ICoD – Euro-Mediterranean Centre on Insular Coastal Dynamics / Malta

Council of Europe

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Created in 1987, the European and Mediterranean Major Hazards Agreement (EUR-OPA) is a platform for co-operation between European and Southern Mediterranean countries in the field of major natural and technological disasters. Its field of action covers the knowledge of hazards, risk prevention, risk management, post-crisis analysis and rehabilitation.

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Project 2014-2015

Coastal landslide susceptibility mapping: a case study from the Island of Malta

A research carried out in the framework of the EUR-OPA Major Hazards Agreement Project "Coupling terrestrial and marine datasets for coastal hazards assessment and risk reduction in changing environments" by:

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Abstract:

Coastal areas are often characterized by high density population and increasing urbanization especially due to tourist activities. For this reason recognition and assessment of active coastal processes plays a key role in land-use planning and risk mitigation. Landslides are among the most hazardous processes along the Mediterranean coasts. Therefore landslide susceptibility assessment becomes crucial for the safety of visitors, buildings and infrastructures. A landslide susceptibility evaluation was performed along the NW coast of Malta which can be considered as an open-air laboratory for the investigation of mass movements.

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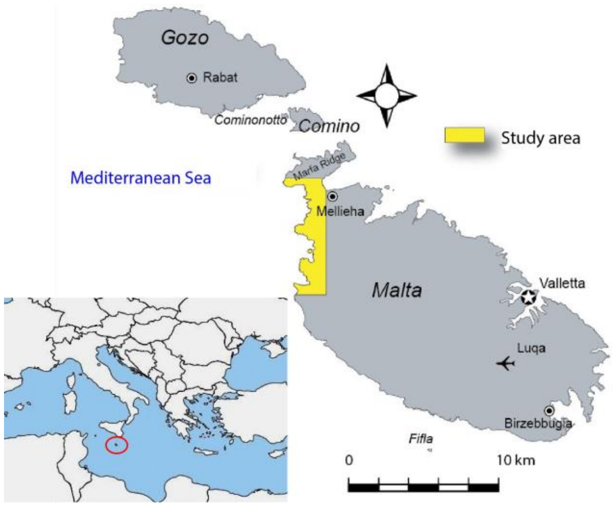
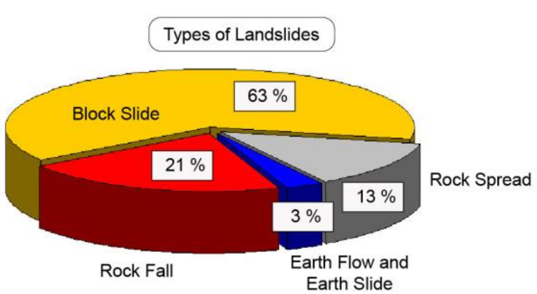
Coastal landslide susceptibility mapping: a case study from the Island of Malta



Location of the Maltese archipelago in Europe and the study area.



Distribution of landslide types along the NW coast of Malta with respect to the total surface affected by slope instability (Devoto et al., 2013).

Context: The Project "Coupling terrestrial and marine datasets for coastal hazards assessment and risk reduction in changing environments" of the EUR-OPA Major Hazards Agreement was focused on risk reduction in coastal areas through the development of coastal susceptibility and hazard mapping procedures, including the impact of sea level rise on coastal processes as a useful basis for multi-hazard assessment.

One of the deliverables of the Project was devoted to test and apply a methodology for landslide susceptibility assessment along the north-western coast of Malta (Central Mediterranean Sea).

Landslide susceptibility is understood as the spatial probability of landslide occurrence based on conditional factors. This evaluation constitutes the basis for the assessment of *landslide hazard* which can be defined as the probability of occurrence of a landslide of a certain intensity within a given area and in a given period of time (Varnes, 1984).

The study area is affected by landslides of different type and size. Attention was focused on block slides which are the most widespread type of landslide along the NW coast of Malta. They occur as the evolution of rock spreading affecting limestone plateaus overlying clayey terrains. Long-term monitoring of their displacement is crucial to better understand their kinematics. The results of a decade of measurements (Mantovani et al., 2013; Devoto et al., 2015) were exploited in order to define an automatic method for landslide susceptibility assessment that could be applied also in other coastal areas.

