MONITORING THE SLOWLY DEVELOPING LANDSLIDE WITH THE INSAR TECHNIQUE IN SAMSUN PROVINCE, NORTHERN TURKEY

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ABSTRACT:

Landslides are prominent natural events with high destructive power. Since they affect large areas, it is important to monitor the areas they cover and analyse their movement. Remote sensing data and image processing techniques have been used to monitor landslides in different areas. Synthetic aperture radar (SAR) data, particularly with the Interferometric SAR (InSAR) method, is used to determine the velocity vector of the surface motion. This study aims to detect the landslide movements in Samsun, located in the north of Turkey, using persistent scattering InSAR method. Archived Copernicus Sentinel-1 satellite images taken between 2017 and 2022 were used in both descending and ascending directions. The results revealed surface movements in the direction of the line of sight, ranging between -6 and 6 mm/year in the study area. Persistent Scatterer (PS) points were identified mainly in human structures such as roads, coasts, ports, and golf courses, especially in settlements. While some regions exhibited similar movements in both descending and ascending results, opposite movements were observed in some regions. The results produced in both descending and ascending directions were used together and decomposed into horizontal and vertical deformation components. It was observed that the western coastal part experienced approximately 4.5 cm/year vertical deformation, while the central part there is more significant horizontal deformation, reaching up to approximately 6 cm/year.

1. INTRODUCTION

In recent decades, an increase in disasters has been observed, which is a cause for concern due to their devastating impact on human society and economy. Both natural and man-made events contribute to this concern. Climate change is considered as one of the most significant factors triggering natural disasters. Urban areas, in particular, are becoming increasingly vulnerable to urbanization as they are home to a large part of the human population (IPCC 2022). Cities and their infrastructure including the built environment, transportation, coastal infrastructure, and ports are at risk from these of hazards. Moreover, agroforestry and water quality are also substantially affected.

Landslides are considered a highly destructive geohazard due to their significant socio-economic and environmental impact. Various factors can trigger landslides including earthquakes (Tanyaş et al., 2022), rainfall (Arnone et al., 2011), and human-induced activities (Sangeeta and Singh, 2023; Gorum and Fidan, 2021). Therefore it is important to monitor the landslides that occur for various reasons in order to reduce the impact and take the necessary precautions. Therefore, it is beneficial to have access to historical inventory data as well as temporal and spatial information on landslides. Several monitoring methods exist based on the size and types of landslides including ground-based and remote sensing monitoring techniques (Kirschbaum and Stanley, 2018; Zhao and Lu, 2018).

Remote sensing technology offers the opportunity to monitor landslides using various satellite sensors. Lidar data is utilized for detailed analysis (Gorum, 2019), while optical satellite data is employed to generate inventory data (Golovko et al., 2017). Microwave remote sensing, specifically Synthetic Aperture Radar (SAR) data, contributes to long-term displacement analysis.

In previous studies, multi-temporal Interferometric SAR techniques have been employed to analyse various surface displacements. These include the study of mining activity, (Abdikan et al., 2013), deformation in Bursa Plain (Aslan et al., 2019), landslide detection in Kaleköy dam reservoir (Tavus et al., 2022), and long-term displacement monitoring in Beylikdüzü-Esenyurt district (Bayik et al., 2021). Persistent Scatterer Interferometry (PSI) has been extensively developed and utilised for long-term displacement analysis, particularly in large areas and urban environments (Blasco et al., 2019; Wu et al., 2022; Imamoglu et al., 2019; Gezgin, 2022; Şireci et al., 2021).

The susceptibility of the Samsun province to landslides has been investigated previously with various methods. These include the application of the Analytical Hierarchy Process (AHP) method (Cihat et al., 2020) and the production of a landslide susceptibility map using the frequency ratio technique (Akinci et al., 2011). However, based on the available information, no prior analysis of the landslides forming in Samsun using InSAR techniques has been conducted to our knowledge.

In this study, Sentinel-1 data was utilized to analyze the spatial pattern of surface displacements in the northern part of Turkey, with a specific focus on slow-moving landslide phenomena observed in the region. The main objective of this study is to determine the time series of the displacement and gain insight

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into the trend behaviour and potential cumulative displacement values. The study presents the first analysis of the landslide activity occurring within the urban area of Samsun province, a coastal city located in the north of Turkey.

