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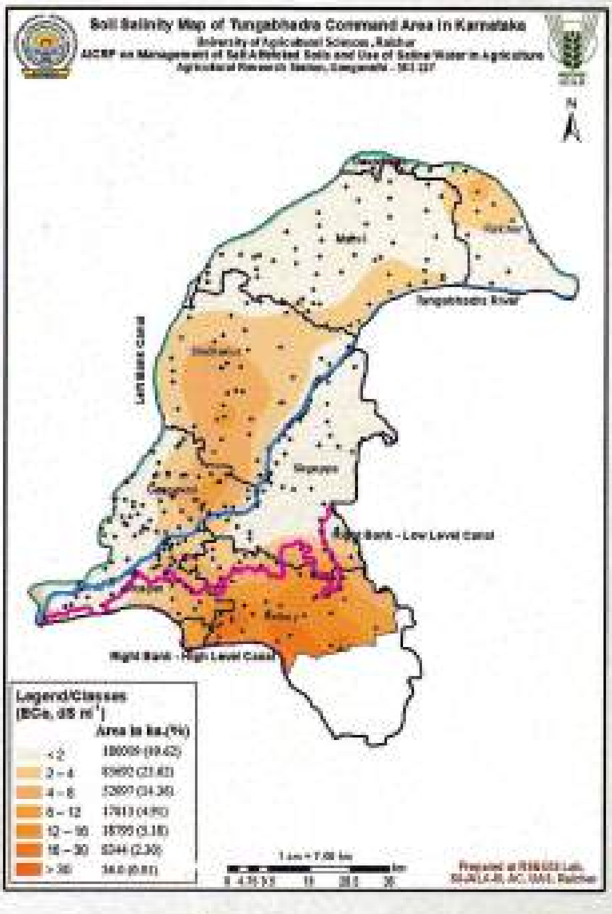
Survey, Characterization and Mapping of Salt Affected Soils in Tungabhadra Project (TBP) Command, Karnataka



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AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Agricultural Research Station, Gangavathi, Karnataka.

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FOREWORD

The world population has reached to 7.9 billion. However, natural resources like land and water, to feed such huge population, are limited and continuously threatened due to industrialization, urbanization, infrastructure development and disposal of waste material. All the countries in the world are trying to increase cropping and irrigation intensity with all means. In this endeavour, all types of soils and all types of available waters, irrespective of their suitability classes, are being used to grow crops. Some of the soils, where irrigation and drainage requirements are not properly addressed, are going out of cultivation due to soil sodicity and soil salinity problems. This is the global phenomenon and most of the countries in world suffer from these problems. As per FAO, over 1100 Mha of soils are affected by salinity and sodicity, of which about 60 percent are saline, 26 percent sodic and the remaining 14 percent saline-sodic. Salt-affected soils are found on all continents. The most affected regions are the Middle East, Australia, North Africa, and Eurasia. Out of total degraded land of 120.70 Mha in India, salt affected land is 6.74 M ha.

The northeastern part of Karnataka comprising Raichur, Koppal, and Bellary districts traditionally suffered from water shortages, being rain shadow region. Therefore, planners at the national level thought of construction of reservoir across Tungabhadra River at village Munirabad (Mallapur). The planning of this reservoir was done prior to the independence of India but it was commissioned in 1953. Violation of cropping pattern in the command areas, by introducing paddy crop, resulted in waterlogging and soil salinity problems on large scale. In view of this background, an assessment and mapping of soil salinity in the command was undertaken by AICRP on Salt Affected Soils and Use of Saline Water in Agriculture, Gangavathi, Karnataka. The results of survey showed that soil salinity (ECe) in surface soil (0-15 cm) was found in the range of 4-8 and >8 dS m^{-1} in around 14.4% (52097 ha) and 12.4% (44986 ha) of the command, respectively. With respect to Sodium Adsorption Ratio (SARe) of soil extract, 22.3% (80904 ha) area of the command had value >13 indicating presence of soil sodicity. Among different districts in the command, Bellary had the highest percent of area i.e., 62.83 (74400 ha) and 54.26 (64251 ha) having EC>4 dS m^{-1} and SARe >13 followed by Koppal (Gangavathi) i.e., 30.19% (10465.6 ha) and 35.12% (12174.7 ha), respectively. This bulletin provides spatial information about soil salinity and also discusses the important technologies developed by the Gangavathi centre through field experimentation of several years, which could be used to reduce the crop yield losses to certain extent ensuring sustainability of agriculture under adverse conditions. I am sure that this publication will be useful to researchers, policy makers and other stake holders involved in sustainable management of waterlogged saline soils in TBP.

Date: 30-09-2022

(PC Sharma)

CONTENTS

LIST OF TABLES

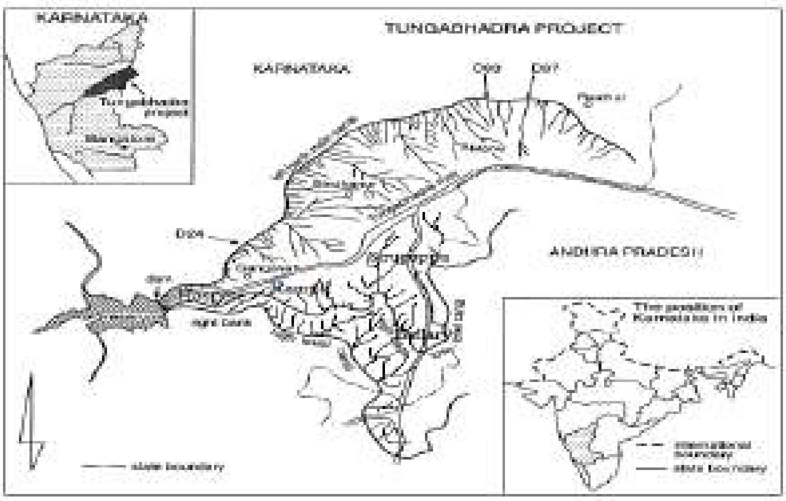
LIST OF FIGURES

1.0 Introduction:

The northeastern part of Karnataka comprising Raichur, Koppal, and Bellary districts is a rain shadow region. It receives an average annual rainfall of 550 mm and it is distributed over just 40 days. The amount of rainfall received is not only inadequate but also unpredictable and it makes agriculture less profitable and unsustainable. The region has high potential evaporation of 1250 mm compared to annual rainfall of 550 mm. Thus the climatic condition of northeastern Karnataka is semi-arid. Traditionally the region suffered from water shortages for irrigation and human life as a result of frequent droughts. In view of this background, planners at the national level thought of construction of reservoir (Fig.1) across Tungabhadra River, a tributary of river Krishna at village Munirabad (Mallapur). The planning of this reservoir was done prior to the independence of India in 1947; however, a reservoir was constructed after independence under the leadership of the first Prime Minister of Late Shri Jawahar Lal Nehru and technical support of great Civil Engineer Late Dr. Thirumalai Iyengar. The project was commissioned in 1953 with an aim to provide only protective irrigation to vast areas in the state of Karnataka and Andhra Pradesh facing a problem of frequent droughts so that the economic status of the farmers in respective states could be improved.

There are two canals on left viz., Left Bank Canal and Left Bank High Level Canal and three canals on right side viz., Right Bank Low Level Canal, Right Bank Higher Level Canal and Raya Basavanna Channel for irrigation and power generation. The details of area irrigated in each of taluks in Bellary, Koppal and Raichur districts are shown in Table 1.

The irrigation authorities planned cropping pattern for Tungabhadra Project (TBP) Command at the time of inception related to Karnataka state and same is provided here for information (Table 2).



Source: Mollinga, 2003 (Slightly modified).

Fig. 1. Map showing Tungabhadra reservoir and canal network system in Karnataka.

Table 1: Details of canals, area of irrigation in each taluks of Bellary, Koppal and Raichur districts in Tungabhadra irrigation project, Karnataka.

(In hectares)

S.No.	Particulars	Left Bank Canal	Left Bank High Level Canal	Right Bank Low Level Canal	Right Bank High Level Canal	Raya Basavanna Channel		Total
						Raya	Basavanna	
1	2	3	4	5	6	7	8	9
1.	Gross command area	364212	469	118976	115334	-	-	598991
2.	Cultivable command area	323744	469	104003	100765	-	-	528991
3.	Localized (Irrigable) area in Karnataka	243912	469	37504	80910	2049	967	362795 (VNC+3016)
4.	Districts benefited in Karnataka	Koppal and Raichur	Koppal	Bellary	Bellary	Bellary	Bellary	
A.	**Bellary District**							
	Bellary Taluk	-	-	8600	73434	-	-	82034
	Hospet Taluk	-	-	3784	5174	2049	967	8960
	Sandur Taluk	-	-	-	420	-	-	420
	Sirguppa Taluk	-	-	25120	1880	-	-	27000
	TOTAL	-	-	37504	80910	2049	967	118414+ 3016
B.	**Koppal District**							
	Koppal Taluk	1875	-	-	-	-	-	1875
	Gangavati Taluk	34666	-	-	-	-	-	34666
	TOTAL	36541	-	-	-	-	-	36541

S.No.	Particulars	Left Bank Canal	Left Bank High Level Canal	Right Bank Low Level Canal	Right Bank High Level Canal	Raya Basavanna Channel		Total
						Raya	Basavanna	
1	2	3	4	5	6	7	8	9
C.	**Raichur District**							
	Raichur Taluk	27966	-	-	-	-	-	
	Deodurga Taluk	1084	-	-	-	-	-	
	Manvi Taluk	88525	-	-	-	-	-	
	Sindhanur Taluk	89796	-	-	-	-	-	
	TOTAL	207371	-	-	-	-	-	207371
	Grand Total	243912	469	37504	80910	2049	967	362795 + 3016 VNC (Vijaya Nagar Channels)

Table 2. Localization of cropping pattern of TBP command area (ha) during inception of the Project.

S.No.	Crops	LBC	LBC (HLC)	RBC	RBC (HLC)	Total	Percentage Area
1	Light irrigated (Kharif)	89,304	74	-	80,910	1,70,288	47.0
2	Light irrigated (Rabi)	88,761	35	23,693	-	1,12,489	31.0
3	Rabi cotton	29,967	8	-	-	29,975	8.0
4	Paddy	21,099	352	7,581	-	29,032	8.0
5	Sugar cane	8,436	-	6,230	-	14,666	4.0
6	Horticulture	6,345	-	-	-	6,345	2.0
	Total	2,43,912	469	37,504	80,910	3,62,795	100.0

(Source: CADA, 2013); LBC: Left Bank Canal, HLC: High Level Canal, RBC: Right Bank Canal

During those periods, the cotton crop was the most remunerative, but slowly it disappeared from the command due to more incidences of pests and diseases. Then farmers preferred sugarcane in some part of the command in view of cooperative sugar mills in nearby areas. However, those mills also stopped their operations due to management issues. Then local farmers were in search of alternative crops. At the same time, farmers from neighboring Andhra Pradesh (AP) migrated to the TBP command and they were well versed in paddy cultivation. They introduced paddy crop in the TBP command. It was the point, when the cropping pattern finalized for the command, got violated. Farmers found paddy more economical than other crops and it became farmers' preference within the whole command. Thus, the paddy area in the command increased from 8 to 40% (29032 to 146974 ha). The *Kharif* paddy (August to December) area is around 47% while summer paddy (January to April) is around 34%. Of course, paddy requires more water and also area increased in head and middle reach areas by accessing more irrigation water than tail reach area. The violation of cropping pattern in the head and middle reach areas by introducing paddy crop, prompted excessive use of irrigation water, resulting in water logging and soil salinity problems on large scale in TBP command. In 1979-80, 20,200 ha land was affected but it increased to about 80,000 ha in 1996-97 (Jayashankar,1997) and presently about 96,200 ha area is suffering from twin problems of waterlogging and soil salinity (CADA, 2013) and about 2500 ha area is being added every year as reported by CADA-TBP. Singh (1995) reported that about 37700 and 20000 ha (i.e. 7.4% and 4.0% of the potential irrigated area) are waterlogged and saline/alkali soils respectively in TBP command area. Similarly, about 30000 and 14800 ha (i.e.10% and 5% of potential irrigated area in TBP command area) are waterlogged and saline/alkali soils respectively in Andhra Pradesh respectively. Majority of the reports vary in their estimates of waterlogged areas in the command as they rely on images which are greatly influenced by the presence of moisture, parent materials and other ground features.

A proper delineation of the area through intensive ground truth is imperative in arriving at a realistic estimate of salt affected area. However, no such delineation of salt affected soils in TBP command is available. Therefore, an assessment and mapping of soil salinity in the command may thus help policy makers and researcher to take up appropriate measures to arrest further increase in salt affected area and also to make salt affected soils productive again.

2.0 Salt Affected Soils

Soil and water are vital natural resources crucial to the sustenance of life on earth. Processes underlying in soils have direct or indirect impact on the ecosystems and ultimately the soil quality determines the prosperity of the nation. Irrigated agriculture is one of the approaches used especially in the semi-arid and arid regions of the world so that food security for the burgeoning population pressure is achieved. However, unscientific soil, water and crop management practices over the years are resulting in altered hydrological balance in soil and thus leading to the degradation of heavy textured low hydraulic conductivity and impervious substrata (poor drainage) of black soils to waterlogging and secondary salinization. Siltation of natural drain was also considered to be one of the major causes for water logging and salinization in the irrigation commands. Due to insufficient rainfall and/or use of marginal quality groundwater for crop production is as well resulting in the development of salt affected soils under rain-fed agriculture situations. The causes may vary but their effects on crop growth and yield are mostly alike through osmotic, ion-specific effects, imbalanced nutrition of crops, soil physical constraints etc. A reconciled estimate in 2006 by CSSRI, NRSA and NBSS&LUP indicated that about 6.73 Mha of land is salt affected in India and is predicted to raise to 16.2 Mha by 2050 (CSSRI 2015) if appropriate steps are not taken to arrest further soil degradation.

The most commonly used USDA classification of salt affected soils considers three main soil criteria viz., soluble salt content as measured in soil saturation paste extract (ECe, dS m^{-1}), Exchangeable sodium percentage (ESP) and pHs or pH_2. The USDA classifies salt affected soils in to i) Saline, ii) Saline-alkali and iii) Alkali soils as shown in Table 3.

Table 3. USDA Classification of salt affected soils (Richards, 1954).

Class	ECe (dS m^{-1})	ESP	$pH_2^{\$}$
Saline soils	> 4	<15	<8.5
Saline-alkali soils	>4	>15	Variable
Alkali soils	<4	>15	>8.5

Note: If pHs (saturation paste extract pH) is measured, the value is taken as 8.2 (Abrol *et al.*, 1980).

Estimation of ESP being cumbersome, efforts were made to establish relationship between ESP and SARe (Sodium adsorption ratio) of saturated extract to categorize salt affected soils as saline or alkali. The relationship indicated that soils having SARe <13 should be categorized as saline while those having SARe >13 as alkali or saline-alkali based on the ECe of the soil. The SARe is the SAR of the extract of saturated paste. Further, it is suggested that soils that have $(CO_3 + HCO_3)/(Cl+SO_4)$ and/or $Na/(Cl+SO_4)$ ratios >1 in meq/L should be treated as alkali from the management point of view under Indian conditions (Chhabra, 2004). Using these criteria, soils in TBP command (Bellary, Koppal and Raichur districts) area of Karnataka were classified accordingly.

2.1 Bellary district

The district Bellary is located in the eastern part of the Karnataka state and lies between the north latitude 14^0 30' - 15^0 47' east longitude 75^0 40' - 77^0 11'. The geographical area of the district is about 8420 sq.km (prior to 2021). The district consists of 7 taluks viz., Siruguppa, Ballari, Sanduru, Hospet, Hadagali, Hagaribommanahalli and Kudligi of which Siruguppa, Bellary, Sanduru and Hospet taluks are in TBP command area (Table 1). The climate of Bellary district is quite moderate with dryness in major part of the year and a hot summer is experienced from March to May months where mean maximum temperatures ranges from 23.2°C to 40.4°C. The southwest monsoon is experienced during June to September with temperature between 19.7°C to 35.1°C, post monsoon period is October to November and monsoon retreats during this period and clear bright weather is experienced with the mean daily temperature between 14.4°C to 31.1°C. During winter season (December to February) weather remains dry and cool. The soils of the district are derived from Granites, Gneisses and Schistose rocks. The Sandy loam soil mixed with black and grey soil occurs along the stream beds. These are originated from gneisses and granites. They are permeable and mildly alkaline in nature. The thickness of the soil varies from 0.2 to 1.00m. The red soil are the major type of soil in the district, found mainly at elevated places especially at fringes of hills due to decomposition of rocks and surrounding granitic and gneissic hills. These soils are with high permeability and neutral pH. Black soil are found in the prolonged submerged areas and canal command areas having low permeability and are derived from schistose rocks. Black soils are calcareous and mildly alkaline in soil reaction.

