World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:16, No:10, 2022

ADA Tool for Satellite InSAR-Based Ground Displacement Analysis: The Granada Region

M. Cuevas-González, O. Monserrat, A. Barra, C. Reyes-Carmona, R. M. Mateos, J. P. Galve, R. Sarro, M. Cantalejo, E. Peña, M. Martínez-Corbella, J. A. Luque, J. M. Azañón, A. Millares, M. Béjar, J. A. Navarro, L. Solari

Abstract**—**Geohazard prone areas require continuous monitoring to detect risks, understand the phenomena occurring in those regions and prevent disasters. Satellite interferometry (InSAR) has come to be a trustworthy technique for ground movement detection and monitoring in the last few years. InSAR based techniques allow to process large areas providing high number of displacement measurements at low cost. However, the results provided by such techniques are usually not easy to interpret by non-experienced users hampering its use for decision makers. This work presents a set of tools developed in the framework of different projects (Momit, Safety, U-Geohaz, Riskcoast) and an example of their use in the Granada Coastal area (Spain) is shown. The ADA (Active Displacement Areas) tool has been developed with the aim of easing the management, use and interpretation of InSAR based results. It provides a semi-automatic extraction of the most significant ADAs through the application ADAFinder tool. This tool aims to support the exploitation of the European Ground Motion Service (EU-GMS), which will offer reliable and systematic information on natural and anthropogenic ground motion phenomena across Europe.

Keywords**—**Ground displacements, InSAR, natural hazards, satellite imagery.

I. Introduction

Satellite interferometry (InSAR) is an established technique for ground movement detection and monitoring that allows processing areas from regional/national scale up to very detailed scale such as single buildings, providing a high number of displacement measurements at low cost [1]-[3]. However, the outputs provided by such techniques usually require an expert to interpret, which might turn out to be a time-consuming task for users who are not familiar with radar data [4].

The availability of Sentinel-1 data at no cost since 2014 has prompted the tendency of increasingly using this technique in institutional risk management activities. The consolidation of the use of InSAR is promoted by the funding of regional, national, and European programs to investigate and improve the processing performances and broaden the operational use and application of the InSAR results to monitor ground displacements [5]. In this scenario, the development of methodologies and tools to automatize the retrieval of information and to ease the interpretation of the results is a need to improve its operational use. In this work, a series of tools developed in the framework of the projects MOMIT, SAFETY, U-Geohaz and RiskCoast is presented and an example of use in the framework of the project RiskCoast is shown. Riskcoast focuses on the development of tools, methodologies and innovative solutions aimed at the prevention and management of geological risks on the coast linked to climate change.

The presented work is as an example of multi scale (medium to large) application of InSAR for geohazard applications exploiting the ADA tools [4] developed with the aim of facilitating the management, use and interpretation of InSAR-based results. The velocity of deformation map and the displacement time series have been estimated over the test area of Granada County (Spain) by processing Sentinel-1 (A and B) Synthetic Aperture Radar (SAR) images. From these initial InSAR outputs, a semi-automatic extraction of the most significant ADA is carried out using the ADAFinder tool [4]. The application of the ADA tool to the Riskcoast project test site encompassing the coast of Granada (Spain) is shown. The ADA tool might ease the interpretation of the information delivered by the EU-GMS [5].

II. Methodology

A. Dataset

A stack of 210 co-registered SAR Sentinel-1 Wide Swath Single Look Complex (SLC) images acquired in Ascending geometry during the period May 2017 to March 2021 has been processed at full resolution. The resolution of Sentinel-1 data is approximately 4×14 m^2. Specifically, two swaths and eight bursts have been processed to cover the area of interest. Images from Sentinel-1A and Sentinel1-B satellites have been exploited with a minimum temporal sampling of 6 days. The SRTM Digital Elevation Model provided by NASA was used to process the interferometric products. Finally, a set of 985 redundant wrapped interferograms was generated with a maximum temporal baseline of 30 days.

B. Data Processing

This section briefly describes the methodology used in this study to generate the ADA maps. The methodology applied is a multi-step processing procedure which includes two main stages: InSAR processing and ADAs extraction.