2. DATA AND METHOD

2.1 The Study Area

The study area, Samsun City, is located in the western part of the Black Sea region, which is known for its high annual precipitation rate within Turkey. The region experiences around 136 days of precipitation per year (Figure 1). Samsun city is the most densely populated city in the Black Sea region, and is undergoing rapid expansion. The average altitude of the region varies between 0 to 1500 meters tow the northeast direction.

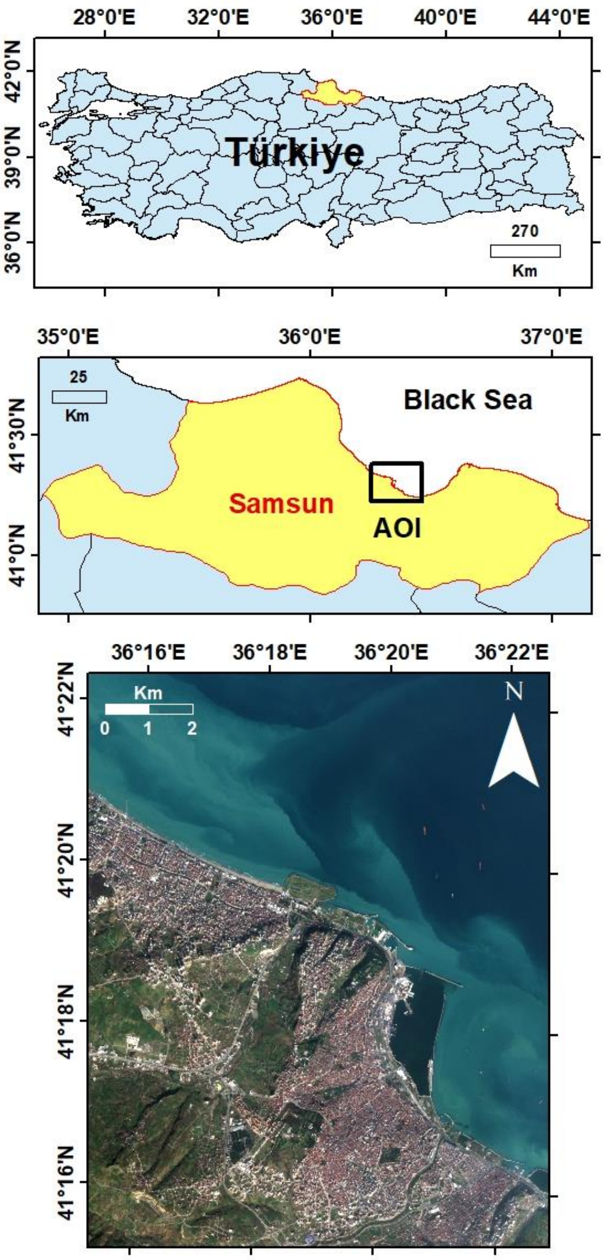

Figure 1. The study area: Samsun city center

2.2 Sentinel-1 Data Analysis

In this study, multi-temporal Interferometric Synthetic Aperture Radar (InSAR) data was utilized for analysis using the StaMPS approach of the Permanent Scattering Interferometry (PSI) method to detect the deformation area. The analysis was carried out using Sentinel-1A satellite images, which were obtained from the NASA Alaska Satellite Facility and distributed with the open data policy of the European Space Agency as part of the Copernicus program.

The dataset used in this study comprised a total of 132 Sentinel-1A Single Look Complex (SLC) Interferometric Wide swath (IW) data for the descending orbit, covering the period from October 2017 to April 2022. Additionally, 191 Sentinel-1A data for the ascending orbit were used, covering the period from April 2016 to October 2022. The images were processed and interferograms were generated using the ESA SNAP v9.0 program. StaMPS 4.1 beta version (Hooper et al., 2012) was used to apply the PSI approach. The data transmitted and recorded in vertical polarization were analyzed to obtain velocity vectors of the landslide zone. To eliminate the atmospheric effect in the produced interferograms, TRAIN software, (Bekaert et al., 2015) which has a linear correction option, was used.

