



Multi-Temporal InSAR Analysis of Karst-Induced Subsidence and Its Effects on Structural Stability at Gharbanyiat Area, Alexandria, Egypt



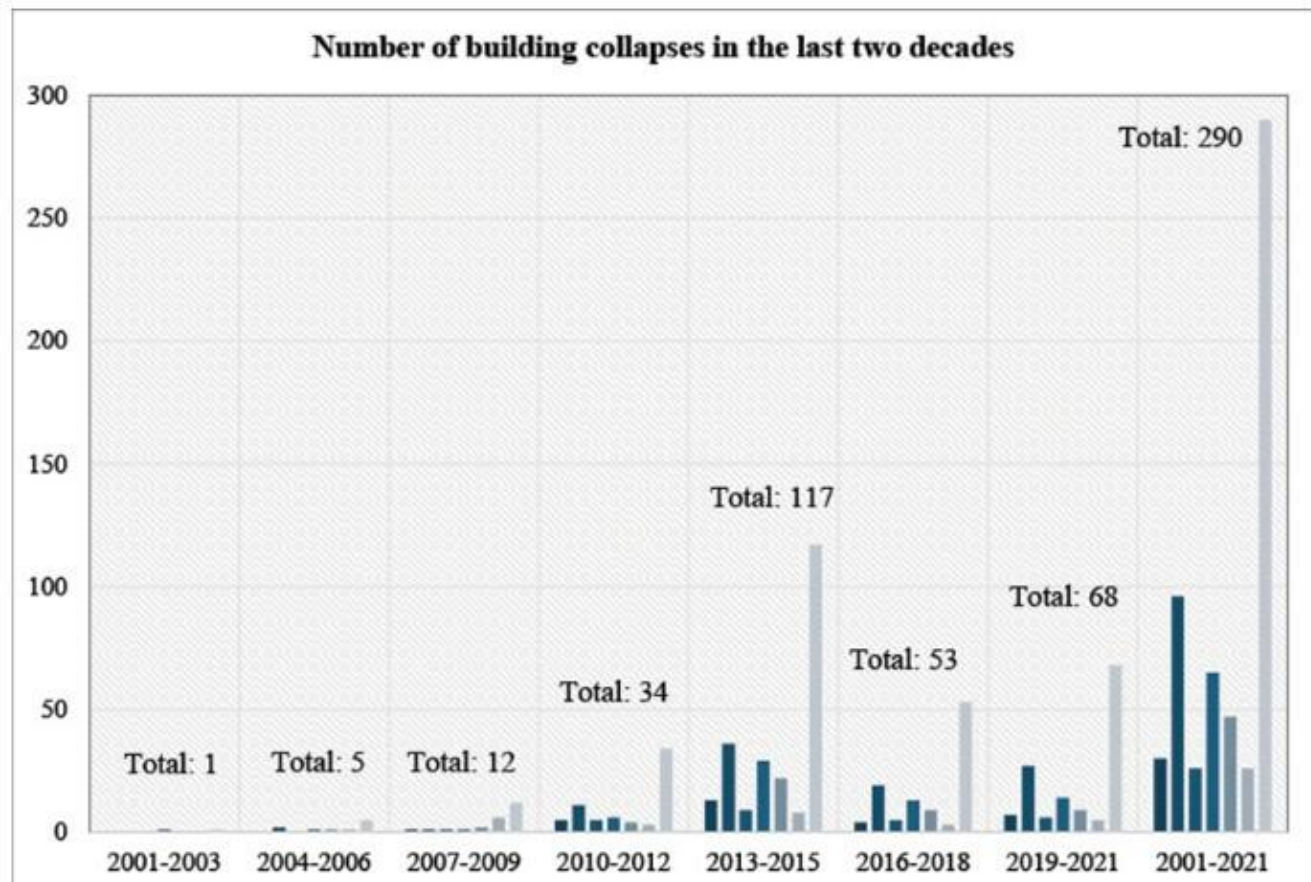
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Abstract

