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Characterisation and Mapping of Salt-affected soils in Tungabhadra Project (TBP) Command, Karnataka

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Abstract

The deviation from the recommended cropping pattern in the command area, particularly through the large-scale adoption of water-intensive paddy cultivation, has led to widespread waterlogging and soil salinity. Against this backdrop, a systematic assessment and spatial mapping of soil salinity in the command area were carried out by the All India Coordinated Research Project (AICRP) on Management of Saline Water and Associated Salinisation in Agriculture, Gangavathi, Karnataka. A total of 407, 391, 306, and 207 soil samples were collected from depths of 0-15, 15-30, 30-60, and 60-90 cm, respectively, using GPS-based grid sampling at 5 km × 5 km intervals. Spatial mapping was performed using geostatistical kriging techniques, and the generated maps were geo-referenced and visually interpreted to delineate salt-affected soils using standard image interpretation elements such as tone, texture, shape, size, pattern, and association. The survey results indicated that surface soil salinity (EC_e, 0-15 cm) ranged from 2-4, 4-8, and >8 dS m^{-1} over approximately 23.62% (85,692 ha), 14.40% (52,097 ha), and 12.40% (44,986 ha) of the command area, respectively. With respect to sodicity, about 22.3% (80,904 ha) of the command area exhibited a Sodium Adsorption Ratio of soil extract (SAR_e) greater than 13, indicating the presence of sodic soils. Among the districts within the command, Bellary recorded the highest proportion of salt-affected area, with 62.83% (74,400 ha) having 54.26% (64,251 ha) having EC > 4 dS m^{-1}, SAR>13, followed by Koppal (Gangavathi) with 30.19% (10,465.6 ha) and 35.12% (12,174 ha), and Raichur with 23.00% (47,707 ha) and 15.60% (32,308 ha), respectively. The continued use of poor-quality *Nala* (drain) water and groundwater for irrigation further aggravated the development of salt-affected soils, particularly in the tail-end regions of the command.

Keywords: Waterlogging, Soluble cations, Electrical conductivity, GPS, Soluble anions

Introduction

Groundwater plays a pivotal role in sustaining agricultural production and meeting domestic water demands in India, contributing nearly 70% of irrigation and about 80% of domestic water requirements (Gupta, 2008). Owing to its widespread availability and relatively dependable supply, groundwater has been extensively exploited, particularly in irrigated agricultural regions. Although groundwater is considered a renewable natural resource, its quality and long-term sustainability are not guaranteed. Unregulated extraction, inadequate natural recharge, and inappropriate land and water management practices have led to a gradual decline in groundwater quality across several parts of the country (Chinchmalatpure *et al.*, 2018) thereby posing serious threats to soil health and agricultural productivity (Vineeth *et al.*, 2023; Vibhute *et al.*, 2024).

Irrigation with good-quality water in the head and middle reaches of the canal generally ensures higher crop yields and better soil conditions. However, in the tail-end reaches, limited availability of canal water often forces farmers to depend on poor-quality surface water and groundwater for irrigation (Rajkumar *et al.*, 2024). Continuous use of such marginal-quality water, coupled with inadequate drainage and cultivation of water-intensive crops, results in waterlogging, accumulation of soluble salts, and subsequent development of saline and sodic soils (Vibhute *et al.*, 2017; Indumathi *et al.*, 2025). These processes ultimately reduce crop yields, impair soil physical properties, and threaten the long-term sustainability of irrigated agriculture.

The Tungabhadra Project (TBP) command area in Karnataka represents one of the major irrigation commands in southern India and has experienced a progressive increase in soil salinity and sodicity since its inception in 1953. Historical records indicate that the extent of salt-affected soils in the command area was approximately 20,200 ha during 1979-80 (Patil *et al.*, 2006). However, this area increased alarmingly to about 96,215 ha by 2013-14 (CADA, 2013), reflecting an estimated annual expansion of salt-affected lands at nearly 3,000 ha per year (Manjunath *et al.*, 2004). The expansion of paddy cultivation beyond the recommended cropping pattern, poor on-farm water management, and inadequate drainage infrastructure have been identified as major contributing factors to this problem (Karegoudar *et al.*, 2019).

In this context, systematic assessment and spatial mapping of soil salinity and sodicity are essential for understanding the magnitude, distribution, and severity of land degradation in the TBP command. The integration of Global Positioning System (GPS)-based soil sampling with geostatistical techniques, such as kriging, offers a reliable approach for generating detailed and accurate salinity maps (Vibhute *et al.*, 2024). Such information is crucial for identifying vulnerable areas, formulating site-specific management strategies, and supporting policymakers, planners, and researchers in designing effective interventions to arrest further expansion of salt-affected soils and to reclaim and restore the productivity of degraded lands in the command area.

