SYNERGY OF ADVANCED PROCESSING TECHNIQUES USING COPERNICUS SAR AND OPTICAL SATELLITE IMAGERY TO DETECT GROUND DISPLACEMENTS: THE CASE STUDIES OF PYRGOS AND PAREKKLISIA VILLAGES IN CYPRUS

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ABSTRACT:

Cyprus has a long history of destructive tectonic activity and related geohazards. This is mainly due to its location on the Mediterranean fault zone and the interaction of the Eurasian and African plates. To study the occurrence of land displacements on a national scale, various space-based monitoring techniques exploiting the Copernicus program's datasets were studied using Sentinel-1 and Sentinel-2 satellite images for the period of 2016-2021. More specifically, differential spectral indices were calculated by subtracting the reference 2016 Sentinel-2 image from an image for every year until 2021, and a parallelised version of Persistent Scatterer Interferometry (PSI) was conducted using a time series of Sentinel-1 data over the same period, to identify ground displacements over time. The PSI analysis in the area around Pyrgos and Parekklisia villages, detected Line-of-Sight (LoS) uplift phenomena of a maximum rate of 8 mm/y, in ascending and descending Sentinel-1 satellite passes. Similarly, deformation was identified from optical image processing. The integration of both techniques provided qualitative and quantitative information about ground deformation events in both areas, showcasing a complementarity of results obtained, with PSI detecting displacements in urban/built-up areas, and multispectral change detection in rural environment. In terms of correlation, the two techniques showed a fit of 31.34% in ascending and 26% in descending pass, providing additional information on the size of affected areas. This synergistic approach facilitates the systematic monitoring of areas of interest, providing significant and timely information to decision-makers, to take actions and adopt protective measures when and where it is required.

1. INTRODUCTION

Ground displacements can be characterised as a frequent phenomenon occurring due to natural hazards, such as earthquakes, landslides, and subsidence, and anthropogenic activities, such as mining, deforestation, and urbanisation. Remote sensing technologies have become a valuable tool for monitoring ground displacements in recent years, allowing scientists to detect and quantify the extent of these events (Tzouvaras et al., 2020), providing an early warning for ground displacements (Tzouvaras, 2021).

Among the most widely remote sensing data sources for ground movements are satellite-based Synthetic Aperture Radar (SAR) and optical imagery, where various studies and techniques in different landscapes have emerged (Zhang et al., 2022; Fotiou et al., 2022; Alatza et al., 2020; Svigkas et al., 2016; Danezis et al., 2022). The combination of SAR and optical satellite data provides a more comprehensive understanding of the underlying processes since this integration detects both vertical and horizontal displacements (Bacques et al., 2020; Prodromou et al., 2023).

In the last decade, the use of Copernicus data became indispensable part of detection and monitoring ground displacements worldwide (Apicella et al., 2022). The main advantage of Copernicus data refers to the open data policy and the non-commercialisation of satellite data, resulting to the reusability of the current study approach on larger spatial and time extent. Copernicus satellite system and specially Sentinel-1 and Sentinel-2 satellite constellations, provide free data with global coverage with a weekly revisit period (Torres et al., 2012; Spoto et al., 2012).

As remote sensing advanced processing techniques have developed over time, a research challenge has risen concerning ground displacement detection in complex and heterogeneous environments in recent years. The main objective of this study is to address this challenge by exploring the full capabilities of an integration of advanced image processing techniques exploiting Sentinel-1 and Sentinel-2 satellite images to detect ground

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displacements in the sub-mountainous villages of Pyrgos and Parekklisia villages in Limassol District, Cyprus, as case studies. The complementarity and/or correlation of results from both techniques is further investigated.

In the next sections of the present study, a brief presentation of the case study sites follows, along with the aim of the study in Section 1. Following, in Section 2, the data used, and the methodologies applied are presented in detail. The results are presented and discussed in Section 3, with the conclusions provided in Section 4.

1.1 Case study

The villages of Pyrgos Lemesou and Parekklisia are in the south-west part of Limassol District, which is located at the south part of the Republic of Cyprus (Figure 1). Their altitude ranges up to 85 meters above mean sea level. In the last five years these regions are experiencing a construction regeneration, since the notable urban sprawl and the related growth of the urban and infrastructure environment are visible in this region, with the main growth observed near the coastal front.

Figure 1. Case Studies of Pyrgos and Parekklisia villages in Limassol District, Cyprus.

