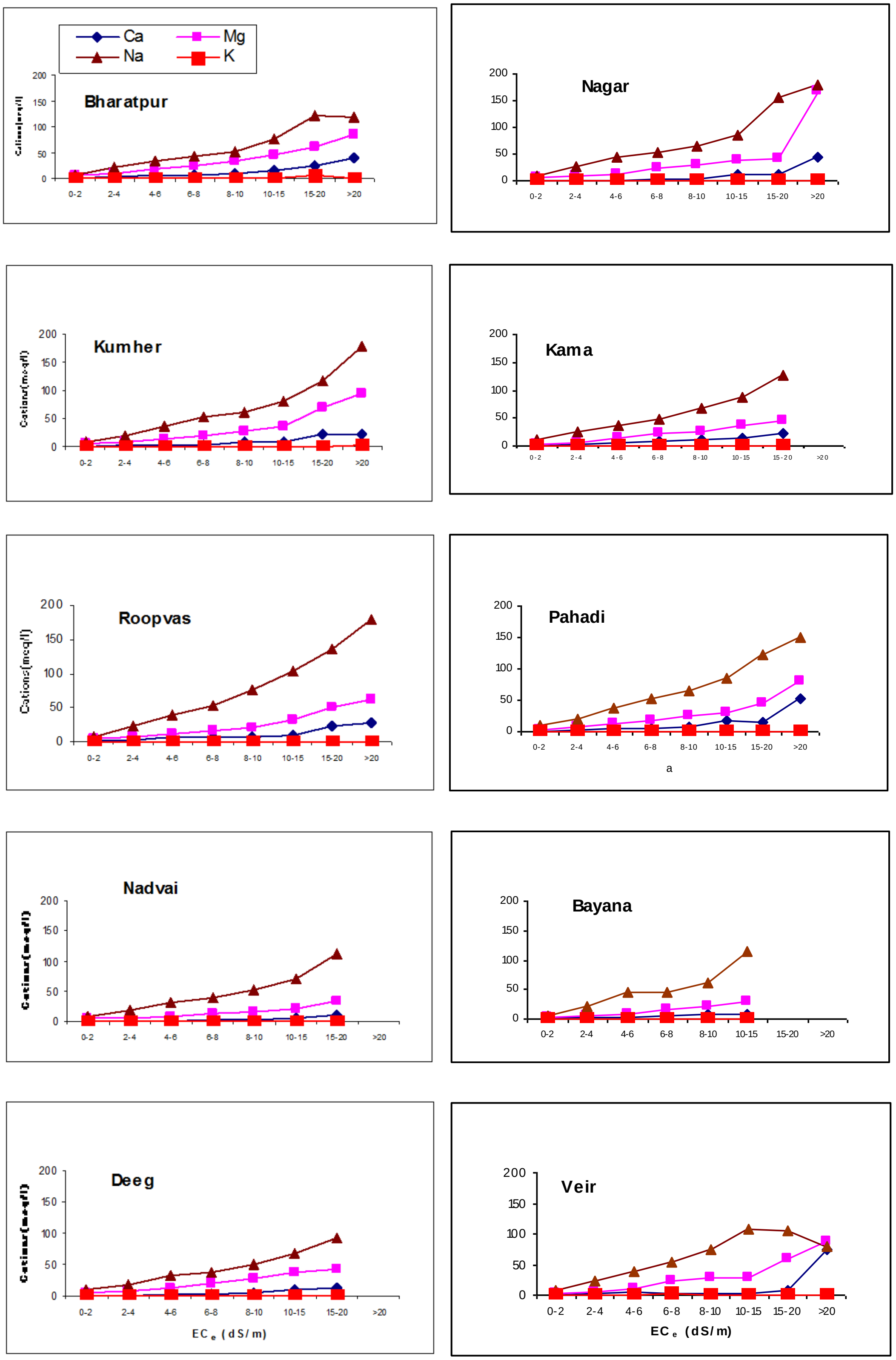

Fig.8.2: Mean cationic composition under different EC classes

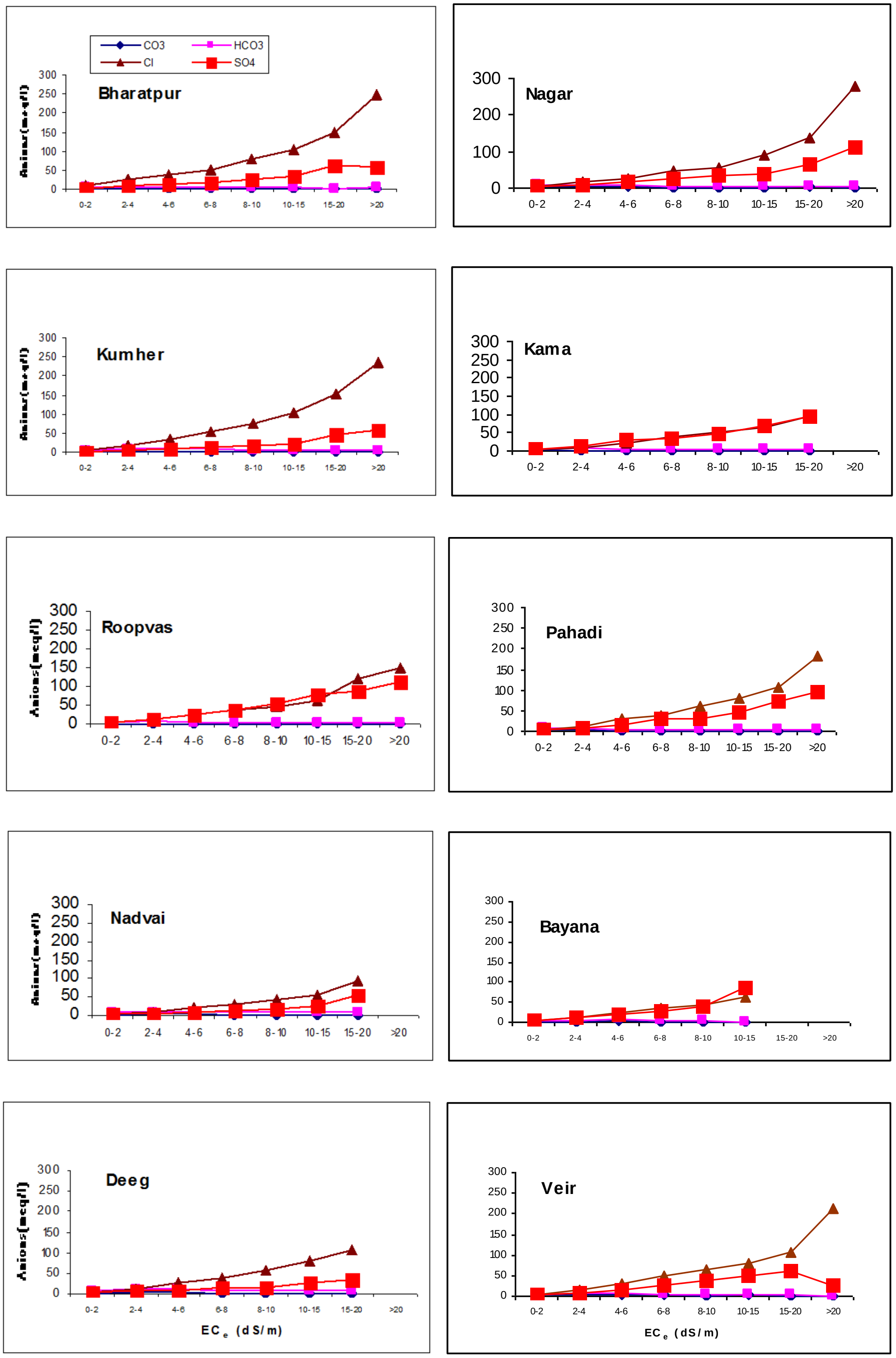

Fig. 8.3: Mean anionic composition under different EC classes

Table 8.4: Distribution of F, Li and NO_3 in different classes and Tehsils (percent samples).

Particulars	Bharatpur	Kumher	Roopvas	Nadvai	Deeg	Nagar	Kama	Pahadi	Bayana	Veir
Fluoride (ppm)										
0-2.5	92.7	89.4	87.8	91.2	69.0	71.2	68.6	77.8	84.0	86.8
2.5-5.0	7.3	6.5	7.7	8.8	31.0	28.8	31.4	20.2	14.4	11.7
5.0-7.5	--	3.3	4.5	--	--	--	--	--	1.6	1.5
7.5-10.0	--	0.8	--	--	--	--	--	1.0	--	0.0
>10	--	--	--	--	--	--	--	1.0	--	0.0
Lithium ((ppm)										
0-2.5	44.0	35.8	79.5	83.2	96.5	5.9	91.5	57.6	68.0	89.0
2.5 –5.0	37.3	30.9	12.2	16.0	--	54.9	7.6	22.2	22.4	8.7
5.0-7.5	8.7	19.5	3.2	0.8	2.6	30.7	0.0	10.1	6.4	0.0
7.5-10.0	2.7	7.3	1.9	--	--	3.9	0.9	4.0	2.4	0.0
>10.0	7.3	6.5	3.2	--	0.9	4.6	0.0	6.1	0.8	2.2
Samples with presence of Nitrate (percent)										
	33	26	9	12	14	20	32	34	5	3
Nitrate (meq/l) for samples containing Nitrate										
0-2.5	30.0	25.0	73.3	73.3	12.5	66.7	94.9	85.3	50.0	--
2.5-5.0	28.0	31.2	--	--	25.0	20.0	2.6	8.8	16.7	75.0
5.0-7.5	4.0	25.0	11.3	13.3	6.2	13.3	2.6	2.9	33.3	--
7.5-10.0	2.0	3.1	6.7	6.7	6.2	--	--	--	--	25.0
>10	36.0	15.6	6.7	6.7	50.0	--	--	3.0	--	--

The distribution of water samples in different water quality classes (Table 8.5) revealed that barring Roopvas, Nadvai, Kama, Bayana and Veir tehsils, in rest of the tehsils only < 10 per cent waters are of good quality showing severity of poor quality water problem. In these tehsils , majority waters were affected with high saline-SAR problem for example 50 per cent in Bharatpur, 69 per cent in Kumher, 42 per cent in Roopvas and Nadvai, 45 per cent in Deeg, 55 per cent in Nagar, 38 per cent in Kama and 71 per cent in Pahadi tehsils whereas comparatively, lower values of this class were recorded in Bayana (9 per cent) and in Veir (16 per cent) tehsils. Regarding alkali problem, it was observed that few water samples had the marginal alkali and alkali problem and contrarily the high alkali problem was more pronounced particularly in Nadvai (27 per cent waters), Deeg (12.9 per cent waters) and 18 per cent waters in Nagar and 14 per cent in Kama, 12 per cent in Pahadi and 25 per cent in Veir tehsils. It might be summarized that all the tehsils had the major problem of salinity (high-saline SAR) but the tehsils Nadvai, Deeg, Nagar, Kama, Pahadi and Veir had good number of samples with high alkali problem.

Table 8.5: Distribution of water samples in different water quality ratings of Bharatpur district

S.No.	Blocks	No. of Samples	Good	Marginally Saline	Saline	High SAR Saline	Marginally Alkali	Alkali	High Alkali
1	Bharatpur	150	7.3	14.0	26.7	50.0	0.0	0.0	2.0
2	Kumhar	123	21.4	6.5	11.4	69.1	0.8	2.4	7.3
3	Roopvas	156	30.8	8.3	2.6	42.3	4.5	6.4	5.1
4	Nadvai	125	14.4	8.0	3.2	42.4	4.8	0.0	27.2
5	Deeg	116	7.8	11.2	21.6	44.8	1.7	0.0	12.9
6	Nagar	153	7.2	7.8	5.2	54.9	3.9	3.3	17.6
7	Kama	99	14.4	15.3	11.0	38.1	4.2	2.5	14.4
8.	Pahadi	118	5.0	6.1	4.0	70.7	2.0	0.0	12.1
9.	Bayan	125	55.2	8.8	0.8	8.8	19.2	0.0	7.2
10.	Veir	137	25.6	14.6	5.1	16.0	11.7	2.2	24.8
Bharatpur district		**1302**	**17.2**	**10.1**	**9.4**	**43.5**	**5.2**	**1.8**	**12.8**

The spatial distribution of these classes in different blocks is shown in Fig. 8.4. Over all conclusion of the district showed that only 17 per cent waters were of good quality. Of the two problem classes, 62.9 per cent waters had the saline problem and 19.8 per cent alkali problem. Further, amongst the saline classes, the majority samples i.e. 43.5 per cent had high-SAR saline problem and 10 per cent as saline and 9.4 percent high saline. In alkali classes, 12.8 percent have high alkali contrary to only 1.8 percent as alkali and 5.2 percent as marginal alkali.