Material and Methods

Study area

The Tungabhadra command area covers approximately 3,627 km² (3,62,795 ha) and encompasses parts of Raichur, Koppal, and Bellary districts in the northeastern region of Karnataka. The command area experiences a semi-arid climate characterized by hot summers and low, erratic rainfall. The mean annual rainfall is about 550 mm, distributed over nearly 40 rainy days. The climate remains relatively cool and pleasant for most of the year, except during the summer months from March to mid-June. The coldest period occurs during December–January, with minimum temperatures dropping to around 16°C, while maximum temperatures during the peak summer months of April and May can reach up to 42°C. Farmers in the region have found paddy cultivation more economically viable than other crops, resulting in a substantial expansion of paddy area from about 8% to 40% (from 29,032 to 146,974 ha). The area under Kharif paddy (August–December) accounts for approximately 47%, while summer paddy (January–April) contributes around 34% of the total paddy area. Paddy cultivation, being highly water-intensive, has expanded predominantly in the head and middle reaches of the command area due to better access to irrigation water compared to the tail-end regions (Karegoudar *et al.*, 2022).

Collection of soil samples

Soil samples were collected on a grid basis (5 km × 5 km) using GPS and Survey of India toposheets (1:50,000 scale). A total of 407, 391, 306, and 207 soil samples were collected from depths of 0-15, 15-30, 30-60, and 60-90 cm, respectively. Spatial interpolation and mapping were carried out using the kriging technique. The resulting maps were georeferenced and visually interpreted to identify salt-affected soils using standard image interpretation elements such as tone, texture, shape, size, pattern, and association.

Analysis of samples

The pH of the soil saturation paste (pH_s) and the electrical conductivity of the saturation extract

(EC_e) were measured using a digital pH meter and a digital electrical conductivity meter, respectively, following the procedures outlined by the U.S. Salinity Laboratory Staff (USSL, 1954). Sodium (Na^+) and potassium (K^+) concentrations in the saturation extract were determined using a flame photometer (Richards, 1954), while calcium (Ca^{2+}) and magnesium (Mg^{2+}) were estimated by the EDTA-versenate titration method (Schwartzenbach *et al.*, 1946). Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in the soil saturation extract were determined by titration with sulfuric acid (H_2SO_4) (Richards, 1954). Chloride (Cl^-) was estimated by titration with silver nitrate ($AgNO_3$) using potassium chromate (K_2CrO_4) as an indicator (USSL, 1954). Sulphate (SO_4^{2-}) concentration was determined using the turbidimetric method (Chesnin and Yien, 1951).

The USDA classification system for salt-affected soils is based on three principal criteria, namely soluble salt content expressed as electrical conductivity of the saturation extract (EC_e, dS m^{-1}), exchangeable sodium percentage (ESP), and soil pH (pHs). Based on these parameters, salt-affected soils are classified into three categories: (i) saline, (ii) saline-alkali, and (iii) alkali soils, as presented in Table 1.

Since direct estimation of ESP is laborious, efforts were made to establish a relationship between ESP and the sodium adsorption ratio of the saturation extract (SAR_e) for categorizing salt-affected soils. The relationship indicated that soils with SAR_e < 13 may be classified as saline, whereas soils with SAR_e > 13 may be categorized as alkali or saline-alkali, depending on their EC_e values. Furthermore, under Indian conditions, soils having (CO_3 + HCO_3)/(Cl + SO_4) and/or Na/(Cl + SO_4) ratios greater than 1 (me L^{-1}) are suggested to be treated as alkali soils from a management perspective (Chhabra, 2004). Based on these criteria, soils of the TBP command area of Karnataka were classified accordingly.

Table 1. USDA Classification of salt-affected soils (Richards, 1954)

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

Results and Discussion

Soil reaction (pH)

In surface soils (0-15 cm), soil pH measured in a 1:2.5 soil-water suspension ($pH_{2.5}$) and saturation paste (pHs) ranged from 5.72 to 10.76 and 4.86 to 10.23, respectively, with mean values of 8.09 and 7.58 (Table 2). Approximately 74% of the command area, covering about 269,992 ha, exhibited pH values between 7.5 and 8.5, indicating predominantly neutral to moderately alkaline soil reaction (Fig. 1).

In subsurface soils (15-30 cm), $pH_{2.5}$ and pHs ranged from 4.76 to 10.60 and 5.45 to 10.30, respectively, with average values of 8.20 and 7.74, respectively. The mean $pH_{2.5}$ and pH_s values at deeper layers (30-60 and 60-90 cm) showed only marginal variation compared to surface and subsurface layers, suggesting relatively uniform soil reaction with depth.

Electrical conductivity (EC)

In surface soils (0-15 cm), electrical conductivity measured in 1:2.5 soil–water suspension ($EC_{2.5}$) ranged from 0.10 to 31.0 dS m^{-1}, while ECe varied from 0.14 to 75.0 dS m^{-1}, with mean values of 2.11 and 5.06 dS m^{-1}, respectively. Subsurface soils (15-30 cm) exhibited $EC_{2.5}$ values ranging from 0.08 to 19.9 dS m^{-1} and ECe values from 0.23 to 35.0 dS m^{-1}, with corresponding mean values of 1.45 and 3.19 dS m^{-1}.

