# Measurement and investigation of surface displacements caused by earthquakes using Differential Interferometric Synthetic Aperture Radar on historical monuments area

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***Keywords:*** *Synthetic Aperture Radar — Earthquake — Surface Displacement*

**CHNT Reference:** Naseri, M. (2022). 'Measurement and investigation of surface displacements caused by earthquakes using Differential Interferometric Synthetic Aperture Radar on historical monuments area,' in CHNT Editorial board. *Proceedings of the 27th International Conference on Cultural Heritage and New Technologies, November 2022.* Heidelberg: Propylaeum.

## Abstract

Afghanistan is one of the mountainous countries in Asia. This country, with its historical background, has many precious historical monuments. Among these historical monuments, we can mention Taq e Zafar in Paghman. The Taq e Zafar is a triumphal arch commemorating Afghanistan's independence after the third Anglo-Afghan war, built around 1919 at a distance of 1120 m west of Paghman hill in Kabul province. Historical monuments of different eras are essential documents for each nation, aiding in shaping the nation's identity. Finally, reconstruction and preserving these relics become important. This relic can be sensitive to fire and natural hazards, e.g., earthquakes, floods, etc., and may face irreparable damage.

Earthquakes are a complex natural hazard that cannot predict as simply as other disasters. For example, Floods, wildfires, and even landslides are anticipatable, but it is different in earthquake monitoring. Earthquakes can cause land displacements vertically and horizontally. Due to the types of shock, the monument may damage after each earthquake and need repair or restoration. With long-term research on earthquake behaviors in ancient places and assessing the impact of earthquakes on them, we will have a better plan for preventing significant damages or funds to maintain and strengthen. On 2020-05-18, a 4.3 Magnitude earthquake, at a depth of 11 km near the main western faults of Kabul Province, shocked Kabul city. So, an attempt has been made to calculate the surface displacement caused by this earthquake in the Taq e Zafar area. Therefore, four sentinel-1 – S1 images have been processed in SNAP software, it is free software developed for Radar image processing by the European space agency – ESA. Finally, two vertical and horizontal surface displacements have been shown.

*Table 1. List of sentinel-1 images.*

| Number | Satellite | Date | Orbit | Mode | Polarization |
|---|---|---|---|---|---|
| 1 | Sentinel-1 A | 2020-05-11 | Ascending | IW | VV |
| 2 | Sentinel-1 A | 2020-05-23 | Ascending | IW | VV |
| 3 | Sentinel-1 A | 2020-05-12 | Descending | IW | VV |
| 4 | Sentinel-1 A | 2020-05-24 | Descending | IW | VV |

Table 1 shows downloaded S1 images in ascending and descending orbits. Two S1 images have been processed for each orbit to calculate surface displacement, ascending east-west displacements, and descending for up-down displacements.

The method used in this research is the Differential interferometric synthetic aperture radar – DInSAR. This technique has been developed to calculate phase differences between pair SAR data over the same area in a period aim of calculating surface displacement.

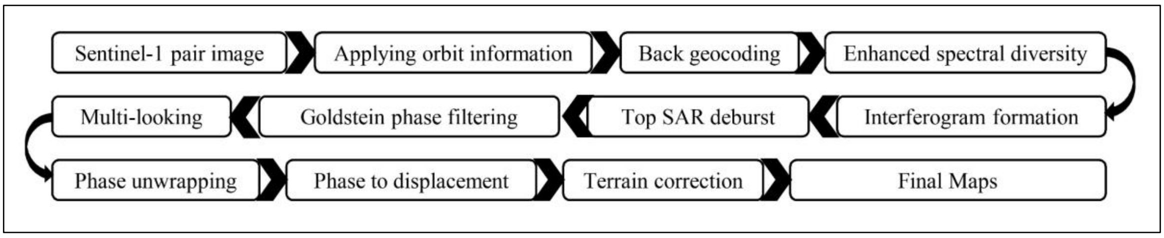


*Fig. 1. Processing steps of Differential Interferometric Synthetic Aperture Radar in SNAP software.*

Figure 1 shows the complete processing steps of the DInSAR technique in SNAP software. This instruction should be followed for each orbit pair image.

