Abstract code: EO3

Landslide susceptibility analysis exploiting Persistent Scatterers data in the northern coast of Malta

M. Mantovani[1], D. Piacentini[2], S. Devoto[3], M. Prampolini[2], A. Pasuto[1] and M. Soldati[2]

[1] CNR-IRPI, Corso Stati Uniti 4, 35127 Padova, Italy.
[2] Department of Chemical and Geological Sciences University of Modena and Reggio Emilia, Largo Sant' Eufemia 19, 41121 Modena, Italy.
[3] Department of Mathematics and Geoscience University of Trieste, Via Weiss 2, 34127 Trieste, Italy.

Corresponding author details:
Matteo Mantovani, CNR-IRPI, Corso Stati Uniti 4, 35127 Padova, Italy.
e-mail: matteo.mantovani@irpi.cnr.it
Tel. (+39) 049 8295801
Fax (+39) 049 8295827

Keywords
Landslides, Susceptibility, Persistent Scatterers Interferometry, Weight of Evidence Analysis, Malta

Extended Abstract

INTRODUCTION

The increased frequency of extreme meteorological events has recently led to face a considerable number of hydrogeological emergencies. However, the rising toll of death and destruction, often ascribed to the supposed impact of climate change, is also the direct consequence of population and economic growth. Constructions of new settlements and infrastructures in hazard-prone areas have therefore to be accounted. These are the main reasons why nowadays we are more vulnerable to catastrophic natural events, such as landslides, and explain the requests of land planning and civil protection authorities to work with more adequate tools than in the past.

Monitoring is essential both in the surveillance of the territory and in the management of the emergencies, since it contributes to decrease the vulnerability of the elements at risk. The major role recently played by monitoring systems is strictly connected to the development of innovative and sophisticated technologies. Among these PSI (Persistent Scatterers Interferometry) technique certainly represents one of the most recognized method to monitor ground surface deformations over large areas with unprecedented accuracy (Ferretti et al., 2001).

Every monitoring system suffers from technical limitations and has some methodological boundaries. Using PSI approaches it is possible to measure deformations affecting natural point-like radar reflectors. We can assess the state of activity of gravitational processes from sparsely distributed targets, but no information can be extracted from reflector-less areas.

In order to circumvent this limitation, we propose a novel approach that exploits the quantitative measurements of the PSI analysis to train a statistical model targeted to the generation of susceptibility maps.

The idea founds upon a way to reduce the overall landslide vulnerability of a region coupling remote sensing measurements, ancillary data, and a Bayesian approach, known as Weight of Evidence (WofE). Since it would be impossible to detect all the active landslides at a regional scale, we tried to assess where they are likely to occur.

We tested this novel approach to the north-western sector of the Island of Malta which is affected by numerous coastal landslides.

STUDY AREA

Malta is the main island of the Maltese archipelago, located in the central Mediterranean Sea between Sicily (Italy) and northern Africa (Figure 1).