The average $EC_{2.5}$ and ECe values at 30-60 and 60-cm depths were comparable to those at 15-30 cm, indicating limited vertical variation in soil salinity. Approximately 20% of surface soil samples had EC_e values exceeding 4.0 dS m^{-1}, classifying them as saline soils (Tables 1 and 3). Spatial analysis revealed that about 23.62% (85,692 ha) and 14.36% (52,097 ha) of the TBP command area fell under ECe ranges of 2.0-4.0 and 4.0-8.0 dS m^{-1}, respectively (Fig. 2). However, nearly 50% of the area had EC_e values below 2.0 dS m^{-1}, indicating non-saline conditions.

In subsurface soils (15-30 cm), about 15% of the samples were saline, with EC_e values greater

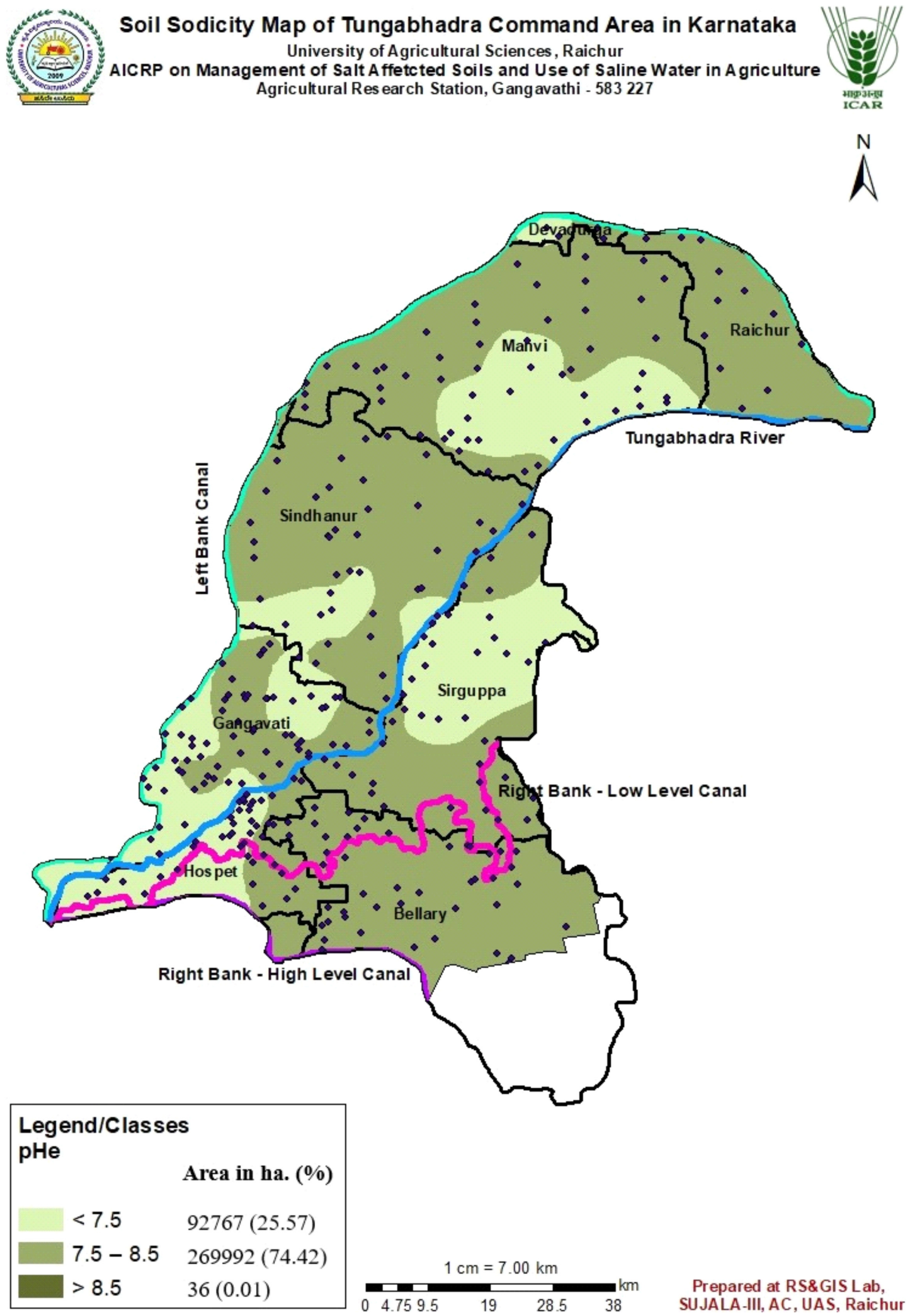

Fig. 1 Map showing the percentage area under different categories of pH in the TBP command area

than 4.0 dS m^{-1}. The observed ECe levels suggest a potential risk of salinity development in parts of the command area. Elevated salinity was primarily attributed to irrigation with poor-quality water, inadequate drainage, and accumulation of salts in low-lying areas. These findings are consistent with earlier studies by Meena *et al.* (2006), Huang *et al.* (2010), Mali *et al.* (2012), and Mustafa *et al.* (2016).