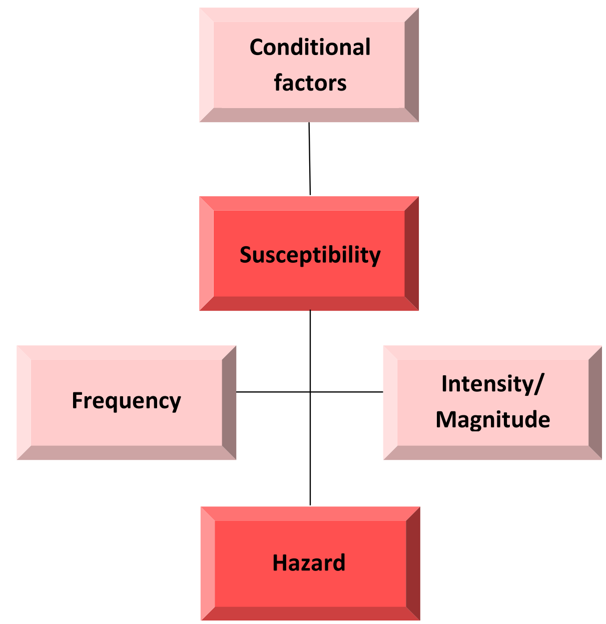


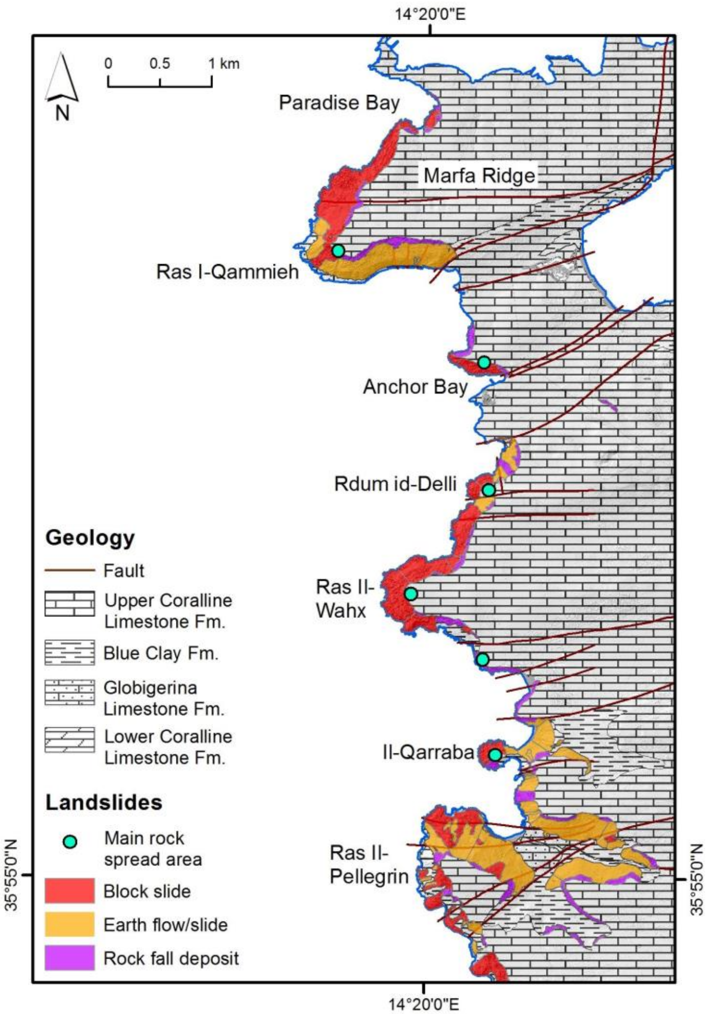
Diagram showing the components of landslide susceptibility and hazard.

