MANTECH Publications
Journal of Remote Sensing, Environmental Science & Geotechnical Engineering
Volume 6, Issue 2, May-August 2021

Hyperspectral Remote Sensing For Detection of Soil Contamination from Industrial Activities

Dr. Anil Verma,
Associate Professor
Department of Environmental Science
Eastern Institute of Technology
Email:*anil.verma@eit.edu*

Ms. Priya Joshi,
Research Scholar
Department of Environmental Science
Eastern Institute of Technology
Email:*priya.joshi@eit.edu*

Abstract

Soil contamination caused by industrial activities poses severe risks to environmental health and human safety. Traditional soil sampling methods are often labor-intensive, costly, and spatially limited. Hyperspectral remote sensing (HRS) has emerged as a powerful technique for detecting and mapping soil contaminants over large areas with high spectral resolution. This paper reviews the principles of hyperspectral remote sensing and its application in identifying soil contamination from heavy metals, hydrocarbons, and other pollutants linked to industrial sources. The integration of HRS data with advanced image processing and machine learning techniques enhances detection accuracy and spatial mapping. Two tables summarize major hyperspectral sensors used in soil contamination studies and compare various spectral indices and classification algorithms for contaminant detection. Challenges such as spectral variability, atmospheric interference, and data processing complexity are discussed. The

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved

study concludes by emphasizing the potential of hyperspectral remote sensing as an efficient tool for environmental monitoring and remediation planning in industrial regions.

Keywords: *Hyperspectral remote sensing, Soil contamination, Industrial pollution, Spectral indices, Machine learning, Environmental monitoring*

INTRODUCTION

Soil contamination is a critical environmental issue predominantly driven by industrial activities such as mining, manufacturing, and chemical processing. Contaminants including heavy metals, petroleum hydrocarbons, and organic pollutants deteriorate soil quality, adversely affecting agriculture, groundwater, and ecosystem health. Early detection and accurate mapping of contaminated soils are vital for effective remediation and risk management.

Traditional soil testing methods rely on ground sampling and laboratory analysis, which are expensive, time-consuming, and spatially limited. Hyperspectral remote sensing (HRS) offers a non-invasive, rapid, and spatially extensive approach for detecting soil contamination. By capturing hundreds of narrow spectral bands across visible to shortwave infrared regions, HRS detects subtle spectral signatures of various contaminants.

This paper presents an overview of HRS technologies and their applications in industrial soil contamination detection, highlighting recent advances, challenges, and future directions.

PRINCIPLES OF HYPERSPECTRAL REMOTE SENSING

Hyperspectral sensors collect data in contiguous narrow spectral bands (typically 5–10 nm bandwidth), providing detailed spectral profiles for each pixel. Unlike multispectral sensors with few broad bands, HRS enables identification of specific chemical and mineralogical features based on unique absorption features in the reflectance spectra.

Industrial contaminants such as heavy metals alter soil spectral properties by changing mineral composition and organic matter content. Hydrocarbons exhibit distinct absorption features in the shortwave infrared region. These spectral characteristics are used to differentiate contaminated from uncontaminated soils.

HYPERSPECTRAL SENSORS FOR SOIL CONTAMINATION DETECTION

A variety of airborne and satellite hyperspectral sensors are utilized:

- **AVIRIS (Airborne Visible/Infrared Imaging Spectrometer):** Offers 224 spectral bands from 400 to 2500 nm with 10m spatial resolution, extensively used for environmental studies.

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved

- **Hyperion (EO-1 satellite):** Provides 220 spectral bands at 30m resolution, widely employed in soil and mineral mapping.
- **PRISMA (Italian Space Agency):** Satellite-based sensor with 30m resolution and 240 spectral bands.
- **EnMAP (Environmental Mapping and Analysis Program):** Upcoming German satellite with 30m resolution, optimized for environmental monitoring.
- **HyMap:** Airborne sensor with 126 spectral bands used in industrial pollution detection.

TABLE 1: MAJOR HYPERSPECTRAL SENSORS FOR SOIL CONTAMINATION STUDIES

Sensor	Platform	Spectral Range (nm)	Spectral Bands	Spatial Resolution (m)	Typical Applications
AVIRIS	Airborne	400–2500	224	10	Soil contamination, mineral mapping
Hyperion	Satellite	400–2500	220	30	Soil pollution, land cover
PRISMA	Satellite	400–2500	240	30	Environmental monitoring
EnMAP	Satellite	420–2450	244	30	Soil and vegetation analysis
HyMap	Airborne	450–2500	126	5–10	Industrial site pollution mapping

Table 1 summarizes key hyperspectral sensors with specifications and applications relevant to soil contamination.

DATA PROCESSING AND ANALYSIS TECHNIQUES

Raw hyperspectral data require advanced preprocessing including atmospheric correction, noise reduction, and geometric correction to extract reliable spectral information. Several analytical methods are then applied:

- **Spectral Indices:** Indices such as Normalized Difference Vegetation Index (NDVI) and Heavy Metal Index (HMI) highlight contamination-related spectral features.
- **Spectral Unmixing:** Decomposes pixel spectra into constituent endmembers representing pure materials, useful in mixed contamination scenarios.
- **Machine Learning Algorithms:** Support Vector Machines (SVM), Random Forest (RF), and Artificial Neural Networks (ANN) classify contaminated areas based on spectral patterns.
- **Anomaly Detection:** Identifies pixels with unusual spectral signatures that may indicate contamination hotspots.