1.2 Aim of the study

The study aims to obtain a more accurate and comprehensive understanding of the ground displacement processes in the study areas. A research question that may arise is "Can this integration of both satellite sensors improve the detection of ground displacement processes in a complex and heterogeneous environment?" This question is addressed by comparing the results of both satellite sensors evaluating simultaneously the accuracy and limitations, providing valuable insights into the practical applications of advanced processing techniques for ground displacement monitoring.

The complementarity and the corelation of the results from the two applied methodologies is studied in an attempt to monitor systematically areas of interest, exploiting the capabilities of the Copernicus Sentinel mission, irrespective of weather conditions and time of the day, as in the case of Sentinel-1 Synthetic Aperture Radar (SAR).

2. DATA AND METHODOLOGY

2.1 Data

The Sentinels is a new family of missions was developed by European Space Agency (ESA) for the operational needs of the Copernicus Programme. For the purpose of this study, Synthetic Aperture Radar (SAR) Sentinel-1 Single Look Complex (SLC) satellite images and multispectral Sentinel-2 satellite images were utilised, covering the period 2015-2021, to create image composites.

2.1.1 Sentinel-1 data

Sentinel-1 data provide an exceptional archive of SLC images for monitoring long-term slow moving deforming phenomena. The short revisit time and the wide spatial coverage, sets Sentinel-1 sensor among the optimal sensors for InSAR time-series analysis. For the identification of ground deformation phenomena in Parekklisia case study, Sentinel-1 data, covering the areas of interest, were provided by the Hellenic Mirror Site and the Sentinel Greek Copernicus Data Hubs (https://sentinels.space.noa.gr/) as shown below in Figure 2. Table 1 provides details on Sentinel-1 datasets employed in the current analysis.

Data	Orbit	Period		No. of images
		From	To	
Sentinel-1	Ascending	20/02/2016	20/12/2021	136
Sentinel-1	Descending	12/10/2015	17/09/2020	139

Table 1. Sentinel-1 data used for the present study.

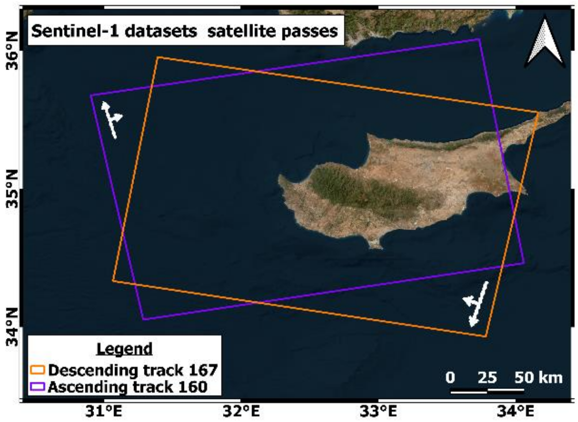

Figure 2. Sentinel-1 data frames employed in the present study.

2.1.2 Sentinel-2 data

Sentinel-2 satellite aims at monitoring variability in the land surface like vegetation, soil, water cover, inland waterways, and coastal areas. It also provides higher spatial resolution than other open access optical satellite data. The S2 satellite's MSI (Multi-Spectral Instrument) sensor has 13 spectral bands with 10–60 m spatial resolution and the pair of the two satellite sensors (S2-A and S2-B) aims at providing multispectral data with a 5-day revisit frequency. The Sentinel-2A satellite was launched on 23 June 2015 and 2B on 7 March 2017. For the purposes of this study, bands with a spatial resolution of 10m were used, as shown in Table 2 and Figure 3 below.

Data	Period		No. of images
	From	To	
Sentinel-2	01/01//2016	31/12/2021	234

Table 2. Sentinel-2 data used for the present study.

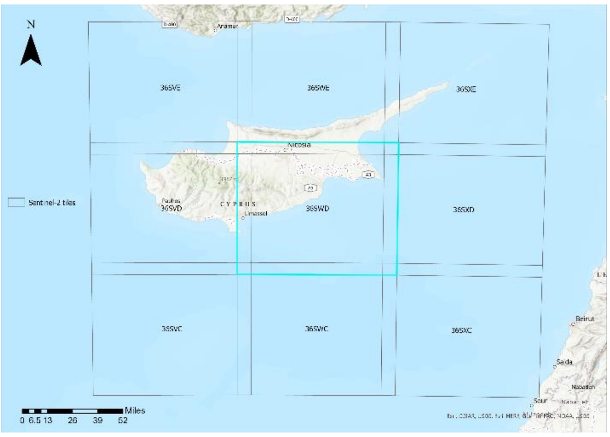

Figure 3. Sentinel-2 data frames.

