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PSI-BASED TIME SERIES ANALYSIS EXPLOITING COPERNICUS SAR IMAGES FOR MONITORING KOURIS DAM IN CYPRUS

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ABSTRACT

Kouris dam is the main water reservoir in Cyprus, located in Limassol, transferring water from the western part of Troodos mountains to the eastern part of the island, both for domestic and irrigation use. It is a 113 m high zoned earthfill dam with a central clay core. Since its construction, in 1988, it has overflown three times in 2004, 2012 and 2020. Therefore, the need for its continuous inspection is of great importance for safety reasons. For the detection of surface deformation in Kouris dam, the Persistent Scatterers Interferometry technique was applied on 167 Sentinel-1 images from 2015 to 2023. The InSAR time-series processing revealed small-scale displacements on the downstream slope of the dam with a maximum rate of -5mm/y. The LOS displacements were validated by geodetic measurements, provided by the Water Development Department of Cyprus. This can serve as a valuable tool for risk assessment and mitigation.

Index Terms— dam monitoring, remote sensing, risk mitigation, persistent scatterers interferometry, Kouris dam

1. INTRODUCTION

The Republic of Cyprus as an island located in the Eastern Mediterranean basin, has a semi-dry climate, and is greatly affected by Climate Change, leading to long periods of drought and short periods of rainfall and limited surface runoff [1, 2]. This in turn leads to water scarcity affecting the population countrywide with the people living in city centers being impacted the most [3, 4]. To mitigate this, among other water resource management schemes, water reservoirs and dams have been constructed throughout the island [5, 6].

The Water Development Department (WDD) is responsible for the protection and sustainable development as well as the rational management of the water resources of Cyprus for various uses, in accordance with European and National legislation [5].

Currently, Cyprus has 108 dams, 56 of which are included in the Register of the International Committee on Large Dams (ICOLD) [7], with a total approximate water storage capacity of 327 million m^3 [5]. Of these, 21 dams have an overall water storage capacity of 300.06 million m^3, with the greatest one in terms of water storage capacity being Kouris dam (Figure 1), built in 1988 in Limassol District, with an overall water storage capacity of 115 million m^3 [5].

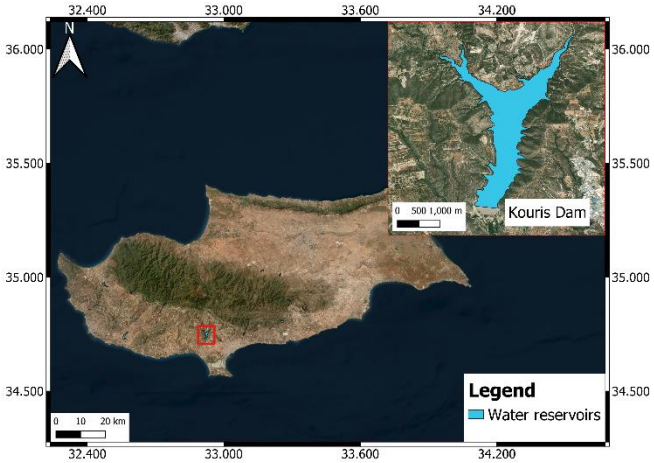

Figure 1. Digitized map of water reservoirs in Cyprus [8].

Due to the aging of critical infrastructure and based on the needs of the WDD to systematically monitor dams nationwide, the present study presents a Persistent Scatterer Interferometry (PSI) time series analysis of Sentinel-1 SAR images using archive data for the period 2015-2023 with the

main focus on Kouris dam. The line of sight (LOS) displacements identified subsidence on the downstream slope of the dam, with a -5mm/y velocity rate.

2. DATA AND METHODS

For monitoring surface deformation in Kouris dam, a nine-year time period was studied from October 12, 2015, to July 14, 2023. 167 Sentinel-1 images of descending satellite pass no. 167 were processed with PSI to assess surface instabilities in Kouris dam. For the processing of Sentinel-1 images a parallelized version of the Persistent Scatterers Interferometry, the so-called P-PSI [9], was employed. The P-PSI is an automated, parallelized processing chain, developed by the Operational Unit BEYOND Center for Earth Observation Research and Satellite Remote Sensing of the Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS) of the National Observatory of Athens (NOA), dedicated to assessing line of sight surface displacements on big EO data.

The creation of the interferometric stack is performed with ISCE [10, 11] software and InSAR time-series analysis with StaMPS [12] software. Interventions to automate and speed-up the processing time, are implemented on both software. The estimation of atmospheric contributions in the final SAR product, is performed with the open-source Toolbox for Reducing Atmospheric InSAR Noise (TRAIN) [13].

