Citation:

Vishwanath J., Hebbar M., Karegoudar A.V., Rajkumar, R.H., Anand, S.R., Ambast S.K. and Gupta, S.K. 2013. Groundwater Quality and Management of Poor Quality Water for Agriculture in Karnataka. Technical Bulletin No. 2013/1, AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Gangavati, Karnataka, India, p-47

Published by:

Chief Scientist & Head, AICRP on Management of Salt Affected Soils, Gangavati – 583 227 India
Telephone: +91-8533-271030; Fax: +91-8533-271030

Printed at:

The Paramount Printers & Services
Next to Vasavi Nursing Home, Islampur
Gangavati-583227. Dt.: Koppal
Telephone: +91-9845-014492

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Vishwanath Book

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June-2013

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Vishwanath Book

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FOREWORD

Water is vital for sustaining life on this planet. Agriculture dominates water use wherein it forms almost 92 percent of total water demand. Of late, due to the inadequacy of surface water, the groundwater is becoming more and more important which is supplementing the total water needs. Karnataka state depends on groundwater for irrigation to the extent of 51percent. It is estimated that the supply capacity of groundwater resource in Karnataka is about 485 TMC and is expected to decline to 376 TMC by 2020 indicating groundwater resource is becoming increasingly meagre over time and space especially in the dry agro climatic zones of Karnataka. Added to that, purchasing power of agriculture for water will not be able to compete with industrial sector due to the higher purchasing power of urban and industrial sector. As a consequence, agriculture will be forced to depend more on poor quality and marginal waters in future as well.

Indiscriminate use of poor quality water in the absence of proper soil-water-crop management practices poses grave risk to soil health and environment. Therefore, survey and characterization is prerequisite for adopting or developing suitable technologies like conjunctive use of poor and good quality water, use of crop and varieties suitable to poor quality use, amendments for amelioration of alkali water, practice of micro-irrigation techniques etc.

I complement the scientists for carrying out such a voluminous work over three decades and bringing out the technical bulletin on "Groundwater quality and management of poor quality water for agriculture in Karnataka". I hope this will prove useful to farmers, researchers and policy makers for enhancing crop production through judicious use of available poor quality water.

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Vishwanath Book

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PREFACE

Water makes the planet earth a livelihood entity. The prosperity of a nation lies in its water resources and its efficient and effective utilization. Lessons of ancient civilization like Mesopotamia wherein its' prosperity as well as its ruin caution us that irrigation could be boon and may become bane if practiced unscientifically and unscrupulously.

Agriculture predominates in its share of water as compared to other sectors like industry and domestic use. Due to the increased pressure for enhancing agricultural production to meet the growing population needs and less purchasing power of water as compared to other sectors, agriculture is relying greatly on underground water resources. Over exploitation of groundwater resulted in increased depth of water table and availability of poor quality water for irrigation. It is established that use of poor quality water in crop production not only adversely affects crop yields but also leads to land degradation in the long-run as land and water use are closely intertwined. Therefore, development of proper soil-water-crop management practices is essential to overcome/minimize the ill effects of poor quality water.

Thus, irrigation water literacy through survey and characterization of underground water especially in arid and semi-arid regions is a key factor in the development of agronomical, chemical, engineering means suitable for a specific soil and crop management in a given location for the quality of underground water available.

I complement the scientists for the conduct of this research program, making groundwater quality maps and bringing out the technical bulletin on "Groundwater quality and management of poor quality water for agriculture in Karnataka". I hope the information presented in the bulletin create awareness about the quality of water available, pros and cons of using poor quality water along with means for judicious use of poor quality water.

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ACKNOWLEDGEMNT

The authors wish to express their sincere gratitude to Dr. B.V. Patil, Hon'ble Vice-Chancellor, Dr. B.S. Janagoudar, Director of Research, formerly Directors of Research and Dr. I. Shankergoud, Associate Director of Research, UAS Raichur, for their continuous support, encouragement and valuable guidance in carrying out the research work and in bringing out this bulletin.

The authors are also indebted to Dr. D.K. Sharma, Director, formerly Directors, CSSRI, Karnal and Dr. S.K. Ambast, Project Coordinator, formerly Project Coordinators, AICRP-SAS&USW, CSSRI, Karnal, for their technical guidance, encouragement and monitoring the activities of the research project.

Our acknowledgement is incomplete without expressing sincere special thanks to formerly Principal Scientist & Head and scientists associated with this work at AICRP-SAS&USW, Gangavati centre.

AUTHORS

1. INTRODUCTION

1.1 PHYSIOGRAPHY

Physiograpically, Karnataka State forms part of two well defined macro regions of Indian Union; the Deccan Plateau and the Coastal plains and Islands. The State has four physiographic regions:

1. **Northern Karnataka Plateau** comprising districts of Belgaum, Bidar, Bijapur and Gulbarga and is largely composed of the Deccan Trap with a general elevation of 300 to 600 metres from the mean sea level. This region is largely covered with rich black cotton soils.
2. **Central Karnataka Plateau** covers the districts of Bellary, Chikmagalur, Chitradurga, Dharwad, Raichur and Shimoga. By and large, this region represents the area of Tungabhadra basin. The general elevation varies between 450 and 700 metres.
3. **Southern Karnataka Plateau** covers the districts of Bangalore, Bangalore Rural, Hassan, Kodagu, Kolar, Mandya, Mysore and Tumkur. This region largely covers the area of the Cauvery river basin lying in Karnataka. It is bounded by 600 metres contour and is characterised by a higher degree of slope. In the west and south, it is enclosed by the ranges of Western Ghats and the northern part is an interrupted but clearly identifiable high plateau. In the east the valleys of the Cauvery and its tributaries open out to form undulating plains. The general elevation of the region varies from 600 to 900 metres. However, residual heights of 1,500 to 1,750 metres are found in the Biligirirangan hills of Mysore district and the Brahmagiri range of Kodagu district.
4. **Karnataka Coastal Region** extends between the Western Ghats, edge of the Karnataka Plateau in the east and the Arabian Sea in the West. It covers Dakshina Kannada and Uttara Kannada districts. This region is traversed by several ridges and spurs of Western Ghats. It has difficult terrain full of rivers, creeks, water falls, peaks and ranges of hills. The coastal region consists of two broad physical units, the plains and the Western Ghats. The northern parts of the ghats are of lower elevation (450-600 metres) as compared to Southern parts (900 to 1,500 metres). The Coastal belt with an average width of 50 to 80 km covers a distance of about 267 km. from north to south.

1.2 CLIMATE

The climate of Karnataka state varies from very humid rainy monsoonal climate in the West Coast, the ghats and malnad areas to semiarid warm dry climate on the east. There is a large variation in the rainfall with higher amounts in the Western Ghats and reducing towards the eastern plains. Along the coastal Dakshina Kannada District, the normal rainfall is about 4000 mm and in the drought prone districts of Bijapur, Raichur, Bellary etc., the rainfall is of the order of 500 mm to 600 mm.

1.3 SURFACE WATER AVAILABILITY

Karnataka accounts for about six per cent of the country's surface water resources of 17 lakh million cubic metres (Mcum). About 40 percent of this is available in the east flowing rivers and the remaining from west flowing rivers. There are seven river systems in the state viz., Krishna, Cauvery, Godavari, West Flowing Rivers, North Pennar, South Pennar and Palar. Utilization of water in the West Flowing Rivers is hampered due to difficulties in construction of large storage reservoirs. Yield in the seven river basins is estimated as 3418 TMC at 50% dependability and 2934 TMC at 75% dependability. Yield in the six basins (excluding west flowing rivers) is estimated as 1396 TMC at 50% dependability and 1198 TMC at 75% dependability. The economically utilizable water for irrigation is estimated as 1695 TMC (Water Resources Department, Govt of Karnataka, 2002).

1.4 GROUNDWATER AVAILABILITY

Availability of ground water is estimated as 485 TMC. Ground water resources have not been exploited uniformly throughout the state. Exploitation of ground water in the dry taluks of North and South interior Karnataka is higher as compared to Coastal, Malnad and irrigation command areas. There is deficiency of water for drinking, agricultural and industrial use in dry taluks of North and South interior Karnataka. Where adequate surface water is available, utilization of ground water resources is minimum. In about 43 taluks there is over exploitation of ground water resources. Further, groundwater exploitation has exceeded 50% of the available ground water resources in 29 taluks of the state. These 72 taluks are critical taluks from the point of view of the ground water exploitation. In the 72 critical taluks about 4 lakh wells irrigate an area of 7.5 lakh ha. Due to over exploitation of ground water resources, more than 3 lakh dug-wells have dried. Shallow bore wells have failed and yield in deep bore wells are declining. Area irrigated by ground water extraction structures is decreasing (Water Resources Department, Govt of Karnataka, 2002).

Ground water is one of the most widely distributed and replinishable resources of the earth. The occurrence of ground water in a formation is largely governed by the hydro-geological setting of the formation, including the degree of cementation and compaction.

1.5 HYDRO-GEOLOGY

The rock types in the region vary in age from Archaean to recent while a major portion is covered by Peninsular gneisses, granites and Dharwar schists of Archaean age. Very large area is underlain by basalts (Karnataka Irrigation Department). The sedimentaries comprising Kaladgis and Bhima occupy a small area and the recent alluvium is restricted to a narrow belt in the coastal area and along stream courses. The changing patterns of physiography, climate and geology in peninsular region influence considerably the occurrence and movement of ground water from place to place. Majority of the geological formations are essentially the "Hard Rocks". The occurrence and distribution of ground water in the major rock formations are as under (Karnataka Irrigation Department):

Granites and Gneisses

The Archaean crystalline rocks occupying nearly 75% of the area constitute the major aquifer system and form more or less plain topography. The gneissic complex is composed of composite gneisses, migmatites, granites and quartz veins. The weathered zone in these crystallines extend from less than a meter to about 20 meter thickness. The secondary porosity due to weathering and tectonic activity, controls the occurrence and movement of ground water. The interstices and inter granular porosity in the weathered mantle and intensity of fracture porosity controls the ground water potentiality of the aquifers. The depth to water levels varies from near surface (i.e. about 0.5 m.) to as much as 21.0 m.bgl. depending on the topography. Accordingly, the depths of the dug wells range from about 3.0 to 24.m. bgl. and the yield is limited to about 50 to 250 cu.m/day. Dug-cum-bore wells are in vogue in certain places which were proved to have augmented the yields. The wells drilled by the Public Health Engineering Department and private agencies for domestic and industrial purpose to a depth range of 22 m to 64 m in different parts of the state are reported to generally yield about 0.2 to 2.5 litres per second, though in certain zones, yield as high as 6.9 lit per second (LPs) has been reported.

Dharwarian Formations

This group consists of volcanic rocks such as rhyolites, felisites, meta sediments as amphibolites, lime stones, dolomites, quartzites and schists. Dharwarian rocks especially the granulite facies usually occupy high grounds forming ridges, hill ranges and hence these are not important from the ground water point of view. The schistose formations, usually lying in valleys and plain areas, are good aquifers and fairly developed for ground water. The foliation planes in the schists constitute the primary porosity. Weathered zone extends from nil in the vicinity of outcrops to about 17 m in valleys. The water levels in the Dharwar rocks vary from 2.2 m to 22 m. bgl. and the depth of wells ranges from 3 m to 27 m.bgl. The yield of the dugwells varies from 5 - 200 cu.m/d., whereas that of irrigation bore wells varies from 0.1 to 6.1 LPs, for a well drilled to a depth range of 16 m to 70 m.bgl.

Kaladgi Formation

The occurrence and movement of groundwater in sedimentary rocks of Kaladgi series is controlled by the fracture porosity due to its indurated nature. The karstification in limestones plays very significant role in their behaviour as potential aquifers. Groundwater occurs under phreatic, semi-confined and also in confined conditions. The groundwater conditions can be differentiated and described under shallow and deep aquifer systems. Yield of bore wells constructed to depth less than 100 m in fractured and Karstified limestones range from 1 to 7 LPs. Open wells tapping shallow aquifers generally yield 30 to 100 cum.m/d. Recent exploration has revealed the presence of buried channels, some of them have good potential of groundwater such as Mamatgeri and Badami. The thickness of clastic sediments consisting predominantly of medium to coarse sand is more than 48 m and even beyond at some places.

Bhima Formation

Groundwater occurs in the shales and limestones of Bhima series under phreatic as well as confined conditions. The potential in these formations is confined mainly to the tectonic zones. Depth of water level varies from 1.2 m to 12.8 m bgl. The deeper levels are conspicuously noticed along the Bhima river course, characterizing it as effluent river and the shallow zones are in the inlands particularly along the major shear zone where the groundwater emerges in the form of seepages. The yield of the wells also varies significantly in the tectonic and non-tectonic zones. In the later case the yield is very poor with a recuperation rate of less than 0.5 m of water column per day both in shale and limestone aquifers. Wells are observed to yield about 30 to 100 cu.m/d. The groundwater conditions of the deeper aquifers can be gauged from the results of the borewells drilled to a depth range of 25 to 68 m bgl. The yield in the non-tectonic zones is reported to be less than 1 LPs, while in the tectonic zones it is up to 5 LPs.

Deccan Traps

The vast pile of Deccan basalt lying one over the other, each ranging six to over seventy meter in thickness is of Cretaceos-Eocene age. The basalts are often fractured in a terrain with undulating topography. The Deccan Traps constitute multi-aquifier system by virtue of variation in composition of the Traps from basaltic to vesicular and Zeolitic as well as with the presence of inter-trappenas and intra-trappeans. In general ground water occurs under both water table and semi-confined/ confined conditions. The near surface weathered and jointed zones of massive and vesicular units together constitute the main water table aquifer which is being developed extensively by dug wells. The saturated zone up to the depth of 15 to 30 meter forms water table aquifers. Below this the deeper aquifers are found under semi-confined/ confined conditions. The depth of water level varies from 0.67 to 16.83 m bgl. depending on the topography. Accordingly, the depth of wells ranges from 3.5 to 20 m bgl. The wells which are located in the weathered basaltic traps in the vicinity of zeolitic flows have very high discharge with unit area specific capacity of 120 lpm/m/sq.m. Zeolitic traps wherever they form aquifers, become promising zones, with an yield raging from 2 to 10 LPs. The red bole bed is clayey and observed to be a poor aquifer. The exploratory bore holes drilled by the Central Groundwater Board (CGWB) in parts of Bidar district in Karnataka, to a depth range of 90.5 to 213.75 m, tapping three vesicular flows, were having yield ranging from 0.55 to 3.3 LPs.

Laterites

In the lateritic aquifers, groundwater occurs mostly under phreatic condition. The movement of groundwater is controlled by the vesicles and interstices. Depth of water level varies from 3.6 to 24.0 m bgl. and the depth of the wells ranges from 5.0 to 25.0 m bgl. During rainy season water level in most of the wells rises upto the surface and in some cases even overflow. However, in summer while some of shallow wells become dry, there are others where yield even upto to 500 cu.m/d have been observed. The vesicular and vermicular varieties of laterite have better yielding capacities than the clayey laterite.