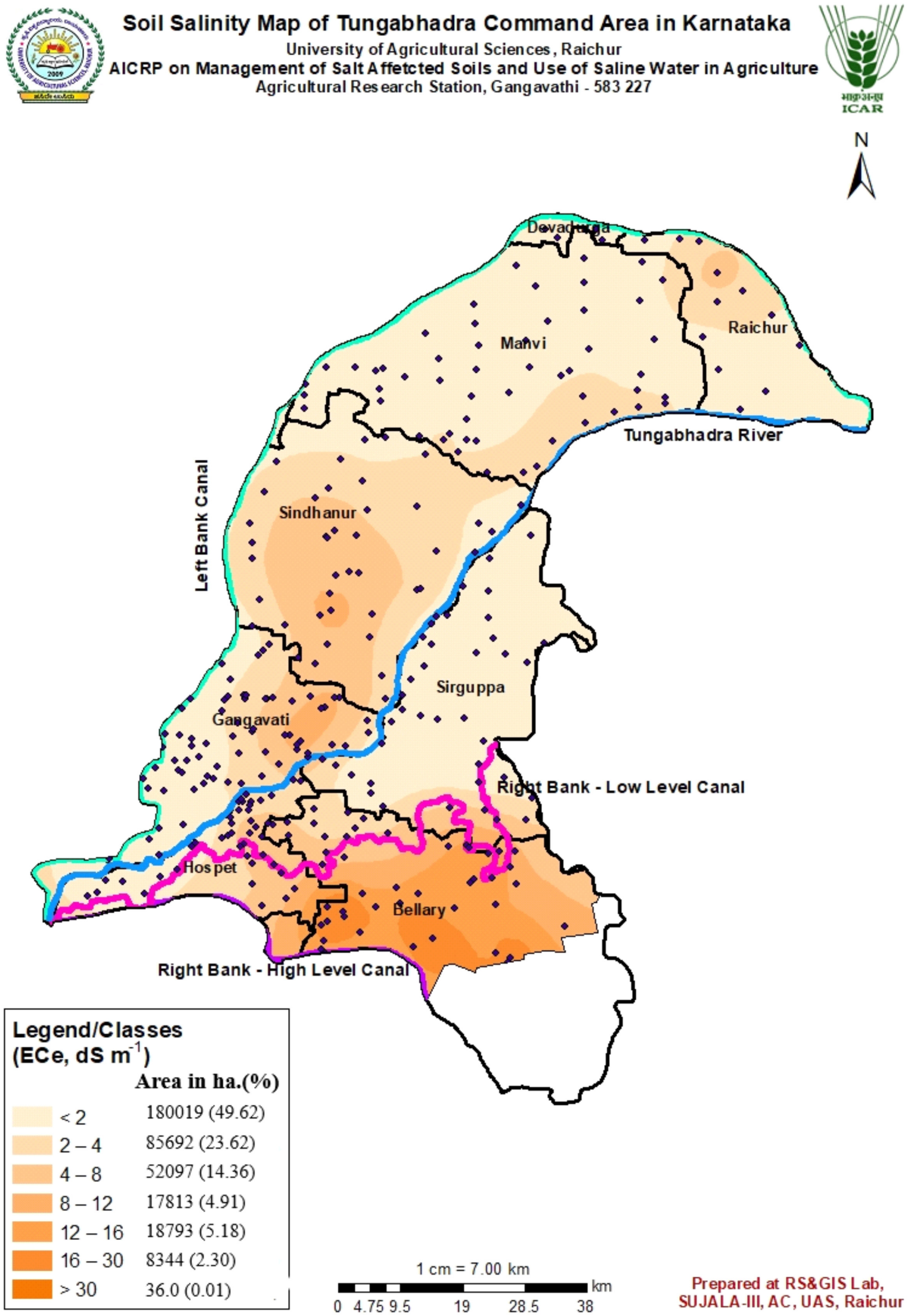

Fig. 2 Map showing the percentage area under different categories of ECe in the TBP command area

Soluble cations

The concentrations of soluble cations in surface soils (0-15 cm) ranged from 0.46 to 634.5 me L^{-1} for Na^+, 1.20 to 155.6 me L^{-1} for Ca^{2+} + Mg^{2+}, and 0.02 to 5.36 me L^{-1} for K^+, with mean values of 40.54, 13.06, and 0.27 me L^{-1}, respectively. In subsurface soils (15-30 cm), Na^+, Ca^{2+} + Mg^{2+}, and K^+ concentrations ranged from 1.16 to 347.0, 2.10 to 108.0, and 0.02 to 0.72 me L^{-1}, with mean values of 27.0, 9.10, and 0.18 me L^{-1}, respectively. Similar cationic trends were observed at depths of 30-60 and 60-90 cm.

Among soluble cations, sodium was dominant at all depths, followed by calcium plus magnesium and potassium. Approximately 77.7% (281,892 ha) of the command area exhibited SAR_e values less than 13, while about 7% (25,577 ha) had SARe values ranging from 13 to 20. Overall, nearly 22.3% of surface soil samples had SAR_e values greater than 13, indicating sodic or potentially sodic conditions. In subsurface soils (15–30 cm), about 23% of samples also recorded SAR_e values above 13, with an increasing proportion observed at deeper depths (30–60 and 60–90 cm) (Table 3).

