Soil Salinity Mapping Of Different Land Forms
in Villages of Taluka Jafrabad, Dist. Amreli in coastal Gujarat

Submitted to

HeidelbergCement India Limited, Gurugram (Haryana)

Submitted by

ICAR-Central Soil Salinity Research Institute

Karnal- 132 001 (Haryana) INDIA

Final Project Report

Soil salinity mapping of different landforms of 891.7185 ha mining lease area of HeidelbergCement India Limited in villages Rohisha, Balana and Vadhera of Taluka Jafrabad, Dist. Amreli in coastal Gujarat

Submitted to

HeidelbergCement India Limited, Gurugram (Haryana)

Dated: February 06, 2025

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By

ICAR-Central Soil Salinity Research Institute

Karnal- 132 001 (Haryana) INDIA

PROJECT TEAM

Dr. Nirmalendu Basak

Dr. Bhaskar Narjary

Dr. Arvind Kumar Rai

Dr. Anil R. Chinchmalatpure

Dr. Rajender Kumar Yadav

CONTENTS

List of Plates, Tables & Figures

PREFACE

India has an extended coastline and the natural resources of this region need to be assessed for optimum usefulness and prosperity of the society. The dynamics influence of the sea, tidal events, intrusion, inundation of sea brackish water, related terrestrial activities, changes in precipitation, raising temperature, evapotranspiration demand, and industry–trade–harbor settlement at the coastal line needs salinity assessment of the soil and water. Resouces for soil salinity assessment is key to successful crop production and optimal use of the resources in these areas. The cropping system intensification to meet the nation's food security and meeting the targets of land degradation neutrality as a signatory of the UNCCD are the two competing targets faced by the scientific community and policy makers. Therefore assessing soil and groundwater salinity and its delineation is a key to the success of the strategies adopted for arresting land degradation and sustainable land use policy.

The ICAR–Central Soil Salinity Research Institute (CSSRI) is a premier unit under the Indian Council of Agricultural Research with a broad national mandate on the development, assessment and management of technologies for salty lands and waters. The HeidelbergCement India Limited, Gurugram, Haryana sponsored a project to the ICAR–CSSRI under a memorandum of understanding (MOU) for Soil salinity mapping of different landforms of 891.7185 ha mining lease area of HeidelbergCement India Limited in villages Rohisha, Balana and Vadhera of Taluka Jafrabad, Dist. Amreli in coastal Gujarat. The Terms of Reference of MOU were to evaluate the soil salinity map of the landform in and around the mining lease area of the HeidelbergCement India Limited, Gurugram (Haryana) at Rohisa, Balana, and Vadhera villages of Jafrabad taluka of Amreli district, Gujarat covering total 891.7185 hectares land.

The project team thanks HeidelbergCement India Limited, Gurugram, Haryana, for providing the opportunity to survey, and interact with residents and farming community of the area and collection of soil and water samples. We express our gratitude to Dr. Rajender Kumar Yadav, Director ICAR–CSSRI for entrusting this responsibility to this team of scientists. The team records its gratitude to Shri Balbir Singh Rawat, General Manager, Geologist, HeidelbergCement India Limited, Gurgaon, Haryana, Shri Vijay Kumar, J M Environet Pvt Ltd. Gurgaon, Haryana and Shri. Haresh Chauhan, Contact person, Jafrabad taluka, Amreli district, Gujarat for providing this opportunity to ICAR–CSSRI. The salinity and soil and water samples analytical support of Shri Sandeep Bedwal, JRF, Shri Aman Kumar, Project Assistant, and Shri Ravish Kumar, Laboratory Technician and Shri Guninder Singh, Laboratory Technician and Shri Ragbir Singh, Laboratory Technician is also acknowledged. Technical support in preparation and design of this report by Yudhvir S Ahlawat, Sen. Technician is also appreciated. All the basic material for this evaluation work was provided by Sh Balbir Singh Rawat and his team. In addition, they offered other operational support for the evaluation process at ICAR–CSSRI, Karnal. The Research Team would like to officially thank them for outstanding support throughout the mapping of different landforms of 891.7185 ha mining lease area of HeidelbergCement India Limited in villages Rohisha, Balana and Vadhera of Taluka Jafrabad, Dist. Amreli in coastal Gujarat.

