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14. Remote Sensing and GIS in Diagnosis and Management of Problem Soil

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Abstract:

Geographic Information Systems (GIS) and remote sensing are essential tools for diagnosing and managing problematic soils. Problematic soils present major obstacles to environmental management and agriculture because of problems including salinity, acidity, and poor structure. Large-scale soil condition monitoring is made possible by remote sensing, which uses satellite imaging and aerial photography to collect spectral data reflecting different soil qualities. After being processed and examined, these data can show trends in soil deterioration and point out locations that need attention. By offering a geographical framework for managing, organizing, and evaluating soil data, GIS enhances remote sensing. In order to build detailed maps and models of soil conditions, it enables the integration of remote sensing data with other geospatial information, such as topography, land use, and climate data. Spatial correlations and trends can be found using GIS, which is useful for developing management plans and detecting soil issues.

Precision agriculture techniques are made easier by the integration of remote sensing and GIS, which allows for site-specific management. This method increases the effectiveness of soil improvement strategies, including crop variety selection, irrigation control, and amendment application. Moreover, these technologies provide long-term evaluation and observation, which is necessary for sustainable soil management. To sum up, GIS and remote sensing offer reliable techniques for the efficient identification and treatment of problematic soils. Their integration improves our capacity to track soil health, pinpoint issue areas, and apply focused management techniques—all of which lead to increased agricultural productivity and environmental preservation in the long run.

Keywords:

Geographic Information Systems (GIS), remote sensing, problematic soil, sustainable soil management (SSM), Soil health.

14.1 Introduction:

"There are some who question the relevance of space activities in a developing nation. To us, there is no ambiguity of purpose. We do not have the fantasy of competing with the economically advanced nations in the exploration of the moon or the planets or manned space-flight." "But we are convinced that if we are to play a meaningful role nationally, and in the community of nations, we must be second to none in the application of advanced technologies to the real problems of man and society."-Dr. Vikram Ambalal Sarabhai, Father of Indian Space Program.

The dynamic terrain of Earth is shaped by the intricate interactions between human activity and natural processes, resulting in a patchwork of various soil types. Among them, unfavourable soils provide serious obstacles to environmental sustainability, infrastructural growth, and agriculture. These soils require creative methods for efficient diagnosis and management because of problems with salt, alkalinity, erosion, waterlogging and pollution (Selvam et al., 2024). Problematic soils are a global problem because they commonly impede plant development and lower agricultural yield. In dry and semi-arid locations, saline and alkaline soils are common and can reduce agricultural yields by restricting the availability of vital nutrients. In a similar vein, topsoil erosion causes degraded soils to lose fertility and become more vulnerable to future deterioration. Soils that are wet prevent roots from growing and oxygen from reaching the roots, making most crops' surroundings unfavourable (Kodaparthi et al., 2024). Ecosystems and human health are at danger from contaminated soils caused by inappropriate waste disposal or industrial pollution. These problems are complicated and require a multidisciplinary approach to diagnosis and treatment (Raj and Das, 2023).

With the use of remote sensing technology, one may see and analyse vast regions without having to physically touch them since it offers a macro view. Remote sensing gathers information in a variety of spectral bands using sensors carried by drones, airplanes, and satellites. This allows for an understanding of the characteristics and circumstances of the soil (Surendran et al., 2024). For soil research, multispectral and hyperspectral imaging are especially useful. Hyperspectral sensors gather data in several tiny bands throughout the electromagnetic spectrum, whereas multispectral sensors only record information in a few wide spectral bands. These features make it possible to identify features of the soil such salinity, organic matter, moisture content, and plant cover. For example, the reflectance characteristics of soil in various spectral bands can reveal the amount of moisture present, which is important to know when to detect regions that are vulnerable to drought or waterlogging (Vairavan et al., 2024).

Geographic Information Systems (GIS) offer a platform for geographic data processing, visualization, and decision-making, which is a complement to remote sensing. To create a comprehensive picture of soil conditions, GIS integrates many data layers, such as soil maps, topography information, land use patterns, and climatic data (Raihan, 2024).