The presence of sodium in soils is largely attributed to the weathering of sodium-bearing minerals such as feldspars and feldspathoids. Calcium originates mainly from the weathering

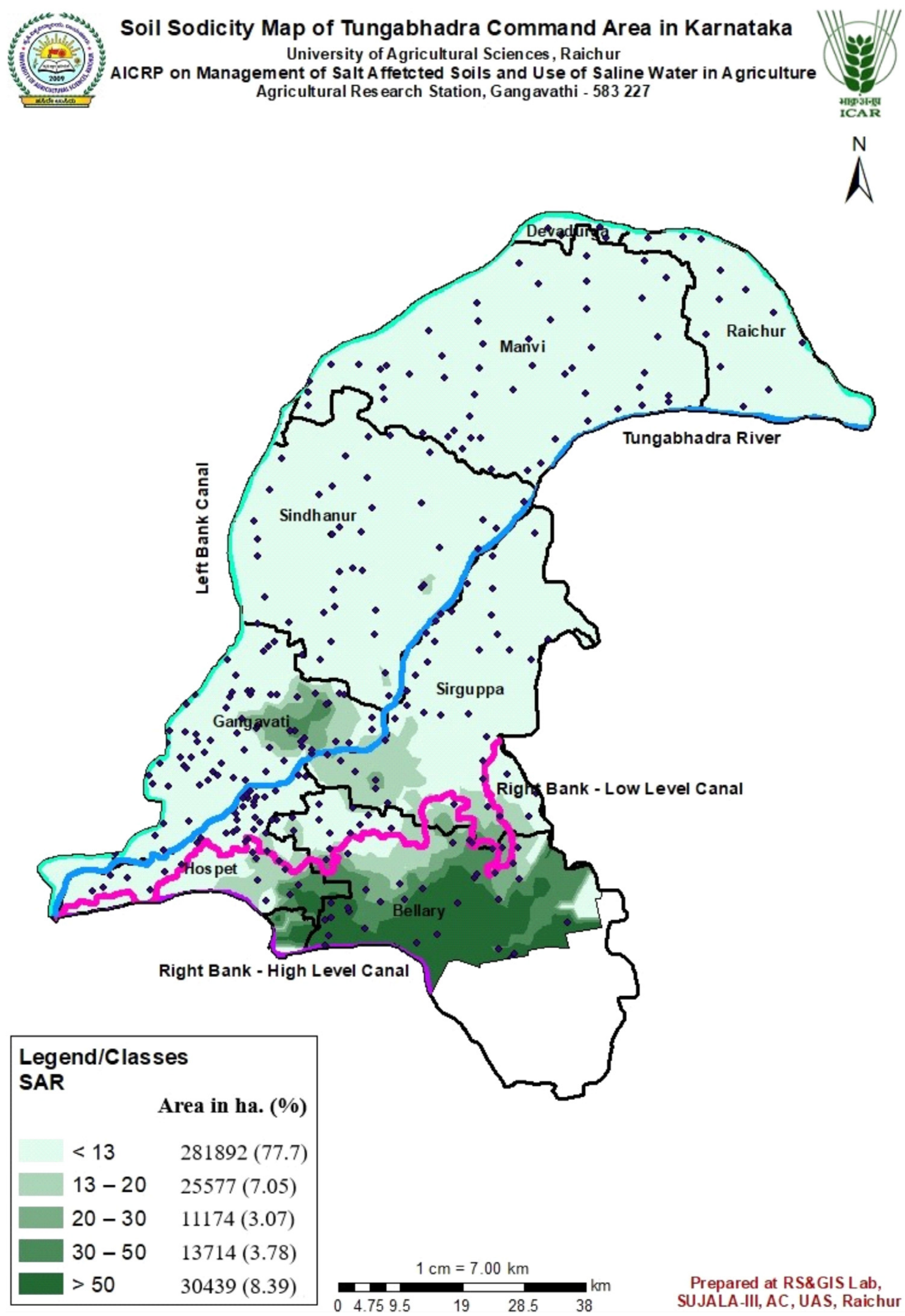

Fig. 3 Map showing the percentage area under different SARe categories in the TBP command area

Table 2. 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
$pH_{2.5}$	10.76	5.72	8.09	10.6	4.76	8.20	10.22	6.54	8.40	10.3	7.06	8.53
$EC_{2.5}$	31.0	0.10	2.11	19.9	0.08	1.45	13.3	0.12	1.56	8.90	0.09	1.40
pH_s	10.23	4.86	7.58	10.3	5.45	7.74	10.08	6.53	7.83	9.65	6.48	7.94
EC_e (ds m^{-1})	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 (me/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 3. Percent distribution of soil properties of samples from TBP command area, Karnataka for soil salinity appraisal