TABLE 2: COMPARISON OF SPECTRAL INDICES AND MACHINE LEARNING METHODS FOR CONTAMINATION DETECTION

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved

Method	Description	Advantages	Limitations
Normalized Difference Vegetation Index (NDVI)	Differentiates vegetated vs. bare soil	Simple, widely used	Limited specificity to contaminants
Heavy Metal Index (HMI)	Highlights spectral features of metals	Sensitive to metal contamination	Requires calibration
Spectral Unmixing	Extracts pure spectral signatures	Effective in mixed pixels	Computationally intensive
Support Vector Machines (SVM)	Classifies based on spectral features	High accuracy, robust	Requires labeled training data
Random Forest (RF)	Ensemble classification approach	Handles large datasets well	Potential overfitting
Artificial Neural Networks (ANN)	Non-linear classification	Learns complex patterns	Needs large training datasets

Table 2 compares spectral indices and machine learning algorithms used for detecting soil contamination from hyperspectral data.

APPLICATIONS IN INDUSTRIAL SOIL CONTAMINATION

HRS has been successfully applied to detect various contaminants near industrial sites:

- **Heavy Metals:** Mapping of lead, arsenic, and cadmium contamination near mining and smelting operations.
- **Hydrocarbons:** Detection of petroleum spill residues around refineries and oil storage facilities.
- **Acid Mine Drainage:** Identification of iron oxide minerals indicating acid mine drainage-affected soils.
- **Industrial Waste Dumps:** Monitoring spread and infiltration of pollutants in soils adjacent to waste disposal sites.

Integration of HRS with ground truth sampling enhances accuracy and facilitates targeted remediation efforts.

CHALLENGES AND LIMITATIONS

Despite its promise, hyperspectral remote sensing faces several challenges:

- **Spectral Variability:** Soil moisture, texture, and organic matter variations affect spectral signatures, complicating contamination detection.
- **Atmospheric Interference:** Atmospheric particles and gases distort spectral data, necessitating complex corrections.

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved

- **Data Volume and Processing:** High spectral resolution generates large datasets requiring substantial computational resources.
- **Limited Spatial Resolution:** Satellite sensors typically provide moderate spatial resolution, sometimes insufficient for small-scale contamination detection.
- **Training Data Requirement:** Machine learning models demand extensive and representative labeled data for reliable classification.

FUTURE TRENDS

Future advancements poised to enhance HRS applications include:

- **Integration with UAVs:** Combining satellite data with drone-acquired hyperspectral imagery for ultra-high resolution local mapping.
- **Deep Learning Algorithms:** Utilizing convolutional neural networks (CNNs) for automated feature extraction and classification.
- **Real-Time Monitoring:** Development of onboard satellite processing for near-real-time contamination detection.
- **Multisensor Fusion:** Combining hyperspectral with LiDAR and thermal sensors for comprehensive environmental assessment.

CONCLUSION

Hyperspectral remote sensing stands as a transformative technology for detecting and monitoring soil contamination caused by industrial activities. Its high spectral resolution enables identification of subtle chemical and mineralogical changes indicative of pollutants. While challenges in data processing and environmental variability remain, ongoing advancements in sensors, algorithms, and integration with ground data enhance its potential as a reliable environmental monitoring tool. Adoption of HRS can significantly improve industrial pollution management, enabling timely intervention and sustainable soil resource conservation.

REFERENCES

[1] S. T. Lee, J. Kim, and M. J. Cho, “Hyperspectral remote sensing for soil contamination detection: A review,” Environmental Science & Technology, vol. 54, no. 12, pp. 7562–7577, 2020.
[2] R. K. Gupta and P. Kumar, “Application of AVIRIS data for heavy metal contamination mapping near mining areas,” International Journal of Applied Earth Observation and Geoinformation, vol. 81, pp. 101–112, 2019.
[3] M. Smith et al., “Hyperspectral detection of petroleum hydrocarbons using machine learning,” Remote Sensing of Environment, vol. 222, pp. 219–232, 2019.
[4] A. Sharma and S. Verma, “Spectral indices for soil contamination assessment,” Journal of Environmental Monitoring, vol. 21, no. 8, pp. 432–444, 2018.
[5] T. Nguyen et al., “Machine learning approaches for hyperspectral soil contamination mapping,” Environmental Modelling & Software, vol. 115, pp. 40–52, 2019.
[6] P. Chen et al., “Hyperspectral remote sensing of acid mine drainage and contaminated soils,”

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved

Science of the Total Environment, vol. 642, pp. 1–12, 2018.
[7] J. Li and X. Wang, "Challenges and opportunities in hyperspectral soil contamination detection," Sensors, vol. 19, no. 6, 2019.
[8] N. Patel et al., "Advances in hyperspectral remote sensing for industrial pollution monitoring," Environmental Science and Pollution Research, vol. 27, pp. 25384–25401, 2020.

Page 42-47 © MANTECH PUBLICATIONS 2021. All Rights Reserved