Specifications	Description	
Sensor	Sentinel-1A	Sentinel-1A
Wavelength	C-band	C-band
Orbit	Descending	Ascending
Acquisitions	01.11.2017-21.04.2022	04.06.2016 24.11.2022
Image Size	132	197
Pixel spacing	14m (Rg:4 Az:1)	14m (Rg:4 Az:1)
Polarization	VV	VV

Table 1. Specifications of the Sentinel-1 data used for the study

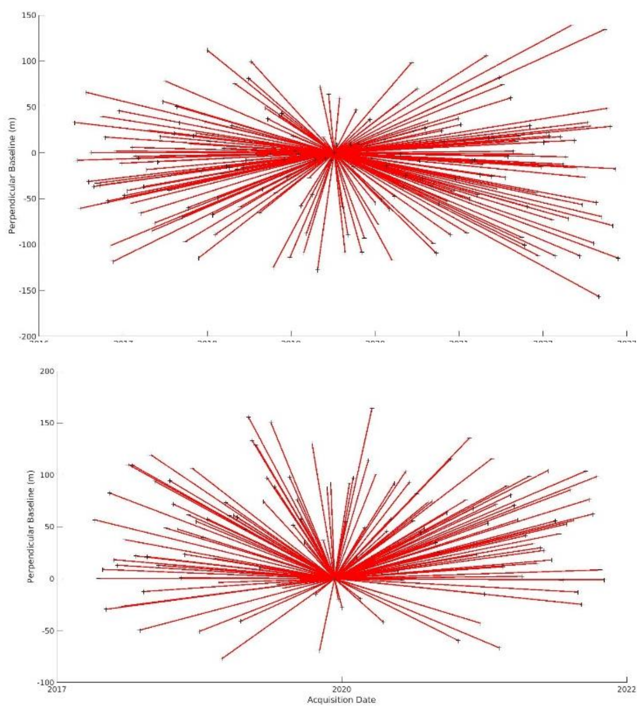

Figure 2. Perpendicular baselines; a)ascending, b)descending

3. RESULTS AND DISCUSSIONS

The results obtained for the five- and half-year time series for the descending orbit showed that the displacement ranged from approximately -5 mm/yr to 5 mm/yr, with a standard deviation of 0.9 mm/yr (Figure 4). Similarly, the results obtained for the six and half year time series for the ascending orbit revealed that the displacement ranged from about -3.5 mm/yr to 2.5 mm/yr, with a standard deviation of 0.47mm/yr (Figure 5). In general, it is also noticed that the density of the PS points in the results of descending is higher than the results of ascending data. In both cases, PS points are distributed along the coastline and inside where the settlements are located. Negative values (shown in red color) indicate the surface is moving away from the sensor and the positive values (shown in blue color) indicate the surface is moving towards the sensor.

The results obtained from the ascending orbit, predominantly negative values are obtained, which are distributed in red to yellow colors in Figure 4. The time series of selected points shows that point A and point B, located in the green zone exhibit a stable behaviour. On the other hand, points C and D display a declining trend with a total displacement of approximately -30 mm (Figure 4).