Soil depth (cm)	pH_s			EC_e (dS m^{-1})			$(CO_3+HCO_3)/(Cl+SO_4)$		$Na^+/(Cl+SO_4)$		SAR_e	
	<7.5	7.5-8.5	>8.5	<2.0	2-4	>4	<1	>1	<1	>1	<13	>13
0-15	35.26	61.86	2.88	51.92	27.56	20.19	87.5	12.50	54.49	45.51	76.28	23.72
	(110)	(193)	(9)	(162)	(86)	(63)	(273)	(39)	(170)	(142)	(238)	(74)
15-30	22.62	73.44	3.93	59.67	25.57	14.75	83.93	16.06	50.49	49.51	77.05	22.95
	(69)	(224)	(12)	(182)	(78)	(45)	(256)	(49)	(154)	(151)	(235)	(70)
30-60	27.08	66.67	6.25	60.42	20.42	19.17	83.33	16.67	35.42	64.58	66.25	33.75
	(65)	(160)	(15)	(145)	(49)	(46)	(200)	(40)	(85)	(155)	(159)	(81)
60 +	16.07	77.38	6.55	54.76	25.0	20.24	81.55	18.45	40.48	59.52	62.50	37.50
	(27)	(130)	(11)	(92)	(42)	(34)	(137)	(31)	(68)	(100)	(105)	(63)

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

of calcium-rich minerals including amphiboles, pyroxenes, and feldspars. Magnesium, derived from the weathering of magnesium-rich minerals like olivine, may partially counteract sodicity by replacing sodium on the exchange complex and promoting flocculation of soil particles. Similar findings have been reported by Ragab *et al.* (2008), Cucci *et al.* (2013), Abegunrin *et al.* (2016), Soni (2016), and Singh *et al.* (2020).

Soluble anions

In surface soils (0-15 cm), soluble anions varied from 5.5 to 554.5 me L^{-1} for Cl^-, 3.5 to 259.5 me L^{-1} for CO_3^{2-} + HCO_3^-, and 0 to 4.87 me L^{-1} for SO_4^{2-}, with mean values of 36.21, 12.02, and 0.66 me L^{-1}, respectively. Subsurface soils (15-30 cm) showed Cl^- concentrations ranging from 3.5 to 254.0 me L^{-1}, CO_3^{2-} + HCO_3^- from 2.5 to 54.6 me L^{-1}, and SO_4^{2-} from 0 to 3.68 me L^{-1}, with mean values of 21.9, 9.0, and 0.55 me L^{-1}, respectively. Variations at deeper depths were minimal.

Among anions, chloride was predominant, followed by bicarbonate plus carbonate and sulphate. About 12.5% and 45.5% of surface soil samples exhibited $(CO_3 + HCO_3)/(Cl + SO_4)$ and Na/(Cl + SO,,) ratios greater than 1, respectively,

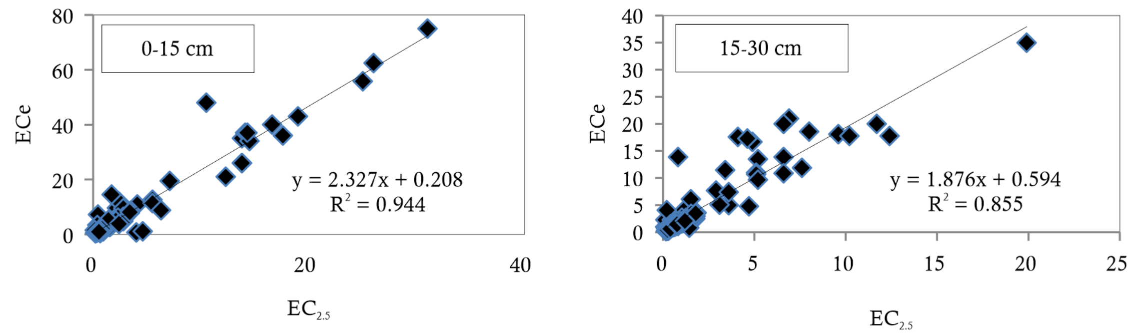

Fig. 4 Relationship between $EC_{2.5}$ and ECe for surface and subsurface soil samples collected from Bellary district

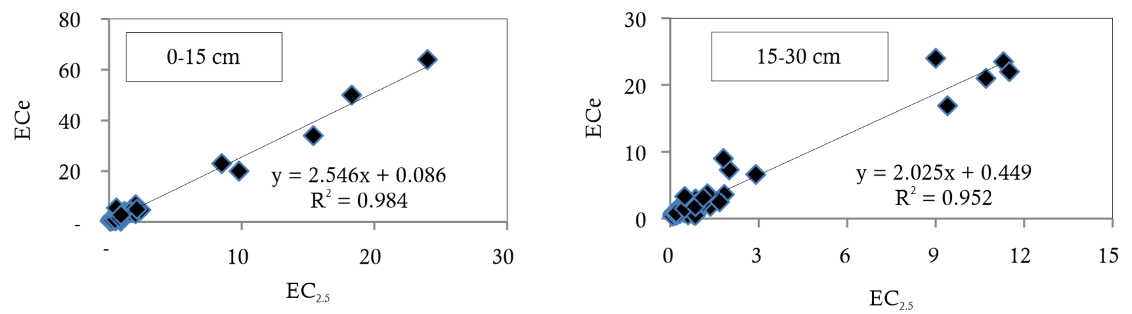

Fig. 5 Relationship between $EC_{2.5}$ and ECe for surface and subsurface soil samples collected from Koppal district

