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Potential Sea Level Rise Inundation in the Mediterranean: From Susceptibility Assessment to Risk Scenarios for Policy Action

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Abstract: Coastal ecosystems and anthropic activities are prone to be affected by the negative impact of marine-related processes induced by climate change, such as erosion, flooding and permanent inundation. Studies aiming at defining potential risk scenarios represent a valuable tool for the identification of the most suitable coastal adaptation measures. After outlining sea level rise implications at the Mediterranean scale, this paper deals with inundation risk scenarios for the years 2050 and 2100 for the north-eastern sector of the Island of Gozo (Malta), central Mediterranean Sea. The analysis, carried out by applying an index-based procedure, firstly required the evaluation of the susceptibility to inundation of the investigated coastal stretch under different sea level projections. Then, the spatial combination of inundation susceptibility with the exposure and vulnerability of the area allowed identification of the most critical sectors in terms of coastal risk. The results of the analysis showed that, under the worst-case climate scenarios, 5.5% and 8.1% of the investigated coastal sector are prone to very high inundation risk (Class R4) in 2050 and 2100, respectively. In particular, the bays of Ramla and Marsalforn, which are characterized by significant economic and touristic activities, were found to be the sites where the expected impacts of future sea level rise will be higher if no management strategy and adaptation action are taken in the near future.

Keywords: sea level rise; coastal geomorphology; vulnerability index; coastal inundation risk; Maltese Islands; Mediterranean Sea

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1. Introduction

As strongly highlighted during the last United Nations Climate Change Conference (COP26, 2021 [1]), climate change represents one of the major global issues to be addressed in the coming years. It can be considered as the "issue of our time" [2] and its effects, in terms of shifting weather patterns and consequent change in spatial and temporal occurrence of the weather-related extreme events (heatwaves, heavy rain, fires, coastal flooding), are already occurring worldwide, as outlined in the 6th Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC) [3]. The First Assessment Report on Climate and Environmental Change in the Mediterranean [4] highlights that this region is warming 20% faster than the global average and that the current changes and future climate scenarios will point to a significant increase in climate-related risks during the next decades. The Mediterranean Sea can therefore be considered as a "hotspot" of climate change since the effects in this area are expected to be stronger than in other areas in the world [5,6].

In this context, the Mediterranean coastal areas are particularly prone to be affected by direct and indirect climate-related impacts including an increase in sea surface temperatures and ocean acidity, northward migration of marine species, changes in phytoplankton communities, increasing risk of water-borne diseases, and losses of ecosystem services. Many of these expected phenomena are related to coastal processes such as erosion, flooding, and saltwater intrusion, which, in turn, are strongly affected by increases in mean sea level, the most important slow-onset consequence of climate change.

In line with the global trend observed from the analysis of tide gauges and, since 1992, from altimetry records [7], mean sea level has risen across the Mediterranean Sea during the 20th century and has accelerated up to 2.44 $\pm$ 0.5 mm year^{-1} during the 1993–2012 period, as observed by Bonaduce et al. [8]. In this time-span period, the Mediterranean Sea shows a remarkable spatial variability in sea level variation among the regions, with positive trends lower in the central part of the basin and higher in the Adriatic and Aegean Seas. In particular, the highest trend has been estimated by analyzing data from a tide gauge station in Crete (Lat.: 35.49, Lon.: 24.08) while the lowest trend has been in Rovinj (Lat.: 45.08, Lon.: 13.63) and La Valletta (Lat.: 35.82, Lon.: 14.53).

Future projections of global mean sea level, which are based on the results of high-resolution numerical models, show that sea level is expected to keep rising during the next decades as a consequence of global warming, under all the proposed climate scenarios and it will continue to rise for thousands of years, even if future CO_2 emissions are reduced to net zero and global warming halts [3]. Climate data are revised and periodically published by the IPCC [3,9,10]. They are provided under different climate scenarios expressed in terms of RCPs (Representative Concentration Pathways) and, more recently, in terms of SSPx-y (where "SSPx" refers to the Shared Socio-economic Pathway describing the socio-economic trends underlying the scenario, and "y" refers to the approximate level of radiative forcing resulting from the scenario in the year 2100). These scenarios reflect the response of the climate system to different concentration levels of climate-altering gases in the atmosphere, which, in turn, depend on socio-economic assumptions, climate change mitigation levels, and air pollution controls [11].