M. Cuevas-González, O. Monserrat, A. Barra, J.A. Navarro and L. Solari are with the Centre Tecnològic de Telecomunicacions de Catalunya, Castelldefels, 08860 Spain (phone +34 936 452 900; fax: +34 93 645 29 01; e-mail: maria.cuevas@cttc.es, oriol.monserrat@cttc.es, anna.barra@cttc.es, jose.navarro@cttc.es, lorenzo.solari@cttc.es).

C. Reyes-Carmona, R.M. Mateos, R. Sarro, E. Peña, M. Martínez-Corbella, J.A. Luque and M. Béjar are with the Geological Survey of Spain.

J.P. Galve, M. Cantalejo, J.M. Azañón and A. Millares are with the University of Granada.

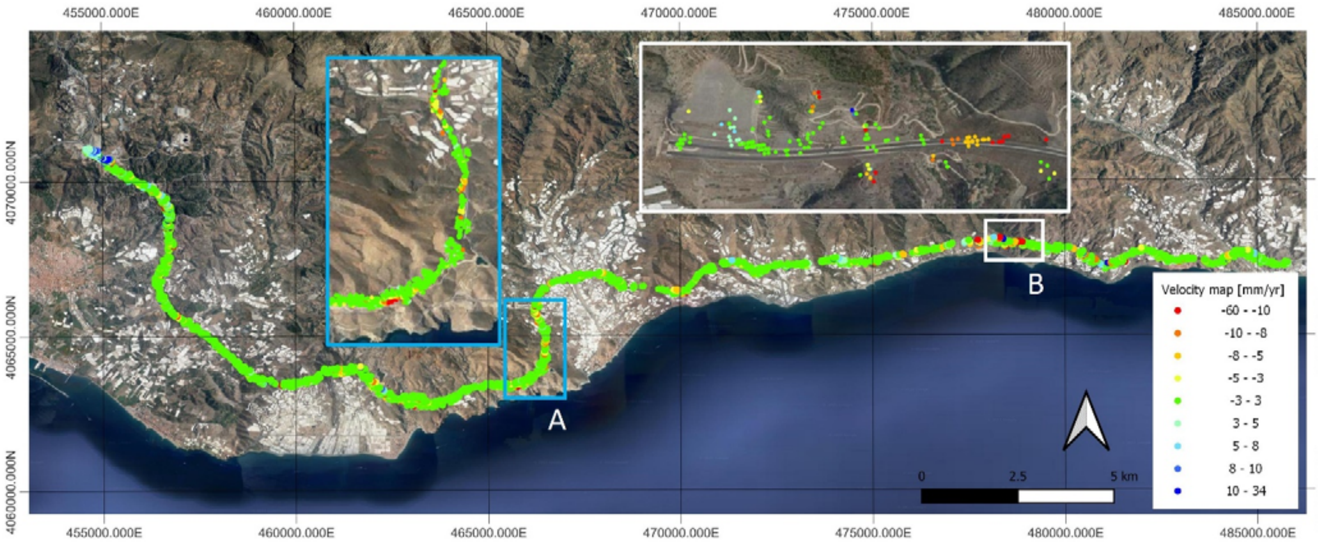

Fig. 1 Deformation velocity map of the section of the A-7 highway between La Gorgoracha and La Rábita (Granada County, Spain): the areas A and B, amplified in the blue and white highlighted areas show the test sites displayed in Figs. 2 and 3, respectively