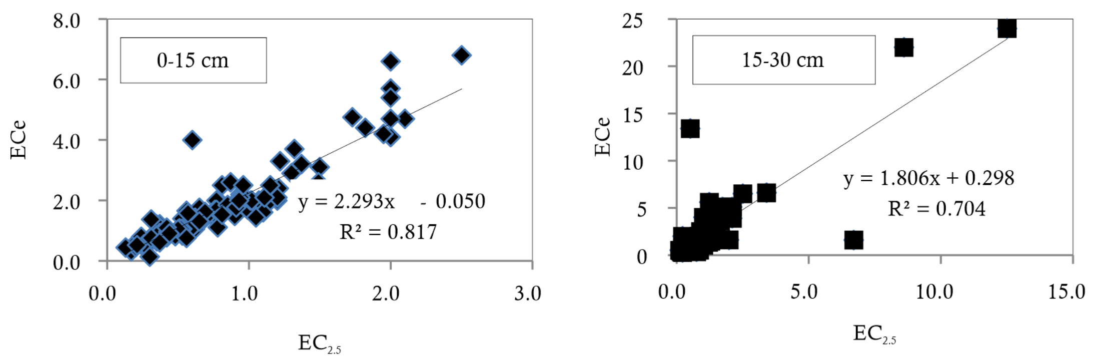

Fig. 6 Relationship between $EC_{2.5}$ and ECe for surface and subsurface soil samples collected from Raichur district

indicating sodic or developing sodic conditions. Consequently, nearly 23.7% of surface samples had SAR_e values exceeding 13. In subsurface soils (15-30 cm), although the overall mean $(CO_3 + HCO_3)/(Cl + SO_4)$ ratio was less than 1, $Na/(Cl + SO_4)$ exceeded 1. Approximately 16% and 49.5% of these samples had ratios greater than 1, respectively, corroborating sodicity risk. Similar trends toward higher salt accumulation were more pronounced at depths of 30-60 and 60-90 cm.

Bicarbonate concentrations were generally higher than carbonate in most irrigated soils, which can be attributed to carbonate weathering and dissolution of carbonic acid in soil solutions. These findings align with reports by Ragab *et al.* (2008), Cucci *et al.* (2013), Abegunrin *et al.* (2016), Soni (2016), and Prabhoo Singh *et al.* (2020). The relationship between $EC_{2.5}$ and EC_e (Figs. 4, 5, and 6) indicated conversion factors of approximately 2.53 and 2.47 for Bellary district, 2.63 and 2.47 for Koppal district, and 2.24 and 2.10 for Raichur district at 0-15 and 15-30 cm depths, respectively.

Conclusions

The present study clearly indicates that soil salinity and sodicity have emerged as serious land degradation problems in the Tungabhadra Project (TBP) command area of Karnataka, primarily due to the violation of recommended cropping patterns, extensive cultivation of water-intensive paddy, and prolonged use of poor-quality surface and groundwater for irrigation. GPS-based grid sampling coupled with geostatistical kriging techniques proved effective in characterizing and spatially delineating salt-affected soils across the command area. The results revealed that a substantial proportion of the command area is affected by varying degrees of salinity and sodicity, with surface soil (0-15 cm) EC_e exceeding 4 dS m^{-1} in about 26.8% of the area and SAR_e values greater than 13 in nearly 22.3% of the command, indicating the prevalence of sodic and saline-sodic soils. Among the districts, Bellary was most severely affected, followed by Koppal (Gangavathi) and Raichur, highlighting spatial variability linked to irrigation practices and drainage conditions. Salt accumulation was more pronounced in subsurface layers, suggesting downward movement and concentration of salts due to inadequate drainage and continuous irrigation. Therefore, in these areas subsurface drainage system is the better option to reduce the soil salinity.

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References

Abegunrin TP, Awe DO, Idowu DO and Adejumobi MA (2016) Impact of wastewater irrigation on soil physicochemical properties, growth and water use pattern of two indigenous vegetables in southwest Nigeria. *Catena* **139:** 167-178.

Command Area Development Authority (CADA), TBP project report 2013, Karnataka, India.

Chhabra R (2004) Classification of salt-affected soils. *Arid Land Research and Management* **1:** 61-79.

Chinchmalatpure AR, Camus D, Vaibhav R, Vibhute S, Kumar S, Prasad I and Shukla M (2018) Assessing groundwater contamination due to heavy metals and their spatial distribution in an industrial area of Western India. *Journal of Soil Salinity and Water Quality* **10(2):** 178-185.

Chesnin L and Yien CH (1951) Turbidimetric determination of available sulphates. *Soil Science Society of America Proceedings* **15:** 149-151.

Cucci G, Lacolla G and Rubino P (2013) Irrigation with saline-sodic water effects on soil chemical-physical properties. *African Journal of Agricultural Research* **8:** 358-365.

Deshmukh KK (2012) Evaluation of soil fertility status from Sangamner area, Ahmednagar district, Maharashtra, India. *Russian Journal of Chemistry* **5:** 398-406.

Huang CH, Xue X, Wang T, Mascellis RD, Mele G, You QG, Peng F and Tedeschi A (2010) Effects of saline water irrigation on soil properties in northwest China. *Environmental Earth Sciences* **63:** 701-708.

Indumathi P, Vishwanatha J, Narayana Rao K, Veeresh H, Mastana Reddy BG and Karegoudar AV (2025) Drip irrigation as a strategy for sustainable paddy cultivation in waterlogged saline Vertisol of TBP command area, Karnataka. *International Journal of Research in Agronomy* **8**(12): 185-195.