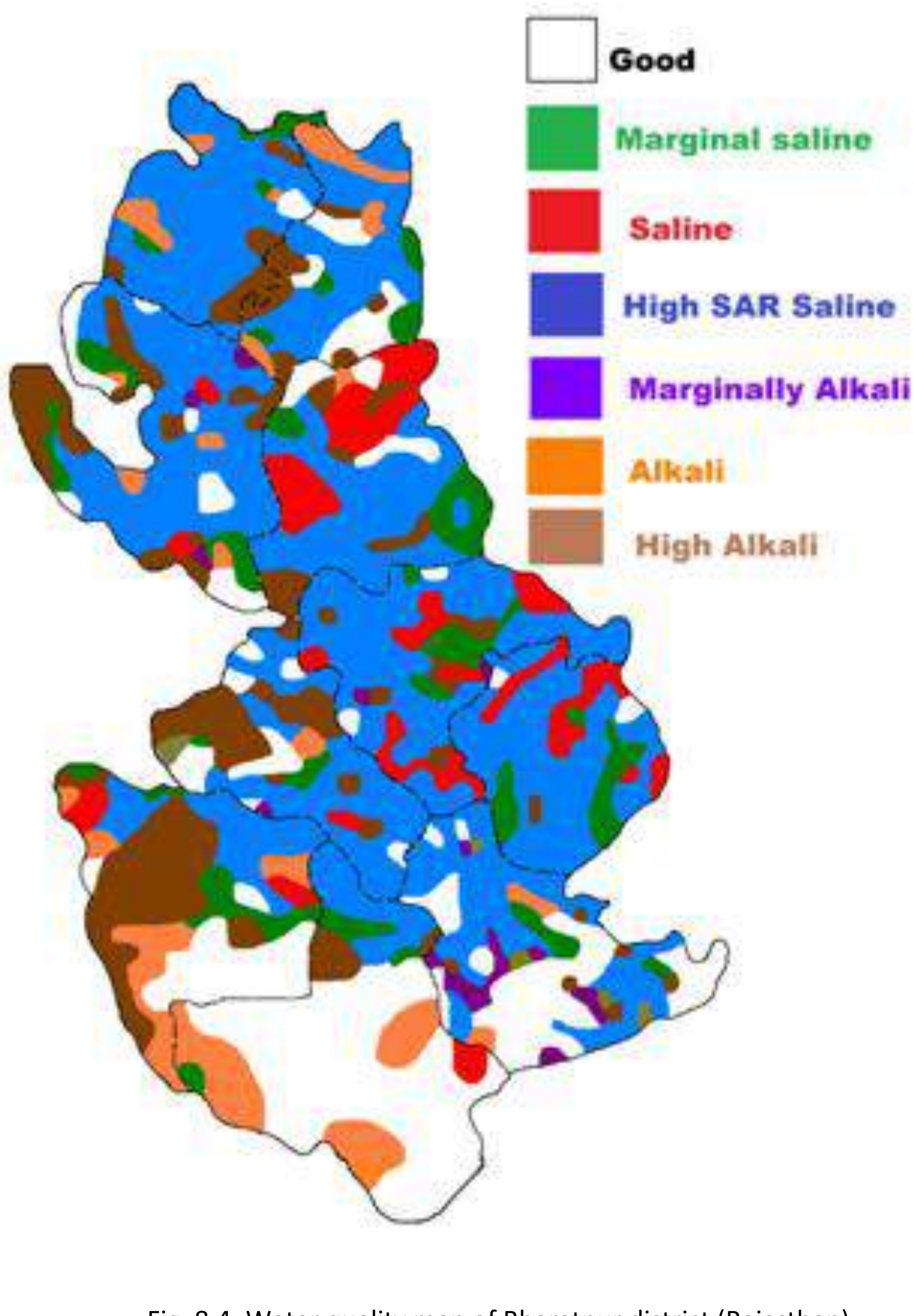

Fig. 8.4: Water quality map of Bharatpur district (Rajasthan)

9. MANAGEMENT STRATEGIES FOR USE OF POOR QUALITY WATER

9.1 Introduction

Water is imporatnat for survival of life on earth. Usable water might come from surface or groundwater. However, its availability in space and time is uneven. Amount water which can be extracted from aquifers depends on overall groundwater recharge of the region and also on aquifer properties. It is to be noted that groundwater is not of good quality always and its quality varies as per geo-hydrological conditions. Despite of poor quality, groundwater is important source of irrigation in many parts of world as there is no other choice. Therefore, judicious use of available poor quality groundwater resources through different management options is required in many water scarce areas for sustainability of agriculture. It is well known that the saline and alkali waters can not be used directly for crop production. The crop, soil, irrigation water management options are very much important for using poor quality waters for irrigation. The rainfall, soil texture, quality of groundwater and tolerance of crop to salinity and sodicity stresses play very important role while finalising the strategy for use of such waters. Numbers of experiments were conducted at AICRP on **Management of Salt Affected Soils and Use of Saline Water in Agriculture, Agra** and other centres for better use of saline and alkali ground water in crop production. The different crop, soil, chemical and irrigation water management based strategies are developed based on results of various experiments and summarised below.

9.2. Types of Management Strategies

In case of management of poor quality waters, different types of management options can be adopted. The management options can be classified as Crop, Agronomic, Chemical, Nutrient and Water management. The use of salt tolerant crop and crop varieties depending on quality of irrigation water is important crop management (Chauhan et al., 2020). Also tolerance of crop varies with crop growth stages and therefore, knowledge of sensitive stages of crops is needed. The irrigation by poor quality water is avoided at crop sensitive stages. The agronomic practices mainly deal with seed rate and land preparation. In case of alkali water, sowing of crops is to be preferred on the beds. It saves water, avoids salt accumulation and water stagnation during rainy season. In case of rice, it is advisable to grow nursery with good quality water on normal soils. Thus, salt stress on rice seedling is avoided. The heathly rice seedling having age of 35-40 days might be used for trasplanting and 3-4 plants /hill should be used and distance between hills should be 15 cm. Also in case of wheat, 25% extra seed rate is recommended. The mulching is also important agronomic practice to maintain soil moisture and to avoid salt stress. The chemical management option is needed in case of alkali water use for neutralization of RSC and gypsum beds can be used for it. Nurient requirement of salinity/ alkalinity stress is slightly different than normal soils and additional nitrogen (25 to 30% extra) is necessary. Also availability micro-nutrients such as Zn, Fe, Mn and Bo is limited under salt affected environment. These issues are to be considered while managing nutrient requirements of crops under alkali and saline water use. The water management is very crucial (Velmurugan et al., 2019). The pre-sowing irrigation by good quality water helps to leach out salts and better germination. The light and frequent irrigations are useful for sodic environment. In case of conjunctive use of alkali / saline and good quality water, the good quality water should be preferred during sensitive stages of crops. The drip irrigation has been found as very useful irrigation method for use of saline and alkali waters. The groundwater recharge to dilute alkali/

saline water in aquifers and then use of diluted groundwater for crop production has become important option. Details of different management options are provided in following subsections. However, integration of different options is required for management of alkali and saline water successfully.