With specific reference to sea level rise (SLR), since no single model can represent all the processes contributing to its variation, each contribution is computed separately and merged into a common probabilistic framework. Sea level rise projections provided in the Special Report on the Ocean and Cryosphere in a Changing Climate [12] showed that global mean sea level will most likely rise between 0.29 m and 1.1 m by the end of this century under the worst-case climate scenario (RCP8.5). These projections have been updated in the last IPCC Assessment Report, released in August 2021, which provides the results obtained from numerical models developed and run by the scientific research institutes participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. These models include new and better representation of physical, chemical, and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports.

In order to allow users to visualize and download sea level projections data included in the AR6, a specific tool has been released by NASA [13]. The tool allows access to global and regional sea level projections from 2020 to 2150, along with how these projections differ depending on future scenarios.

At the regional and local scale, coastal sea level changes may be different from what is observed and modelled in open-ocean [14] due to several factors, which also include natural vertical ground movements (VGMs) related to tectonic, glacio-hydro-isostatic, and volcanic processes. VGMs are often enhanced by anthropic activities mainly related to groundwater overexploitation, gases extraction, and coastal over-settlement that can cause relative sea level (RSL) variations higher than those expected at the global and regional scale.

Due to the relevant influence that sea level rise can have both on the coastal landscape evolution and on the local socio-economic asset, in the last decades a large number of investigations aimed at assessing potential impacts of future RSL at the regional and local scale have been carried out. With regards to the Mediterranean, preliminary studies have been focused on the assessment of the proneness of the alluvial coastal plains to be impacted by future RSLs accounting for future sea level projections coupled with tectonic and glacio-hydro-isostatic contributions (e.g., [15–21]). Several coastal studies have also considered the local contribution of vertical ground movements by assessing displacement rates from satellite data [22–27] and Global Navigation Satellite System (GNSS) stations [28]. These studies highlight the fact that wide areas of the Mediterranean are considered particularly prone to be affected by shoreline retreat and permanent submersion processes by the end of the century as a consequence of RSL increase. In addition to site specific studies, Antonioli et al. [29] defined relative sea level scenarios and potential submersions maps for 16 Mediterranean coastal plains located in Italy, France, Spain, Tunisia, and Cyprus, thus increasing the number of coastal sites for which potential inundation scenarios for the year 2100 are available. Such studies highlight that anthropic and natural assets, as well as coastal cultural heritage sites, are at risk from coastal processes related to sea level rise. Examples are provided by Frihy et al. [30], who focused on risk assessment to sea level rise along the Mediterranean coast of Egypt, Azidane et al. [21], who assessed the socio-economic impacts of sea level rise along Northeast Morocco, and Reimann et al. [31], who evaluated the risk level of the Mediterranean cultural World Heritage Sites under four climate scenarios until 2100.