Among major soils, about 26.23% (2,20,441 ha) of the land area is occupied by medium deep red gravelly clay soils; followed by deep black clayey soils; (12.49%; 1,05,865 ha), deep, black calcareous clayey irrigated soils (salt affected patches) (10.93%; 91,823 ha), deep, alluvial clayey soils (salt affected patches); (10.78%; 90,580 ha) and deep, black calcareous clayey soils (6.92%; 58,187 ha).

The major crops grown in the district include cereals (sorghum, paddy, maize, bajra, ragi and millets) to the extent of 41095 ha, pulses (bengal gram, horse gram, black gram, green gram, cowpea etc) to the extent of 32834 ha, oilseed crops (groundnut, sunflower, castor, sesamum etc.) to the extent of 79001 ha, and also commercial crops (cotton, sugarcane, tobacco etc). The net sown area comprises about 56% of the district total geographical area. Nearly, 20.4% of the net sown area is irrigated through surface water source and about 13.15% of the area is through ground water.

2.1.1 Bellary Taluk

With the aid of GPS and toposheet (1:50000), soil samples were collected on a grid basis (5' x 5') from Bellary taluks during May 2016. A total of 172 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 27 grid points (52 sampling stations) were collected, processed and analyzed for soil salinity-sodicity appraisal.

The results (Table 4) revealed that at surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 10.76 to 7.82, 10.23 to 7.45, 31.0 to 0.19 dS m^{-1} and 75.0 to 0.64 dS m^{-1}) respectively with an average of 8.55, 8.11, 5.39 dS m^{-1}, and 13.2 dS m^{-1} respectively. Among cations, average Na content was more than Ca+Mg followed by K. In case of anions, average Cl^- content was more than HCO_3^- followed SO_4^{2-}. Nearly 40 per cent of surface samples had ECe > 4.0 dS/m reflecting that these soils are saline. However, per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ were nil whereas $(Na/(Cl+SO_4)$ samples were to the extent of nearly 56. Accordingly, nearly 48 per cent of surface samples had SARe >13.

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varying from 10.55 to 7.43, 10.33 to 7.55, 19.9 to 0.12 and 35.0 to 0.37 dS m^{-1} respectively with an average of 8.34, 8.21, 2.90 dS m^{-1} and 7.18 dS m^{-1}, respectively. Similar to surface soils, average Na content was more than Ca+Mg followed by K. In case of anions, average Cl^- content was more than HCO_3^- followed by SO_4^{2-}.Nearly 40 per cent of sub surface samples were considered to be saline as the ECe of these samples was >4.0 dS m^{-1}. The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ was >1. However, about 4 and 58 percent of these samples (Table 5) had values more than 1 indicating that these samples could be considered as salt affected soils in particular sodic or developing into sodicity. Similar to surface samples, about 48 per cent of samples analyzed had SARe >13. At 30-60 and 60+ cm depths, about 42 and 46 per cent of samples had ECe >4, 64 and 84 per cent of samples with Na/(Cl+SO4) >1 and 51.1 and 61.1 per cent of samples had SARe >13 at these depths, respectively.

Table 4. Characterization of soil samples collected from Bellary taluk in Bellary district, Karnataka for soil salinity appraisal.

Properties	**Depth (cm)**											
	0-15 cm			**15-30 cm**			**30-60 cm**			**60+ cm**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
pH (1:2.5)	10.76	7.82	8.55	10.55	7.43	8.34	10.2	7.22	8.55	10.3	8.12	8.78
EC (1:2.5)	31.0	0.19	5.39	19.90	0.12	2.90	9.40	0.16	2.71	8.40	0.20	2.69
pHs	10.23	7.45	8.11	10.33	7.55	8.21	10.1	7.63	8.35	9.65	7.76	8.33
ECe (dS/m)	75.0	0.64	13.20	35.00	0.37	7.18	24.0	0.43	5.28	19.30	0.55	5.69
Cation/Anion based on extract of saturated paste												
Ca+Mg	126.0	3.20	19.27	55.20	2.70	13.06	38.0	2.30	11.4	37.10	2.40	13.8
Na+	634.5	1.83	117.6	262.8	1.43	66.15	196.5	1.88	45.4	145.6	2.60	45.9
K+	1.56	0.04	0.30	0.60	0.02	0.16	0.36	0.02	0.11	0.45	0.03	0.10
HCO_3^-	259.5	5.25	24.2	54.6	2.50	13.24	41.5	2.50	15.4	35.4	2.10	16.3
Cl^-	554.5	6.52	109.2	254.6	5.20	54.39	120.4	4.80	35.2	142.1	4.21	38.9
SO_4^{2-}	4.87	0.06	1.26	3.68	0.03	1.42	3.20	0.05	1.24	2.82	0.07	1.35
SARe	290.7	1.07	38.9	122.9	1.16	23.45	83.1	1.32	19.14	41.4	1.57	17.5
$(CO_3+HCO_3)/(Cl+SO_4)$	2.80	0.04	0.50	1.23	0.07	0.46	2.24	0.15	0.53	0.76	0.10	0.50
$Na/(Cl+SO_4)$	2.13	0.14	1.00	3.83	0.27	1.18	2.20	0.35	1.14	1.60	0.55	1.17

Note: No. of samples: 0-15 cm (52), 15-30 cm (50), 30-60 cm (45) and 60+ cm (26) depths respectively.

Table 5. Percent distribution of soil properties of samples collected from Bellary taluk, Bellary district, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	1.92 (1)	84.61 (44)	13.5 (7)	25.0 (13)	34.61 (18)	40.38 (21)	100.0 (52)	0.00	44.2 (23)	55.8 (29)	51.9 (27)	48.1 (25)
15-30	0.00	80.0 (40)	20.0 (10)	34.0 (17)	26.0 (13)	40.0 (20)	96.0 (48)	4.00 (2)	42.0 (21)	58.0 (29)	52.0 (26)	48.0 (24)
30-60	0.00	73.3 (33)	26.7 (12)	37.8 (17)	20.0 (9)	42.2 (19)	97.8 (44)	2.20 (1)	35.6 (16)	64.4 (29)	48.9 (22)	51.1 (23)
60+	0.00	76.9 (20)	23.1 (6)	30.8 (8)	23.1 (6)	46.2 (12)	100.0 (26)	0.00	15.4 (4)	84.6 (22)	38.5 (10)	61.5 (16)

Note: Values in parentheses are number of samples.

2.1.2 Hospet Taluk

With the aid of GPS and toposheet (1:50000), soil samples were collected on a grid basis (5’ x 5’) during May 2016. A total of 121 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 17 grid points in Hospet taluk, Bellary district were collected for soil salinity appraisal.

The results (Table 6) revealed that at surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 8.74 to 5.72, 8.26 to 5.88, 19.0 to 0.15 dS m^{-1} and 43.0 to 0.39 dS m^{-1} respectively with an average of 7.51, 7.25, 1.28, and 2.96 dS m^{-1} respectively. Among cations, average Na content was more than Ca+Mg followed by K. In case of anions, average Cl^- content was more than HCO_3^- followed SO_4^{2-}. Nearly 15 per cent of surface samples had ECe > 4.0 dS m^{-1} reflecting that these soils are saline. However, per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 42 and 39 respectively. About 19.5 per cent of samples had SARe>13.

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varying from 8.56 to 4.76, 8.14 to 6.49, 12.4 to 0.16 and 17.8 to 0.23 dS m^{-1} respectively with an average of 7.55, 7.45, 1.03 dS m^{-1} and 1.57 dS m^{-1} respectively. Nearly 10 and 7 per cent of samples (Table 7) had ECe >4 and SARe>13. At 30-60 cm depth, nearly 12.5 and 25 per cent of samples had ECe >4 and SARe>13. At 60+ cm, nearly 20 and 60 per cent of samples had ECe >4 and SAR>13 respectively. At lower depths, per cent of samples with $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ ratios >1 varied from 20 (60+ cm) to 31.7 (15-30 cm) and 19.5 (15-30 cm) to 62.5 (30-60 cm) respectively.

Table 6. Characterization of soil samples collected from Hospet taluk, Bellary district, Karnataka for soil salinity appraisal.

Properties	Depth (cm)											
	0-15 cm			15-30 cm			30-60 cm			60+ cm		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH (1:2.5)	8.74	5.72	7.51	8.56	4.76	7.55	8.69	6.72	7.87	8.76	7.06	7.93
EC (1:2.5)	19.0	0.15	1.28	12.40	0.16	1.03	8.80	0.20	1.17	6.50	0.19	1.26
pHs	8.26	5.88	7.25	8.14	6.49	7.45	8.29	6.53	7.45	8.10	6.48	7.57
ECe (dS/m)	43.0	0.39	2.96	17.80	0.23	1.57	12.3	0.30	1.77	8.80	0.36	2.02
Cation /Anion based on extract of saturated paste												
Ca+Mg	46.60	4.20	11.93	64.80	2.40	8.74	31.2	3.20	8.80	22.20	3.7	8.11
Na+	153.2	1.59	21.4	62.5	1.2	10.5	168	2.0	25.1	141.7	2.72	28.8
K+	1.24	0.08	0.37	0.58	0.23	0.33	0.35	0.03	0.12	1.05	0.05	0.19
HCO_3^-	35.0	6.50	10.67	18.0	5.00	8.26	22.0	5.0	8.79	15.0	6.00	8.10
Cl^-	346.0	5.50	21.24	87.5	4.50	11.41	44.5	6.50	11.9	26.0	5.00	10.7
SO_4^{2-}	2.71	Tr	0.50	2.30	0.01	0.28	2.21	0.01	0.48	2.22	0.04	0.66
SARe	42.1	0.94	7.90	33.6	0.07	4.98	45.4	1.29	10.4	54.2	1.22	13.1
$(CO_3+HCO_3)/(Cl+SO_4)$	3.21	0.04	0.92	2.33	0.10	0.94	1.28	0.12	0.82	1.59	0.30	0.81
$Na/(Cl+SO_4)$	3.41	0.23	1.10	4.61	0.14	0.86	6.30	0.26	1.64	11.1	0.14	2.40

Note: No. of samples: 0-15 cm (41), 15-30 cm (41), 30-60 cm (24) and 60+ cm (15) depths, respectively.

Table 7. Percent distribution of soil properties of samples collected from Hospet taluk, Bellary district, Karnataka for soil salinity appraisal

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	73.2 (30)	26.8 (11)	0	70.7 (29)	14.6 (6)	14.6 (6)	58.5 (24)	41.5 (17)	61.0 (25)	39.0 (16)	80.5 (33)	19.5 (8)
15-30	51.2 (21)	48.8 (20)	0	85.4 (35)	4.80 (2)	9.80 (4)	68.3 (28)	31.7 (13)	80.5 (33)	19.5 (8)	92.7 (38)	7.3 (3)
30-60	54.2 (13)	45.8 (11)		79.2 (19)	8.30 (2)	12.5 (3)	75.0 (18)	25.0 (6)	37.5 (9)	62.5 (15)	75 (18)	25 (6)
60+	40.0 (6)	60.0 (9)	0	66.7 (10)	13.3 (2)	20.0 (3)	80.0 (12)	20.0 (3)	80 (12)	20 (3)	40 (6)	60 (9)

Note: Numbers in parenthesis indicate number of samples under each category.

2.1.3 Siruguppa Taluk

A total of 126 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 16 grid (39 sampling stations) points were collected on a grid basis (5' x 5') from Siruguppa taluk in Bellary district during summer 2017.

The results of the study (Table 8) revealed that at surface soil (0-15 cm) $pH_{(1:2.5)}$, pHe, $EC_{(1:2.5)}$ and ECe varied from 8.96 to 7.48, 8.10 to 6.98, 6.30 to 0.33 (dS m^{-1}) and 14.5 to 0.69 (dS m^{-1}) respectively with an average of 8.0, 7.50, 1.68 dS m^{-1} and 3.76 dS m^{-1} respectively. Among cations, average Na content was more than Ca+Mg followed by K. In case of anions, average Cl^- content was more than HCO_3^- followed SO_4^{2-}. Nearly 20 per cent of surface samples had ECe > 4.0 dS m^{-1} reflecting that these soils are saline (Table 9). However, per cent of samples with >1 $(Na/(Cl+SO_4)$ ratios was to the extent of nearly 65 indicating that the soils could be sodic or developing into sodic. Accordingly, nearly 30 per cent of surface samples had SAR >13.

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHe, $EC_{(1:2.5)}$ and ECe varied from 9.45 to 7.60, 8.92 to 7.05, 7.60 to 0.25 (dS m^{-1}), and 11.9 to 2.42 (dS m^{-1}) respectively with an average of 8.15, 7.71, 1.21 and 2.42 respectively. Nearly 8.0 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS m^{-1}. The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ was >1. However, about 5 and 85 percent (Table 9) of these samples had derived parameters (1 and 2) values more than 1 indicating that these samples could be considered as salt affected soil in particular sodic or developing into sodicity. Accordingly, nearly 33.3 per cent of samples had SARe values >13.

At lower depths, the mean ECe was slightly lower than the surface value. The per cent of samples having >4 dS m^{-1} were 11 and 20 at 30-60 and 60+cm, respectively. Similar to surface soil, Na^+ and Cl^- were dominant among cations and anions respectively at lower depths. The per cent of samples with >1 of $(Na/(Cl+SO_4)$ ratios were 79 and 65, respectively. The per cent of sample with SARe >13 was 32 and 30 at 30-60 and 60+ cm respectively which were similar to the upper layers i.e., 0-15 and 15-30 cm.

Table 8. Characterization of soil samples from Siruguppa taluk, Bellary district, Karnataka for soil salinity appraisal.

Properties	Depth (cm)											
	0-15 cm			15-30 cm			30-60 cm			60+ cm		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH (1:2.5)	8.96	7.48	8.0	9.45	7.60	8.15	9.12	7.68	8.20	8.63	7.70	8.18
EC (1:2.5)	6.30	0.33	1.68	7.60	0.25	1.21	6.60	0.32	1.47	3.80	0.30	1.21
pHs	8.10	6.98	7.50	8.92	7.05	7.71	8.48	6.96	7.58	8.26	7.13	7.58
ECe (dS/m)	14.50	0.69	3.76	11.90	0.46	2.42	11.9	0.62	2.61	8.90	0.55	2.54
Cation/Anion based on extract of saturated paste												
Ca+Mg	58.3	4.50	16.36	35.40	2.70	7.87	33.8	2.60	6.87	29.3	3.00	6.14
Na+	125.0	2.22	33.38	155.8	3.84	27.24	100	4.82	23.7	62.9	3.47	21.2
K+	0.72	0.07	0.28	0.36	0.036	0.16	0.50	0.02	0.13	0.16	0.03	0.07
HCO_3^-	13.50	5.50	8.95	13.60	5.00	7.69	35.4	3.21	8.19	19.6	3.50	8.91
Cl^-	124.5	10.5	25.44	27.5	3.50	13.0	96.8	4.20	18.8	55.2	7.50	15.7
SO_4^{2-}	1.76	0.09	0.85	2.35	0.11	0.59	2.50	0.20	0.72	2.02	0.10	0.62
SARe	37.50	1.18	11.30	37.04	2.99	13.48	27.6	4.07	11.7	29.40	2.31	11.9
$(CO_3+HCO_3)/(Cl+SO_4)$	0.93	0.09	0.44	2.42	0.28	0.65	0.86	0.10	0.55	0.65	0.03	0.19
$Na/(Cl+SO_4)$	2.89	0.21	1.18	7.47	0.40	1.83	1.77	0.87	1.21	3.18	0.45	1.26

Note: No. of samples: 0-15 cm (39), 15-30 cm (37), 30-60 cm (28) and 60+ cm (20) depths respectively.

Table 9. Percent distribution of soil properties of samples from Siruguppa taluk, Bellary district, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	46.2 (18)	53.8 (21)	0	23.0 (9)	48.7 (19)	28.3 (11)	100 (39)	0	35.9 (14)	64.1 (25)	69.2 (27)	30.8 (12)
15-30	25.7 (10)	69.2 (27)	5.10 (2)	43.6 (17)	48.7 (19)	7.70 (3)	94.9 (37)	5.10 (2)	15.4 (6)	84.6 (33)	66.7 (26)	33.3 (13)
30-60	50.0 (14)	50.0 (14)	0	60.7 (17)	28.6 (8)	10.7 (3)	100 (28)	0	21.4 (6)	78.6 (22)	67.9 (19)	32.1 (9)
60+	35.0 (7)	65.0 (13)	0	65.0 (13)	15.0 (3)	20.0 (4)	100 (20)	0	35.0 (7)	65.0 (13)	70.0 (14)	30.0 (6)

Note: Numbers in parenthesis indicate number of samples under each category.