9.3 Management of Sodic/ Alkali Groundwater for crop production

Crop management

Farmer should select salt tolerant crops for sodic conditions. Details of crops indentified on basis of field experimentatios at Agra centre and other AICRP centres for sodic conditions are provided in Table 9.1, 9.2 and 9.3.

Table 9.1: Sodicity tolerant crops with relative yield (percent) at different RSC levels

RSC(meq/l)	Relative yield (percent) of different crops					
	Wheat	Pea	Gram	Lentil	Mustard	Soybean
Control	100	100	100	100	100	100
05	98.5	91.7	90.8	90.6	96.2	53.6
10	95.8	69.9	65.8	80.4	92.1	28.9
15	84.9	64.7	44.7	76.1	80.5	20.4
20	75.2	-	-	-	70.6	15.1

(Bhudayal et.al. 2011)

The use of RSC waters for crop production results in soil sodification. The soil ESP can be used as indicator of soil sodicity and sodicity tolerant crops can be selected (Anonymous, 2004) on the basis of details given in the Table 9.2. The soil pH is also good indicator of soil sodicity in Indo-gangetic plain and important sodicity tolerant crop varieties including developed by ICAR-CSSRI for sodic environment are provided in Table 9.3.

Table 9.2: Relative tolerance to sodicity of soils

Soil ESP	Crops
10-15	Safflower, Mash, Peas, Lentil, Pigeon-pea, Urd-bean, Banana
16-20	Bengal gram, Soybean, Papaya, Maize, Citrus
20-25	Groundnut, Cowpea, Onion, Pearl-millet, Guava, Bel, Grapes
25-30	Linseed, Garlic, Guar, Palmarosa, Lemon grass, Sorghum, Cotton
30-50	Mustard, Wheat, Sunflower, Ber, Karonda, Phalsa, Vetiver, Sorghum, Berseem
50-60	Barley, Sesbania, Paragrass, Rhoades grass
60-71	Rice, Sugarbeat, Karnal grass

Table 9.3: ICAR-CSSRI recommended crop varieties for cultivation in sodic soils

Crop	pH	Varieties
Rice	9.8-10.2	CSR 10
	9.4-9.8	CSR 10, CSR 13, CSR23, CSR 27, CSR 36, CSR43, CSR46, CSR56, CSR 60
	<9.4	Basmati CSR30
Wheat	9.2 - 9.3	KRL-1-4, KRL-19, WH 157, Raj. 3077, KRL210, KRL213, KRL 283
Mustard	Up to 9.3	Pusa bold, Varuna, Kranti, CS52, CS54, CS56, CS58, CS60
Barley	Up to 9.3	CSB 1, CSB 2, CSB 3, DL 200, DL 348. Ratna, BH 97, AZAD
Chickpea	Up to 9.0	Karnal Chana 1

Most of the crop plants are sensitive during the stage of emergence and early seedling growth. This may cause either poor plants stand or delayed germination. The higher concentration of the salts at the soil surface caused by evaporation cast bad effect again on the crop. Relative sensitivity of crop growth stages of some crops for irrigation with poor quality water is given below (Table 9.4).

Table 9.4: Relative sensitivity of crop growth stages to poor quality irrigation

Crop	Relative sensitivity
Mustard	Pre sowing > Flower initiation > Secondary Branching
Wheat	Pre Sowing > Flowering > Milking > Crop root initiation > Jointing
Barley	Crown root initiation > Pre Sowing > Flowering/ Booting >Jointing
Safflower	Pre sowing > Rosette > Flower initiation > Main head opening

Selection of suitable crop rotation in case of alkali water use is also important and discussed below.

- Since use of sodic water required repeated application of gypsum, only tolerant or semi-tolerant crops having low water requirement such as barley, wheat, mustard, pearl millet and sorghum should be grown while crops with high water requirement (rice, sugarcane and berseem) should be avoided.
- If good quality canal water is not available, kharif season crop should be taken only using rain water to provide salt free root zone for rabi crop which is precious and important for farmers. Sodic water should not be used for growing summer crop.
- In low rainfall areas (average annual rainfall<400 mm) if good quality canal water is not available, it is advisable to keep the fields fallow during kharif season. During rabi, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown.
- In areas having rainfall>400 mm annum-1, sorghum-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be practiced, provided it is ensured that the sowing, particularly of kharif crops is completed with rainwater or good quality canal water.
- Sodic waters should not be used for growing summer crops.

Sodic water use guidelines and application of amendments

If we refer guidelines for use sodic waters by CSSRI, PAU and HAU (Table 9.5) by Minhas and Gupta (1992) and Gupta, et al. (1994) at this stage, it could be easily understood that Agra and nearby districts have rainfall more than 550 mm and soils are basically moderately fine (clay per centage between 20 to 30) and moderately coarse (clay per centage between 10 to 20). As per guidelines, waters with RSC from 3.5 to 5.00 meq/l and SAR less than 10 could be used for moderately fine soils while waters with RSC from 5.0 to 7.5 meq/l and SAR less than 15 could be usd for moderately coarse soils.

Table 9.5: Guidelines for sodic groundwaters with RSC > 2.5 meq L^{-1} and ECiw < 4.0 d Sm^{-1}

Soil texture (% clay)	Upper limits of SAR (m mol $L^{-1})^{1/2}$	RSC meq L^{-1}	Remarks
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm
Moderately fine (20-30)	10	3.5-5.0	When water has Na < 75%, Ca+Mg >25% or rainfall >550mm, the upper limit of RSC becomes safe
Moderately coarse (10-20)	15	5.0-7.5	For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif.
Coarse (<10)	20	7.5-10.0	

In case of double cropping on moderately coarse soils, RSC neutralization with gypsum is essential based on quantity of water used during *rabi* season. The sodicity hazard of the irrigation waters on the soil can be mitigated by neutralization of the RSC of irrigation water with gypsum. If the RSC of irrigation water is less than 2.5, the water is considered as of good quality and in that case it is not necessary to add gypsum or any other amendments.