Coastal risk to sea level rise is generally expressed as the spatial combination of susceptibility to sea level rise, natural and anthropic exposure, and social vulnerability levels; it is calculated by applying indicator-based procedures, as performed at the European scale in the framework of the EUROSION Project in 2004 [32]. Several studies have applied the methodological procedure proposed in this project for the assessment of coastal exposure to marine-related processes, including both flooding and erosion (e.g., Bruno et al. [33]). Other studies have applied a modified version of the index-based method proposed in the frame of the Risc-kit Project [34–36] where vulnerability, exposure and hazard indices are coupled to estimate a synthetic coastal risk index that allows identifying "hot-spot" coastal sectors for which deeper modelling investigations are required. By way of example, an index-based procedure developed by considering the Risc-kit approach has been applied in Aucelli et al. [37] and Di Paola et al. [27] to evaluate the exposure and the social vulnerability of the municipalities within different study areas in southern Italy. With regards to the Maltese Islands, they have been deeply investigated in the frame of a number of research projects, which contributed to collect, analyze, and interpreting a significant amount of geological and geomorphological data, with specific reference to the Gozo Island. In addition, Rizzo et al. [38] carried out for the north-eastern part of the island, a detailed exposure and social vulnerability analysis, supported and validated by expert-based judgments, which has led to the evaluation of the Overall Vulnerability Index (OVI). Nevertheless, the analysis of relevant peer-review literature showed a lack of investigations aimed at assessing the local coastal risk to future sea level impacts. In 2015, Formosa [39] published a preliminary assessment of the areas potentially impacted by future sea levels along the Maltese Islands. However, the proneness analysis carried out in that study was based on fixed sea levels (ranging from 0.5 m to 13 m) that do not correspond to any expected climate scenarios.

A comprehensive overview about lessons learnt and potential challenges in using integrated multidisciplinary instruments and approaches for assessing coastal vulnerability to erosion and sea level rise is provided in Bonaldo et al. [40] and Anfuso et al. [41], while an up-to-date coastal database for the Mediterranean intended for coastal impact and adaptation assessment to sea level rise and associated hazards on a regional scale was provided in 2018 by Wollf et al. [42].

A number of European projects have addressed the need for enhanced mapping of the most vulnerable areas and to identify the most suitable adaptation measures to reduce the impacts of future sea level. By way of example, SAVEMEDCOASTS addresses the challenge of mitigating the risk related to sea level rise in the Mediterranean areas by providing multi-temporal scenarios of expected inland extension of marine flooding in consequence to sea level rise, preparing people to face the effects of future coastal changes [43]. The project highlighted that 163 Mediterranean coastal plains are highly prone to marine flooding because of sea level rise for 2100, land subsidence, tsunamis and storms. Many studies are also focused on the assessment of the potential sea level impacts on critical infrastructures, such as ports [44], airports [45,46], and railways (e.g., ongoing study financed by the Italian Ministry of Sustainable Infrastructures and Mobility).

The foregoing concepts of risk, defined in terms of different components of hazard, vulnerability and exposure, interpreted in the context of modeling of specific climate change effects under different scenarios, are all useful constructs that provide a clearer understanding of future outcome scenarios. At the more general level, there is room for a much-needed bridge between the results of analyses and models used for expert-based risk assessments and inference of their results in such a way that can be readily understood and adopted by policy makers. The operationalization of conceptual definitions and transposition of results from evidence-based assessment of certain climate change risks (e.g., of coastal inundation from sea level rise) into policy action is key to moving towards more sustainable outcomes for the future. The wider communication of risk assessment and the broader understanding of its impacts on wellbeing, beyond the circle of academics and experts, is pivotal for political mobilization towards concerted action to combat and mitigate climate change effects in practice. Developing evidence-based risk assessment tools and methodologies that provide this interface with the wider policy realm is therefore important.

This study focuses specifically on the incidence of the climate change effect of sea level rise, particularly under the 2050 and 2100 inundation risk scenarios.

The central aim of the paper is firstly to adopt a methodology that can define and map the inundation risk under different scenarios of future sea levels in a readily communicable manner. Secondly, the approach to climate risk assessment adopted by this study also aims to bridge the gap between local-level susceptibility analysis and risk assessments and national policy action in practice. By assessing coastal susceptibility to future sea levels and integrating this physical aspect with exposure and vulnerability, this study comprehensively portrays the medium- and long-term inundation risk scenarios for policy consideration, by presenting results in readily communicable form for specific areas, whereby their wider implications can be evaluated. In order to achieve these two aims in this study, we focus our attention on a coastal area in Gozo, the second largest island in the Maltese archipelago which, being located in the center of the Mediterranean Sea, represents a key site for studies related to the potential impacts of sea level rise.

