Pengembangan Algoritma InSAR untuk Pemantauan Deformasi Penurunan Muka Tanah dan Gunung Api di Indonesia

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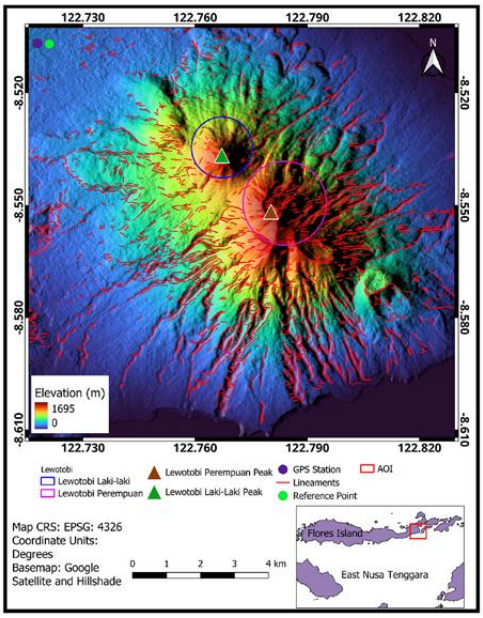
Abstract

Lewotobi is one of the active volcanoes in Eastern Indonesia. The volcanic activity at Lewotobi has created an interesting geodetic phenomenon characterized by ground surface deformation. This study aims to monitor the surface deformation dynamics of Lewotobi over an 8-year period using InSAR and determine the depth, location, and volume changes of magma source under two peaks using geodetic inversion. The results of the deformation study identified inflation at both peaks, with accumulated deformation of 326 mm at Lewotobi Laki-laki and 142 mm at Lewotobi Perempuan. Mogi modeling indicates the source of deformation is located at shallow depth. These shallow source depths indicate relatively rapid magma migration and a high potential for hazard, thus requiring vigilance in monitoring.

Keyword: Satellite geodesy, source modelling, shallow source.

Introduction

Volcanic activity at Lewotobi presents an interesting geodetic phenomenon characterized by ground surface deformation. Moreover, areas that have previously experienced deformation may undergo renewed deformation in subsequent periods (Biggs et al., 2014).



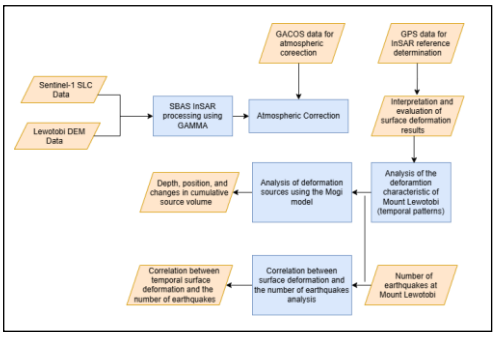
Picture 1. Overview map of Mount Lewotobi Laki-laki and Perempuan.

InSAR provides an effective tool for monitoring volcanic deformation. Previous observations at Lewotobi (2021–2024) revealed inflation prior to eruptions and deflation afterward (Agustan et al., 2024). However, previous studies mainly focused on displacement patterns, leaving the location and volume of magma sources insufficiently explored.

This study further investigates deformation patterns to estimate magma source location and volume

Research Method

This study employed the Small Baseline Subset (SBAS) InSAR method to derive cumulative ground deformation during 2018–2025. The resulting deformation was then modeled using the Mogi model, which represents the magma chamber as a spherical pressure source embedded in an elastic half-space. The model estimates the source location (X and Y coordinates) and depth.



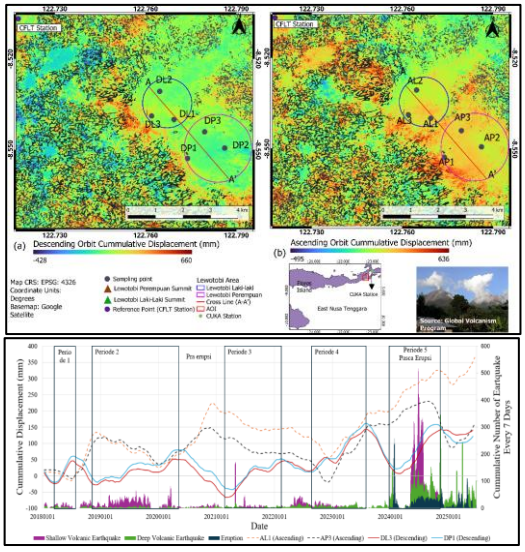
Picture 2. Flowchart of research methodology

Discussion & Results

Cumulative time-series analysis (2018–mid-2025) revealed both uplift and subsidence across the volcano summits. In the ascending orbit, the maximum cumulative displacement reached 326 mm at AL1 and 142 mm at AP3. Meanwhile, the descending orbit recorded 240 mm at DL3 and 127 mm at DP1, indicating surface deformation associated with changes in volcanic activity.

Source Modeling

Mogi modeling results (Table 1) indicate shallow deformation sources at Lewotobi Laki-laki and Lewotobi Perempuan, with optimal depths of 957 m and 2,172 m, and volume changes of 1.21 × 10^6 m^3 and 1.07 × 10^6 m^3, respectively, relative to a flat surface.

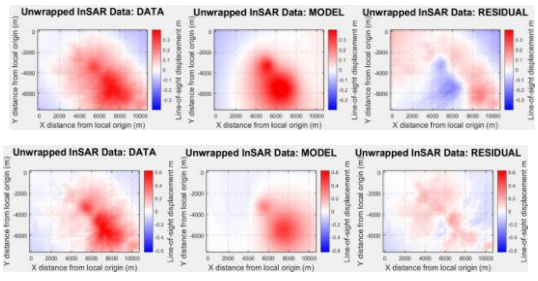


Picture 3. Cumulative displacement and number of earthquake

The estimated volume changes (ΔV) indicate magma accumulation associated with surface deformation. Combined with shallow source depths, these changes may generate pressure variations within fractures of the volcanic edifice.

Table 1. The best estimated parameters for the Mogi point-source model

Reference Point (EPSG:32751)	Location	MODEL PARAMETER	OPTIMAL	2,50%	97,50%
468954.0E, 9059661.4N	Lewotobi Laki-laki	MOGI X (m)	5295.54	4357.97	5548.25
		MOGI Y (m)	-3224.37	-3464.11	-2345.66
		MOGI Depth (m)	957.92	937.01	5192.72
		MOGI DV (m^3)	1.21×10^6	1.07×10^6	3.66×10^6
	Lewotobi Perempuan	MOGI X (m)	7048.57	6942.8	7465.54
		MOGI Y (m)	-5443.23	-5843.74	-5220.98
		MOGI Depth (m)	2172.76	1811.82	2858.46
		MOGI DV (m^3)	1.09×10^7	7×10^6	$1,99\times10^7$



Picture 4. Inversion of the Lewotobi deformation field

Conclusion

- Maximum uplift reached 326 mm (ascending) and 154 mm (descending) at Lewotobi Laki-laki, and 142 mm and 127 mm, respectively, at Lewotobi Perempuan.
- Mogi inversion identified shallow deformation sources beneath Lewotobi Laki-laki (**957 m**) and Lewotobi Perempuan (**2,172 m**), with volume changes of **1.21 × 10^6 m^3** and **1.09 × 10^7 m^3**, respectively.

Output

- Published "Unveiling subsurface volume dynamics: Spatio-temporal deformation analysis of Lewotobi Volcano using SBAS-InSAR and Mogi modelling"
- Under review "The Impact of Land Subsidence on Topographic Changes Associated with Flood Hazards in the Bandung Basin"

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