



Quantifying Ionic Imbalances and Salinity Risks in Semi-Arid Soils of Daund Taluka: Village-Level Geochemical Study

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Manuscript details:

Received: 29.07.2026
Revised : 05.08.2026
Accepted: 22.09.2026
Published: 30.09.2026

Cite this article as:

Gummalla Devadanam and Kanikaram Sunita (2026) Evaluation of antioxidant and antimicrobial properties of the muscle extracts of *Chrysochir aureus* and *Otolithes ruber* from Kakinada Harbour, Andhra Pradesh, India. *Int. J. of Life Sciences*, 14 (3): 249-254.

Available online on <http://www.ijlsci.in>

ISSN: 2320-964X (Online)

ISSN: 2320-7817 (Print)



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ABSTRACT

Soil Science Soil salinity is one of the major abiotic stresses limiting agricultural productivity worldwide. Excess accumulation of soluble salts adversely affects soil physicochemical properties, resulting in osmotic stress, ion toxicity, nutrient imbalance, and deterioration of soil structure. Elevated concentrations of sodium and chloride ions reduce water uptake, impair soil permeability, and negatively influence plant growth and crop yield. Therefore, assessment of ionic composition and salinity status of agricultural soils is essential for developing effective reclamation and sustainable soil management strategies.

Saline soil samples collected from Dapodi, Nangaon, Pargaon, and Amoni Mal villages of Daund Taluka, Pune District, Maharashtra, were analyzed for major cations and anions. Carbonate ions were absent in all samples, whereas bicarbonate and sulphate concentrations were recorded at 6.5 meq/L and 104 meq/L, respectively. Chloride concentration was markedly high (191 meq/L), indicating severe salt accumulation. Among the cations, sodium was dominant with an exceptionally high concentration of 1434.75 meq/L, followed by calcium (475 meq/L) and magnesium (220 meq/L), while potassium content remained comparatively low (3.2 meq/L). The predominance of sodium and chloride ions revealed severe ionic imbalance and high salinity stress, which may adversely affect soil aggregation, hydraulic conductivity, and nutrient availability.

The present investigation demonstrated that the studied soils are severely affected by salinity, primarily due to excessive sodium and chloride accumulation. Such ionic dominance may lead to soil structural degradation, reduced permeability, and restricted crop productivity. The findings highlight the urgent need for integrated soil reclamation strategies, including gypsum amendment, leaching practices, improved drainage systems, and cultivation of salt-tolerant crop varieties. Adoption of these management approaches may contribute to restoration of soil fertility, enhancement of agricultural sustainability, and long-term productivity of salt-affected soils.

Keywords: Chemical Composition, Electrical Conductivity (EC), Ionic Composition, pH, Sodium Adsorption Ratio (SAR), Soil analysis, Soil Salinity.

INTRODUCTION

Soil salinity is one of the most pressing environmental challenges affecting agricultural productivity and ecological sustainability worldwide (Singh, 2022). Excess accumulation of soluble salts in the soil profile alters its physical and chemical properties, leading to reduced fertility, impaired plant growth, and long-term land degradation (Chhabra, 2022). In semi-arid and irrigated regions of India, salinity has emerged as a critical constraint to sustainable farming, demanding systematic assessment and remediation strategies (Mishra et al., 2023).

The study areas, Dapodi, Nangaon, Pargaon, and Amoni Mal represent diverse agro-ecological settings where salinity stress is increasingly evident due to irregular irrigation practices, groundwater quality, and climatic variability (Miah, 2022). These villages are agriculturally significant, yet their soils face varying degrees of salt accumulation that threaten crop yields and local livelihoods (Thiam et al., 2019). A comprehensive survey and chemical analysis of soil salinity was conducted in these villages of Daund Taluka, Pune District, Maharashtra. Such investigations are essential to establish baseline data on salt concentration and distribution, which serve as a foundation for monitoring long-term changes (Manders et al., 2010). They also help identify spatial variability in salinity levels across different sites, thereby guiding site-specific management practices (Van Camp & Walraevens, 2008). Detailed insights into the chemical composition of salts, including dominant cations and anions, provide a clearer understanding of their influence on soil health and crop productivity (Xing et al., 2025). Furthermore, these findings support the development of effective strategies for phytoremediation, bioremediation, and sustainable land management, ensuring ecological restoration and agricultural resilience in saline regions (Phang et al., 2024).

