Analysis of Long-term Ground Subsidence Displacement of a Transmission Facilities using Multi-temporal SAR Imagery and PSInSAR

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1. Introduction

Transmission towers are critical infrastructure in the power grid, supporting the uninterrupted supply of electricity across large areas. However, the stability of these structures can be compromised by ground displacement, which can arise from various natural factors such as soil erosion, earthquakes, or gradual subsidence. Ground displacement poses a risk to the structural integrity of transmission towers, potentially leading to instability or even collapse, which can disrupt electricity supply and cause significant economic and social impacts.

Traditional methods of monitoring ground displacement, such as ground surveys, are often labor-intensive, time-consuming, and limited in coverage, especially for remote or large areas. As a result, there is a need for more efficient and reliable monitoring techniques. Synthetic Aperture Radar (SAR) has emerged as a valuable tool for monitoring ground displacement due to its high-resolution imagery and ability to capture data under all weather conditions, both day and night. Unlike conventional ground-based surveys, SAR allows for large-scale, continuous observation of surface changes over time.

One of the most advanced techniques for analyzing SAR data is Persistent Scatterer Interferometric SAR (PSInSAR). PSInSAR provides precise measurements of ground displacement by identifying stable scatterers, such as buildings or towers, that consistently reflect radar signals. Transmission towers, being highly reflective, are ideal for this type of analysis, allowing for detailed tracking of ground movements over extended periods.

The main objective of this study is to apply PSInSAR to monitor ground displacement around a transmission tower located in Gimpo-si, Gyeonggi-do, Republic of Korea. This city has numerous transmission towers of various sizes, including the largest in South Korea, making it an ideal site for this investigation. By utilizing PSInSAR, the study aims to detect any significant ground displacement and assess its potential impact on the stability of the transmission towers.

The scope of this research is limited to the area around the transmission tower in Gimpo-si but holds broader implications for monitoring transmission infrastructure worldwide. The study's findings will contribute to improving the methods used for infrastructure monitoring and could help prevent service disruptions caused by ground displacement. This research is significant for its potential to enhance the safety and reliability of transmission networks, providing a proactive approach to infrastructure management.

2. MATERIALS AND METHODS

2.1 Study area:

The study area is located in Gimpo-si, Gyeonggi-do, Republic of Korea. Fig. 1 shows the location of Gimpo-si and the transmission towers under study. The red box highlights the study area, and each transmission tower site is marked with a cross.

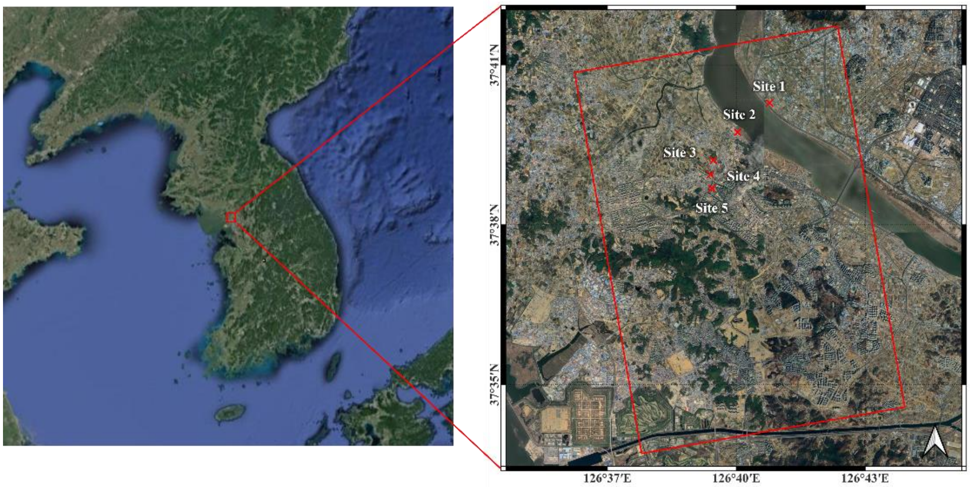

Figure 1: The Location and View of Gimpo-si.