2.1.4 Bellary district

A total of 419 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 60 grid points were collected from Bellary, Hospet and Siruguppa taluks in Bellary district.

The results revealed that Bellary district as a whole (Table 10), at surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 10.76 to 5.72, 10.2 to 5.88, 31.0 to 0.12 (dS m^{-1}) and 75.0 to 0.39 (dS m^{-1}) respectively with an average of 8.07, 7.66, 3.02 dS m^{-1}, and 7.23 dS

m^{-1}respectively. Among cations, average Na content was more than Ca+Mg followed by K. In case of anions, average Cl^- content was more than HCO_3^- followed by SO_4^{2-}. Nearly 29 per cent of surface samples had ECe > 4.0 dS m^{-1} reflecting that these soils are saline (Table 11). With respect to area (Fig.2), about 28% (33180 ha) and 26 % (30835 ha) of the command area in Bellary district (118414 ha) had soil ECe 2.0-4.0 and 4.0-8.0 dS m^{-1} respectively. Nearly 12, 15 and 9% of the area had soil ECe 8.0-12.0, 12.0-16.0 and 16.0-30.0 dS m^{-1} respectively. Less than 10% of the area had ECe < 2.0 dS m^{-1}. In about 46% (54163 ha) of the area, the SARe was < 13. About 19% (22984 ha), 8.54% (10113 ha) and 12.6% (14944 ha) of the area had SARe in the range of 13-20, 20-30 and 30-50 respectively. Soil pHs in the range of 7.50 – 8.50 was in about 76472 ha (64.6 %) of the command area in Bellary district.

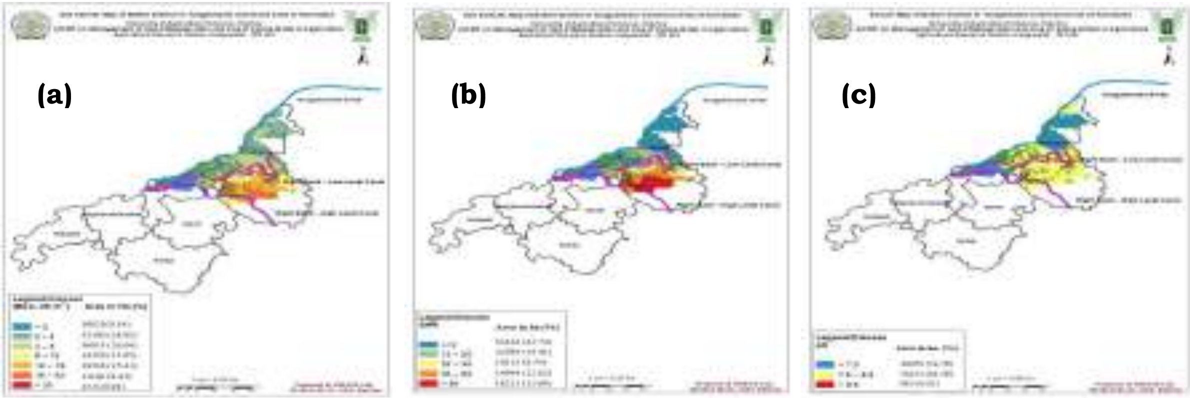


Fig.2. Maps showing per cent area under different categories of ECe (a), SAR (b) and pH (c) in Bellary district.

The per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 13.6 and 52.3 respectively indicating that the soils could be Alkali/sodic or developing into Alkali/sodic. Accordingly, nearly 33 per cent of surface samples had SAR >13.

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 10.55 to 4.76, 10.33 to 6.49, 19.9 to 0.12 (dS m^{-1}), and 35 to 0.23 (dS m^{-1}) with an average of 8.04, 7.82, 1.80 dS $m^{-1}$and 3.98 dS m^{-1} respectively. Nearly 21 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS m^{-1}. The per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 13.1 and 53.9 respectively. Nearly 31 per cent of the sub-surface samples had SARe >13.

At 30-60 cm, the $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$, and ECe varied from 10.2 to 6.72, 10.1 to 6.53, 9.4 to 0.16 dS $m^{-1}$and 24.0 to 0.30 dS m^{-1} with an average of 8.28, 7.90, 1.97 dS m^{-1} and 3.64 dS m^{-1} respectively. Similar to above depths, Na^+ and Cl^- were the dominant cation and anion respectively. Nearly 25.8 per cent of samples were found to be saline as their ECe was >4.0 dS m^{-1}.The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ ratio was >1. However, about 7.2 and 68 percent of these samples had values more than 1. Nearly 39 per cent of the samples had SARe >13.

At 60+ cm, the $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$, and ECe varied from 10.3 to 7.06, 9.65 to 6.48, 8.40 to 0.19 dS $m^{-1}$and 19.3 to 0.36 dS m^{-1} with an average of 8.37, 7.90, 1.85 dS $m^{-1}$and 3.76

dS m^{-1} respectively. Similar to above depths, Na^+ and Cl^- were the dominant cation and anion respectively. Nearly 31 per cent of samples were found to be saline as their ECe was >4.0 dS m^{-1}.The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ ratio was >1. However, about 4.9 and 72 percent of these samples had values more than 1. Nearly 43 per cent of the samples had SARe >13.

Table 10. Characterization of soil samples from Bellary district, Karnataka for soil salinity appraisal.

Properties	**Depth (cm)**											
	0-15 cm			**15-30 cm**			**30-60 cm**			**60+ cm**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
pH (1:2.5)	10.76	5.72	8.07	10.55	4.76	8.04	10.22	6.72	8.28	10.30	7.06	8.37
EC (1:2.5)	31.0	0.15	3.02	19.90	0.12	1.80	9.40	0.16	1.97	8.40	0.19	1.85
pHs	10.23	5.88	7.66	10.33	6.49	7.82	10.08	6.53	7.90	9.65	6.48	7.90
ECe (dS/m)	75.0	0.39	7.23	35.0	0.23	3.98	24.0	0.30	3.64	19.30	0.36	3.76
Cation/Anion based on extract of saturated paste												
Ca+Mg	126.0	3.20	16.13	64.8	2.40	10.2	38.0	2.30	9.46	37.10	2.40	9.87
Na+	634.5	1.59	62.84	262.8	1.16	36.9	196.5	1.88	33.9	145.6	2.60	33.6
K+	1.56	0.04	0.31	0.60	0.02	0.21	0.50	0.02	0.12	1.05	0.03	0.12
HCO_3^-	259.5	5.25	15.5	54.6	2.50	10.0	41.5	2.50	11.7	35.40	2.10	11.9
Cl^-	554.5	5.50	57.12	254.6	3.50	28.4	120.4	4.20	24.7	145.1	4.21	24.4
SO_4^{2-}	4.87	Tr	0.90	3.68	Tr	0.81	3.20	Tr	0.90	2.82	0.04	0.94
SARe	290.7	0.94	21.1	122.9	0.68	14.63	83.1	1.29	14.9	54.3	1.22	14.6
$(CO_3+HCO_3)/(Cl+SO_4)$	3.21	0.04	0.62	2.42	0.07	0.67	2.24	0.10	0.61	1.59	0.03	0.47
$Na/(Cl+SO_4)$	3.41	0.14	1.08	7.47	0.14	1.27	6.30	0.26	1.29	11.1	0.14	1.50

Note: No. of samples: 132 (0-15 cm), 130 (15-30 cm), 97 (30-60 cm) and 61 (60 + cm) depths, respectively.

Table 11. Percent distribution of soil properties of samples from Bellary district, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	37.12 (49)	57.58 (76)	5.30 (7)	38.6 (51)	32.6 (43)	28.8 (38)	86.4 (114)	13.6 (18)	47.7 (63)	52.3 (69)	66.7 (88)	33.3 (44)
15-30	23.85 (31)	66.9 (87)	9.23 (12)	53.1 (69)	26.2 (34)	20.8 (27)	86.9 (113)	13.1 (17)	46.2 (60)	53.9 (70)	69.2 (90)	30.8 (40)
30-60	27.84 (27)	59.8 (58)	12.4 (12)	54.6 (53)	19.6 (19)	25.8 (25)	92.8 (90)	7.22 (7)	32.0 (31)	68.0 (66)	60.8 (59)	39.2 (38)
60 +	21.31 (13)	68.9 (42)	9.84 (6)	50.8 (31)	18.0 (11)	31.2 (19)	95.1 (58)	4.92 (3)	27.9 (17)	72.1 (44)	57.4 (35)	42.6 (26)

Note: Numbers in parenthesis indicate number of samples under each category.

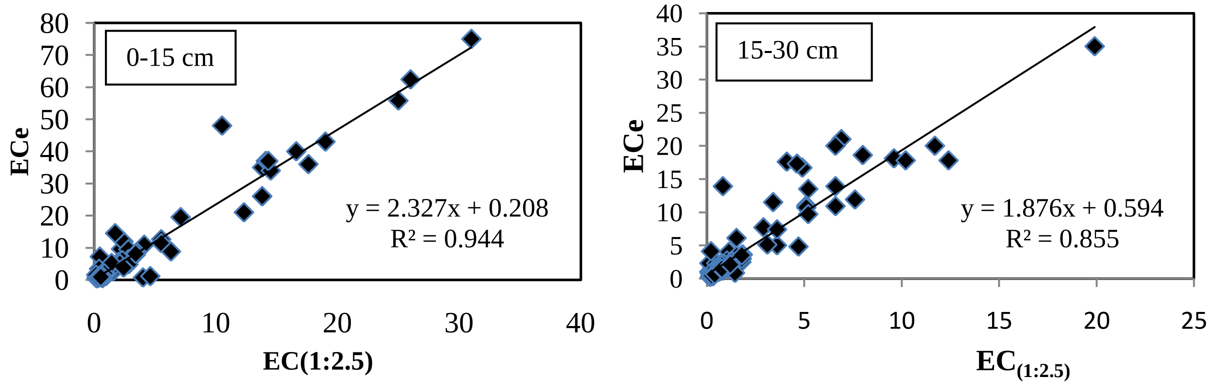


Fig. 3. Relationship between $EC_{(1:2.5)}$ and ECe for surface and subsurface soil samples collected from Bellary district.

As shown in Fig. 3, the relationship between ECe and $EC_{(1:2.5)}$ revealed that the conversion factor from EC $_{(1:2.5)}$ to ECe (saturation paste extract) would be around 2.53 and 2.47 at 0-15 and 15-30 cm depths for soils of Bellary district respectively.

2.2. Koppal district

The district Koppal is a newborn district of Karnataka state, bifurcated from Raichur district with a geographical area of 5559 sq.km. It is situated between 15^0 09′ 00″ to 16^0 03′ 30″ North Latitude and 75^0 47′ 30″ to 76^0 48′ 10″ East Longitude. It consists of four taluks Koppal, Gangavathi, Kushtagi, Yelburga and newly formed three talukas Kanakagiri, Karatagi and Kukanoor. The area falls in the Tugabhadra sub-basin of the Krishna basin. The net irrigated area in the district is 1,78,938 ha (Koppal district at a glance – 2016-17, Govt. of Karnataka) of which 36541 ha is being irrigated only in Gangavathi (34,666 ha) and Koppal (1,875 ha) taluks by left bank canal and left bank high level canal of TBP.

Koppal district experiences a semi-arid type climate characterised by hot summer and low rainfall. It is cool and pleasant during major part of the year except during the summer months of March to middle of June. The coldest period is December to January minimum temperatures reaches up to 16°C and maximum reaches 42°C during hot summer in the months of April and May. The district represents typical dry land ecosystem, as all the taluks of Koppal have average annual rainfall ranging from 546 to 701mm in 38 to 47 rainy days. The north-east monsoon contributes nearly 44% and prevails from October to early December. The south-west monsoon contributes about 56% rainfall during June to September.

Predominant geological formations in the district are Peninsular gneissic complex consisting of Granites, Gneisses and Dharwar group consisting of schist's. Among major soils in the district, about 38% (2,11,356 ha) of the land area is occupied by medium deep (50-100 cm), red gravelly clay soils, followed by medium deep, black clayey soils (15.28%; 85,006 ha), deep (>100 cm), black calcareous clayey irrigated soils (salt affected in patches) (12.70%; 70,647 ha), and deep, alluvial clayey soils (salt affected in patches) (7.57%; 42,116 ha).

The major crops grown in the district include cereals (paddy, sorghum, bajra and maize), pulses (black gram, green gram and bengal gram), oilseed crops (sunflower and groundnut), commercial crops (sugarcane and cotton), vegetables and fruits (Karnataka at a glance, DIC-Koppal, 2013-14) with a net sown area of 71%.

2.2.1 Koppal District (Gangavati Taluk)

Soil sampling was carried out using GPS and topo-sheet (1:50000) from 59 different villages in Gangavathi taluk (1328 sq.km; 132131 ha) of Koppal district wherein paddy-paddy is a major cropping system. A total of 282 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 16 grid points (5' x 5' m) from these villages (Fig. 4) were collected during May 2014.

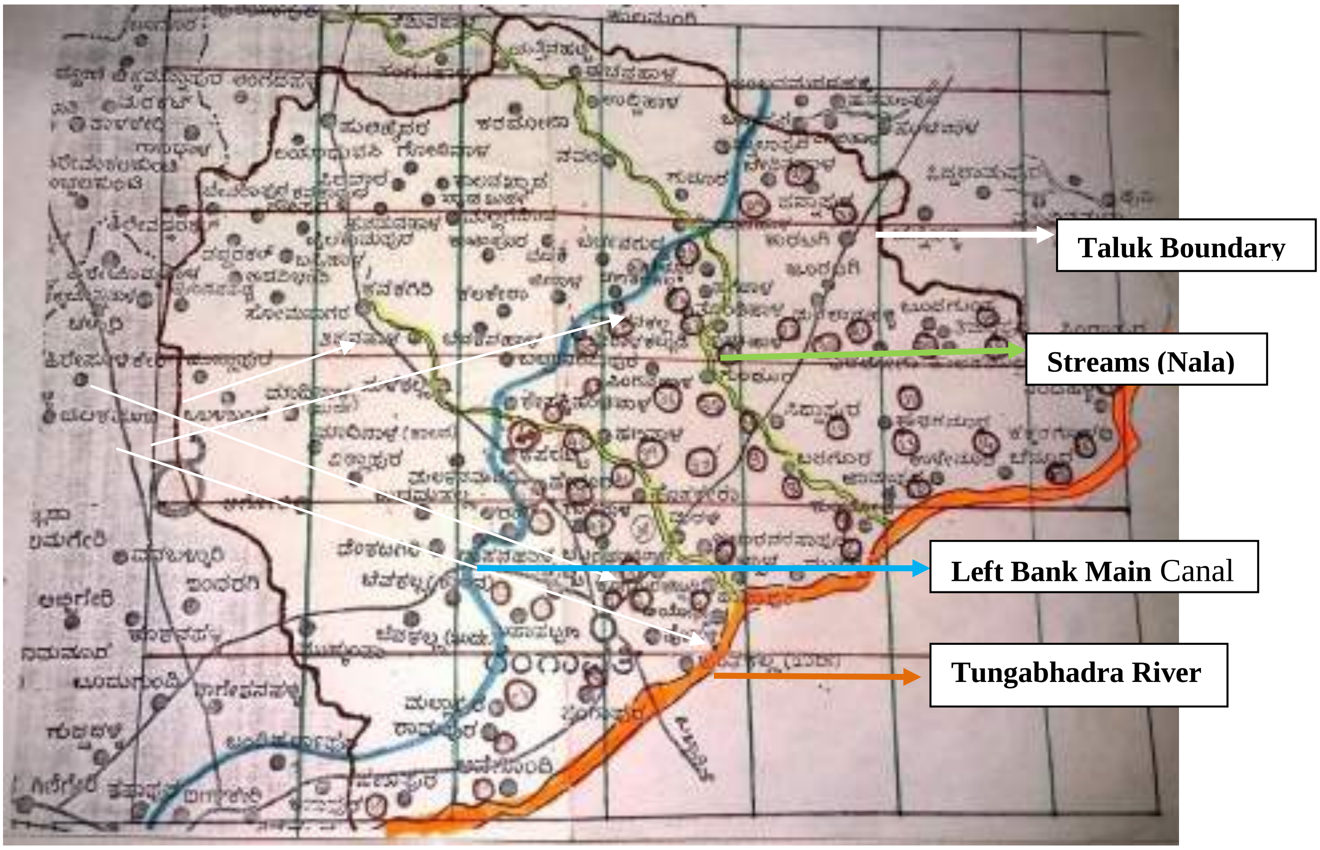


Fig. 4. Soil sampling from grids (5'x5') from Koppal district (Gangavathi) for soil salinity appraisal.