2. Study Area

2.1. Physical Setting

The Maltese Islands, which are located in the center of the Mediterranean Sea, comprise of three main islands, namely Malta, Gozo and Comino, together with smaller uninhabitable islets [47]. The landscapes and landforms of the Maltese Islands derive from the complex interplay of long-term tectonic processes, sea level changes and geomorphological processes, the latter being controlled by the physical and mechanical properties of the outcropping rocks [48–55].

From a geomorphological viewpoint, the stretch under investigation is characterized by a geological sequence ranging in age from the late Oligocene to the late Miocene (Figure 1). The top of the sequence is made up by the Upper Coralline Limestone Formation which forms limestone plateaus bounded by steep structural scarps constantly reshaped by gravity-induced and degradation processes [56]. Gentle slopes reaching the sea are determined by the presence of the underlying Blue Clay Formation, while the Globigerina Limestone Formation forms flattened areas along the coast as shore platforms. Clayey and marly slopes from the Blue Clay Formation host terraced fields of active or abandoned agricultural land [56]. Upper Coralline Limestone blocks lying on marls and clay from the Blue Clay determine the extensive screes where the Blue Clay outcrops at sea level.

Most of these boulders ended up on these slopes by rock falls and topples at the bottom of the limestone plateaus and movement by earth flow/slide over the clayey terrain or by block sliding (cf. [57–59]). The more resistant Lower Coralline Limestone Formation, representing the bottom of the stratigraphic sequence, creates a sloping coast formation that can be found in the eastward side of the coast under investigation, from Dahlet Qorrot Bay to Ras il-Qala.