Making soil maps is one of the main ways GIS is used in soil management. These maps are vital resources for farmers, land managers, and policymakers since they illustrate the many types of soil and their characteristics.

Targeted treatments can be guided by using GIS-based soil maps to identify locations with excessive salinity, erosion risk, or nutrient deficits. For instance, precision agriculture uses GIS to apply water, fertilizer, and other inputs as efficiently as possible to maximize crop output and reduce environmental impact (Kaliraj et al., 2024).

The combination of remote sensing and GIS improves each technology separately and provides a strong foundation for managing and diagnosing soil. While GIS gives advanced analytical tools and geographical context, remote sensing delivers wide coverage and real-time data. When combined, they make it possible to manage soil proactively, resolving problems before serious.

For instance, regions at risk of waterlogging or drought can be predicted by integrating remote sensing data on soil moisture with GIS-based hydrological models (Zhang et al., 2023). Similarly, land management methods may be tracked by combining GIS-based land use data with vegetation indices produced from remote sensing to track their effects on soil health. This coordinated strategy makes adaptive management easier and guarantees that interventions are founded on current, correct data (Soubry et al., 2021).

Sustainable agriculture, environmental preservation, and infrastructure development all depend heavily on the identification and treatment of problematic soils. Our understanding and handling of soil-related problems has been completely transformed by remote sensing and GIS, which provide accurate, scalable, and fast answers. Through leveraging the capabilities of these technologies, may create practical plans to lessen the effects of problematic soils, guaranteeing a more robust and healthier environment for coming generations. With further advancements in these disciplines, the combination of GIS and remote sensing will become more and more important for sustainable soil management, spurring creativity and well-informed choices (Balyan et al., 2024).

What is GIS (Geographic Information Systems)?

Gis is a Systems for capturing, storing, manipulating, analysing, managing, and presenting geographical or geographic data are known as geographic information systems (Daniel, 2024).

Through the integration of diverse data sources, GIS enables users to perceive, decipher, and comprehend linkages and patterns within spatial contexts. GIS connects data to maps, offering strong tools for resource management, decision-making, and spatial analysis in a variety of domains, including agriculture, urban planning, environmental research, and more (Nath, et al. 2000).

What is remote sensing?

The science and technique of gathering data on things, regions, or events from a distance usually with the use of airplanes or satellites is known as remote sensing. In order to examine and evaluate the properties of the target, this method entails detecting and measuring radiation emitted or reflected from the Earth's surface (Patra, 2010).

14.2 Problematic soil in India and their characteristics:

Different soil types have been created by India's varied temperature, geography, and land use practices; some of these soil types pose serious problems for infrastructure, agriculture, and environmental management.

With their distinct qualities, these problematic soils call for specialized management techniques to guarantee production and sustainable use (Lal, 2007). The examine primary categories of problematic soils in India along with their characteristic attributes.

14.2.1 Saline soil:

Characteristics

- High concentration of soluble salts, especially sodium, calcium, and magnesium chlorides and sulphates.
- Inadequate soil structure, which results in inadequate water infiltration and permeability.
- High pH—often greater than 8.5.
- Toxic salt levels and nutrient imbalances cause poor soil fertility.
- The surface of the soil has a white crust because of accumulation of salt (Choudhary and Kharche, 2019; Wali et al., 2019; Srivastava et al., 2019).

Region Affected

- Dry and semi-arid areas, such as regions of the Punjab, Gujarat, Rajasthan, and Haryana.
- Regions along the coast where contamination by seawater is frequent (Ahamad et al., 2023).

Alkaline Soil

Characteristics:

- High pH resulting from the presence of bicarbonate and sodium carbonate; typically, above 8.5.
- High exchangeable sodium percentage (ESP) and sodium absorption ratio (SAR).
- Fragmented soil particles that cause inadequate drainage and soil structure.
- Restricted access to vital nutrients such as iron, zinc, and phosphorus.
- Also called "sodic soils (Chhabra, 2022; Mandal, 2019).

Region Affected:

Punjab, Haryana, Uttar Pradesh, and regions of Maharashtra and Andhra Pradesh.