The data on soil pH, EC, saturation paste extract for pHs, ECe, cations, anions, SARe, and $(CO_3+HCO_3)/(Cl+SO_4)$ and (Na/(Cl+SO4) ratios at different depths are presented in Table 12. Further, percent distribution of these parameters at all the depths is presented in Table 13.

Surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 9.40 to 5.85, 8.65 to 5.52, 24.0 to 0.10 (dS m^{-1}) and 64 to 0.25 (dS m^{-1}) respectively with an average of 8.12, 7.46, 1.68, and 4.38 dS m^{-1} respectively. Soil $pH_{(1:2.5)}$ increased with depth. Among cations, the mean Na content was more than Ca+Mg followed by K. In case of anions, the mean Cl^- content was more than HCO_3^- followed by SO_4^{2-}. Nearly 15 per cent of surface samples had ECe > 4.0 dS/m. Further, per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and (Na/(Cl+SO4) ratios were to the extent of nearly 22 and 43 respectively indicating that the soils could be sodic or developing into sodic. Accordingly, nearly 18 per cent of samples had SARe >13. With respect to area (Fig. 5), about 25.5% (8839.8 ha), 18.6 % (6451.3 ha) and 11.3% (3914 ha) of the command area in Koppal district (37010 ha) had soil ECe 2.0-4.0 dS m^{-1} 4.0-8.0 and 8.0-12.0 dS m^{-1} respectively. In about 65% (22491 ha) of the area, the SARe was < 13. About 22.6% (7848.4 ha) and 12.2% (4222 ha) of the area had SARe in the range of 13-20 and 20-30 respectively. Soil pHs (7.50 – 8.50) was in about 19649 ha (56.7 %) of the command area in Koppal district.

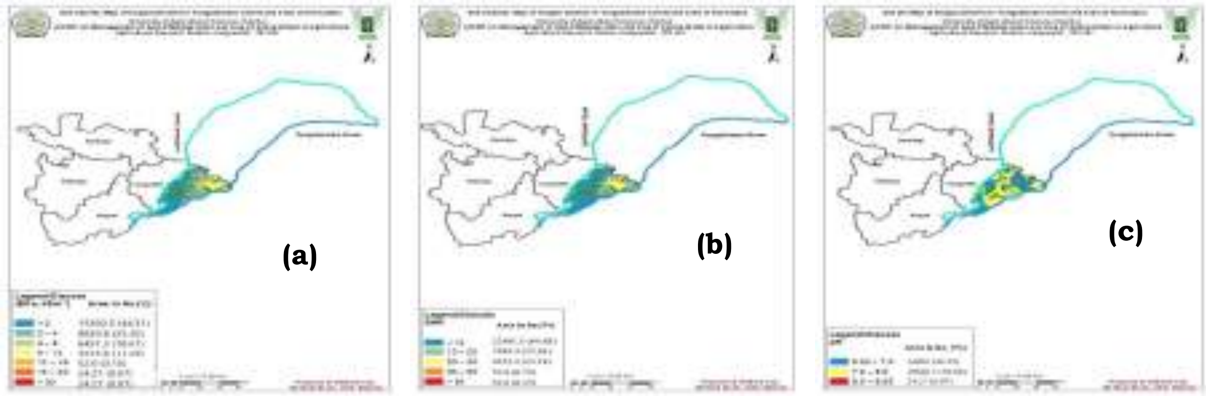


Fig.5. Maps showing per cent area under different categories of ECe (a), SAR (b) and pH (c) in Koppal district (Gangavati Taluk).

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHe, $EC_{(1:2.5)}$ and ECe varied from 9.34 to 6.08, 8.22 to 5.45, 11.5 to 0.08 (dS m^{-1}), and 24.0 to 0.38 (dS m^{-1}) respectively with an average of 8.33, 7.60, 1.32 and 3.12 dS m^{-1} respectively. Nearly 11.0 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS m^{-1}. The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ was >1. However, about 26 and 46.6 percent of these samples had derived parameters (1 and 2) values more than 1 indicating that these samples could be considered as salt affected soil in particular sodic or developing into sodicity. Accordingly, nearly 28.8 per cent of samples had SARe values >13.

At lower depths, the mean ECe was slightly lower than the surface value. The per cent of samples having >4 dS m^{-1} were 13.9 and 12.5 at 30-60 and 60+cm respectively. Similar to surface soil, Na^+ and Cl^- were dominant among cations and anions respectively at lower depths. Not only the values of $(CO_3+HCO_3)/(Cl+SO_4)$, $(Na/(Cl+SO_4)$ ratios and SARe were increased with depth but also the percent of samples having ratios >1 increased with depth. The per cent of samples with >1 of $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were 30.6 and 29.7 and 65.3 and 51.6 respectively at 30-60 and 60+cm. The per cent of sample with SARe >13 was 33.3 and 34.4 at 30-60 and 60+ cm respectively which were slightly higher compared to upper layers i.e., 0-15 and 15-30 cm.

Table 12. Characterization of soil samples from Koppal district, Karnataka for soil salinity appraisal.

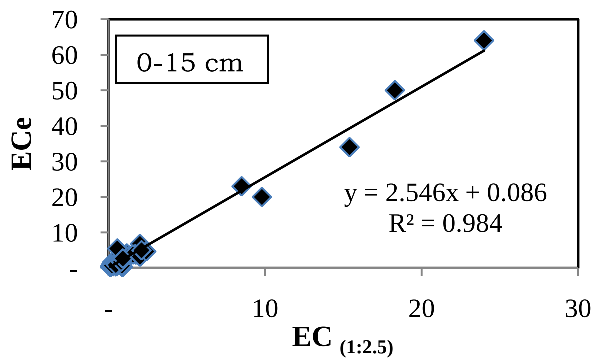
Properties	Depth (cm)											
	0-15 cm			15-30 cm			30-60 cm			60+ cm		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH (1:2.5)	9.40	5.85	8.12	9.34	6.08	8.33	9.68	7.25	8.58	9.72	7.14	8.67
EC (1:2.5)	24.0	0.10	1.68	11.5	0.08	1.32	13.3	0.12	1.24	8.90	0.09	1.05
pHs	8.6 5	5.52	7.46	8.22	5.45	7.60	8.77	6.76	7.88	8.98	6.85	7.92
ECe (dS/m)	64.0	0.25	4.38	24.0	0.38	3.12	26.2	0.41	2.96	17.8	0.31	2.51
Cation/Anion based on extract of saturated paste												
Ca+Mg	155.6	1.90	12.65	108.1	2.30	9.50	48.0	1.60	6.92	33.9	1.50	5.79
Na+	528.7	1.11	34.88	347.7	1.30	30.1	370.9	1.55	31.3	212.2	2.23	23.6
K+	0.77	0.05	0.25	0.72	0.05	0.18	0.96	0.04	0.16	0.72	0.03	0.13
HCO_3^-	34.0	3.50	9.01	23.0	4.75	8.90	19.0	5.00	8.82	20.0	2.50	9.41
Cl^-	316.0	6.00	25.3	206.0	6.00	20.84	234.0	5.50	20.0	177.8	5.20	17.0
SO_4^{2-}	2.50	0.05	0.71	2.31	0.02	0.43	2.82	0.01	0.43	2.10	Tr	0.40
SARe	102.1	0.42	11.22	86.1	0.77	11.90	75.5	1.19	13.8	56.5	2.35	12.3
$(CO_3+HCO_3)/(Cl+SO_4)$	1.96	0.05	0.71	1.58	0.04	0.76	1.53	0.04	0.80	1.49	0.04	0.81
$Na/(Cl+SO_4)$	4.86	0.06	1.04	5.05	0.16	1.18	3.89	0.20	1.35	4.39	0.25	1.23

Note: No. of samples: 73 (0-15 cm), 73 (15-30 cm), 72 (30-60 cm); 64 (60 + cm).

Table 13. Percent distribution of soil samples from Koppal district, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	7.5-8.5	>8.5	<2.0	2-4	>4	<1	>1	<1	>1	<13	>13
0-15	41.1 (30)	58.9 (43)	0	58.9 (43)	26.0 (19)	15.1 (11)	78.1 (57)	21.9 (16)	57.5 (42)	42.5 (31)	82.2 (60)	17.8 (13)
15-30	30.1 (22)	69.9 (51)	0	61.6 (45)	27.4 (20)	11.0 (8)	74.0 (54)	26.0 (19)	53.4 (39)	46.6 (34)	71.2 (52)	28.8 (21)
30-60	20.8 (15)	75.0 (54)	4.2 (3)	66.7 (48)	19.4 (14)	13.9 (10)	69.4 (50)	30.6 (22)	34.7 (25)	65.3 (47)	66.7 (48)	33.3 (24)
60 +	20.3 (13)	71.9 (46)	7.8 (5)	62.5 (40)	25.0 (16)	12.5 (8)	70.3 (45)	29.7 (19)	48.4 (31)	51.6 (33)	65.6 (42)	34.4 (22)

Note: Numbers in parenthesis indicate number of samples under each category.



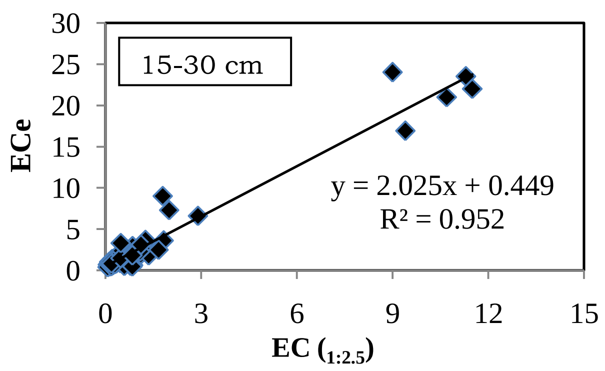


Fig.6. Relationship between EC(1:2.5) and ECe for surface and subsurface soil samples collected from Koppal district.

As shown in Fig. 6, the relationship between ECe and $EC_{(1:2.5)}$ revealed that the conversion factor from EC $_{(1:2.5)}$ to ECe (saturation paste extract) would be around 2.63 and 2.47 at 0-15 and 15-30 cm depths for soils of Koppal district (Gangavati taluk) respectively.

2.3 Raichur district

Raichur district is situated in northeastern part of Karnataka state. The geographical area of the district is 8383.00 sq km (835843 ha). The district has five taluks (Sindhanur, Manvi, Devadurga, Raichur, and Lingasugur). It falls in the Northern Maidan region which is drought prone and falls in the arid tract between 15^0 33' – 16^0 34' north latitudes and 76^0 14' – 76^0 36' east longitudes. It lies between the two major rivers namely the Krishna and the Tungabhadra which form the northern and southern boundary of the district respectively and are perennial in nature. Nearly 20% of the geographical area in the district is under irrigation. Canals, tanks, wells, bore wells, lift irrigation are the important sources for irrigation. The gross and net irrigated area is 293030 and 230298 ha respectively (Raichur district at a glance, 2013-14, Govt. of Karnataka). The average annual rainfall of the district is about 658 mm. 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° C, while May is the hottest month with mean daily maximum temperature of 39.8° C and often day time temperature reaches up to 45^0 C.

The soils of the district can be classified broadly into the following four types namely: Mixed red and black soils, Medium black soils, Deep black soils and Red sandy soils. About 30.55% (2,58,924 ha) of the land area is occupied by deep black calcareous clayey soils followed by medium deep, red gravelly clay soils (19.86%; 1,68,306 ha), Deep, black clayey soils (15.66%; 1,35,235 ha) and shallow, red loamy soils (gravelly in patches) to the extent of 10.54% (89,238 ha) and the remaining types with less than 5% of the land area.

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. The net sown area comprises 69% (5814 sq.km) of the total geographical area of the district. The crops grown under rain fed cultivation are jowar, cotton, groundnut, chillies, wheat and pulses. The crops grown under irrigation are paddy, sugarcane, maize, wheat, chillies, cotton, pulses, tobacco and plantains. Medium black soils are seen in the western part of the district overlying the peninsular gneisses. The soils are moderately deep about one metre thick, and are dark to grayish, brown to dark reddish brown or black in colour, usually calcareous cracking clayey soils. Deep black soils occur on gently sloping to nearly even or low grounds on parent rocks like gneisses, schist's of mixed origin and occupy considerable areas in the northern parts of the district. Nearly a metre thick, these soils are dark brown, dark grayish brown, or black in colour. The texture is usually clayey through the section, and at places on the surface clayey loam to silty clay texture. Lime concretions on the surface and sub surface are also present. Crops similar to medium black soils can be grown here. Red sandy soils occur on undulating landscape on acidic rocks like granites and granitic gneisses. Crops grown are ragi, jowar, millets, pulses, groundnut, castor and cotton under rain fed and under irrigation crops like paddy, sugarcane, ragi, potato, etc, are grown.

2.3.1 Sindhanur taluk

A total of 141 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 20 grid (41 sampling stations) points were collected on a grid basis (5' x 5') from Sindhanur taluk in Raichur district during summer 2015.

Characterization of soil samples from Sindhanur taluk revealed that soil pH varied from 7.30 to 8.90, 7.59-9.03, 7.60-9.0 and 7.87-9.0 with a mean value of 8.10, 8.30, 8.30 and 8.54 at 0-15, 15-30, 30-60 and 60+ cm depths respectively (Table 14). Soil salinity expressed as ECe varied from 0.50-47.0, 0.47-24.0, 0.40-14.0 and 0.52-6.40 dS/m with a mean value of 4.40, 3.04, 3.00 and 2.35 dS/m, at 0-15, 15-30, 30-60 and 60+ cm depths respectively. Among cations and anions, the mean values indicated that Na^+ (21.1, 15.15, 15.5 and 19.9 meq/L) and Cl^- (22.2, 18.2, 17.1 and 12.9 meq/L at 0-15, 15-30, 30-60 and 60+ cm depths respectively) ions are the dominating ones at all depths. The SARe values varied from 1.43-26.8, 1.56-22.1, 1.80-19.8 and 2.79-21.3 with a mean value of 8.83, 7.45, 9.26 and 11.8 at 0-15, 15-30, 30-60 and 60+ cm depths respectively. The mean (CO_3+HCO_3)/ (Cl+SO_4) ratios were less than 1.0 at all the depths. Whereas, Na/(Cl+SO_4) ratios were either close to 1.0 at 0-15 and 15-30 cm but were more than 1.0 (1.14 and 1.52) at 30-60 and 60+ cm depths.

Percent distribution of soil properties (Table 15) revealed that 66.6 (0-15 cm) to 95.2 (60+ cm) per cent of samples had pHs in the range of 7.5-8.5 and none in >8.5 category at all depths. As far as soil salinity is concerned 14.3 (60+ cm)-21.4 (0-15 cm) dS/m per cent of samples had ECe > 4.0 dS/m respectively. At 0-15 cm, one hundred per cent of sample had (CO_3+HCO_3)/ (Cl+SO_4) of <1.0. However, at lower depths the per cent of samples with (CO_3+HCO_3)/ (Cl+SO_4) of >1.0 varied from 7.14 (15-30 cm) to 13.9 (30-60 cm), respectively. Unlike (CO_3+HCO_3)/ (Cl+SO_4), the Na/(Cl+SO_4) ratio of >1.0 increased with depth varying from 35.7 (0-15 cm) to 61.9 per cent (60+ cm) reflecting the dominance of Na+ and the possibility of soils becoming sodic. Accordingly, SARe (>13) also found to increase with depth varying from 9.5 (15-30 cm) to 42.9 per cent (60+ cm) respectively.