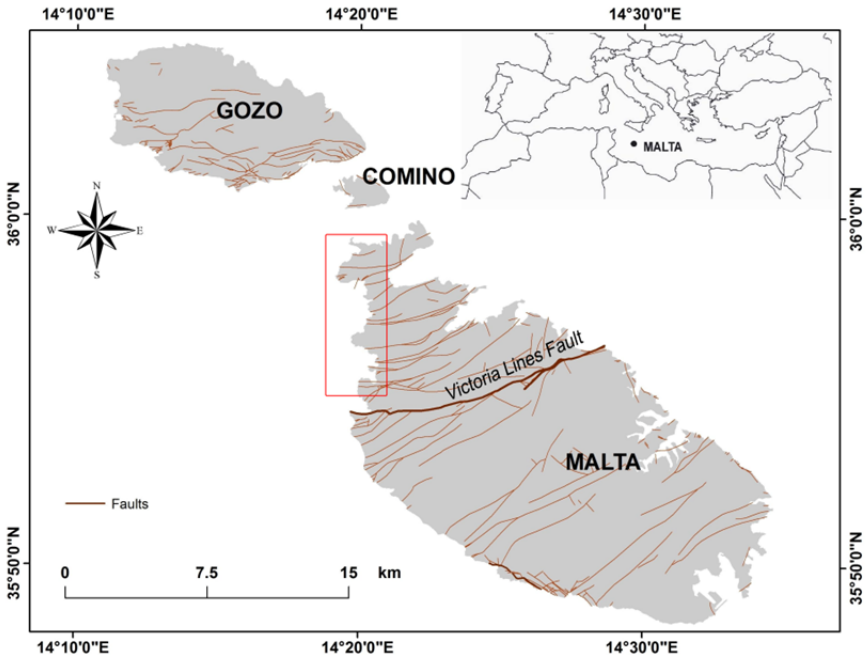

Figure 1. The Maltese Archipelago. The study area is highlighted by a red box.

Malta is crossed by a ENE-WSW oriented tectonic discontinuity, named Victoria Lines fault, which structurally divides the island in two sectors. Northward the occurrence of Upper Coralline Limestone Formation overlaying Blue Clay Formation (Pedley and Clarke, 2002), characterizes a horst-and-graben morphology. Southward the Lower Coralline Limestone Formation, which is the older geological unit, is responsible for forming spectacular sea cliffs, some reaching 140 m in height, which bound the island especially in the west (Magri et al., 2008).
The study area is located in the northern part and covers approximately 11 km^2. In this sector, the combination of structural and karst processes in addition to the different geotechnical properties between limestones and underlying clays (Dykes, 2002) favours the occurrence of extensive landslides (Mantovani et al., 2013), which are rare south of Victoria Line fault (Figure 2). Devoto et al. (2012) recognised and classified approximately 86 landslides.

Figure 2. Rock spreading and block sliding north of Victoria Lines fault (A, B) and Lower Coralline Limestone cliffs southward (C, D).

METHODOLOGY

The PSI analysis was performed using the IPTA (Interferometric Point Target Analysis) algorithm (Werner et al., 2003). We processed 50 ERS and 33 ENVISAT ASAR images acquired between 1992-2009 over the same descending track (494-frame 2889). Figure 3 sums up the results of the PSI analysis in terms of colour coded deformation rates for each persistent scatterer position. Several stretches of the north western coast of the island are affected by deformations (estimated along the line of sight of the sensor) that in average reaches a rate of 5 mm/yr for the most actives, with peaks of 20 mm/yr.
We isolated 115 natural reflectors located over the slopes with an aspect angle congruent with the line of sight of the sensor (from 270° to 315°). These were divided into two sets: a training set (60% of the total), for the statistical analysis, and a validation set (40% of the total) to evaluate the success rate of the method.
We used the Weight of Evidence method (Guzzetti et al., 1999; Piacentini et al., 2012) to analyse the relationship between the supporting evidence provided by the PSI data and factors that could be considered as predisposing to coastal landslides. These were identified in terms of distances of the radar targets from the faults, from the scarps, from the joints and from the coastline. We also analysed several morphometric factors such as the slope angle, the curvature and the Topographic Position Index. Weights were assigned to each factors' class and validated for every single factor. We investigated 14 different combinations of factors (Table 1).