Methodology principles

In literature a number of different methods are described to produce landslide susceptibility maps which are comprised within the so-called (1) heuristic methods, (2) statistical methods, (3) deterministic methods. In this study a statistical method was applied that allows an automatic, repeatable and objective definition of the areas most prone to landsliding. The approach is based on the assumption that "future landslides will occur under similar conditions to those contributing to previously occurred landslides and that predisposing [conditional] factors remain constant over time" (Piacentini et al., 2015 and references therein).

The innovative aspect of this method consists on the measurement of mass movement displacements from satellite images and the successive exploitation of the outcomes as input data of the susceptibility model, instead of using landslide inventories which are generally cost and time consuming. The Weight of Evidence (WofE) statistical model has been applied by means of the GIS extension ArcSDM (Sawatzky et al., 2009). The WofE is an established methodology usually exploited in the context of multidisciplinary risk assessment; for instance US EPA Guidelines reported since the '80s the WofE as a component to evaluate health risk (Linkov et al., 2009 and references therein). On the other hand, the employment of PSI as input to implement susceptibility models has been applied only recently by Oliveira et al. (2014).

The procedure used to train and validate the susceptibility model consists of 4 steps: (1) identification of active mass movements; (2) selection of factors contributing to slope instability (conditional factors); (3) elaboration of the susceptibility map; (4) validation of results.

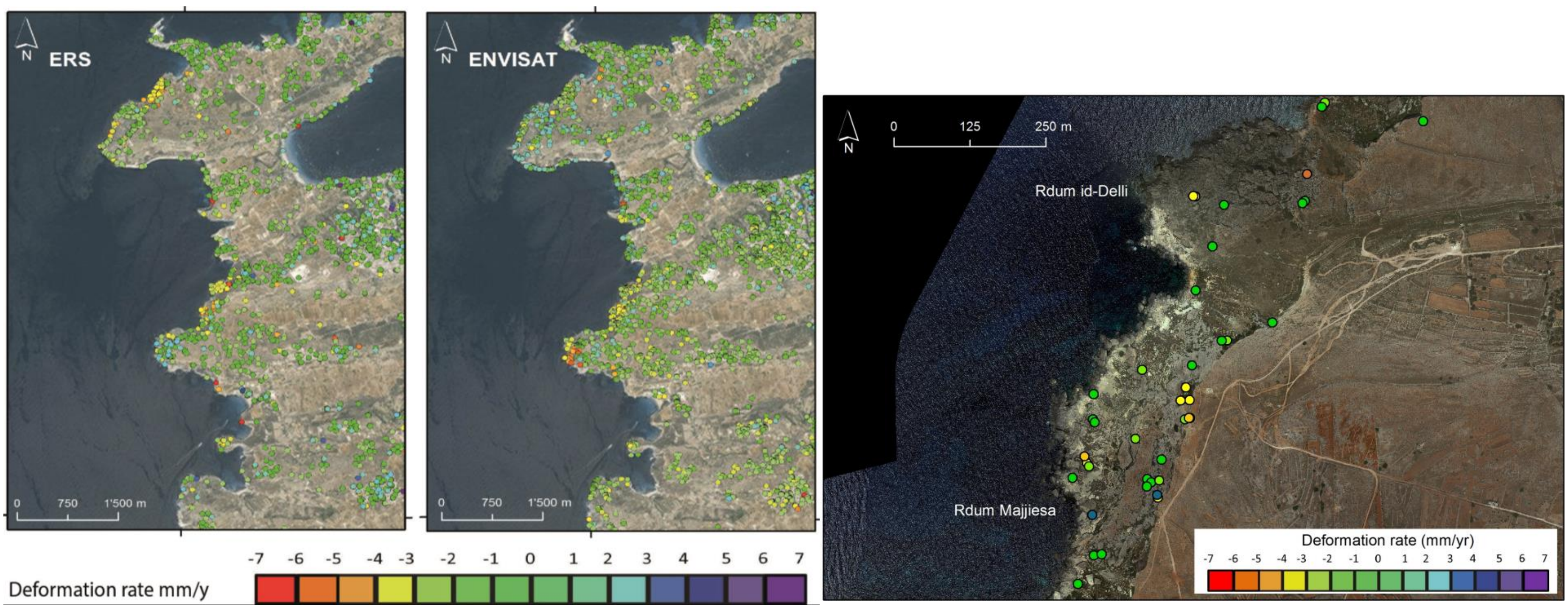


Simplified geological sketch and landslides distribution along the NW coast of Malta.