Moreover, Sentinel-2 data were used directly through Google Earth Engine (GEE), which is a planetary-scale platform for scientific analysis and visualisation of geospatial datasets.

2.2 Methodology

The methodologies implemented in the current analysis using Sentinel-1 and Sentinel-2 are presented in detail in the paragraphs to follow.

2.2.1 InSAR time-series analysis using Sentinel-1

A Persistent Scatterer Interferometry (PSI) analysis was carried out to detect ground displacements at Parekklisia village in Cyprus during the same period. The P-PSI (Papoutsis et al., 2020), a fully automated parallelised processing chain for PSI analysis on big Earth Observation data, was employed. The P-PSI is developed by, and operates at, the Operational Unit BEYOND Centre for Earth Observation Research and Satellite Remote Sensing IAASARS/NOA. Line of Sight (LoS) displacements were estimated using Sentinel-1 SLC images from both ascending and descending satellite passes.

The P-PSI uses ISCE software (Rosen et al, 2012; Fattahi et al, 2017) for the creation of the coregistered stack and the Stanford method for Persistent Scatterers (StaMPS) (Hooper et al, 2004) for InSAR time-series analysis. The open-source Toolbox for Reducing Atmospheric InSAR Noise (TRAIN) (Bekaert et al, 2015), is used for the removal of atmospheric contributions in the estimated LoS displacements. Precise orbit data were provided by ESA and the Shuttle Radar Topography Mission (SRTM) DEM (Farr et al, 2000) with a resolution of one arc-second, were used during the coregistration step of primary and secondary images.

2.2.2 Multitemporal change detection using Sentinel-2

For the detection of ground displacements, Sentinel-2 satellite data were also used through the Google Earth Engine (GEE) platform. Furthermore, the proposed methodology uses the per pixel multitemporal change detection technique which provides an efficient and effective approach for the rapid land cover changes detection. The multitemporal change detection technique has used in several studies such as (Close et al., 2021; Gruenhagen and Juergens, 2022; Pacheco-Pascagaza et al., 2022). This technique is based on the subtraction of an image before an event from the post-event image.

Specifically, S2 level-2A, cloud-free satellite data were utilised, covering the period 2016-2021, to create yearly image composites. Furthermore, for all image composites, the Normalised Difference Vegetation Index (NDVI) was calculated and added as a new band to the yearly image composites. The values range is from -1 to +1 where the higher values indicate the healthier vegetation and the lower values indicate no vegetated features, such as barren surfaces (rock and soil), water, snow, ice, and clouds. The NDVI was proposed by Tucker (Tucker, 1979) and is calculated based on Equation 1 below. The NIR refers to the Near-infrared band, whereas the RED represents the red band.

$$NDVI = \frac{NIR-RED}{NIR+RED} \tag{1}$$

After the calculation of the NDVI index for each yearly composite it was used for the calculation of dNDVI. The difference images were produced by subtracting each year from the following year consecutively from 2016 to 2021 (e.g., 2017 from 2016, 2018 from 2017, etc.). After that the thresholding approach was applied on the difference images in order to distinguish the landslide affected areas from unchanged areas. The threshold values were implemented using the values below the lower confidence limit (i.e., three standard deviations from the mean) for the identification of possible displacement events.

3. RESULTS AND DISCUSSION

Concerning vegetation removal after the displacement events NDVI is used to detect vegetation changes. Specifically, removing the surface vegetation along the displacements exposes underground soil and rock as a result to have higher brightness than neighbouring areas (Tehrani et al., 2021). The resulting features of multi-temporal dNDVI are presented in Figure 4 below. The multi-temporal images have the advantage of reducing noise, in contrast with bi-temporal images (Lindsay et al., 2022). The result of this subtraction highlights the areas of change between the time periods.