Nirmalendu Basak

Bhaskar Narjary

Arvind Kumar Rai

Anil R. Chinchmalatpure

Rajender Kumar Yadav

EXECUTIVE SUMMARY

ICAR–Central Soil Salinity Research Institute, Karnal, and HeidelbergCement India Limited, Gurugram (Haryana) together conducted a collaborative research project to develop soil salinity map of the landform in the lease area of Rohisa, Balana and Vadhera villages, Jafrabad, Amreli. As per the term of reference (ToR), a field survey of mining lease areas of Rohisa, Balana and Vadhera villages, Taluka Jafrabad, Dist. Amreli of total 891.7185 hectares areas was conducted using grid sampling. The biophysical data including information about landform and land use were collected from date 25 April to 4th May, 2024. A proximal ground–based electromagnetic induction soil sensor (EM38MK2) survey was conducted for soil salinity monitoring. The objective of the current study was to develop a soil salinity map of the landform in the lease area of the sponsoring agency HeidelbergCement India Limited, Gurugram (Haryana). For this purpose, depth-wise fifty-two soil samples of 0–15, 15–30, 30–45, 45–60, 60–80, and 80–100 cm were collected from the different landforms and land uses of the mining lease area for detailed analysis. Around 183.6332 ha area falls under the coastal–regulation zone (CRZ) which is around 20.6% of the entire mining lease area. Overall salinity of soils (electrical conductivity of soil water saturation paste extract, (EC_e) was greater (44.84 ppt) under CRZ than the soil collected from non- CRZ areas in villages (1.58 ppt), irrespective of the depth of soil upto 100 cm. The EM38MK2 data showed that 172.833, 175.433, 165.033, and 171.933 ha areas under CRZ had electrical conductivity (EC) >5 ppt at 0–15, 15–30, 30–60 and 60–100 cm depth. Along soil depth *kankar* (calcium carbonate) and amorphous calcium carbonate content increased. Amorphous calcium carbonate ($CaCO_3$) content (w/w) was greater in cultivated soils of villages than in soils under CRZ. Mono cropping and at few places, two hundred percent cropping intensity with pearl millet–channa, cotton–pearl millet, cotton–wheat, cotton–fallow, fallow–Chana, isolated orchards of coconut, barren fallow land are followed in three villages. The soils of these land uses have a salt content of <2.0 ppt irrespective of soil depth up to 100 cm. The groundwater of these villages is mostly saline to strongly saline in categories. About 333 ha area has high sodium adsorption ratio (SAR) groundwater. About 155 ha area had the Mg to Ca ratio>1.2. Further, 574 ha areas showed high chloride to carbonate content in their groundwater (>2.0). Amorphous and *crystalline* calcium carbonate (*kankar)* constitutes about 50–60% of total soil mass in an entire profile of 0–100 cm. Therefore, supply of organic amendments, compost, brown manure, and cultivation salt–tolerant crops, and salt–tolerant cultivars are recommended for cultivation in Rohisa, Balana and Vadhera villages at Jafrabad Taluka, Amreli, Gujarat. These areas need good quality water irrigation through rainwater harvesting for prevention of soil salinization due to groundwater–dependent cultivation.

1. INTRODUCTION

Coastal regions are rich in natural resources, important minerals–limestone, lignite, bauxite, soda ash, production of various types of salts. Coastal talukas of Gujarat state have extensive deposits of Miliolitic rocks and these are very important areas for mining leases of soda ash and cement–producing raw materials. The country's leading cement and salt manufacturing agencies produce an appreciable quantity of cement from the coastline of Gujarat. India has an extended coastline, and many countrymen like to reside in coastal areas. The natural resources, demographic exploration, resourceful habitation, and industry–trade–harbor settlement enrich the sea–coastline's urbanization. Therefore, the land use and landform changes because of marine and terrestrial processes, coastal erosion, urbanization, mining of natural resources and changes in rainfall patterns, the arrival of frequent storm surges, tidal events, and temperature aberrations are threatening the ecosystem services in the coastal region of India. The common ecological constraints are the intrusion of brackish water, sea level rise, congestion of ingress saline and high sodium or magnesium–rich sea water, impedes drainage, waterlogging and shortage of freshwater, and occurrence of acid sulphate soil, the serious threat for land degradation and buildup salinity in coastal soils. Further, rises in temperature, drought, and anthropogenic activities, and erratic rainfall behavior increase soil evaporation demand. Soils of the coastal region are saline in nature. There are rhythmic changes in electrolyte concentrations in summer, *monsoon* (July–Sept), and spring seasons (March–May) because of intrusion of ingress brackish water alters the soil's physical structure.

The ICAR–Central Soil Salinity Research Institute (CSSRI) was established in 1969 to initiate systematic research on salt–affected soils (SAS) and poor–quality water resources in the country. The mandate of the institute is to i) identify the nature and characteristics of salinity/water quality problems and areas prone to salinity development in a GIS framework; ii) undertake strategic and adaptive research to manage salinity–related problems at different scales and develop options for preventing land degradation due to excess salts based on better understanding of salt and water balances; iii) develop a national level network of salinity related activities and provide funding support to address location–specific problems; and iv) build research capacity for prevention, control, and management of salinity problems. The objective of the project was to develop soil salinity map of the land form in and around the mining lease area of the HeidelbergCement India Limited, Gurugram (Haryana) at Rohisa, Balana, and Vadhera villages of Jafrabad taluka of Amreli district, Gujarat covering total 891.7185 hectares land.

2. METHODOLOGY

Soil sample analysis

Depth-wise soil samples were collected from 0–15, 15–30, 30–45, 45–60 and 60–80 and 80–100 cm of location as mentioned in Table I during April 5 to May 4, 2024. After receipt of soil samples at the laboratory of ICAR CSSRI, Karnal, the soil samples were air dried at shadow and weight of soil was measured. Further, soil samples were sieved using 2-mm sieve and the large sized *kankar* were separated and its weight was measured to calculate the *kankar* content (w/w). Then the rest soil samples were ground using a wooden pestle and mortar to pass through a 2–mm sieve, and used for analyzed of soil chemical attributes. The soil pH_s was determined in aqueous soil paste of the soil and water by using a digital pH meter (**Richards, 1954**). For the determination of electrical conductivity of saturation extract (EC_e), the aqueous extract of saturated soil paste was readily removed from the soil paste under suction at 0.88 kg cm^{-2} force (**Richards, 1954**). Calcium carbonate was determined by a manometric method using Collin's calcimeter (**Allison and Moodie, 1965**). Organic C content of the soils under different land uses was determined following Walkley and Black's method (**Jackson, 1967**). Ca^{2+} and Mg^{2+} in saturation extract (EC_e), the aqueous extract were estimated by complexometric titration involving ethylene diaminetetraacetic acid (EDTA) developed by Schwarzenbach, Biedermann, and Bangerter (1946) and Na concentration measured in Flame photometers. Sodium adsorption ratio (SAR_e) saturated soil paste was determined as

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}}$$

Where, [ ] represents the concentration of cations me L^{-1}.

