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Comparing land motion in Chiang Mai and Bangkok, Thailand, using Sentinel-1 InSAR time series

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Abstract

Bangkok, Thailand's capital, and Chiang Mai in northern Thailand are both susceptible to land motion due to natural and human influences. They differ significantly in geological settings: Bangkok is characterized by Neogene clay deposits prone to compaction-induced land subsidence, while Chiang Mai's motion is driven by factors like geological structure and morphology, leading to slope instability and subsidence. Sustainable development in these cities necessitates precise monitoring of geological hazard-prone areas. Radar interferometry, particularly the persistent scatterer interferometry (PS-InSAR) technique, offers a high-resolution, cost-effective solution. This study utilizes Sentinel-1 data to monitor land deformation in both cities, combining geological, morphological, and ground measurements to create deformation maps. Analysis of 61 images for Bangkok and 62 images for Chiang Mai from January 2020 to May 2023 reveals Bangkok's subsidence driven by the early Miocene geological evolution of the Thon Buri Basin, exacerbated by construction and groundwater extraction. Chiang Mai experiences vertical and horizontal motion influenced by factors like depositional environment, morphology, and lithology. Both cities face land subsidence challenges due to rapid urbanization, leading to structural damage and heightened flood risk. This research highlights the potential of PS-InSAR techniques for geological hazard and land deformation monitoring, addressing city-specific challenges and advantages.

1. Introduction

In the picturesque landscapes of northern Thailand, Chiang Mai and the bustling metropolis of Bangkok present captivating contrasts. Chiang Mai, nestled amidst mountains in a basin plain, is celebrated for its ancient temples, traditional festivals, and harmonious fusion of tradition and modernity. However, the very geological setting that makes it a tourist haven also exposes it to land motion hazards, including floods in lower plains and landslides during the monsoons. On the other hand, Bangkok, situated in a deltaic plain along the Chao Phraya River, dazzles with its royal history, iconic landmarks, and rapid modernization. Its skyline, adorned with futuristic structures, mirrors Thailand's economic ascent but is marred by rampant land subsidence, a consequence of unchecked urban development and groundwater overuse.

This study leverages Sentinel-1 satellite data and the Persistent Scatterer Interferometry Synthetic Aperture Radar (PS-InSAR) technique to monitor land motion in both cities. Its primary objectives encompass measuring land motion, dissecting its direction using ascending and descending orbits, and discerning the influence of varied geological and depositional settings. In a world where many capitals grapple with land subsidence, Bangkok's plight underscores the ramifications of unchecked urbanization. Conversely, Chiang Mai faces a different set of challenges rooted in its geological landscape. Through this research, the interplay of natural and human-induced factors shaping land motion in these critical economic centers will be unveiled, aiding in disaster preparedness and decision-making while showcasing the potential of advanced satellite technology for precision monitoring of land deformation.

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2. Method

2.1. The study area and datasets

Bangkok is in a floodplain and deltaic plain and reaches towards the southern Gulf of Thailand. The research focuses on an area of about 1,385 square kilometers within Bangkok City, delineated by latitudes 13.634–13.916°N and longitudes 100.374–100.787°E. In parallel, the research encompasses an approximate expanse of 1,405 square kilometers within Chiang Mai City, demarcated by latitudes 18.824806–18.511480°N and longitudes 98.800152–99.181851°E. A distinctive NNE-SSW trending fault line prominently features in the rugged mountainous terrain of this area, residing at the basin's edge, and connects with tertiary extensional basins constituting the Chiang Mai basins, extending seamlessly from the western to the eastern stretches (Morley, 2009; Mankhemthong et al., 2019).

The Sentinel-1A images utilize Single Look Complex (SLC) data, featuring a wavelength of 5.547 centimeters and an interferometric wide swath spanning 250 kilometers. These images provide a resolution of 5x20 meters and include a comprehensive selection of both descending and ascending orbit. Specifically, there are 61 images covering the Bangkok City area and 62 images encompassing the Chiang Mai City area, spanning from January 2020 to May 2023. This comprehensive dataset, combined with geological insights, forms the foundation for precise monitoring and analysis of land motion in these diverse geological and depositional settings, aiding in disaster preparedness.