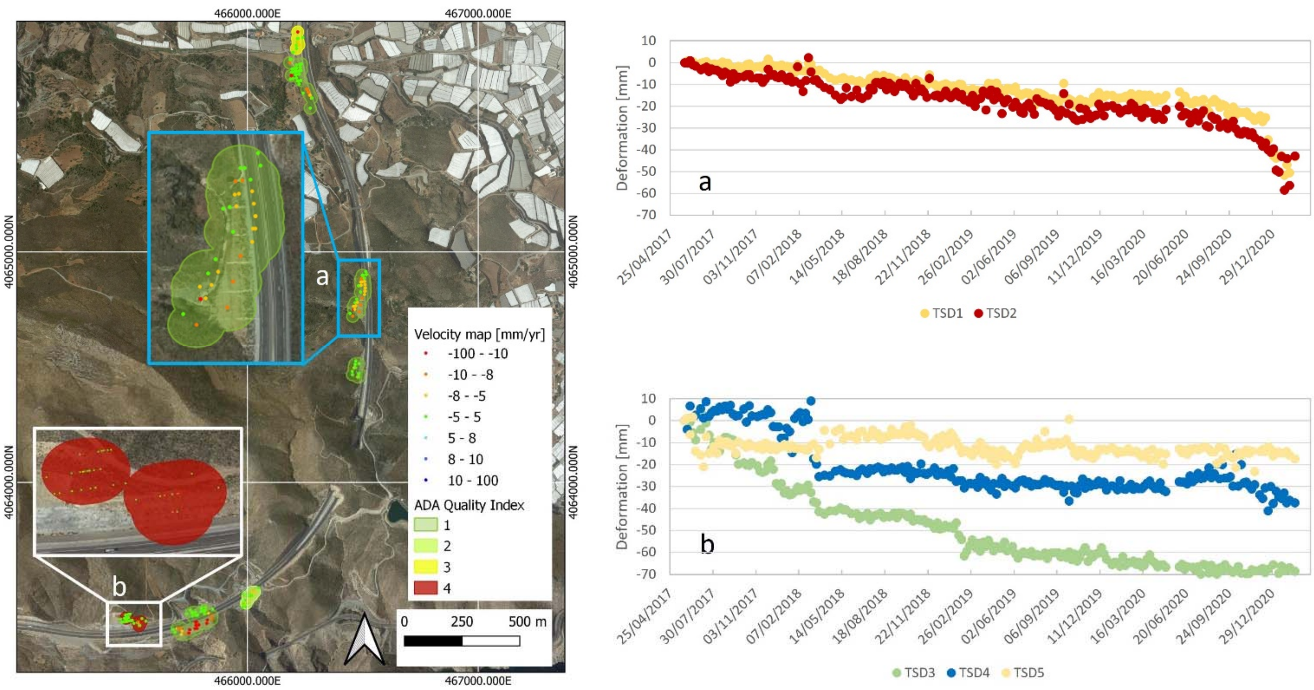

Fig. 2 ADA map of the area A highlighted in blue in Fig. 1, with two amplified ADAs ((a) and (b)) affecting two sectors of the A-7 highway: The velocity of deformation of the active PSs showing instability are displayed in this map; stable PSs have been filtered out by the ADAfinder tool; two TSD are displayed for each sector as example

The goal of the InSAR processing stage of the procedure is to derive the deformation information of the area of interest from SAR data. The Persistent Scatterer Interferometry chain of the Geomatics (PSIG) Division of the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) described in [7] has been used in this study. The main steps of the InSAR processing carried out in this study are: (1) interferogram generation; (2) interferogram network selection performed with a statistical evaluation of the coherence of the study area in order to locate and remove those interferograms characterized by low coherence (e.g., snow periods in mountain areas); (3) selection of points based on the dispersion of amplitude; (4) estimation of the residual topographic error and subsequent removal from original single-look interferograms; (5) 2+1D phase unwrapping of the redundant interferograms which generates a set of N unwrapped phase images, which are temporally ordered in correspondence with the dates of the SAR images processed, hereafter referred as time series of deformation (TSD); (6) atmospheric phase screening estimation using spatio-temporal filters and removal from the TSDs generated in the previous step; (7) estimation of the velocity of deformation from the TSDs and; (8) geocoding of the results.

