

STUDY OF GEOSPATIAL ASSESSMENT OF SALT CULTIVATION SUITABILITY USING SENTINEL-2 IMAGERY AND TERRAIN ANALYSIS

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Abstract

Salt cultivation is an important coastal economic activity that depends strongly on environmental conditions such as soil salinity, terrain characteristics, and water availability. Traditional methods for identifying suitable land for salt farming rely on field surveys and local knowledge, which are often time-consuming, labour-intensive, and difficult to apply over large areas. This study aims to identify suitable zones for salt cultivation in Thoothukudi district, Tamil Nadu, using an integrated remote sensing and Geographic Information System (GIS) approach.

Sentinel-2 satellite imagery was used to derive vegetation and salinity indices, including the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Salinity Index (NDSI), and salinity indices SI5 and SI7, to assess surface salinity and vegetation conditions. Terrain-related parameters such as Digital Elevation Model (DEM), slope, and Topographic Wetness Index (TWI) were generated to evaluate surface morphology and moisture accumulation patterns. Proximity analysis to drainage networks and coastal features was also performed to represent the influence of water sources on salt deposition. All derived parameters were normalized and integrated using a weighted overlay method to generate a salt cultivation suitability map. Areas with high salinity concentration, sparse

vegetation cover, gentle slopes, favorable moisture conditions, and close proximity to drainage and coastal features were identified as highly suitable for salt cultivation.

Introduction

Salt cultivation refers to the production of salt through the evaporation of saline water, a process that is most effective in coastal and arid regions where high temperatures and low rainfall support natural crystallization. In India, salt farming is an important contributor to the coastal economy, especially in states such as Gujarat, Tamil Nadu, and Andhra Pradesh. The country ranks among the world's leading salt producers, generating livelihoods for thousands of coastal residents and supplying raw material to industries such as food processing, chemicals, and pharmaceuticals. Coastal districts like Thoothukudi are particularly suitable for salt production due to their level terrain, saline soil characteristics, and favourable climatic conditions.

Conventionally, the identification of land suitable for salt cultivation relies on field surveys and indigenous knowledge related to soil salinity and water availability. While these approaches are effective at local scales, they are labour-intensive, time-consuming, and difficult to implement over extensive areas. Additionally, variations in land use, climatic factors, and drainage systems can cause changes in soil salinity over time, making continuous field-based monitoring impractical.

Remote sensing and Geographic Information System (GIS) technologies offer a reliable and efficient alternative for large-scale land suitability assessment. Satellite imagery enables regular monitoring of surface conditions, while GIS facilitates the integration and spatial analysis of multiple environmental variables. Spectral indices derived from satellite data are useful for assessing vegetation cover and soil salinity, whereas terrain parameters extracted from elevation models provide insights into surface slope, drainage patterns, and moisture accumulation.

In the present study, salt cultivation suitability in Thoothukudi district is evaluated using Sentinel-2 satellite imagery along with GIS-based terrain information. A study area boundary was delineated to extract location-specific data, and several vegetation and salinity indices, including NDVI, SAVI, SI5, and SI7, were computed from the Sentinel imagery. Terrain and hydrological factors such as Digital Elevation Model

(DEM), slope, Topographic Wetness Index (TWI), and distance from drainage networks and the coastline were also generated. These parameters were integrated to classify the region into low, moderate, and high suitability zones for salt cultivation. The primary objective of this study is to develop a systematic and spatially accurate framework for identifying potential salt farming areas using geospatial techniques.

Literature Review

This section presents a review of previous studies related to soil salinity mapping and land suitability analysis using remote sensing and GIS methodologies. Earlier research highlights the effectiveness of satellite-derived salinity indices, vegetation indicators, and terrain parameters in identifying salt-affected regions. The reviewed studies employ various techniques and analytical approaches, providing valuable insights that support the methodology adopted in the present study. Sarkar et al., 2023 investigated soil salinity mapping in the coastal Satkhira district of Bangladesh by integrating Landsat 8 OLI imagery with 241 [1] ground soil samples. Thirteen salinity indices were computed and classified using machine learning techniques such as Random Forest, Bagging-RF, and Artificial Neural Networks (ANN). Model performance was evaluated using ROC/AUC analysis, with ANN achieving the highest accuracy (AUC = 0.921). The study successfully delineated

low, moderate, and high salinity zones, demonstrating the effectiveness of ML-based approaches for coastal land management and crop planning. This framework can be adapted for predictive modelling in the present study.

Habibi et al., 2021 mapped soil salinity in arid environments using Landsat 8 imagery, 72 soil samples, and a combination of spectral indices [2] (NDVI, SI5) and topographic parameters (DEM, TWI, TCI). Various ANN models, including GFF, MLP, MNN, and RBF, were tested, with the GFF model showing the best performance ($R^2 \approx 0.82$). The results indicated that salinity was predominantly concentrated in low-lying and floodplain areas, emphasizing the importance of integrating terrain attributes with spectral data for accurate salinity prediction. Gad et al., 2021 conducted soil salinity mapping in the East Nile Delta, Egypt, using Landsat 5 TM imagery and 200 field-based electrical conductivity measurements. The study involved atmospheric correction, computation of multiple salinity indices (SI1-SI7 and NDSI), and NDVI-based masking of vegetated areas [3]. Correlation and regression analyses revealed that SI5 had the strongest relationship with EC values (correlation coefficient of 0.87), enabling effective spatial mapping of salinity. This research highlights the efficiency of multi-index remote sensing approaches for rapid and cost-effective salinity assessment.