By combining field surveys with laboratory-based chemical analysis, this study aims to generate reliable data that can guide both scientific understanding and practical interventions. The findings will contribute to regional soil management plans, enhance awareness among farmers, and serve as a foundation for further research into salt tolerance mechanisms and ecological restoration (Somawanshi et al., 2012).

MATERIALS AND METHODS

Study area and soil Sampling:

Soil samples were collected from Dapodi, Nangaon, and Amoni Mal villages in Daund Taluka, Pune District, Maharashtra, India (Jagtap, 2015). The sampling was carried out at a depth of 0–30 cm using a stainless steel auger to avoid contamination (Allekotte et al., 2008). At each site, four to five subsamples were randomly collected from agricultural fields and then mixed to prepare a composite sample representing the location (Lark et al., 2025). The collected samples were placed in clean, labeled polythene bags with details of site name, GPS coordinates, and date of collection. The samples were transported to the laboratory, air-dried at room temperature, gently ground, and passed through a 2 mm sieve to remove debris. Duplicate samples were collected at random sites to ensure quality control. All prepared samples were stored in airtight containers until chemical analysis was performed (Carré et al., 2007).

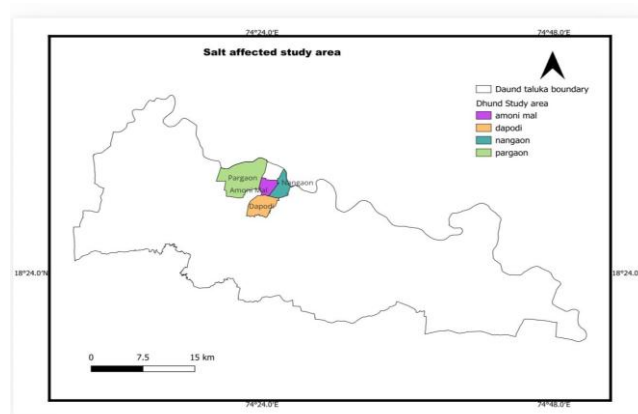


Fig. 1 Spatial Distribution of Salt Affected Villages in Daund Taluka, Pune District MS, India

Analytical Methods

Soil saturation extract was prepared as per the method of Richards (1954) and used for all chemical analyses. All ionic concentrations are expressed in meq/L.

Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-):

Determined by double-indicator titration method (Somawanshi et al., 2012). A 10 mL aliquot of soil saturation extract was diluted to 25 mL with CO_2 -free distilled water in a conical flask. Three drops of phenolphthalein indicator were added. If a pink color appeared, the solution was titrated with standard 0.02 N H_2SO_4 until the color disappeared. The volume used

was recorded as 'P' mL. Then, three drops of methyl orange indicator were added, and titration was continued until the color changed from yellow to orange-red. The additional volume used was recorded as 'M' mL. Carbonate and bicarbonate were calculated using the following formulas:

- CO_3^{2-} (meq/L) = $2P \times \text{Normality of acid} \times 1000 / \text{Volume of sample}$
- HCO_3^- (meq/L) = $(M - P) \times \text{Normality of acid} \times 1000 / \text{Volume of sample}$

Chloride (Cl^-): Estimated by Mohr's argentometric titration method (Somawanshi et al., 2012). A 10 mL aliquot of extract was diluted to 25 mL with distilled water. Five drops of 5% potassium chromate (K_2CrO_4) indicator were added, and the solution was titrated against standard 0.02 N AgNO_3 until a persistent brick-red precipitate appeared.