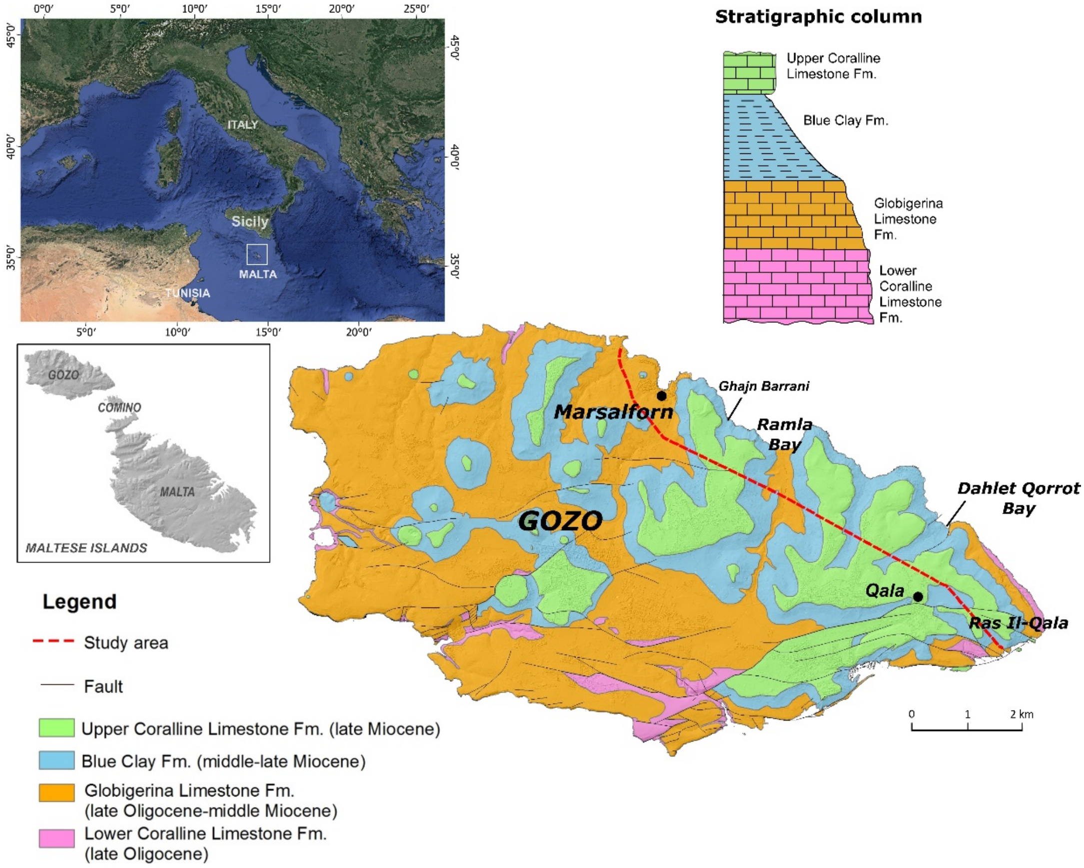

Figure 1. Study area location and geological setting.

The main fluvial features in the area consist of V-shaped valleys and flat bottom valleys. More recent ephemeral watercourses caused the deposition of alluvium at the end of the main valleys that are Ramla Bay and Marsalforn. Aquifers form all over the islands as water infiltrates the heavily karstified limestone plateaus. This rainwater passes through channels of the karstic landscape to sit upon impermeable blue clay. Some of this water seeps out over the blue clay slopes to create gullies and rills. Through this dissolution process, several caves can be found exposed at the base of the limestone plateaus [56]. The coastline investigated also has an array of inlets and promontories. The accumulation of sand and mixed grainsize deposits, results in the creation of pocket beaches where this corresponds with bays and coves. Meanwhile, Marsalforn Bay is lined by anthropogenic influences and is heavily urbanized [38,56].

As far as coastal geomorphology is concerned, Prampolini et al. [56] identified a wide range of geomorphic features along the north-eastern sector of Gozo including block slides, rock falls, plunging cliffs, sloping coast, shore platforms, pocket beaches, Blue Clay cliffs and built-up coast (Figure 2); all potentially subject to climate and marine generated coastal hazards.

