PERSISTENT SCATTERERS INTERFEROMETRY FOR LANDSLIDE STUDY IN A SMALL SCALE INHABITED AREA

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ABSTRACT

The aim of this study concerns the development a ground deformation monitoring based on PSI (Persistent Scatterers Interferometry) processing of radar data in order to predict and mitigate the risk of ground displacement cased by slope instability. The study area is located in Kerasia village at Plastiras Lake Municipality (Central Greece). The problem under treatment is a creeping landslide in an inhabited area. PSI processing using a data set of ERS-1/2 scenes for the period 1992-2000 was applied to retrieve the displacement history of the of the area for the considered time interval.

INTRODUCTION

Numerous phenomena can induce displacements of the earth surface and thus cause dislocations in structures and infrastructures particularly in urban areas. Landslides affect many areas of Greece and are characterized by low probability of evolution into a catastrophic event but can have very large direct and indirect impacts on man-made structures (1,2,3). Methodologies for the risk assessment and mitigation are therefore a major issue. Conventional methods of ground deformation monitoring, present many disadvantages such as high costs and time consuming. The space based Differential Interferometry Synthetic Aperture Radar (DInSAR) techniques could present a valuable tool for detecting, monitoring, quantifying the deformation and with field-work contribution can identify causes which may induce deformation. DInSAR has already proven its potential for mapping ground deformation phenomena, e.g. earthquakes, volcano dynamics, etc. and to cover in continuity large areas. In recent years the innovative Persistent or Permanent Scatterers Interferometry (PSI) technique (4,5), which overcomes several limitations of repeat-pass interferometry, has been widely applied for monitoring of slope instability with millimetric precision (6,7,8,9,10,11,12,13,14,15,16). According to this technique reliable deformation measurements can be obtained in a multi-image frame work on a small subset of image pixels corresponding to stable areas. These point-targets could be used to monitor terrain motion by analysing the phase history of each one. The response of clays along slip surfaces includes considerable strain softening at large displacement (17). The area of study is located in the region of the Municipal Department of Kerasia in Plastiras Municipality (Central Greece).

THE AREA OF INTEREST

The area of study is in the Kerasia village in Plastiras Municipality Figure 1. The problem under treatment is landslide in inhabited area. The broad area belongs to the lower part of Agrafa mountain range with an average altitude of 910 m. Average slope in this zone is of the order of 20% or 35%. The broad area is characterized by one of the highest rainfall-snowfall quantities in Greece; the average annual equivalent rainfall height is about 1200 mm with the 80% of this fall between months of October to April. The area of study is classified as belonging to Category II of seismic action with ground acceleration A = a x g = 0.24 g. The area is characterized from a complex geological structure. It primarily consists of limestones, strata of the transitional type to flysch and the particular phases of flysch of the Olonos-Pindos zone. Intense tectonic deformation is observed. The typical geological profile consists of limestone bedrock, on which sandstone and clayey schist phases of flysch are deployed. Thus, slopes of the residential area consist principally from sediments of flysch. An upper completely weathered layer that is soil of clay, sand-clay and clay-sand composition and a lower mildly weathered layer of the formation are distinguished. The existence of many springs indicates a rich water load in the subsoil. Water moves both through the limestones and the flysch. The weathered zone and the fractured zone of flysch develop shallow depth and no permanent flow water tables and springs and surficial water tables and springs. The water from springs and outflows within the residential area usually move uncontrollably causing soil formations to saturate thus weakening their geomechanical behavior and developing excess pore water pressures.

Figure 1. Location of the study area showing in Google Earth environment

The nature of the movements are creeps, translatory slides (planar or either), rotational - cycloid slides, settlements, falls and mudflows. The phenomenon is known to occur since early in the last century and various reports refer to it. Landslides have caused ruptures in walls and floors of buildings, wall turnings, cracks on the road surfaces of the municipal road network, the creation of soil cracks, tilting and uprooting of trees Figure 2. As main causes of these phenomena, the following have been identified : (a) Steep morphological gradients, (b) nature of formations, thickness and the poor mechanical properties of surface materials in the weathered zone, recent refills etc. (c) Inadequate surface drainage, (d) soaking of loose materials by water from intense rainfalls, cultivation and irrigation of slopes during summer, leakages and the absence of a drainage system, (e) the absence or inadequate function of retaining measures, (f) insufficient foundations and age of houses that have been damaged, (g) undercuts and scouring.