2. SURVEY AND CHARACTERIZATION OF UNDERGROUND WATER FOR IRRIGATION

Water a very precious natural resource sustains life on earth. Demand for water for domestic, industrial and irrigation purposes has significantly increased to meet the requirements of the growing population. Of late, due to the inadequacy of surface water, the groundwater is becoming more and more important which is supplementing the total water needs. Though it is widely distributed and renewable resource of the earth but the quality of which is not assured at all times. Supply of quality water through irrigation especially in scanty rainfall areas in enhancing crop yields is very well understood and documented. Similarly, use of poor quality water in crop production not only adversely affects crop yields but also leads to land degradation in the long-run since land and water use are closely intertwined. Introduction of irrigation in many arid and semi-arid regions of the world and in India have largely resulted in the development of twin problems of water logging and salinization, with considerable area is either gone out of cultivation or experiencing reduced crop yields. Research activities to develop technologies for these waste lands has become increasingly important to suit local situation and developing site specific recommendations. Hence, periodical assessment of the groundwater quality on a scientific basis for its optimal utilization with suitable recommendation in a specific location for a specific crop is a prerequisite for sustainable agriculture.

In this endeavor, research efforts were made at ARS, Gangavati through AICRP on Management of Salt-affected Soils and Use of Saline Water in Agriculture sponsored by ICAR (CSSRI, Karnal) on survey and characterization underground water for irrigation in selected districts of Karnataka where poor quality underground water is suspected based on geographical settings and on effective utilization of poor quality water in agriculture.

Assessment of ground water quality of villages in Bijapur (1688 samples), Raichur (1867), Bellary (1366), Davanagere (1986), Gulbarga (1729), Gadag (527) and Dharwad (313) district in Karnataka have been completed. In total 9476 ground water samples collected from these districts have been analyzed and categorized (except Bijapur district) based on the criteria of CSSRI, Karnal as detailed below:

Water quality	**EC_{iw} (dS/m)**	**SAR_{iw} $(mmol/l)^{1/2}$**	**RSC (me/l)**
Good	< 2	< 10	< 2.5
Marginally saline	2-4	< 10	< 2.5
Saline	> 4	< 10	< 2.5
High SAR-saline	> 4	> 10	< 2.5
Marginally alkali	< 4	< 10	2.5-4.0
Alkali	< 4	< 10	> 4.0
Highly alkali	Variable	> 10	> 4.0

The details of taluk-wise ground water quality in each of the above seven districts is discussed in this chapter.

2.1 Bijapur District

Bijapur district is located in the northern maidan region of Karnataka state and lies between 15^0 50'and17^0 28' north latitudes and 74^0 59' and 76^0 28' east longitudes. The district experiences semi-arid climate with extreme summers. The district experiences the temperature variation between 20^0C and 42^0C. The district receives an average annual rainfall of 578 mm. Physiographically, it can be divided into four physiographic units viz., residual hills, pediments, pediplains and valleys. The ground altitude varies from 470 to 650 m above MSL. Soils are medium to deep derived from range of parent materials including lime stone, basalt, sandstone, etc. Medium black soils, shallow black soils and deep black soils constitute about 40, 26 and 23 per cent respectively in the district. A major area of the district is under black soils (60-70 per cent) followed by red soils (30-40 per cent). The irrigation is mainly through underground water sources. In view of arid climate and prone for drought due to frequent failures of mansoons (North-East), farmers have gone in for extensive exploitation of under ground water resources in the district. The district has gross irrigated area of 294000 ha of which irrigation through borewell constitutes about 27%. The major crops of the district include sunflower, sorghum, pigeonpea, pearlmillet, maize, chickpea and horticultural crops like grapes, citrus, banana and mango.

Survey and characterization of underground water of Bijapur district was initiated during 1977 and continued till 1990. The district comprises eleven taluka (prior to 2000 AD) and falls in to northern dry zone.

Among eleven taluks, 25-30% of water samples in Mudhol, Bilagi and Sindagi taluks had pH > 8.5 indicating considerable potential alkali hazard on soil and crop growth upon use of such water. Bagalkot taluk had the highest percentage (72.0) of water samples registering pH < 7.5 followed by Badami (55.0) taluk. In the pH range of 7.5 to 8.5, Muddebihal (90.2) had the highest percentage of water samples followed by Indi (84.0). Sindagi and Hunugunda taluks registered the highest (96.5) and lowest (44.8) percentage of occurrence of water samples having EC < 2.0 dS/m respectively (Table 1). In accordance to this, Sindagi taluk had the lowest percentage of water samples having EC 2-4 (2.10) and EC> 4 dS/m (1.40). Mudhol (38.20) and Hunugunda (23.60) taluks recorded the highest percentage of occurrence of water samples having EC 2-4 and EC >4.0 dS/m respectively.

District as a whole 70.2, 20.9 and 8.9 per cent of water samples were found to be in the salinity class of EC <2, 2-4 and >4.0 dS/m respectively.

In the samples Na^{+} ion was dominent followed by Mg^{2+} and Ca^{2+} in all the taluks. The mean Mg/Ca ratio in all the taluks remained higher than 0.63 with Mudhol (3.29) and Jamkhandi (0.99) taluks having the highest and lowest Mg/Ca ratios in the district respectively. Among anion, except Sindagi, Muddebihal and Bilagi taluks, Cl^{-} ion was dominant in all the taluks followed by HCO_3^{-} or SO_4^{2-}. The mean chloride contents were much higher than 3.0 me/l (Tabe 2) in all the taluks and are considered not best suited for chloride sensitive horticultural crops.

Sl.No.	Taluk	EC (dS/m) Range		
		<2.0	2.0-4.0	>4.0
		Percent		
1	Bagalkot	77.8	21.0	1.2
2	Badami	62.4	25.7	11.9
3	Hunugund	44.8	31.6	23.6
4	Mudhol	50.7	38.2	11.1
5	Bilagi	84.0	15.0	1.0
6	Bagewadi	78.5	15.8	5.7
7	Jamakhandi	63.0	25.0	12.0
8	Muddebihal	63.9	25.6	10.5
9	Bijapur	64.2	21.6	14.2
10	Indi	86.4	8.8	4.8
11	Sindagi	96.5	2.1	1.4

The mean SAR was less than 10 in all the taluks with the highest mean SAR value (8.40) observed in Muddebihal taluk. The mean RSC was either negative or less than 2.5 me/l in all the taluks except in Bilagi taluk (4.59 me/l) which is considered to be a limiting factor in considering the suitability of water for irrigation. As shown in the table 3, frequency of occurrence of good quality water in the district surveyed found to be highest in Bagalkot taluk (90.2%) and lowest in Muddebihal taluk (12.5%). Except Badami and Hungunda taluks, the extent of occurrence of saline water and/or saline-sodic water was considerably less (<5.00%) in other taluks surveyed. Meddebihal and Indi taluks have registered the highest (84.5) and lowest (0.80) per cent of occurrence of RSC waters in the district. District as a whole, per cent occurrence of good quality, marginally saline and RSC waters were found to be 65.23, 10.43 and 20.11 respectively. The problem of salinity and saline sodicity was less than 5 per cent of 1688 samples analysed.

Table 2. Mean chemical composition of ground waters of different taluks of Bijapur district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Bagalkot	81	Max.	8.0	3.4	8.2	9.8	26.0	16.8	12.9	23.8	-
		Min.	6.5	0.15	1.0	0.8	0.3	1.9	0.10	2.6	-
		Mean	7.4	1.06	3.1	4.0	8.7	6.3	1.40	6.1	-
Badami	210	Max.	8.5	10.5	26.0	26.0	67.3	94.6	17.4	16.2	-
		Min.	7.0	0.29	0.8	0.4	0.9	2.3	0.03	2.4	-
		Mean	7.5	1.69	3.5	4.7	10.8	10.6	1.7	6.6	-
Hungund	136	Max.	9.3	8.68	20.0	28.4	82.46	48.2	54.69	18.4	-
		Min.	7.1	0.36	0.6	0.4	2.17	2.3	0.05	2.4	-
		Mean	7.6	2.27	4.19	6.68	13.2	11.23	5.66	7.18	-
Bilagi	100	Max.	9.2	3.5	8.4	8.0	37.84	23.4	nd	17.46	-
		Min.	7.7	2.5	0.4	0.2	0.82	1.8	nd	2.91	-
		Mean	8.3	1.16	2.62	3.38	8.2	5.94	nd	9.14	-
Mudhol	144	Max.	9.1	5.7	8.0	24.2	35.67	31.9	nd	13.58	5.82
		Min.	7.3	0.20	0.3	0.5	0.44	1.1	nd	0.97	1.94
		Mean	8.3	1.58	1.78	5.84	9.48	7.52	nd	5.03	2.19
Jamakhandi	123	Max.	8.2	7.4	25.8	25.8	52.6	23.0	60.2	16.2	6.20
		Min.	7.1	0.2	0.8	0.2	0.40	1.3	0.02	0.96	-
		Mean	7.7	1.54	5.50	5.47	9.55	5.1	5.55	5.29	1.9
B.Bagewadi	277	Max.	8.9	7.2	17.6	28.7	120.6	118.0	nd	22.5	18.0
		Min.	7.0	0.3	0.2	0.2	0.35	0.35	nd	1.00	0
		Mean	7.3	1.15	1.91	4.62	9.16	6.59	nd	4.78	0.94
Muddebihal	133	Max.	9.0	7.4	7.8	11.8	91.5	41.0	48.3	76.0	2.4
		Min.	7.1	0.40	0.5	0.4	2.5	1.0	0.02	5.2	0.2
		Mean	8.1	1.61	2.2	4.3	15.1	3.9	4.27	13.9	0.2
Bijapur	154	Max.	9.0	18.0	36.16	83.16	100.0	100.5	57.8	16.0	-
		Min.	7.1	0.43	0.56	1.16	0.86	0.46	Tr	1.0	-
		Mean	7.7	2.20	7.3	8.8	11.2	6.89	8.8	6.89	-
Indi	125	Max.	8.4	8.1	9.45	10.44	63.91	55.0	nd	11.3	3.6
		Min.	7.2	0.49	0.7	0.51	0.87	0.3	nd	0.8	0
		Mean	7.8	1.27	2.92	3.20	6.42	8.96	nd	2.63	0.51
Sindagi	143	Max.	9.0	4.6	13.6	15.48	40.83	25.42	nd	10.23	4.19
		Min.	7.4	0.42	0.44	0.48	1.41	0.67	nd	1.12	0.19
		Mean	8.4	1.1	1.36	2.69	5.83	4.26	nd	4.36	0.44
District Average		Max.	9.3	18.0	36.16	83.16	100.0	118.0	-	23.8	18.0
		Min.	6.5	0.15	0.2	0.2	0.3	0.3	-	0.8	0.19
		Mean	7.49	1.46	3.11	4.78	9.50	6.93	-	6.93	-

Table 3. Underground Water quality ratings for Bijapur district of Karnataka.

Sl.No	Taluka	Year	Good	Water quality ratings			
				Marginally saline	Saline	Saline sodic	RSC waters
1.	Bagalkot	77-78	90.2	4.9	-	-	4.9
2.	Badami	79-80	68.1	8.6	1.9	6.7	14.7
3	Hunugund	80-81	52.9	24.3	6.6	7.4	8.8
4	Bilagi	82-83	58.0	5.0	-	-	37.0
5	Mudhol	82-83	68.1	19.4	1.4	2.8	8.3
6	Jamakhandi	85-86	71.6	19.5	2.4	2.4	4.1
7.	B.Bagewadi	87-85	69.0	5.8	-	2.5	22.7
8.	Muddebihal	86-87	12.5	-	-	3.0	84.5
9.	Bijapur	87-88	70.9	16.2	3.4	0.7	8.8
10.	Indi	88-89	85.6	9.6	0.8	3.2	0.8
11.	Sindagi	89-90	70.6	1.4	-	1.4	26.6

Values indicates the percent of total samples in each taluka

Total samples drawn – 1688

2.2 Raichur District

Raichur district is located in the northern maidan region of Karnataka state and lies between 15^0 09’ and 16^0 34’ north latitude and 75^0 46’ and 77^0 35’ east longitude. The district is bounded on the north by the district of Gulbarga, on the west by the districts of Bijapur and Dharwar, on the east by the district of Mahboobnagar of Andhra Pradesh, and on the south by the districts of Kurnool, also of Andhra Pradesh and Bellary. The geographical area of the district is about 8383.00 sq.km. The climate of the district can be termed as mild to severe, with mild winters and hot summers. December is the coldest month with mean daily minimum of 17. 7^0C, while May is the hottest month with mean daily maximum temperature of 39 .8^0C. The day temperature in May often touches 45.0^0C. Relative humidity of over 75% is common during monsoon period. The normal annual rainfall of the district is 621mm.

The soils of the district comprise mixed red and black soils, medium black soils, deep black soils and red sandy soils. Mixed red and black soils usually occur on gently undulating plains or complex geological formations comprising of granitic gneisses and schist’s, which occupy the central parts of the district. Since the district is covered predominantly by black cotton soils, which inhibit percolation and circulation of water, there are pockets of poor quality ground water in the area. The gross irrigated area is

240200 ha and irrigation through borewells constitutes about 10.4 per cent. The major crops grown in the district are paddy, sunflower, sorghum, bengal gram, bajra, groundnut, cotton, redgram and main horticultural crops include citrus, mango, pomegranate, sapota and papaya.

The ground water survey for its irrigability in Raichur district (prior to reorganization of the district) was carried out during 1995-96 to 1997-98. A total of 1867 ground water samples representing each village from seven taluks viz., Yelburga (383), Koppal (389), Kustagi (349), Lingasugur (290), Deodurg (170), Sindhanur (150) and Raichur (136) were collected and analyzed.

Among seven taluks, 91 percent of water samples in Yelburga taluk had pH > 8.5 followed by Raichur (50%), Lingasugur (36%), Kustagi (35%), Koppal (24%) and Sindhanur (19.33%) indicating considerable potential alkali hazard upon use of such water. About 74% of water samples in Deodurg taluk had pH $\leq$8.0. District as a whole about 38.91 % and 36.76 % of water samples had pH in the range of 8.0-8.5 and pH >8.5, respectively. Except Sindhanur taluk (Table 4), majority of water samples (69.9% in Raichur taluk to 90% in Yelburga taluk) in all the six taluks at the time of sampling were found to be non-saline (EC < 2 dS/m) leading to occurrence 75.3% non-saline under ground water samples in the district as a whole. Sindhanur taluk recorded the highest percentage of water samples having pH >4.0 reflecting cautious use of such water for irrigation purpose. Almost equal percentage of water samples in the district as a whole recorded EC 2-4 dS/m (13.1%) and >4.0 dS/m (11.6%).

Table 4. Frequency distribution of water samples of different taluks of Raichur district in respect of EC.