Karegoudar AV, Vishwanath J, Anand SR, Rajkumar RH, Ambast SK and Kaledhonkar MJ (2019) Feasibility of controlled drainage in saline vertisols of TBP command area of Karnataka, India. *International Journal of Irrigation and Drainage* **68**: 969–978.DOI:10.1002/ird.2374

Karegoudar AV, Viswanath J, Rajkumar RH, Anand SR, Polisgowdar BS, Ayyanagowdar BS, Nemichandrappa M and Kaledhonkar MJ (2022) Economic feasibility of subsurface drainage to control waterlogging and soil salinity under different scenarios in Tungabhadra project command, Karnataka. *International Journal of Irrigation and Drainage* **71:** 1063-1076. DOI: 10.1002/ird.2716

Mali BS, Thengal SS and Pate PN (2012) Physico-chemical characteristics of salt affected soil from Barhanpur, Maharashtra, India. *Annals of Biological Research* **3:** 4091-4093.

Manjunath MV, Oosterbaan RJ, Gupta SK, Rajkumar H and Jansen H (2004) Performance of subsurface drains for reclaiming waterlogged saline lands under rolling topography in Tungabhadra irrigation project in India. *Agricultural Water Management* **69(1):** 69-82.

Meena HB, Sharma PR. and Rawat US (2006) Status of macro-micronutrients in some soils of Tonk district of Rajasthan. *Journal of the Indian Society of Soil Science* **54:** 508-512.

Mustafa AA, Singh M, Ahmed N, Sahoo RN, Khanna M, Sarangi A and Mishra AK (2016) Soil suitability analysis of crop planning in Kheragarah tehsil of Agra district, Uttar Pradesh. *Journal of the Indian Society of Soil Science* **64:** 311-318.

Patil SG, Hebbara M, Ravishankar G. and Mastanareddy BG (2006) *50 years Journey of Agricultural Research Station, Gangavati. University of Agricultural Sciences, Dharwad*. Shri Bhavani Offset Printers, Hubli.

Ragab AAMM, Helial FA and Abd El-Hady M (2008) Irrigation water salinity effect on some soil water constants and plant. *Twelfth International Water Technology Conference*, IWTC, 12 Alexandria, Egypt pp.1.

Rajkumar RH, Vishwanath J, Annanagouda V Karegoudar, Malharimartand J Kaledhonkar, Anand SR, Anilkumar T Dandekar and Raj Kumar Thakur (2024) Drip irrigation for sustaining high sugarcane (*Saccharum officinarum*) yield in marginally to moderately waterlogged saline vertisols of Karnataka, India. International Commission for Irrigation and Drainage. 1-17. DOI:10.1002/ird.2990.

Raut MM, Raut PD and Balpande SS (2017) Nutrient Status of Some Soil Series of Bhiwapur and their relationship with Physico-Chemical Properties. *International Journal of Pure & Applied Bioscience* **5(6):** 1218-1222.

Richards LA (1954) *Diagnosis and Improvement of Saline and Alkaline Soils.* USDA Hand Book No. 60. Oxford and IBH Pub. Co., New Delhi.

Schwartzenbach G, Biedermann W and Bangerter F (1946) Komplexone VI. Meueeinfache Titrimethodenzur Bestimmung der Wesserharte. *Helvetica Chimica Acta* **29:** 811-818.

Singh P, Sharma KK and Bana RC (2020) Characterization and Mapping of Salt-affected soils of Nagaur District in Rajasthan, India. *Journal of Soil Salinity and Water Quality* **12(2):** 148-154.

Soni M (2016) Analysis of soil samples for its physico-chemical parameters from Abohar city. *The Pharma Innovation Journal* **5(11):** 37-39.

Vibhute SD, Sarangi A, Singh DK, Bandyopadhyay KK, Parihar SS and Kumar D (2017) Comparative evaluation of water budgeting parameters under different rice (Oryza sativa L.) cultivation methods. *Journal of Applied & Natural Science* **9(3)**.

Vibhute SD, Chinchmalatpure AR, Vineeth TV, Kumar S, Gorain B, Prasad I, Camus DD and Shukla M (2024) Alternate use of fresh and saline waters to improve water productivity and soil sustainability of drip irrigated wheat in a semi-arid region. *Arid Land Research and Management* **38(4):** 571-590.

Vibhute SD, Kamra SK, Pathan AL, Bundela DS, Abhishek R, Kumar S and Kumar J (2024) Rapid assessment and mapping of soil salinity in subsurface drainage project using electromagnetic induction and geostatistical analysis. *Journal of Soil Salinity and Water Quality* **16(2):** 249-256.

Vineeth TV, Vibhute SD, Ravikiran KT, Prasad I, Chinchmalatpure A and Sharma, PC (2023) Biosaline agriculture and efficient management strategies for sustainable agriculture on salt affected Vertisols. In *Plant Stress Mitigators* (pp. 249-269). Academic Press.

USSL (1954) In: Richards LA (ed.) *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Handbook, Washington, DC, pp 60.

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