Figure 2. Kerasia village photos showing damage at houses due to landslide

DATA AND METHODS

In this study SAR scenes from ERS-1 and 2 satellites operating in C-band were used. In total 29 Single Look Complex (SLC) scenes of VV polarization acquired in descending orbit (track: 279, frame: 2835) and covering the period 1992–2000 were utilized. Moreover, a Digital Elevation Model (DEM) produced by the Shuttle Radar Topography Mission (SRTM) of approximately 90 m spatial resolution was used for topography removal. Finally, precise orbit state vectors were ingested in processing to enhance the accuracy of the satellite's orbit and estimate the initial interferometric baselines. Specifically, for the ERS scenes, orbit data from DELFT Institute (NL) for Earth-Oriented Space Research (DEOS) (18) were obtained. The methodology that has been used in this study was basically the Persistent Scatterers Interferometry (PSI) based on the Interferometric Point Target Analysis (IPTA) algorithm of the GAMMA software suite. The IPTA is a toolbox that can support many different processing schemes including different techniques for candidate point scatterers selection, spatial and temporal phase unwrapping, etc. The first step of processing chain was the coregistration of the SLCs scenes to a common master geometry. For our dataset the scene of 23 Februry-1997 was selected as reference. The achieved coregistration accuracy was satisfactory with standard deviations of individual range and azimuth offsets from the offset regression fit, less than 0.3 pixels. Based on the coregistered SLCs scenes, two candidate lists of point scatterers (PSs) were initially generated using two different selection approaches. The first list was generated based on phase properties and the second based on low intensity variability as the intensity and phase depend on the point-target cross section and position. Then, the two candidate point lists were combined into a single one, which finally was used for the analysis. The IPTA methodology requires one single scene as reference in order to form multiple pairs and produce interferograms. The criteria by which the reference scene was selected were the following: (i) forming interferometric pairs with the minimum baseline (Bp), (ii) acquisition date near the central date of the time period for which there are available SAR acquisitions, and (iii) reference scene to present low atmospheric distortions. For the specific project the ERS scene acquired on 23 Februry-1997 was selected as reference scene. Afterwards the initial differential interferograms were generated using the coregistered SLCs, the DEM heights, and the preceding point lists. This is performed by simulation of the unwrapped interferometric phase based on the initial baselines and the DEM. Then, the differential interferograms were analyzed in the temporal and spatial domain in order to obtain information on the atmospheric phase term, deformation phase term, and baseline errors. Thus, processing proceeds by applying a least-squares regression on the differential phases in order to estimate terrain height and deformation rate relative to a reference point target. The selection of the reference point is considered to be the most critical part of the processing, as final deformation rates and histories are greatly affected by this decision. Some criteria for the selection of the reference point are dictated by the applied method, such as the high quality of the point in terms of phase stability overtime. Others are related to the regional geodynamic setting of the area and the related pattern of deformation which needs to be extracted. In this case the selected reference point-target is located at 561094.00 E, 4351207.50 N position, about 4.5 km towards southeast at Kalyvia village. Based on the regression analysis, the quality of the PS candidates was further evaluated through the estimated standard deviation of the phase difference. PSs with a phase standard deviation larger than the indicated threshold (in this case 1.0 radian), significantly reducing the number of points. The majority of the rejected points were located over mountainous areas. Moreover, because residual phases contain the atmospheric term, nonlinear deformation, and error terms, they were further processed in order to compensate atmospheric and noise effects. Thus, residual phases were spatially filtered by applying a low-pass spatial filter. Atmospheric and error terms were reduced by the spatial filtering around the reference points, assuming that stability occurred in the region of the area. Further iteration was done in order to improve the estimated error in the final regression model. The generated results consist of height corrections, linear deformation rates, atmospheric phase, refined baselines, temporal coherence, and nonlinear deformation histories for each scatterer. Finally the deformation phases were transformed into displacements and geocoded to the selected cartographic reference system (UTM projection, WGS'84 datum). Following the transformation of the interferometric phases from range–Doppler coordinates into map geometry (geographic coordinates) PSs were imported into a GIS environment and plotted on a high-resolution Quickbird image in Google Earth environment. Finally, a total number of 223 scatterers for the time period 1992–2000 were identified with average annual motion about -1.37 mm/year and their density is approximately 60 points/km2 Figure 3 and the point scatterers motion statistics (mm/year classes) are shown in the Table 1.