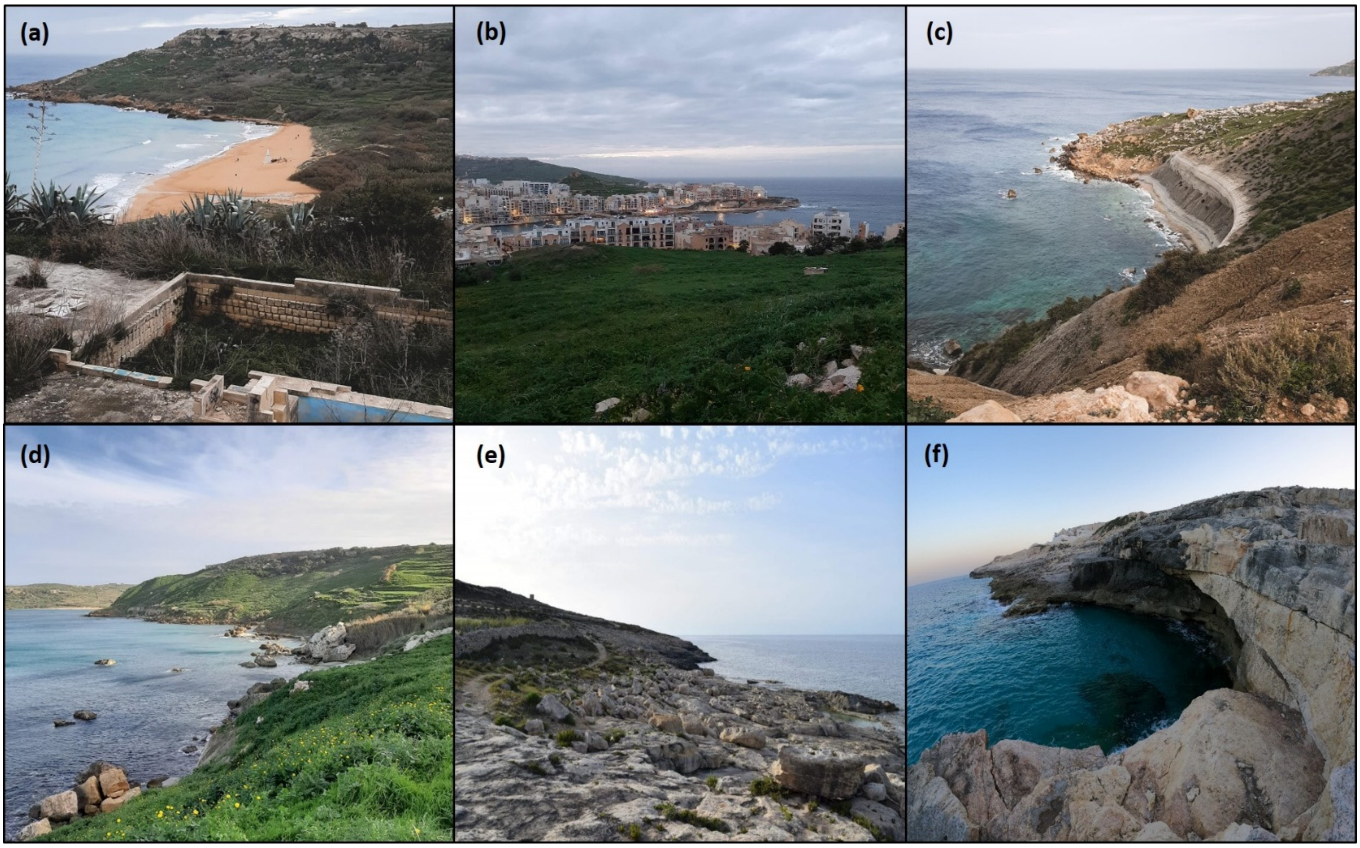

Figure 2. Examples of the main coastal landscape features in the study area: (**a**) the sandy beach of Ramla Bay; (**b**) the coastal village of Marsalforn; (**c**) Blue clay outcrops at Marsalforn; (**d**) terraced slopes in Blue Clay terrains affected by rock falls detached from the limestone plateau of Upper Coralline Limestone at Ghajn Barrani, between Marsalforn Bay and Ramla Bay; (**e**) sloping coast near Dahlet Qorrot Bay; (**f**) plunging cliff in the Lower Coralline Limestone affected by rock collapses at Ras Il-Qala coastal sector. For the locations of the sites mentioned above, see Figure 1.

2.2. Natural and Anthropic Exposed Elements and Tourist Setting

The study area may be considered as representing significant economic, cultural and ecological elements at risk. Ramla Bay is a largely undisturbed and scenically very attractive embayment, possessing the largest sand beach on the island of Gozo (Figures 2a and 3a,c) and the best-preserved dune system on the Maltese Islands as-a-whole. The beach itself is characterized by a very attractive golden-reddish colour, a result of an aluminosilicate mineral (glauconite) in the Upper Coralline Limestone Għajn Melel rock strata [60]. The area also boasts several features of cultural heritage including the buried remains of a Roman villa (Figure 3c), a *Fougasse* (a stone-firing cannon hollowed out in the rock) and the remains of a submerged seawall built by the Knights of St. John of Jerusalem during their presence on the island, to protect the bay from seaborne invaders. As a consequence, it is a relatively unique area with high attraction to substantial local and overseas tourism.

The village of Marsalforn (Figures 2b and 3a,d) has two main types of inhabitants: a generally local (Gozitan) population in the autumn and winter months and a much larger population in the spring/summer months that is expanded with a large influx of Maltese and overseas tourists. Its popularity and the availability of a significant number of facilities (including a range of accommodation facilities, shops, restaurants, diving centers, sandy beach and rock shore bathing environments) make it a remarkable inhabited coastal center. Following upgrading works on the bay's inner harbour, described as a drive to improve the locality's tourism offering, the seafront at Marsalforn has in 2021, benefitted from a €3 million government investment [61]. In this context, the Marsalforn component of the study site represents primarily, an economic resource. It is also worth noting that the recent seafront investment is likely to influence its vulnerability as considered by Rizzo et al. [38].

