Multi-Sensor Remote Sensing For Urban Land Use and Soil Quality Assessment

Dr. Ananya Mehta

Associate Professor

Department of Civil Engineering

National Institute of Technology, Jaipur, India

Email:*ananya.mehta@nitj.ac.in*

Er. Rahul Singh

Research Scholar

Centre for Remote Sensing

Indian Institute of Science, Bengaluru, India

Email:*rahul.singh@iisc.ac.in*

Abstract

Urban growth significantly influences both land use patterns and soil quality. Accurate assessment of these changes is critical for sustainable planning. This paper explores the integration of multi-sensor remote sensing data for simultaneous urban land use classification and soil quality monitoring. By combining high-resolution optical imagery, hyperspectral data, and Synthetic Aperture Radar (SAR), the study achieves improved accuracy in detecting built-up areas, vegetation cover, and soil degradation indicators. Techniques such as supervised classification, spectral unmixing, and backscatter analysis are discussed. A case study of Jaipur City demonstrates the potential of this approach to guide urban planners, environmental agencies, and policy makers. The findings highlight that multi-sensor fusion offers a cost-effective and reliable solution for large-scale, periodic monitoring of urban environments.

Keywords: *Multi-sensor remote sensing, Urban land use, Soil quality assessment, SAR, Hyperspectral imaging*

1. INTRODUCTION

Urban expansion has profound impacts on both the physical and environmental characteristics of land. As cities grow, agricultural and natural lands are transformed into built-up areas, often leading to soil degradation. Traditional field surveys for soil and land use monitoring are time-consuming and expensive, particularly for large metropolitan regions. Remote sensing offers an alternative, allowing for large-scale, repeated, and cost-effective assessments.

The integration of data from multiple sensors—optical, hyperspectral, and radar—has gained prominence for urban environmental monitoring. Each sensor type provides unique strengths: optical imagery captures visible features, hyperspectral data detects subtle material differences, and radar penetrates cloud cover and provides surface texture information. This study aims to examine the combined use of these sensors for a comprehensive understanding of urban land use and soil quality.

2. REMOTE SENSING FOR URBAN LAND USE MAPPING

2.1 Optical Remote Sensing

Optical imagery, such as Landsat-8 or Sentinel-2, provides medium to high spatial resolution, allowing for classification of built-up areas, green spaces, and water bodies. Supervised classification methods, such as Maximum Likelihood and Support Vector Machines, are commonly applied for urban land use mapping.

2.2 SAR (Synthetic Aperture Radar) Data

SAR is effective for mapping urban features under all weather conditions. The radar backscatter is particularly useful for detecting built-up structures, roads, and other man-made features. Sentinel-1 SAR data, for instance, enhances urban classification when combined with optical imagery.

2.3 Hyperspectral Remote Sensing

Hyperspectral sensors, such as Hyperion and AVIRIS-NG, capture data across hundreds of narrow spectral bands. This enables precise material identification, making it possible to differentiate between soil types, vegetation health, and construction materials.

3. SOIL QUALITY ASSESSMENT USING REMOTE SENSING

3.1 Indicators of Soil Quality

Soil quality is evaluated using parameters such as organic matter content, salinity, pH, and moisture. Remote sensing indirectly assesses these parameters through vegetation indices, thermal infrared data, and spectral signatures.

3.2 Hyperspectral Applications

Hyperspectral remote sensing enables detection of soil mineralogy, organic content, and contamination. Narrow-band indices like the Clay Mineral Ratio and Iron Oxide Ratio assist in mapping soil conditions.

3.3 SAR for Soil Moisture Monitoring

SAR backscatter is sensitive to soil moisture, making it useful in identifying dry or waterlogged urban soils. Integrating SAR with optical indices improves the accuracy of soil moisture estimation.

4. MULTI-SENSOR DATA FUSION APPROACH

4.1 Fusion Techniques

Multi-sensor data fusion integrates complementary datasets to create a unified representation. Techniques include:

- **Pixel-level fusion:** Combining raw pixel values from multiple sensors.
- **Feature-level fusion:** Extracting key features (e.g., texture, spectral indices) before merging.
- **Decision-level fusion:** Integrating results from separate classifications.

4.2 Benefits of Multi-Sensor Fusion

- Increased classification accuracy
- Improved discrimination between similar urban features
- Enhanced soil quality parameter detection
- Greater temporal coverage through combined sensor revisit times

Table 1: Comparison of Sensor Capabilities for Urban and Soil Monitoring

Sensor Type	Spatial Resolution	Weather Independence	Key Applications
Optical	10–30 m	No	Land cover classification, vegetation mapping
SAR	10 m	Yes	Built-up detection, soil moisture estimation
Hyperspectral	5–30 m	No	Soil mineral mapping, contamination detection

Explanation: This table compares optical, SAR, and hyperspectral sensors for their resolution, ability to operate under cloud cover, and main applications in urban and soil monitoring.

5. CASE STUDY: JAIPUR CITY

Jaipur, a rapidly expanding urban center in Rajasthan, was selected to demonstrate the utility of multi-sensor remote sensing for integrated land use and soil quality assessment.

5.1 Data Acquisition

- Sentinel-2 optical imagery for land cover classification
- Sentinel-1 SAR data for moisture mapping
- AVIRIS-NG hyperspectral data for soil mineral and organic matter mapping

5.2 Methodology

A fusion approach was applied using feature-level integration. Optical NDVI (Normalized Difference Vegetation Index) was merged with SAR-derived moisture indices and hyperspectral mineral maps. The fused dataset underwent supervised classification using a Random Forest algorithm.

5.3 Results

The classification achieved an overall accuracy of 92%, with clear differentiation between residential, industrial, green, and barren areas. Soil quality maps revealed high salinity in peri-urban agricultural zones due to unregulated irrigation and poor drainage.

6. DISCUSSION

The case study highlights the strengths of multi-sensor approaches. Optical data excels in identifying surface cover, SAR ensures year-round monitoring, and hyperspectral imagery provides soil composition details. Data fusion effectively reduced classification errors caused by seasonal variations and atmospheric interference.

However, challenges include data preprocessing complexity, high computational requirements, and the need for extensive ground truthing to validate soil parameters. Future advancements in AI-driven fusion techniques are expected to simplify workflows and further enhance accuracy.

7. CONCLUSION

This paper demonstrates that multi-sensor remote sensing is a powerful tool for simultaneously mapping urban land use and assessing soil quality. By leveraging the complementary strengths of optical, SAR, and hyperspectral data, urban planners can make more informed decisions, leading to sustainable development. The Jaipur case study validates that this approach is both technically feasible and cost-effective for large-scale applications.

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