Pluvial-coastal flood hazard modelling and damage estimation for the central part of Malta Island

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Highlights

- Development of a 1D-2D hydrological/hydraulic model for the central part of the Malta Island
- Pluvial flood modelling combined with hydrostatic sea level rise
- Estimation of flood damages for different rainfall return periods and climate change scenarios

Introduction

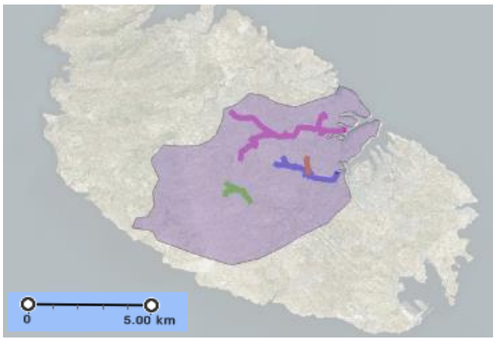
The Mediterranean area is likely to become one of the most vulnerable areas of the World in the very next decades concerning recent Climate Change projections. A significant increase in the number of extreme events, a decrease in the total amount of rainfall along the year as well as a tangible increment of the average temperature across the seasons are expected (IPCC 2014). In this context, the CRISI-ADAPT 2 Project, funded by the European Institute of Innovation & Technology (EIT) Climate-KIC, pretends to offer a portfolio of solutions to monitor and improve the adaptation planning through a real-time implementation and validation according to near and seasonal range climate risk forecasting. Malta is one of the four pilot cases (Valencia, Andalucía region, Cyprus) together with other eight receiving regions across Italy, Portugal and Spain. The Mediterranean Island provide an important case study for pluvial flash floods and storm surges with evident chances to see its vulnerability strongly affected by climate change in the very next decades. Despite a reasonable number of studies have been conducted (EWA 2010; EWA 2015; EWA 2021), Malta's flood problems persist (Flood 2018; Flood 2019), therefore further investigations were requested by local Stakeholders by employing innovative modelling techniques and adopting detailed field data and measures to fulfil EU Flood Directive 2007/60/EC (EU 2007) as a whole. The Island's northern shorelines and inlands main roads are affected by a strong mix between pluvial and coastal floods, causing considerable direct and indirect damages. Heretofore, Malta relied mostly on the surface drainage systems and natural ponds, however recent years development (MTIC 2013) led to the construction of the very first underground drainage system, targeting flood problems up to 5 years return period in the worst-hit areas. This system upgrade helped to reduce considerably those damages related to higher frequency rainfall events and set the basis for Malta's urban resilience potential advances. Although the implementation of this extensive network of underground tunnels, canals and water storages for agricultural purposes, flooding issues persist for higher return periods, arguing its viability also for expected climate change predictions. The Malta case study is presented as the aim of the publication, explaining modelling criteria adopted assumptions to perform a compound events flood risk damage assessment for 5-10-20 years return periods, also considering RCP 8.5 (IPCC 2014) climate change scenario for rainfall variability.

Material and methods

Basin-scale modelling involving both coastal and pluvial floods was crucial to provide a holistic analysis, in contrast with done by Malta's Stakeholders, who preferred modelling just the pluvial issues no less at Municipality scale (EWA 2021); in this sense, considerable support has been found in recent years publications (Russo et al 2015; Moftakhari et al 2017; Zscheischler et al 2018; Ghanbari et al 2019; Fang et al 2020). The model covers an area of around 6900 hectares, from the south-western part to the north-eastern part of the Island (Figure 1), embracing the capital Valletta as well as some of the most densely populated neighborhoods in the surroundings (Birkirkara, Msida, Qormi, Gzira) and related shorelines. Different modelling approaches were discussed (Henonin et al 2013) and the 1D-2D physically based technique was preferred contrary to the faster but less accurate fully-1D or classic 1D-1D modelling adopted by Malta's

Stakeholders in previous investigations (MTIC 2013; EWA 2021) which did not consider the drainage system and any climate change assessment at all.