On the left, block slides south of Rdum id-Delli; on the right, block slides at Marfa Ridge.

Identification of active landslides

The identification of the active landslides is the first step to obtain a susceptibility map. This was made with the aid of the Persistent Scatter Interferometry (PSI) technique. The latter requires the detection of the so-called Persistent Scatters (PS) which are natural point-like reflectors visible by the satellite during its periodical passage above the study area. The PS are located on the detached blocks which slowly move downhill within the block slide deposits. The PS showing a displacement rate higher than 1 mm/year were considered as representative of active landslides. 60% of the identified PS was used for the statistical analysis and remaining 40% for its validation.



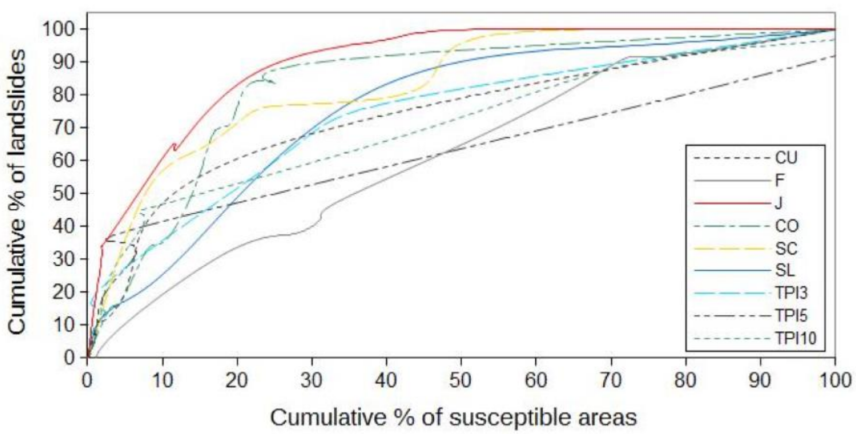
PSI analysis results of ERS and ENVISAT datasets (modified from Piacentini et al., 2015) and detail of the location of active PS on limestone blocks within the landslide deposits. Negative values correspond to an increase of the distance between blocks and satellite (i.e. block lowering) and positive values to a decrease of that distance (i.e. block uplift).

Selection of factors contributing to slope instability

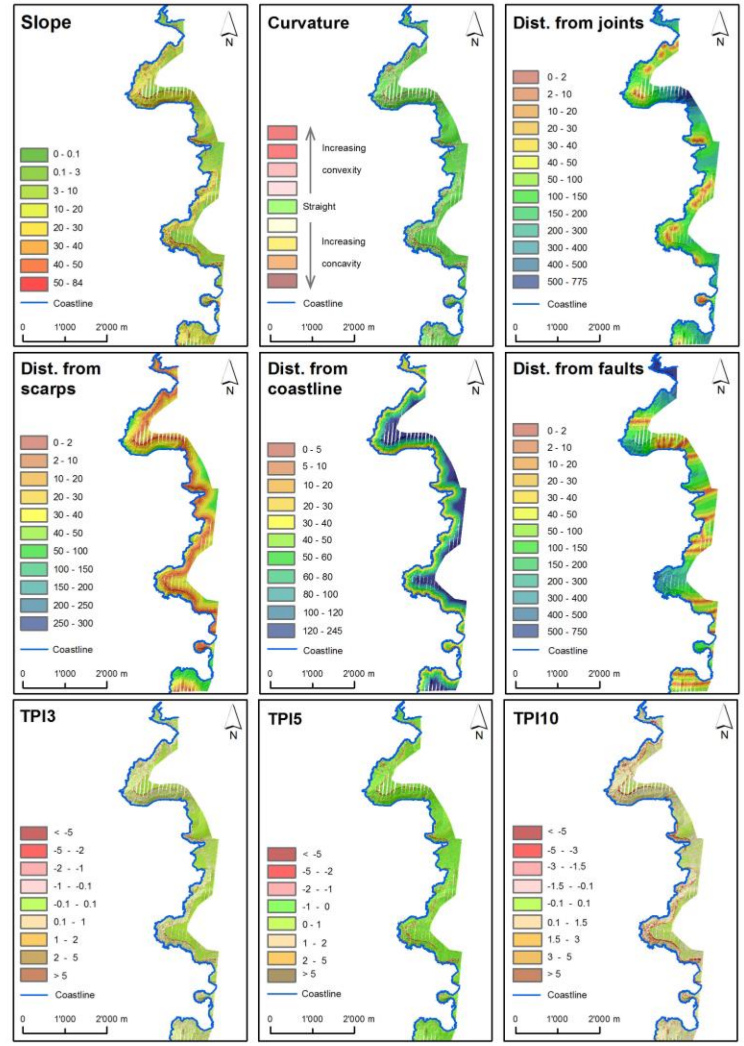
The selection of conditioning (i.e. predisposing) factors to block sliding was based on morphometric indices (derived by a Digital Elevation Model) and data collected by means of geomorphological observations (cf. Devoto et al., 2012).

