Estimation of land deformation using the PSInSAR technique in Taiwan

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1. Introduction

Taiwan, a mountainous island in East Asia off the southeastern coast of China, is renowned for its vibrant cities, advanced technology industry, and rich cultural heritage. However, the country faces significant challenges with land subsidence, particularly during periods of severe drought. The severe drought that struck Taiwan in 2021 intensified these issues. Drought conditions can lead to excessive groundwater extraction, as industries, agriculture, and households attempt to maintain water supplies. This over-reliance on groundwater causes the underground aquifers to deplete, leading to the gradual sinking of the land, particularly in regions with loose soils or clay. The resulting land subsidence poses serious risks to Taiwan's infrastructure, agriculture, and ecosystems, making it a critical issue for the nation's future. Subsidence can damage roads, bridges, and railways, complicating transportation and raising costs for maintenance and repair. Farmland is also at risk, as subsidence can disrupt irrigation systems, increase flooding, and reduce soil quality, which impacts food security and farmer livelihoods. Coastal areas face the additional threat of saltwater intrusion, which can degrade freshwater resources and damage ecosystems. Moreover, subsidence exacerbates vulnerability to other natural hazards, such as earthquakes and typhoons, by weakening soil stability and increasing the likelihood of landslides. Addressing this issue requires a comprehensive approach involving water management reforms, sustainable land use planning, and advancements in monitoring technologies. Taiwan has been actively investing in PS-InSAR and GNSS technologies, along with satellite imagery, to track land subsidence in real-time. These tools help identify high-risk areas and allow authorities to monitor changes with high precision, even at millimeter scales. Public awareness and stricter regulations on groundwater extraction are also crucial for promoting sustainable water usage. As climate change intensifies the frequency and severity of droughts, Taiwan must strengthen its

efforts to secure its water resources and protect its infrastructure and ecosystems from the compounded impacts of subsidence and other environmental stresses.

2. Materials and Methods

In this experiment, we used Sentinel-1 satellite imagery and employed PS-InSAR technology to monitor ground deformation across Taiwan from 2019 to 2023. For image preprocessing, we utilized SNAP software to select the master image and generate interferograms with the other slave images. In the PS-InSAR processing, we applied the amplitude dispersion index (ADI) indicator proposed by Esmaeili, calculated by equation (1), which is an estimation for the phase stability in scatterers. After unwrapping and atmospheric filtering, preliminary results were obtained.

$$ADI = \frac{\sigma_a}{\bar{a}} = \frac{\sqrt{\frac{\sum_{i=1}^{N}(|s_i| - \overline{|s|})^2}{N}}}{\frac{1}{N}\sum_{i=1}^{N}|s_i|} \quad \text{(Esmaeili et al., 2016)}$$

σ_a : the standard deviation of amplitude
S : a complex value of a SLC pixel
$|S_i|$: the amplitude of the pixel in the ith image
$\bar{a}, \overline{|s|}$: the mean amplitude
N: the number of images

(1)

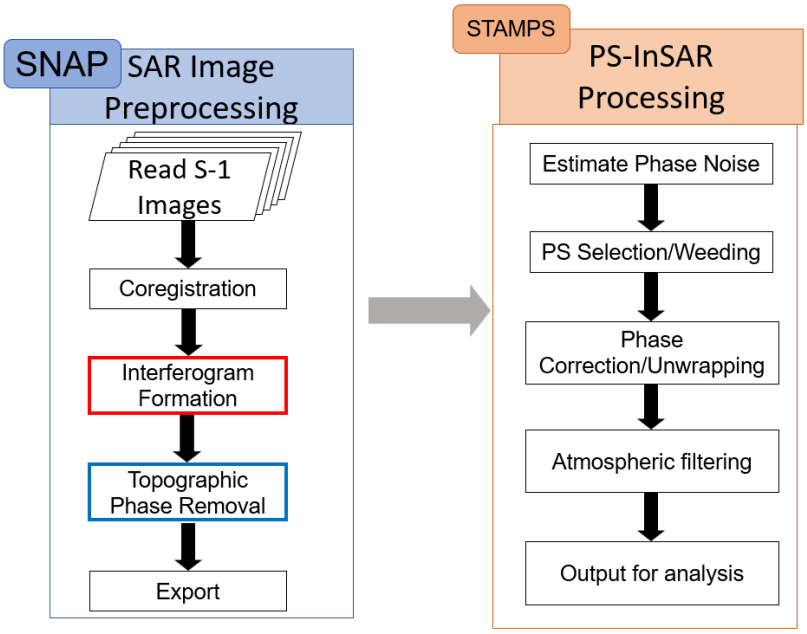

Figure 1: Workflow of methodology.