Figure 3. Anthropic elements and sites potentially exposed to the effects of sea level rise along the north-eastern coast of Gozo: (**a**) 3D view of the investigated coastal stretch; (**b**) boathouses in Dahlet Qorrot Bay; (**c**) ruins of a Roman villa (in the dashed red circle) in Ramla Bay; (**d**) the urbanized and tourism-oriented center of Marsalforn located in the homonymous bay. Images (**a**,**d**) are from Google Earth.

Apart from stone quarrying activities present on the immediate northern coast below Qala village, and some traditional boathouses located on the Dahlet Qorrot inlet (Figure 3b), the intervening areas of the study site mostly consist of largely undisturbed coastal slopes, inclusive of two legally protected zones that form part of the Natura 2000 network [56]. Representing a mix of natural and cultural features, these coastal slopes hold a strong potential for ecotourism, thus contributing an additional economic component to their overarching significant ecological value (cf. [62,63]).

Overall, therefore, within the study area, a wide range of elements may be considered to be at risk from a variety of coastal hazards such as erosion, landsliding, sea level rise and sea storm impact/inundation, poorly planned anthropogenic interventions and precipitation storm/flash flood runoff from minor and major valley/fluvial systems. The elements at risk may be considered to include an array of coastal geomorphotypes (Figure 2c–f), ecologically important areas, coastal footpaths, cultural heritage, recreational tourism potential and related economic generators and local infrastructure.

Notwithstanding the recent negative impacts of the COVID-19 pandemic on worldwide tourism (e.g., 2 million less tourist arrivals in Malta in 2020 compared to 2019 [64]), the tourism market in the Maltese Islands has rapidly reflected a potentially healthy rebound. In the second quarter of 2021, total guests and nights in Gozo and Comino increased to 11,331 and 27,621 respectively from 3477 and 8796 registered in 2020. The net occupancy rate in Malta increased by 18.5%, and that in Gozo and Comino increased by 23.4% [65].

Since the onset of international tourism, and particularly during the summer months, the island of Gozo has attracted many tourists, many seeking the quiet and relatively underdeveloped environment of this quaint small island. Despite its very small size, the island is host to a rich cultural and geological heritage within a typically Mediterranean natural environment. As a consequence and with a population of only 33,388 [66], tourism-related economic revenue is an important component of the island's economy, accounting for nearly half of the island's GDP, and employing 20% of its workforce [67].

In 2021, travel between Malta and Gozo was up by a massive 25.6% when compared to the same period of 2020, although this was still less than 2019 numbers before the pandemic. The introduction of a fast ferry service to Gozo (from Malta's Grand Harbour) in addition to the existing ferry service has facilitated travel to Malta's sister island. No doubt, a proposed road tunnel between the two islands and upgrading of the heliport on Gozo will further stimulate Gozo's inbound tourism, which while good for the economy, has raised concerns regarding the sustainability of current and forecasted increase in numbers.

In their assessment of coastal vulnerability of the area, Rizzo et al. [38] evaluated a number of physical and social indicators that they considered representative of the various elements at risk and, based on expert judgment, allocated exposure level to each category. The physical (anthropic and natural) assets potentially exposed to coastal hazards, were represented by land use, transport networks and utilities indicators. The social indicators (considered with regard to the population most likely to be impacted by coastal hazards i.e., those living within the study zone), evaluated health care, disability, old age, children, and unemployment. Rizzo et al. [38] identified this area of study as potentially vulnerable to the impact of climate and marine-related processes.