Sulphate (SO_4^{2-}): Determined by turbidimetric method (Somawanshi et al., 2012). A 100 mL aliquot of the extract was taken in a volumetric flask, 5.0 mL of conditioning reagent was added, followed by 0.5 g of barium chloride crystals. The mixture was stirred for exactly one minute, and absorbance was measured at 420 nm using a spectrophotometer. The concentration was determined from a standard calibration curve.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}): Determined by complexometric titration using EDTA (Somawanshi et al., 2012). A 10 mL aliquot of extract was diluted to 25 mL with distilled water. $\text{NH}_4\text{Cl-NH}_4\text{OH}$ buffer (pH 10) and Eriochrome Black T (EBT) indicator were added. The solution was titrated against 0.01 N EDTA until the color changed from wine red to pure blue.

Sodium (Na^+) and Potassium (K^+): Determined using a Flame Photometer (Somawanshi et al., 2012). Standard curves for Na^+ and K^+ were prepared using a series of working standards. The soil extract was appropriately diluted and aspirated into the flame photometer. Concentrations were read directly from the calibration curves.

RESULTS

The geochemical analysis of the soil saturation extract from the studied village in Daund Taluka, Pune district, Maharashtra, Western India, revealed severe ionic imbalances with extreme sodium dominance and high salinity (Table 1). Carbonate (CO_3^{2-}) was absent, while

bicarbonate (HCO_3^-) was recorded at 6.5 ± 0.04 meq/L. Among anions, sulphate (SO_4^{2-}) and chloride (Cl^-) concentrations were 104 ± 0.08 meq/L and 191 ± 0.92 meq/L, respectively. Cation concentrations were as follows: Na^+ 1434.75 ± 0.02 meq/L, Ca^{2+} 475 ± 0.04 meq/L, Mg^{2+} 220 ± 0.05 meq/L, and K^+ 3.2 ± 0.33 meq/L.

Soil quality indices were calculated as:

- **Sodium Adsorption Ratio (SAR)** = $\text{Na}^+ / \sqrt{[(\text{Ca}^{2+} + \text{Mg}^{2+})/2]} = 1434.75 / \sqrt{[(475 + 220)/2]} \approx 76.97$
- **Residual Sodium Carbonate (RSC)** = $(\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) = -688.5$ meq/L
- **Sodium Percentage (Na%)** $\approx 67.3\%$

These values indicate a strongly saline-sodic soil with pronounced Na^+ and Cl^- dominance.

Table 1. Chemical Composition of Saline Soil (1:5 Soil-Water Extract)

Sr. No.	Ion/Element	Concentration (meq/L)
1	Carbonate (CO_3^{2-})	Absent
2	Bicarbonate (HCO_3^-)	6.5 ± 0.04
3	Sulphate (SO_4^{2-})	104 ± 0.08
4	Chloride (Cl^-)	191 ± 0.92
5	Potassium (K^+)	3.2 ± 0.33
6	Sodium (Na^+)	1434.75 ± 0.02
7	Calcium (Ca^{2+})	475 ± 0.04

DISCUSSION

The exceptionally high SAR value (76.97) greatly exceeds the critical threshold of 13, classifying the soil as strongly sodic. This poses severe risks of clay dispersion, reduced hydraulic conductivity, and deterioration of soil structure (Choudhary et al. 2004). The strongly negative RSC (-688.5 meq/L) indicates no residual alkalinity hazard, suggesting that the substantial Ca^{2+} and Mg^{2+} concentrations could help mitigate further sodicity development if appropriately managed. However, the overwhelming dominance of Na^+ (67.3% of total cations) remains a major concern for soil permeability and long-term productivity.