There are various structural types of substations in Korea, and Shingimpo substation is a representative one. The Shingimpo substation, completed in 2011, operates at a transmission voltage of 345kV and plays a critical role in transmitting electricity produced from power plants near Incheon through Paju-si and up to Yangju-si. The transmission line connecting the Shingimpo and Shinpaju substations must cross the lower Han River, which spans approximately 1.5km in width. As a result, the transmission towers located on the border between Gimpo- and Paju-si are designed to be exceptionally tall to span the river. Notably, the transmission tower at site 1, shown in Fig. 1, stands at 195 meters tall and approximately 36 meters wide, making it the largest transmission tower in Korea. Fig. 2 shows the appearance of the transmission tower at site 1.


Figure 2: The Tower in Site 1.

2.2 PSInSAR:

PSInSAR is a method used to detect surface displacement with millimeter-level precision by analyzing time-series SAR images and the radar signals that are consistently backscattered from persistent scatterers (PS) (Ferritti *et al.*, 2001). PS refers to stable surface features, such as man-made structures or rock formations, that consistently produce strong backscatter. In this study, PSinSAR was processed using the Stanford Method for Persistent Scatterers (StaMPS) package (Hooper, 2007).

2.3 Datasets:

The SAR imagery used in this study was acquired from Sentinel-1A. Sentinel-1 is a SAR satellite operated by the European Space Agency (ESA), orbiting the Earth in a sun-synchronous orbit at an altitude of 693 km, obtaining images every 12 days. The satellite operates with a C-band sensor at a center frequency of 5.4 GHz (wavelength of approximately 5.6 cm). For time-series InSAR analysis, 25 Single Look Complex (SLC) images were acquired from July 2023 to May 2024.

3. Results and Discussion

The PSInSAR analysis, processed using 25 SAR images, identified 228,126 PSs within the study area. Fig. 3 shows the PSInSAR result and the average coherence image during the study period. On average, the PS used in the analysis detected a displacement rate of about -4.7 mm/year and was found to be highly stable at most sites. Fig. 4 shows the displacement results derived from the PSInSAR for each site. At site 1(126˚41'07"E, 37˚40'37"N), representing the largest transmission tower in the study area, a maximum line-of-sight (LOS) displacement of about 15 mm was observed over the 10-month period. However, this displacement occurred primarily during the summer months, from July to October 2023, and stabilized with minimal change after November 2023.

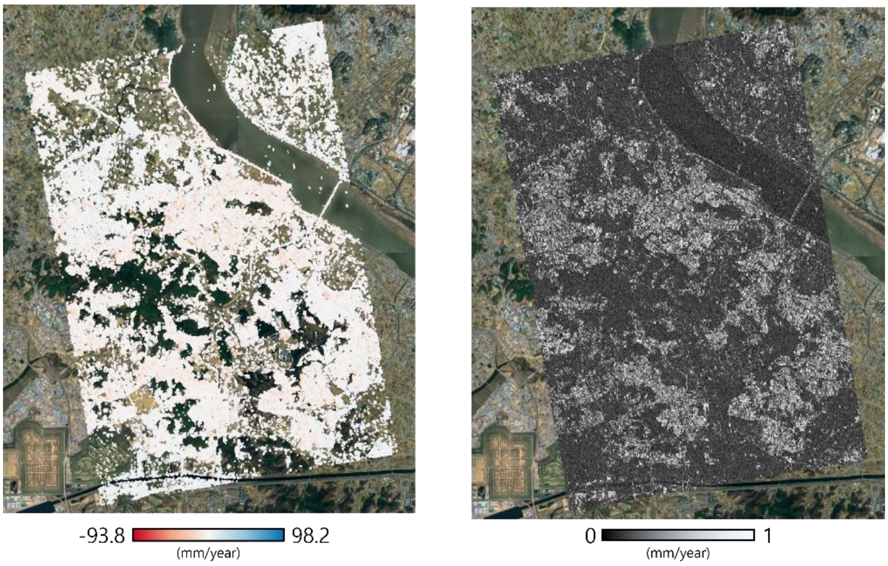

Figure 3: Result of PSInSAR and Averaged Coherence Window.