2.2. PS-InSAR time series technique

The SAR system transmits the phase and amplitude of a pulse, and the phase difference between two SAR images reveals land movement ($\Delta\phi$), but unwrapping this interferometric phase is crucial for measuring satellite line-of-sight land deformation as shown in Equation 1. This fundamental InSAR principle leverages differential SAR interferometry (DInSAR) using two images to process the phase difference. However, the accuracy of deformation readings is influenced by factors such as satellite positioning errors, topography, and atmospheric delay, all of which contribute to the observed phase difference ($\Delta\phi$) as shown in Equation 2 and must be accounted for in the analysis (Ferretti et al., 2001; Kampes et al., 2001).

$$\Delta\phi = \phi 1 - \phi 2 = \frac{4\pi}{\lambda}\Delta r \quad (1)$$

where
$\phi 1$, $\phi 2$: the phase of each acquisition
Δr: the difference in range between two SAR acquisitions
λ: wavelength of the radar

$$\Delta\phi = \phi def + \phi orbit + \phi topo + \phi noise + \phi atm \quad (2)$$

where
$\Delta\phi$: phase difference
ϕdef: phase contribution related to ground deformation
$\phi orbit$: Orbit Error
$\phi topo$: Topographic Effect
$\phi noise$: Noise
ϕatm: Atmospheric Delay

The PS-InSAR method uses the strong stable point to minimize the impact of the atmosphere and geometric correlation. This technique can detect land displacement with comparatively high precision in the line-of-sight velocity (Perissin, 2008). The approach entails pre-processing, processing (geocoding), and InSAR processing, as shown in Fig. 1. Moreover, SARPROZ software typically follows a well-defined methodology to monitor land displacement over time.

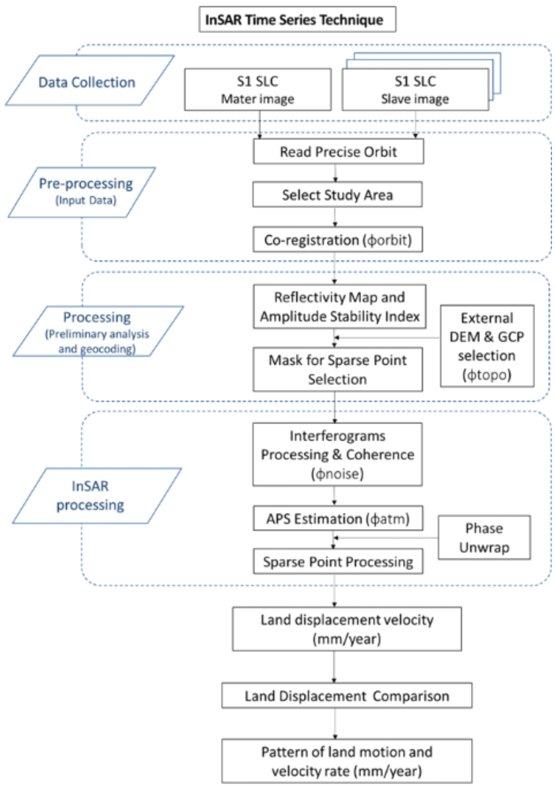

Figure 1. The method workflow

3. Results

The study examines land surface movement in both descending and ascending tracks of PS-InSAR in Bangkok. The findings highlight PS-InSAR data in both tracks, indicating a deficit range of 0.8 to 2.2 mm with standard deviations (SD) between 1 and 3. Notably, ascending time series have lower significant standard deviations than descending ones. Linear regression analysis shows a declining trend, suggesting subsidence. As shown in Table 1, surface displacement rates from PS-InSAR range from -11.3 mm/year to -24.4 mm/year. Furthermore, this study expands its investigation to evaluate land surface movement speed in Chiang Mai. Focusing on PS points on both descending and ascending tracks, the research identifies a range of -2.3 to -33 mm, with standard deviations from 1.5 to 2.7. Remarkably, descending time series exhibit lower standard deviations compared to ascending ones. Through thorough linear regression analysis, the study reveals a declining vertical motion trend in several areas, including San Patong, San Kamphang, and Muang Lamphun. Intriguingly, Hang Dong displays distinctive patterns: uplift in the descending track and subsidence in the ascending track, with horizontal motion. The PS-InSAR pairs in Table 1 display vertical displacement rates ranging between -7.8 mm/year and -14.7 mm/year. This meticulous analysis unveils the intricate vertical motion patterns in Chiang Mai, offering valuable insights into its geological factors.