The Water Development Department has been systematically monitoring the dam through geodetic measurements since 1990. Historical data for the period 2015-2023 are used for the verification of the LOS displacement results obtained through the PSI satellite image processing.

3. RESULTS

The estimation of LOS displacements in Kouris dam, identified surface deformation on the downstream slope of the dam. Figure 2 presents LOS displacements away from the satellite with a maximum value of -5mm/y. A 3D view of the deforming scatterers identified on the dam is provided in Figure 3. To further analyze instabilities in Kouris dam, a time-series plot was generated for selected scatterers, included in the area with the maximum LOS displacement rates. In the time-series analysis plot in Figure 4, scatterers on the downstream slope of the dam are experiencing subsidence. The causes triggering the deformations should be urgently studied as these could be either caused by harmless consolidation phenomena or by dangerous sliding movements or piping phenomena.

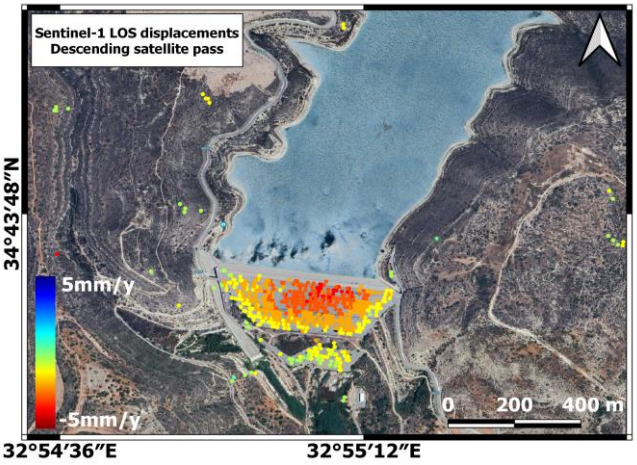

Figure 2. Sentinel-1 line of sight displacements in Kouris dam from 2015 to 2023.

Figure 3. 3D view of Sentinel-1 line of sight displacements in Kouris dam from 2015 to 2023.

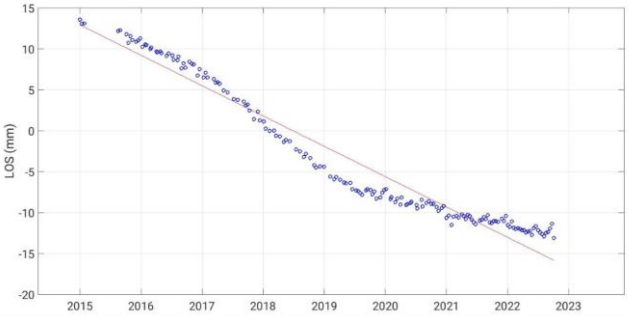

Figure 4. Time-series plot for selected scatterers identified in the deforming dam area.

4. DISCUSSION

The verification of the LOS displacements that were estimated via PSI techniques on Sentinel-1 data, is performed

using archive geodetic measurements, that were kindly provided by the Water Development Department of Cyprus. These measurements are collected systematically over six (6) points, i.e., the Embankment Crest Movement Indicators (E.C.M.I), located on the roadway at the embankment crest. The vertical and horizontal motion trends in these six points over the period 2015-2023 are presented in Figures 5 and 6 respectively.

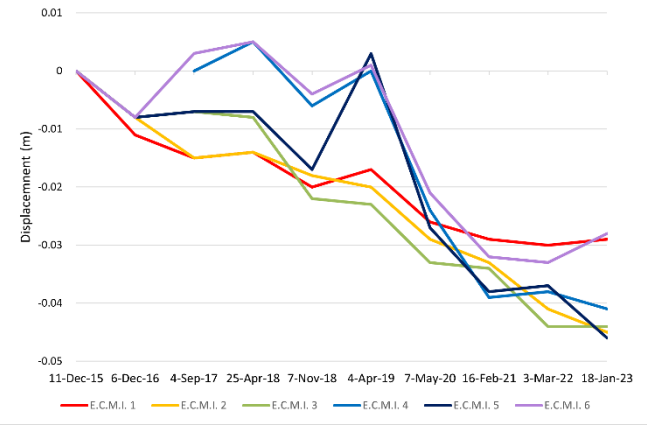

Figure 5. Vertical displacement trends from geodetic measurements on six points located at Kouris dam crest over the period 2015-2023.

