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"LITERATURE REVIEW ON REMOTE SENSING METHODS FOR SOIL SALINIZATION RESEARCH"

Abstract. *Soil salinity is a critical environmental issue that poses significant challenges to agricultural productivity, ecosystem health, and water resource management, particularly in arid and semi-arid regions. Traditional methods of soil salinity assessment, such as field sampling and laboratory analysis, are often labor-intensive, time-consuming, and limited in spatial coverage. Remote sensing technologies have emerged as a cost-effective and efficient alternative for monitoring soil salinity over large areas with high temporal and spatial resolution. This review analyzes existing literature on remote sensing methods for soil salinity assessment, focusing on their advantages, limitations, and potential applications.*

Key words: *Soil, Soil salinization, GIS, Remote sensing, MODIS*

Аннотация. *Засоление почвы является критической экологической проблемой, которая создает значительные проблемы для производительности сельского хозяйства, здоровья экосистемы и управления водными ресурсами, особенно в засушливых и полузасушливых регионах. Традиционные методы оценки засоления почвы, такие как полевой отбор проб и лабораторный анализ, часто являются трудоемкими, отнимают много времени и ограничены в пространственном охвате.*

Технологии дистанционного зондирования появились как экономически эффективная и действенная альтернатива для мониторинга засоления почвы на больших территориях с высоким временным и пространственным разрешением. В этом обзоре анализируется существующая литература по методам дистанционного зондирования для оценки засоления почвы, с упором на их преимущества, ограничения и потенциальные области применения.
Ключевые слова: *Почва, Засоление почвы, ГИС, Дистанционное зондирование, MODIS*

1. Introduction

Soil salinity is a pervasive environmental issue that poses significant challenges to agricultural productivity, water resource management, and ecosystem sustainability. According to Allbed and Kumar [1], soil salinity is particularly problematic in arid and semi-arid regions where high evaporation rates lead to the accumulation of salts in the soil profile. This phenomenon not only reduces crop yields but also degrades soil structure, leading to long-term ecological and economic consequences. The Food and Agriculture Organization (FAO) estimates that over 1 billion hectares of land worldwide are affected by soil salinity, with this figure expected to rise due to climate change and unsustainable land-use practices [2, 13].

Traditional methods of assessing soil salinity, such as field sampling and laboratory analysis, have been widely used for decades. However, these methods are often labor-intensive, time-consuming, and limited in spatial coverage [3, 12]. For instance, Corwin and Lesch [4] highlight that traditional techniques require extensive ground-based measurements, which are impractical for large-scale monitoring. Furthermore, these methods often fail to capture the dynamic nature of soil salinity, which can vary significantly over short distances and time periods.

In recent years, remote sensing technologies have emerged as powerful tools for monitoring and mapping soil salinity over large areas with high temporal and spatial resolution. Remote sensing offers several advantages over traditional methods, including cost-effectiveness, rapid data acquisition, and the ability to cover vast geographic regions [5, 11, 15]. Satellite-based platforms such as Landsat, Sentinel-2, and MODIS have been extensively used for soil salinity assessment, providing valuable insights into the spatial distribution and temporal dynamics of salt-affected soils [6, 13, 14]. Additionally, advancements in spectral indices and machine learning algorithms have further enhanced the accuracy and reliability of remote sensing-based soil salinity assessments [7, 12, 15].

This review aims to analyze existing literature on remote sensing methods for soil salinity assessment, focusing on their advantages, limitations, and potential applications. By synthesizing findings from diverse studies, this paper seeks to provide a comprehensive overview of the current state of knowledge in this field. The review is structured as follows: Section II outlines the research methodology, Section III presents the results of the literature analysis, Section IV discusses the implications of the findings, and Section V provides recommendations for future research. The final section concludes the paper with a summary of key insights.

The significance of this review lies in its contribution to advancing the understanding of remote sensing technologies for soil salinity assessment. By identifying gaps in current research and highlighting opportunities for innovation, this paper aims to inform future studies and support the development of more effective soil salinity management strategies.