Sl.No.	**Taluk**	**EC (dS/m) Range No. of samples**		
		<2.0	**2.0-4.0**	**>4.0**
1	Yelburga	345 (90)	22 (6)	16 (4)
2	Koppal	341 (88)	32 (8)	16 (4)
3	Kustagi	304 (87)	32 (9)	13 (4)
4	Lingasugar	235 (81)	45 (15)	10 (4)
5	Deodurg	124 (73)	19 (11)	27 (16)
6	Sindhanur	57 (38)	38 (25.3)	55 (36.7)
7	Raichur	95 (69.9)	24 (17.7)	17 (12.5)
District Average		1501 (75.3)	212 (13.1)	154 (11.6)

Values in parenthesis indicate percentage of samples

In the samples analyzed Na^+ ion was dominent followed by Mg^{2+} and Ca^{2+} Irrespective of levels of EC, the mean Mg/Ca ratio in all the taluks and district as a whole remained higher than 0.63 which was reported to be critical for causing Mg hazard. Further, Mg/Ca ratio was highest at 2.0-4.0 dS/m EC levels compared to EC <2.0 and > 4.0 dS/m. Among anion, Cl^- ion was dominant in all the taluks followed by either HCO_3^- or SO_4^{2-}. The mean chloride contents were much higher than 3.0 me/l in all the taluks except Koppal taluk with a district average of 8.03 (Table 5). Except in Kustagi and Raichur taluks, the Cl/SO_4 ratios were also much higher than 2.0 in all the taluks at all different EC levels indicating the potential chloride injury of these waters in sensitive crops. District as whole had an average Cl/SO_4 ratios of 12.42, 16.55 and 6.04 at EC <2.0, 2-4 and > 4.0 dS/m respectively.

The maximum and minimum SAR were observed in Sindhanur (115.4) and Yelburga (0.07) taluks respectively with the mean SAR values being less than 10 in all the taluks except Sindhanur taluk (14.1). Both the maximum (24.2) and minimum (nil) Residual Sodium Carbonate (RSC) values were observed in Sindhanur taluks respectively with the mean RSC values being less than 1.25 in all the taluks.

With regards to the overall water quality (Table 6), frequency of occurrence of good quality water in the taluks surveyed followed the order: Yelburga and Koppal (82% each)>Lingasugur (78.0%) >Kustagi (75.0%) > Deodurg (57.0%) > Raichur (40.45%) > Sindhanur (12.67%). Sindhanur taluk which recorded the least percentage of occurrence of good quality water had high SAR saline and highly alkali quality water to the extent of 30 and 20% respectively. In Raichur taluk nearly 15% each of M.Alkali-I and M.Alkali-II are the predominant type of water found next to good quality water. Raichur district as a whole, registered 61.02% of occurrence of good quality water and the percentage distribution of poor quality water in the district ranged between 2.40% (saline) to 8.72% (high SAR Saline).

Table 5. Mean chemical composition of ground waters of different taluks of Raichur district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					- - - (me/l) - - -						
Yelburga	383	Max	9.70	8.7	20.2	33.4	56.5	58.4	35.3	6.6	3.8
		Min	8.01	0.07	0.2	0.0	0.2	0.6	0.03	0.7	0.0
		Mean	8.80	1.79	1.79	3.76	6.88	5.62	1.75	2.68	0.92
Koppal	389	Max	8.90	7.10	38.1	54.3	41.1	45.5	38.2	6.5	3.4
		Min	7.28	0.21	0.30	0.3	1.0	6.44	0.1	0.0	0.0
		Mean	8.30	1.18	2.23	4.19	7.35	0.20	2.35	2.39	1.11
Kustagi	349	Max	9.33	19.8	9.0	82.8	156.5	150	37.4	13.6	9.0
		Min	7.30	0.31	0.3	0.4	0.97	0.2	0.03	0.0	0.06
		Mean	8.33	1.29	1.34	4.01	8.65	3.78	3.19	3.12	1.39
Lingasugar	290	Max	9.18	6.9	10.5	25.0	57.7	41.8	6.84	22.0	12.0
		Min	7.35	0.34	1.0	0.5	1.0	1.1	0.02	0.02	0.8
		Mean	8.34	1.42	2.96	3.59	9.45	8.78	1.27	4.13	2.69
Deodurg		Max	9.60	17.4	45.5	70	170	116	90.8	33.3	25.8
		Min	7.00	0.46	1.1	0.0	0.65	0.68	0.13	1.6	1.0
		Mean	7.80	2.4	5.62	5.35	13.9	13.2	4.8	6.5	3.9
Sindhanur	150	Max	8.90	21.9	24.4	31.4	160.1	96.4	104.4	53.0	32.0
		Min	7.40	0.6	0.2	-	2.2	-	-	0.0	0.0
		Mean	8.20	4.1	3.4	6.1	30.3	16.5	14.6	6.5	3.1
Raichur	136	Max	9.20	19.1	24.8	33.14	163	100.8	91	10.78	12.72
		Min	7.20	0.36	0.34	-	0.86	-	-	0.09	-
		Mean	8.40	2.22	2.15	3.75	16.47	8.14	7.89	2.88	3.27
District Average		Max	9.70	21.90	45.5	82.80	160.1	116.0	104.4	53.00	32.00
		Min	7.00	0.07	0.20	-	0.20	-	-	-	-
		Mean	8.31	2.06	2.53	4.39	13.28	8.03	5.12	4.03	2.34

Table 6. Water quality ratings of ground waters of different taluks of Raichur district.

Taluk	Sample size	Good	M.Saline	Saline	High SAR Saline	M.Alkali I	M.Alkali II	Alkali
Yelburga	383	82(314)	4(17)	2(7)	3(12)	6(24)	2(7)	1(2)
Koppal	389	82(319)	7(27)	1(4)	3(12)	5(19)	-	2(8)
Kustagi	349	75(260)	6(21)	1(4)	1(5)	9(32)	5(18)	3(9)
Lingasugr	290	78(226)	5(14)	2(6)	5(16)	2(6)	1(3)	7(19)
Deodurg	170	57(97)	3(5)	6(10)	8(13)	10(18)	4(6)	12(21)
Sindhanur	150	12.7(19)	11.3(17)	3.3(5)	30(45)	10.7(16)	12(18)	20(30)
Raichur	136	40.5(55)	6.6 (9)	1.5(2)	11.0(15)	15.5(21)	14.7(20)	10.3(14)
District Average	1867	61.0(1290)	6.1(110)	2.4(38)	8.7(118)	8.3(136)	5.5(72)	7.9(103)

Figures in the parenthesis represent number of samples

2.3 Bellary District

Bellary district situated on the eastern side of Karnataka state and lies between 15° 30' and 15°50' north latitude and 75° 40' and 77° 11' east longitude. This district is bounded by Raichur district on the north, Koppal district on the west, Chitradurga and Davanagere districts on the south, and Anantapur and Kurnool districts of Andhra Pradesh on the east. The geographical area of the district is about 8420 Sq.kms. Physiographically, it is occupied by hills in the central part with plains on the east and west. The climate of Bellary district is quite moderate shows dryness in major part of the year and a hot summer from March to May months. The mean maximum temperature in the district is 40.4°C. and the mean minimum temperature is 14.3°C (January month). The area is generally classified as moderate to low rainfall receiving area. The analysis of the last ten years rainfall data (1996-2005) shows that the highest rainfall occurred in Sandur taluk with 732.1 mm and the lowest at Bellary with 452mm and over all annual normal rainfall in the district is 611mm. Relative humidity ranges from 48 to 74% in the morning and in the evening it ranges from 27% to 61%. Hydrogeologically, the district forms a part of hard rock terrain comprising Granites, Gneisses and Schistose formation of Archean age. The granitic gneiss and gneissic granite which form major aquifers in the district recorded a weathered and semi weathered zone up to 25m. Schistose formation has weathered formation with less granular and fractured as openings than granites and gneisses.

The major soils in the district comprise of black in irrigated land and red soils in elevated places. Sandy loam and sandy soils also occur along the stream beds. The district has gross irrigated area of 281300 ha and irrigation through borewell accounts to 32 per cent. The important crops grown are paddy, sunflower, maize, groundnut, sorghum, bengalgram, cotton, bajra. Horticultural crops are banana, pomegranate, mango, citrus and fig. The net irrigated area is 37% to the net area sown.

A total of 1366 ground water samples from seven taluks viz., Huvinahadagali (205), Hagaribommanahalli (185), Kudligi (383), Sandur (265), Siruguppa (173), Bellary (63) and Hospet (92) were collected and analyzed during 1998-99 to 2000-01.

Among seven taluks, majority of water samples in Huvinahadagali (60.90%), and Hagaribommanahalli (65.4%) taluks had pH > 8.5 indicating considerable potential alkali hazard upon use of such water. About 38 % of water samples of the district as a whole had pH in the range of 8.0-8.5 and 21.42 of samples had pH >8.5. Except Siruguppa and Bellary taluks, majority of water samples (83.9 to 89.6%) in other five taluks at the time of sampling were found to be non-saline (EC < 2 dS/m) leading to occurrence of 79.4% non-saline water samples in the district as a whole (Table 7). Only less than 50% of water samples of Siruguppa taluk were found to be non-saline with considerable extent (39.3%) of samples recording marginally saline (2-4 dS/m) and 11% recording EC > 4.0 dS/m reflecting cautious use of such water for irrigation/domestic purposes.

Table 7. Frequency distribution of water samples of different taluks of Bellary district in respect of EC of water.

Sl.No.	**Taluk**	**EC (dS/m) Range**		
		<2.0	**2.0-4.0**	**>4.0**
		Percent		
1	Huvinahadagali	172 (83.9)	30 (14.6)	3 (1.5)
2	Hagaribommanahalli	162 (87.6)	21 (11.4)	2 (1.1)
3	Kudligi	343 (89.6	36 (9.4)	4 (1.0)
4	Sandur	231 (87.2)	29 (10.9)	5 (1.9)
5	Siruguppa	86 (49.7)	68 (39.3	19 (11)
6	Bellary	44 (69.8)	13 (20.6)	6 (9.6)
7	Hospet	81 (88)	9 (9.8)	2 (2.2)
	District average	1119 (79.4)	206 (16.57)	41 (4.04)

In the samples analyzed Na^+ ion was dominent followed by Mg^{2+} and Ca^{2+} (Table 8). Irrespective of levels of EC, the mean Mg/Ca ratio in all the taluks and district as a whole remained higher than 0.63 which was reported to be critical for causing Mg hazard. The district mean values were 3.41, 4.09 and 3.97 at <2.0, 2.0-4.0 and >4.0 dS/m respectively. Among anion (Table 8), Cl^- ion was dominant in all the taluks followed by HCO_3^-, CO_3^- and SO_4^{2-}. The mean chloride contents were much higher than 3.0 me/l in all the taluks with a district average of 4.36. In general, the Cl/SO_4 ratios were also much higher than 2.0 in all the taluks at all different EC levels indicating the potential chloride injury of these waters in sensitive crops. District as a whole had an average Cl/SO_4 ratios of 23.72, 20.44 and 24.95 at EC <2.0, 2-4 and > 4.0 dS/m respectively.

The maximum and minimum SAR values were observed in Siruguppa (50.5) and Sandur (0.31) taluks respectively with the mean SAR values being less than 10 in all the taluks except Bellary taluk. The maximum and minimum RSC values were observed in Huvinahadagali (22.4) and Siruguppa (nil) taluks respectively with the mean RSC values being less than 1.25 in all the taluks except in Huvinahadagali taluk (6.1).

With regards to the overall water quality (Table 9), frequency of occurrence of good quality water in the taluks surveyed followed the order: Sandur (80.4%) >Kudligi(79.4%) >Hospet (78.3%) > Hagaribommanahalli (70.0%) > Bellary (61.9%) > Siruguppa (53.2%) > Huvinahadagali (27.0%). Bellary district as a whole, registered 66.2% of occurrence of good quality water. Huvinahadagali taluk which recorded the lowest percentage of occurance of good quality water had 7%, 47.6% and 10% of its samples falling under M.Alkali-I, M.Alkali-II and highly Alkali category respectively. Water samples of Bellary taluk indicated about 17.4% and 14.3% of water samples were under high SAR saline and highly alkali classes respectively.

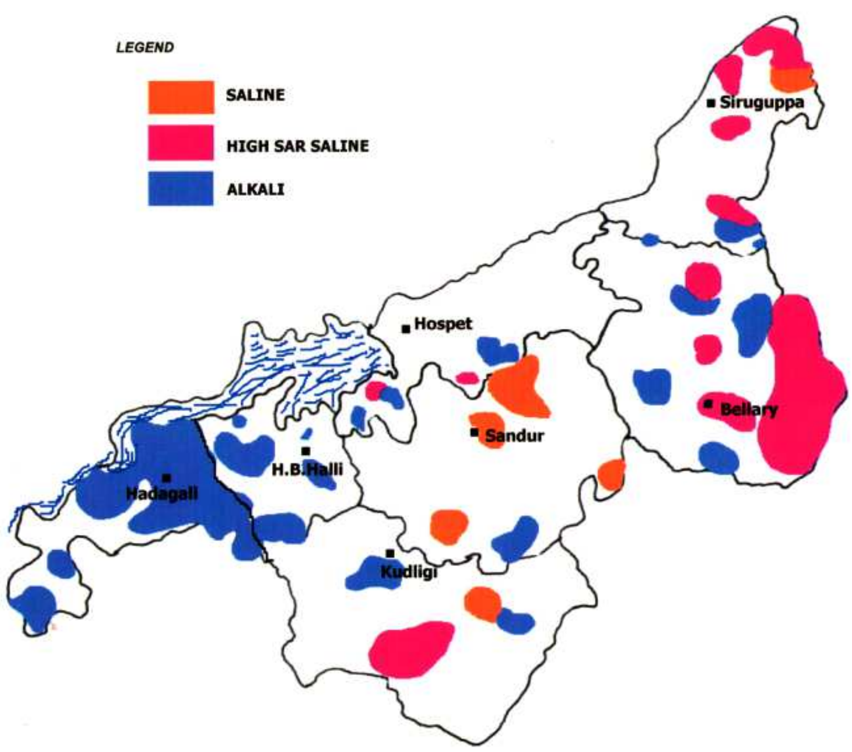
Table 8. Mean chemical composition of ground waters of different taluks of Bellary district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Huvinaha dagali	205	Max.	9.3	4.7	9.2	12.4	25	25.6	3.26	21.1	10.4
		Min.	7.6	0.3	0.4	0.1	2.2	0.4	0.01	0.4	0.4
		Mean	8.52	1.37	1.13	3.37	8.79	6.26	0.29	5.68	2.26
Hagaribom manahalli	185	Max.	9.1	4.1	10.8	15.1	16.57	20	2.18	10	2.18
		Min.	7.18	0.06	0.2	0.2	1.7	0.6	0.01	0.6	0.01
		Mean	8.32	1.25	2.06	1.61	7.89	5.75	0.3	4.03	0.3
Kudligi	383	Max.	8.75	5.50	7.8	22.6	32.0	42	30.6	8.0	7.2
		Min.	7.14	0.36	0.4	0	1.76	0.8	0.0	0.0	0.0
		Mean	7.99	1.38	1.38	4.48	8.93	9.13	1.39	2.7	1.68
Sandur	265	Max.	9.75	8.5	14.4	33.6	23.2	28.2	16.73	7.4	4.4
		Min.	6.99	0.24	0.2	0.2	1.3	0.0	0.08	0.0	0.0
		Mean	7.93	1.54	1.4	6.08	6.75	4.66	1.09	2.55	1.67
Siruguppa	173	Max.	10.9	13.0	31.4	33.4	68.3	168	32.3	12.1	7.4
		Min.	7.0	0.33	0.6	0.0	0.95	1.2	0.0	0.0	0.0
		Mean	8.02	2.46	2.69	5.75	16.32	19.02	2.56	3.5	1.4
Bellary	63	Max.	8.74	7.7	33.0	18.2	52.3	71.0	18.9	14.4	5.20
		Min.	6.97	0.29	0.4	0.0	1.37	2.0	0.3	0.0	0.0
		Mean	7.99	2.01	2.69	4.86	13.0	14.3	2.29	3.33	1.26
Hospet	92	Max.	8.59	7.5	8.80	21.2	63.4	64.0	4.40	6.80	7.0
		Min.	7.21	0.35	0.40	0.0	1.73	1.2	0.30	0.0	0.0
		Mean	7.93	1.42	1.81	4.4	8.62	10.91	0.94	3.23	1.26
District Average		Max.	10.9	13	33	33.6	68.3	71	32.3	21.1	10.4
		Min.	6.97	0.06	0.2	Tr	0.95	Tr	Tr	Tr	Tr
		Mean	8.10	1.63	1.88	4.36	10.04	10.00	1.27	3.57	1.40

Table 9. Water quality ratings of ground waters of different taluka of Bellary district.