Sinkhole is a depression and a pervasive geohazard in karst terrains, where the progressive dissolution of carbonate bedrock leads to subsurface void formation and eventual ground collapse. These phenomena pose substantial risks to urban infrastructure, as their concealed development often precedes sudden surface subsidence, resulting in structural and settlement damage. The Gharbanyiat area located in the western part of Borg Al Arab region exemplifies such challenges, with documented cases of ongoing cavity propagation beneath populated areas. In this study, we employ Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) approaches using Sentinel-1 SAR imagery to monitor and analyze surface deformation associated with sinkhole development. Furthermore, we integrate field data to frame InSAR-derived deformation within the region's hydrogeological framework. Results demonstrate that areas exhibiting the highest subsidence rates correlate with zones of unconsolidated sediments overlying carbonate rocks, a configuration prone to exposure-collapse sinkholes. we detect and quantify subtle ground displacements, revealing a direct correlation between subsidence patterns and active sinkhole formation. Time-series analysis reveals localized subsidence patterns aligned with known sinkhole occurrences, validating the technique's sensitivity to incipient karst-induced instability. Our findings underscore PS-InSAR utility as a proactive monitoring tool for sinkhole risk assessment in urbanized karst environments.

Introduction



Main driving factors for buildings collapse in Alexandria city.

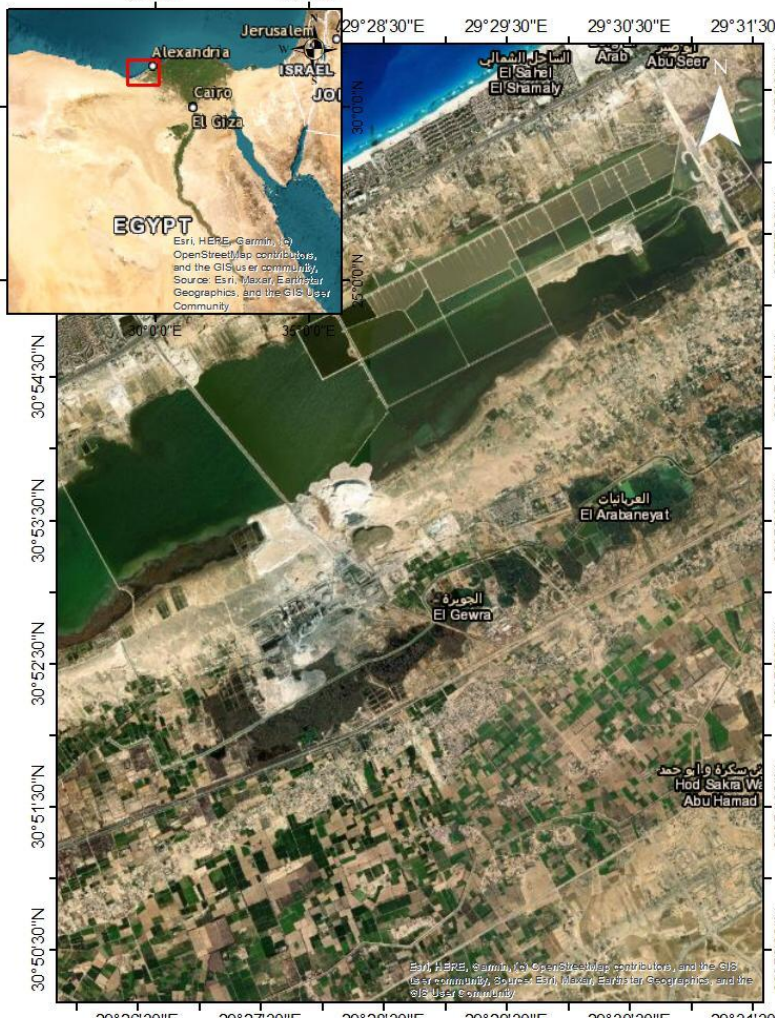
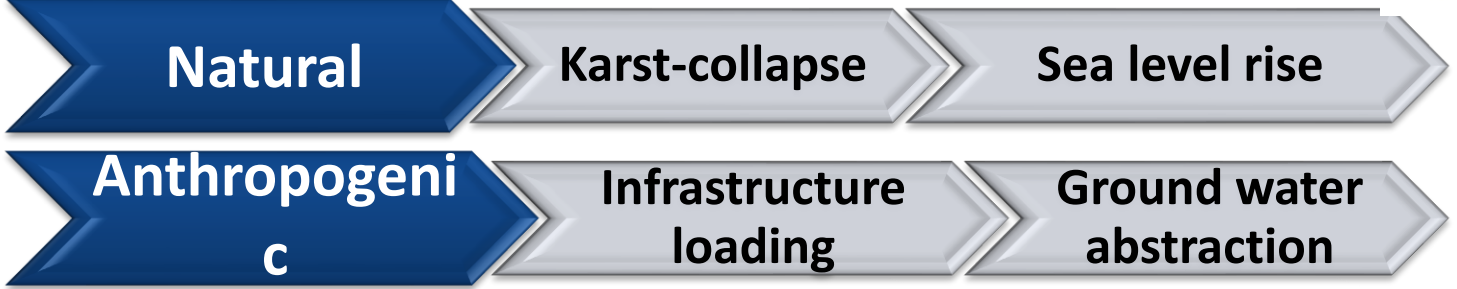