Supplementary table 1. Classes of soil salinity

Classes	Soil salinity level	TDS (ppt)	Effect on plant
1	Non saline	<0.5	No adverse effects
2	Slightly saline	0.5-1.5	Minor effects on sensitive crops
3	Moderately saline	1.5-3.0	Affects some crops, but manageable
4	Strongly saline	3.0-5.0	Significant effects on most crops
5	Very strongly saline	>5.0	Only salt-tolerant crops can survive

Supplementary table 2. Classes of water salinity

Classes	Soil salinity level	TDS (ppt)
1	Fresh water	<2.0
2	Saline	2.0-4.0
3	Strongly saline	>4.0

Supplementary table 3. Degree of contamination groundwater [Chloride/Carbonates (Cl/CO_3)]

Classes	Degree of contamination of groundwater	Chloride/Carbonates
1	Fresh groundwater	≤1
2	Slightly contaminated	1-2
3	Moderately contaminated	2-6
4	Injuriously contaminated	6-15
5	Highly contaminated or sea water	>15

Soil salinity mapping of different landforms of 891.7185 ha mining lease area

As per the term of reference (ToR), a field survey of mining lease and surrounding areas in villages Rohisa, Balana and Vadhera villages of Jafrabad taluka of Amreli district of Gujarat covers total 891.7185 hectares area was conducted using grid sampling. The biophysical data including information about landform and land use were collected from 25th April to 4th May, 2024. A proximal ground–based electromagnetic induction soil sensor (EM38MK2) survey was conducted for soil salinity monitoring. The depth–wise soil samples (0–15, 15–30, 30–45, 45–60, 60–80, and 80–100 cm) were collected from the different landforms and land uses of the mining lease areas for detailed analysis (**detail at Annexure I ; Plate 1, 2, and 3**). Further, the geographical position of each soil and water sampling point and field measurement points of EM38MK2 data were marked in the Google Earth for demarcated soil sampling points (**Plate 4**).

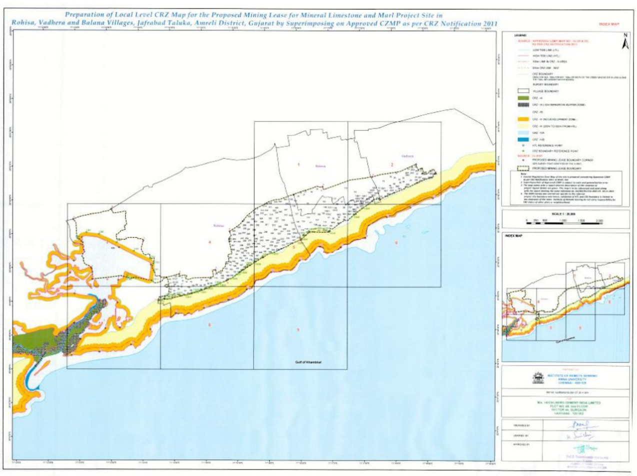

Plate 1. Map of studied areas (Provided by HiedelbergCement India Ltd.)

Plate 2. a) Collection of depth–wise soil sampling from barren fallow, b) cropland,c) hard calcareous deposit, d) coastal regulation zone (CRZ), e) pearl millet field f) EM based salinity measure

Plate 3. a) Groundwater sampling; b) Coastal regulation zone sampling

Plate 4. Sampling point: The small red point showing the proximal EM38MK2 based soil salinity data and wide green point showing the soil and water sample collecting points (data points incorporated in https://earth.google.com/).

3. RESULT AND SALIENT FINDINGS

Among the studied villages - Rohisa, Balana and Vadhera, around 183.6332 ha area of total mining lease falls under coastal regulation zone (CRZ) which is around 20.56% area of the lease area. Irrespective of soil depth (0–15, 15–30, 30–45, 45–60, 60–80 and 80–100 cm), overall salinity of soils (electrical conductivity of soil water saturation paste extract, EC_e) was greater (43.09 ppt) under CRZ than the soil collected from villages (1.51 ppt) (**Table 1 and 2; Fig. 1**). Soil salinity was similar upto 60 cm soil depth and thereafter it increased 60 to 75 cm depth and remained similar upto 90 cm for soil collected from CRZ. However, the salinity of the soils was nearly identical in all the depths collected from villages. The EM38MK2 data showed that 172.833, 175.433, 165.033, and 171.933 (red zone) under CRZ had electrical conductivity (EC) >5 ppt at 0–15, 15–30, 30–60 and 60–100 cm depth (**Table 3**; **Plate 5, 6, 7 and 8**). Further, around 10.7, 7.1, 10.2, 4.9 ha area had EC within a range of 3.0–5.0 ppt (orange) at 0–15, 15–30, 30–60, and 60–100 cm depth. Areas of 0.1, 1.1, 6.6, and 6.8 ha had EC 1.5–3.0 ppt (green zone), respectively. In Rohisa, Balana, and Vadhera villages, around 649.8668 ha area was under cultivated land, settlement, and road, which is around 80% of these villages (**Table 3**). The EM38MK2 analysis showed that 7.9, 17.3, and 21.8 ha in the depth of 0–15, 15–30, and 60–90 cm ha (blue) areas had EC between <1.5 ppt (**Table 3**; **Plate 5, 6, 7 and 8**). Further, appreciable areas around 457.1, 451.3, 114.0, and 305.5 ha in the depth of 0–15, 15–30, 30–60 and 60–90 cm (green) areas had EC between 1.5–3.0 ppt (**Table 3; Plate 5 to 8**). Similarly, 162.4, 146.0, 344.2, and 175.2 ha in the depth of 0–15, 15–30, 30–60 and 60–90 cm (orange) areas had EC between 3–5 ppt. Further, 22.5, 35.2, 191.6 and 147.4 ha had EC >5 ppt at 0–15, 15–30, 30–60, and 60–100 cm depth.