Taluk	Sample size	Good	M.Saline	Saline	High SAR Saline	M.Alkali –I	M.Alkali-II	Alkali
Huvinahadagali	205	27.0 (56)	7.0 (15)	0.5 (1)	0.9 (2)	7.0 (15)	47.6 (98)	10.0 (19)
Hagaribommana halli	185	70.0 (129)	7.0 (13)	1.0 (2)	0.0	15.0 (27)	5.0 (10)	2.5 (5)
Kudligi	383	79.4 (304)	6.7 (26)	0.3 (1)	4.2 (16)	6.8 (26)	0.5 (2)	2.1 (8)
Sandur	265	80.4 (213)	10.9 (29)	1.9 (5)	0.4 (1)	4.5 (12)	1.1 (3)	0.8 (2)
Siruguppa	173	53.2 (92)	11.0 (19)	1.7 (3)	19.1 (33)	4.0 (7)	6.4 (11)	4.6 (8)
Bellary	63	61.9 (39)	3.2 (2)	1.6 (1)	17.4 (11)	1.6 (1)	-	14.3 (9)
Hospet	92	78.3 (72)	-	1.1 (1)	6.5 (6)	8.7 (8)	1.1 (1)	4.3 (4)
Overall Average		66.2 (905)	7.6 (104)	1.0 (14)	5.1 (69)	7.0 (95)	9.1 (124)	4.0 (55)

Figures in the parenthesis represent number of samples



GROUND WATER QUALITY MAP OF BELLARY DISTRICT

2.4 Davanagere District

Davangere district covers a geographical area of 5975.97 sq.kms and comprises of six taluks. Agriculture is the main source of income of the people in the district. The district enjoys semi arid climate with hot summer and dryness in major part of the year. Average rainfall of the district is 607 mm. The geomorphology of the district is characterised by vast stretches of undulated plains interspersed with sporadic ranges or isolated clusters of low ranges of rocky hills. Groundwater occurs under phreatic and semi-confined conditions in the weathered and fractured rock formations of the 'Peninsular Gneissic Group' of rocks comprising of granites, gneisses and schist. The soils in the district comprise mixed red and black (42%), red sandy (33%) and deep to medium deep black soil (14%). The major crops of the district include maize, rice, sorghum, groundnut, sunflower, ragi, cotton and redgram. Nearly 56 per cent of total irrigated area is met through borewell.

The ground water survey for its irrigability in Davangere district was carried out during 2001-02 to 2003-04. A total of 1986 ground water samples representing different villages from six taluks viz., Harapanahalli (514), Harihara (219), Davanagere (311), Jagalur (325), Honnali (305) and Channagiri (312) were collected and analyzed.

Among six taluks, majority of water samples in all the taluks (66.50 to 98.15% in Harapanahalli and Jagalur taluks respectively) had pH > 8.5 indicating considerable potential alkali hazard upon use of such water. Continuous use of such waters without amendments is likely to result in soil sodication and affect crop growth. About 15.31 % of water samples of the district as a whole had pH in the range of 8.0-8.5 and 83.43% of samples had pH >8.5.

Majority of water samples (81.3% in Harapanahalli taluk to 87.9% in Honnali taluk) in all the six taluks at the time of sampling were found to be non-saline (EC < 2 dS/m) leading to occurrence of 85.2% non-saline ground water samples in the district as a whole (Table 10). The percentage of water samples which recorded EC in the range of 2-4 dS/m in all the taluks were 11.0% to 16.9%. Less than 2% of water samples in the district as a whole recorded EC >4.0 dS/m.

In the samples analyzed, Na^{+} ion was dominated followed by Mg^{2+} and Ca^{2+} (Table11). Irrespective of levels of EC, the mean Mg/Ca ratio in all the taluks and district as a whole remained higher than 0.63. The relationship between Mg/Ca ratio and EC was not consistent in the taluks surveyed. However, district as a whole, this ratio increased (3.16 to 4.37 dS/m) with increase in EC from <2 to >4.0 dS/m.

Table 10. Frequency distribution of water samples of different taluks of Davanagere district in respect of EC.

Sl.No.	Taluk	EC (dS/m) Range		
		<2.0	2.0-4.0	>4.0
		Percent		
1	Harapanahalli	418 (81.3)	87 (16.9)	9 (1.8)
2	Harihara	187 (85.3)	24 (11.0)	8 (3.7)
3	Davanagere	264 (84.9)	42 (13.5)	5 (1.6)
4	Jagalur	280 (86.2)	43 (13.2)	2 (0.60)
5	Honnali	268 (87.9)	34 (11.1)	3 (1.0)
6	Channagiri	267 (85.6)	39 (12.5)	6 (1.9)
	District Average	1684(85.2)	269(13.0)	33(1.77)

Values in the parenthesis indicate percentage of samples

Among anion, Cl^- ion was dominant in all the taluks. The mean chloride contents were much higher than 3.0 me/l in all the taluks with a district average of 6.82 (Table 11). In general, the Cl/SO_4 ratios were also much higher than 2.0 in all the taluks at all different EC levels indicating the potential chloride injury of these waters in sensitive crops. District as a whole had an average Cl/SO_4 ratios of 13.48, 8.63 and 3.97 at EC <2.0, 2-4 and > 4.0 dS/m respectively. There was a declining Cl/SO_4 ratio with increase in EC of water (Fig.1) in all the taluks. Though there was no consistent relationship between pH and Cl/SO_4 ratio among the taluks, district as a whole, in general, Cl/SO_4 ratio increased from 4.58 to 12.28 with increase in pH from <8.0 to > 9.0.

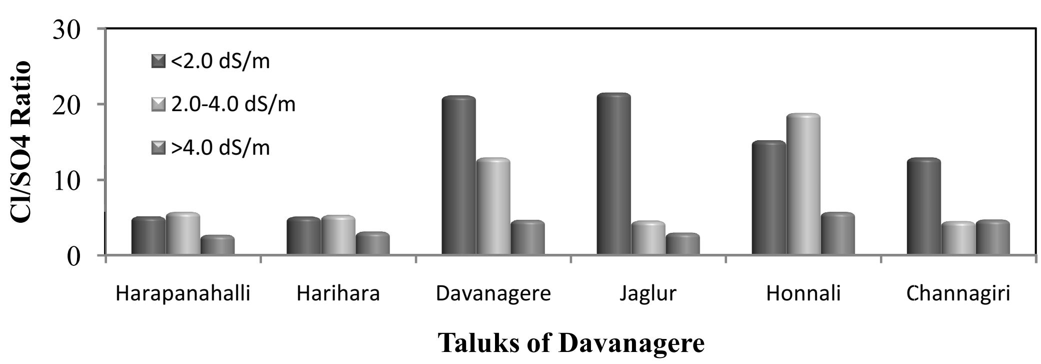


Fig. 1. Relationship between Cl/SO_4 ratio and salinity of ground waters of different taluks of Davanagere district.

The maximum and minimum SAR values were observed in Harapanahalli (30.8) and Channagiri (0.42) taluks respectively with the mean SAR values being less than 10 in all the taluks. The maximum and minimum RSC values were observed in Channagiri

(12.9) and Harihar (Nil) taluks respectively with the mean RSC values being less than 1.25 in all the taluks except in Jagalur (2.99) and Channagiri (1.63).

With regards to the overall water quality (Table 12), frequency of occurrence of good quality water in the taluks surveyed followed the order: Davanagere (55.3%)>Harihar (54.8%)>Harapanahalli (54.1%) > Honnali (46.2%) > Channagiri (42.3%) > Jagalur (26.5%). Davanagere district as a whole, registered 46.8%, 26.4% and 11.6% of occurrence of good quality, M.Alkali and M. Saline water, respectively. Jagalur taluk which recorded the lowest percentage of occurrence of good quality water had 50.5%, and 12% of its samples falling under M.Alkali-I and highly Alkali category respectively. In general, district as a whole 26.4% of water samples tested were under M.Alkali-I category. Water samples of the district falling under saline and/or high SAR saline were less than 5% with Davanagere taluk recording the highest percentage i.e., 8.4% of water sample falling under high SAR saline followed by Harihara (5.5%), Harapanahalli (4.7%), Channagiri (4.2%), Jagalur (4.0%) and Honnali (1.0%) taluks.

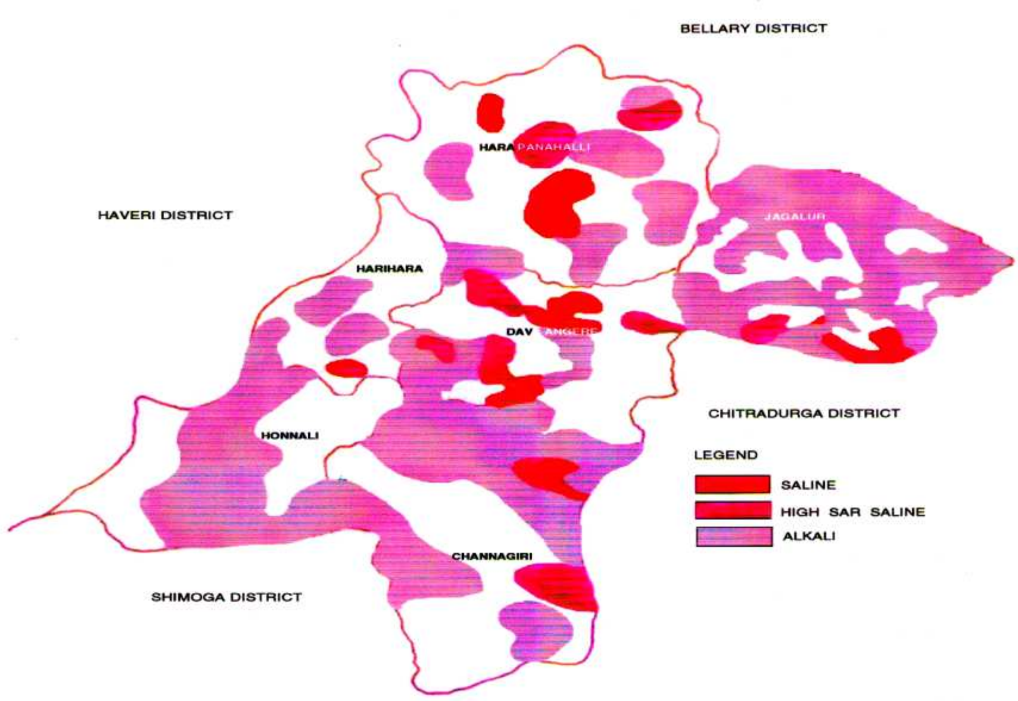
Table 11. Mean chemical composition of ground waters of different taluks of Davanagere district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Harapanahalli	514	Max.	9.3	5.4	13.3	20.5	56.5	44.5	48.5	12.4	5.0
		Min.	7.6	0.2	0.10	0.3	Tr	Tr	0.01	0.20	0.00
		Mean	8.6	1.6	1.3	5.5	12.0	8.70	4.9	4.20	1.0
Harihara	219	Max.	9.8	7.1	8.2	46.7	71.7	44.6	58.2	8.60	3.40
		Min.	7.4	0.2	0.1	1.0	1.30	0.35	0.02	0.40	0.0
		Mean	8.8	1.4	0.8	5.3	11.1	6.7	5.50	4.30	1.30
Davanagere	311	Max.	9.97	9.90	19.4	17.8	70.0	85.0	28.3	13.0	6.00
		Min.	8.15	0.25	0.25	0.02	1.50	0.71	0.01	0.00	0.00
		Mean	9.09	1.45	1.93	2.12	11.23	8.90	1.70	2.20	2.72
Jagalur	325	Max.	9.52	4.30	4.75	13.2	39.5	28.0	13.6	8.00	8.00
		Min.	8.30	0.30	0.38	0.02	2.75	1.00	0.00	0.00	0.00
		Mean	9.12	1.44	1.32	1.91	12.2	6.92	2.44	3.09	3.13
Honnali	305	Max.	9.26	5.90	11.2	14.8	45.8	44.0	31.6	11.0	8.00
		Min.	7.96	0.14	0.02	0.19	0.57	0.19	0.01	1.00	0.00
		Mean	8.75	1.07	1.60	2.93	6.87	4.91	1.26	4.41	0.83
Channagiri	312	Max.	9.58	5.70	7.60	12.7	43.0	46.0	23.3	13.0	3.00
		Min.	7.38	0.17	0.24	0.08	0.70	0.20	0.01	0.80	0.00
		Mean	8.76	1.14	1.35	1.83	8.21	4.80	1.79	4.80	0.003
District Average		Max.	9.97	9.90	19.4	46.7	71.7	85.0	58.2	13.0	8.00
		Min.	7.38	0.14	0.02	0.02	Tr	Tr	Tr	Tr	Tr
		Mean	8.85	1.35	1.38	3.27	10.27	6.82	2.93	3.83	1.50

Table 12. Water quality ratings of ground waters of Davanagere district

Taluk	Sample size	Good	M.Saline	Saline	High SAR Saline	M.Alkali –I	M.Alkali-II	Alkali
Harapanahalli	514	54.1 (278)	20.2 (104)	0.8 (4)	4.7 (24)	11.9 (61)	5.4 (28)	2.9 (15)
Harihara	219	54.8 (120)	10.0 (22)	1.4 (3)	5.5 (12)	18.7 (41)	4.6 (10)	5.0 (11)
Davanagere	311	55.3 (172)	12.2 (38)	-	8.4 (26)	16.4 (51)	3.2 (10)	4.5 (14)
Jagalur	325	26.5 (86)	4.6 (15)	-	4.0 (13)	50.5 (164)	2.5 (8)	12.0 (39)
Honnali	305	46.2 (141)	8.9 (27)	0.7 (2)	1.0 (3)	29.8 (91)	12.1 (37)	1.3 (4)
Channagiri	312	42.3 (132)	7.7 (24)	0.3 (1)	4.2 (13)	37.5 (117)	4.5 (14)	3.5 (11)
District (Overall)		46.8 (929)	11.6 (230)	0.5 (10)	4.6 (91)	26.4 (525)	5.4 (107)	4.7 (94)

Values in parenthesis indicate number of samples



DISTRIBUTION OF POOR QUALITY GROUND WATERS IN DAVENGERE DISTRICT

2.5 Gulbarga District

Gulbarga district lies in the northern plains of Karnataka and has semi - arid type of climate. It lies between 16° 11’ and 17° 45’ north latitudes and 76° 03' and 77° 30' east longitudes, with a geographical area of 16,174 sq. km. The district is bounded by Bidar district in the north, Bijapur district in west, Raichur district in south and Andhra Pradesh in the east. The southern part of the district comprises the Peninsular Gneiss and granites. Central, northeastern and southwestern part comprises of sedimentary formations viz. sandstone, quartzite, shale, slate, limestone and dolomite. Deccan Trap basalt basalts cover northern and northwestern parts. A small portion in the north is covered by alluvium and in the North-eastern part by laterite. Dry climate prevails for most part of the year. December is the coldest month with mean daily maximum and minimum temperatures being 29.5°C and 15° to 10°C respectively. During peak summer, temperature shoots up to 45°C. Relative humidity varies from 26% in summer to 62% in winter.