However, every additional 1 meq/l of RSC is to be neutralized by application of agriculture grade gypsum (70 percent purity) @ 12 kg/ha per cm of irrigation water applied. The quantity of gypsum to be added is thus, determined by the RSC of irrigation water and quantity of water required for irrigation during the growing season or on yearly basis as under:

The water of a tube well has a RSC of 10.5 meq. The water is to be used to irrigate wheat crop. The wheat requires about 5 irrigations of 6 cm each. The calculation of gypsum requirement to treat the soil to avoid adverse effects as below:

RSC to be neutralized = 10.5 - 2.5 = 8
Number of irrigation = 5 (6 cm each)
Gypsum to be added (t/ha) = (12 x 8 x 5 x 6)/1000 = 2.88 t/ha.

In case of unavailability of gypsum and easily available of other amendments, their relative quantities may be calculated with the help of details provided below in Table 9.6.

Table 9.6: Equivalent quantities of some common amendments for alkali (RSC) soil reclamation

Amendments	Relative quantity
Gypsum ($CaSO_4$ $2H_2O$) *	1.0
Calcium chloride ($CaCl_2$ $2H_2O$)	0.85
Sulphuric acid (H_2SO_4)	0.57
+Sulphur (S)	0.19
Pyrite (FeS_2: 30 percent S)	0.63

*These quantities are based on 100 per cent pure materials. If the material is not 100 per cent pure, necessary correction must be made. Thus, if the sulphur is only 80 percent pure, the factor applied will be 100 x 0.19/80 = 0.238 (Table 9.6).

+hundred per cent oxidation is assumed. In practice, it rarely happens. As such these amendments are less effective than the other listed. To compensate slightly higher dose should be applied.

The gypsum should be added both on the basis of soil requirement as well as to neutralize the RSC of irrigation water. Since, water is used year after year; application of gypsum should be repeated after certain years. Gypsum is added to the soil, being easier to accomplish, than treating the water itself. Evidences are now made available that it would be more appropriate to treat the water.

Gypsum bed

As explained in the previous sections, addition of gypsum to the soil or to the water is required to neutralize the adverse effect of RSC. It has been observed that response of gypsum application is better when applied after each irrigation than the seasonal or annual application. Since soil application after each water would pose problems, therefore technology to treat irrigation water with gypsum has been developed so that there is no need to add gypsum to the soil. The easiest and the most practical way to treat irrigation water with gypsum is to construct a gypsum bed. Gypsum bed is cement tank in which gypsum is kept of perforated platform. The alkali water from tubewell is passed through gypsum and neutrilised. This practice eliminates the costs involved in powdering, bagging and proper storage before its actual use. AICRP on Use of Saline Water located at CSSRI, Karnal has also tested the performance of pyrites beds to compare the relative performance of gypsum and pyrites in treating high RSC water. Results showed that treatment with pyrite was quite effective.

Other important considerations (including agronomic) for management of sodic/ alkali waters

- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and / or Mg: Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity (SAR > 20) is helpful for low rainfall areas.
- Fertilization with additional phosphorus is beneficial especially when C1:SO4 ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre-sowing irrigation in conjunctive use mode.
- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help in better germination.
- Accumulation of B, F, NO3, Fe, Si, Se and heavy metals beyond critical limits with irrigation is toxic.
- Expert advice prior to use of such water is essential.
- Jower-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be successfully grown in areas having rainfall > 400 mm/annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops.
- In rice-wheat belt of alluvial plains having rainfall ≥600 mm, rice-wheat, rice-mustard, sorghum mustard, and dhainacha (GM)-wheat rotations can be successfully practiced with gypsum application.
- Green manuring at interval of 2- 3 years helps in improving soil physical, chemical and biological properties of soils particularly where alkali water is used for irrigation.
- Sodic water should not be used for summer crops in the months of April to June.
- Drip experiments at Tiruchirapalli centre of AICRP have shown that among different irrigation methods, drip is the most suitable for sodic/ alkali environment. Treated alkali water by gypsum/ distillery spent wash can be used effectively through drip for growing vegetable crops.
- Sowing of crops on the beds in alkali water irrigated areas/ alkali soils is very beneficial to the farmers by saving of irrigation water, avoiding salt accumulation around root zone and avoiding crop failure due to water stagnation in rainy season.
- Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas, where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used.

Nutrient management for alkali water irrigation

Since sodic waters cause a rise in soil pH that leads to greater nitrogen losses through volatilization and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates (Meena et al., 2019). Some other beneficial tips as regards fertilizer use are.

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg ha should be added, particularly to the rabi crop.

- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil values.
- Some sodic waters may be rich in nutrients like nitrogen, potassium and sulphur such waters should be analyzed and the fertilizer dose of concerned nutrient reduced accordingly as per their composition in such water.
- For high yields, organic materials (such as FYM etc) should be used. The organic manures (i.e. FYM etc) supply not only nutrients to the plants, but also play an important role in improving soil physical properties (Meena et al., 2018). As such, its application enhances leaching of salts accumulated in the root zone.

Irrigation water management through conjunctive use

In the area where the availability of good quality water through either canal or other sources is limited, alkali water can be used for agriculture production by blending or mixing of alkali water with canal water or by applying canal and alkali water in cyclic or rotational mode considering sensitive stages of crops and availability of fresh water for irrigation. Possibilities have now emerged to safely use the water otherwise designated unfit. Some important things are discussed below.

- Appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies are to be adopted so that high level of soil moisture and low level of salts/ exchangeable sodium are to be maintained in the rhizosphere.
- Land management practices are to be designed in such way that uniformity of water distribution, infiltration and salt leaching are to be ensured.
- In case of irrigation by sodic waters, the conjunctive use strategy should either minimize the precipitation of calcium or maximize the dissolution of precipitated calcium. This is particularly relevant to the areas, where canal water supplies are either un-assured or less than required, and farmers often pump sodic groundwater for crop production. For the efficient use of waters of different qualities, good quality waters can be used for sensitive crops and sodic waters for tolerant crops. The most appropriate practice, however, can be the conjunctive use of these waters by: i) blending in supply network, making appropriate water quality available for each crop irrespective of soil conditions; ii) alternate use of sodic and canal water according to availability and crop needs; and iii) switching these water sources during the growing season according to critical stages of crop growth. The blending of sodic water and canal water is done in such proportion so that final RSC is maintained below the threshold limit of the crop to be grown. The alternate use is preferable and has operational advantages.