The selected factors are:

- Slope (SL)
- Curvature (CU, quantitative description of the landforms)
- Topographic Position Index (TPI, quantitative description of topography)
- Distance of the landslide from coastline (CO)
- Distance of the landslide from scarps (SC)
- Distance of the landslide from faults (F)
- Distance of the landslide from joints (J)



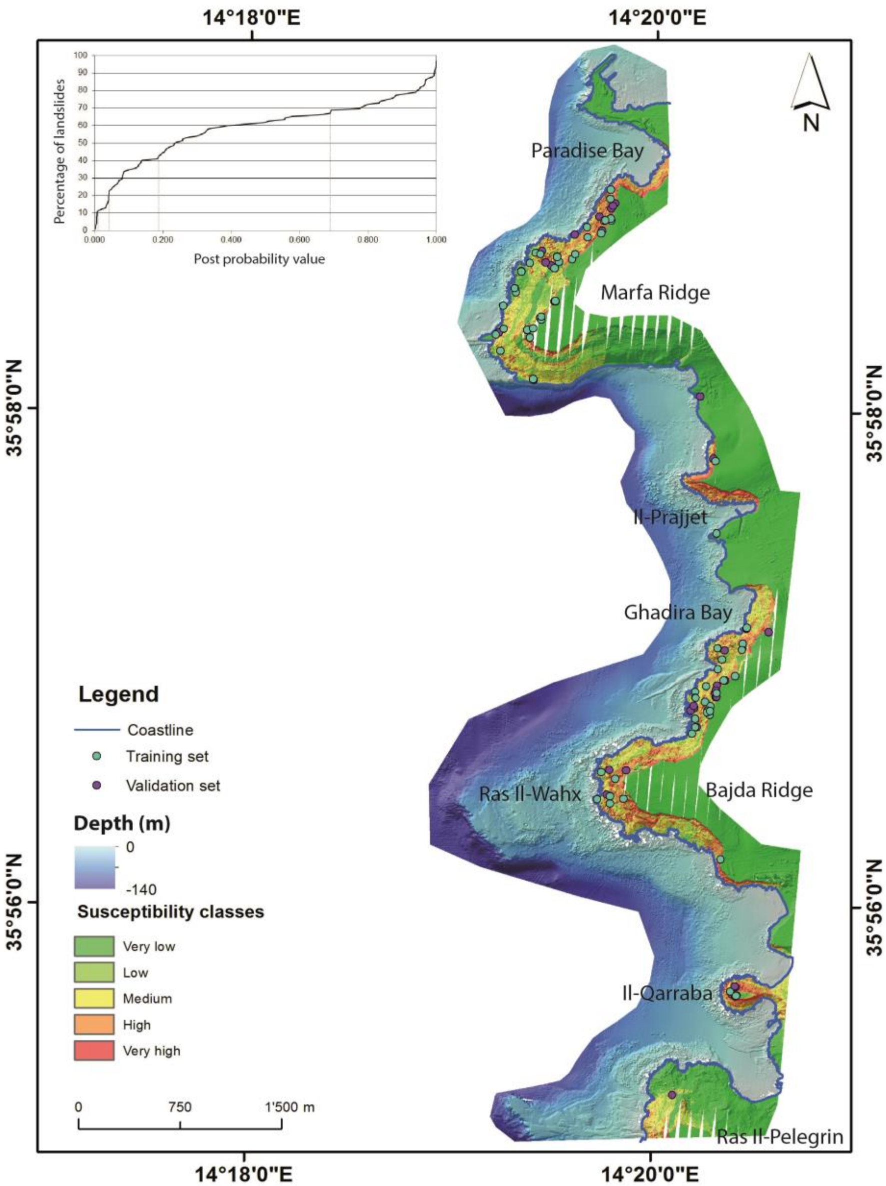
On the right, the dataset of the conditioning factors; on the left, their prediction rate curves which are descriptive of their contribution to landslide susceptibility (Piacentini et al., 2015).