Table.14.Characterization of soil samples from Sindhanur taluk in Raichur district, Karnataka for soil salinity appraisal

Properties	Depth (cm)											
	0-15 cm			15-30 cm			30-60 cm			60+ cm		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH (1:2.5)	8.90	7.30	8.10	9.03	7.59	8.30	9.00	7.60	8.30	9.00	7.87	8.54
EC (1:2.5)	21.0	0.20	1.90	12.5	0.30	1.43	6.90	0.30	1.50	3.30	0.30	1.17
pHs	8.10	1.80	7.40	8.34	7.00	7.86	8.20	7.30	7.70	8.59	7.48	7.99
ECe (dS/m)	47.0	0.50	4.40	24.0	0.47	3.04	14.0	0.40	3.00	6.40	0.52	2.35
Cation/Anion based on extract of saturated paste												
Ca+Mg	154.8	2.30	14.0	49.2	3.10	9.29	29.0	1.90	7.40	25.8	2.20	6.10
Na+	81.7	1.91	21.1	49.3	2.17	15.15	44.6	2.10	15.5	50.0	3.50	19.9
K+	0.43	0.02	0.18	0.43	0.04	0.16	0.41	0.02	0.07	0.15	0.02	0.05
HCO_3^-	28.0	4.50	9.10	18.0	3.50	7.70	12.0	3.00	7.30	10.5	4.00	6.93
Cl^-	139.0	7.00	22.2	115	5.00	18.2	76.0	5.50	17.1	53.0	7.00	12.9
SO_4^{2-}	2.29	0.09	0.61	2.10	Tr	0.40	2.08	0.02	0.47	1.64	0.04	0.55
SARe	26.8	1.43	8.83	22.1	1.56	7.45	19.8	1.80	9.26	21.3	2.79	11.8
$(CO_3+HCO_3)/(Cl+SO_4)$	0.97	0.20	0.54	1.13	0.12	0.63	1.40	0.06	0.67	1.09	0.16	0.65
$Na/(Cl+SO_4)$	2.26	0.22	0.98	2.79	0.12	0.98	2.59	0.21	1.14	2.76	0.43	1.52

Note: Total number of samples was 45, 42, 36 and 21 at 0-15, 15-30, 30-60 and 60+ cm depths respectively.

Table 15. Percent distribution of soil samples from Sindhanur taluk in Raichur district, Karnataka for soil salinity appraisal

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	7.5-8.5	>8.5	<2.0	2-4	>4	<1	>1	<1	>1	<13	>13
0-15	33.33 (14)	66.66 (28)	0	57.1 (24)	21.4 (9)	21.4 (9)	100 (42)	0	64.3 (27)	35.7 (15)	85.7 (36)	14.3 (6)
15-30	9.52 (4)	90.5 (38)	0	59.5 (25)	23.8 (10)	16.7 (7)	92.9 (39)	7.14 (3)	54.8 (23)	45.2 (19)	90.5 (38)	9.5 (4)
30-60	25.00 (9)	75.00 (27)	0	55.6 (20)	25.0 (9)	19.4 (7)	86.1 (31)	13.9 (5)	41.7 (15)	58.3 (21)	77.8 (28)	22.2 (8)
60+	4.80 (1)	95.2 (20)	0	42.9 (9)	42.9 (9)	14.3 (3)	90.5 (19)	9.50 (2)	38.1 (8)	61.9 (13)	57.1 (12)	42.9 (9)

Note: Numbers in parenthesis indicate number of samples under each category.

2.3.2 Manvi taluk

A total of 144 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 23 grid (53 sampling stations) points were collected on a grid basis (5' x 5') from Manvi taluk in Raichur district during summer 2015.

Characterization of soil samples from Manvi taluk revealed that soil pH varied from 5.80 to 9.00, 6.14-9.66, 6.54-9.60 and 8.0-9.48 with a mean value of 8.06, 8.32, 8.56 and 8.77 at 0-15, 15-30, 30-60 and 60+ cm depths respectively (Table 16). Soil salinity expressed as ECe varied from 0.14-6.60, 0.28-6.60, 0.48-9.90 and 0.68-11.60 dS/m with a mean value of 1.79, 1.64, 2.23 and 2.67 dS/m, at 0-15, 15-30, 30-60 and 60+ cm depths respectively. Among cations and anions, the mean values indicated that Na^+ (15.8, 14.1, 19.0 and 23.9 meq/L) and Cl^- (14.7, 11.7, 11.0 and 16.0 meq/L at 0-15, 15-30, 30-60 and 60+ cm depths respectively) ions are the dominating ones at all depths. The SARe values varied from 0.44-23.2, 1.02-57.1, 1.23-33.2 and 3.95-36.9 with a mean value of 8.72, 9.03, 10.4 and 11.8 at 0-15, 15-30, 30-60 and 60+ cm depths respectively. The mean (CO_3+HCO_3)/ (Cl+SO_4) ratios were less than 1.0 at all the depths. Whereas, Na/(Cl+SO_4) ratios were either close to 1.0 at 0-15 cm but were more than 1.0 (1.19, 1.55 and 1.24) at 15-30, 30-60 and 60+ cm depths respectively.

Percent distribution of soil properties (Table 17) revealed that 56.7 (30-60 cm) to 100 per cent (60+ cm) of samples had pHs in the range of 7.5-8.5 and none in >8.5 category at all depths. As far as soil salinity is concerned 4.35 (15-30 cm)-16.7 (60+cm) per cent of samples had ECe > 4.0 dS/m respectively. The per cent of samples with (CO_3+HCO_3)/(Cl+SO_4) of >1.0 increased with depth varying from 4.0 (0-15 cm) to 27.8 (60+ cm) respectively. Similarly, the Na/(Cl+SO_4) ratio of >1.0 also increased with depth varying from 42.0 (0-15 cm) to 63.3 per cent (30-60 cm) reflecting the dominance of Na+ and the possibility of soils becoming sodic. Accordingly, SARe (>13) also found to increase with depth varying from 8.70 (15-30 cm) to 33.3 per cent (30-60 cm) respectively.

Table 16. Characterization of soil samples from Manvi taluk in Raichur district, Karnataka for soil salinity appraisal.

Properties	**Depth (cm)**											
	0-15 cm			**15-30 cm**			**30-60 cm**			**60+ cm**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
pH (1:2.5)	9.00	5.80	8.06	9.66	6.14	8.32	9.60	6.54	8.56	9.48	8.00	8.77
EC (1:2.5)	2.00	0.17	0.78	3.40	0.11	0.80	4.30	0.20	1.00	5.40	0.37	1.32
pHs	8.49	4.86	7.52	8.05	6.66	7.67	8.52	6.94	7.74	9.03	7.52	8.24
ECe (dS/m)	6.60	0.14	1.79	6.60	0.28	1.64	9.90	0.48	2.23	11.60	0.68	2.67
Cation/Anion based on extract of saturated paste												
Ca+Mg	45.7	1.20	6.73	31.4	2.10	5.77	29.5	2.40	6.47	22.6	2.60	7.56
Na+	69.6	0.46	15.8	69.6	1.39	14.1	99.0	1.80	19.0	123.9	5.30	23.9
K+	5.36	0.03	0.28	0.37	0.02	0.10	0.68	0.03	0.13	0.26	0.02	0.11
HCO_3^-	12.0	4.00	8.00	13.5	4.50	7.63	10.5	5.50	7.87	13.5	6.50	11.4
Cl^-	61.00	7.00	14.7	46.5	6.50	11.70	27.0	6.50	11.0	49.5	9.50	16.0
SO_4^{2-}	1.67	Tr	0.39	1.48	0.02	0.25	1.02	0.04	0.40	1.96	0.05	0.66
SARe	23.2	0.44	8.72	57.1	1.02	9.03	33.2	1.23	10.4	36.9	3.95	11.8
(CO_3+HCO_3)/ (Cl+SO_4)	1.25	0.14	0.62	1.51	0.19	0.74	1.26	0.27	0.77	1.41	0.24	0.81
Na/(Cl+SO_4)	3.34	0.05	0.99	7.67	0.17	1.19	7.33	0.26	1.55	2.89	0.41	1.24

Note: Total number of samples was 50, 46, 30 and 18 at 0-15, 15-30, 30-60 and 60+ cm depths respectively.

Table 17. Percent distribution of soil samples from Manvi taluk in Raichur district, Karnataka for soil salinity appraisal

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	30.0 (15)	70.0 (35)	0	62.0(31)	30.0 (15)	8.00 (4)	96.0 (48)	4.00 (2)	58.0 (29)	42.0 (21)	82.0 (41)	18.0 (9)
15-30	15.22 (7)	84.8 (39)	0	67.4 (31)	28.3 (13)	4.35 (2)	87.0 (40)	13.0 (6)	50.0 (23)	50.0 (23)	91.3 (42)	8.70 (4)
30-60	43.3 (13)	56.7 (17)	0	66.7 (20)	23.3 (7)	10.0 (3)	83.4 (25)	16.6 (5)	36.7 (11)	63.3 (19)	66.7 (20)	33.3 (10)
60+	0	100 (18)	0	50.0 (9)	33.3 (6)	16.7 (3)	72.2 (13)	27.8 (5)	55.5 (10)	44.5 (8)	72.2 (13)	27.8 (5)

Note: Numbers in parenthesis indicate number of samples under each category.

2.3.3 Raichur district

A total of 339 soil samples (0-15, 15-30, 30-60 and 60+ cm) from 53 grids (107 sampling points) were collected from Sindhanur, Manvi, Devadurga and Raichur taluks in Raichur district during May 2015.

At surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 9.0 to 5.80, 8.50 to 4.86, 21.0 to 0.13 (dS/m) and 47 to 0.14 (dS/m) respectively with an average of 8.09, 7.56, 1.19, and 2.68 respectively (Table 18). Among cations, average Na content (390.1 meq/L) was more than Ca+Mg (9.54 meq/L) followed by K. In case of anions, average Cl^- content was more (17.84 meq/L) than HCO_3^- (9.77 meq/L) followed SO_4^{2-}. Nearly 13 per cent of surface samples had ECe > 4.0 dS/m reflecting that these soils are saline (Table 19). However, per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 6 and 36 respectively indicating that the soils could be sodic or developing into sodic. Accordingly, nearly 16 per cent of surface samples had SARe >13. With respect to area (Fig. 4), about 46% (953284 ha), 31% (64285 ha) and 23 % (47509 ha) of the command area in Raichur district (207371 ha) had soil ECe < 2.0, 2.0-4.0 and 4.0-8.0 dS m^{-1} respectively. In about 15.5% (32225 ha) of the area, the SARe was in the range of 10-15. Soil pHs (7.50 – 8.50) was in about 157021 ha (75.72 %) of the command area in Raichur district (Fig. 7).

Fig.7. Maps showing per cent area under different categories of ECe (a), SARe (b) and pH (c) in Raichur district.

Sub-surface (15-30 cm) soils had $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varying from 9.66 to 6.14, 8.42 to 6.66, 12.5 to 0.11 (dS/m), and 24 to 0.28 (dS/m) respectively with an average of 8.33, 7.75, 1.08 dS/m and 2.25 dS/m respectively (Table 18). Similar to surface soils, average Na content (15.1 meq/L) was more than Ca+Mg (7.44 meq/L) followed by K. In case of anions, average Cl^- content was more (14.35 meq/L) than HCO_3^- (7.79 meq/L) followed by SO_4^{2-}. Nearly 10 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS/m (Table 16). The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas $Na/(Cl+SO_4)$ was >1. However, about 13 and 48 percent of these samples had values more than 1 indicating that these samples could be considered as salt affected soil in particular sodic or developing into sodicity. About 12 per cent of samples analyzed had SARe >13.

Though a slight increase in soil pH was observed at 30-60 and 60+ cm depths compared to upper layers not much variations were observed with respect to mean ECe, Ca+Mg, K^+, Cl^-, HCO^{3-}, $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ contents at 30-60 and 60+ cm depths. However, Na+ and SARe values were higher than the corresponding 0-15 and 15-30 cm depths. As far as per cent distribution is considered, 30-60 and 60+ cm depths samples had higher percentage of ECe (>4.0 dS/m), SARe (>13), and $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ >1 compared to respective 0-15 and 15-30 cm depths.

Table 18. Characterization of soil samples from Raichur district, Karnataka for soil salinity appraisal.

Properties	**Depth (cm)**											
	0-15 cm			**15-30 cm**			**30-60 cm**			**60+ cm**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
pH (1:2.5)	9.0	5.80	8.09	9.66	6.14	8.33	9.21	6.54	8.38	9.58	7.87	8.67
EC (1:2.5)	21.0	0.13	1.19	12.5	0.11	1.08	6.90	0.24	1.32	5.40	0.30	1.26
pHs	8.49	4.86	7.56	8.42	6.66	7.75	8.24	6.94	7.66	9.03	7.48	8.14
ECe (dS/m)	47.0	0.14	2.68	24.0	0.28	2.25	14.0	0.38	2.70	11.6	0.52	2.51
Cations/Anions (meq/L) based on extract of saturated paste												
Ca+Mg	154.8	1.20	9.54	49.2	2.1	7.44	31.5	1.90	7.16	25.80	2.20	6.93
Na+	4400	7.83	390.1	110.9	1.39	15.11	117	1.80	17.9	123.9	3.48	22.2
K+	5.36	0.02	0.22	0.43	0.02	0.12	0.68	0.02	0.10	0.26	0.02	0.08
HCO_3^-	144.0	4.0	9.77	18.0	3.5	7.79	14.0	3.00	7.69	19.0	4.00	9.28
Cl^-	139.0	7.0	17.84	115.0	5.0	14.35	76.0	5.50	14.6	53.0	7.00	14.1
SO_4^{2-}	2.50	Tr	0.46	2.08	Tr	0.32	2.40	0.02	0.46	1.96	0.04	0.59
SARe	615.5	3.18	187.9	57.07	1.02	8.42	33.2	1.23	9.78	36.9	2.79	11.8
$(CO_3+HCO_3)/(Cl+SO_4)$	7.94	0.14	0.68	1.51	0.12	0.72	1.40	0.06	0.72	1.72	0.16	0.75
$Na/(Cl+SO_4)$	76.8	0.24	21.27	7.67	0.12	1.14	7.33	0.21	1.31	2.89	0.41	1.39

Note: Total number of samples was 107, 102, 71 and 43 at 0-15, 15-30, 30-60 and 60+ depths respectively.

Table19. Percent distribution of soil samples from Raichur district, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	31.8 (34)	68.2 (73)	0	64.5 (69)	22.4 (24)	13.1 (14)	94.4 (101)	5.6 (6)	64.2 (68)	35.8 (39)	84.0 (89)	16.0 (18)
15-30	15.7 (16)	84.3 (86)	0	66.64 (68)	23.5 (24)	9.80 (10)	87.2 (89)	12.7 (13)	51.9 (53)	48.1 (49)	88.2 (90)	11.8 (12)
30-60	32.4 (23)	67.6 (48)	0	62.0 (44)	22.5 (16)	15.5 (11)	84.5 (60)	15.5 (11)	40.8 (29)	59.2 (42)	73.2 (52)	26.8 (19)
60+	2.33 (1)	97.7 (42)	0	48.8 (21)	34.9 (15)	16.3 (7)	79.1 (34)	20.9 (9)	46.5 (20)	53.5 (23)	65.1 (28)	34.9 (15)

Note: Numbers in parenthesis indicate number of samples under each category.

As shown in Fig. 8, the relationship between ECe and $EC_{(1:2.5)}$ revealed that the conversion factor from EC (1:2.5) to ECe (saturation paste extract) would be around 2.24 at 0-15 cm and 2.10 at 15-30 cm depths for soils of Raichur district respectively.

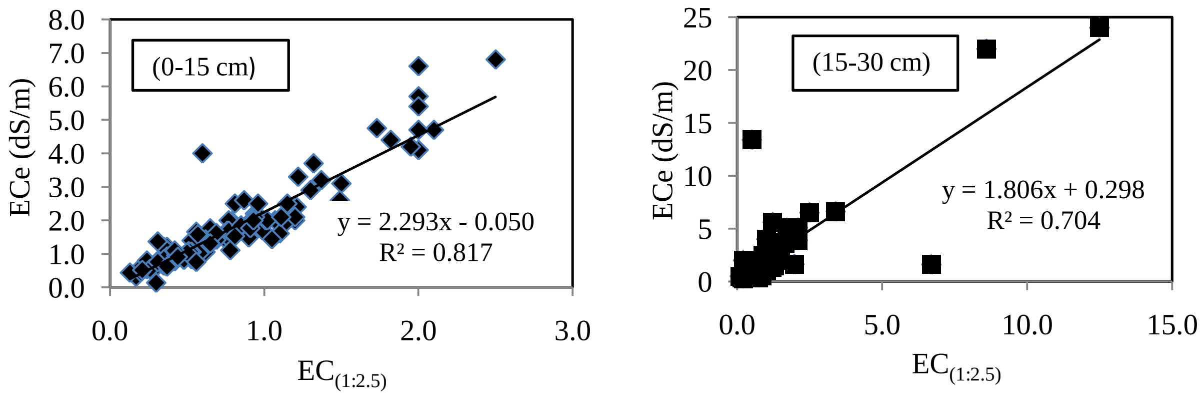


Fig 8. Relationship between ECe and $EC_{(1:2.5)}$ at surface and subsurface soils in Raichur district.