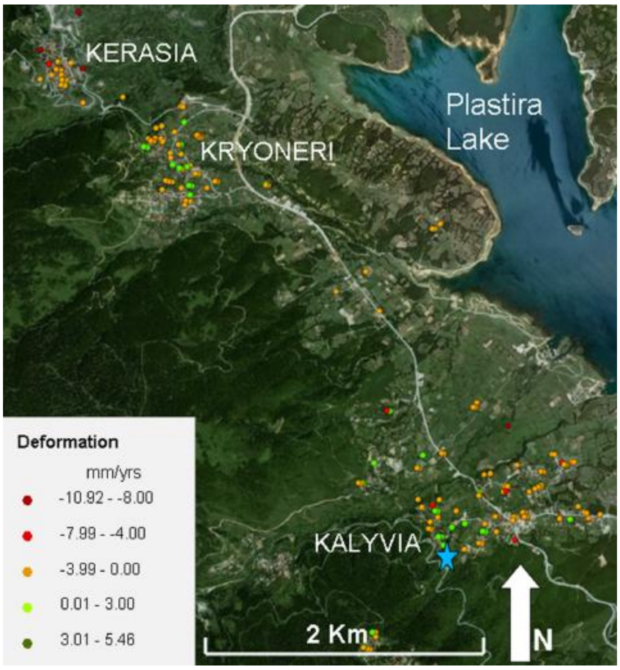

Figure 3. Point targets deformation map of the broader area produced by permanent scatterers interferometry method and plotted in Google earth environment. The blue star represents the reference point target.

Table 1: Point targets motion statistics

Point-target motion classes in mm/year	% of point-targets in each ass
>-3.5	8.09%
-3.5 to -1.5	36.77%
-1.5 to + 1.5	50.22%
+1.5 to + 3.5	4.48%
+3.5 to +max	0.44%

Within Kerasia village, where the study is focused, a number of 22scatterers was identified having average annual motion rates of -2.9 mm/year Figure 4. It is obvious that the majority of the scatterers show subsidence and are located within the settlement of Kerasia with major rates of deformation located in the northern part of the village.

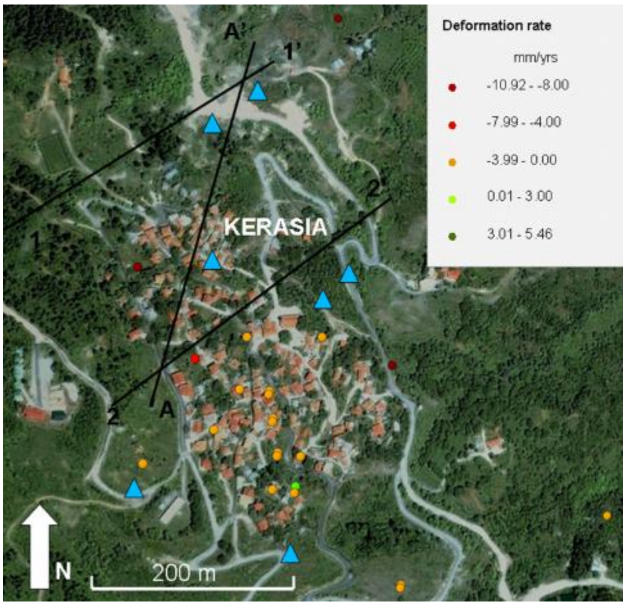

Figure 4. Point targets deformation map for Kerasia in Google Earth environment, the sections studied and location of boreholes (triangles).

RESULTS

The case of Kerasia in Plastiras Municipality as a continuous “creeping” slide is a typical example of all those phenomena that occur in Greek hilly and mountainous areas particularly in zones of considerable precipitation, triggered principally by water movement and favored by soil composition and stratification, weakness of surface formations, steep morphological gradients and not well studied human interventions. Many of them as in Kerasia go back for a long time in the past. There may be hundreds of similar cases developing in rural residential areas and many others may emerge in the near future. They affect houses and other structures which are most vulnerable since the overwhelming majority has not been built with modern codes and usually with no design at all. But they affect also utility networks (water, telephone lines, electricity etc.), roads, bridges and other infrastructure. Damage of roads is of particular concern because of their length of exposure and their function connecting different places. The social and economic impact of incurred loss and damages is apparent. This phenomenon can sharply increases and accelerates due to strong rain events or earthquake. In this case not only material damage is involved but risk for human lives too. Satellite data available, even though not many in this study, covering a certain period in the past (1992 to 2000) have been useful to indicate not only the location, but also the magnitude of sliding movements of an average rate of 8.4 mm/year. But the real importance of the access to these data is the acquired capability of using this technology in the future not only for the area of Kerasia but for many other areas too. By monitoring displacements and their rate variation due to slow soil motion from satellites focusing in areas where initiation of phenomenon is manifested or suspected and in other sites of significance, timely preparation for treating the problem can be ensured. This shall be of important social, economic and environmental benefit.