Hydrogeologically major water bearing formation include granite, gneiss, vesicular basalt and limestone.Deep black clayey soils, shallow mixed black clayey and loamy soils, deep alluvial black calcareous clayey soils in the district constitute about 35, 34 and 20 percent respectively. Major crops in the district are redgram, sorghum, chickpea, sunflower, and bajra. The irrigated crops are sugarcane & paddy. Mango, banana and citrus are the major horticultural crops. Gulbarga district in Karrnataka has sizable area under rainfed agriculture, which is characterized by not only low rainfall but also erratic monsoonal climate. Though canal irrigation has been extended to some taluks, ground water exploitation is also in vogue in some taluks in this district. Farmers of district have gone in for extensive exploitation of ground water wherever potential exists. It is reported that ground water resources (wells and bore wells) contribute for nearly 20.8 per cent of total irrigated area in the district.

Village-wise ground water samples from each of the nine taluks of the district (prior to the reorganization of the district) were analyzed for various quality parameters. A total of 1729 ground water samples from nine taluks viz., Jewargi (167), Gulbarga (195), Shahapur (253), Surpur (266), Chittapur (188), Sedam (130), Chincholli (156), Afjalpur (154) and Aland (220) were collected during 2004-2008 and the results are as follows.

Among the nine taluks, majority of water samples in Chincholli (68.80%), Chittapur (65.4%), Sedam (63.10%) and Shahapur (43.10%) taluks had pH > 8.5 indicating considerable potential alkali hazard upon use of such water. Continuous use of such waters without amendments is likely to result in soil sodication and affect crop growth.

Majority of water samples (89.1 to 98.7%) in all nine taluks at the time of sampling were found to be non-saline (EC < 2 dS/m) leading to occurrence 94.06% non-saline under ground water samples in the district as a whole (Table 13). Afjalpur (8.4%) and Chincholli (1.3%) recorded the maximum and minimum percentage of water samples falling under marginally saline class respectively. Only 1.16% of samples in the district as a whole recorded salinity > 4.0 dS/m reflecting that salinity hazard due to irrigation with ground water in the district is negligible.

Table 13. Frequency distribution of water samples of different taluks of Gulbarga district in respect of EC

Sl.No.	Taluk	EC (dS/m) Range		
		<2.0	**2.0-4.0**	**>4.0**
		Percent		
1	Jewargi	160 (95.8)	4 (2.4)	3 (1.8)
2	Gulbarga	187 (95.9)	8 (4.1)	0 (0)
3	Shahapur	233 (92.1)	14 (5.5)	6 (2.4)
4	Surpur	237 (89.1)	18 (6.8)	11 (4.1)
5	Chittapur	175 (93.1)	11 (5.9)	2 (1.0)
6	Sedam	123 (94.6)	7 (5.4)	0 (0)
7	Chincholli	154 (98.7)	2 (1.3)	0 (0)
8	Afjalpur	140 (90.9)	13 (8.4)	1 (0.7)
9	Aland	212 (96.3)	7 (3.2)	1 (0.5)
10	Gulbarga district	1621 (94.06)	84 (4.78)	24 (1.16)

In the samples analyzed Na^+ ion was dominent (Table 14) followed by Mg^{2+} and Ca^{2+} except in Sedam and Aland where Na^+ ion is followed by Ca^{2+} and Mg^{2+}. The mean Mg/Ca ratio in all the taluks remained higher than 0.63 which was reported to be critical for causing Mg hazard (Fig.2). In general, the relationship between EC and Mg/Ca and pH and Mg/Ca ratio revealed a positive relationship between them (Fig. 2 and 3). Ground waters with higher Mg/Ca ratio (possibly > 0.63) are likely to have higher pH.

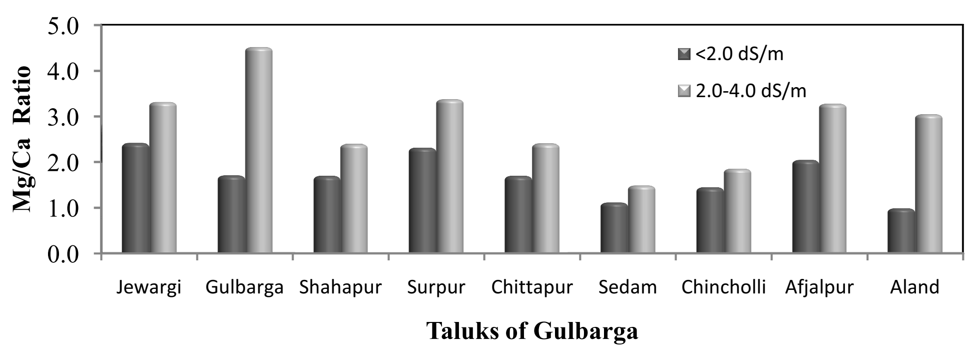


Fig. 2. Relationship between Mg / Ca ratio and salinity of ground waters of different taluks of Gulbarga district

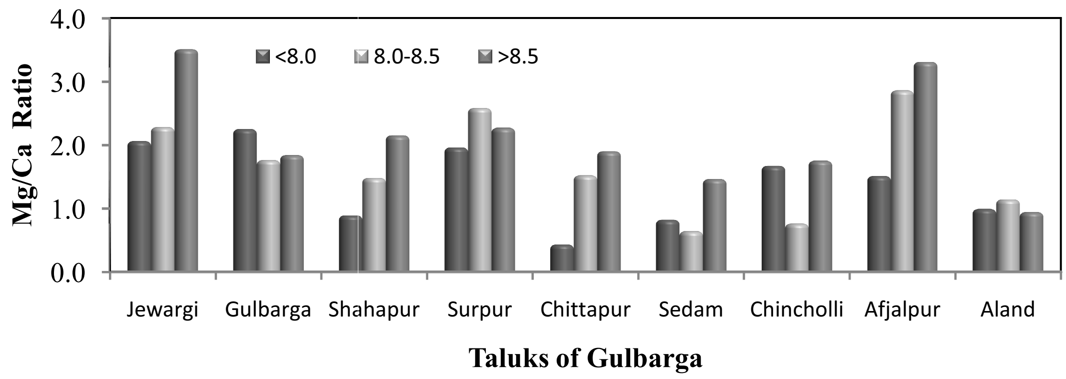


Fig. 3. Relationship between Mg / Ca ratio and pH of ground waters of different taluks of Gulbarga district

Among anion, except Chincholli taluk, Cl^- ion was dominant in all the taluks followed by HCO_3^- or SO_4^{2-}. The mean chloride contents (Table 14) were much higher than 3.0 me/l in all the taluks except Chincholli and are considered not best suited for chloride sensitive horticultural crops. In general, the Cl/SO_4 ratio was also >2.0 (Fig. 4) in majority of samples with the maximum and minimum values observed in Shahapur (12.97) and Afjalpur (2.46) respectively at EC < 2.0 dS/m indicating the potential chloride injury of these waters in sensitive crops. District as whole had an average Cl/SO_4 ratio of 8.92 and 4.05 at EC <2.0 and 2-4 dS/m respectively. The chloride: sulphate ratio decreased with increasing salinity in the ground water (Fig. 4).

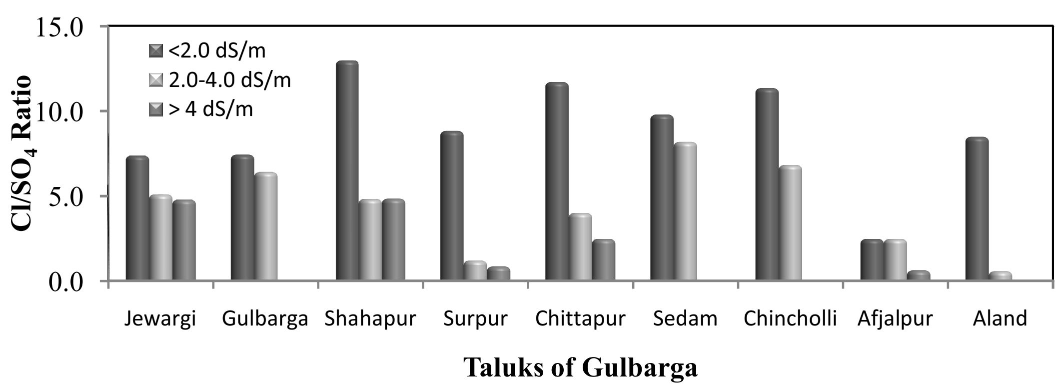


Fig. 4. Relationship between Cl/SO_4 ratio and salinity of ground waters of different taluks of Gulbarga district

The relationship between Cl:SO_4 ratio vs. pH in general, reavled a positive trend wherein increased pH increased the mean Cl:SO_4 ratio. The mean sodium absorption ratio (SAR) was less than 10 in all the taluks with the highest mean SAR value (9.10) observed in Sedam taluk. The mean residual sodium carbonate (RSC) was either negative or less than 2.5 me/l in all the taluks with the highest mean RSC value (2.14) observed in Sedam taluk.

Table 14. Mean chemical composition of ground waters of different taluks of Gulbarga district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Jewargi	167	Max.	8.99	7.30	13.0	10.2	80.6	80.0	30.5	10.6	-
		Min.	7.73	0.27	0.02	0.10	1.74	1.00	0.04	0.30	-
		Mean	8.24	0.94	1.29	2.23	6.58	6.38	2.29	1.43	-
Gulbarga	195	Max.	9.06	3.40	10.9	13.9	26.5	35.0	8.30	8.80	-
		Min.	7.50	0.24	0.20	0.00	1.91	0.40	0.03	0.30	-
		Mean	8.35	0.86	1.49	2.15	5.68	6.12	1.60	1.58	-.
Shahapur	253	Max.	9.11	6.50	12.2	12.3	55.3	46.0	21.8	11.1	4.00
		Min.	7.71	0.32	0.20	0.12	1.00	0.50	0.01	0.60	0.00
		Mean	8.43	1.12	1.23	1.74	8.28	5.96	1.53	2.94	0.83
Surpur	266	Max.	9.37	11.6	12.9	25.1	130.0	49.0	81.6	14.6	3.00
		Min.	7.38	0.38	0.08	0.02	0.22	1.00	0.01	0.40	0.00
		Mean	8.27	1.29	1.64	2.95	9.42	4.95	4.24	4.60	0.21
Chittapur	188	Max.	9.29	4.40	7.8	8.50	37.0	23.5	18.9	14.0	0.80
		Min.	7.93	0.33	0.20	0.05	2.0	0.60	0.01	1.00	0.00
		Mean	8.60	0.99	1.22	1.78	7.51	5.02	1.40	3.96	0.13
Sedam	130	Max.	9.56	3.80	5.0	4.90	32.0	19.5	9.07	10.0	0.60
		Min.	7.89	0.27	0.18	0.05	2.00	0.80	0.04	1.00	0.00
		Mean	8.58	0.94	0.91	0.82	7.83	4.40	1.29	3.65	0.22
Chincholli	156	Max.	9.25	2.50	6.10	3.85	18.0	13.0	9.07	10.0	0.80
		Min.	7.93	0.28	0.20	0.10	1.65	0.50	0.04	0.10	0.00
		Mean	8.58	0.74	0.88	1.00	5.37	2.94	1.29	3.29	0.13
Afjalpur	154	Max	8.87	8.90	30.50	26.80	38.90	31.70	64.50	10.50	4.50
		Min	6.76	0.44	0.30	0.10	1.74	0.90	0.02	0.00	0.00
		Mean	7.96	1.33	2.88	4.25	7.45	6.78	3.46	3.77	0.56
Aland	220	Max	9.26	3.40	10.00	13.00	24.60	15.60	25.00	8.50	2.00
		Min	7.22	0.18	0.50	0.00	1.20	0.05	0.00	0.50	0.00
		Mean	8.20	0.94	2.46	2.41	5.56	3.79	2.90	3.25	0.49
District Average		Max	9.56	11.6	30.5	26.8	130	80	81.6	14.6	4.5
		Min	6.76	0.18	0.02	0.02	0.22	0.05	0.01	0.1	Tr
		Mean	8.35	1.03	1.57	2.20	7.20	5.17	2.32	3.21	0.31

As shown in the table 15, frequency of occurrence of good quality water in the taluks surveyed followed the order: Jewargi (94.60%) >Gulbarga (90.80%) >Aland (87.30%) > Afjalpur (83.80%) > Chincholli (77.00%) > Surpur (74.00%)> Shahapur (72.70%) > Sedam (60.80 %) > Chittapur (57.50%). Gulbarga district as a whole, registered 77.61% of occurrence of good quality water. Except Afjalpur and Surpur taluks, the extent of occurrence of saline water with or without high SAR was considerably less (<4.00%) in other taluks surveyed. Among the problematic waters, marginal alkali (RSC 2.5-4.0 me/l) was predominant in Chittapur (28.10%), Sedam (19.20%), Chincholli (17.30%), Shahapur (17.00%) and Surpur (10.1%) taluks with an overall district average of 12.12%. The Sedam taluk registered the highest percentage (15.40%) of highly alkali water compared to other taluks.

Table 15. Water quality ratings (%) of ground waters of different taluka of Gulbarga district.

Sl.No.	Taluka / District	Sample size	Good	M. Saline	Saline	High SAR saline	M.alkali –I	M.alkali –II	Alkali
1	Jewargi	167	94.6 (158)	0.6 (1)	0.6 (1)	3.0 (5)	1.2 (2)	0	0
2	Gulbarga	195	90.8 (177)	3.6 (7)	0	0.5 (1)	4.6 (9)	0	0.5 (1)
3	Surpur	266	74.0 (197)	2.6 (7)	0.8 (2)	6.4 (17)	10.1 (27)	2.3 (6)	3.8 (10)
4	Shahapur	253	72.7 (184)	0.8 (2)	1.2 (3)	3.9 (10)	17.0 (43)	0.8 (2)	3.6 (9)
5	Chittapur	188	57.5 (108)	5.9 (11)	-	2.1 (4)	28.1 (53)	0.5 (1)	5.90 (11)
6	Sedam	130	60.8 (79)	-	-	1.5 (2)	19.2 (25)	3.1 (4)	15.4 (20)
7	Chincholi	156	77.0 (120)	0.6 (1)	-	-	17.3 (27)	1.9 (3)	3.20 (5)
8	Afjalpur	154	83.8 (129)	4.5 (7)	-	7.8 (12)	3.9 (6)	-	-
9	Aland	220	87.30 (192)	3.60 (8)	-	1.4 (3)	7.7 (17)	-	-
10	Gulbarga district		77.61 (1344)	2.46 (44)	0.28 (6)	2.97 (54)	12.12 (209)	0.96 (16)	3.6 (56)

Figures in the parentheses indicate number of samples.