2.4 TBP command

A total of 312 (0-15 cm), 305 (15-30 cm), 240 (30-60 cm) and 168 (60 + cm) soil samples were collected and analyzed for salinity appraisal from Bellary, Koppal (Gangavati), and Raichur districts in TBP command area of Karnataka.

At surface soil (0-15 cm) $pH_{(1:2.5)}$, pHs, $EC_{(1:2.5)}$ and ECe varied from 10.76 to 5.72, 10.23 to 4.86, 31.0 to 0.10 (dS/m) and 75.0 to 0.14 (dS/m) respectively with an average of 8.09, 7.58, 2.11, and 5.06 respectively (Table 20). Among cations, average Na content (40.57

meq/L) was more than Ca+Mg (13.06 meq/L) followed by K. In case of anions, average Cl^- content was more (36.21 meq/L) than HCO_3^- (12.02 meq/L) followed SO_4^{2-}. Nearly 20 per cent (Table 18) of surface samples had ECe > 4.0 dS/m reflecting that these soils are saline (Table 21). With respect to area (Fig. 9), about 23.62% (85692 ha) and 14.36 % (52097 ha) of the TBP command area had ECe 2.0-4.0 dS m^{-1} and 4.0-8.0 dS m^{-1} respectively. However, nearly 50% of the area had ECe < 2.0 dS m^{-1}. In about 80% (281892 ha) of the command area, the SARe was < 13 and 7% (25577 ha) of the command area had SARe in the range of 13-20. Soil pHs in the range of 7.50 – 8.50 was in about 269992 ha (74%) of the command.

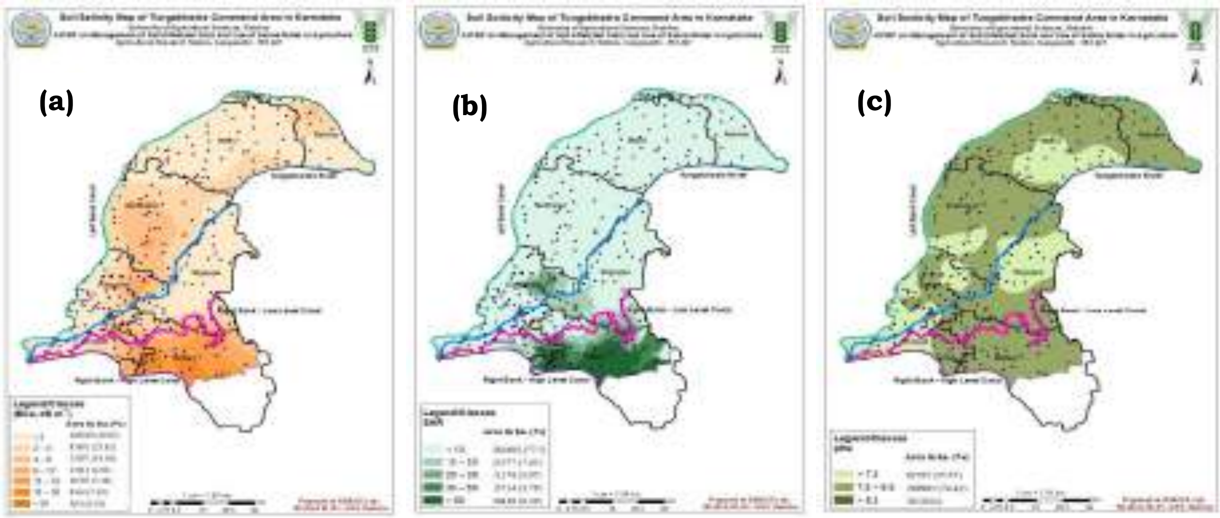


Fig.9. Maps showing per cent area under different categories of ECe (a), SARe (b) and pH (c) in TBP command area.

The per cent of samples with >1 $(CO_3+HCO_3)/(Cl+SO_4)$ and $(Na/(Cl+SO_4)$ ratios were to the extent of nearly 12.5 and 45.5 respectively indicating that the soils could be sodic or developing into sodic. Accordingly, nearly 23.7 per cent of surface samples had SARe >13.

Sub-surface (15-30 cm) soils had pH(1:2.5), pHs, EC(1:2.5) and ECe varying from 10.6 to 4.76, 10.3 to 5.45, 19.9 to 0.08 (dS/m), and 35.0 to 0.23 (dS/m) respectively with an average of 8.20, 7.74, 1.45 dS/m and 3.19 dS/m respectively (Table 20). Similar to surface soils, average Na content (27.0 meq/L) was more than Ca+Mg (9.10 meq/L) followed by K. In case of anions, average Cl^- content was more (21.9 meq/L) than HCO_3^- (9.00 meq/L) followed by SO_4^{2-}. Nearly 15 per cent of samples were considered to be saline as the ECe of these samples was >4.0 dS/m. The overall mean of the $(CO_3+HCO_3)/(Cl+SO_4)$ was less than 1 whereas Na/(Cl+SO4) was >1. However, about 16 and 49.5 percent of these samples had values more than 1 indicating that these samples could be considered as salt affected soil in particular sodic or developing into sodicity. About 23 per cent of samples analyzed had SARe >13.

Not much variation was observed with respect to the average pH, EC, pHs and ECe at 30-60 and 60+ cm depths compared to 15-30 cm. So also with respect cations and anions. About 19 and 20 per cent of soil samples had ECe> 4.0 dS m^{-1} at 30-60 and 60+ cm respectively. The mean ECe, Ca+Mg, K^+, Cl^-, HCO^{3-}, $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ contents at 30-60 and 60+ cm depths. Furthermore, 30-60 and 60+ cm depths samples had higher percentage of ECe (>4.0 dS/m), SARe (>13), and $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ >1 compared to respective 0-15 and 15-30 cm depths indicating that salts accumulation is much more at lower depths.

Table 20. Characterization of soil samples from TBP command area, Karnataka for soil salinity appraisal.

Properties	**Depth (cm)**											
	0-15 cm			**15-30 cm**			**30-60 cm**			**60+ cm**		
	Max	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**
pH (1:2.5)	10.76	5.72	8.09	10.6	4.76	8.20	10.22	6.54	8.40	10.3	7.06	8.53
EC (1:2.5)	31.0	0.10	2.11	19.9	0.08	1.45	13.3	0.12	1.56	8.90	0.09	1.40
pHs	10.23	4.86	7.58	10.3	5.45	7.74	10.08	6.53	7.83	9.65	6.48	7.94
ECe (dS/m)	75.0	0.14	5.06	35.0	0.23	3.19	26.20	0.30	3.16	19.3	0.31	2.96
Cations/Anions (meq/L) based on extract of saturated paste												
Ca+Mg	155.6	1.20	13.06	108	2.10	9.10	48.0	1.60	8.02	37.1	1.50	7.56
Na^+	634.5	0.46	40.54	347	1.16	27.00	370.9	1.55	28.4	212.2	2.23	26.9
K^+	5.36	0.02	0.27	0.72	0.02	0.18	0.96	0.02	0.13	1.05	0.02	0.11
$CO_3^-+HCO_3^-$	259.5	3.50	12.02	54.6	2.50	9.00	41.5	2.50	9.65	35.40	2.10	10.3
Cl^-	554.5	5.50	36.21	254	3.50	21.9	234	4.20	20.3	177.8	4.21	19.0
SO_4^{2-}	4.87	0.0	0.66	3.68	0	0.55	3.20	0.0	0.63	2.82	0.0	0.64
SARe	290.7	0.23	14.46	123	0.68	11.63	83.09	1.19	13.0	56.51	1.22	13.0
$(CO_3+HCO_3)/(Cl+SO_4)$	3.21	0.02	0.63	2.42	0.04	0.71	2.24	0.04	0.70	1.72	0.03	0.67
$Na/(Cl+SO_4)$	4.86	0.04	1.03	7.67	0.12	1.19	7.33	0.20	1.31	11.13	0.14	1.37

Note: The total number of samples was 312 (0-15 cm), 305 (15-30 cm), 240 (30-60 cm) and 168 (60 + cm) depths respectively.

Table 21. Percent distribution of soil properties of samples from TBP command area, Karnataka for soil salinity appraisal.

Soil Depth (Cm)	pHs			ECe (dS/m)			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na/(Cl+SO_4)$		SARe	
	<7.5	**7.5-8.5**	**>8.5**	**<2.0**	**2-4**	**>4**	**<1**	**>1**	**<1**	**>1**	**<13**	**>13**
0-15	35.26 (110)	61.86 (193)	2.88 (9)	51.92 (162)	27.56 (86)	20.19 (63)	87.5 (273)	12.50 (39)	54.49 (170)	45.51 (142)	76.28 (238)	23.72 (74)
15-30	22.62 (69)	73.44 (224)	3.93 (12)	59.67 (182)	25.57 (78)	14.75 (45)	83.93 (256)	16.06 (49)	50.49 (154)	49.51 (151)	77.05 (235)	22.95 (70)
30-60	27.08 (65)	66.67 (160)	6.25 (15)	60.42 (145)	20.42 (49)	19.17 (46)	83.33 (200)	16.67 (40)	35.42 (85)	64.58 (155)	66.25 (159)	33.75 (81)
60 +	16.07 (27)	77.38 (130)	6.55 (11)	54.76 (92)	25.0 (42)	20.24 (34)	81.55 (137)	18.45 (31)	40.48 (68)	59.52 (100)	62.50 (105)	37.5 0(63)

Note: Numbers in parenthesis indicate number of samples under each category.

3.0 Conclusion:

In TBP command area of Karnataka, surface (0-15 cm) soil salinity (ECe) was about 14.4% (52097 ha) and 12.3% (44696 ha) in the range of 4-8 and >8 dS m^{-1} respectively. With respect to SARe, 22.3% (80867 ha) area of the command had value >13. However, percent samples with $(CO_3+HCO_3)/(Cl+SO_4)$ and $Na/(Cl+SO_4)$ ratios >1 were to the extent of 12.50 and 45.50 respectively. Among different districts in the command, Bellary had the highest percent of area i.e., 62.83 (74400 ha) and 54.26 (64251 ha) having EC>4 dS m^{-1} and SARe >13 followed by Koppal (Gangavati) i.e., 30.19% (11173 ha) and 35.12% (12998 ha) respectively.

4.0 Technologies:

Technologies tested and developed at AICRP on Management of Salt Affected Soils, Gangavathi centre which could serve as remedies for the management and reclamation of waterlogged saline vertisols in Tungabhadra Project and some of them are briefed as follows:

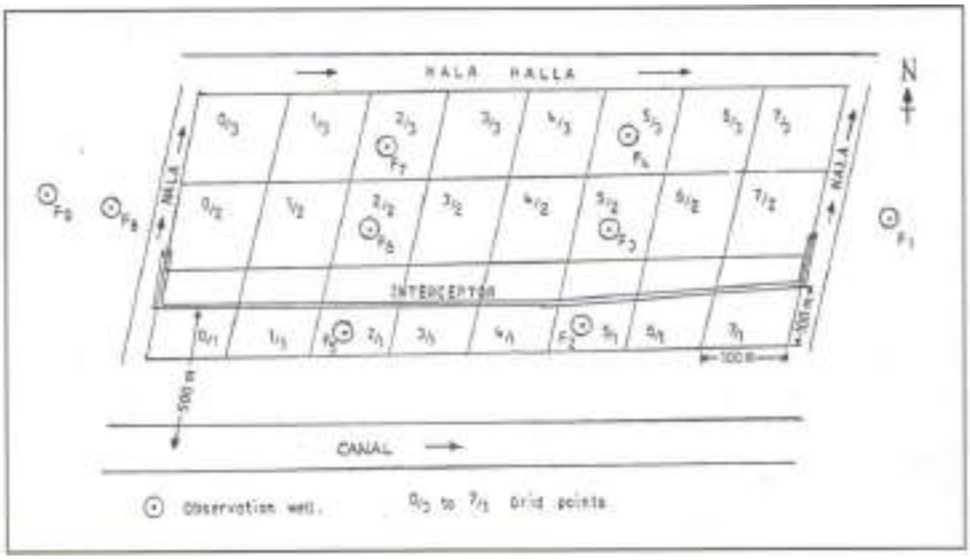
Interceptor Drainage:

Interceptor drain (Single)

It is often experienced that the low lying terrain fields are prone to seepage from the adjacent improper or unlined canals. The rise of water table in the low lying terrain due to canal seepage could be arrested through interceptor drainage.

Field experiments were conducted during 1992-93 to 1997- 98 at distibutary-36/1, Gorebal village, Sindhanur (Fig. 10) to evaluate the performance of single-layered interceptor drainage system on changes in soil salinity, depth to water table and crop yield. An interceptor drain (clay pipes) of 10 cm diameter was laid during 1992 parallel to a distributary at a depth of 1.7 m from the surface to intercept the seepage flows from canal and to prevent water logging and salinisation in low-lying areas. The drain was located 500m downstream from canal and 250 m upstream from the nala, with a running length of 800 m draining into two minor natural nalas, which in turn is connected to a major nala. This distributary canal runs on a well-defined ridge perpendicular to the main canal. Site characteristics of the study area reveal that it represents a typical undulating terrain, which also holds for the whole command area. Soils of the area are mainly Vertisols (over 85%) but occasionally red soils are also found on the ridges, covering 10 to 15% of the command.

The results of the study revealed that soil salinity decreased over a period of time at all the grid points. The mean decrease in soil salinity at the area upstream to the interceptor drain was from 3.4 to 0.9 dS/m. Soil salinity at the downstream area of the interceptor drain but away from nala also showed a considerable decline from 5.9 to 0.8 dS m^{-1}. The area near to downstream nala, which was highly salinised earlier, was also de-salinised considerably (from 10.1 to 1.2 dS/m). The decrease in soil salinity was as a result of removal of dissolved salts from the area through the interceptor drain effluent. The amount of salt removal was of higher during October 1996 and 1997 (5.17 and 5.52 tonnes), which coincided with canal running period and post monsoon rains, resulting in a higher rate of drain discharge. Over a period of two years, the total salts removed from the soil rhizosphere were to the extent of 87.4 tonnes. The leaching efficiency was higher at downstream (85.2 %) and downstream nala (87.4 %) than upstream side (71.7%). This was mainly due to higher initial salt concentration in the downstream (5.9 dS m^{-1}) and downstream nala (10.1 dS m^{-1}) than upstream (3.4 dS m^{-1}) resulting more salt removal from the area due to effective functioning of the interceptor drainage system.



Source: Indo-Dutch Network Project (IDNP). 2002.

Fig.10. Layout of the single interceptor drainage system.

The water table conditions on the upstream side declined from 123 to 158 cm (28.4.0%) due to introduction of interceptor drain over five years of study (1992 to 1998). Similarly, fall in water table from 102 to 140 cm (37.2 %) and 70 to 105 cm (50.0%) was observed in area below the interceptor (downstream and Near Nala, respectively) over the years. Consequently, the per cent decline in soil salinity at these positions was to the extent of 73.5 (up-stream), 86.4 (down-stream) and 88.1 (down-stream nala) respectively. Hence, the decreased depth to water table amply proved the role of interceptor to overcome/prevent the canal seepage from the upstream side and thus preventing secondary salinization in the low-lying areas and also helps to reclaim the affected low lying areas.

Rice yields registered a marked improvement both above as well as below the interceptor drain from 1992 to 1997. Performance of crop was understandably much better below the interceptor drain than above the interceptor except during 1997. This was observed both during *kharif* and rabi/summer seasons. Paddy yields improved from 2.29 to 7.37, 2.14 to 7.13 and 2.24 to 6.60 t ha^{-1}, respectively at upstream, downstream and downstream nala during *kharif* season. While, it varied from 2.50 to 7.54, 2.30 to 7.81 and 2.40 to 6.54 t ha^{-1} during rabi/summer. A higher yield obtained was primarily due to increased salt output from the interceptor area over the years. The decreased depth to water table amply proved the role of interceptor in preventing seepage from the upstream side and thus preventing secondary salinization in the low-lying areas. Thus, interceptor drain has been found to be most cost effective for situation where canal seepages are repeated to overcome the canal seepage which causes water logging and salinisation and also helps to reclaim the affected low lying areas.