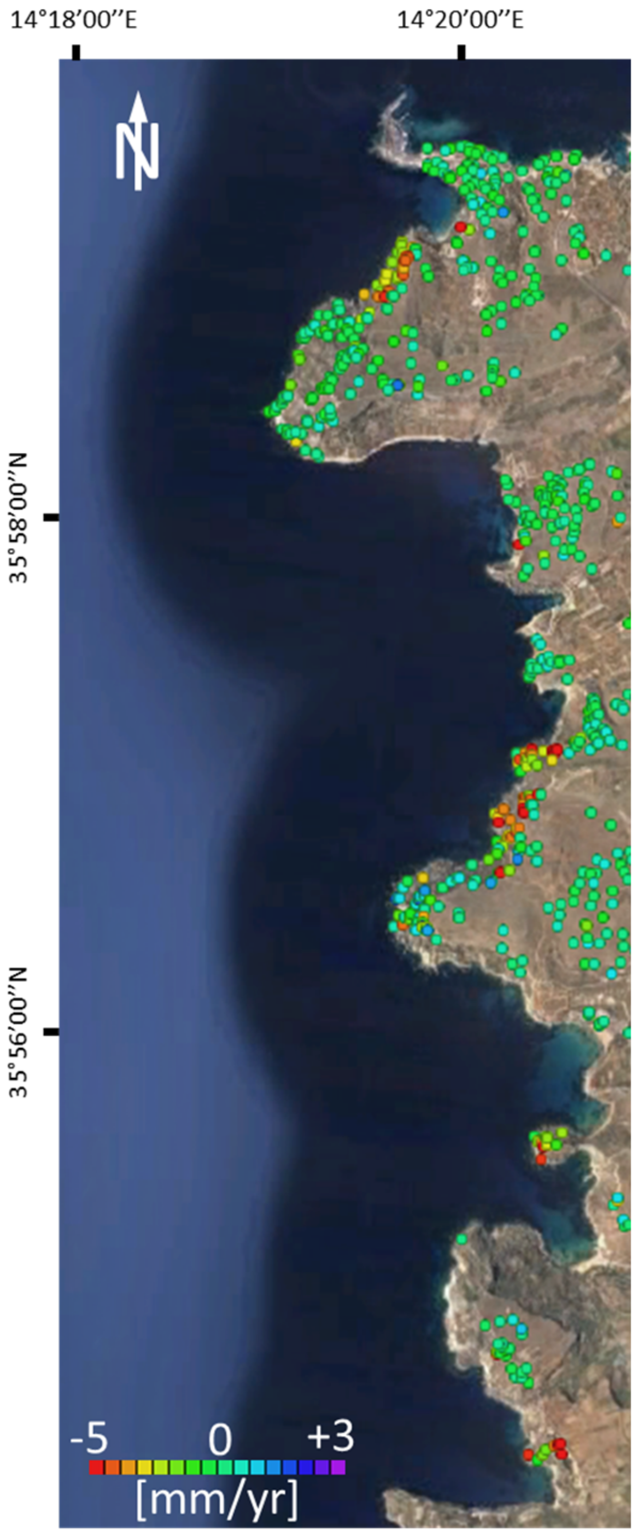

Figure 3. Results of the PSI analysis in terms of colour coded line of sight deformation rates.

The best statistical performance, obtained combining 6 of the above mentioned predisposing factors, resulted in success rate curve with a reliability of 95% (i.e. the capability of the model to describe the distribution of landslides). This combination was used to create the final susceptibility map.

Table 1. AUC (Area Under Curve) values of the best 14 combinations. Higher the value of AUC better the capability of the model to describe the distribution of landslides. The factors considered are: curvature (CU), distance from faults (F), distance from joints (J), distance from coastline (CO), distance from scarps (SC), slope angle (SL), and Topographic Position Index for cells of 3, 5, 10 meters respectively (TPI3, TPI5, TPI10).

Combination n.	Predisposing Factors	ACU
1	J, SC, CO, TPI3, TPI5, TP10	0.95
2	J, SC, CO, TPI3	0.94
3	J, SC, CO, TPI5	0.94
4	J, SC, CO, TPI10	0.94
5	J, SC, CO, TPI3, TPI10	0.94
6	J, SC, CO, TPI3, TPI5, TPI10, CU	0.94
7	J, SC, CO, TPI3, TPI5, TPI10, F	0.94
8	J, SC, CO, TPI3, TPI10, CU	0.94
9	J, SC, CO	0.93
10	J, SC, CO, SL	0.93
11	J, SC, CO, TPI3, SL	0.93
12	J, SC, CO, TPI3, TPI5, TPI10, SL	0.93
13	J, SC, CO, TPI3, TPI5	0.93
14	J, SC, SL	0.90

Counting the number of cases correctly classified by the model, the points included in the validation set are distributed with respect to the susceptibility classes as follow: 0% on the very low class, 18 % on the low class, 10 % on the medium class, 21 % on the high class and 41 % on the very high class. It is noteworthy that approximately 41% of the total moving PSI falls into the very high class, which occupies just the 2% of the total area (Figure 4).
Geomorphological investigations carried out in the study area allowed to confirm the output of the model, with a satisfying fitting between the inventoried block slides and the spatial distribution of high or very high susceptibility class.