Figure 1. Study Area Map of Alexandria City.

Objectives

subsidence	detect and map the spatial distribution of ground surface displacement.
Assessment	Integrate the field data and InSAR-derived deformation patterns into actionable insights for urban planners, supporting early-warning strategies and infrastructure resilience.
Study Area	Alexandria has experienced considerable ground subsidence over the past several decades due to the hydroclimatic and anthropogenic drivers that accelerate buildings collapse .

Materials and Methods

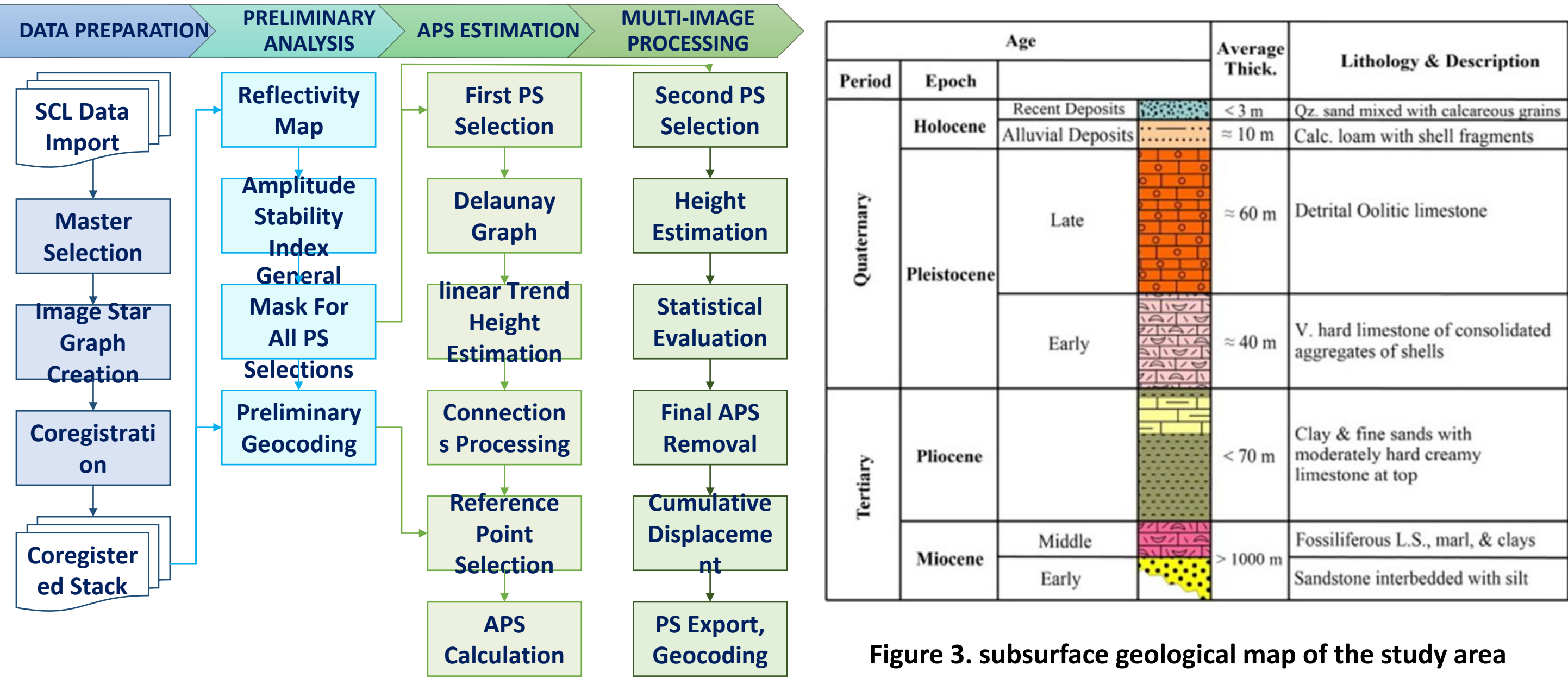


Figure 2. Standard PSInSAR Processing in SARProZ

We employed the Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) technique to analyze ground deformation associated with sinkhole development. The processing was implemented using SARPROZ software (Perissin et al., 2012), following the standard workflow illustrated in Figure 2.

A dataset of 29 ascending-track Sentinel-1 images (VV polarization) was processed, covering the period from 8 February 2024 to 21 January 2025. These C-band SAR images enabling the detection of millimeter-scale surface displacements. In addition to this, Field Validation and Geological Characterization has integrated to geolocate active sinkholes and map their spatial distribution, characterize subsurface stratigraphy, focusing on the interface between unconsolidated sediments and underlying carbonate bedrock, and Document sinkhole dimensions (aperture, depth) and structural controls. This combined InSAR-derived deformation and field-based methodology ensures robust identification of high-risk zones.