14.2.2 Acidic Soil:

Characteristics:

- Low pH, usually less than 6.5, is frequently caused by the build-up of acidic cations such as aluminium and hydrogen and the leaching of base cations.
- Insufficiency in vital minerals such phosphorus, magnesium, and calcium.
- Toxic concentrations of manganese and aluminium, which prevent plants from growing.
- Low pH causes poor microbial activity, which affects the breakdown of organic matter and the cycling of nutrients (Osman et al., 2018; Muindi, 2016).

Region Affected:

- Assam, Meghalaya, Manipur, Mizoram, Tripura, West Bengal, Kerala, and portions of Odisha and Karnataka are among the humid and heavily precipitated regions.

14.2.3 Waterlogged Soil:

Characteristics:

- Excessive saturation of the root zone with water, resulting in anaerobic conditions.
- Root development and respiration are negatively impacted by inadequate drainage and poor oxygen supply.
- Build-up of harmful elements such as decreased iron and manganese.
- Reduced uptake of nutrients resulting in stunted plant growth and leaf yellowing (Bhattacharya and Bhattacharya, 2021).

Region Affected:

- Locations in Bihar, Uttar Pradesh, West Bengal, and Assam that are prone to flooding.
- In places like some of Punjab and Haryana with poor drainage systems, irrigation is in charge.

14.2.4 Eroded Soil:

Characteristics:

- Reduction in soil depth and fertility brought on by topsoil loss as a result of wind or water erosion.
- Reduced nutritional content and organic matter.
- Exposed subsurface layers, which are frequently less productive and more likely to deteriorate further.
- In extreme situations, gullies and ravines form (Kumar et al., 2020; Kuhn et al., 2023).

Region Affected:

- Hilly terrain, such as the Deccan Plateau, the Himalayas, the Western and Eastern Ghats, and others.
- Regions like sections of Rajasthan, Madhya Pradesh, and Uttar Pradesh that are heavily agriculturalized and deforested.

14.2.5 Contaminated Soil:

Characteristics:

- Presence of organic pollutants, heavy metals (such as mercury, lead, cadmium, and arsenic), and hazardous compounds as a result of mining, industry, and poor waste disposal.
- Adverse impact on plant development, soil health, and animal and human health.
- pH and biological activity changes in the soil can cause disturbances to the nutrient cycles (Kumari and Mishra, 2021).

Region Affected:

- mining and industrial regions, including the industrial belts of Maharashtra, Gujarat, and Tamil Nadu, as well as portions of Jharkhand, Chhattisgarh, Odisha, and West Bengal.

Sustainable land use and agricultural output in India are faced with a complex task due to the variety of problematic soil types. It is essential to comprehend these soils' properties in order to create management plans that work. The monitoring, analysis, and management of these soils can be greatly improved by integrating cutting-edge technology like remote sensing and GIS, assuring their rehabilitation and sustainable usage. India's agricultural and environmental sustainability would be greatly dependent on how well-informed decision-making and creative approaches are used to address the problems associated with poor soils.

14.3 Remote Sensing Technique for Problematic Soil Assessment:

The identification and analysis of soil problems such salinity, pollution, erosion, and compaction are the main goals of remote sensing techniques for problematic soil evaluation (AbdelRahman, 2023). The following are some particular methods and how they are used:

Multispectral and Hyperspectral Imaging:

- Salinity Identification: Different spectral fingerprints are seen in saline soils. Saline patches can be detected using multispectral and hyperspectral sensors by examining the reflectance in particular bands (Kumar et al., 2024).
- Contamination Mapping: By recognizing each pollutant's distinct spectral fingerprint, hyperspectral imaging can identify chemical contaminants in soil (Pabón et al., 2019).

Thermal Imaging:

- **Temperature and Soil Moisture:** Thermal sensors take measurements of the soil's temperature, which can reveal its moisture content. Soil moisture variations might draw attention to places that are more vulnerable to erosion or compaction (Abdulraheem et al., 2023).