The ionic composition ($\text{Na}^+\text{-Cl}^-\text{-SO}_4^{2-}$ type) is characteristic of semi-arid basaltic terrains in Maharashtra, resulting from intense evaporative concentration, poor drainage, silicate weathering, and

prolonged irrigation with saline groundwater. These findings align with previous studies on saline-sodic soils in western and north-western India (Mukherjee et al. 2022; Choudhary et al. 2025).

From an agronomic perspective, such extreme Na^+ dominance induces osmotic stress, specific ion toxicity (particularly Cl^-), nutrient imbalances (especially Ca^{2+} and K^+), and oxidative damage in crops, leading to significant yield reductions even in moderately salt-tolerant species. In the context of Daund Taluka, these results highlight localized salinity-sodicity hotspots that threaten sustainable agriculture in rainfed and semi-irrigated ecosystems.

Urgent reclamation measures including gypsum application, leaching, drainage improvement, organic amendments, and cultivation of salt-tolerant crops are strongly recommended (Rengasamy 2006; FAO 2015; Mishra et al. 2023). Without timely intervention, progressive sodification may cause irreversible land degradation, consistent with trends observed across semi-arid regions of India (Navarro-Torre et al. 2023).

Future studies integrating electrical conductivity (ECe), exchangeable sodium percentage (ESP), and long-term field monitoring are necessary to develop robust site-specific management strategies for similar semi-arid environments.

CONCLUSION

The present village-level geochemical investigation in Daund Taluka, Western India, conclusively demonstrates extreme ionic imbalances and severe salinity-sodicity risks in semi-arid soils. The saturation extract exhibited an exceptionally high sodium concentration ($\text{Na}^+ = 1434.75 \text{ meq/L}$), accompanied by elevated chloride ($\text{Cl}^- = 191 \text{ meq/L}$) and sulphate ($\text{SO}_4^{2-} = 104 \text{ meq/L}$), resulting in a sodium adsorption ratio (SAR) of approximately 77.0 and sodium percentage (Na%) of 67.3%. These values far exceed critical thresholds for sodicity ($\text{SAR} > 13$), indicating pronounced cationic imbalance and potential for clay dispersion, reduced permeability, and progressive structural degradation. The strongly negative residual sodium carbonate ($\text{RSC} = -688.5 \text{ meq/L}$) confirms the absence of residual alkalinity hazard, yet the overwhelming Na^+ dominance relative to Ca^{2+} and Mg^{2+} underscores an urgent threat to soil

health and agricultural sustainability in this rainfed/semi-irrigated agro-ecosystem.

These findings highlight the localized yet critical salinity hotspots typical of basaltic terrains under high evapotranspiration and intensive groundwater irrigation in Maharashtra. Without timely intervention through gypsum application, organic amendments, leaching practices, or adoption of salt-tolerant cropping systems the continued sodification process could render substantial areas unproductive, mirroring widespread land-degradation trends reported across semi-arid regions of India. The granular, site-specific data generated in this study provide a robust baseline for precision soil-management strategies and underscore the necessity of regular village-level monitoring to safeguard food security and ecosystem services in vulnerable semi-arid landscapes.

Future research integrating electrical conductivity, exchangeable cation ratios, and long-term field trials will further strengthen predictive models for salinity risk assessment and remediation in similar agro-climatic zones. Overall, this work emphasizes that proactive, data-driven reclamation is essential to mitigate the escalating geochemical constraints on sustainable agriculture in Western India's semi-arid soils.

Acknowledgements:

We are gratefully acknowledge financial assistance from (SARTHI), and authorities of Shirur Shikshan Prasarak Mandal's Chandmal Tarachand Bora College of Arts, Commerce and Science.

Author contribution: HSK and NMG designed the study. HSK and RRI has performed laboratory experimental work and data analysis. HSK and NMG wrote the manuscript. NMG edited and revised the manuscript and approved the final version of manuscript.

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Ethical approval and consent to participate: Not applicable.

Funding: Not applicable.

Conflict of interest The authors declare no competing interests.
Data Availability Statement: Not applicable.

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