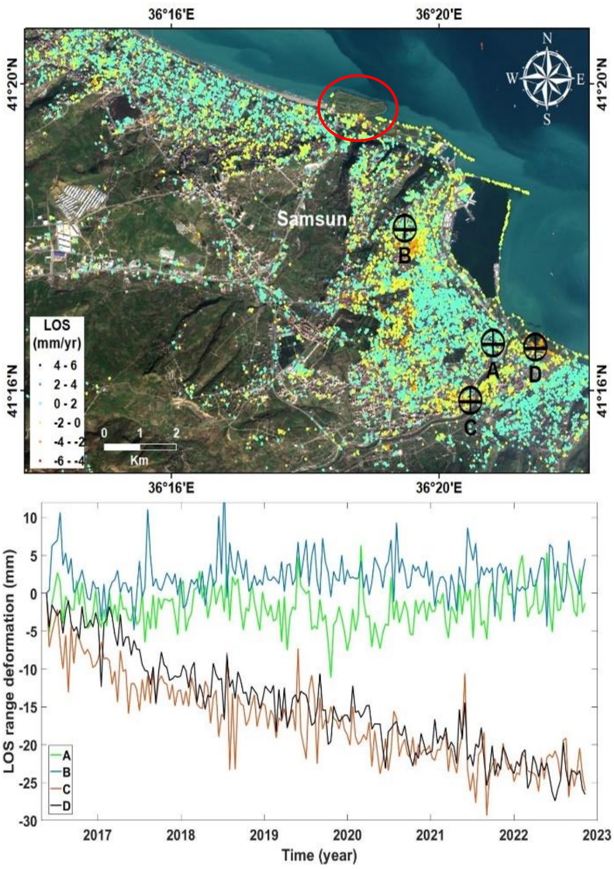

Figure 4. Ascending Orbit PSI velocity results

The results of obtained from the descending orbit show a combination of both negative and positive values. Positive values reaching up to 6 mm/year, are observed in the interior part of the region, while the negative values are noticeable along the river where it meets with the sea (Figure 5). A similar displacement pattern is observed in this area compared to the ascending orbit results. Analyzing the time series of points E and F from the descending orbit, a positive increasing trend is observed. Conversely, points G and H, located along the river, exhibit displacement in the opposite direction and are consistent with the results from the ascending orbit.

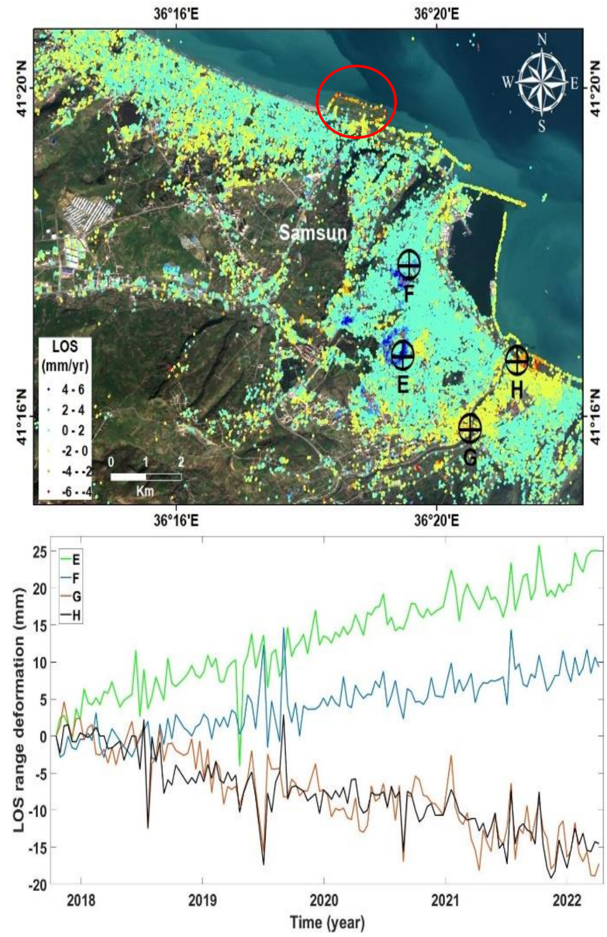

Figure 5. Descending Orbit PSI velocity result

The results of descending data also indicate an additional displacement that is not detected in the results of ascending data (Figures 4 and 5). The red circle in both results shows the location of the golf course that was constructed partially filled seashore. The sub-sections of the area are shown in both ascending (Figure 6a) and descending images (Figure 6ab). In the ascending results, there are more points distributed over the buildings and roads, however, over the golf course, there are no PS points due to green land which causes decorrelation in the analysis. In the results of descending product, there are more points distributed over the region. It is noticed that maximum displacement is determined along the breakwater that borders the course (Figure 6b). The common output seen in both results is the absence of points on the coastline. The reason for this is that the moisture in the sand has negative effects on PS point acquisition. It is operational since 2016 and the PSI results show that there is a slow-moving displacement along the borders. The result of the study proves the presence of deformation areas detected with the multi-temporal satellite images. By the analysis of the time series, the existence of a slowly forming horizontal movement with the displacement moving towards the satellite in the descending orbit and away from the satellite in the ascending orbit is indicated.