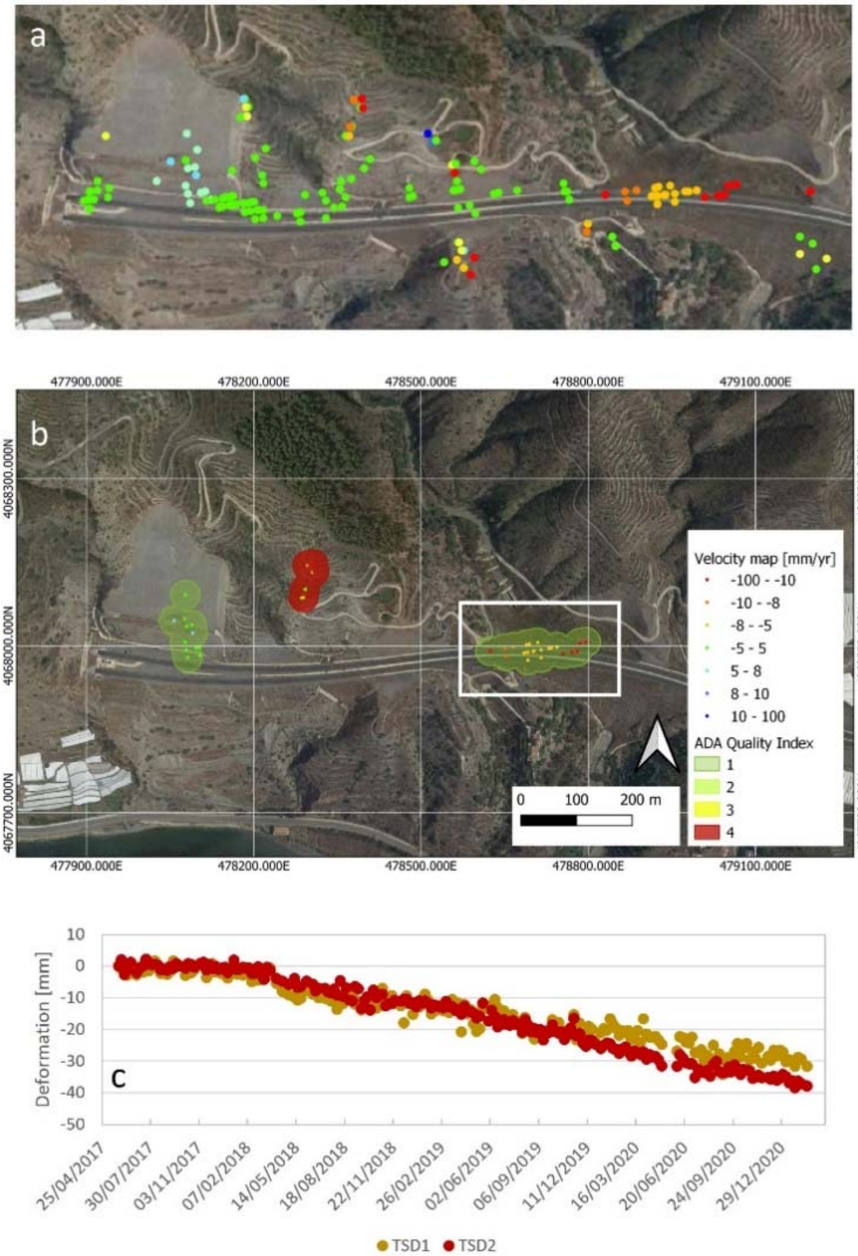

Fig. 3 ADA map of the area B highlighted in white in Fig. 1: Two ADAs with QI = 1 and one with QI = 4 have been extracted in this area; the velocity of deformation of the active PSs showing instability are displayed in this map; stable PSs have been filtered out by the ADAfinder tool; TSD of two of the PSs making the ADA highlighted in white are displayed as example

The output of the InSAR processing stage is a deformation map composed of a set of selected points, called Persistent Scatterers (PSs), with information on the estimated Line-of-Sight (LOS) velocity of deformation and the accumulated deformation at each Sentinel-1 image acquisition time, i.e. TSDs.

The ADAs extraction stage is aimed at the generation of the ADA map. The main goal is the identification and mapping of those areas where deformation has been measured by the PSIG processing. The ADAfinder tool [4], [6], [8] has been used with that purpose. The input of this stage is the deformation map of the area of interest generated in the previous step. ADAfinder includes the option to filter the input deformation map from the isolated or potential outlier PSs, which has been done in order to ease the detection of ADAs and avoid spurious results in the final ADA map. The ADAfinder employs the information contained in the filtered deformation map to define each ADA on the basis of their location and density of PSs, i.e., some thresholds as the minimum number of PSs making an ADA or the area of influence of each PS need to be defined. The minimum number of PSs making an ADA was set to 5 and the area of influence of each PS was set to 26 m. A quality index is calculated to provide an estimation of the level of noise of the displacement TSDs of the PSs making each ADA. The QI ranges from Class 1, which represents the ADA characterized by very high quality TSDs to Class 4. Specifically, Class 1 means reliable ADA and TSD; Class 2 means reliable ADA, but a further analysis of the TSD is recommended; Class 3 means reliable ADA but TSD cannot be exploited; and Class 4 denotes a not reliable ADA. For detailed information regarding the procedure to identify the ADAs and assess their quality please refer to [4] and [6].