The studied soils were alkaline in reaction (**Table 1; Fig. 1**). Along depth soil pH_s (pH of soil water saturation paste extract) increased and the mean values of pH_s were greater for soil of cultivated areas of villages than soil under CRZ. The *kankar* (lime nodules) content (w/w) was greater in soils of CRZ than cultivated areas of village. Along soil depth *kankar* content increased. Whereas, amorphous calcium carbonate ($CaCO_3$) content (w/w) was greater in cultivated soils of villages than soils under CRZ. Likewise, amorphous $CaCO_3$ increased along depth. Sodium adsorption ratios (SAR_e) of soil water saturation paste extract indicate the sodicity hazard was many-fold higher for soils under CRZ than cultivated soils under villages. Along depth, SAR_e slightly increased for soils under cultivated areas of the village whereas, these values decreased in soils under CRZ. The Walkley Black organic carbon content was greater for soils under CRZ than cultivated soils under villages. With an exception at 30–45 cm soil depth in CRZ, organic C content decreased along depth.

Table 1. Physiochemical properties of collected soils along depth (n indicated the number of soil samples mean ± standard error)

Soil depth (cm)	Electrical conductivity (EC, ppt)		pHs		Kankar (Calcium carbonate) (%)	
	CRZ (n=3)	Cultivated village land (n=12)	CRZ (n=3)	Cultivated village land (n=12)	CRZ (n=3)	Cultivated village land (n=12)
0-15	39.17±16.53	1.44±0.36	7.46±0.08	7.68±0.04	20.08±4.99	13.90±1.60
15-30	37.97±17.24	1.33±0.32	7.71±0.05	7.85±0.04	23.60±5.66	14.84±1.39
30-45	34.98±16.55	1.16±0.33	7.79±0.07	7.84±0.04	22.92±4.20	17.22±1.78
45-60	51.29±15.96	1.36±0.38	7.79±0.07	7.92±0.04	27.72±4.88	17.69±1.75
60-80	47.97±24.94	2.19±1.14	7.82±0.05	8.01±0.05	27.37±5.18	19.79±2.25
80-100	47.13±23.59	1.59±0.45	7.75±0.05	8.00±0.05	26.96±5.88	18.23±1.75
Mean	43.09	1.51	7.72	7.88	24.78	16.95

Soil depth (cm)	SAR_e		Amorphous $CaCO_3$ (%)		Walkley Black organic C ($g\ kg^{-1}$)	
	CRZ (n=3)	Cultivated village land (n=12)	CRZ (n=3)	Cultivated village land (n=12)	CRZ (n=3)	Cultivated village land (n=12)
0-15	71.07±15.8	13.87±2.5	18.80±3.8	39.37±2.9	9.53±0.57	7.08±0.63
15-30	66.61±15.7	11.26±2.3	23.22±4.0	45.82±4.3	10.62±3.64	5.56±0.65
30-45	72.32±23.8	10.14±2.3	28.55±7.6	47.50±4.4	8.56±1.53	5.06±0.64
45-60	64.40±18.9	10.58±1.1	30.18±9.9	43.67±6.3	13.02±2.01	4.42±0.69
60-80	31.28±6.2	18.54±6.9	44.88±8.1	46.23±5.2	4.63±1.66	5.01±0.60
80-100	26.94±18.9	18.56±6.1	43.84±7.0	48.26±5.1	4.83±2.18	5.33±0.70
Mean	55.44	13.83	31.58	45.14	8.53	5.41

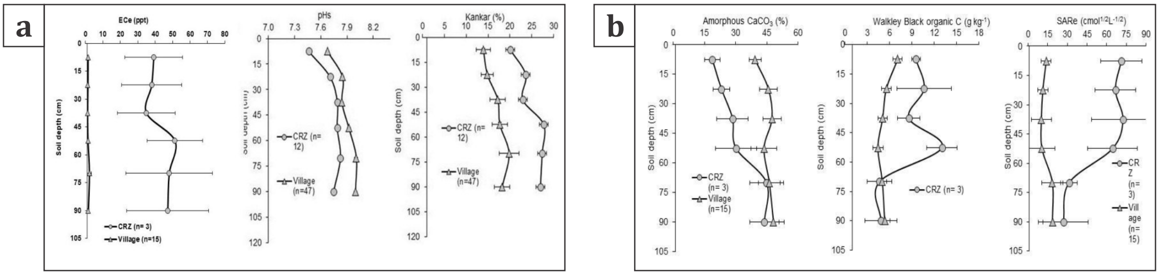

Fig. 1. Physiochemical properties of collected soils along depth (n indicated the number of soil samples mean ±standard error); CRZ: coastal regulation zone; village: cultivated village land

Table 2. Physiochemical properties of collected soils along depth (range); n indicated the number of soil samples mean ±standard error

Landuse/soil depth (cm)	0–15	15–30	30–45	45–60	60–80	80–100
			EC_e (ppt)			
CRZ (n= 12)	7.45–63.09	7.44–67.11	5.65–62.92	23.79–79.08	2.96–89.09	3.71–84.84
Cultivated village land (n=47)	0.26–4.74	0.20–4.11	0.04–4.68	0.15–5.15	0.13–17.80	0.14–5.90
			pHs			
CRZ (n= 12)	6.98–7.86	7.39–7.96	7.28–8.06	7.42–8.10	7.58–8.17	7.43–8.08
Cultivated village land (n=47)	7.03–8.36	7.30–9.09	7.27–8.89	7.46–9.25	7.63–9.14	7.49–9.06
			Kankar (%)			
CRZ (n=12)	8.7–69.6	10.2–69.6	9.1–58.7	10.9–64.2	9.5–67.9	7.0–68.2
Cultivated village land (n=47)	2.2–68.5	1.8–44.4	2.0–71.9	2.1–63.2	2.8–87.8	2.6–62.2

Table 3. Distribution of the soil salinity (ppt) in surveyed areas (ha) of coastal regulation zone(CRZ) and village cropland along depth (cm) of Rohisa, Balana and Vadhera villages, Jafarabad, Amreli (Gujarat) in April–May 2024; non–saline to slightly saline < 1.5; moderately saline 1.5–3.0; strongly saline 3.0–5.0; very strongly saline >5.0.