Synthetic Aperture Radar (SAR):

- **Moisture and Texture of Soil:** SAR can pierce soil to reveal details about moisture and texture. In overcast conditions, where optical sensors may malfunction, it is very helpful (Tsokas et al., 2022).
- **Identification of Soil Structure Changes:** SAR is helpful for tracking compaction and erosion since it can identify changes in soil structure over time (North et al., 2017).

Spectroscopy:

- **Luminance Spectroscopy:** By measuring soil reflectance in-situ, field portable spectrometers can provide instant information on soil characteristics like organic matter, nutrient level, and pollution (Ben-Dor et al., 2018).

Drone Based Remote Sensing:

- **High-Resolution Imaging:** By capturing high-resolution data over particular problem areas, drones fitted with multispectral, hyperspectral, thermal, and LIDAR sensors provide thorough monitoring and assessment (Zhang and Zhu, 2023).

Problematic soils can be efficiently evaluated, tracked, and managed with the use of these remote sensing techniques, improving land use policies and promoting environmental sustainability.

14.4 GIS Technique for Problematic Soil Assessment:

Geographic Information Systems (GIS) are essential for managing and evaluating problematic soils.

Comprehensive analysis and visualization are made possible by the integration of spatial data from several sources through GIS (Oyana, 2020). The following GIS methods are especially designed for evaluating problematic soils:

Data Integration and Management:

- Layers of Spatial Data: To assess and visualize soil conditions, combine various data layers, including topographic maps, soil maps, land use, and vegetation cover.
- Database management: For simple access, updating, and querying, keep track of and manage soil data in a centralized GIS database (Reddy, 2018).

Soil Mapping:

- Soil Type Mapping: Classify soil types using information from field surveys, laboratory analysis, and remote sensing data to create comprehensive soil maps.
- Issue Soil Identification: Using geographical analysis and classification approaches, identify and map problematic soils, such as polluted, acidic, or salty soils (Mahajan et al., 2020).

Contamination Assessment:

- Pollutant Dispersion Modelling: To determine regions at risk of contamination spread and evaluate the success of remediation activities, model the spread of soil contaminants using GIS.
- Risk Mapping: To support focused actions and monitoring, create risk maps that shows locations that are vulnerable to soil pollution (Huang et al., 2018).

Hydrological Modelling:

- Runoff Modelling: To simulate surface runoff and evaluate the effects of problematic soils on water flow and quality, use GIS-based hydrological models.
- Flood Risk Assessment: Determine regions at risk of soil erosion and degradation during flooding events by analysing flood-prone areas using a combination of soil, hydrological, and topographical data (Olorunfemi et al., 2020).

3D visualisation and terrain analysis:

- Utilize digital elevation models (DEMs) to examine aspect, slope, and topography all of which are important variables in the processes of soil erosion and sedimentation.
- 3D Visualization: To more fully comprehend spatial relationships and evaluate troublesome soil areas, create 3D visualizations of soil and terrain data.

14.5 The challenge and opportunity of using remote sensing and GIS to manage problematic soil:

Challenges:

Data availability and quality:

- Access to High-Resolution Data: It can be expensive and difficult to obtain current, high-resolution satellite imagery and other remote sensing data.
- Variability in data quality and accuracy can have an impact on the dependability of soil assessments, particularly in remote places (Bünemann et al., 2018).

Technical Limitations:

- Sensor Restrictions: The kinds of soil parameters that can be reliably evaluated may be limited by the penetration depth, spatial resolution, and spectral range restrictions of remote sensing sensors.
- Computational Complexity: Expertise in advanced GIS and remote sensing techniques, as well as substantial computational resources, are needed for processing and evaluating huge datasets (Abdollahi et al., 2020; Lian et al., 2020).

Environmental and atmospheric interference:

- Cloud Cover and Weather: Acquiring clear and reliable remote sensing data can be hampered by vegetation, atmospheric conditions, and cloud cover.
- Temporal Changes: It is challenging to keep up-to-date evaluations because of the rapid changes in the environment, such as droughts or floods, which can drastically alter soil conditions (Gezie, 2019; Hossain et al., 2020).

