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Land Subsidence Monitoring With InSAR Techniques

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ABSTRACT

Interferometric Synthetic Aperture Radar (InSAR) has emerged as a revolutionary geodetic technique for precise monitoring of land subsidence phenomena. This remote sensing method leverages the phase difference between repeated radar satellite passes to detect millimeter-scale ground deformations over large areas. Land subsidence, caused by factors such as groundwater over-extraction, mining, and tectonic activity, has severe implications on infrastructure stability, water resource management, and urban planning. This paper examines the principles, processing workflows, and applications of InSAR for subsidence monitoring, emphasizing case studies from urban and agricultural regions. Additionally, it outlines challenges like atmospheric artifacts and temporal decorrelation, while discussing emerging solutions such as Persistent Scatterer InSAR (PSInSAR) and Small Baseline Subset (SBAS) approaches. The discussion aims to provide insights into how

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InSAR contributes to sustainable land and resource management strategies.

Keywords: *InSAR, Land Subsidence, Remote Sensing, PSInSAR, SBAS, Ground Deformation, Satellite Radar*

INTRODUCTION

Land subsidence is a gradual settling or sudden sinking of the Earth's surface, often resulting from the extraction of subsurface resources such as water, oil, and gas, or due to natural processes like tectonic movements. It poses significant risks to infrastructure, agriculture, and the environment. The consequences include damage to buildings, bridges, roads, and pipelines, as well as increased flooding risk in low-lying areas. With rapid urbanization and industrial development, the demand for groundwater extraction has intensified, making land subsidence a global concern.

Conventional ground-based methods like leveling, GPS, and extensometers, while accurate, are often costly, labor-intensive, and spatially limited. In contrast, Interferometric Synthetic Aperture Radar (InSAR) provides a powerful, cost-effective, and wide-area monitoring solution. By comparing radar signals acquired at different times from the same location, InSAR detects subtle surface changes with centimeter to millimeter accuracy. Over the past two decades, advancements in satellite missions, such as Sentinel-1, TerraSAR-X, and ALOS PALSAR, have enabled near real-time monitoring of land deformation.

This paper aims to explore the mechanisms, processing techniques, and applications of InSAR in detecting and analyzing land subsidence. It will also address the inherent limitations of the technology and suggest strategies to improve accuracy, including multi-temporal analysis and integration with other geospatial datasets.

Table 1: Major Causes of Land Subsidence

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Cause	Description
Groundwater extraction	Over-pumping reduces pore water pressure, causing compaction of aquifer materials.
Mining	Removal of underground materials leads to voids and collapse of overlying strata.
Tectonic activity	Natural crustal movements causing displacement or sinking of land.

LITERATURE REVIEW

Over the last two decades, InSAR has evolved into a mainstream technique for monitoring land deformation with remarkable precision. Gabriel et al. (1989) were among the pioneers to demonstrate radar interferometry for measuring Earth surface deformation. Subsequent studies expanded the application scope from volcanic monitoring to urban subsidence detection. The introduction of Persistent Scatterer InSAR (PSInSAR) by Ferretti et al. (2001) addressed the issue of temporal decorrelation, enabling reliable measurements in urban and semi-urban environments. Small Baseline Subset (SBAS) methods, such as those proposed by Berardino et al. (2002), further improved coherence over vegetated areas by minimizing baseline lengths.

Recent research highlights the fusion of InSAR data with GNSS, leveling, and hydrological modeling to achieve higher accuracy in subsidence estimation. For example, Chaussard et al. (2014) demonstrated the use of multi-sensor approaches to link groundwater extraction with subsidence rates in Jakarta, Indonesia. Advancements in satellite missions like Sentinel-1A/B, with their free and open data policy, have accelerated research and operational use in resource-limited regions.

Table 2: Comparison of InSAR Techniques

Technique	Advantages	Limitations
DInSAR	Detects cm-mm changes	Sensitive to atmospheric

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	over wide areas.	delays, decorrelation.
PSInSAR	High accuracy in urban areas.	Requires stable reflectors.
SBAS	Good for vegetated/rural areas.	Lower temporal resolution than PSInSAR.

METHODOLOGY

The methodology for land subsidence monitoring using InSAR involves several steps:
1. **Data Acquisition** – Collect SAR images from satellites such as Sentinel-1, ALOS PALSAR, or TerraSAR-X.
2. **Image Preprocessing** – Correct for orbit errors, radiometric distortions, and remove noise.
3. **Interferogram Generation** – Pair SAR images with small temporal and spatial baselines to create interferograms.
4. **Phase Unwrapping** – Convert relative phase measurements into absolute displacement values.
5. **Time-Series Analysis** – Apply PSInSAR or SBAS to track displacement trends over time.
6. **Validation** – Cross-check results with GNSS, leveling, or ground truth data.
This workflow ensures reliable detection of subtle subsidence phenomena over large spatial extents.

FUTURE SCOPE

Future advancements in InSAR technology will focus on increasing temporal resolution, improving atmospheric corrections, and integrating Artificial Intelligence (AI) for automated anomaly detection. Upcoming missions like NASA-ISRO SAR (NISAR) will provide dual-frequency L- and S-band data, enhancing penetration through vegetation and improving measurement accuracy. The fusion of InSAR with Internet of Things (IoT) ground sensors could enable real-time hazard early warning systems.

CONCLUSION

InSAR has revolutionized the monitoring of land subsidence by offering millimeter-level precision over vast areas at relatively low cost. Its ability to capture temporal

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evolution of subsidence makes it invaluable for urban planning, infrastructure safety, and environmental conservation. While atmospheric effects and decorrelation remain challenges, advancements in processing algorithms, sensor technology, and data integration are rapidly overcoming these limitations. The technology will continue to play a critical role in sustainable resource management and disaster risk reduction.

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