Salinity class /soil depth	0–15 cm	15–30 cm	30–60 cm	60–100 cm	Salinity class	0–15 cm	15–30	30–60 cm	60–100cm
< 1.5	–	–	1.8	–	< 1.5	7.9	17.3	–	21.8
1.5–3.0	0.1	1.1	6.6	6.8	1.5–3.0	457.1	451.3	114	305.5
3.0–5.0	10.7	7.1	10.2	4.9	3.0–5.0	162.4	146	344.2	175.2
>5.0	172.833	175.433	165.033	171.933	>5.0	22.5	35.2	191.6	147.4
CRZ	183.6332	183.6332	183.6332	183.6332	Village area	649.8668	649.7668	649.7668	649.8668

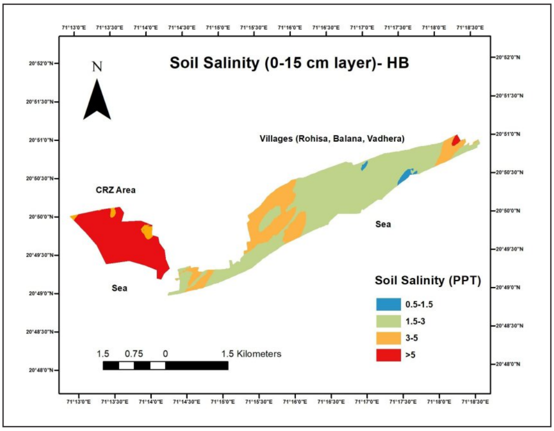

Plate 5. Spatial soil salinity (EC_e) map of studied village for soil depth 0–15 cm

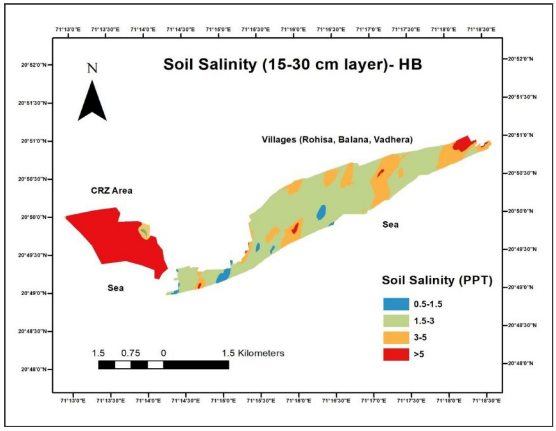

Plate 6. Spatial soil salinity (EC_e) map of studied village for soil depth 15–30 cm

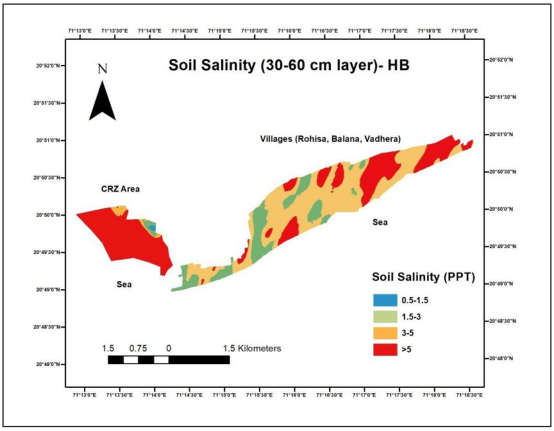

Plate 7. Spatial soil salinity (EC_e) map of studied village for soil depth 30–60 cm

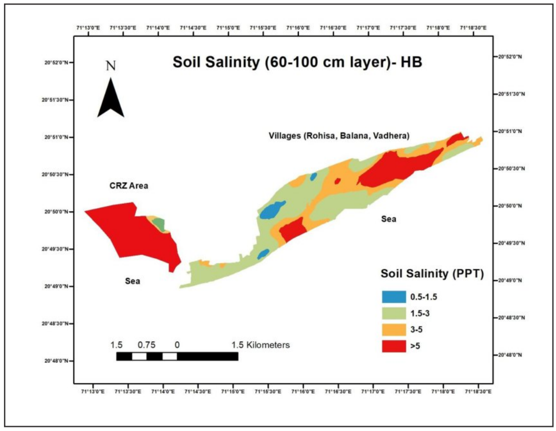

Plate 8. Spatial soil salinity (EC_e) map of studied village for soil depth 60–100 cm

Groundwater quality

In Rohisa, Balana and Vadhera villages, the electrical conductivity of groundwater sample varied from 0.87–44.71 ppt and SAR 2.61–18.09 $cmol^{1/2}L^{-1/2}$, the presence of Mg in comparison to Ca varied from 0.86 to 1.62 and chloride to carbonate ratio varied from 0.54–65.31 (Table 4; Annexture ii). Overall the groundwater was alkaline in reaction and carried soluble salts of mean 4.72 ppt. Around 52.2 ha (green), 389.8 ha (yellow brown), and 188.6 ha (red) area had EC <2.0, 2–4, and > 4.0 ppt (Table 5; Plate 9). Around 135 ha (blue), 162 ha (dark green), 176 ha (light green), 78 ha (yellow), 71 ha (orange), and 8 ha (red) areas of these villages had groundwater SAR of 2–6, 6–8, 8–10, 10–12, 12–14 and 14–20 $cmol^{1/2}L^{-1/2}$ (Plate 10 and Table 5). Further, 170 ha (green) and 461 ha (blue) areas had pH 7.6–7.8 and 7.4–7.6 (Plate 11). An area of about 59 ha, 418 ha, 154 ha and 1.0 ha areas had Mg to Ca ratio 0.8–1.0, 1.0–1.2, 1.2–1.4 and 1.4–1.6, respectively (Plate 12). The level of contamination of groundwater by sea water was calculated by chloride carbonate ratio were 11.2, 45.4, 375.7, 159.0, and 39.3 ha under fresh groundwater (blue), slightly contaminated (light green), moderately contaminated (yellow), injuriously contaminated (orange) and highly contaminated (red) of ratios <1.0, 1–2, 2–6, 6–15 and >15. Areas of 59, 418, 154, and 1 ha had Mg to Ca ratio in groundwater 0.8–1 (blue), 1–1.2 (green), 1.2–1.4 (orange), 1.4–1.6 (red).