Cost and accessibility:

- High Costs: For many enterprises, the cost of acquiring sophisticated remote sensing hardware, software, and high-resolution imagery may be unaffordable.
- Accessibility: The widespread implementation of remote sensing and GIS techniques may be impeded by limited access to equipment and expertise, particularly in poor regions (Moomen et al., 2019).

14.6 Future Direction:

Advancement in sensor technology:

- More Bands and Higher Resolution: Accuracy and detail in soil assessments will be enhanced by the development of sensors with more bands and higher spatial, spectral, and temporal resolution.
- Improved LIDAR and radar technology will make it easier to evaluate soil qualities under a variety of circumstances, such as in foggy or vegetated environments (Tehrany et al., 2017).

Machine Learning and AI Integration:

- Automated Data study: By using AI and machine learning to automate the study of big datasets, problematic soils can be identified and monitored more accurately and efficiently.
- Predictive Modelling: Trends in soil deterioration and the effects of different land management techniques can be predicted by AI-powered predictive models (Natcvetova, 2021).

Education and Capacity Building:

- Training Programs: Both developed and developing regions will gain capacity by increasing training offerings and resources for GIS and remote sensing applications in soil management.
- Collaborative Research: Innovation and best practices will be fostered by encouraging collaborative research and knowledge exchange between academic institutions, governmental organizations, and business (O'Dwyer et al., 2023).

A significant advance in soil science and land management has been made with the use of remote sensing and Geographic Information Systems (GIS) in the diagnosis and treatment of distressed soils. This chapter has demonstrated how different remote sensing methods, including thermal imaging, Synthetic Aperture Radar (SAR), multispectral and hyperspectral imaging, and LIDAR, can be used to provide vital information on the characteristics and states of soil. These technologies, when paired with GIS, allow for thorough spatial analysis, accurate mapping, and efficient visualization, which leads to better informed soil management decision-making.

These technologies offer several advantages, including as efficient monitoring of vast regions, accurate and detailed assessment of soil parameters, long-term cost-effectiveness, and improved data integration from various sources. These benefits ultimately result in enhanced soil health and productivity by helping to identify and manage problems like salinity, pollution, erosion, and compaction more accurately.

Expanded educational initiatives and supportive policy frameworks are also essential for fostering innovation and increasing capacity in this sector. Remote sensing and GIS may greatly support sustainable soil management techniques, guaranteeing the health and production of soils for future generations, by tackling present issues and welcoming future developments.

14.7 References:

1. AbdelRahman MA. 2023. An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications. *Rendiconti Lincei. Scienze Fisiche e Naturali*, *34*(3): 767-808.
2. Abdollahi A, Pradhan B, Shukla N, Chakraborty S and Alamri A. 2020. Deep learning approaches applied to remote sensing datasets for road extraction: A state-of-the-art review. *Remote Sensing*, *12*(9): 1444.
3. Abdulraheem MI, Zhang W, Li S, Moshayedi AJ, Farooque AA and Hu J. 2023. Advancement of remote sensing for soil measurements and applications: A comprehensive review. *Sustainability*, *15*(21): 15444.
4. Ahamad F, Tyagi SK, Singh M and Sharma AK. 2023. Groundwater in arid and semi-arid regions of india: a review on the quality, management and challenges. *Groundwater in Arid and Semi-Arid Areas: Monitoring, Assessment, Modelling, and Management*, 11-52.