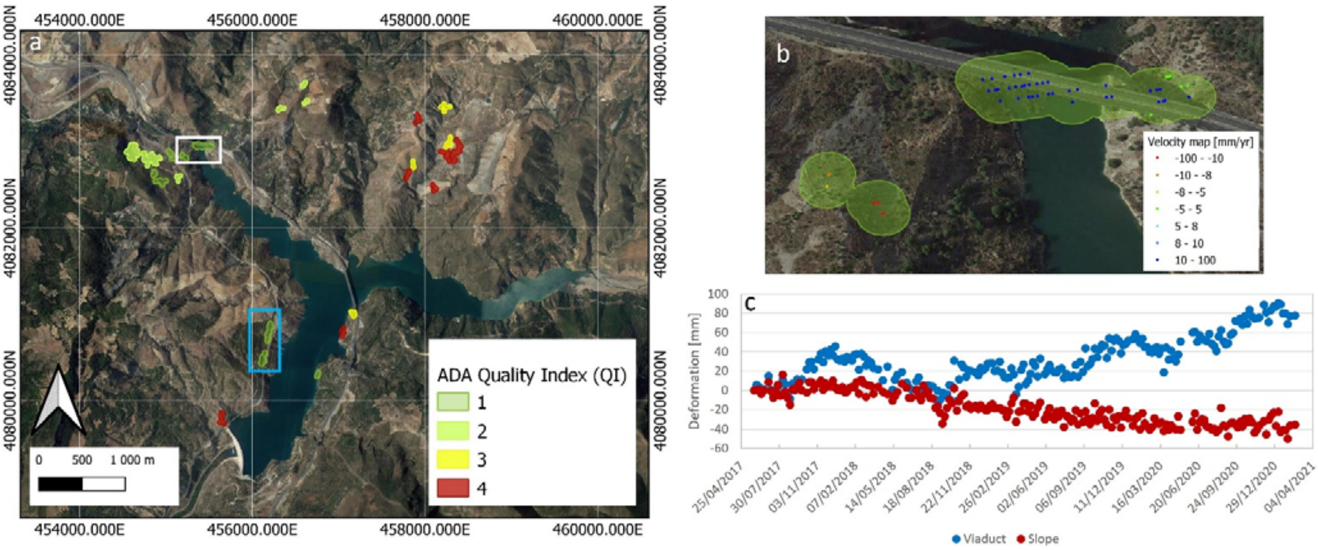

Fig. 4 (a) ADA map of the Rules reservoir with two areas highlighted in white and blue (shown in Fig. 5); (b) Amplification of the area highlighted in white in (a); (c) TSDs of a PS located in the ADA extracted on the viaduct (b) showing movements towards the satellite (blue line) and a PS located in the ADA detected on the slope located in the southwestern part of (b) displaying movements away from the satellite (red line)

The outputs of the ADAs extraction stage are two shapefiles containing the filtered deformation map and the ADA map. Regarding the filtered deformation map, the user can decide whether to keep all the filtered PSs available in the area under study or just keep the PSs included in the extracted ADAs. The ADA map contains the polygons defining the boundaries of the ADAs.

III. Results

The results of the application of the InSAR processing and the ADAfinder tool to the region of interest are described in this section. Specifically, we are going to focus on two critical infrastructures located in the area under study, a section of the A-7 highway (Fig. 1) as it passes through Granada County (Spain) and the Rules Reservoir (Fig. 4), due to their relevance in the communications and water supply in the area.