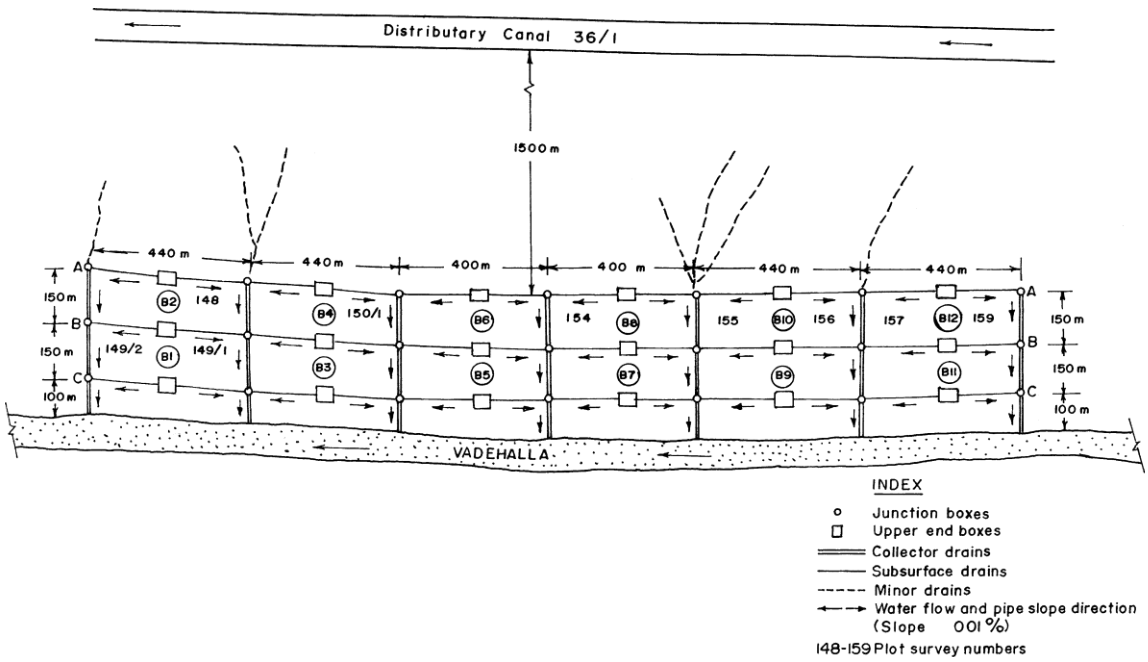
Interceptor Drain (Multiple)

In low-lying areas where water table is higher and inflicted by salinity, intervention through drainage is essential to improve the productivity of such areas. Preliminary studies conducted in TBP indicated the need for a lateral drain spacing of 18 to 30 m underlining the belief that a higher drainage coefficient is required to leach salts from saline vertisols.

Field performance of such sub surface drainage systems installed on farmers fields at four different locations around Gangavati viz. Vaddarahatti, Gundur, Siddapur and Gangavati were studied in terms of changes in soil salinity, hydrological parameters and crop yield. The sub-surface drainage systems with a uniform spacing of 27 m, and laterals (10 cm dia.) were placed at a depth of 0.9 m and connected to a collector (1.05 m depth). The collectors were connected to minor natural drains for disposal of drain water. Clay pipes with 5 cm thick gravel as an envelope were used before refilling back with black soils. Results indicated that a considerable reduction in soil salinity and depth to water table resulted in improvements of crop yield suggesting the need of sub-surface drains for reclaiming saline vertisols. Based on its economic analysis, payback period of the system ranged from 2 to 5 years indicating the sub-surface drainage system is remunerative and cost effective.

However, with paddy crop requiring ponding of water, it was argued that the lateral drain spacing may be increased which finally minimize the system cost. In pursuance of this, performance of SSD in rolling topography of TBP was initiated during *kharif* (i.e. from August to December) 1998 covering an area of 62 ha (Fig. 11) and continued to monitor up to *rabi/summer* (i.e. from January to May) 2005-06. Three drains (A, B and C, 0.10 m dia.) running parallel to D-36/1 spaced at 150 m intervals were laid at a depth of 0.75 m from the surface. The drain placement was about 100 m away from the natural drain (Vade halla) and 1500 m from the canal. Subsurface drain was laid with corrugated and perforated PVC pipes with filters.

The drains were laid in 1998 parallel to the natural drain (named Vade halla) and D-36/1 distributary canal at a spacing of 150 m. The first drain was installed at about 400 m from the natural drain and 1500 m from the distributary canal and the third drain was about 100 m away from the natural drain. The drains consist of corrugated perforated PVC pipes with nylon filter (Manjunath *et al.*, 2004).



Source: *Indo-Dutch Network Project (IDNP). 2002.*

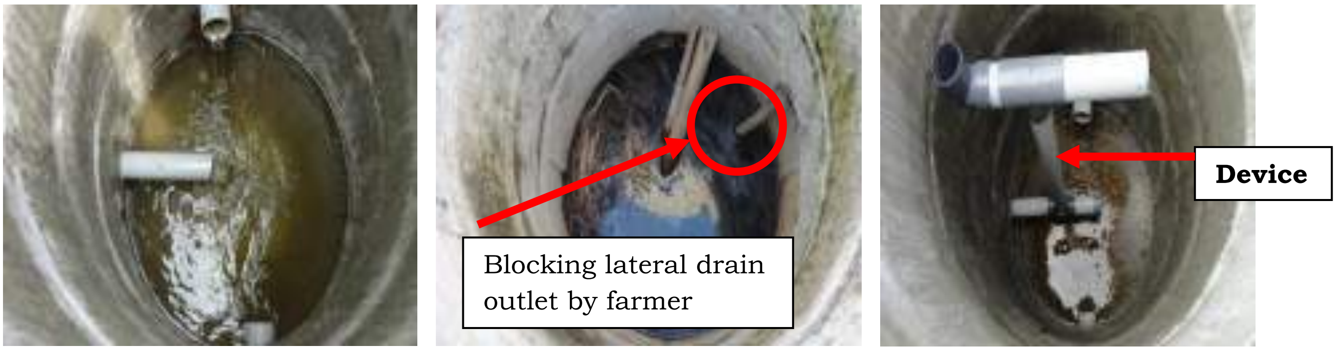
Fig.11. Layout of the interceptor drainage system (Multiple)

Water table depths were recorded on fixed grid points (B1 to B12) in each crop season after the harvest of the crop. During the period water table receded from 50 cm to 85 cm. This improvement in the soil salinity and receding water table improved crop performance. Rice yields increased from 2.20 to 6.30 t ha^{-1} with a cropping intensity changing from 143 to 191 percent signifying the role of sub-surface drainage in improving crop productivity. It is confirmed from this investigation that even relatively small drainage coefficient which is equivalent to a drain spacing of 150 m has been found to reclaim saline soils. Further, this confirms that the drainage requirement of the land is largely governed by the crop intended to be raised.

However, the soil salinity showed an increasing trend after *kharif* 2000. This was due to tendency of the farmers to block the drain outlets in order to save water and possibly nutrients. Surprisingly this small change in the SSD did not affect crop performance even after two years of such practice. However such blockage of drain may become detrimental once the soil salinity builds up reaches beyond a threshold value of the crop. The nutrient loss (mainly N) was monitored and estimated to be about 7.0 kg ha^{-1} season^{-1} for the design drainage coefficient of 1.0 mm day^{-1} in the vertisols of TBP, which is only around 5 per cent of the N applied for the rice crop. This can further be reduced by adopting selective blocking (controlled drainage), especially during fertilizer application.

Controlled Sub-surface Drainage System

It is well established that subsurface drainage improves crop productivity in canal command areas suffering from waterlogging and salinity problems (Fig. 12a). However, excessive drainage of paddy under conventional subsurface drainage (SSD) not only causes irrigation water shortage during critical growth stages of rice but also results in excessive leaching of nitrogenous fertilizers. To overcome these problems, farmers used to block the outlets of lateral drains of the system (Fig.12b). In order to provide a lasting solution to this problem, AICRP on SAS&USW, Gangavathi has designed a small device made up of PVC pipes which is fitted with the outlet of lateral drain (Fig. 12c) in tail ends of Tungabhadra Project (TBP) command of Karnataka where paddy is grown with limited canal water. In this system, an 80 mm PVC pipe fitted with outlet of lateral drain pipe inside the man hole and other end of “T” pipe is closed with end cap. The riser with variable height, depending on the minimum water table depth desired in paddy field, is fitted to this “T” pipe. Again one more “T” pipe is fitted at top of riser pipe. This simple device made up of two PVC “T” pipes and one riser pipe is efficient in maintaining desirable water table at desired depth in paddy fields. A field study for performance evaluation of conventional and controlled SSD systems was initiated in saline waterlogged Vertisols in TBP command during *Kharif* 2012 on 1.4 ha area each to understand their influences on the rate of reclamation, nutrient losses and crop yield.



a) Conventional Subsurface Drainage
b) Conventional Drainage with blocking of lateral by farmer
c) Controlled Subsurface Drainage

Fig.12. Comparison of conventional drainage and controlled drainage subsurface systems.

Initial layer wise mean ECe of the experimental field was 6.97, 8.09, 9.43 and 10.45 dS m^{-1} for 0-15, 15-30, 30-60 and 60-90 cm depths, respectively. The saturated hydraulic conductivity (K) at 1 m depth was 0.397 m day^{-1}. In both conventional and controlled systems, 80 mm PVC corrugated perforated lateral pipes covered with synthetic were installed at 50 m spacing and 1.0 m depth at 0.1 to 0.2% slope while 100 mm PVC corrugated collector pipes, directly draining into adjacent surface drain (Nala), were installed at 1.10 m depth at 0.2 to 0.3% slope. In the case of controlled drainage above explained device was fitted with the lateral to control the water table depth.

The results of the study over four seasons (2012 to 2014 during *Kharif* and *Rabi*) revealed that average drain discharge and salinity of the drainage water were 3.28 mm day^{-1} and 3.02 dS m^{-1}, respectively, under conventional drainage compared to 1.11 mm day^{-1} and 2.95 dS m^{-1} respectively, under controlled drainage. Thus, salt removal rate (3.51 t ha^{-1}) was more under conventional drainage as compared to 1.0 t ha^{-1} under controlled drainage. In general, there was a reduction in drain discharge depth of 64% in the case of controlled drainage over conventional SSD, with average irrigation water saving of about 17%. Average nitrogen loss was also reduced by 50.4% (5.32 kg ha^{-1} vs. 11.20 kg ha^{-1}) compared to conventional drainage. Paddy grain yield improvement was slightly higher (from 3.84 to 5.14 t ha^{-1}) for conventional compared to controlled conditions (3.76–4.83 ha^{-1}). Hence, it is advised to go for conventional SSD in the initial years of reclamation and switching over to controlled SSD later on so as to ensure faster soil reclamation and to attain sustained crop yields. Substantial improvements were observed in field conditions over the years (26-34%) irrespective of the drainage system. Slightly higher yield obtained in conventional drainage over controlled drainage can be compensated by savings in irrigation water and fertilizer use. Besides these direct benefits, prevention of surface water bodies from pollution was an indirect environmental benefit of controlled drainage.

Subsurface Drainage under Different Water Availability and Soil salinity Scenario

The Tungabhadra irrigation command area (TBP) in Karnataka, has three scenarios: the head, mid and tail reach command areas. The head reach has ample good quality canal water availability, and the mid reach area has limited canal water availability. In recent decades, rice–rice monocropping in vertisols, especially by these head and mid reach farmers, has led to not only water shortages but also the development of waterlogging and secondary soil salinization in the tail (lower) reach of the command due to seepage.

To assess the economic feasibility of subsurface drainage to control waterlogging and soil salinity under these three different scenarios, a field experiment was conducted in farmers' field near Mallapur village, Sindhanur. (15^0 47' 44.55" N, 76^0 43' 49.23" E to 15^0 47' 16.90" N, 76^0 44' 29.54" E), in the semi-arid region of the TBP command area, Karnataka over six seasons from rabi/summer 2012-13 to *kharif* 2016-17 (Karegoudar *et al.*, 2022). The waterlogged saline areas in the head, middle and tail reaches of the 45th distributary under the left bank canal of the TBP command were selected for this study to address three scenarios.

As the soil salinity in the head reach was less severe, a slightly wider drain spacing of 60 m was adopted over 15 ha. In the case of the mid reach, salinity was slightly higher than the head reach but slightly less than the tail reach, hence 50 m drain spacing was laid out over 24 ha. Due to the slightly higher soil salinity at the tail end of the command, a closer drain spacing of 40 m was adopted over 11 ha. In all these scenarios, the drain depth was 1.0 m.

The results of the study revealed that, the depth to the water table was deeper (23 and 39 cm) in the head reach area, followed by the middle (19 and 34 cm) and tail reach areas (15 and 27 cm) during *kharif* and *rabi/summer* seasons, respectively. The shallower water table at tail reach areas could be attributed to the cumulative effect of lateral seepage from both head and middle reach areas.

Performance evaluation of SSD systems indicated that these systems were able to reduce soil salinity, decrease subsurface waterlogging and increase rice yields despite differences in irrigation water availability and different soil salinity conditions. The rate of soil salinity reduction was slightly lower in the lower reach areas. The rate of increase in paddy yield due to SSD was 32, 29 and 26% in the head, mid and tail reach areas, respectively, with an average of 29%. This result suggested that SSD systems satisfied their functional requirements and that investment in SSD was economically acceptable and thus is a viable solution for the reclamation of waterlogged saline soils and enhancing rice productivity in all three scenarios of the TBP command. Policy makers may go ahead with projects under all three scenarios irrespective of the differential availability of irrigation water.

Vertical drainage for saline/waterlogged soils

An investigation on drainage requirement of saline soils with an acute outlet problem such as in case of saucer type of basin of Agricultural Research Station, Gangavathi, was investigated during 1983-93. Results of the experiment in terms of soil salinity, chloride salinity, carbonates and bicarbonates removal and de-sodification pattern revealed that for short term gains, a vertical drain with lateral (15 m length) was better than vertical drains without laterals. However, for long term gains, a vertical drain without lateral was as effective as with lateral. The cost comparison favoured a vertical drain without lateral (Rs. 34605/- per hectare) than both the vertical drain with lateral (Rs. 68033/-per ha) and the conventional horizontal system (Rs. 43328/- per ha) for 15 m drain spacing.

Integrated Drainage Systems

The functioning of drainage system largely depends on adequate gravity outlets. Several reports have revealed that many of the drainage systems suffer from inadequate gravity outlets due to siltation of natural brooks /drains (locally called nalas) during flash foods and excess irrigation. For a proper functioning of SSD, nala cleaning plays a vital role in improving drainage efficiency of the system. An investigation (Anonymous, 2000) to evaluate the influence of nala cleaning with and without SSD initiated during 1997-98 revealed that the depth to water table declined (over five seasons) from 24 to 66 cm, 42 to 76 cm, 50 to 105 cm and 25 to 86 cm with a mean value of 45.0, 63.0, 87.0 and 63.0 cm at No SSD and No nala cleaning, No SSD but nala cleaning, SSD with nala cleaning and SSD without nala cleaning respectively reflecting that SSD with nala cleaning is more effective compared to other systems tested . As a result of decline in water table depth, irrespective of treatments soil salinity also decreased over the season from its initial level. The effect was more prominent when nala cleaning was combined with sub-surface drainage system (SSD), wherein it decreased from 5.60 to 3.4 dS m^{-1} followed by SSD without nala cleaning (10.2 to 4.0 dS m^{-1}) and nala cleaning without SSD (5.8 to 4.9 dS m^{-1}) . Thus, it is clear that integrated drainage approach is required for effective reclamation of waterlogged saline lands.

Leaching Requirement of Saline Vertisols

When accumulation of salts reach levels beyond the threshold level of crop of choice, the foremost option available is leaching of salts out of root zone to bring salinity below the threshold level and create conditions favourable for raising field crops. This option is pursued under conditions where farmers are less endowed with financial resources to reclaim by engineering means. In pursuance of this endeavor and to make soil environment more feasible for raising field crops, field leaching was carried out during the year 1995-96. Leaching curves were constructed for soils under fluctuating water table conditions viz., 70, 95 and 120 cm. From the curves, depth of pre irrigation required bringing the salinity down to a desirable level specific to crops and water table was arrived. Under extreme hostile conditions of high salinity and water table, leaching is pursued with interest as a means of reclamation and rice crop is raised while the process is on to take advantage of the crop which likes ponded conditions. Interestingly from our studies it has been proved that 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 to the extent of depth of cracks.

In another study, the decrease in salinity was found accompanied by decrease in SAR and predicted ESP (ESP_p). Leaching efficiency of only 40-45 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 (@ 10 t/ha) although favoured leaching remained only marginal. On the basis of results, it was predicted that a minimum of 150-160 cm depth of irrigation water was required to bring the prevailing soil salinity to levels favourable for most field crops.