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REFERENCES

1 Marinos, P., Kavvadas, M., Tsiambaos, G., Saroglou, H., 2002. Rock slope stabilization in Mythimna castle, Lesvos island, Greece. 1st European Conference on landslides, Balkema Publ., ed: Rybar Stembeck and Wagner, Prague, 635-639.

2 Sabatakakis, N., Koukis, G., Mourtas, D., 2005. Composite landslides induced by heavy rainfalls in suburban areas: City of Patras and surrounding area, western Greece. Landslides 2, 202-211.

3 Koukis, G., Sabatakakis, N., Ferentinou, M., Lainas, S., Alexiadou, X., Panagopoulos, A., 2009. Landslaide phenomena related to major fault tectonics: rift zone of Corinth Gulf, Greece. B. Eng. Geol. Envirn. 68, 215-229.

4 Ferretti, A., Prati, C., Rocca, F., 2001. Permanent scatterers in SAR interferometry. IEEE T. Geosci. Remote 39, 8–20.

5 Werner, C., Wegmüller, U., Strozzi, T., Wiesmann, A., 2003. Interferometric point target analysis for deformation mapping. In Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, Toulouse, France, July 2003, 7, 4362–4364

6 Strozzi, T., Farina, P., Corsini, A., Ambrosi, C., Thüring, M., Zilger, J., Wiesmann, A., Wegmüller, U., Werner, C., 2005. Survey and monitoring of landslide displacements by means of L-band satellite SAR interferometry. Landslides 2 (3), 193–201.

7 Colesanti, C. Wasowski, J., 2006. Investigating landslides with space-borne Synthetic Aperture Radar (SAR) interferometry. Eng. Geol. 88, 173-199.

8 Rott, H., Nagler, T., 2006. The contribution of radar interferometry to the assessment of landslide hazards. Adv. Space Res. 37, 710-719.

9 Corsini, A., Farina, P., Antonello, G., Barbieri, M., Casagli, N., Coren, F., Guerri, L., Ronchetti, F., Sterzai, P., Tarchi, D., 2006. Space-borne and ground-based SAR interferometry as tools for landslide hazard management in civil protection. Int. J Remote Sens. 27(12), 2351-2369.

10 Bovenga, F., Nutricato, R., Refice, A., Wasowski, J., 2006. Application of multi-temporal differential interferometry to slope instability detection in urban/peri-urban areas. Eng. Geol. 88, 218-239.

11 Delacourt, C., Allemand, P., Berthier, E., Raucoules, D., Casson, B., Grandjean, P., Pambrun, C., Varel, E., 2007. Remote sensing techniques for analysing landslide kinematics : a review. B. Soc. Geol. Fr. 178, 2, 89-100.

12 Peyret, M., Djamour, Y., Rizza, M., Ritz, J.-F., Hurtrez, J.-E., Goudarzi, M, Nankali, H., Chery, J., Le Dortz, K., Uri, F., 2008. Monitoring of the large slow Kahrod landslide in Alborz mountain range (Iran) by GPS and SAR interferometry. Eng. Geol. 100, 131-141.

13 Meisina, C., Zucca, F., Notti, D. Colombo, A., Cucchi, A., Savio, G., Giannico, C. Bianchi, M., 2008. Geological interpretation of PSInSAR data at regional scale. Sensors 8, 7469-7492.

14 Castaneda, C., Gutierrez, F., Manunta, M., Galve J., 2009. DInSAR measurements of ground deformation by sinkholes, mining subsidence and landslides, Ebro River, Spain. Earth Surf. Proc. Land. 34, 1562-1574.

15 Del Ventisette, C., Casagli, N., Fortuny-Guasch, J., Tarchi, D., 2012. Ruinon Landslide (Valfurva, Italy) ctivity in relation to rainfall by means of GB-InSAR monitoring. Landslides 9, 497–509.

16 Lu, P., Stumpf, A., Kerle, N., and Casagli, N.: Object-oriented change detection for landslide rapid mapping, Geosci. Remote Sens. Lett., 8, 701–705, 2011

17 Stark, T.D., Contreras, I.A., 1996. Constant volume ring shear apparatus. Geotech Test J 19(1), 3-11.

18 Scharoo, R. Visser, P.N.A.M., 1998. Precise orbit determination and gravity field improvement for the ERS satellites. J. Geophys. Res. 103, 8113-8127.