2.6 Gadag district:

Gadag district falls in the semi arid tracts and is located in northern parts of Karnataka and situated in between north latitudes of 15° 15' and 15° 45' and east longitudes of 75°20' and 75°47'. It is bounded by Koppal district on east, by Bagalkot district on north, by Haveri district on south and by Dharwad district on west. The average annual rainfall is 613 mm. About 17% of the net sown area has irrigation facility and irrigation through borewells and wells comprise about 40% of the total irrigated area. The average maximum and minimum air temperature are 42°C during summer (April and May) and 16°C during winter (December and January). The area of the district is generally covered by medium to deep black soils and extends up to1.80 m bgl average being1.10 mbgl. The medium black soils, deep black soils and shallow black soils comprise 46.1, 40.7 and 9.2 percent respectively. Hydrologeologically, the district is underlain by hard rock formations like granites, gneisses and schists. These rocks have no primary porosity or permeability. Ground water occurs under phreatic conditions in weathered zone of these formations. Major crops grown in the district include sorghum, turdal, groundnut, cotton, paddy, wheat, maize and other pulses and fruit crops include mango, banana, sapota, pomegranate etc.

During 2009-10 and 2010-11, survey and collection of ground water samples village-wise from Gadag, Mundaragi, Ron, Shirhatti and Nargunda taluks was carried out. A total of 527 samples representing almost all the villages from these taluks were collected and analyzed.

Nearly 100 per cent of water samples in all the taluks had favorable pH i.e., $\leqslant$ 8.0 without any potential alkali hazard upon use for irrigation. Less than 75% of water samples in Gadag, Mundaragi, Rona and Shirhatti were found to be non-saline (EC< 2.0 dS/m) (Table 16). Considerable percentage of samples (20-25%) were found to marginally saline (EC 2-4 dS/m). Whereas, Nargunda taluk where only meager borewells are in usage registered almost equal percentage of samples under non-saline, marginally saline and saline

Table 16. Frequency distribution of waters in respect of various quality parameters.

Quality Parameter	Class Interval	Gadag	Mundaragi	Ron	Shirhatti	Nargunda
EC (dS/m)	**<2.0**	94 (60.25)	74 (75.50)	86(72.9)	98(73.7)	8(36.4)
	2.0 – 4.0	45 (28.85)	20 (20.40)	24(20.3)	34(25.5)	7(31.8)
	>4.0	17(10.90)	4 (4.10)	8(6.8)	1(0.8)	7(31.8)

In the samples analyzed Na^+ ion was dominant followed by Mg^{2+} and Ca^{2+}. At all the levels of EC, the mean Mg/Ca ratio in both the taluks were higher than 0.63 which was reported to be critical for causing Mg hazard. Generally, the ratio was maximum at 2.0-4.0 dS/m EC level in all the taluks. The general agreement that ground waters with higher Mg/Ca ratio (possibly > 0.63) are likely to have higher pH was not the case in these taluks.

Among anion, Cl^- ion was dominant followed by HCO_3^-, SO_4^{2-} and CO_3. The mean chloride contents (Table 17) were higher than 3.0 me/l in both the taluks resulting the Cl/SO_4 ratio was also >2.0 in majority of samples. The Cl/SO_4 ratio found to decrease with the increase in EC values in all the taluks (Fig. 5).

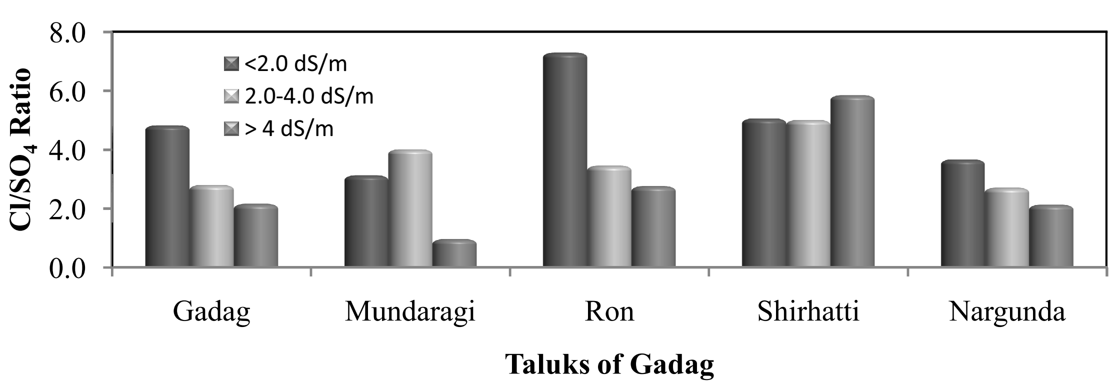


Fig. 5. Relationship between Cl/SO_4 ratio and salinity of ground waters of different taluks of Gadag district.

Table 17. Mean chemical composition of ground waters of different taluks of Gadag district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Gadag	156	Max.	8.1	6.7	16.5	26.5	39.13	46.56	28.22	14.0	5.0
		Min.	6.1	0.36	0.30	0.2	1.63	0.96	0.10	1.0	Tr
		Mean	7.3	2.05	2.79	6.44	12.37	9.31	5.10	5.38	2.57
Mundaragi	98	Max.	8.0	5.2	10.5	22.5	46.74	27.84	31.71	10.5	12.0
		Min.	6.9	0.38	0.3	0.1	1.85	0.96	Tr	1.00	1.0
		Mean	7.37	1.63	2.07	5.11	11.18	5.95	4.51	5.19	3.09
Ron	118	Max.	8.20	8.8	25.0	55.4	67.8	95.2	21.73	10.40	4.40
		Min.	6.7	0.21	0.50	0.10	1.30	0.20	0.00	0.30	0.20
		Mean	7.2	1.64	3.30	4.74	11.16	8.70	3.31	3.79	1.40
Shirahatti	133	Max.	7.61	4.30	18.90	20.00	44.35	30.3	22.70	13.00	4.80
		Min.	6.65	0.42	0.30	0.30	2.35	0.80	0.00	0.70	0.00
		Mean	7.13	1.45	2.41	3.82	10.98	7.59	2.01	4.14	1.68
Nargunda	22	Max.	7.50	6.70	20.20	25.80	72.17	65.0	24.63	5.70	2.20
		Min.	6.75	0.44	1.00	0.00	2.61	1.50	0.00	0.60	0.40
		Mean	7.21	3.05	5.93	6.62	23.26	19.45	9.13	3.07	1.36

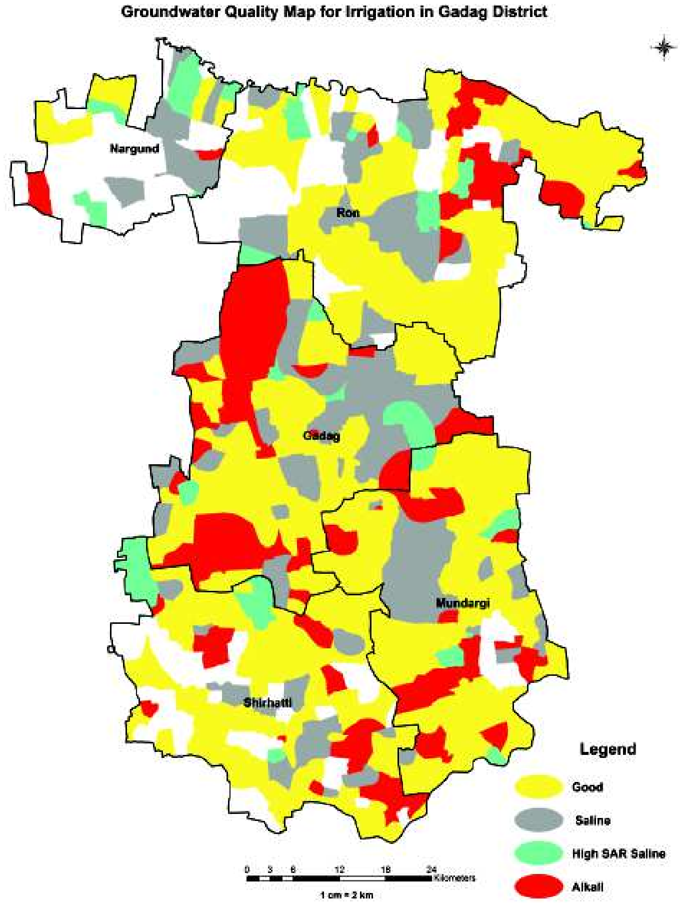
The mean SAR and RSC values in both the taluks were less than 10 and 2.5 me/l respectively. With regards to the overall water quality (Table 18), less than 50% of samples in Gadag and Mundaragi taluks and nearly 60% of samples in Ron and Shirhatti taluks were of good quality. About 14% each in Gadag and Mundaragi taluks were of highly alkali (SAR > 10 and RSC > 4.0 meq/l). Gadag district as a whole, less than 50% of samples were good followed by M.Saline (16.0%). And nearly 40% of samples were found to be problematic of different nature (saline, high SAR saline and alkali) requiring special attention and suitable recommendation for their use in agriculture. Taluk-wise as well as district map showing the distribution of different qualities of water is prepared for quick reference.

Table 18. Water quality ratings of ground waters of different taluka of Gadag district.

Taluk	Sample size	Good	M.Saline	Saline	High SAR Saline	M.Alkali -I	M.Alkali-II	Alkali
Ron	118	59.3 (70)	11.86 (14)	5.93 (7)	5.93 (7)	6.78 (8)	4.24 (5)	5.93 (7)
Shirhatti	133	59.4 (79)	14.29 (19)	0.75 (1)	5.26 (7)	11.30 (15)	3.01 (4)	6.02 (8)
Nargunda	22	22.73 (5)	18.18 (4)	18.18 (4)	22.73 (5)	18.18 (4)	-	-
Gadag	156	31.41 (49)	21.15 (33)	8.33 (13)	5.13 (8)	12.18 (19)	8.33 (13)	13.46 (21)
Mundaragi	98	45.92 (45)	14.29 (14)	1.02 (1)	4.08 (4)	8.16 (8)	12.24 (12)	14.29 (14)
District	527	43.75 (248)	15.95 (84)	6.84 (26)	8.63 (31)	11.32 (54)	5.56 (34)	7.94 (50)

Figures in the parenthesis represent number of samples

Groundwater Quality Map for Irrigation in Gadag District



2.7 Dharwad district

The district Dharwad with an area of 4273 sq. km (427329 ha) lies in the northern part of Karnataka state between 15^0 02'to 15^0 48' north latitude and 74^0 43' to 75^0 33' east longitudes. The average annual rainfall of the district is 769 mm. The mean maximum and minimum air temperature are 38^0C (April-May) and 16^0C (Dec-Jan). The district comprises five taluks. The district is bounded on the North by the district of Belgaum, on the East by the district of Gadag, on the South Haveri and on the West by Uttara Kannada district. Main rock formations in the area are the Gneissic-granites and Schists, the secondary structures like joints, fissures and faults present in them act as a porous media-the Aquifer. The lateritic layer overlying in moderate thickness and alluvium occurs along the riverbanks in less than 3.00 metres thickness acts as an aquifer locally. Ground water in the aquifer generally occurs under unconfined/phreatic and semi-confined conditions. Tubewells contribute 30 percent of net irrigated area (50995 ha) in the district (Motebennur, 2013). Major crops of the district include cotton, wheat, ragi, jowar and oil seeds in black soils and paddy in red soil.

During 2011-2012 and 2012-13, a total of 313 underground water samples representing different villages in Dharwad, Navalgund, Hubli, Kalaghatagi and Kundagol taluk were collected, analyzed and categorized into different water quality.

Nearly 100 percent of water samples in all the taluks had favorable pH (7.5 – 8.5). As far as EC is considered, majority of water samples in Kalghatagi (93.8%) followed by Dharwad (85.5%), Hubli (80.4%), Kundagol (71.9%) and Navalgund (50%) were of non-saline (<2 dS/m) at the time of smpling (Table 19). Mean Cl content was beyond 3 meq/l (Table 20) and Cl/SO_4 ratio was also >2.0 in all the taluks which is considered to be not desirable. Irrespective of EC levels, mean Mg/Ca ratios were also much greater than 0.63 varying from 1.8 to 15.7 which is considered not safe. The general agreement that ground waters with higher Mg/Ca ratio (possibly > 0.63) are likely to have higher pH was not the case in these taluks.

Table 19. Frequency distribution of water samples of different taluks of Dharwad district in respect of EC.

Sl.No.	Taluk	EC (dS/m) Range		
		<2.0	2.0-4.0	>4.0
		Percent		
1	Dharwad	59 (85.5)	9 (13.0)	1(1.45)
2	Navalgund	17 (50.0)	12 (35.3)	5 (14.7)
3	Hubli	45 (80.4)	9 (16.1)	2 (3.6)
4	Kalaghatagi	91 (93.8)	6 (6.2)	-
5	Kundagol	41 (71.9)	11 (19.3)	5 (8.8)
	District	253(76.3)	47 (17.98)	13(7.14)

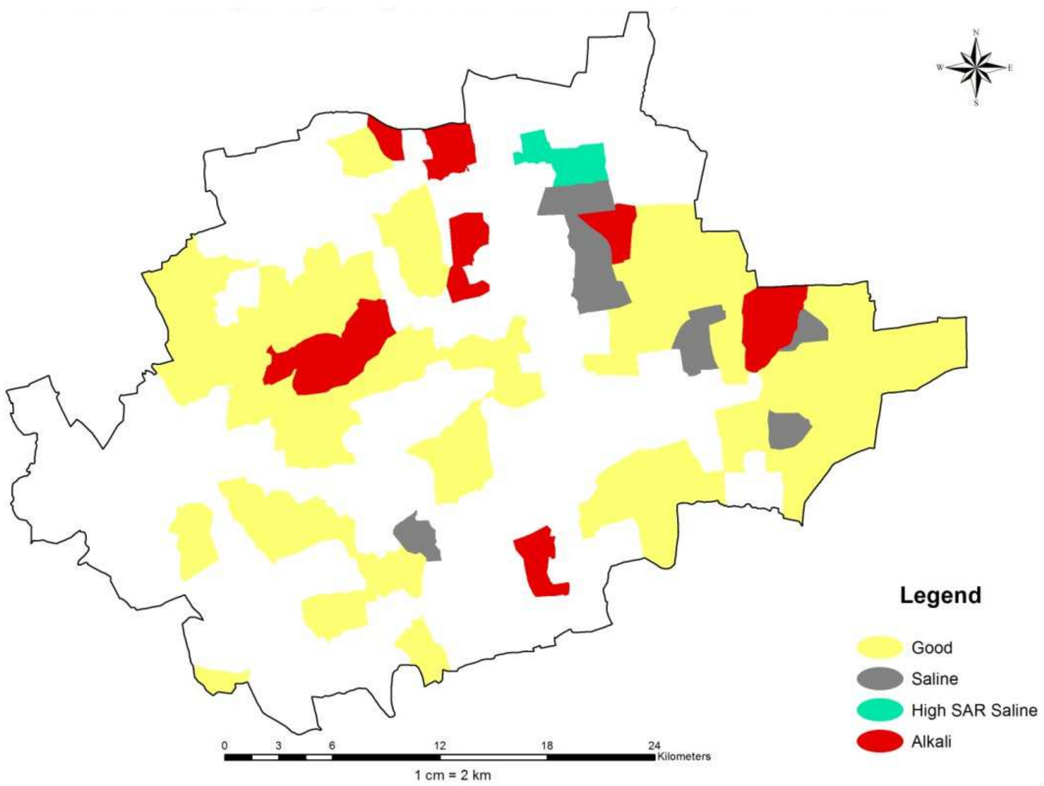
Frequency of occurrence of good quality water in the taluks surveyed followed the order (Table 21): Kalghatagi (93.80%) > Hubli (71.4%) >Dharwad (65.2%) > Kundagol (63.2%) > Navalgund (23.5%). Dharwad district as a whole, 63.4% of ground water samples was good quality water. Saline water samples were reported only from Kundagol and Navalgund to the extent of 8.8%. Alkali waters were found in Hubli, Kundagol, Dharwad and Navalgund to the extent of nearly 12, 12, 21 and 35% respectively. However, district as a whole different categories of problematic water altogether were less than 10%.