Improved irrigation management

Use of alkali water enhances soil sodifiation process and soil physical properties are adversely affected. Light and frequent irrigation are useful under sodic environment. Drip and sprinkler systems are useful for application light and frequent irrigations. Nowdays, ameliorated alkali water using gypsum or distillery spent wash is applied through drip irrigation for vegetables or cotton crop. The results are very much promising.

9.4 Management of Saline Groundwater for Crop Production

It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, depth to water table, irrigation water quality, soils and crops are integrated with appropriate crop and irrigation management practices (Minhas and Gupta 1992). The different crop, soil, chemical and irrigation water management based strategies are developed based on results of various experiments and summarised below.

Crop management

In general list of crops and crop varieties tolerant to salinity are provided in Table 9.7 and Table 9.8, respectively. Farmer should select salt tolerant crops for saline conditions.

Table 9.7 Crop groups based on Tolerance to Salinity

Sensitive Group		**Resistant Group**	
Highly sensitive	**Medium sensitive**	**Medium tolerant**	**Highly tolerant**
Lentil	Radish	Spinach	Barley
Mash	Cow Pea	Sugarcane	Rice (transplanted)
Chickpea	Broad bean	Indian mustard	Cotton
Beans	Vetch	Rice(direct sowing)	Sugar beet
Peas	Cabbage	Wheat	Turnip
Carrot	Cauliflower	Pearl millet	Tobacco
Onion	Cucumber	Oats	Safflower
Lemon	Gourds	Alfalfa	Taramira
Orange	Tomato	Blue panic grass	Karnal grass
Grape	Sweet Potato	Para grass	Date palm
Peach	Sorghum	Rhodes grass	Ber
Plum	Minor millets	Sudan grass	Mesquite
Pear	Maize	Guava	Casuarina
Apple	Clover, berseem, Acacia	Pomegranate, Salvadora	Tamarix

Table 9.8: Salinity tolerant varieties of different crops (Bhudayal et.al. 2011)

Crops	Salt tolerant varieties
Wheat	Raj 3077, Raj 2560, Raj 3765, HD 2278, Bhp 36&37, Raj 2325, WH 157
Mustard	CS 330-1, CS 416, Pusa Bold, CS 52, Kranti, RH-30, CS54, CS56, CS58, CS60
Barley	Ratna, RL 345, CS 19, DL 348, DL 88, RD103, RD137, K169
Sorghum	SPV 881, CSH 11, SPV-475, SPV-678, SPV 669
Cotton	G.A., H 777, DHY 286, CPD 404, G 17060, JK276-10-5, GDH 9, G, Cot-23
Safflower	SF 5, K 1852, Raj. 2325,HUS 305, A-1, Bhima
Pearl millet	MH 269, MH 427, HHB 392, MBH 163, MRB 204,MH 331, HHB-60
Sunflower	MSFH 7, 17, Modern
Cluster bean	Durgapura Safed
Lady Finger (Bhindi)	Mahyco No. 10

Details of crops tolerant to salinity indentified on basis of field experimentatios at Agra centre for saline conditions (Table 9.9).

Table 9.9: Salt tolerant crops with relative yield of 90, 75 and 50 per cent at different levels of irrigation water salinity (EC_{iw}) as per Bhudayal et.al. (2011)

Crops	Previous Crop	ECiw (dS/m) for relative yields		
		90 percent	75 percent	50 percent
Cereals				
Wheat	Pearlmillet	6.6	10.4	16.8
Wheat (Late)	Toria	4.3	6.6	11.0
Barley	Fallow	7.2	11.3	18.0
Rice	Berseem	2.3	4.6	8.6
Perlmillet	Wheat	5.4	9.0	15.0
Sorghum (seed)	Mustard	7.0	11.2	18.1
Sorghum (Fodder)	Berseem	5.2	10.2	18.4
Oilseeds				
Mustard	Sorghum	6.6	8.8	12.3
Toria	Wheat	4.7	5.1	5.9
Pulse/Legume				
Pigeon Pea	Onion	1.3	2.3	3.9
Berseem	Rice/Sorghum	2.5	3.2	4.4
Soybean	Wheat	2.5	4.7	8.4
Vegetables				
Onion	Pigeon Pea	1.8	2.3	3.3
Potato	Okra	2.1	4.3	7.8
Okra	Potato	2.7	5.6	10.5

Saline water use guidelines

If we refer guidelines for use saline waters by CSSRI, PAU and HAU (Table 9.10) by Minhas and Gupta (1992) and Gupta, et al. (1994) , it could be easily understood that Agra and nearby districts have rainfall more than 550 mm and soils are basically moderately fine (clay per centage between 20 to 30) and moderately coarse (clay per centage between 10 to 20). As per guidelines, waters with electrical conductivity upto 2.5 dS/m might be used for sensitive crops, upto 4.5 dS/m and 8.0 dS/m might be used for semi-tolerant and tolerant crops, respectively, in case of moderately fine soils. The limits irrigation water salinity would be slightly higher for moderately coarse soils. Irrigation waters with electrical conductivity upto 3.0 dS/m might be used for sensitive crops, upto 8.00 dS/m and 10.0 dS/m might be used for semi-tolerant and tolerant crops, respectively, in case of moderately fine soils.

Table 9.10: Guidelines for use of saline water (RSC < 2.5 meq/1)

Soil texture (% clay)	Crop Tolerance	Upper limits of ECiw (dS/m) in rainfall regions		
		350 mm	350-550 mm	550-750 mm
Fine (> 30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately Fine (20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately Coarse (10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (< 10)	S	- -	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

Note: S, ST and T denote sensitive, semi-tolerant and tolerant crops

Other important considerations (including agronomic) for management of saline waters

- Semi-tolerant to tolerant crops with low water requirements might be selected so that fewer salts would be added to rootzone.
- Selection of crop sequence is also important like selction of salt tolerant crops.
- Saline water use during initial growth stages should be avoided. Pre-sowing irrigation by good quality water is given for leaching salts and better germination.
- If saline water is used for pre-sowing irrigation, 20 percent extra seed rate and a quick post-sowing irrigation will ensure better germination.
- If saline water is used for irrigation, more irrigation water compared to irrigation water requirement is applied to meet leaching requirement of soils.
- Alternating the area/ area switching i.e. irrigate the selected area with saline water for 3-4 years and then switch to next area so that leaching salts takes automatically by rain water.