A. Section of the A-7 Highway

Fig. 1 shows the deformation velocity map generated with the InSAR processing in a section of the A-7 highway of approximately 40 km between La Gorgoracha and La Rábita (both located in Granada County, Spain). The green points indicate stability, the red colors indicate movements away from the satellite and the blue colors are movements towards the satellite. A total of 6850 PSs was measured in that section of the A-7 highway. Several road sectors affected by deformation phenomena have been detected. These unstable areas are located in the cut slopes or the pavement of the A-7 highway as can be seen in Figs. 2 and 3. The ADAfinder tool extracted 29 ADAs in the 40 km section of the A-7 highway under study, of which 15 display QI = 1, 3 exhibit QI = 2, 3 correspond to QI = 3, and 8 to QI = 4. The seven ADAs extracted in the section of the A-7 shown in Fig. 2 exhibit different QI values, and thus different levels of reliability. For example, ADA (a) is a reliable ADA as indicates its QI = 1. In this case, the TSDs (Fig. 2 (a)) shown as example display a low level of noise and display a consistent deformation behavior with movements away from the satellite of up to -60 mm. On the contrary, ADA (b), with a QI = 4, represents the lowest quality of ADA that can be extracted. The TSDs of three of the PSs (Fig. 2 (b)) that make that ADA show a higher level of noise and different behavior. In this case, TSD3 exhibits a near linear movement away from the satellite that seems to stabilize at the end of the observation period with a maximum displacement of up to -70 mm, TSD4 displays stability at the beginning of the observation period followed by a small window of time where there is movement away from the satellite and then stability with a maximum displacement of -40 mm, and finally TSD5 showing a smaller movement away from the satellite at the beginning of the observation period and then remains more or less stable compared with the other two TSDs.

Fig. 3 illustrates another sector of the A-7 highway where three ADAs have been extracted (Fig. 3 (b)), two of them have QI = 1 and the other QI = 4. The TSDs (Fig. 3 (c)) shown as example display a low level of noise, similar behavior but different maximum displacement. This is a good example to show the filtering approach of the ADAfinder. Fig. 3 (a) shows the InSAR generated velocity map and Fig. 3 (b) only those PSs kept after filtering the PSs showing stability (green points) and isolated PSs or those that do not meet the 5 PSs criteria set to make an ADA.

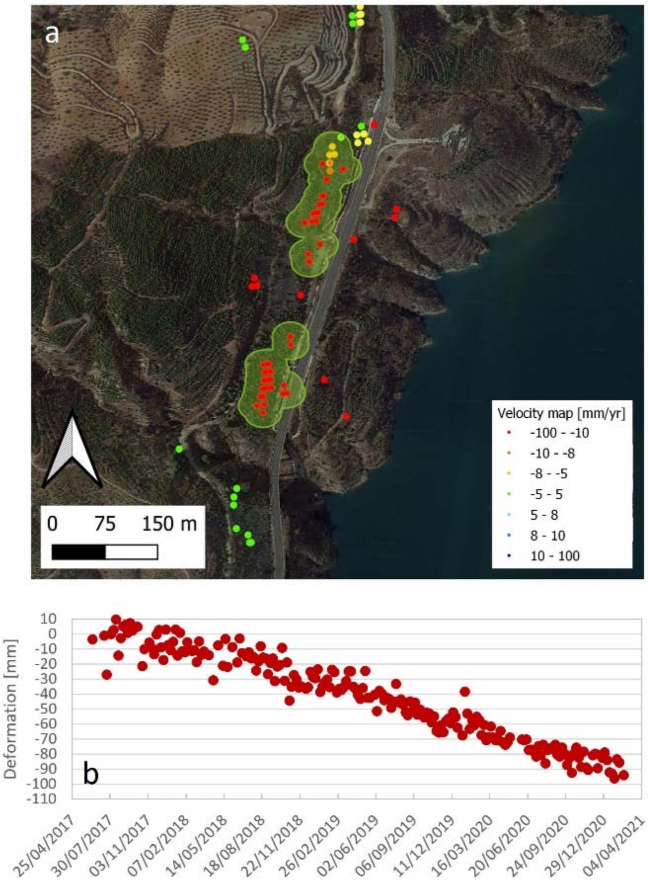

Fig. 5 ADA map and deformation velocity map of the area highlighted in blue int Fig. 4: Two ADAs with QI = 1 are displayed