Table 4. Groundwater quality attributes of collected water (n=23)

Parameter	pH	EC (ppt)	SAR	Mg to Ca ratio	Cl/CO_3
Range	7.21–8.14	0.87–44.71	2.61-18.09	0.86–1.62	0.54–65.31
Mean	7.6	4.72	8.9	1.1	6.59
S.E. (±)	0.1	1.77	0.9	0.01	2.63

Table 5. Variation of salinity (EC, ppt), SAR, pH, and abundance of Mg to Ca and their estimated areas (ha) in groundwater of Rohisa, Balana and Vadhera villages, Jafarabad, Amreli (Gujarat) in April–May 2024 (n=24)

Salinity class (EC, ppt)	Area (ha)	SAR	Area (ha)	pH	Area (ha)	Mg/Ca	Area (ha)	Cl/CO3	Area (ha)
Fresh water <2	52.2	2–6	135.0	7.4–7.6	461.0	0.8–1	59.0	Fresh groundwater (<1.0)	11.2
Saline 2-4	389.8	6–8	162.0	7.6–7.8	170.0	1–1.2	418.0	Slightly contaminated (1–2)	45.4
>4									
Strongly saline	188.6	8–10	176.0			1.2–1.4	154.0	Moderately contaminated (2–6)	375.7
		10–12	78.0			1.4–1.6	1.0	Injuriously contaminated (6–15)	159.0
		12–14	71.0					Highly contaminated or sea water (>15)	39.3
		14–20	8.0						

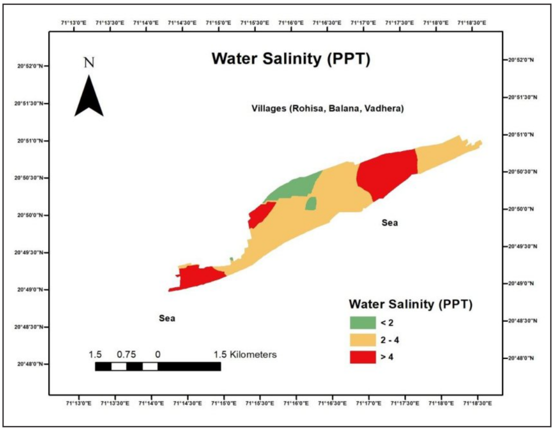

Plate 9. Groundwater salinity (EC) map of studied villages

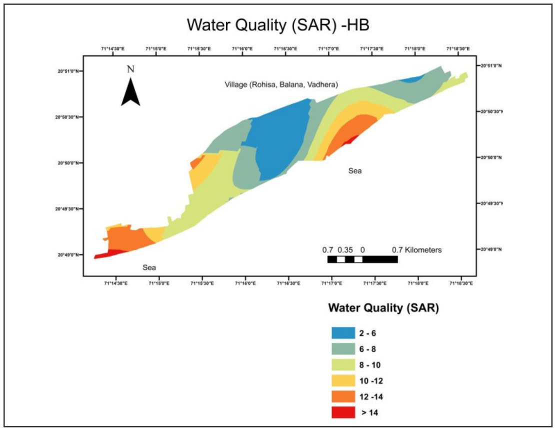

Plate 10. Groundwater salinity SAR map of studied villages

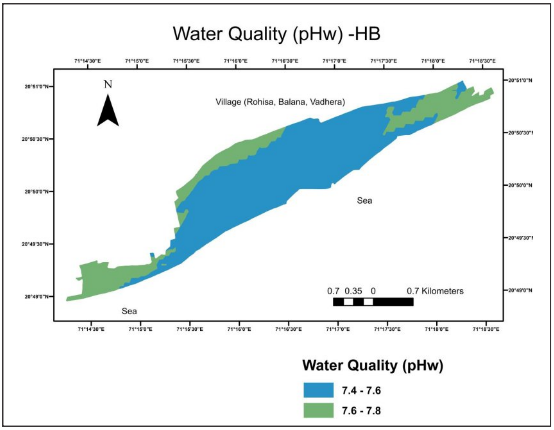

Plate 11. Groundwater pH map of studied villages

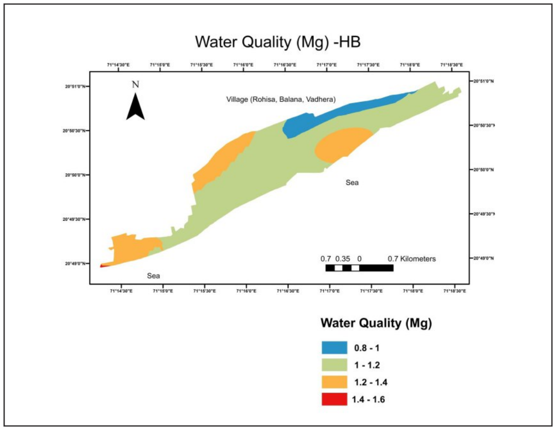

Plate 12. Groundwater Mg to Ca ratio map of studied villages

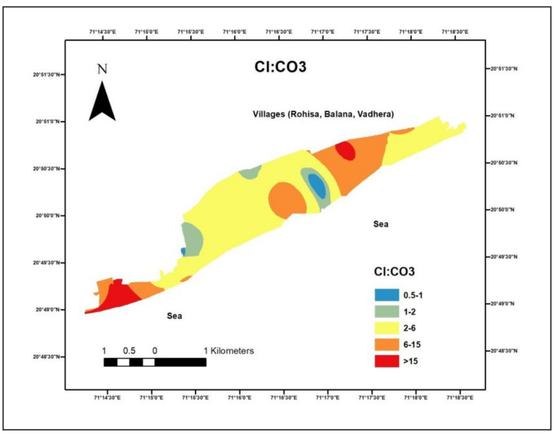

Plate 13. Groundwater chloride carbonate (Cl–CO_3) ratio map of studied villages

4. CONCLUSIONS

Irrespective of analyses of both soil and water testing and field survey of EM-38 based soil salinity made the following conclusion:

i) Around 183.6332 ha area falls under coastal regulation zone (CRZ) which is around 20.56% of the entire mining lease area of 891.7185 ha.