Nutrient management for saline water irrigation

- Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments.
- Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly 50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available P.
- For sulphate rich waters, no additional application of phosphate fertilizers is required and the dose recommended under normal conditions may be applied.

- For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.
- Farmyard manure (FYM): FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Therefore, the addition of FYM and other organic/green manure should be made to the maximum possible extent.

Irrigation water management through conjuctive use

Long-term salt balance has important role in case of sustainability of crop production under saline irrigation. However, temporal changes in root zone salinity are important for immediate crop yield prediction as salinity tolerance of crop varies with stage of crop. Simulation study by Kaledhonkar et al. (2006a) and field experiment by Naresh et al. (1993) for five conjunctive use practices of saline and canal water for wheat crop namely, SW: CW alternate, CW: SW alternate, 2CW: 2SW, 2SW: 2CW and Mix (1:1), where SW, CW and Mix represent Saline Water, Canal Water and Mixed (Blended) water of saline and canal water, indicated that 2CW: 2SW mode was the best option (Rank 1), as root zone salinity under this mode remained low for almost two months (during initial crop growing period). The CW: SW was second preference (Rank 2) as it ensured low salinity for initial month. The mix (1:1) mode was the third preference (Rank 3) and was better than SW: CW mode (Rank 4). It is obvious that 2SW: 2CW (Rank 5) got the least preference. Electrical conductivity of saline water, canal water and mixed water was 12, 0.60 and 6.3 dS/m, respectively. The ranking of conjunctive water use developed through modeling was veified with field experimental data and found correct (Table 9.11). Though the amount of salt load added under different conjunctive use practices to root zone of wheat crop was same, temporal changes in root zone salinity were different. In case of wheat crop, critical growth stages such as vegetative (crown root initiation, tillering and late jointing), reproductive (flowering) and maturation (milk stage and dough) stages are identified for irrigation, which are in addition to pre-sowing. Vegetative stage of wheat crop is sensitive to salinity. Reproductive stage is less sensitive and the maturation stage is least sensitive (Mass and Poss, 1989). Therefore, selection of proper mode of conjunctive use is required for suitable salinity management at the root zone for optimum crop yields. The conjunctive use preference order discussed here for use of canal and saline groundwater also holds true for conjunctive use canal and alkali groundwater. One more important thing is to be mentioned that preference/ ranking order gets violated, if initial root zone salinity is higher and it affects germination. Such type of preference order can be prepared for other crops on basis field experimentation, salinity tolerance at different crop growth satges and modeling studies.

Table 9.11: Modeling based ranking of conjunctive use of canal and saline water and verification of ranking with experimental data

Sr. No.	Conjunctive use practice	Description	Rank	Wheat yields (t/ha) by Naresh et al. (1993)	Wheat yields (t/ha) by Sharma et al. (1994)
1	All canal	All canal irrigations	1	5.45	6.49
2	2CW: 2SW	Two canal and two saline water irrigations	2	5.22	6.25
3	CW: SW	Canal and saline water alternate irrigation	3	5.38	6.25
4	Mix (1:1)	Irrigation by canal and saline water mix (1:1)	4	4.96	---
5	SW: CW	Saline and canal water alternate irrigation	5	4.01	6.09
6	2SW: 2CW	Two saline and two canal water irrigations	6	----	6.08

Improved irrigation management

The pressurized irrigation methods such as sprinkler and drip are more efficient as the quantity of water applied can be adequately controlled. These systems have on the other hand, great potential of application in the arid and semi-arid regions particularly on the light textured soils and the land having undulating topography. In case of use of saline water, drip has advantage over sprinkler as leaching of salts takes place at low application rate and low leaching leaching fraction. Frequent irrigation water application through drip helps to maintain high moisture content and to reduce salinity stress. It has been observed that it was possible to apply water of higher salinity through drip without yield reduction. Drip experiments at Bikaner, Hisar, Gangavathi centres of AICRP have shown that saline water can be effectively for vegetables and field crops reducing effect of salinity (i.e. osmotic stress) as well as reducing fertilizer requirement (AICRP-SAS&USW, 2017, Singh et al. 2018). Further, use of mulching along with drip is very effective in reducing adverse effect of salinity.

9.5 Conservation Agriculture Practices and Use of Microbes for Micro-Nutrient Management

Experimental results have shown that conservation agriculture practices such as incorporation of crop residues improve soil health and enhance availability of major and micro nutrients in case of semi-reclaimed soils as well as salt affected soils. In recent days, researchers are trying to improve the solubility of P, Zn and Fe in salt affected soils with help microbes. It might become an effective way of micro-nutrients management of such soils in future (AICRP-SAS&USW, 2017).

9.6 Rain Water Conservation and Groundwater Recharge in Poor Quality Groundwater Area

Land leveling and construction of bunds should be done in summer before the commencement of rain to harvest all rain water in the field itself. The harvested rain water helps in leaching os salts from root zone both in saline and sodic soils. The soil properties of sodic soils are poor. The staganation of harvested rain water can damage crop. Further, harvested of rain water is in sufficient amount, it can be used for groundwater recharge. The centre has developed **Low Cost Groundwater Recharge Structure** (Fig.9.1) and demonstrated on farmers' fields.

Fig. 9.1: Low Cost Groundwater Recharge Structure developed by Agra centre

The results of 9 farmers' field demonstrations at Odhara village in Bharatpur district with reference to improvement in groundwater quality, crop yield, and groundwater availability are discussed below. During 2012-13, wheat crop was grown at demonstration fields. Initial salinity of groundwater from farmers' tubewells at start of *rabi* season varied from 10.9 to 23.5 dS/m.

Recharge of groundwater by excess surface run off improved its quality due to dilution. Average pumped groundwater quality (dS/m) at time of different irrigations of wheat during 2012-13 is provided in Table 9.12.