B. Rules Reservoir

The Rules reservoir is the second critical infrastructure located in the area under study that will be further analyzed in this work due to its relevance to the water supply in the area. Fig. 4 (a) illustrates the ADA map generated for the reservoir and its surroundings. A total of 24 ADAs has been detected in this area with different levels of QI. Due to their significance, we focus of two ADAs detected over a viaduct and in the slope located on the southwestern part of that viaduct (Fig. 4). All the PSs belonging to the ADA located over the viaduct (Fig. 4 (b)) show movements towards the satellite (blue points) while the PSs located in the ADA on the slope display movements away from the satellite (red points). The TSDs of the PSs located in each ADA provide very useful information on the deformation phenomena occurring in those areas. A representative TSD of the PSs making each of the two ADAs is shown in Fig. 4 (c). The TSD of the viaduct, represented with blue points, show a seasonal displacement that might be compatible with a thermal expansion phenomenon characteristic of the viaducts and an uplift displacement beginning at the end of 2018. The PS located on the ADA extracted on the slope (red points) shows a displacement away from the satellite starting in the same period that the uplift movement detected on the viaduct. Furthermore, Fig. 5 shows two ADAs detected in the cut slopes of a road that surrounds the reservoir. A TSD representative of the displacement detected by the InSAR processing is shown in Fig. 5 (b). This TSD shows a linear movement away from the satellite with displacements of up to 100 mm. The movement detected in these ADAs is compatible with a landslide that might pose a risk to the road.

IV. Discussion

The work presented in this article represents an integration of the PSIG processing chain and the ADAfinder tool developed at the Geomatics Division of the CTTC. The main goal is simplify and facilitate the interpretation of the velocity map and TSDs resulting from the PSIG processing chain by semi-automatically identifying with the ADAfinder tool unstable areas or ADAs. It is worth emphasizing that the ADA detection does not overcome the intrinsic limitations of the InSAR techniques, i.e., the absence of ADAs does not necessarily imply stability since it could also mean non-detectable movement due to unfavorable geometry [9] or lack of information due to low coherence.

Two regions of interest, located in Granada County (Spain), have been analyzed due to their significance in the communication and water supply in the region. The first one corresponds to a section of approximately 40 km of the A-7 highway that has been affected by landslides and cut slope failures in several sections of its path as it passes through the territory of Granada County (Spain). InSAR and the ADAfinder tool have been exploited to assess and monitor road stability. In this area of interest, a total of 29 ADAs have been detected, of which 18 display QI 1 or 2, and 11 QI 3 or 4. An experienced user might be able to exploit information from the TSDs associated to the PSs belonging to low quality ADAs, i.e. QI 3 and 4. However, for non-expert users, the information provided by the QI related to the reliability of the extracted ADAs might prove useful to decide to contemplate, for example, only ADAs displaying QI 1 and 2, while disregarding QI 3 and 4. In any case, the methodology exploited in this work has been able to detect, with a high degree of reliability, 18 sectors of the A-7 highway characterized by instability which might pose a risk to the communications in the region and passing by drivers. Furthermore, a thorough analysis of the remaining 11 ADAs indicate that the information contained in some of the TSDs of the PSs making that ADAs might be exploited by experienced interpreters.

Regarding the Rules reservoir, several areas around this reservoir are known to be affected by instability processes. The ADAs located along the road (Fig. 5 (a)) are related to the El Arrecife Landslide, a large and complex landslide described in [10] and [11] that may imply a potential hazard not only for the road but also for the entire reservoir and its surroundings. In this region, 24 ADAs displaying different levels of QI have been detected. Specifically, 14 of them have QI 1 or 2 and the other 14 QI 3 or 4. Many of the ADAs extracted in this region are located in isolated slopes that might not pose too much risk. However, a few of them affect two relevant infrastructures, a viaduct and a road. These results obtained prove that the method applied in this work might prove useful for a fast and semi-automatic detection of geohazards. The ADAfinder tool provides an approach to rapidly assess the InSAR products to detect critical unstable areas that can be easily used by Civil Protections and Geological Surveys.

V. Conclusions

The methodology implemented to detect and analyze ground displacements based on satellite InSAR techniques and the ADAfinder tool, and a description and analysis of the results obtained for a regional area located in Granada County (Spain) have been presented in this paper. The complementarity of the PSIG InSAR technique and the ADAfinder tool has been demonstrated. On one hand, InSAR techniques are able to provide displacement measurements over large areas at low cost, but the difficulty to interpret those results by non-expert users hamper their use by decisions makers. On the other hand, the ADAfinder tool allows a semi-automatic identification of critical areas affected instability, i.e., the ADAs, satisfying the need for post-processing tools that ease the interpretation of the InSAR based outputs. The ADA tool might be exploited to obtain a fast selection of deformation areas. However, an advanced analysis and interpretation is possible with the combination of all outputs as presented in this work. An integrated analysis of the velocity of deformation map, the TSDs and the ADA map might prove very useful to interpret the geological and geotechnical processes affecting wide areas. Furthermore, this set of techniques will support the exploitation and interpretation of ground motion phenomena provided by the EU-GMS.