Bio-drainage

The problem of salinity and water logging are considered as regional and global problems and the engineering means of reclamation are often cost prohibitive and remain out of the economic realms of most farmers. In addition, in areas where development of shallow water table due to canal seepage may have limited water disposal options, deep rooted fast growing perennial trees with greater evapo-transpiration rates may help to combat and even reverse waterlogging and secondary salinization. In this regard, Manjunath *et al.* (2005) studied the performance of six tree species, viz. *Hardwickia binata, Sesbania grandiflora*, *Acacia nilotica, Dalbergia sissoo, Casuarina equisetifolia* and *Azardirachta india* and three grass species, viz. *Brachiaria mutica, Cenghrus ciliaris and Pennisetum purpureum* on a saline Vertisol at ARS Gangavathi. The experimental site was located between 75^{o} 31' 40" E longitude and 15^{0} 15' 40" N latitude with an altitude of 419 m above MSL, which represented a typical undulating terrain of the TBP area with natural land slope (0.41 %) in north direction. The distributary D-17 of Left Bank Canal of TBP, a source for seepage, was located at the southern end at higher elevation. In the first phase of the study (1991-1993), canal seepage based on amount of water collected in the interceptor drain revealed quite a significant quantum of seepage emerging from canal in control plot (0.899 m^3 day^{-1} 12 m^{-1} strip), which is expected to reach low-lying areas causing waterlogging and salinization.

Among the tree species, *A. nilotica* with a higher canopy spread (4.22 m) was observed to intercept about 86% of incoming seepage when compared to control (no trees) and this was followed by *Dalbergia sissoo* that intercepted 84% of the flow. Performance of *Sesbania grandiflora* and *Casuarina equisetifolia* was almost equal (72% despite the latter having only 50% of the canopy area). The synergetic effect of grasses along with tree species was found to be slightly more efficient in intercepting seepage than trees alone. *Acacia nilotica*-napier combination proved to be more efficient (87%) followed by *Dalbergia sissoo*-napier (80%). In the second phase (1995-99), water table depths were monitored within and outside the study area both during canal flow (August/September) and canal lean period (May/June). Water table depth receded considerably in the plantation area during both the periods. Within three years of establishment, plantations receded water table from 0.79 to 1.34 m during canal flow and 0.79 to 1.76 m during canal lean period in the plantation area. By the 8th year, it further receded to 1.80 m and 2.08 m, respectively. On the contrary, gradual build up of water table (0.062 m yr^{-1}) was observed outside the plantation area. The mean soil salinity of the plantation was reduced to the extent of 49 to 60% from its initial levels (12.2 to 17.0 dS m^{-1}). Thus, the study established that tree species can play a vital role in lowering of water table on marshy lands.

Alternate Land Use Practices

Multipurpose tree and fruit species for saline water logged soils

Under extreme conditions of salinity where cropping is not possible, alternate strategies of managing these have been pursued with renewed interest and vigor to arrest further salinization. Field experiments were carried out at ARS, Gangavati between 1989 to 2000.

Fruit species in saline-waterlogged soils

Saplings of twelve fruit species (mango, sapota vars. Kalipatti and Cricket Ball, wood apple, tamarind, pomegranate, custard apple, fig, guava, *ber, aonla, jamun* and pummelo) were planted during 1990 in three salinity blocks at ARS, Gangavati. Performance of fruit species was 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 such as mango, custard apple, fig, guava and pummelo were found not suitable for soils having salinity in the range of 9.3 dS m^{-1} and higher. *Jamun* and sapota survived and grew better under relatively lower salinity and shallower water table conditions, whereas wood apple was found promising under relatively high salinity and deeper water table conditions. Pomegranate and *ber* maintained a moderate survival and steady growth rate in low salinity and shallow water table conditions.

Syziium cuminii (Jamun) – a highly potential species for high water table and saline wastelands

Multi-purpose tree species on saline-waterlogged soils of TBP

A field experiment was conducted at Agricultural Research Station, Gangavati, Karnataka, to evaluate the performance of 23 multi-purpose tree species on saline water-logged soils of Tungabhadra command during 1989-2000. Tree performance of tree species was evaluated in terms of survival per cent, height and collar diameter. Changes in soil nutrient status due to tree plantation were also studied. Based on 11 years of study, tree species such as *Acacia ferugenia, Albizzia lebbeck, Glyricidia maculata* and and *Casuarina equisetifolia* performed better under saline (10-12 dS m^{-1}) 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 .

Acacia auriculiformis, a promising fuel wood species for shallow water table and saline conditions

Irrigation Management of Crops in Saline Vertisol

Cotton (*Gossypium hirsutum* L.)

Cotton is the second largest crop grown in the TBP command after paddy. It is extensively grown by the tail end farmers of the command due to insufficient or non-availability of irrigation water for paddy crop. To enhance crop productivity in saline soils with limited available water sources, micro-irrigation with mulch would be the best options. A field experiment was conducted in a saline (ECe 6-8 dS m^{-1}) Vertisol during 2011-12 to 2013-14 to study the response of cotton (*Gossypium hirsutum* L.) to irrigation water application [(0.8, 1.0 and 1.2 times the evapotranspiration (ET)] through drip irrigation and normal furrow irrigation method under zero till mulch (paddy straw @ 6.85 Mg ha^{-1} with 1.25 cm thick) and no mulch treatments. The results revealed that the moisture content was significantly higher under mulch with 1.2 ET level as compared to no mulch with furrow irrigation at all the growth stages of the crop and at all the four depths of soil (0-15, 15-30, 30-45 and 45-60 cm). The downward flux of salt was more in drip irrigated with 1.2 ET compared to furrow method of irrigation. The crop responded to applied water levels and significantly higher seed cotton yield was obtained in case of drip irrigated at 1.2 ET (27.16 q ha^{-1}) compared to furrow irrigation (21.04 q ha^{-1}) but was on par with drip irrigated at 1.0 ET (26.16 q ha^{-1}). Among mulch treatments, significantly higher yield was obtained in case of mulch treatment (26.49 q ha^{-1}) compared to no mulch treatment (23.01 q ha^{-1}). The yield advantage due to irrigation scheduling through drip based at 1.2 ET and mulching were 22.5 and 13.0 per cent over furrow irrigation and without mulch, respectively. Net saving in irrigation water through drip irrigation was 44, 29.4 and 16.8 per cent at the irrigation levels of 0.8, 1.0 and 1.2 ET, respectively as compared to furrow irrigation. Water production efficiency was significantly higher under drip irrigated with 0.8 ET (0.78 kg m^{-3}) followed by drip irrigated with 1.0 ET (0.67 kg m^{-3}), drip irrigated with 1.2 ET (0.59 kg m^{-3}) and least in flood irrigated treatment (0.38 kg m^{-3}). Similar to yield, significantly higher water production efficiency was obtained under mulch treatment (0.65 kg m^{-3}) compared to no mulch treatments (0.56 kg m^{-3}). Among irrigation levels, net seasonal income and B:C ratio were significantly higher with drip irrigation at 1.2 ET (Rs. 33,245 and 1.67) as compared to other irrigation levels. Significantly higher net seasonal income and B:C ratio (Rs. 29,459 and 1.59) were observed under mulch compared to no mulch treatment. The payback period was lesser in case drip irrigation at 1.2 ET with mulch treatment (3.15 years) compared to other treatments.

General view of the cotton experimental plot in saline vertisol

In an another experiment (Daleshwar *et al.,* 2006), the growth and yield performance of cotton irrigation through furrows during 2002-2002, even though with good quality canal water (ECw 0.25 dS m^{-1}) was poor when compared with drip irrigation with marginally saline water (Cw 2.2 dS m^{-1}). The crop responded to applied water and average maximum cotton yield (1.78 Mg ha^{-1}) over two years was from block I having initial ECe and average depth to water table of 8±0.4 dS m^{-1} and 1.25±0.08 under drip irrigation applied at 1.2ET while the lowest yield (0.18 Mg ha^{-1}) was from block IV having initial ECe and average depth to water table of 15.1±0.8 dS m^{-1} and 0.95±0.07 when applied water equaled 0.8 ET with furrow irrigation. Due to creation of better salt and moisture regimes, water productivity also considerable improved with drip irrigation. Though the gross income (US$ 223-690 ha^{-1}) was more with drip than furrow (US$ 67-545 ha^{-1}) irrigation, the net profit per unit of applied water was higher with furrow irrigation. It was concluded that the drip system provide for opportunities to enhance the use of saline waters in water scarcity areas especially those existing at the tail end of canal commands.

Sugarcane *(Saccharum officinarum)*

In the Tungabhadra project command (TBP) area, subsurface drainage systems are being installed to reclaim waterlogged and salinity area, but due to higher investment cost per unit area and lack of proper technical knowledge on installation and maintenance, adoption of this technology not quite viable particularly for individual small fields. In some fields lack of required elevational difference for natural drainage could be the major constraint for considering subsurface drainage system. Under such situations, soft options like surface or subsurface drip irrigation technology for waterlogged and saline area could be a better option.

In this regard, a field experiment was conducted at Agricultural Research Station, Gangavathi, Karnataka, India, to know the effect of different irrigation techniques and irrigation levels on soil properties, growth and yield of salt-tolerant sugarcane *(Saccharum officinarum)* in saline Vertisols of TBP command. The experiment was laid out in saline soils (4-6 dS m^{-1}) with irrigation methods *viz.,* surface drip, subsurface drip (SSDI), and furrow irrigation as main treatments and with irrigation levels *viz.,* 0.8, 1.0, and 1.2 evapotranspiration (ET) as sub treatments.

The results revealed that, higher moisture was retained and more salts were leached out from the root zone in subsurface drip-irrigated with 1.2 ET level treatments and water table was deeper. Among different irrigation techniques, higher cane yield (131.0 t ha^{-1}) was recorded in subsurface drip irrigation and among different irrigation levels, the higher yield was recorded in 1.2 ET level (124.7 t ha^{-1}). Similarly, higher water use efficiency (WUE) and sugar water use efficiency of 83.0 kg $ha^{-1}mm^{-1}$ and 1.72 kg m^{-3} respectively along with greater leaching of salts from the root zone were recorded in SSDI. Higher moisture retention, lowering of water table and greater leaching of salts resulted in higher sugarcane yield under SSDI with 1.2 ET. Hence, this practice can be considered as a viable option to improve the crop productivity of sugarcane and could be an alternative to drainage system for the reclamation of waterlogged saline soils in Tungabhadra project area.

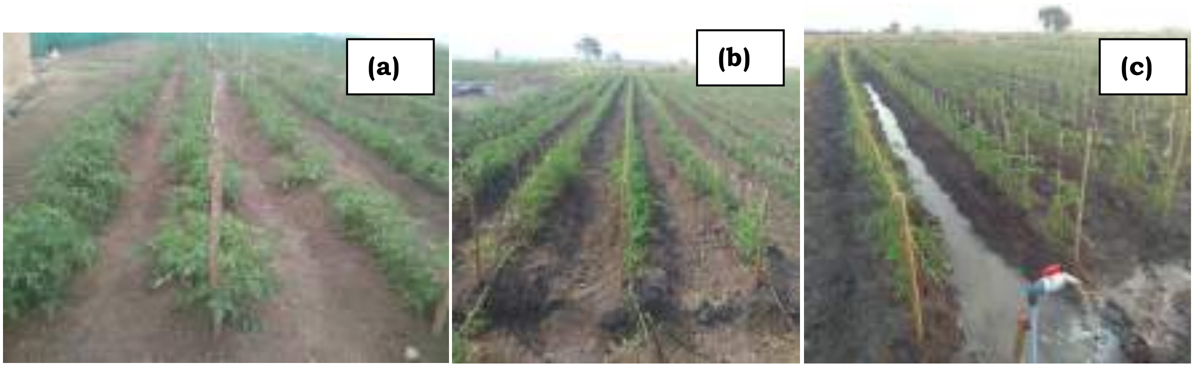
General view of salt-tolerant sugarcane (Saccharum officinarum) in saline Vertisols of TB project area.

Tomato *(Solanum lycopersicum)*

Influence of saline water and different micro-irrigation techniques on soil properties, yield and water use efficiency of tomato *(Solanum lycopersicum)* and simulation modeling (HYDRUS) in Tungabhadra Command area was initiated during late *rabi* 2017-18 and continued during *rabi* 2018-19 at Agricultural Research Station, Gangavathi. The experiment was laid out in three replications with main treatments (Irrigation methods) such as furrow irrigation as control (M_0), surface drip (M_1), subsurface drip (M_2) and sub treatments (Irrigation water quality) such as normal water/BAW i.e. canal water (S_0), ECiw (Electric conductivity of irrigation water)-2 dS m^{-1} (S_1), ECiw-3 dS m^{-1}(S_2), ECiw-4 dS m^{-1}(S_3) and ECiw-5 dS m^{-1}(S_4) of saline water treatments. From the two years data, it was found that highest water requirement (563.4 mm) was in furrow irrigation followed by surface (538.6 mm) and subsurface drip (247.6 mm) irrigation. The water saved in surface drip and subsurface drip over furrow irrigation was to the extent of 41.0 to 45.7% and 46.3 to 54.7% from 0.65 dS m^{-1} to 5 dS m^{-1} saline water treatments respectively. At a depth of 0–15 and 15–30 cm, more salts were accumulated near the plant and horizontal distances in furrow irrigation, in case of surface drip more salt was present at 20 cm distance away from the dripper. In subsurface drip irrigation salt accumulation was more at the soil surface (0-15 cm) but it was lesser near and below the buried dripper, and increased away from the dripper.

The pooled data of two years results revealed that the maximum total yield (27.3 t ha^{-1}) was recorded in M_2 followed by M_1 (26.67 t ha^{-1}) and M_0 (20.38 t ha^{-1}). Similarly, under saline water treatments the maximum total tomato yield was significantly higher under control- S_0 (29.59 t ha^{-1}) compared to other treatments but at par with S_1 (28.42 t ha^{-1})(ECiw =2 dS m^{-1}).The yield decreased with increase in salinity levels of irrigation water.

The two year pooled data showed higher (98.65 kg ha^{-1} mm^{-1}) water use efficiency (WUE) under M_2 followed by M_1 (84.2 kg ha^{-1} mm^{-1}) and least in case of M_0 (37.55 kg ha^{-1} mm^{-1}). Decreased WUE with increased in salinity levels of irrigation was observed. The results of simulation through HYDRUS-1D model revealed that model is able to predict the soil water and soil salinity. Calibration and validation results showed better R^2 and RMSE values. The highest benefit cost ratio of 1.84 was obtained under M_2S_0 followed by M_1S_0 (1.8) and M_2S_1 (1.78). The minimum (0.524 year) payback period was obtained under M_1S_0 followed by M_2S_0 (0.544 year), M_1S_1 (0.548 year) and M_2S_1 (0.567 year). In conclusion, in northern dry semi arid zone no III, saline water with salinity 2 dS m^{-1} can be used through either surface or sub-surface drip as a safe alternative water source for tomato cultivation without any harmful effect to the soil and crop yield.



A view of tomato crop under subsurface drip (a), surface drip (b) and furrow irrigation (c) methods

Green Manure in Economizing Nitrogen Use Efficiency under Saline Soils

Nitrogen losses are well known especially in irrigated agriculture which is a environmental concern. To reduce the entry of reactive nitrogen into the environment and to improve its use efficiency under varying salinity and water table situations, various agronomic practices have been evolved including use of crop residues / green manures, special size formulations, solubility etc. Organic residues became foci of our study to reduce use of N. Application of dhaincha or glyricidia @ 10 t ha^{-1} 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 irrigation command. This practice saved 87.5 kg N ha^{-1} yr^{-1} in maize-wheat cropping sequence besides preventing leakage of reactive N into environment and thus improving soil health. In paddy-paddy cropping sequence, nitrogen management holds key and revealed that 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. It decreased nitrogen losses and increases yield to achieve environmental sustainability. Similar efforts were also made for wheat where crop could be still raised in high water table condition without reduction in yield, preventing further salinization. A threshold water table depth of 45 cm was found critical for the crop

In order to make use of the locally available organic sources as an alternate to FYM in paddy, different organic sources viz., pressmud, poultry manure, dhaincha, paddy straw and FYM were evaluated during 2002-07. Results indicated that application of pressmud @ 2.5 t ha^{-1} or poultry manure @ 2.5 t ha^{-1} or dhaincha @ 5 t ha^{-1} or FYM @ 10 t ha^{-1} to the paddy crop along with 125 % of the recommended nitrogen has recorded significantly higher yield.

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