Results

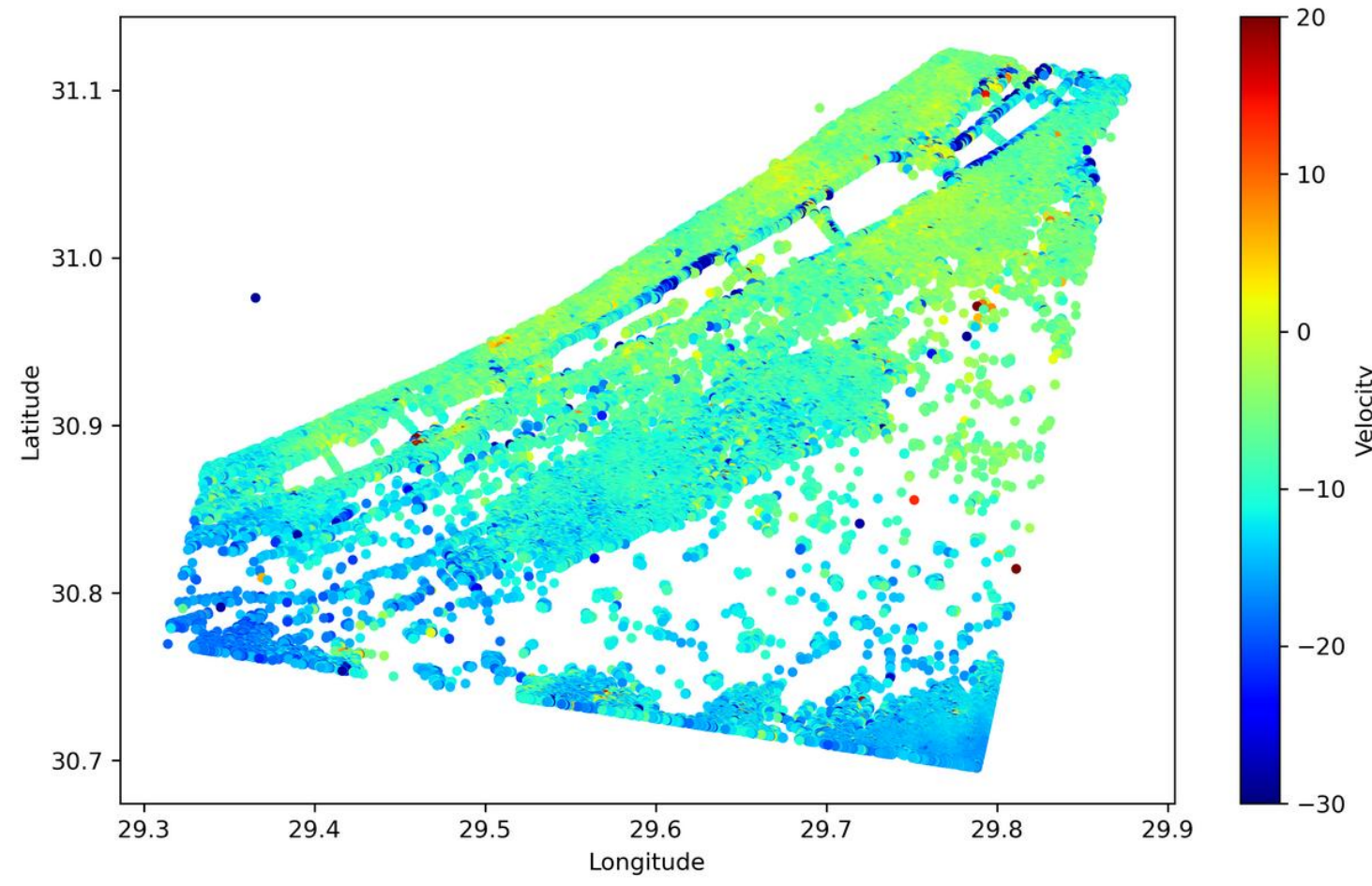


Figure 4. Velocity map using S-1A generated by SARPROZ.



Figure 6. Manifestations of karst subsidence (a, b) sinkholes that formed due to karst, most of them filled with water. (C, d) Structural damage to buildings including tension cracks and subsurface voids



Figure 5. optical image portraying the profile (red line) in the investigated area