Once the input data and the conditional factors were selected, a weight to each factor's class was automatically assigned by means of WofE method according to its role in predisposing slope instability. Each factor was validated by means of prediction rate curve analysis observing a diagram where cumulative percentage of susceptible areas is plotted versus the cumulative percentage of landslides. The larger the Area Under the Curve (AUC), the greater the contribution of factors to landslide susceptibility. Several combinations of different factors were tested and their AUC values were compared. The one showing the highest AUC value was selected as the combination of factors the most favourable to block sliding: *distance from joints - distance from scarps - distance from coastline - Topographic Position Index considering a surrounding area of 3 (TPI^3) - 5 (TPI^5) - 10 (TPI^{10})m.*

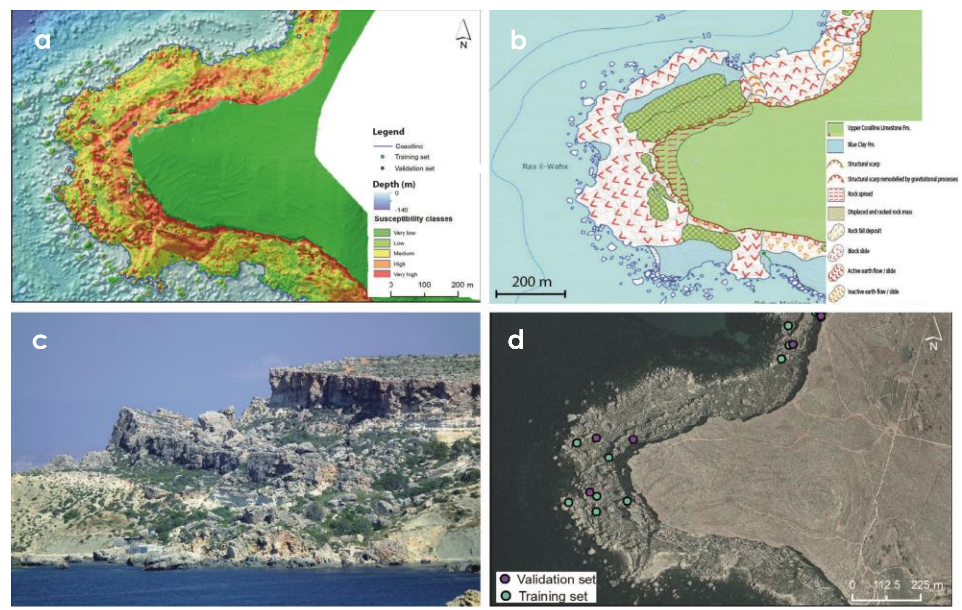
Implementation and validation of the susceptibility map

The WofE model was run using 60% of the PS and the selected combination of conditioning factors previously described was validated by means of remaining 40% of PS as independent information not included in the input dataset.



Block slide susceptibility map of the NW coast of Malta (from Piacentini et al., 2015).