To analyze the spatial distribution of the deformation the LOS values are converted to east-west and up-down directions using the equations below (Arikan et al., 2010);

$$d_{LOS} = S^{T}.d \quad (1)$$

$$S = (-\cos\eta\sin\theta \quad \sin\eta\sin\theta \quad \cos\theta)^{T} \quad (2)$$

Where d_{LOS}, S, and d are displacements at LOS direction, unit vector of satellite, and vector of surface displacement, respectively. In equation 2, η and θ are the heading and incidence angle of the sensor.

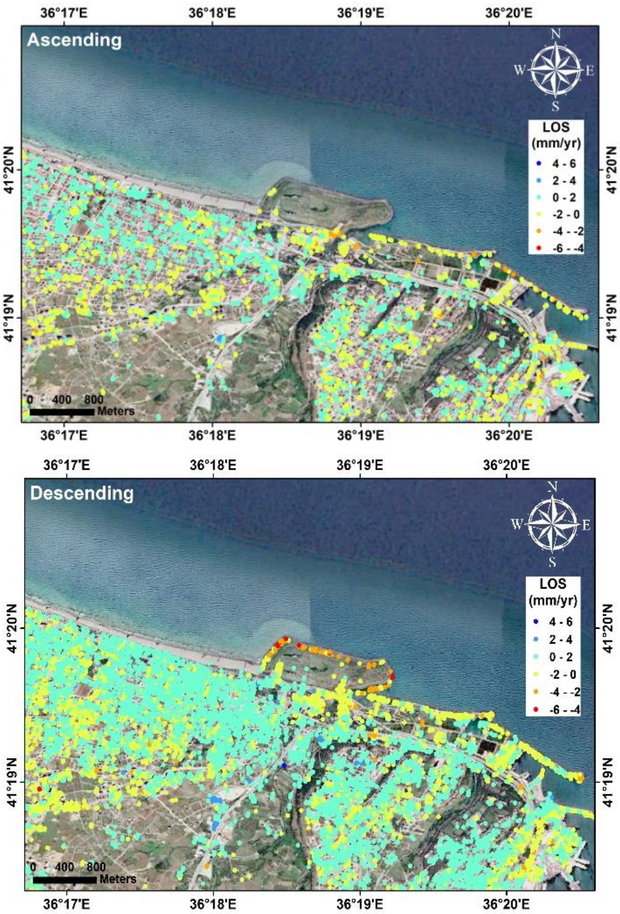

Figure 6. Displacement over golf course in ascending (up) and descending (down) images.

For the decomposition of LOS values, the spatial distribution of the displacement should overlap with ascending and descending results. The results indicate that a horizontal movement pattern is detected where the LOS displacement is negative in both cases (Figures 4 and 5). The positive values (shown in blue color) indicate movement towards the east, reaching up to 6 mm/year (Figure 7). The rest of the region appears mostly stable. When we examine the vertical results, subsidence movement is observed along the river, with maximum subsidence (shown in red color) occurring at the shoreline (Figure 7). There is also a slight uplift where the horizontal movement is located. It appears as a circle shape in light blue over the settlements (Figure 7). The rest of the region appears mostly stable in the vertical direction. As the LOS displacement is only detected in the descending direction, the horizontal, and vertical deformation of the golf course could not determine (red circles in Figures 7 and 8). This movement was observed on man-made structures in the urban area, highlighting the potential impact on infrastructure and human life. In the displacement maps, besides the main landslide zone, traces of deformation were also found in the old riverbeds of the Mert River, which passes through the middle of the city, and in the sea-filled areas.