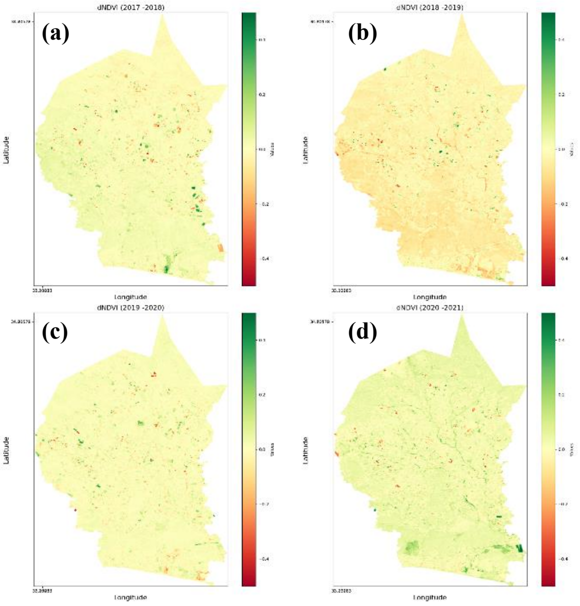

Figure 4. Results of the applied multi-temporal dNDVI during (a) 2017-2018, (b) 2018-2019, (c) 2019-2020 and (d) 2020-2021.

Furthermore, based on the thresholding results a binary image for each year was generated where the pixels with 0 value represent areas without changed and pixels with 1 value indicates the areas with changes. The results from each year were stacked and presents the possible displacements from 2016 until 2021 as shown in Figure 5 below.

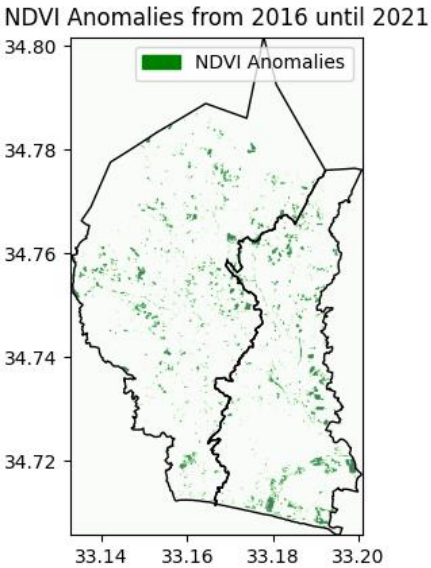

Figure 5. NDVI anomalies from 2016 until 2021 based on Sentinel-2 imagery.

Due to the fact that the results derived from the PSI analysis (Figure 6) refer to stable targets on the ground, the combination of optical and radar results was a challenging task. An attempt to resample InSAR and optical results to a common resolution was performed. Additionally, an identification of the nearest point to the detected landslide event was conducted, estimating the nearest distance from each point.

Figure 6. Points derived from P-PSI analysis.

In the P-PSI analysis positive LoS displacements dominate in the broader Parekklisia and Pyrgos Lemesou regions. In both ascending (Figure 7) and descending (Figure 8) Sentinel-1 satellite passes, an uplifting motion trend is identified, from 2015 to 2021. The LoS velocities, as derived from InSAR time-series analysis and presented in the current study are filtered to positive values greater that 2mm/y, that served as input for the analysis of optical data. For the integration of PSI and optical results, only PS with positive (>2mm/y) LoS displacements were considered as possible deforming sites in Parekklisia.

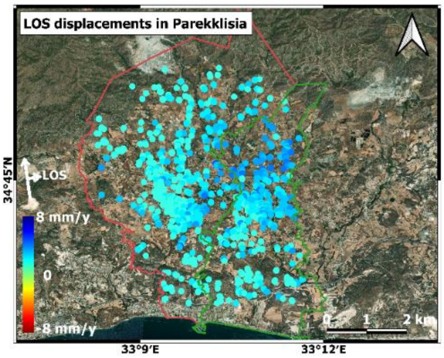

Figure 7. Positive LoS displacements for ascending satellite pass, derived from the P-PSI analysis.

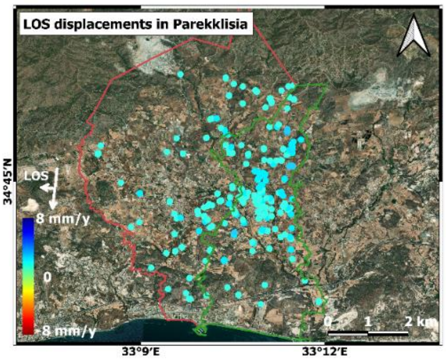

Figure 8. Positive LoS displacements for descending satellite pass, of Sentinel-1 sensor, derived from the P-PSI analysis.

The results of this study were validated using high-resolution images from Google Earth. Over five ground displacement events were detected using the Sentinel-2 satellite data, with some of them being presented below in Figure 9.

Figure 9. Ground truth data derived from Google Earth.