5. Balyan S, Jangir H, Tripathi SN, Tripathi A, Jhang T and Pandey P. 2024. Seeding a Sustainable Future: Navigating the Digital Horizon of Smart Agriculture. *Sustainability*, *16*(2): 475.
6. Ben-Dor E, Chabrillat S and Demattê JA. 2018. Characterization of soil properties using reflectance spectroscopy. In *Fundamentals, sensor systems, spectral libraries, and data mining for vegetation* (pp. 187-247). CRC press.
7. Bhattacharya A and Bhattacharya A. 2021. Mineral nutrition of plants under soil water deficit condition: A Review. *Soil water deficit and physiological issues in plants*, 287-391.
8. Bünemann EK, Bongiorno G, Bai Z, Creamer RE, De Deyn G, De Goede R and Brussaard L. 2018. Soil quality–A critical review. *Soil biology and biochemistry*, *120*: 105-125.
9. Chhabra R. 2022. *Salt-affected soils and marginal waters: global perspectives and sustainable management*. Springer Nature.
10. Choudhary OP and Kharche VK. 2018. Soil salinity and sodicity. *Soil science: an introduction*, *12*, 353-384.
11. Daniel E and Mbon N. 2024. Application of Geographic Information Systems (GIS) and the Practice of Public Administration.
12. Gezie M. 2019. Farmer's response to climate change and variability in Ethiopia: A review. *Cogent Food & Agriculture*, *5*(1), 1613770.
13. Hossain A, Krupnik TJ, Timsina J, Mahboob MG, Chaki AK, Farooq M and Hasanuzzaman, M. 2020. Agricultural land degradation: processes and problems undermining future food security. In *Environment, climate, plant and vegetation growth* (pp. 17-61). Cham: Springer International Publishing.
14. Huang Y, Chen Q, Deng M, Japenga J, Li T, Yang X and He Z. 2018. Heavy metal pollution and health risk assessment of agricultural soils in a typical peri-urban area in southeast China. *Journal of environmental management*, *207*, 159-168.
15. Kaliraj S, Adhikari K, Dharumarajan S, Lalitha M and Kumar N. 2024. Remote sensing and geographic information system applications in mapping and assessment of soil resources. In *Remote Sensing of Soils* (pp. 25-41). Elsevier.
16. Kodaparthi A, Prajna KVBS, Tabassum SA, Harikrishna K, Sri RB, Manish M and Chepuri K. 2024. Topsoil Regeneration and Bio-sequestration. In *Prospects for Soil Regeneration and Its Impact on Environmental Protection* (pp. 123-157). Cham: Springer Nature Switzerland.
17. Kuhn CES, Reis FAGV, Zarfl C and Grathwohl P. 2023. Ravines and gullies, a review about impact valuation. *Natural Hazards*, *117*(1): 597-624.
18. Kumar G, Adhikary PP and Dash CJ. 2020. Spatial extent, formation process, reclaimability classification system and restoration strategies of gully and ravine lands in India. *Gully erosion studies from India and surrounding regions*, 1-20.
19. Kumar P, Tiwari P, Biswas A and Srivastava PK. 2024. Spatio-temporal assessment of soil salinization utilizing remote sensing derivatives, and prediction modeling: Implications for sustainable development. *Geoscience Frontiers*, *15*(6): 101881.
20. Kumari S and Mishra A. 2021. Heavy metal contamination. In *Soil contamination-threats and sustainable solutions*. IntechOpen.
21. Lal R. 2007. Soil science and the carbon civilization. *Soil Science Society of America Journal*, *71*(5), 1425-1437.