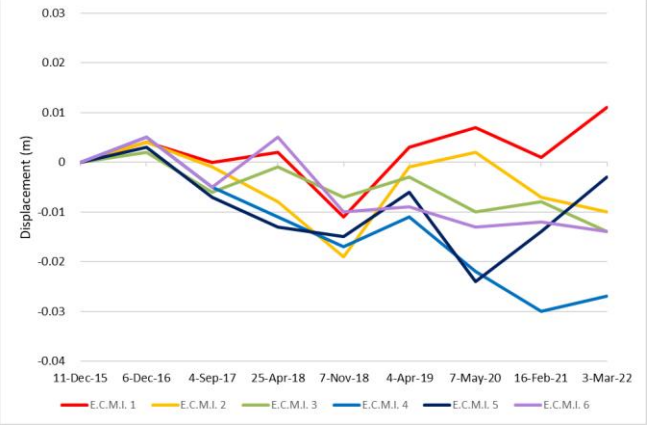

Figure 6. Horizontal displacement trends from geodetic measurements on six points located at Kouris dam crest over the period 2015-2023.

As presented in Figure 5, the vertical displacement rate is the same in all 6 points located on the roadway at the Kouris dam embankment crest. Accordingly, in Figure 4, negative InSAR LOS displacements in the dam crest are also present in the time-series plots of the geodetic measurements. The horizontal motions present differences in the displacement rates. Points 1-3 show horizontal motion stability while points 4-6 experience horizontal movements with an increasing rate. Horizontal movements in 4-6 are probably attributed to landslide phenomena.

It is worthwhile noticing that negative LOS displacements observed by InSAR and validated by geodetic measurements, require further investigation, to identify the triggering factors of the observed deformation phenomena and their correlation with InSAR displacements. Future work will focus on a detailed analysis and integration of InSAR and geodetic measurements in Kouris dam, to assess dam stability and dam safety.

5. CONCLUSIONS

InSAR time-series analysis was implemented on Sentinel-1 SAR images from 2015 to 2023 to monitor instabilities in Kouris dam, in Cyprus. Some first results, present small-scale subsidence in the downstream slope of the dam with a maximum rate of -5mm/y. The InSAR LOS displacements were validated by ground-truth data, provided by the Water Development Department of Cyprus. Since Kouris dam is the biggest dam in Cyprus, with the largest water capacity, continuous monitoring with remote sensing techniques and the addition of ground truth data, can serve as a valuable tool for risk assessment and mitigation, and is of great significance for the safe operation of the dam and the safety of people and properties located downstream.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] H. Beck, N. Zimmermann, T. McVicar, N. Vergopolan, A. Berg, and E.F. Wood, Present and future Köppen-Geiger climate classification maps at 1-km resolution., Scientific Data 5, 2018.

[2] M.C. Peel, B. L. Finlayson, and T. A. McMahon, Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 2007.

[3] A. Sofroniou, and S. Bishop, Water Scarcity in Cyprus: A Review and Call for Integrated Policy. Water, 2898-2928, 2014.

[4] T. Zachariadis, Residential Water Scarcity in Cyprus: Impact of Climate Change and Policy Options. Water, 788-814, 2010.

[5] Ministry of Agriculture, Rural Development and Environment, Water Development Department. (https://www.moa.gov.cy)

[6] C. Papadaskalopoulou, C. Giannakopoulos, G. Lemesios, M. Zachariou-Dodou, and M. Loizidou, Challenges for water resources and their management in light of climate change: the case of Cyprus, Desalination and Water Treatment, 3224-3233, 2015.

[7] International Commission On Large Dams, (https://www.icold-cigb.org/GB/world_register/world_register_of_dams.asp)

[8] Geoportal of Water Development Department in Cyprus. (https://geoportal-wdd.hub.arcgis.com/)

[9] I. Papoutsis, C. Kontoes, S. Alatza, A. Apostolakis, C. Loupasakis, InSAR Greece with Parallelized Persistent Scatterer Interferometry: A National Ground Motion Service for Big Copernicus Sentinel-1 Data, Remote Sensing, 2020.

[10] P.A. Rosen, E. Gurrola, G.F. Sacco, H. Zebker, The InSAR scientific computing environment. In Proceedings of the EUSAR 9th European Conference on Synthetic Aperture Radar, Nuremberg, Germany, 23–26 April 2012.

[11] H. Fattahi, P. Agram, M. Simons, A network-based enhanced spectral diversity approach for TOPS Time-Series Analysis. IEEE Trans. Geosci. Remote Sens., 55, 777–786. 2017.

[12] A. Hooper, H. Zebker, P. Segall, B. Kampes, A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. Geophys. Res. Lett., 31, L23611, 2004.

[13] D.P.S Bekaert, R.J. Walters, T.J Wright, A.J. Hooper, D.J. Parker, Statistical comparison of InSAR tropospheric correction techniques. Remote Sens. Environ., 170, 40–47, 2015.