2. Materials and methods

This review is based on an extensive analysis of peer-reviewed articles, conference papers, and technical reports sourced from reputable databases such as Scopus, ResearchGate, and Google Scholar. Keywords such as "remote sensing," "soil salinity," "satellite imagery," "spectral indices," and "geospatial analysis" were used to identify relevant studies published between 2010 and 2023 [9, 17]. The selected literature was categorized into three main themes: (1) remote sensing platforms and sensors, (2) spectral indices and algorithms for salinity detection, and (3) integration of remote sensing with ground-based data. Each study was critically evaluated for its methodology, accuracy, scalability, and applicability.

For instance, Corwin and Lesch [4] emphasized the importance of validating remote sensing outputs using ground-based measurements, particularly electrical conductivity (EC) and sodium adsorption ratio (SAR). Similarly, Farifteh et al. [7] highlighted the role of machine learning algorithms in improving the accuracy of soil salinity predictions by integrating spectral data with environmental variables.

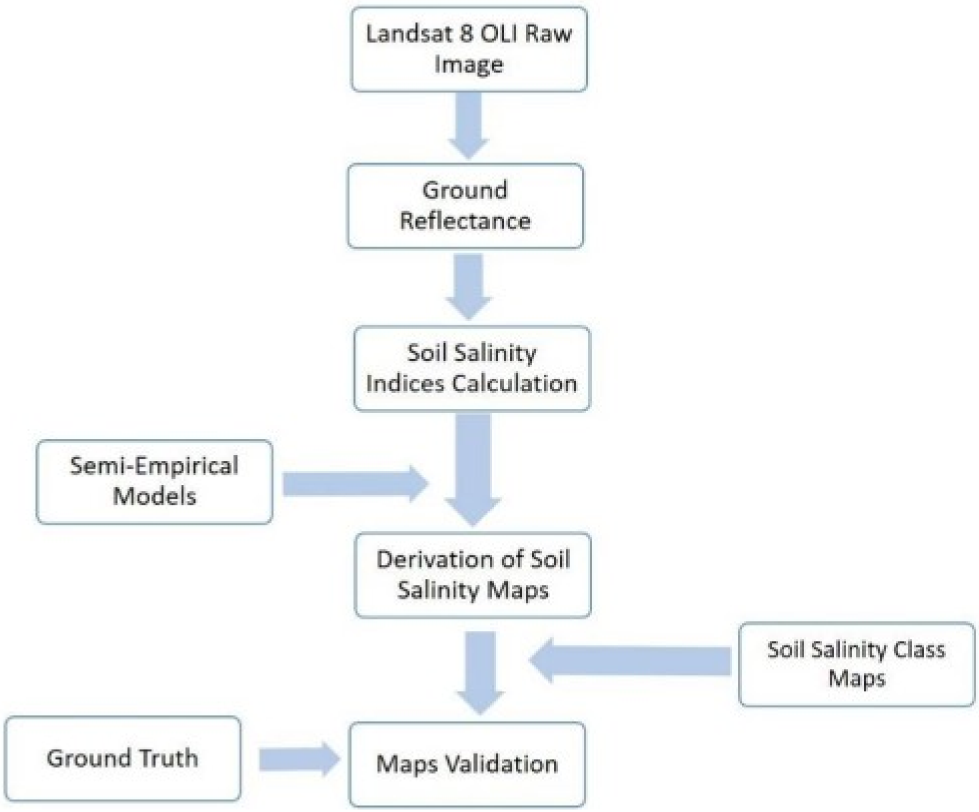

Figure 1: Soil salinity class mapping methodology [10]

In attempt to develop a new empirical model the NSI values for the field soil sampling locations were regressed with the lab estimated salinity EC measurements. Various regression models were developed, and the exponential relation portrayed the highest R-square values. The exponential relation is ideal with soil salinity indices due to their low saturation levels. The developed semi-empirical models were later applied for the Landsat 8 OLI for generating soil salinity and soil salinity class maps. The overall methodology followed in this study has been summarized in Figure 1.