Table 9.12: Salinity (dS/m) of pumped ground water at different irrigations at rain water recharging sites

Name of farmer with demonstration	Salinity of pumped groundwater (dS/m) at different times					
	Initial	First Irrigation	Second irrigation	Third irrigation	Fourth irrigation	Fifth irrigation
Lal Hans	10.9	7.7	9.3	10.3	11.1	10.9
Ram Bharosi	15.0	10.7	11.8	13.1	14.6	14.4
Jagan Singh	12.6	9.2	11.0	13.0	14.1	10.8
Dhara Singh	15.2	9.1	11.8	13.2	15.3	13.7
Mukesh Kumar	13.8	9.1	10.3	11.5	13.7	13.4
Hari Prasad	13.5	10.0	11.9	13.1	13.5	13.5
Dinesh Chand	11.0	8.8	9.6	10.4	11.5	11.0
Birendra Singh	19.9	9.9	12.9	16.2	19.1	16.6
Roop Singh	23.5	8.9	12.9	17.2	20.1	20.5

Average pumped groundwater salinity after recharge varied from 7.7 to 10.7 dS/m at time of first/pre-sowing irrigation, 9.3 to 13.4 dS/m at second irrigation, 10.3 to 17.2 dS/m at third irrigation, 11.1 to 20.1 dS/m at fourth irrigation and 10.9 to 20.5 dS/m at fifth irrigation. The improvement in pumped groundwater quality (i.e. irrigation water quality) resulted improvement in yields of *rabi* crops. The wheat yields of demonstration fields were compared with yields of nearby farmers. The average wheat yield varied from 3.9 to 4.7 t/ha during 2012-13 (Table 9.13) at demonstration fields while on nearby farmers' fields (without low cost recharge structure), yield varied from 3.67 to 4.45 t/ha.

Table 9.13: Effect of groundwater recharge on yield of wheat and soil characteristics at recharge sites

Name of ORP farmer	Average yield (t/ha)		Yield increase under ORP (%)	ECe (dS/m)	pH2	SAR (mmol/l)½
	ORP	Nearby farmer				
Jagan Singh	5.4	4.7	13.3	15.1	7.3	22.3
Mukesh Kumar	4.7	4.1	14.0	13.5	7.6	19.4
Birendra Singh	47	4.1	14.7	14.2	7.5	20.2
Lal Hans	47	4.2	12.8	15.8	7.8	24.4
Dinesh Chand	47	4.2	13.1	11.8	8.0	19.7
Dhara Singh	50	4.4	152	11.9	7.7	21.1
Ram Bharosi	4.5	3.9	15.4	17.3	7.7	27.4
Roop Singh	4.8	4.1	171	19.3	7.8	29.8
Hari Prasad	5.0	43	16.3	15.3	7.6	14.8

The increase in wheat yield due to recharge structure varied from 7.7 to 12.1 per cent over other farmers' fields. The farmers of Agra and Bharatpur region are adopting the technology.

10. SUMMARY AND CONCLUSIONS

AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Agra carried out the work on survey, characterization and mapping of ground water quality in 8 districts namely Agra, Mathura, Aligarh, Firozabad, Etah, Mainpuri, Etawa in Uttar Pradesh and Bharatpur in Rajasthan. The significant results of the ground water quality surveys and different field experiments for use of poor quality waters are provided below:

- In Agra district, 23.9, 45.6 and 30.7 per cent ground water samples were of good, saline and alkali type. Saline waters are dominant compared to others. Amongst the saline waters, high SAR water samples were 38.8 per cent.

- In Mathura district, 21.0, 45.3 and 33.7 per cent ground water samples were of good, saline and alkali type. High SAR saline, marginally saline and saline samples were 17.4 per cent, 17.2 per cent and 10.7 per cent, respectively. Under alkali group, marginal alkali, alkali and high alkali samples were 16.2, 9.0 and 8.5 per cent, respectively.

- In case of Aligarh district, 32.0, 60.0 and 8.0 per cent ground water samples were of good, alkali and saline type. Under alkali group, 15.4, 30.8 and 14.4 per cent groundwater samples belonged to marginally alkali, alkali and high alkali class.

- In case of Etah district, 78.0, 16.0 and 6.5 per cent ground water samples were of good, alkali and saline type. Under alkali water categories such as marginally alkali, alkali and high alkali with per cent of samples were as 5.0, 7.1 and 2.3 per cent, respectively.

- In case of Firozabad district, 36.5, 53.9 and 9.5 per cent samples were of good, alkali and saline type. Within alkali type of groundwater, 23.0, 22.1 and 8.8 per cent samples belonged to alkali, marginally alkali and high alkali, class, respectively.

- In case of Mainpuri, 78.2, 16.9 and 3.6 per cent samples were of good, alkali and saline type. Among alkali group, 11, 5.5 and 1.4 percent were of marginally alkali, alkali and high alkali class, respectively.

- In case of Etawah district, 51.6, 40.3 and 8.1 per cent ground water samples belonged to good, alkali and saline group. The marginal alkali was dominant with 20.9 per cent of samples and it was followed by high alkali with 17.2 per cent samples.
- In case of Bharatpur district, 17.0, 62.9 and 19.8 per cent samples were of good, saline and alkali type. Further, amongst the saline classes, 43.5, 10.0 and 9.4 per cent were of high-SAR saline, saline and high saline class. In alkali classes, 12.8, 1.8 and 5.2 percent samples were of high alkali, alkali and marginal alkali, respectively.

- In case of management of poor quality waters, different types of management options such as crop, agronomic, chemical, nutrient and water management options can be selected. The use of salt tolerant crop and crop varieties may be identified depending on quality of groundwater. The agronomic practices mainly deal with seed rate and land preparation. The mulching helps to maintain soil moisture and to avoid salt stress. The chemical management option is needed in case of alkali water use for neutralization of RSC and gypsum beds can be used for it. Green manuring has positive effect in both saline and sodic environment. Nutrient requirement of salinity/ alkalinity stress is slightly different than normal soils and additional nitrogen (25 to 30% extra) is necessary. Also availability micro-nutrients such as Zn, Fe, Mn and Bo is limited under salt affected environment. The pre-sowing irrigation by good quality water helps to leach out salts and better germination. The light and frequent irrigations are useful for sodic environment. In case of conjunctive use of alkali / saline and good quality water, the good quality water should be preferred during sensitive stages of crops. The drip irrigation has been found as very useful irrigation method for use of saline and alkali waters. The groundwater recharge to dilute alkali/ saline water in aquifers and then use of diluted groundwater for crop production has become important option. Integration of different options is required for management of alkali and saline water successfully.

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For Further details, contact:

Officer in Charge
All India Coordinated Research Project
Management of Salt Affected Soils and Use of Saline Water in Agriculture
Raja Balwant Singh College, Bichpuri, Agra-282002 (Uttar Pradesh)
Email: aicrp.salinity@gmail.com