Figure 1 *1D-2D model extension*



The commercial software Innovyze Infoworks ICM 8.5 (Innovyze ICM) was used to build the model while aftermath events photos were employed to calibrate due to a lack of historical water depth and discharge measurements. Local sub-hourly rainfall data was obtained from the closest rain-gauge station, located at the Meteorological Office of the Luqa Airport at less than 5 km from the study area. Despite the scarcity and the poor redundancy of official rainfall data availability all over the Island, these records were enough to obtain reliable and consistent Intensity-Duration-Frequency curves up to a 20 years return period in line with previous studies (EWA 2010, EWA 2015, Galdies 2011). Climate change factors for rainfall variability were adopted by following CRISI ADAPT 2 outcomes from work-package 1 and varying from 1.4 for 5 years Rp up to 1.6 for 20 years Rp. High-resolution Digital Terrain Model was obtained from Maltese official channels (MSDI) and scaled from 0,25 meters up to 1-meter precision. The surface drainage system was modelled at the inlet scale (Gómez et al 2009; Russo et al 2011), providing enough details to reproduce inlets hydraulics. Storm surge was reproduced with a hydrostatic model set to 1 meter high, following local observation (LISCOAST) obtained from nearest sea ranger buoys; this value ensured no combination between pluvial and coastal flood probability of occurrences and representing just an average sea level rise during historical storm surge events. Buildings and infrastructures were extracted from OpenStreetMap and post-processed due to the lack of enough detailed information available in shape format. Land use and geology were obtained from official sources (MSDI) while Horton's infiltration parameters were set and adjusted by experience. The adopted hazard criteria (Russo et al 2020) combines water depth and runoff velocity to identify the most dangerous areas for pedestrians. Flood damages estimation were considered by implementing validated strategies used in similar case studies (Martínez et al 2021) and comparing the results with those found by the Maltese Stakeholders (EWA 2015). The 2D mesh was adjusted from 1 sq. meter up to 100.000 sq. meters, allowing the software to tailor the elements to the terrain; the result was an unstructured 2D mesh with more than 1.4 million triangular elements. Simulations were conducted and post-processed employing a personal computer with the following specifications: Windows 7 SP1 64bit, Intel(R) Core (TM) i5-3570 CPU with 3.40GHz, 12 GB RAM and 2 GB dedicated NVIDIA Geforce GTX 680. The average computational time was around 5 hours/simulation, to complete a 3 hours simulation with a minimum timestep of 5 seconds.

Results

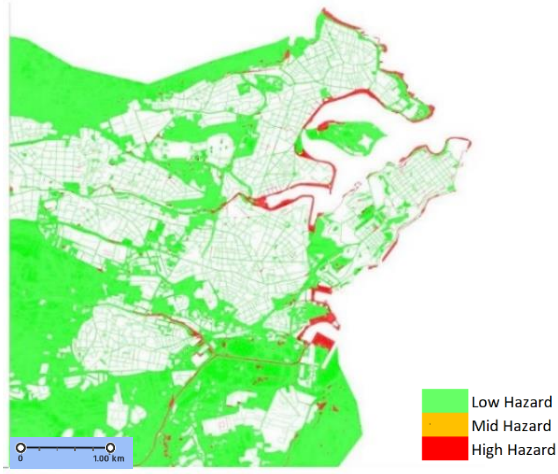
A total of 6 simulations were completed for this paper, providing enough results to compare the effects of storm surge combined with heavy rainfalls on compound events. The image (Figure 2) represent the post-processed hazard map for compound event with 5 years rainfall return period, according to the hazard criteria explained in previous section. The increase of the high hazard area is evident when considering storm surges also and it is confirmed by the area estimation summarized in Table 1.

Table 1 *High hazard area quantification for different return periods*

Rp	Pluvial [ha]	Pluvial + Coastal [ha]	Difference [%]
5	56,5	99,1	43
10	67,4	109,5	38
20	87,3	129,2	32

An average increase of about 38% of the area is expected, with a decreasing tendency when higher return periods are considered; this can be justified as an increase of flooded areas for lower probability events. Simulation results did show negative interactions between sea and drainage system, although this is limited to a specific area and did not affect the hydraulic condition of the upper drainage system. Tangible damages were calculated only for the most densely populated areas considered in the model (Birkirkara, Msida, Qormi, Gzira) and resulting in the order 15 million euros for 5 years return period, with the real chances to raise up to more than 30 million of euros for worst case climate change scenario of rainfall variability. For 10 years return period the damage would rise from 19 million up to 39 million of euros while for 20 years return period from 26 million to more than 60 million of euros.

***Figure 2** Hazard map for pedestrian (compound events pluvial T5 + coastal flood hazard)*



Conclusions and future developments

Thanks to the CRISI ADAPT 2 Project, it has been possible to deepen Malta's flood risk awareness concerning expected climate change variability in the very next decades, whilst they were not presented in this publication. Model results will be used as a tool for the Maltese Stakeholders as support for the development of the dedicated flood risk adaptation strategies in the case study areas. Flood hazard and risk maps will be adopted by Malta's First Responders for planning and operation during pre and post flood events. Obtained results demonstrated the importance of considering compound events such as pluvial and coastal flooding while providing a flood risk assessment on shoreline areas. Such work represents the very first step towards a detailed monetary damages estimation concerning those areas characterized by high flood hazard and risk. Further investigations are necessary to combine more pluvial and coastal flood probability of occurrences, expanding the knowledge of compound events consequences as well as the damage estimation for the entire Island of Malta.

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