As illustrated in Figure 10 below, the pixels corresponding to the thresholds defined for creating the mask for landslide identification are shown in blue, along with high-resolution background images from Google Earth and the nearest PS points derived from the PSI analysis, in red. Furthermore, in order to correlate the results derived from the two datasets we estimate the distance between the PSI points for ascending and the anomalies were detected by Sentinel-2 using the NDVI index. For this reason, the "Generate Near Tool" which provided by ArcGIS pro was used. This tool calculates distances and other proximity information between the features in the buffer of the 30m.

Figure 10. Comparison of the results derived from PSI analysis with masked pixels derived from optical data (blue colour) in a wide spatial coverage (in the range of the 30m from each point derived via PSI-red colour) in Parekklisia Village, Cyprus.

Based on the near table for the ascending orbit, the 31.34% of the points in the buffer of the 30m are near to the NDVI anomalies, as presented in Figure 11 and for the descending orbit the 26% of them, as presented below in Figure 12.

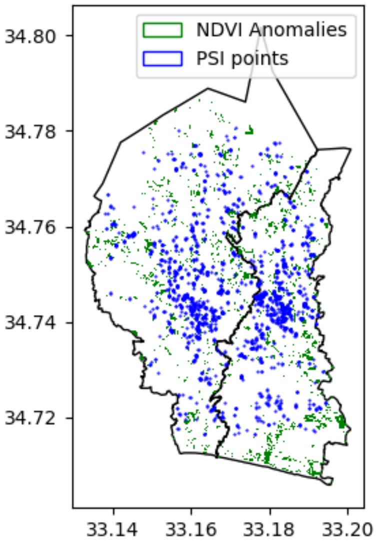

Figure 11. NDVI Anomalies and PSI points (Ascending Orbit) overlapping.

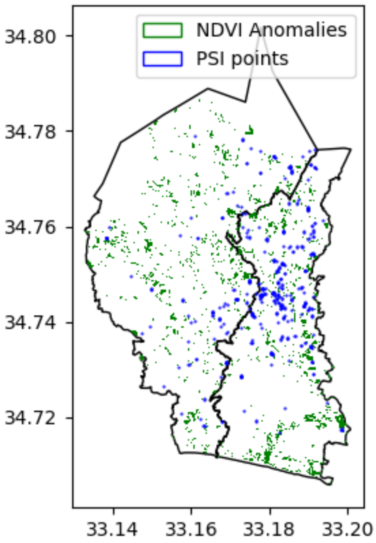

Figure 12. NDVI Anomalies and PSI points (Descending Orbit) overlapping.

Specifically, the process concerns the classification (determine the areas with subsidence, stability, and uplift) of PSI in both satellite passes (ascending and descending), comparing the mean velocities of the points from PSI with optical data, in a wide spatial coverage (in the range of the 30m from each point).

Despite that the combination of ground displacement measurements derived by optical and SAR image processing methods faces several challenges, it can serve as a valuable tool for monitoring ground displacement phenomena.

Validation of the observed displacements can be performed with site investigations and correlation of the results with existing landslide inventories in the future steps of our research. Overall, the fusion of different datasets and methods when studying geohazards, taking advantage of the optical and SAR satellites' different characteristics, provides a better overview of the displacement mechanisms in the area under investigation.

4. CONCLUSIONS

This study aims to investigate satellite-image-based change detection approaches for ground displacements in Parekklisia and Pyrgos villages in Cyprus to improve the completeness of landslide inventories. Specifically, the aim was to investigate the optimisation of PSI techniques on dual-pass Sentinel-1 data and multitemporal change detection techniques on Sentinel-2 imagery, to improve their performance in identifying valid coherent pixels in order to estimate displacements more accurately.

Based on the results derived from this study, the PSI technique extracted more coherent pixels in urban than in non-urban areas in contrast with the multi-temporal change detection technique, which was implemented through the use of Sentinel-2 satellite data by calculating the NDVI index. The low correlation observed proves this case, as the two methodologies applied offer valuable information in different areas.

However, the correlation in some of the results of the two methodologies applied could be an indicator of the size of the area affected by the land displacement phenomena, having impact on urban and rural areas at the same time, so it would provide additional information to stakeholders and decision-makers.

Our future steps focus on the implementation of Small Baseline Subset (SBAS) technique, which is more evident in rural regions, and will allow us to study further the correlation of these methodologies. Last but not least, the use of higher resolution data, such as that of Planet for optical and COSMO-SkyMed for SAR imagery can provide more detailed information on areas of interest regarding land movements, and due to their more frequent revisit times, fill the observation gaps we currently encounter with the free Copernicus datasets.

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