Acknowledgment

This work was mainly supported by the European Regional Development Fund (ERDF) through the project "RISKCOAST" (SOE3/P4/E0868) of the Interreg SUDOE Programme.

References

[1] Carlà, T., Intrieri, E., Raspini, F., Bardi, F., Farina, P., Ferretti, A., Colombo, D., Novali, F., Casagli, N. (2019). Perspectives on the prediction of catastrophic slope failures from satellite InSAR. Scientific Reports, 9, pp. 1-9. https://doi.org/10.1038/s41598-019-50792-y

[2] Galve, J.P., Pérez-Peña, J.V., Azañón, J.M., Closson, D., Caló, F., Reyes-Carmona, C., Jabaloy, A., Ruano, P., Mateos, R.M., Notti, D., Herrera, G., Béjar-Pizarro, M., Monserrat, O., Bally, P. (2017). Evaluation of the SBAS InSAR service of the European space Agency's Geohazard Exploitation Platform (GEP). Remote Sensing, 9(12), 1291.

[3] Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., Crippa, B. (2016). Persistent scatterer interferometry: A review. ISPRS Journal of Photogrammetry and Remote Sensing, 115, 78-89.

[4] Barra, A., Solari, L., Béjar-Pizarro, M., Monserrat, O., Bianchini, S., Herrera, G., Crosetto, M., Sarro, R., González-Alonso, E., Mateos, R.M., Ligüerzana, S., López, C., Moretti, S. (2017). A methodology to detect and update active deformation areas based on Sentinel-1 SAR images. Remote Sensing 9, 1002. https://doi.org/10.3390/rs9101002

[5] Crosetto, M., Solari, L., Mróz, M., Balasis-Levinsen, J., Casagli, N., Frei, et al. (2020). The evolution of wide-area DInSAR: From regional and national services to the European Ground Motion Service. Remote Sensing, 12(12), 2043.

[6] Tomás, R., Pagán, J. I., Navarro, J. A., Cano, M., Pastor, J. L., Riquelme, et al (2019). Semi-automatic identification and pre-screening of geological–geotechnical deformational processes using persistent scatterer interferometry datasets. Remote Sensing, 11(14), 1675.

[7] Devanthéry, N., Crosetto, M., Monserrat, O., Cuevas-González, M., Crippa, B. (2014). An approach to Persistent Scatterer Interferometry. Remote Sensing, 6, 6662–6679.

[8] Navarro, J.A., Tomás, R., Barra, A., Pagán, J.I., Reyes-Carmona, C., Solari, L., Vinielles, J.L., Falco, S., Crosetto, M. (2020). ISPRS International Journal of Geo-Information, 9, 584. doi:10.3390/ijgi9100584

[9] Ferretti, A., Monti-Guarnieri, A., Prati, C., Rocca, F., Massonet, D. (2007). InSAR Principles-Guidelines for SAR Interferometry Processing and Interpretation, TM-19; ESA Publications: Auckland, New Zealand.

[10] Reyes-Carmona, C., Barra, A., Galve, J.P., Monserrat, O., Pérez-Peña, J.V., Mateos, R.M., Notti, D., Ruano, P., Millares, A., López-Vinielles, J., Azañón, J.M. (2020). Sentinel-1 DInSAR for Monitoring Active Landslides in Critical Infrastructures: The Case of the Rules Reservoir (Southern Spain). Remote Sensing, 12, 809. https://doi.org/10.3390/rs12050809

[11] Reyes-Carmona, C., Galve, J.P., Moreno-Sánchez, M, Riquelme, A., Ruano, P., Millares, A., Teixidó, T., Sarro, R., Pérez-Peña, J.V., Barra, A., Ezquerro, P., López-Vinielles, J., Béjar-Pizarro, M., Azañón, J.M., Monserrat, O., Mateos, R.M. (2021). Rapid characterisation of the extremely large landslide threatening the Rules Reservoir (Southern Spain). Landslides. https://doi.org/10.1007/s10346-021-01728-z