22. Lian R, Wang W, Mustafa N and Huang L. 2020. Road extraction methods in high-resolution remote sensing images: A comprehensive review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *13*: 5489-5507.
23. Mahajan G, Das B, Morajkar S, Desai A, Murgaokar D, Kulkarni R and Patel K. 2020. Soil quality assessment of coastal salt-affected acid soils of India. *Environmental Science and Pollution Research*, *27*(21): 26221-26238.
24. Mandal AK. 2019. Modern technologies for diagnosis and prognosis of salt-affected soils and poor-quality waters. *Research developments in saline agriculture*, 95-152.
25. Moomen AW, Bertolotto M, Lacroix P and Jensen D. 2019. Inadequate adaptation of geospatial information for sustainable mining towards agenda 2030 sustainable development goals. *Journal of Cleaner Production*, *238*: 117954.
26. Muindi EM. 2016. *Phosphorus retention and the interactive effects of phosphorus, lime and tillage on maize in acid soils of the Kenya highlands* (Doctoral dissertation, Sokoine University of Agriculture).
27. Natcvetova A. 2021. The role of Artificial Intelligence in measuring and modelling soil organic carbon in agricultural lands.
28. Nath SS, Bolte JP, Ross LG and Aguilar-Manjarrez J. 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural engineering*, *23*(1-3): 233-278.
29. North M, Farewell T, Hallett S and Bertelle A. 2017. Monitoring the response of roads and railways to seasonal soil movement with persistent scatterers interferometry over six UK sites. *Remote sensing*, *9*(9): 922.
30. O'Dwyer M, Filieri R and O'Malley L. 2023. Establishing successful university–industry collaborations: barriers and enablers deconstructed. *The Journal of Technology Transfer*, *48*(3): 900-931.
31. Olorunfemi IE, Komolafe AA, Fasinmirin JT, Olufayo AA and Akande SO. 2020. A GIS-based assessment of the potential soil erosion and flood hazard zones in Ekiti State, Southwestern Nigeria using integrated RUSLE and HAND models. *Catena*, *194*: 104725.
32. Osman KT and Osman KT. 2018. Acid soils and acid sulfate soils. *Management of Soil Problems*, 299-332.
33. Oyana TJ. 2020. *Spatial analysis with r: statistics, visualization, and computational methods*. CRC press.
34. Pabón REC, de Souza Filho CR and de Oliveira WJ. 2019. Reflectance and imaging spectroscopy applied to detection of petroleum hydrocarbon pollution in bare soils. *Science of the total environment*, *649*: 1224-1236.
35. Patra P. 2010. Remote sensing and geographical information system (GIS). *The Association for Geographical Studies*.
36. Raihan A. 2024. A systematic review of Geographic Information Systems (GIS) in agriculture for evidence-based decision making and sustainability. *Global Sustainability Research*, *3*(1): 1-24.
37. Raj K and Das AP. 2023. Lead pollution: Impact on environment and human health and approach for a sustainable solution. *Environmental Chemistry and Ecotoxicology*, *5*: 79-85.
38. Reddy GO. 2018. Spatial data management, analysis, and modeling in GIS: principles and applications. *Geospatial Technologies in Land Resources Mapping, Monitoring and Management*, 127-142.

39. Selvam R, Kalaiyarasi G and Saritha B. 2024. Heavy Metal Contamination in Soils: Risks and Remediation. *Soil Fertility and Plant Nutrition*, 141.
40. Soubry I, Doan T, Chu T and Guo X. 2021. A systematic review on the integration of remote sensing and GIS to forest and grassland ecosystem health attributes, indicators, and measures. *Remote Sensing*, *13*(16): 3262.
41. Srivastava P, Wu QS and Giri B. 2019. Salinity: an overview. *Microorganisms in saline environments: strategies and functions*, 3-18.
42. Surendran U, Nagakumar KCV and Samuel MP. 2024. Remote Sensing in Precision Agriculture. In *Digital Agriculture: A Solution for Sustainable Food and Nutritional Security* (pp. 201-223). Cham: Springer International Publishing.
43. Tehrany MS, Kumar L and Drielsma MJ. 2017. Review of native vegetation condition assessment concepts, methods and future trends. *Journal for Nature Conservation*, *40*: 12-23.
44. Tsokas A, Rysz M, Pardalos PM and Dipple K. 2022. SAR data applications in earth observation: An overview. *Expert Systems with Applications*, *205*: 117342.
45. Vairavan C, Kamble BM, Durgude AG, Ingle SR and Pugazenthi K. 2024. Hyperspectral Imaging of Soil and Crop: A Review. *Journal of Experimental Agriculture International*, *46*(1): 48-61.
46. Wali SU, Gada MA, Umar KJ, Abba A and Umar A. 2021. Understanding the causes, effects, and remediation of salinity in irrigated fields: A review. *International Journal of Agriculture and Animal Production (IJAAP) ISSN*, 2799-0907.
47. Zhang J, Pan B, Shi W and Zhang Y. 2023. Monitoring Waterlogging Damage of Winter Wheat Based on HYDRUS-1D and WOFOST Coupled Model and Assimilated Soil Moisture Data of Remote Sensing. *Remote Sensing*, *15*(17): 4133.
48. Zhang Z and Zhu L. 2023. A review on unmanned aerial vehicle remote sensing: Platforms, sensors, data processing methods, and applications. *drones*, *7*(6): 398.