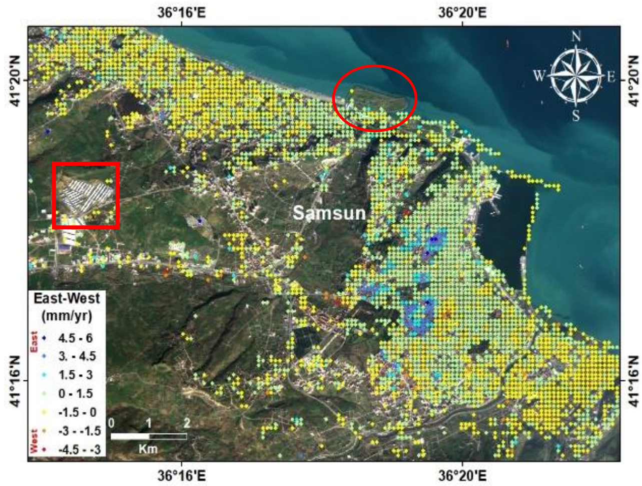

Figure 7. East-West velocity result

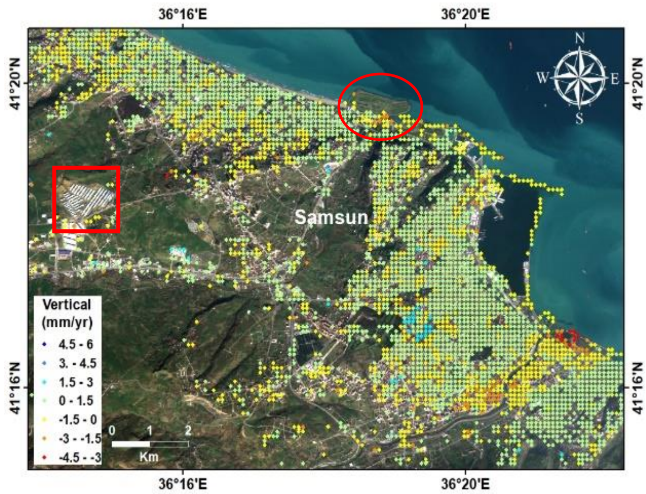

Figure 8. Up-Down velocity result

The results showed the current situation of the deformation distributed in the city. However, certain man-made structures, as indicated by the red square in Figures 7 and 8 were not detected in the analysis. The reason is that even though it has the potential to be a persistent scatterer and detected by the PSI method, the structure was under construction in the data acquisition period. Figure 9 illustrates the land cover type was agriculture before the buildings were constructed.

11.01.2020

07.02.2022

Figure 9. Google Earth, Samsun Turkiye, Maxar Technologies (14.06.2023)

4. CONCLUSIONS

In this study, we investigated a slowly developing landslide in the city of Samsun, Turkiye. The northern part of the Turkiye is prone to landslides due to factors such as rainfall and the topographical and geological characteristics of the area as well as the spatial distribution of built-up areas. This study presents the first to analysis of deformation values of this region using the PSI technique. The analysis, based on a five-and-a-half-year InSAR analysis using archived Sentinel-1 data, revealed the presence of a gradual movement in the city center. In addition to displacement in the line of sight (LOS) direction, deformation in vertical and east-west direction was also determined. Temporal analysis indicated deformation rate of approximately 6 cm/year in east-west direction and 4.5 cm/year in vertical directions. The spatial distribution of deformation coincided with man-made structures such as settlements and ports. However, due to the presence of newly constructed buildings in the image acquisition period, deformation information on these structures could not be produced.

Determining the displacement behaviour is crucial for assessing the impact of horizontal movement on the superstructure, infrastructure, and human life. In this way, precautions can be considered for the infrastructures and buildings using the current deformation map. To further enhance the analysis of the region, increasing the number of PS points, and evaluating other multi-temporal InSAR techniques such as small baseline methods can provide more detailed information and facilitate long-term monitoring.

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REFERENCES

Abdikan, S., Arıkan, M., Sanli, F.B., Cakır, Z., Kemaldere, H., 2013: Monitoring of Coal Mining Subsidence in Peri-Urban Area of Zonguldak City (NW Turkey) with Persistent Scatterer Interferometry Using ALOS-PALSAR. *Environmental Earth Sciences* 71, 4081–4089.

Akinci, H., Doğan, S., Kilicoglu, C., Temiz, S.M., 2011: Production of Landslide Susceptibility Map of Samsun (Turkey) City Center by Using Frequency Ratio Method. *International Journal of the Physical Sciences*, 6(5), 1015–1025.

Arikan M., Hooper A., Hanssen R., Radar time series analysis over west anatolia, in: Proc. FRINGE Workshop, 2010, pp. 1–6.

Arnone E., Noto L.V., Lepore C., Bras R.L., 2011. Physically-based and distributed approach to analyze rainfall-triggered landslides at watershed scale, Geomorphology, 133, 3-4, 121-131.