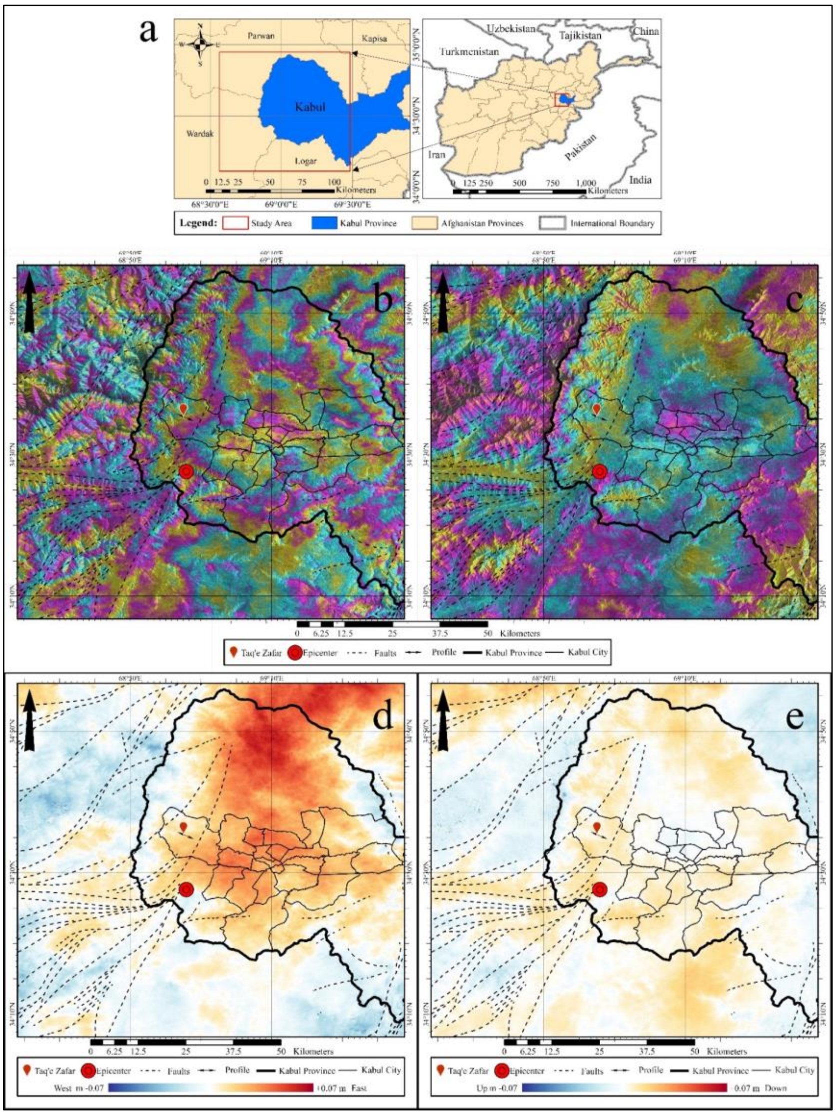


*Fig. 2. The geographical location of the Area of study-AOS (2-a), differential phase of ascending and descending (2-b and c), and displacement maps of ascending and descending (2-d and e).*

Figure 2-a shows the area of study-AOS. The AOS is in the western part of Kabul province, and the epicenter is in the middle part of AOS. In figure 2-b, the location of Taq e Zafar is 14.4 km from the top of the epicenter. This figure shows the differential phase of ascending orbit. A large number of closer fringes means that severe shocks and countless displacements have occurred in that area. Besides, figure 2-c shows the differential phase of descending orbit, which is interpretable like figure 2-b. The number of closer fringes in this figure is less than in figure 2-b. Thus, It is clear that the rate of displacement at the Taq e Zafar location in the mode ascending has been higher (figure 2-b) than descending mode (figure 2-c). It means that higher displacement in the west-east direction is more expected than displacement in the up-down direction. Figures 2-d and 2-e have been produced after phase to displacement converting. These figures show the displacement in meters in two vertical (figure 2-e) and horizontal (figure 2-d) directions. As explained before, due to a large number of closer fringes in the epicenter and Taq e Zafar locations in figure 2-b in ascending mode, a large amount of eastward displacement is visible in the center and north parts of the AOS (figure 2-d). While these areas in the mode descending have experienced less displacement rate than in ascending mode (figure 2-e).