Table 20. Mean chemical composition of ground waters of different taluks of Dharwad district

Taluka	No. of samples	Range/ Mean	pH	EC (dS/m)	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	CO_3^{2-}
					(me/l)						
Dharwad	69	Max.	8.29	5.40	7.50	13.50	37.55	36.50	2.48	14.45	2.30
		Min.	6.84	0.27	0.25	0.05	1.02	1.00	0.10	2.16	0.27
		Mean	7.51	1.22	1.89	3.79	5.62	5.05	1.08	5.45	0.93
Navalgund	34	Max.	8.49	8.60	17.10	47.40	80.23	80.25	3.97	14.58	2.29
		Min.	7.14	0.19	0.10	1.15	0.27	0.80	0.33	1.62	0.13
		Mean	7.76	2.43	2.81	8.19	15.03	16.55	1.58	5.39	0.98
Hubli	56	Max.	7.8	10.2	13.8	31.1	60.9	71.0	31.21	8.50	-
		Min.	6.07	0.48	0.5	1.2	1.2	0.8	0.09	1.70	-
		Mean	7.18	1.57	1.375	5.6	8.4	6.64	4.24	4.59	-
Kalghatagi	97	Max.	8.35	2.30	2.60	16.80	9.95	15.50	8.66	6.20	-
		Min.	6.67	0.36	0.40	1.40	0.69	1.00	0.02	1.60	-
		Mean	7.22	0.97	1.15	4.82	3.21	3.74	1.46	4.03	-
Kundagol	57	Max.	7.87	7.00	10.30	41.20	21.20	63.00	31.94	13.70	-
		Min.	6.16	0.20	0.50	0.70	1.04	1.15	0.07	1.30	-
		Mean	7.34	1.85	1.55	8.15	7.92	8.60	3.81	5.34	-

Table 21. Water quality ratings of ground waters of different taluka of Dharwad district.

Taluk	Sample size	Good	M.Saline	Saline	High SAR Saline	M.Alkali -I	M.Alkali-II	Alkali
Dharwad	69	65.21 (45)	11.6 (8)	--	1.44 (1)	11.6 (8)	8.7 (6)	1.45 (1)
Navalgund	34	23.53 (8)	26.47 (9)	8.82 (3)	5.88 (2)	2.94 (1)	20.6 (7)	11.76 (4)
Hubli	56	71.4 (40)	10.70 (6)	0	5.4 (3)	8.9 (5)	1.80 (1)	1.8 (1)
Kalghatagi	97	93.8 (91)	6.2 (6)	0	0	0	0	0
Kundagol	57	63.2 (36)	15.8 (9)	8.8 (5)	0	3.5 (2)	7.0 (4)	1.8 (1)
District	313	63.4 (220)	14.2 (38)	3.5 (8)	2.5 (6)	5.4 (16)	7.6 (18)	3.4 (7)



Groundwater Quality Map of Dharwad Taluk, Dharwad District

3. MANAGEMENT OF POOR QUALITY WATER

It is known that plant species differ in their ability to withstand the adverse effects of saline water use depending on nature and extent of soluble salts, rainfall, soil type, drainage, nature and varieties of crops grown, soil and water management practices etc. Generally, the growth as well as the productivity of plants is adversely affected by use of saline water primarily through the osmotic stress and excessive absorption of ions like Na, Cl, B etc. Excessive uptake of these ions not only become toxic to plants but also may hinder the uptake of essential plant nutrients by the plant. Apart from its direct ill effect on plants, soil solution concentration could reach threshold salinity level leading to soil moisture deficit which in turn causing plants to suffer from meeting its water requirement.

Most often use of saline water would generally immediately affect the germination of crops and in later stages retardation of growth of survived plants. Obviously, reduced vegetative growth especially the leaf area results in uneconomical crop yields.

Under unavoidable conditions to make use of saline water in crop production, different strategies/technologies are being developed/practiced viz., selection of crops/varieties, irrigation and leaching requirement, amendments and fertilizer, agronomic and cultural practices, alternate land use patterns, etc.

3.1 Selection of elite lines/genotypes of crops for salt tolerance

A number of reports on list of crops and varieties adaptable to saline environment are available in the literature (Mass and Hoffman, 1977, Minhas and Gupta 1992, Gupta and Gupta, 2002, and Gupta et al., 2002). Minhas and Gupta (1992) have documented tolerance limits of crops to the saline water conditions in different agro-ecological regions of India. In general, the following some of the criteria are recommended in choosing crop(s).

- Semi-tolerant to tolerant crops with low water requirement should be considered for successful utilization of saline waters. In areas receiving less than 400 mm annual rainfall, mono-cropping is recommended to maintain salt balance.
- Apart from ionic constituents of saline water, soil texture and annual rainfall of the area modify the extent of salt accumulation vis-à-vis tolerance limits of crops (Minhas, 1996). With the same level of water salinity, accumulation of salts would be one half, nearly equal and more than two times that of irrigation water in coarse textured (loamy sand and sand), medium textured (sandy loam to loam) and in fine textured (clay and clay loam) soils respectively. Thus, highly saline water could be used to grow tolerant and semi-tolerant crops in coarse textured soils without any salinity build up in the soil. Whereas, only low to medium salinity water could be used in medium and fine textured soils which are bound to be salt affected due to the use of such water.
- Chloride concentrations of irrigation water in excess of 3.0 me/l is considered to be toxic/harmful for sensitive horticultural crops and thus known to reduce the tolerance limits of such crops to the extent of 1.2-1.5 times as compared to sulphate rich waters (Manchanda, 1998). So also with irrigating water having high SAR, as these waters tend to accumulate salts in the soil.

- It is established that there are significant physiological differences to responses to salinity not only among crops but also within a crop. As such, germination and early seedling establishment stages are considered to be most crucial under saline environment and in general their tolerance increases with advance in age. The other critical stage of a crop to salinity effect would be the transition between vegetative to reproductive or heading and flowering to seed setting (Minhas et al., 2004). Experiments conducted to evaluate the sensitivity of crop growth stages by application of saline irrigation waters at Dharwad (Black silty clay loam soil) revealed that presowing followed by tasseling stages are the most sensitive stages in maize. In case of pigeonpea and safflower, germination and flowering (Chimmad and Viswanath, 1989), germination followed by rosette, respectively were found sensitive to saline irrigation. Whereas, in case of groundnut, application of saline water at all the stages proved detrimental as yield was declined by 50% over best available water. With the proper understanding of the physiological behavior of a crop at different stages of growth (Table 1), fresh water and saline water could be used at sensitive and tolerant growth stages respectively.

Table 1. Relative tolerance of the crops to salinity at their growth stages.

Crop	**Relative sensitivity**
Paddy	Transplanting (2.7 dS/m)>50% flowering (6.0)>end of flowering(7.3)
Wheat	Presowing (2.9 dS/m)>CRI (5.7) > milking(6.7) > flowering(8.9)> jointing(9.2)
Maize	Silking (6.9 dS/m) > tasseling (7.6) > presowing (14.1) > knee height
Pigeon pea	Presowing (2.1 dS/m) > flowering to pod development (4.2) > flowering (5.7) > seeding to flowering (7.1)

source: Minhas et.al. (1998).

- Further, in addition to intergenic variations, varieties of a crop may also differ in their tolerance to salinity. In this context, extensive programme on screening major crops of the area was pursued at ARS Gangavati and the results are as follows:

Crops	No. of entries tested each year	No. of years conducted	Varieties	Threshold range of salinity (dS/m)	Threshold range of WT (m)
Cotton	50	7	RAHS-14, Sarvottam, GDH-9, Laxmi, DHY-286, AKH-4.	8-10	0.95
Wheat	12-20	4	KRL-1-4 DWR-39, K-65, SW-2560, DWR-162.	6-8	0.45
Safflower	15-20	4	A-1, Bhima, K-1, Manjira.	6-8	-
Sunflower	45	3	KBSH-1, P-64 A 43, PAC-36, Co-2, PKVSH-27.	6-8	-
Paddy	60-70	4	Karekagga, KR-21, Vyt-3, CSR-5, Pokkali, CSR-22.	2-9*	-
Mustard	10-15	2	CS-12, CS-52, CS 416.		
Groundnut	-		DH-3-30, ICGS-11	4.6*	-
Jowar**		2	ICSV112, S35, Hybrid PSH1	6.0	-

* denotes EC of standing/irrigating water.
** Identified in collaboration with ICRISAT, Hyderabad.

- Despite maintaining better soil and water relations, identifying different crop/ cropping sequences for saline vertisols is another way of managing saline soils and at the same time arresting further degradation of such soils. Investigations on the alternate cropping sequence to rice-rice followed in Tungabhadra project area revealed that though rice-wheat has the potential to replace traditional rice-rice cropping sequence, rice-rice-green manure cropping sequence was found most remunerative and sustainable as the former remained locally unpopular as canal water release does not match wheat growing season.

3.2 Irrigation and leaching requirement

Irrigation:

The suitability of waters for crop production is best known through its long term effect on soil productivity. In this direction, field trials initiated on black clay loam soil in 1973 at Dharwad **(**Table 2**)** revealed that the yields obtained under different rotations show a linear decrease with increase in ECiw.

Table 2. Yields of crops as affected by saline water at Dharwad

ECiw (dS/m)	Average yield (q/ha)						
	Sorghum	Wheat	Maize	Safflower	Itallian Millet	Sunflower	Cottton
No. of years	7	6	6	6	2	2	2
1.0	78.5	32.3	73.7	23.2	23.4	29.6	14.6
2.7	67.7	29.2	68.4	21.3	23.9	33.2	----
4.2	65.8	27.3	62.4	20.3	24.3	31.6	12.3
5.8	60.3	25.8	58.6	18.6	----	----	----
7.2	53.4	23.3	53.3	16.1	20.6	33.6	12.0
9.7	42.2	19.6	47.7	13.3	15.3	23.5	----
16.3	33.3	14.5	42.2	11.2	8.9	----	10.9

Use of available saline water during canal lean period was evaluated based on the experience of decreased yield due to delay in sowing. As a part of efficient use of natural resources cotton crop was raised with available saline water (4-6 dS/m) and then switched over to good quality canal supplies. A pooled data of over 6 years have conclusively established that early sowing (June) with available saline (with 4 irrigations) and then switching over to canal (August) water realized a highest kapas yield (22.1 q/ha) compared to late sown with good water during August (12.6 q/ha). The salt balance remained favorable and did not cause any concern of using saline water. With a similar approach, a large-scale field demonstration also confirmed (Table 3) the findings of the farm results.

Table 3. Results of large scale demonstration on the use of saline water followed by canal water on growth and yield of cotton during 2003.

Parameter	**T1: Early sowing (June first week sowing with 4 saline water)**	**T2: Normal sowing (August first week with only canal water)**
Plant height (cm)	105	101
No. of branches/plant	20	13
No. of bolls/plant	34	21
Seed cotton yield (q/ha)	23.4	13.8

Surface irrigation methods generally have an overall low water application/use efficiency resulting in increased water logging and thus leading to problems of salinity and alkalinity. Micro irrigation techniques are the most suitable irrigation water management technique followed especially to use poor quality waters and also when the soils are saline. Cotton and brinjal receiving saline water of 2.2 dS/m through drip irrigation to meet 1.2 evaporanspiration (ET) responded well and found ideal when compared to surface irrigation. A highest kapas yield of 17.8 q/ha in cotton and 26.2 t/ha of brinjal were realized even with the poor quality water provided.

In case of ridge gourd, highest yield was recorded under drip irrigation at 1.4 ET. A build-up in soil salinity was observed in both the methods of irrigation, however with slightly higher salinity in surface than drip irrigation. Further, drip irrigation helped to reduce water requirement by 35 per cent without compromising yield and economic returns in saline vertisols of TBP. To minimize the cost of drip irrigation system for cotton, single and paired rows were evaluated during kharif, 2003 to kharif, 2005 and found that paired row proved to be cost effective.

Leaching requirement:

When accumulation of salts reach levels beyond the threshold level of crop of choice, the foremost option available is flushing of salts out of root zone to bring salinity below the threshold level accomplished through leaching process. Leaching create conditions favourable for raising field crops. This option is available for farmers who are less endowed with financial resources to reclaim by engineering means. In pursuance of this endeavour and to make soil environment more feasible for raising field crops, leaching of soils was carried out to determine the leaching requirement of crops under varying water tables during the 1995-96. Leaching curves were constructed for water table of 70, 95 and 120 cm. From the curves, depth of pre irrigation to bring the salinity down to a desirable level specific to crops and water table was arrived. On the basis of results, it was predicted that a minimum of 150-160 cm of D_{iw} was required to bring the prevailing soil salinity to levels favorable for most field crops. Under hostile conditions of high salinity leaching is pursued with interest as a means of reclamation. In rice, a continuous ponding was more beneficial than intermittent which is otherwise practiced. The intermittent ponding was found to be detrimental by way of damaging roots when soils were allowed to crack. Besides damage, the cracks developed may reduce leaching efficiency of surface soils to the extent of depth of cracks.

In another study, a decrease in salinity was also accompanied by the decrease in SAR and ESP. Leaching efficiency of only 40-50 per cent was achieved even when D_{iw} was 100 cm, in presence of sub-surface tiles. As the depth of flushing zone (from 0-30 to 0-90 cm) increased, leaching efficiency decreased. Incorporation of green manure (@10t/ha) although favored leaching remained only marginal.