ii) Overall salinity of soils (electrical conductivity of soil water saturation paste extract, EC_e) was greater (44.84 ppt) under CRZ than the soil collected from villages adjacent to CRZ (1.58 ppt), irrespective of the depth of soil upto 100 cm. Further, the depth–wise salinity in soil (EC_e) were 39.17±16.53, 37.97±17.24, 34.98±16.55, 51.29±15.96, 47.97±24.94, 47.13±23.59 ppt (mean± standard error) within the CRZ while 5.39±0.34, 4.80±0.42, 4.33±0.44, 5.30±4.53, 13.43±8.33 and 13.93±7.85 ppt adjacent to CRZ and 1.46±1.09, 1.11±0.38, 0.78±0.27, 1.00±0.35, 0.98±0.44 and 0.56±11 ppt at the farthest points from CRZ boundary (1.40 km) at 0–15, 15–30, 30–45, 45–60, 60–80 and 8–100 cm soil depth, respectively.

iii) The EM38MK2 a data showed that 172.833, 175.433, 165.033, and 171.933 ha areas under CRZ had electrical conductivity (EC) >5 ppt at 0–15, 15–30, 30–60 and 60–100 cm depth.

iv) Along soil depth *kankar* (calcium carbonate) and amorphous calcium carbonate content increased. Amorphous calcium carbonate ($CaCO_3$) content (w/w) was greater in cultivated soils of villages than in soils under CRZ.

v) Sodium adsorption ratios (SAR_e) of soil water saturation paste extract indicate the sodicity hazard was higher for soils under CRZ than cultivated soils under villages.

vi) The Walkley Black organic carbon content was greater for soils under CRZ than cultivated soils under villages.

vii) The electrical conductivity of groundwater sample varied from 0.87–44.71 ppt and SAR 2.61–18.09 $cmol^{1/2}L^{-1/2}$, the presence of Mg in comparison to Ca varied from 0.86 to 1.62 and chloride to carbonate ratio varied from 0.54–65.31.

An area of about 59 ha, 418 ha, and 154 ha had Mg to Ca ratio 0.8–1.0, 1.0–1.2, and 1.2–1.4, respectively. Chloride carbonate ratios calculated that the level of contamination of groundwater by sea water was 11.2, 45.4, 375.7, 159.0, and 39.3 ha under fresh groundwater, slightly contaminated, moderately contaminated, injuriously contaminated and highly contaminated of ratios <1.0, 1–2, 2–6, 6–15 and >15. Further, the depth–wise salinity in soil (EC_e.). The influence of seawater was prominent in the coastal regulation zone (in all the studied depths 0–100 cm) and the Sarkeshwar Beach areas (60–100 cm depth) as evidenced by high sodium adsorption ratio (SAR), high Mg to Ca ratio and chloride to carbonate ratio. The values of the salinity in soil and water samples in these two areas were higher.

5. RECOMMENDATION

Field visits, soil survey analyses of depth–wise soil and water samples, and *in situ* measurement of EM38MK2 showed that coastal regulation zone (CRZ) had salinity much higher than the upper limit of even the salt–tolerant crop. It had sodicity problem (high sodium adsorption ratio) and an abundance of amorphous and *kankar* calcium carbonate.

Mono cropping and a few places two hundred percent cropping intensity with pearl millet–channa, cotton–pearl millet, cotton-wheat, cotton-fallow, fallow-chana, isolated orchard of coconut, barren fallow land are followed in three villages. The soil of these land uses has salt content of <2.0 ppt irrespective of soil depth upto 100 cm.

Soils of the lower layers (above 15 cm to 100 cm) are alkaline in nature and carry nearly mild sodicity to sodicity (SAR_e 10.6 to 18.6).

The groundwater of these villages is mostly saline to strongly saline in categories. About 333 ha area has high SAR groundwater. About 155 ha area had the Mg to Ca ratio>1.2. Further, 574 ha areas showed moderate to high contamination by seawater.

These areas need good quality water irrigation. Therefore, for any rehabilitation plan, the development of water harvesting structures at suitable places may be a promising options for reclamation and prevention of soil salinization.

Amorphous and *crystalline* calcium carbonate (*kankar)* constitutes about 50–60% of total soil mass in entire profile of 0–100 cm.

The large abundance of calcium carbonate is not suitable for optimum crop productivity and interfere with nutrient availability of crop plant. As a subtropical situation, the soil carries a marginal to moderate (only surface 0–15 cm) amount of Walkley Black organic C. Therefore supply of organic amendments, compost, brown manure, and cultivation salt–tolerant crop and salt–tolerant pearl millet, wheat (KRL 210, KRL 213), cotton and chhana (Karnal Chhana) is recommended.