Aslan, G., Cakir, Z., Lasserre, C., Renard, F., 2019: Investigating Subsidence in the Bursa Plain, Turkey, Using Ascending and Descending Sentinel-1 Satellite Data. *Remote Sensing*, 11(1).

Bayik, C., Abdikan, S., Ozdemir, A., Arıkan, M., Sanli, F.B., Dogan, U., 2021: Investigation of the Landslides in Beylikdüzü-Esenyurt Districts of Istanbul from InSAR and GNSS Observations. *Natural Hazards*, 109(1), 1201–1220.

Bekaert, D. P. S., Walters, R. J., Wright, T. J., Hooper, A. J., Parker, D. J. 2015: Statistical Comparison of InSAR Tropospheric Correction Techniques. Remote Sensing of *Environment*, 170, 40–47.

Blasco, J. M. D., Foumelis, M., Stewart, C., Hooper, A., 2019: Measuring Urban Subsidence in the Rome Metropolitan Area (Italy) with Sentinel-1 SNAP-StaMPS Persistent Scatterer Interferometry. *Remote Sensing*, 11(2).

Cihat, A., Tabar, E., Sisman, M.Y., 2020: Turkish Journal of Geographic Information Systems Landslide Susceptibility Mapping of Samsun (Turkey) Province Using Frequency Ratio and AHP Methods. Turkish Journal of Geographic Information Systems, 3(1), 24–30.

Gezgin, C., 2022: The influence of Groundwater Levels on Land Subsidence in Karaman (Turkey) Using the PS-InSAR Technique. *Advances in Space Research* 70(11) 3568-3581.

Golovko D, Roessner S, Behling R, Wetzel H-U, Kleinschmit B., 2017: Evaluation of Remote-Sensing-Based Landslide Inventories for Hazard Assessment in Southern Kyrgyzstan. *Remote Sensing*. 9(9):943.

Gorum T., 2019: Landslide recognition and mapping in a mixed forest environment from airborne LiDAR data, *Engineering Geology*, 258, 105155.

Gorum, T., Fidan S., 2021: Spatiotemporal variations of fatal landslides in Turkey, *Landslides*, 18, 1691-1705.

Hooper, A., Bekaert, D., Spaans, K., Arıkan, M. 2012: Recent Advances in SAR Interferometry Time Series Analysis for Measuring Crustal Deformation. *Tectonophysics*, 514–517, 1-13.

Imamoglu, M., Kahraman, F., Cakir, Z., Sanli, F. B., 2019: Ground Deformation Analysis of Bolvadin (W. Turkey) by Means of Multi-Temporal InSAR Techniques and Sentinel-1 Data. *Remote Sensing*, 11(9).

IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056-pp., doi:10.1017/9781009325844.

Kirschbaum D., Stanley T., 2018: Satellite-Based Assessment of Rainfall-Triggered Landslide Hazard for Situational Awareness, *Earth's Future*, 6, 3, 505-523.

Sangeeta, Singh, S.K, 2023: Influence of anthropogenic activities on landslide susceptibility: A case study in Solan district, Himachal Pradesh, India. *J. Mt. Sci*. 20, 429–447.

Sireci, N., Aslan, G., Çakır, Z., 2021: Long-Term Spatiotemporal Evolution of Land Subsidence in Konya Metropolitan Area (Turkey) Based on Multisensor SAR Data. Turkish Journal of Earth Sciences, 30(5), 681–697.

Tanyaş, H., Görüm, T., Fadel, I., Yildirim C., Lombardo L., 2022: An open dataset for landslides triggered by the 2016 Mw 7.8 Kaikōura earthquake, New Zealand. *Landslides* 19, 1405–1420.

Tavus, B., Kocaman, S., Nefeslioglu, H. A., 2022: Landslide detection using InSAR Time Series in the Kalekoy Dam Reservoir: Bingol, Türkiye. Proceedings Volume 12267, Image and Signal Processing for Remote Sensing XXVIII; 122670U https://doi.org/10.1117/12.2638608

Wu, P. C., Wei, M., D'Hondt, S, 2022: Subsidence in Coastal Cities Throughout the World Observed by InSAR. *Geophysical Research Letters*, 49(7).

Zhao, C.; Lu, Z. 2018: Remote Sensing of Landslides—A Review. *Remote Sensing*, 10, 279.