3. Results and Discussion

Our preliminary results reveal that Yilan County experienced significant subsidence between 2019 and 2023 (Figure 2), with the most pronounced sinking occurring during the severe drought in 2021. This intensified subsidence suggests a strong link between drought conditions and accelerated ground deformation, underscoring how sensitive subsidence rates can be to changes in water availability. During the drought, the heightened demand for groundwater extraction likely led to rapid depletion of aquifers, resulting in an increase in subsidence as the underlying soils compacted and lost structural stability. The impact was especially noticeable in areas with clay-rich or loose soils, which are particularly prone to compaction when groundwater levels drop. This correlation highlights the urgent need for improved groundwater management policies, especially in regions vulnerable to drought-induced stress. Implementing sustainable water management strategies, such as stricter regulation of groundwater extraction and investment in alternative water sources, could help reduce the pressure on groundwater reserves. In the face of intensifying climate change and the likelihood of more frequent and severe droughts, such measures are essential for protecting both the environment and infrastructure. Enhanced monitoring, coupled with PS-InSAR technology, offers a valuable tool for identifying critical areas where immediate action can mitigate further subsidence, ultimately supporting long-term urban resilience and sustainable resource management in Yilan and similar regions across Taiwan.

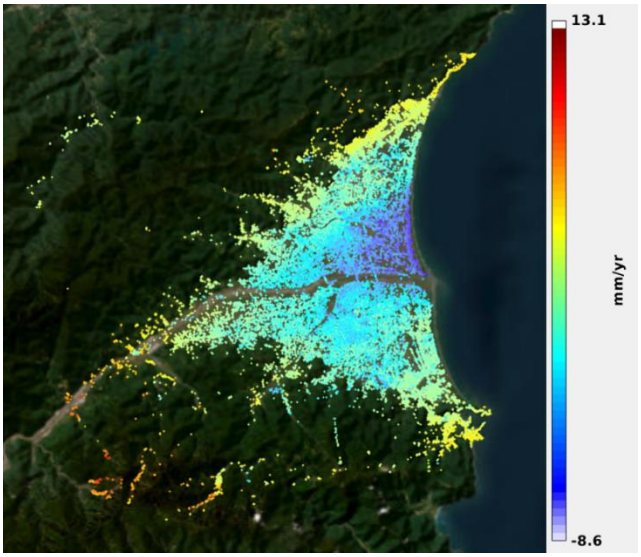

Figure 2: Results in Yilan County.

4. Conclusion and Recommendation

Using PS-InSAR technology, we have successfully gained insights into long-term ground

deformation in urban areas across Taiwan. This advanced satellite-based technique has enabled us to accurately track and analyze ground changes over time, capturing even minute shifts in elevation with millimeter-level precision. By correlating these changes with natural weather conditions, such as droughts, heavy rainfall, and seasonal temperature variations, we have identified significant relationships between environmental factors and subsidence patterns. For example, drought-induced groundwater depletion has been linked to increased subsidence rates, particularly in regions where water demand from industries and agriculture is high. This comprehensive understanding enhances our ability to predict and manage the impacts of natural events on urban infrastructure. The data collected not only reveals current trends but also offers insights into future risks, allowing for predictive models that can guide urban planning and infrastructure design. For instance, understanding subsidence-prone areas helps authorities prioritize where to reinforce or redesign infrastructure, such as roads, bridges, and utilities, to withstand gradual sinking or uneven ground surfaces. Additionally, by examining patterns of subsidence in relation to rainfall and groundwater levels, we can better anticipate the effects of climate change, which is expected to bring more extreme weather events and exacerbate subsidence issues. The strategic planning supported by PS-InSAR data also extends to disaster preparedness, as identifying high-risk zones enables authorities to implement preventive measures and optimize emergency response plans. In coastal areas, where subsidence can increase the risk of flooding and saltwater intrusion, insights from PS-InSAR help shape sustainable water management practices and guide urban zoning laws that protect vulnerable ecosystems. This valuable data aids in informed decision-making across multiple sectors, empowering government agencies, urban planners, and environmental groups to work together in mitigating the impacts of land subsidence. As Taiwan continues to embrace technological solutions to safeguard its cities, PS-InSAR serves as a cornerstone for sustainable development, enhancing resilience against both natural and human-induced environmental challenges.

References

Bamler, R. (2000). Principles of synthetic aperture radar. Surveys in Geophysics, 21(2), 147-157.

Hooper, A., Zebker, H., Segall, P., & Kampes, B. (2004). A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. Geophysical research letters, 31(23).

Hooper, A., Spaans, K., Bekaert, D., Cuenca, M. C., Arıkan, M., & Oyen, A. (2010). StaMPS/MTI manual. Delft Institute of Earth Observation and Space Systems Delft University of Technology, Kluyverweg, 1, 2629.