Table 1. An association between the velocity of RSQ, which is equal to or higher than 0.8, and significant statistics of descending (DES) and ascending (AS) orbits in the Bangkok and Chiang Mai.

Study area	PS point	Velocity (mm/year)	SD	Motion pattern
Bangkok				
Phasi	DES152636	-24.4	3.0	Vertical
Charoen	AS339321	-22.2	1.6	
Lak Si	DES247645	-13.4	1.6	Vertical
	AS137679	-12.1	1.0	
Huai Khang	DES144500	-13.7	2.8	Vertical
	AS262611	-14.9	2.3	
Phra	DES66521	-12.1	1.9	Vertical
Khanong	AS355551	-11.3	2.2	
Lat Krabang	DES145019	-14.9	2.7	Vertical
	AS235791	-13.5	1.2	
Chiang Mai				
Hang Dong	DES39167	4.7	1.5	Horizontal
	AS93781	-28.3	2.7	
San Patong	DES111105	-12.4	2.3	Vertical
	AS23702	-14.7	2.5	
San	DES73824	-11.8	2.0	Vertical
Kamphang	AS30539	-7.8	2.4	
Muang	DES108573	-13.0	1.9	Vertical
Lamphun	AS10289	-10.0	2.2	

4. Discussion

The geological factors, namely tectonic settings, fault zones, rock type and strength, and sedimentary deposition and compaction, underpin the significant influence of land deformation patterns. Distinct geological characteristics within regions like Bangkok and Chiang Mai yield divergent land motion dynamics. Tectonic settings near plate boundaries produce pronounced deformation, exemplified by Chiang Mai's active tectonic boundaries and LANF, driving continuous crustal extension (Morley, 2009). In contrast, Bangkok's stability arises from its distance from tectonic zones. The presence of fault zones contributes to this disparity, with Chiang Mai exhibiting both vertical and horizontal land motion, while Bangkok predominantly experiences vertical motion. Moreover, the nature of rocks significantly dictates deformation, and Chiang Mai's resilient metamorphic rocks resist deformation, reducing subsidence. In contrast, Bangkok's softer sediments, prone to compaction, result in a higher rate of land subsidence (Sinsakul, 2000). In addition, sedimentary deposition and compaction also play a pivotal role, with Bangkok's extensive fine-grained sediment deposits susceptible to subsidence, while Chiang Mai's coarser-grained sediment exhibits less responsiveness to deformation. In conclusion, the profound effect of geology on land deformation is evident through these factors, offering valuable insights into the dynamic relationship between Earth's surface and its underlying geological foundation.