3. Results and discussion

Remote Sensing Platforms and Sensors. Remote sensing platforms for soil salinity assessment include satellite-based systems (e.g., Landsat, Sentinel-2, MODIS), airborne sensors, and unmanned aerial vehicles (UAVs). Satellite imagery has been widely used due to its global coverage and cost-effectiveness. For example:

- Landsat : Studies have demonstrated the utility of Landsat's multispectral bands in detecting salt-affected soils through vegetation indices like NDVI (Normalized Difference Vegetation Index) and SI (Salinity Index). According to Scudiero et al. [6, 14, 16], Landsat data can be effectively used for regional-scale soil salinity mapping.
- Sentinel-2 : With its higher spatial resolution (10 m), Sentinel-2 provides more detailed information about small-scale variations in soil salinity. Taghadosi et al. [8] reported that Sentinel-2 multispectral imagery could retrieve soil salinity with high accuracy when combined with advanced algorithms.
- Hyperspectral Sensors : Airborne hyperspectral sensors, such as AVIRIS and Hyperion, offer fine spectral resolution, enabling the identification of specific mineral compositions associated with salinity. Farifteh et al. [7] noted that hyperspectral data could distinguish between different types of salt-affected soils based on their spectral signatures.

Spectral Indices and Algorithms. Several spectral indices and machine learning algorithms have been developed to enhance the accuracy of soil salinity mapping:

- Salinity Indices : Commonly used indices include the Salinity Index (SI), Brightness Index (BI), and Normalized Difference Salinity Index (NDSI). These indices leverage the reflectance properties of salt-affected soils in visible and near-infrared wavelengths. [1, 13] reviewed various salinity indices and concluded that NDSI performed well in identifying saline soils.
- Machine Learning Models : Algorithms such as Random Forest (RF), Support Vector Machines (SVM), and Artificial Neural Networks (ANN) have

shown promising results in predicting soil salinity levels. For example, Farifteh et al. [7] compared ANN with Partial Least Squares Regression (PLSR) and found that ANN provided better accuracy in quantifying soil salinity.

Integration with Ground-Based Data. While remote sensing provides valuable spatial information, its accuracy can be significantly improved when combined with ground-based measurements. Corwin and Lesch [4] emphasized the importance of validating remote sensing outputs using soil samples analyzed for electrical conductivity (EC) and sodium adsorption ratio (SAR). Such integration ensures that the remote sensing data aligns with actual field conditions.

4. Recommendations

Based on the reviewed literature, the following recommendations are proposed:

1. Enhanced Sensor Development : Future research should focus on developing advanced sensors capable of capturing finer spectral and spatial details of salt-affected soils. For example, hyperspectral sensors with higher resolution could improve the detection of subtle variations in soil salinity [7, 11].

2. Hybrid Approaches : Combining remote sensing with geophysical techniques (e.g., electromagnetic induction) and machine learning models can improve the precision of salinity assessments. Taghadosi et al. [8] demonstrated that hybrid approaches yielded more accurate results than standalone methods.

3. Long-Term Monitoring : Establishing long-term monitoring programs using remote sensing data can help track changes in soil salinity over time and evaluate the effectiveness of mitigation strategies. Scudiero et al. [6] highlighted the importance of continuous monitoring for sustainable soil management.

4. Capacity Building : Training programs should be organized to equip researchers and practitioners with skills in remote sensing technologies and data analysis. Allbed and Kumar [1] suggested that capacity building is essential for the widespread adoption of remote sensing tools.

5. Conclusion

Remote sensing offers a robust and efficient solution for assessing soil salinity at various scales. By leveraging advancements in sensor technology, spectral indices, and machine learning, researchers can gain deeper insights into the dynamics of soil salinity and its impacts on ecosystems and agriculture. However, challenges such as cloud cover, atmospheric interference, and the need for ground-truthing remain barriers to widespread adoption. Addressing these challenges through interdisciplinary collaboration and technological innovation will pave the way for more accurate and sustainable soil salinity management practices.

This review highlights the potential of remote sensing as a transformative tool for soil salinity assessment. By synthesizing findings from diverse studies, it underscores the importance of integrating multiple data sources and analytical techniques to achieve reliable and actionable results. Future research should prioritize the development of user-friendly tools and decision-support systems that can facilitate the adoption of remote sensing technologies by stakeholders in agriculture, environmental management, and policy-making.

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