Land Surface Analysis of Salt-Affected Soils Using DEM and GIS

examined the relationship between topography and soil salinity using SRTM DEM data in alluvial and aeolian soil environments. GIS-based spatial analysis [4] revealed that salt-affected soils were primarily associated with flat, low-lying areas, with a stronger correlation to water table depth in aeolian plains. The findings emphasize the critical role of terrain factors in salinity distribution, supporting their inclusion in suitability assessments. NDVI - NASA Earthdata provides standardized NDVI-based vegetation monitoring using red and near-infrared bands from satellite missions such as MODIS and Landsat. NDVI values range from -1 to +1 and effectively represent vegetation density and health[5]. This index is widely used for large-scale environmental and agricultural monitoring. In the present study, NDVI is integrated with terrain and salinity indices to enhance soil quality evaluation and land suitability analysis.

Sentinel-2 satellite imagery in SAFE format was obtained from the Copernicus Open Access Hub for the study region.

Spectral Index Calculation

Several vegetation and salinity indices were derived from Sentinel-2 satellite imagery to assess land surface characteristics relevant to salt cultivation. The Normalized Difference Vegetation Index (NDVI) was computed to evaluate vegetation density and health, where lower NDVI values indicate sparse or

absent vegetation typically associated with salt-affected surfaces. The Normalized Difference Salinity Index (NDSI) was applied to identify saline features by exploiting spectral contrasts between visible and shortwave infrared bands. In addition, salinity indices SI5 and SI7 were generated to enhance the reflectance patterns of salt crusts and saline soils. Together, these indices provide an effective means of assessing surface salinity conditions and distinguishing salt-affected areas from non-saline land.

Terrain and Proximity Analysis

Terrain-related parameters were extracted from Digital Elevation Model (DEM) data to examine surface characteristics and moisture dynamics. Slope analysis was conducted to identify flat or gently sloping areas that are suitable for salt pan development, as such terrain facilitates water retention and promotes efficient evaporation. The Topographic Wetness Index (TWI) was calculated to represent the spatial distribution of potential soil moisture accumulation, which plays a significant role in salinity concentration.

Proximity analysis was carried out by generating distance layers from drainage networks and coastal features. Areas located closer to these water sources generally experience increased salinity due to periodic inundation and salt deposition, making them more favorable for salt cultivation activities.

Spatial Analysis and Suitability Mapping

Following the derivation of salinity and terrain parameters, each factor was analyzed individually to assess its influence on salt cultivation potential. Regions exhibiting high salinity index values combined with low NDVI were identified as salt-affected surfaces suitable for salt pan formation. Areas with gentle slopes derived from DEM analysis demonstrated greater water retention capacity, supporting evaporation-based salt production. Zones with high TWI values indicated locations where moisture and saline water tend to accumulate. Additionally, proximity to drainage networks and coastal features contributed to enhanced salt deposition, increasing the suitability of nearby areas. This individual assessment aided in understanding the relative contribution of each parameter to salt farming suitability.

Subsequently, all salinity indices and terrain parameters were processed using Python-based geospatial libraries such as Rasterio and NumPy. The raster layers were resampled to a uniform spatial resolution to ensure pixel-level consistency during analysis. Each parameter was normalized to a common scale to reduce disparities in value ranges among spectral indices, terrain attributes, and distance measures. Distance-based influence maps were generated for drainage and coastal proximity to represent the effect of water sources. The normalized layers were then integrated

using a weighted overlay technique, in which each factor contributed to the final suitability score according to its relative importance in salt cultivation. The resulting composite map represents the overall spatial suitability for salt cultivation across the study area.

Based on the integrated spatial analysis, the study area was classified into three categories: high, moderate, and low suitability for salt cultivation. Areas characterized by high salinity levels, sparse vegetation, gentle slopes, favorable moisture conditions, and close proximity to drainage and coastal features were classified as highly suitable. Moderate suitability zones exhibited partially favorable conditions, while low suitability areas were associated with low salinity, steep terrain, dense vegetation, or limited moisture influence. This classification provides a clear spatial framework to support effective land-use planning and salt farming management.

Conclusion

This study demonstrates the effectiveness of integrating remote sensing and Geographic Information System (GIS) techniques for assessing land suitability for salt cultivation in Thoothukudi district, Tamil Nadu. By combining Sentinel-2-derived spectral indices with terrain and hydrological parameters, the study provides a systematic and spatially explicit approach to identifying potential salt farming areas.

Vegetation and salinity indices such as NDVI, SAVI, NDSI, SI5, and SI7 successfully highlighted salt-affected surfaces characterized by sparse vegetation and high salinity levels. Terrain parameters derived from the Digital Elevation Model, including slope and Topographic Wetness Index (TWI), proved crucial in identifying flat, low-lying areas with favorable moisture accumulation that support efficient evaporation and salt crystallization. Proximity to drainage networks and coastal features further influenced salinity distribution by enhancing salt deposition through periodic inundation.

The integration of all normalized parameters using a weighted overlay method enabled the classification of the study area into high, moderate, and low suitability zones for salt cultivation. Highly suitable zones were primarily associated with high salinity concentration, gentle slopes, low vegetation cover, and close proximity to water sources. Moderate and low suitability zones reflected varying degrees of limitation related to terrain, vegetation density, and moisture availability.

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