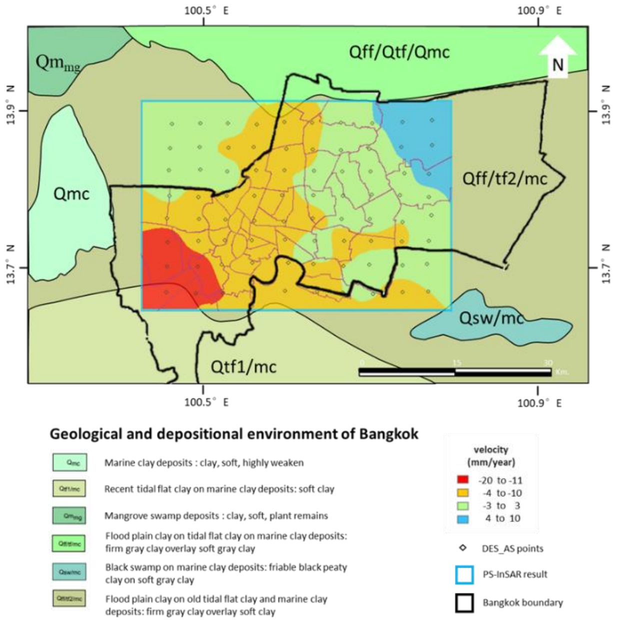

Figure 2. The vertical motion of Bangkok relates to a geological and depositional environment where the red area shows the high rate of subsidence and is flood plain clay and recent tidal flat clay on marine clay deposits; the yellow area shows the moderate rate of subsidence and is flood plain clay on old tidal flat clay and marine clay deposits; the green area shows the low to stable rate; and the blue area shows the uplift area where there is higher terrain and near the mountain on the east of Bangkok.

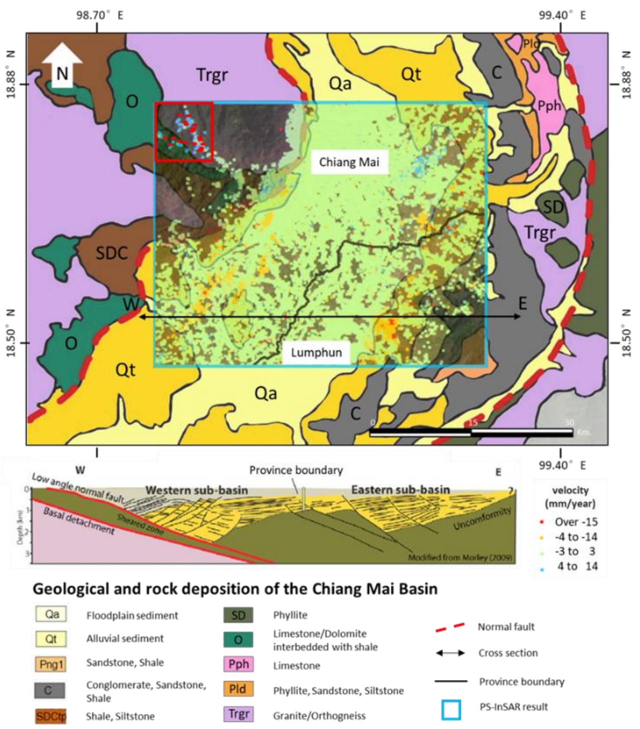

Figure 3. The land motion of Chiang Mai relates to a geological map and deposition environment where the small yellow area shows the subsidence is near the edge of the Chiang Mai basin and it's a floodplain-alluvial deposition, while a mountain area on the west of Chiang Mai is represented by the red (indicating subsidence from an ascending track) and blue (indicating uplift from a descending track), and the different directions of motion indicate horizontal motion

Furthermore, the influence of land deformation patterns is compounded by human activities, including groundwater extraction and construction, which have a significant impact in specific regions. For example, excessive groundwater extraction can induce land subsidence as it depletes underground aquifers, causing surrounding rocks or sediments to compress and the land surface to sink. Similarly, substantial construction can disrupt the stress distribution within the Earth's crust, leading to localized deformation. The population density and construction activity in cities like Bangkok and Chiang Mai are closely linked to the respective subsidence rates observed. In addition, natural factors such as heavy rainfall on steep slopes contribute to horizontal motion in Chiang Mai, particularly through landslides, which have been observed to damage both high-terrain and lower-plain areas. Sentinel-1's temporal data analysis has unveiled long-term trends in land motion, facilitating the monitoring of these patterns and the assessment of their environmental consequences. This study underscores the importance of community engagement and informed policymaking to mitigate the impacts of land motion in urban areas, with collaborative efforts essential for the judicious management of water resources and land utilization in response to the discernible trends influenced by geological traits and human activities in Bangkok and Chiang Mai.

5. Conclusion

Bangkok and Chiang Mai exhibit distinct land motion patterns due to their unique geological characteristics and local factors. Bangkok experiences primarily vertical subsidence driven by soft clay deposits and exacerbated by human activities, while Chiang Mai experiences a combination of vertical and horizontal motion influenced by geological structure, sediment deposition, mountainous terrain, rock type, and heavy rainfall that also trigger the land motion. Both cities face challenges related to land motion, but the scale and specific factors involved differ significantly between the two regions.

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