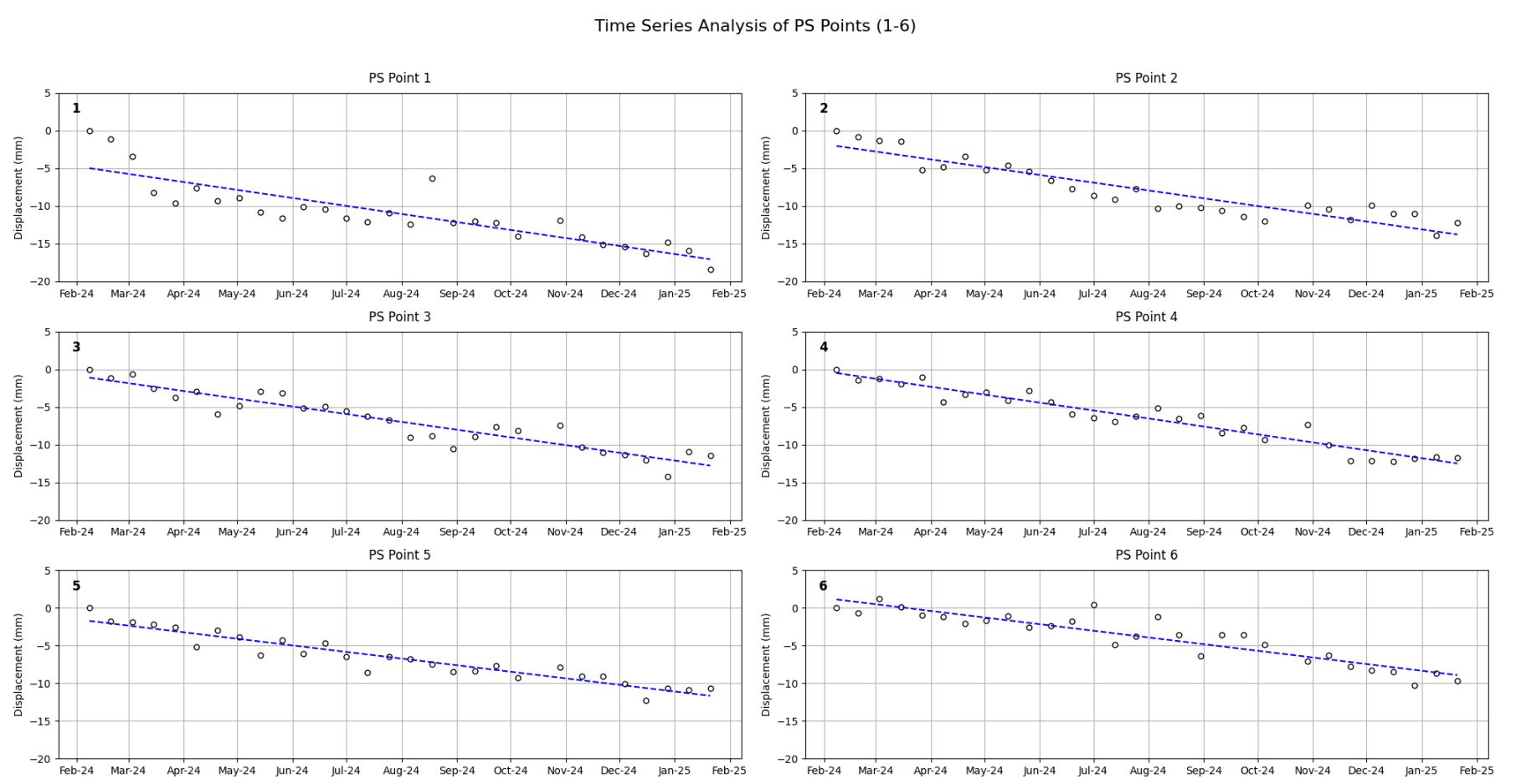


Figure 2. Standard PSInSAR Processing in SARProZ

No.	Region	Depth (m)	Diameter(m)
1	Agharbanaat	1	2
2	Station	6	5
3	area	8	7.5
4		4	3

Table 1. Characteristics of sinkholes around Agharbanaat station

The field-verified sinkholes (Fig. 6) and their documented characteristics (Table 1) were integrated with satellite-derived deformation data. A linear deformation model was applied to estimate ground displacement, yielding a velocity map (Fig. 4) with line-of-sight (LOS) deformation rates ranging from -30 mm/year to +10mm/year. Spatial analysis revealed maximum deformation rates localized in the central and southwestern sectors of the study area. To investigate localized subsidence patterns associated with the sinkholes, a 5-km transect (red line, Fig. 5) was analyzed using persistent scatterer (PS) time series. The PS points along this profile exhibited homogeneous displacement behavior, suggesting consistent subsidence dynamics linked to karst processes.

Discussion

The observed homogeneous displacement behavior along the transect corroborates the hypothesis that subsidence is governed by systematic geological processes, predominantly karst dissolution and progressive ground stabilization. While abrupt deformation events were not directly detected in this study, the gradual accumulation of strain prior to sinkhole formation aligns with established failure mechanisms in karst terrains, where subsurface voids evolve incrementally until reaching critical collapse. The subsidence trend serves as a geotechnical precursor, highlighting the potential for sudden ground failure even in the absence of immediate surface manifestations.

