

Mapping Land Subsidence in Mining Areas Using Remote Sensing Techniques

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Abstract

Land subsidence in mining areas is a critical geo-environmental hazard that can severely impact infrastructure, ecosystems, and human settlements. It is primarily caused by underground void formation due to mineral extraction, leading to gradual or sudden sinking of the ground surface. Remote sensing techniques, especially Interferometric Synthetic Aperture Radar (InSAR), LiDAR, and optical imagery analysis, have emerged as cost-effective, large-scale, and repeatable tools for mapping and monitoring subsidence. This paper discusses the principles, methodologies, and practical applications of these remote sensing techniques in mining regions, with specific reference to case studies from India and abroad. It also highlights the integration of remote sensing outputs into Geographic Information Systems (GIS) for spatial risk assessment, and outlines the advantages and limitations of each method. By synthesizing recent advancements and field applications, the paper emphasizes a multi-sensor, hybrid approach to achieve precise and sustainable subsidence monitoring in mining zones.

Keywords: *Land subsidence, Mining areas, Remote sensing, InSAR, LiDAR, GIS mapping, Deformation monitoring*

INTRODUCTION

Land subsidence refers to the lowering of the Earth's surface due to the displacement of underground material. In mining areas, subsidence occurs mainly as a result of underground mineral extraction, creating voids that collapse over time. This process can lead to **serious damage** to roads, buildings, pipelines, and water channels, as well as disrupt agricultural productivity and natural drainage patterns.

Historically, monitoring subsidence relied on **ground-based techniques** such as levelling surveys, total station measurements, and GPS-based monitoring. Although these methods provide high accuracy, they are labor-intensive, time-consuming, and cover limited areas. The need for **large-scale, cost-effective, and frequent monitoring** has driven the adoption of remote sensing techniques, which provide synoptic, multi-temporal, and high-resolution observations.

REMOTE SENSING TECHNIQUES FOR SUBSIDENCE MAPPING

Interferometric Synthetic Aperture Radar (InSAR)

InSAR uses phase differences between radar images taken at different times to detect ground deformation at millimeter-level precision. In mining areas, **Persistent Scatterer InSAR (PS-InSAR)** and **Small Baseline Subset (SBAS)** techniques are widely used to map subsidence bowls and deformation patterns.

LiDAR

Light Detection and Ranging (LiDAR) uses laser pulses to create high-resolution 3D models of the terrain. It is particularly effective in detecting subtle changes in elevation and identifying **micro-topographic features** in post-mining landscapes.

Optical Remote Sensing

High-resolution satellite or aerial imagery detects surface changes such as ground cracks, vegetation stress, and alterations in drainage. While less precise in vertical deformation detection compared to radar, it provides **valuable contextual and land-use information**.

CASE STUDIES

Jharia Coalfield, India

InSAR time-series analysis revealed subsidence rates exceeding 10 cm/year over active mining panels. The data helped authorities plan **rehabilitation and relocation** of affected settlements.

Appalachian Coalfields, USA

LiDAR datasets captured the gradual lowering of surface elevations over abandoned mines, enabling early-warning systems for infrastructure maintenance.

Shenhua Coalfield, China

Multi-sensor fusion of optical imagery and InSAR provided both quantitative displacement data and qualitative land-use change insights, leading to improved **risk zoning maps**.

DATA INTEGRATION WITH GIS

The power of remote sensing is maximized when outputs are **integrated into GIS platforms**. Subsidence maps can be overlaid with layers such as **infrastructure, hydrology, land-use, and population density** to identify areas of high vulnerability. GIS also supports **predictive modeling** by combining spatial datasets with geological and mining activity data.

ADVANTAGES AND LIMITATIONS

Technique	Application	Advantages
InSAR	Detecting vertical displacements in mining areas	High precision, large area coverage
LiDAR	High-resolution topographic mapping	Detailed terrain analysis
Optical Imagery	Surface change detection, vegetation stress mapping	Cost-effective, widely available

Advantages:

- Non-intrusive data acquisition
- Large spatial coverage
- High temporal resolution (repeat monitoring)

Limitations:

- InSAR is affected by atmospheric disturbances and decorrelation over vegetated areas.
- LiDAR acquisition can be expensive.
- Optical imagery is dependent on weather and lighting conditions.

RESEARCH METHODOLOGY FOR SUBSIDENCE MAPPING

A typical remote sensing workflow for mapping mining-induced subsidence includes:

1. **Data Acquisition** – Selecting appropriate sensors (Sentinel-1 for InSAR, airborne LiDAR, or high-resolution optical imagery).

2. **Pre-processing** – Includes radiometric calibration, atmospheric correction, and geometric alignment.
3. **Change Detection** – Applying InSAR algorithms or DEM differencing for elevation changes.
4. **Validation** – Using ground-truth measurements such as GPS benchmarks.
5. **GIS Integration** – Overlaying results with socio-economic and environmental data.
6. **Output Generation** – Producing thematic maps and risk assessment reports.

FUTURE PROSPECTS

Emerging technologies like **UAV-based LiDAR**, cloud-computing platforms for big data processing, and AI-driven change detection are enhancing the speed and precision of subsidence mapping. Sentinel-1 SAR's free availability has democratized deformation monitoring, making it feasible even for resource-limited regions.

CONCLUSION

Remote sensing techniques have revolutionized the monitoring of land subsidence in mining areas by providing accurate, repeatable, and cost-effective solutions. InSAR, LiDAR, and optical imagery, when integrated within GIS, enable comprehensive risk assessments that are vital for **sustainable mining and urban planning**. The future lies in **multi-sensor, hybrid approaches**, supported by cloud-based processing and AI analytics, to deliver timely information for mitigation and adaptation strategies.

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