CONCLUSIONS

Nowadays PSI is the only technique that can quantitatively assess the state of activity of landslides at a regional scale with an acceptable cost-efficiency ratio. Yet, due to well-known technical limitations, is not possible to detect all the active landslides within the framed area. Instead of coping with the methodological boundaries of the PSI technique, our approach circumvents the problem and focuses on the outcomes of the interferometric analysis.
The idea founded upon a way to reduce the overall landslide vulnerability of a region from sparsely distributed deformation measurements, inferring the results to the entire image frame. Exploiting the quantitative effects over a set of natural point-wise radar target, we trained a Bayesan model whose final product resulted in a map of potential unstable areas. We tested the model over the northern part of the island of Malta, where dozens of landslides affect the coast. Using ancillary data, acquired from former investigations, we selected the predisposing factors of the WofE analysis and validated the results.
We demonstrated that the resulting susceptibility map is consistent and accurate. We proved that this novel approach can provide reliable data to perform a successful statistical analysis and can overcome the limitations inherent the possibility to extract “supporting evidences” from the available inventory maps. This methodology is nowadays of particular interest and for sure it will be in the next future since the latest space-borne interferometric mission (e.g. Sentinel) can constantly provide updated and accessible training datasets at a regional scale for statistical models.

Susceptibility maps are helpful in land management, can assist in hazard mitigation and decrease the vulnerability. The outcomes of this study aimed at reducing the landslide risk over the coast of Malta.