Conclusions

This study demonstrated the application of PS-InSAR analysis using Sentinel-1 data to monitor pre-collapse deformation patterns in sinkhole-prone areas, providing valuable insights into precursory ground movements. the methodology proved effective in detecting subsidence associated with potential sinkhole development. However, the development of reliable early-warning systems requires extended long-term coverage to: (i) characterize complete deformation time series across the regional scale, (ii) validate InSAR measurements against documented sinkhole events, and (iii) statistically correlate displacement rates with spatial probability of collapse.

References

- Perissin, D., Wang, Z., & Lin, H., 2012. Shanghai subway tunnels and highways monitoring through Cosmo-SkyMed Persistent Scatterers. ISPRS Journal of Photogrammetry and Remote Sensing, 73. <https://doi.org/10.1016/j.isprsjprs.2012.07.002>
- Khoshlahjeh Azar, M., Hamedpour, A., Maghsoudi, Y. and Perissin, D., 2021. Analysis of the deformation behavior and sinkhole risk in Kerdabad, Iran using the PS-InSAR method. Remote sensing, 13(14), p.2696.
- Fouad, S.S., Heggy, E., Amrouni, O., Hzami, A., Nijhuis, S., Mohamed, N., Saleh, I.H., Jomaa, S., Elsheshtawy, Y. and Weilacher, U., 2025. Soaring building collapses in southern mediterranean coasts: Hydroclimatic drivers & adaptive landscape mitigations. Earth's Future, 13(2), p.e2024EF004883.