3.3 Agronomic and cultural practices

Under traditional method, majority of crops are sown after the soil attaining good tilth. Whereas, seeds sown in saline water irrigated soils are bound to be exposed to soil water of higher salinity ($EC_{sw} > EC_{iw}$) resulting in either poor germination and/or establishment of crops. Hence, to mitigate the adverse effect of saline water on crop and to enhance crop yields, following suitable agronomic and cultural practices could be practiced.

- Leveling, grading and smoothing of the land;
- To encourage flushing of soluble salts present in the root (seed) zone, provide pre-sowing irrigation with good quality water;
- Provide quick post-sowing irrigation with saline water to facilitate seed germination while taking care to avoid soil crusting;
- Use either more seed rate (20-25%) or number of seedlings than recommended for fresh water irrigated fields. Otherwise, reduce inter or intra row spacing to accommodate more number of seedlings;
- Practice rainwater conservation technology to leach down the salts. A field experiment conducted on black soils at ARS, Gangavati revealed that tied-ridges and furrow method of planting sunflower not only flushed down soluble salts (reduction in soil ECe to the extent of 26.2% over control) but also conserved rainwater (22.50% more over control) and thus increased seed yield compared to flat bed method of planting;
- Modify seedbed i.e., sow seeds on both sides of the ridge and irrigate in alternate row and
- Avoid blocking completely the drain outlets (subsurface drainage) in order to save water and possibly plant nutrients. Such blockage of drain may become detrimental once the soil salinity build-up reaches beyond a threshold value of

the crop. However, loss of nutrients (mainly nitrogen) can be reduced by adopting selective blocking (controlled drainage), especially during fertilizer application.

3.4 Amendments and fertilizers

Green manure: Green manure, farmyard manure, compost and other organic materials not only are the source of plant nutrients but also play an important role in modifying/improving soil physical, chemical and biological properties. Especially, soil structural improvement which in turn reduces the accumulation of salt through effective leaching from the root zone is an important feature in saline water irrigated soils. The other prominent advantage of using organic materials as amendments especially in saline water irrigated soils would be enhancement of nutrient (more so nitrogen) use efficiency by plants. Application of dhaincha or glyricidia @ 10 tonnes/ha along with 50 per cent RDN to wheat during rabi followed by 75 per cent RDN to succeeding kharif maize crop found suitable in the Tungabhadra irrigation command. This practice saved 87.5 kg N/ha/year in maize-wheat cropping sequence besides preventing leakage of reactive N into environment (volatilization losses) and thus improving soil health. In paddy-paddy cropping sequence, application of 100 per cent RDN along with green manure in the sequence performed equally good as the 125 per cent RDN application during both the seasons due to decreased volatilization losses of nitrogen wherever nitrogen was substituted through organics. This practice not only reduced nitrogen losses but also increased yield and prevented further salinization. Similarly, consideration of management of phosphorus is also an important criterion under saline environment wherein research results indicate that additional dose of P over the recommended had a better effect on crop yields by mitigating the adverse effects of salinity.

3.5 Alternate land use practices

Under extreme conditions of high water table and salinity and where vast areas have become salinized, in such areas option(s) for cultivation of agricultural crops along with prevention of secondary salinization is limited. Alternate strategies to prevent further salinization have been pursued with renewed interest and vigor. Field experiments were carried out to identify suitable tree and fruit species during 1989 to 2000 at ARS farm Gangavati.

Performance of fruit species in saline-waterlogged soils

Saplings of twelve fruit species viz., mango, sapota (var. kalipatti and cricket ball), wood apple, tamarind, pomegranate, custard apple, fig, guava, ber, anola, jamun and pummelo were planted during 1990 in three salinity blocks, Performance of fruit species were evaluated during 1990-2000 in terms of survival percentage, plant height and diameter at stump height. Based on survival percentage and growth of different fruit species, mango, custard apple, guava and pummelo were found not suitable for soils having salinity in the range of 8-15 dS/m and water table in the range of 0.40-0.70m. Jamun and sapota crops survived and grew better under relatively lower salinity and shallower water table conditions, whereas wood apple was promising under relatively high salinity but deeper water table conditions. Pomegranate and ber maintained a moderate survival and steady growth rate in low salinity and shallow water table conditions.

Salinity level/water table	**Promising fruit species**
Salinity: 8-15 dS/m	**Most tolerant:** Jamun and Wood apple
Water table: 0.40-0.70 m	**Moderately tolerant:** Pomegranate and Ber
	Susceptible: Mango, Custard apple, Guava and Pummelo.

Performance of multi-purpose tree species on saline-waterlogged soils of TBP

A field experiment was conducted to evaluate the performance of 23 multi-purpose tree species on saline-waterlogged soils at Agricultural Research Station, Gangavati during 1989-2000. Based on 11 years of study, tree species sush as *Acacia auriculiformis, Acacia ferugenia, Albizzia lebbeck, Glyricidia maculate, and Casuarina equisetifolia* performed better under saline (10-12 dS/m) and high water table conditions (0.75 to 1.0 m). Moderately tolerant species identified were *Dalbergia sissoo, Inga dulse, Eucalyptus hybrid* and *Pongamea pinnata*. All the tree species enriched the soil nutrient pool (NPK) and organic carbon.

Salinity level/water table	**Promising fruit species**
Salinity: 8-12 dS/m	**Most tolerant:**
Water table: up to 0.75 m	*Acacia auriculiformis, Acacia ferugenia, Albizzia lebbeck, Glyricidia roboretu, and Casuarina equisetifolia*
	Moderately tolerant:
	Dalbergia sissoo, Inga dulse, Eucalyptus hybrid and *Pongamea pinnata*.

3.6 Management of alkali waters

Alkali waters are characterized by low total salt concentration (EC < 4.0 dS/m) with often > 70 per cent Na and much smaller proportion of Ca and Mg contents. Such waters usually have bicarbonates (in some cases carbonates) as predominant anion associated with Na resulting in residual sodium carbonate (RSC) of water in excess of 2.5 me/l. Predominance of Na in alkali water tend to deteriorate soil physical properties including water infiltration and soil aeration. Further, waters with low Ca^{2+} (< 2 me/l) and high amounts carbonates known to result in specific toxicity symptoms on plants such as scorching and leaf burning at the early seedling development stage of crops. Similar to saline water usage, crop selection, application of amendments (gypsum), nutrient management etc., are some of the strategies which could be considered in the reclamation of alkali soils and/or minimizing the ill effects of alkali water.

Crop selection: Depending upon the soil and the environmental conditions, continuous use of high RSC water tend to increase the pH and exchangeable sodium percentage (ESP) of soil. Accordingly, crops need to be selected based on the expected sodicity build-up in the soil. A list of crops and their varieties suitable at specific ESP levels are available in the literature. A list of such few promising cultivars for alkali environment is given in table 5.

Table 5. Promising cultivars of field crops for alkali environment.

Crop	Varieties
Paddy	CSR10, CSR 11, CSR 30, CSR 36
Cotton	HY 6, Sarvottam, LRA 5166
Sorghum	SPV 475, 1010, CSH 1, 11, 14
Sugar beet	Ramonsakya-06, Polyrava-E, Tribal,
Wheat	KRL1-4, KRL 19, Raj 3077, HI 1077, WH 157
Pearl millet	MH 269, 280, 427, HHB 392
Mustard	CS15, CS 52, CS 54, Varuna, DIRA 336.
Safflower	Manjira, APRR 3, A 300
Barely	DL 4, 106, 120, DHS 12.

Note: Varieties of sugar beet also known to suit for saline environment.

Source: Adapted from Minhas et al. (1998).

Application of amendment: In order to replace sodium on soil exchange complex, amendments which contain calcium viz., gypsum, phosphogypsum, distillery spent wash, acids, or the acid forming substances like sulphuric acid or pyrites can be used. Generally, gypsum the most economical and easy for handling is widely used. The rate of application of agricultural grade gypsum (70% purity) is arrived at by considering the RSC of water, number and depth of irrigation. In addition to this, consideration should also be given for the gypsum requirement of soil, if required. Generally, to neutralize each me/l of RSC, gypsum @ 90 kg/ha per irrigation of 7.5 cm depth is used as a guideline.

Method and time of application: Gypsum can be applied either directly to the soil or with irrigation water. Though soil application is easier to accomplish, trials conducted at Tiruchinapalli and Kanpur revealed that dissolution of gypsum directly in water through gypsum beds or its application to the irrigation channels would be an economical proposition.

As for as time of application is concerned, just prior to onset of monsoon with adequate soil moisture in the soil would be the best time. Gypsum could be applied even in the standing water, as it will hasten leaching of salts and the reclamation process as well. The soil should then be ploughed upon attaining proper soil moisture condition.

Nutrient management: Availability of nutrients in soil for plant uptake is affected through rise in soil pH upon use of alkali water. Loss of nitrogen through volatilization and non-availability of micronutrients like Zn, Fe, Mn, Cu etc due to their precipitation as hydroxides and carbonates pose deficiency of these nutrients in the soil. Hence, application of 25% extra nitrogen over the recommendation for normal soil conditions is considered essential. Application of Zn @ 25-40 kg/ha as $ZnSO_4$ especially for paddy is also advisable. Sometimes, nutrient dose to the crop may be required to be reduced accordingly if alkali water is rich in such nutrients.

3.7 Reclamation of waterlogged and salt-affected soils

Land resources are decreasing and demand for more grain yield from the available land resources is increasing thereby drawing greater attention of rehabilitation of waste lands in particular the salt affected soils (saline or sodic) as there is possibility that the productivity of these soils either improved or restored. Rehabilitation of such soils through engineering means (intercepter/subsurface/vertical drainage) or through bioamelioration are in vogue. Field drainage requirements depend on surface features, soil type, soil hydrological parameters and crop salt tolerance. In this regard, performance of interceptor drainage, sub-surface drainage, effect of nala cleaning on water table depth and secondary salinization were evaluated over 10-12 years in TBP area.

Intercepter drain: In most of the irrigation command areas, seepage from canal networks having improper lining has been attributed to the rise of water table and secondary salinization especially in low-lying areas. This option is found to be most cost effective for situation where canal seepages are repeated. Interceptor drains concept is conceived and adopted to arrest seepage and prevent salinization in the low lying areas. An interceptor drain of 10 cm dia placed at a depth of 1.7m from the surface, 500 m down stream from the canal and 250m upstream from the natural nala with a running length of 800 m draining into two minor natural nala which in turn connected to major nala was installed to intercept seepage flow in Distributory No. 36 and 36/1 canal command near Gorebal, Sindhnur during 1991.Monitoring of the system for about 7 years revealed that soil salinity decreased and water table lowered from 134 cm to 171 cm on the upstream side of the interceptor drain. A similar fall (73 to 185 cm) of water table over the years on the down stream side of the interceptor was also noticed. Such a favourable changes in water table and soil salinity improved rice yield from 22.9 to 738 q/ha and 22.4 to 66.0 q/ha in upstream and downstream side respectively. Yield increases were significantly higher during rabi-summer (December-March) compared to kharif (July-December).

Subsurface drainage (SSD): Where water table is within the threshold limits and inflicted by salinity, intervention through drainage is essential to improve the productivity. Preliminary studies conducted in TBP indicated the need for a lateral drain spacing of 18 to 30m underlining the belief that a higher drainage coefficient is required to leach salts from saline vertisols. Field performance of sub surface drainage systems at four different locations around Gangavati indicated a considerable reduction in soil salinity and improvement in crop yields suggesting the need of such drains for reclaiming saline vertisols. Based on its economic analysis, pay back period of 2 to 5 years indicated that the sub surface drainage system is a remunerative and cost effective system. Further, the drainage requirement was known to be governed by the crop intended to be raised. With paddy requiring ponding of water lateral drain spacing of 150 m was found to be reasonable to control water table and soil salinization.

As predicted by the SALTMOD model, root zone soil salinity will be reduced to about 2.5 dS/m from an initial value of 8.5 dS/m with sub surface drainage (uncontrolled), whereas controlled drainage during rabi and at critical crop stages (kharif and rabi) to save water and possibly nutrients had little effect on root zone soil salinity build-up but maintained ECe within a safe limit (<4 dS/m).

Vertical drainages for saline/waterlogged soils

Saline soils with an acute outlet problem such as in case of saucer type of basin require special efforts, energy etc. which was investigated through 1983 to 1993. Results of experiment in terms of soil salinity, chloride salinity, caronates and bicarbonates removal and de-sodification pattern revealed that for short term gains, vertical drain of 3 m deep and 1.5 m diameter connecting main drains was better than vertical drains without laterals. The cost comparison favored a vertical drain without lateral (Rs. 34,605/- per ha) than both the vertical drain with lateral (Rs. 68,033/- per ha) and the conventional horizontal system (Rs. 43,328/- per ha) for 15 m drain spacing.

Integrated drainage systems

The functioning of drainage system largely depends on adequate gravity outlets since systems with inadequate gravity outlets suffer due to siltation of nalas during flash floods and excess irrigation. For a proper functioning of SSD, nala cleaning plays a vital role in improving drainage efficiency of the system. An experiment to study influence of nala cleaning (to a total length of 12 km and 1.0 m depth) with or without SSD was initiated during 1997-98 at ARS, Gangavati. Observations on grids of 25, 50, 100 and 250 m away from the nala revealed considerable lowering of water table from within 24 to 87 cm on either side of nala bed due to nala cleaning under SSD system which in turn had tremendous positive influence on paddy crop yields. Whereas, this decrease in water table was not noticed with mere nala cleaning i.e., without SSD.

Reclamation of water logged and saline soils through bioamelioration

The problem of salinity and water logging have been considered as regional and global problems and the engineering means of reclamation are most often cost-prohibitive and remain out of the economic realms of most farmers. Tree species with high evapotranspiration (ET) have attracted the attention of farmers and scientists as an alternative mode to the cost-prohibiting engineering solutions of reclamation. Field studies conducted at ARS, Gangavati revealed that 15 years after establishment of different tree species, *Acacia nilotica* remained the most promising at all soil salinity levels ranging from <5 to >15 dS/m . *Casuarina equisetifolia* though performed well initially, shown high mortality and cease to grow 6-8 years after its establishment. However, *Hardwickia binata* which was less promising initially became promising after 6-8 years. From the point of bioameliorative effects C. *equisetifolia* still holds promise with suitable planting and harvesting strategies based on the biomass production adapted. *A. nilotica* followed by *C. equisetifolia* improved soil organic carbon status and porosity thus decreasing bulk density. Trees had the potential to improve hydraulic conductivity and infiltration rate and brought about a significant change in soil stability by improving soil aggregates, decreased soil and water erosion.

Further, *A. nilotica* and *C. equisetifolia* were effective in arresting emerging seepage flow from the canals. These two species intercepted seepage over 80 per cent and remained most promising over other species. The grasses in between complimented the effects. The water table receded significantly underneath the plantation while increased at the rate of 10 cm rise outside the plantation area. The results after 8 years of a study to arrive at proper spacing of *A. nilotica* (as test species), revealed a direct relationship between increasing strip width and lowering of water table. Two to four rows of *A. nilotica* with a spacing of 4 m (intra-row) x 2 m (inter-row), parallel to canals/distributaries (5 m away from the canals/distributaries) helped in controlling canal seepage in TBP irrigation command.

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