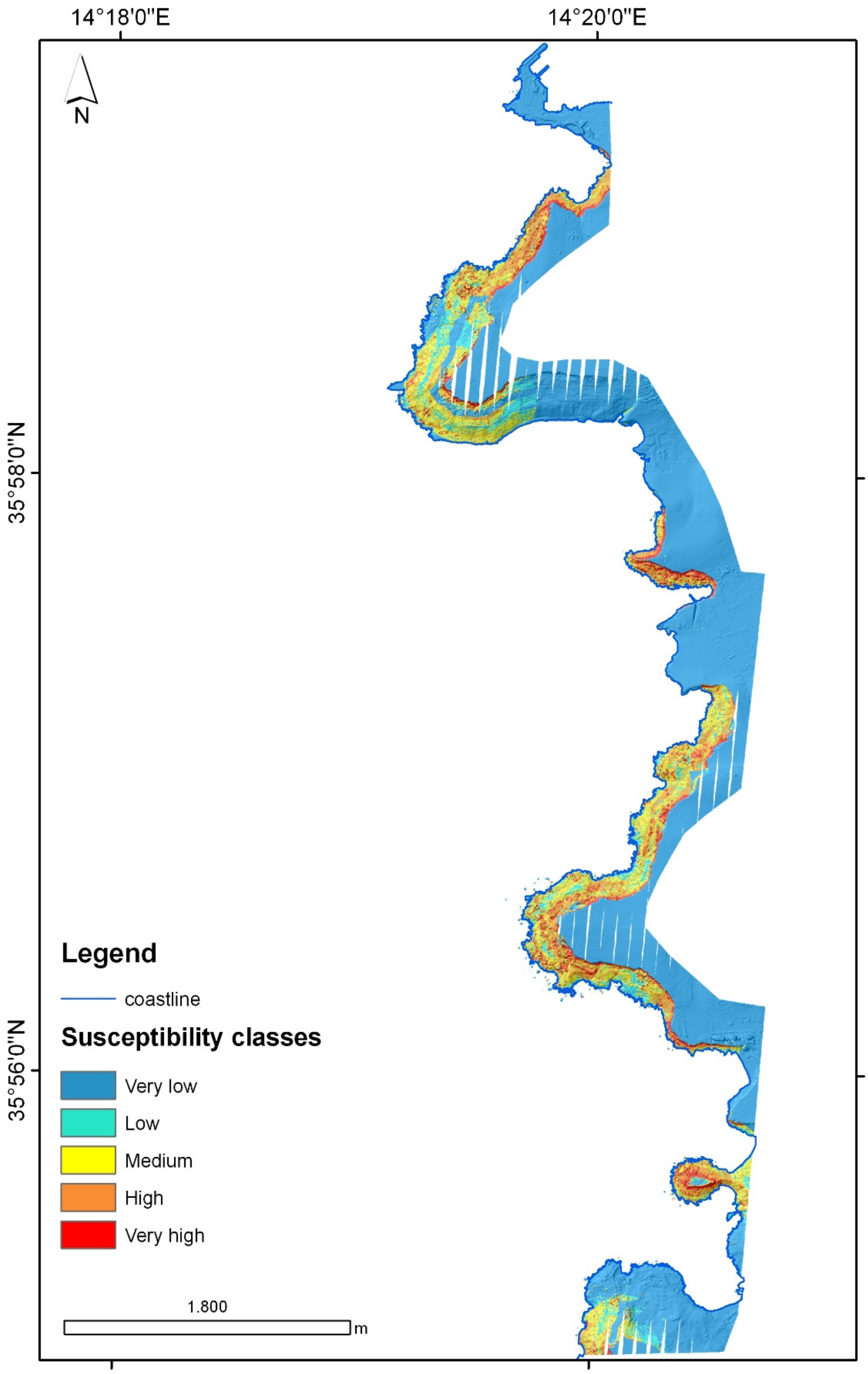

Figure 4. Susceptibility map of the north-western coast of Malta.

AKNOWLEDGMENTS
The authors acknowledge European Space Agency for providing ERS and ENVISAT radar images (C1P.7044). SAR processing was performed using Gamma Software. The research is part of a project of the Euro-Mediterranean Centre on Insular Coastal Dynamics (ICoD) funded by the EUR-OPA Major Hazards Agreement of the Council of Europe (2013-2014).

REFERENCES
Devoto S, Biolchi S, Bruschi VM, Furlani S, Mantovani M, Piacentini D et al (2012) Geomorphological map of the NW Coast of the Island of Malta (Mediterranean Sea). Journal of Maps, 8(1), 33-40.
Dykes A. (2002) Mass movements and conservation management in Malta. Journal of Environmental Management, 66(1), 77-89.
Ferretti A, Prati C, Rocca F (2001) Permanent scatterers in SAR interferometry. Geoscience and Remote Sensing, IEEE Transactions on, 39(1), 8-20.
Guzzetti F, Carrara A, Cardinali M, Reichenbach P (1999) Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. Geomorphology, 31(1), 181-216.
Magri O, Mantovani M, Pasuto A, Soldati M (2008) Geomorphological investigation and monitoring of lateral spreading along the north-west coast of Malta. Geografia Fisica e Dinamica Quaternaria, 31(2), 171-180.
Mantovani M, Devoto S, Forte E, Mocnik A, Pasuto A, Piacentini D et al (2013) A multidisciplinary approach for rock spreading and block sliding investigation in the north-western coast of Malta. Landslides, 10(5), 611-622.
Pedley M, Clarke MH (2002) Limestone Isles in a Crystal Sea: the geology of the Maltese Islands. Publishers Enterprises Group.
Piacentini D, Troiani F, Soldati M, Notarnicola C, Savelli D, Schneiderbauer S et al (2012) Statistical analysis for assessing shallow-landslide susceptibility in South Tyrol (south-eastern Alps, Italy). Geomorphology, 151, 196-206.
Werner C, Wegmuller U, Strozzi T, Wiesmann A (2003) Interferometric point target analysis for deformation mapping. In Geoscience and Remote Sensing Symposium, 2003. IGARSS'03. Proceedings. 2003 IEEE International (Vol. 7, pp. 4362-4364). IEEE.