Annexure- I

Soil sampling locations and land uses at collected sites during April 25 –May 5, 2024

Sr. No.	Sample code	Land use	Latitude, N	Longitude, E
1	HB1D1	Fallow-Fallow-Chana	20° 49’ 54.72’’	71° 13' 31.39”
2	HB2D1	Pearl millet	20° 50’ 10.88”	71° 17' 10.13”
3	HB3D1Extra	Fallow	20° 50' 22.11”	71° 17' 06.35”
4	HB3D1	Cotton-Pearl millet	20° 50' 22.03”	71° 17' 06.35”
5	HB4D1Ex	Barren, very hard	20° 50' 39.96”	71° 17' 20.15”
6	HB4D1	Pearl millet-Channa	20° 50' 30.03”	71° 17' 23.53”
7	HB5D1Extra	Barren; very hard	20° 50' 32.44”	71° 17' 10.61”
8	HB5D1	Cotton-Pearl millet	20° 50' 29.49”	71° 17' 05.61”
9	HB6D1	Cotton-Pearl millet	20° 50' 00.62”	71° 16' 45.31”
10	HB7D1	Baran soil profile photo	20° 51' 39.81”	71° 10' 04.05”
11	HB8D1	Baran fallow	20° 49' 46.84”	71° 13' 42.95”
12	HB9D1	Sea water inundation in 15 days CRZ	20° 49' 46.80”	71° 13' 42.93”
13	HB10D1	Sea water inundation in 15 days CRZ	20° 49' 52.51”	71° 13' 18.61”
14	HB11D1	Sea water inundation in 15 days CRZ	20° 49' 42.33”	71° 13' 19.57”
15	HB12D1	Sea water inundation in 15 days CRZ,	20° 49' 43.38”	71° 13' 19.78”
16	HB13D1	Barren fallow very hard calcareous layer	20° 50' 38.81”	71° 13' 50.10”
17	HB14D1	Cotton-Pearl millet	20° 50' 35.09”	71° 16' 49.69”
18	HB15D1	Fodder-fodder-fodder	20° 50' 28.62”	71° 16' 25.08”
19	HB16D1	Cotton-Pearl millet	20° 50' 28.60”	71° 16' 24.99”
20	HB17D1	Barren fallow Profile	20° 50' 35.90”	71° 17' 00.10”
21	HB18D1	Cotton-wheat	20° 49' 59.30”	71° 16' 35.40”
22	HB19D1	Cotton-wheat	20° 49' 49.60”	71° 16' 30.20”
23	HB20D1	Coconut	20° 49' 49.70”	71° 16' 22.00”
24	HB21D1	Cotton-Fallow	20° 50' 05.80”	71° 16' 54.60”
25	HB22D1	Cotton-Fallow	20° 50' 54.30”	71° 17' 51.20”
26	HB23D1	Pearl millet	20° 51' 00.60”	71° 18' 17.70”
27	HB24D1	Fallow gocharan	20° 50' 42.60”	71° 17' 50.30”
28	HB25D1	Vegetables	20° 50' 42.20”	71° 18' 01.10”
29	HB26D1	Pearl millet	20° 50' 57.00”	71° 18' 19.60”

Sr. No.	Sample code	Land use	Latitude, N	Longitude, E
30	HB27D1	Pearl millet-cotton	20° 49' 12.70”	71° 15' 07.80”
31	HB28D1	Pearl millet-cotton	20° 49' 17.80”	71° 15' 10.00”
32	HB29D1	Pearl millet-cotton	20° 49' 23.80”	71° 15' 07.60”
33	HB30D1	Pearl millet-cotton	20° 49' 31.70”	71° 15' 06.60”
34	HB31D1Extra	Chattan CaCO3	20° 49' 07.90”	71° 15' 13.20”
35	HB31D1	Pearl millet-cotton	20° 49’ 42.2”	71° 15' 11.80”
36	HB32D1	Pear millet fidder	20° 49' 00.00”	71° 00' 17.50”
37	HB33D1	Cotton-pearl mitter, Sarkeshwar	20° 49' 54.30”	71° 17' 03.30”
38	HB34D1	Cotton-pearl mitter	20° 49' 50.00”	71° 16' 47.30”
39	HB35D1	Cotton-pearl mitter	20° 49' 46.30”	71° 16' 42.20”
40	HB35D1Ex	Fallow barren	20° 49' 47.20”	71° 16' 39.60”
41	HB36D1	Chick pea gram, Waterlogging in monsoon	20° 50' 16.90”	71° 17' 46.00”
42	HB37D1	Fallow	20° 50' 15.70”	71° 17' 49.80”
43	HB38D1	Pearl mittet	20° 50' 01.10”	71° 17' 05.60”
44	HB39D1	Cotton caster	20° 50' 14.50”	71° 16' 15.50”
45	HB40D1	Coconut orchard	20° 50' 09.40”	71° 16' 22.20”
46	HB41D1	Cotton-pearl mitter	20° 50' 23.30”	71° 16' 00.30”
47	HB42D1Ex	Fallow barren	20° 49' 43.90”	71° 13' 58.50”
48	HB43D1Ex	Barren Fallow	20° 49' 43.10”	71° 14' 00.50”
49	HB42D1	Barren CRZ	20° 49' 20.40”	71° 14' 07.60”
50	HB43D1	Barren fallow	20° 49' 13.80”	71° 14' 08.30”
51	HB44D1Ex	Barren CRZ	20° 48' 44.60”	71° 14' 15.00”
52	HB44D1	Cotton	20° 48' 58.80”	71° 14' 36.80”
53	HB45D1	Pearl millet-cotton, no sea water	20° 50' 00.97”	71° 12' 53.80”
54	HB46D1	Barren CRZ	20° 50' 12.50”	71° 13' 14.30”
55	HB47D1	Castor cotton, sandy soil	20° 49' 07.60”	71° 14' 36.90”
56	HB48D1	Cotton-pearl millet	20° 49' 41.30”	71° 15' 38.90”
57	HB49D1	Cotton, hard soil	20° 49' 34.00”	71° 15' 40.40”
58	HB50D1	Cotton	20° 49' 23.60”	71° 15' 44.60”
59	HB51D1	Cotton-pearl millet, Balaji temple	20° 50' 31.10”	71° 16' 00.10”

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ई-मेल : director.cssri@icar.gov.in

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