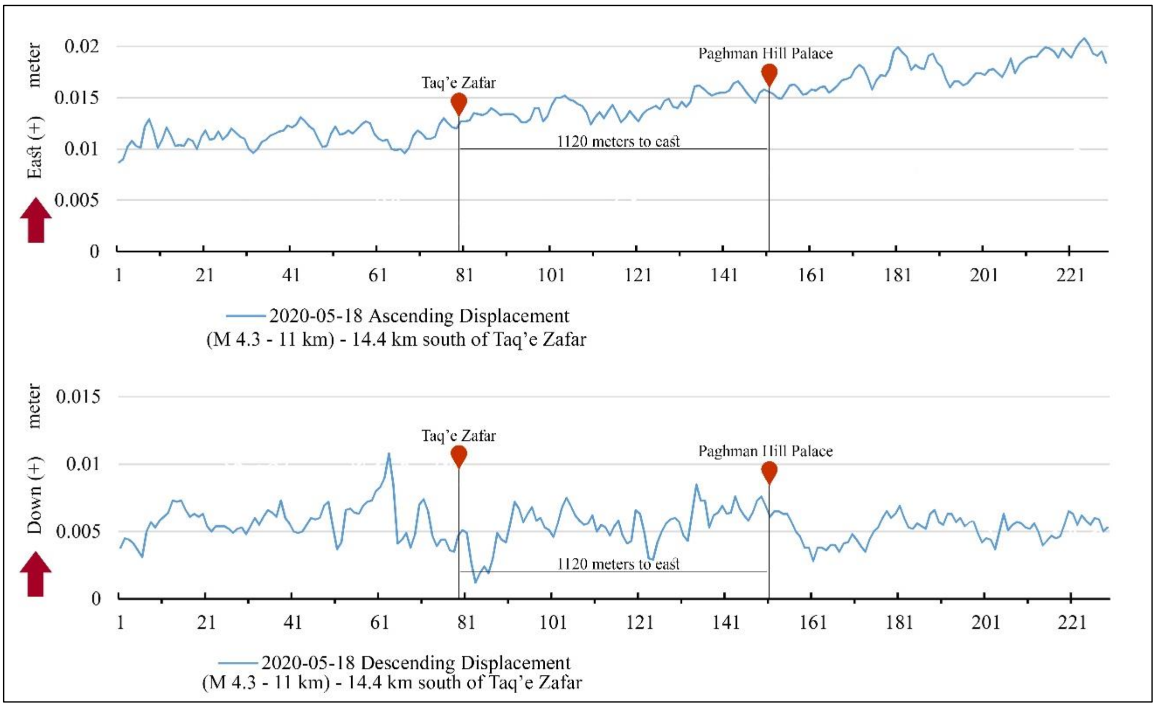


*Fig. 3. Ascending displacement (Up) and Descending displacement (Down) charts of drawn Profile.*

Figure 3 shows two-dimensional displacement in Profile location from west to east. As shown, the Taq e Zafar area has experienced eastern displacement up to 13 mm, and subsidence of 5 mm is visible. Two-dimensional deformation monitoring caused by earthquakes affecting man-made structures like historical relics is of crucial relevance for preserving historical arts. Such information can help us prevent more significant damages or strengthen historical monuments considerably after each earthquake. The DInSAR technique has already been introduced as an effective and powerful tool for land surface deformation analyses over large areas by producing differential phase and displacement maps with cm to mm accuracy. This research investigates the effectiveness of two-dimensional DInSAR in detecting and monitoring displacements affecting historical monuments.

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