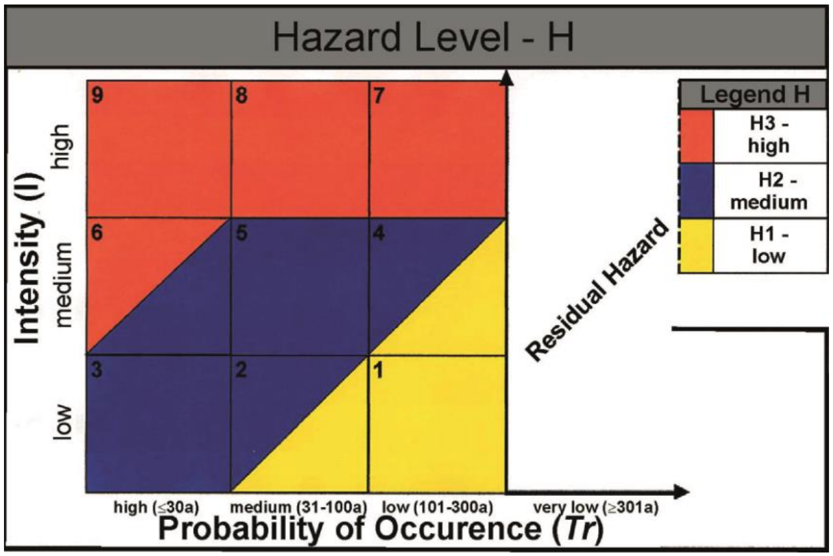
The output of the model was a landslide susceptibility map. This map was qualitatively compared with field-survey observations and the geomorphological map by Devoto et al. (2012). Finally a quantitative comparison between the susceptibility map and GPS measurements of surface displacements (Devoto et al., 2015 and references therein) was performed at Il-Prajjet (one of the most active sectors in the study area). The areas showing the highest displacement rates from GPS measurements were actually characterized by high or very high classes of landslide susceptibility.
The above mentioned validation tests revealed that the WofE statistical analysis is a reliable model for landslide susceptibility mapping.



Comparison between susceptibility map (a), geomorphological map (b), E-W view of Ras Il-Wahx promontory (c) and location of PS (d) (Piacentini et al., 2015).

Conclusion and further enhancements

The research carried out exploited a new approach that joins the WofE statistical method and outcomes of Persistent Scatter Interferometry analysis for the implementation of landslides susceptibility maps. This reliable, objective and cost- and time-effective strategy can be applied also in areas not directly accessible and without using landslides inventories.



BUWAL hazard matrix (Heinimann et al., 1998).

Further actions

Starting from landslide susceptibility assessment, the upcoming goal of the research is the evaluation of landside hazard (as defined by Varnes, 1984). Actually, landslide susceptibility maps provide the spatial probability of landslide occurrence without considering intensity and return time of the expected phenomena. However, since the latter are crucial to define possible dangers for population and infrastructures, it is paramount important to assess them within a wider landslide hazard evaluation. Several models are used to evaluate landslide hazard according to the type and quality of available data. The BUWAL matrix is proved to be an effective method for the implementation of hazard maps. So far it has been used especially in alpine areas (Heinimann et al., 1998), but preliminary checks have shown that it may be successfully used also in coastal areas. The BUWAL matrix combines phenomena intensity (velocity x thickness) with their return time by means of the matrix shown in the figure on left. The hazard maps produced with this methodology would constitute useful and comprehensible tools for local authorities.
A further step would be the evaluation of the effects of global climate changes on landslide processes. Models to predict the consequences of sea level rise, increase in extreme events and decrease in annual precipitation amount would be crucial for landslide hazard assessment in a dynamic environment.

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The Euro-Mediterranean Centre on Insular Coastal Dynamics (ICoD) forms part of a network of specialised Centres pertaining to the EUR-OPA Major Hazards Agreement of the Council of Europe. EUR-OPA is a platform for co-operation between European and Southern Mediterranean countries in the field of major natural and technological disasters.

Through an agreement between the Council of Europe and the government of Malta, ICoD was established in 1988 within the framework of the Foundation for International Studies at the University of Malta. Since its inception it has addressed various issues concerning the marine and coastal environment. More recently, the Centre has re-oriented its objectives and activities towards a greater focus on the interactive processes which occur within the coastal zone and, in particular, those concerning insular areas.