The transmission tower at site 2(126˚40'21"E, 37˚40'03"N), which is directly connected to site 1 and is of similar size, also showed no significant displacement (with a displacement rate of up to -5.2 mm/year) and remained very stable. The series of towers connected to site 2—site 3 (126˚39'54"E, 37˚39'44"N), site 4 (126˚39'42"E, 37˚39'23"N), and site 5 (126˚39'46"E, 37˚39'09"N)— are relatively smaller in scale, with some located in mountainous areas (especially, site 3 had only one PS identified). While fewer PSs were detected compared to the larger towers, the detected PSs showed stable displacements. Sites 3 to 5 show displacement rates of -6.7, -1, and -7.2 mm/year, respectively.

In this study, we utilized Sentinel-1 SAR imagery to analyze displacements around transmission towers located in urban and some mountainous areas. Although each tower was represented by only 2-4 pixels in the Sentinel-1 imagery, the results indicate that meaningful displacement analysis is achievable.

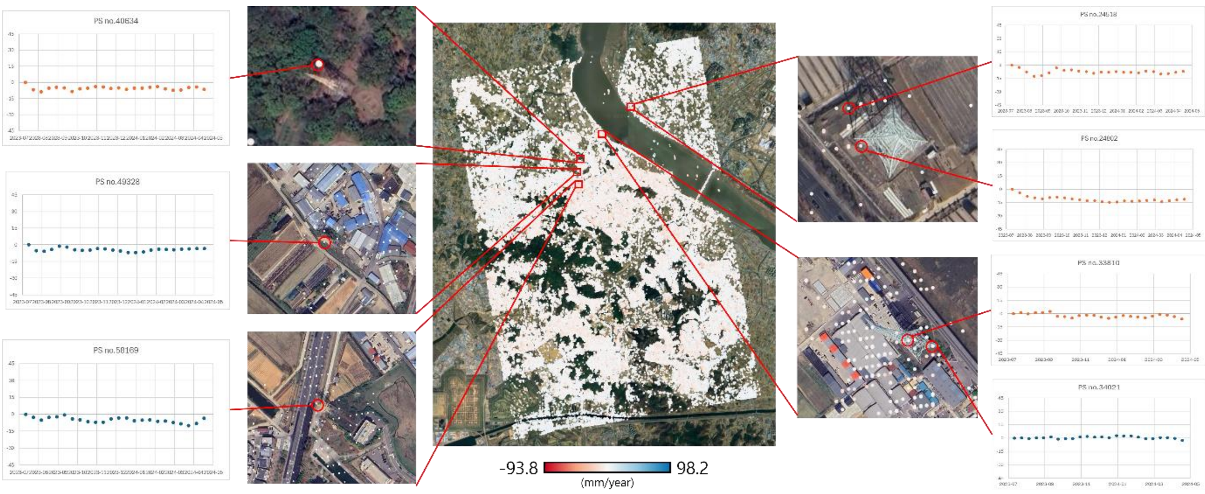

Figure 4: Results of PSInSAR.

4. Conclusion and Recommendation

This study applied the PSInSAR technique to analyze ground displacement around transmission towers in Gimpo-si, Gyeonggi-do. Using Sentinel-1 SAR imagery, we successfully monitored the displacement of transmission towers located in both urban and mountainous areas. The displacement from the transmission towers was mostly stable, with the largest displacement being within about 15 mm of the maximum over a 10-month period (site 1). Notably, the displacement at site 1 was concentrated during the summer months, indicating that seasonal factors may influence the stability pf transmission towers. These findings provide valuable insights for developing long-term maintenance strategies. Despite the resolution limitations of Sentinel-1, this study demonstrated that meaningful displacement analysis is feasible through stable PS identification.

These results suggest that future studies could improve the precision of infrastructure monitoring by combining PSInSAR with higher resolution SAR data or other remote sensing data. Therefore, we recommend the continued use of SAR-based techniques, including PSInSAR, for the long-term monitoring and management of critical infrastructure like transmission towers. Additionally, further research is needed to examine the impact of seasonal or climatic factors more thoroughly. This would enable the development of strategies to enhance the stability of transmission towers and prevent potential failures.

References

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Acknowledgments

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