3. Maltese Policies with Respect to Sea Level Rise and Its Impacts

It is important to understand what factors determine whether or not local level susceptibility analysis and risk assessment are effective tools to bring about policy action. This requires a wider appreciation of the different factors that influence national policy making from two different directions. These include top-down international influences from the higher-level policy realms, at EU level, and bottom-up domestic influences, coming from specific attention given to local vulnerability and risk assessments, as a basis for national policy development at the level. Different dynamics shape policy action in bottom-up as well as top-down fashion, and vulnerability/susceptibility analysis and risk assessment at the local level can act as an agent for policy action in both cases. On the one hand, vulnerability assessment tools can inform policy makers and instigate bottom-up national policy development to target specific sea level rise impacts if the results are salient enough and gain priority on the political agenda. For risk assessments to yield results that shape the policy agenda in a relevant way, they need to gain credibility. This requires that the approach is backed by sound methodology, is evidence-based and uses local data about the assets at risk, and also incorporates models representative of the hazards creating the risk being assessed. Furthermore, risk assessment tools also need to yield results that are readily and effectively communicable, outside the sphere of academics and experts, in order to mobilize interests to address those risks in the policy field. Thus, climate risk assessment can be effective for bottom-up policy action if it is evidence-based, methodologically sound and easily communicable outside the technical.

On the other hand, EU and other high-level policy directions could have a top-down influence, instigating a focus on specific issues if there is concordance between priorities at the different levels. This can be instigated through top-down pressure to address specific issues (such as climate change or sea-level rise) once these become widely accepted policy priorities at higher levels of governance (e.g., EU or global levels). Policy convergence towards higher policy priorities can be pushed by obligations and policy commitments (e.g., Directives). Meanwhile, policy convergence can be instigated further once a link can be made between these higher-level policy priorities and the impact of climate change at the more localized level. The relevance of wider policy goals can be asserted through results of more localized susceptibility assessment to the given risk scenarios, whereby issues and concerns recognized at higher governance levels are also verified as being significant to the local context.

The EU is actively engaged in international diplomacy and partnerships on climate change. Leading by positive example, it emerged as a leader in green global climate policy at COP26, bringing forth the highest level of ambition and it demonstrates significantly larger financial contributions per year (of the order of 21 billion annually). It is therefore a strong policy shaping force across Europe itself and also in the wider global milieu, and it thus provides an undeniable pointer for country-specific national policy development and for policy concordance with priorities recognized at EU level. For its Member States (MS), it provides a roadmap to 2050 and enshrines 2030 intermediate targets and the 2050 climate neutrality objectives into legislation under the European Climate Law, strengthening the framework for ambitious climate action. Meanwhile, the European Green Deal provides a design that countries and key actors at different governance levels can relate to readily as a set of deeply transforming policies for tangible action in key areas.

Malta enacted the Climate Action Act in 2015 institutionalizing these priorities into its legislation with a strong accent on mitigation, and not as much on adaptation or on building resilience. The Maltese Parliament reaffirmed the country's commitment to combat climate change in 2019 with the adoption of the climate emergency motion, and Malta also developed a National Energy and Climate Plan in 2019, again maintaining a predominant focus on mitigation measures. Malta's Low Carbon Development Strategy (LCDS) shares the same focus and sets out mitigation measures to be achieved by 2030, 2040 and 2050, targeting seven specific sectors from an abatement point of view.

Policy attention to adaptation and building resilience in the face of foreseeable climate change has increased. The European Commission adopted its new EU strategy on adaptation to climate change on 24th February 2021. The new strategy sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. Key policy priorities are for smarter, faster and more systemic adaptation. The main aim of the EU Strategy on Climate Adaptation is to prepare for the unavoidable impacts of climate change and make the EU climate resilient. Climate risk assessment is one of the steps identified as being important to reach this aim, alongside with improving knowledge of climate impacts [68].

The EU Adaptation Strategy 2013 focuses on three objectives of promoting comprehensive climate action by Member States, "climate proofing" action by promoting adaptation in key vulnerable sectors, and better-informed decision making, addressing knowledge gaps and further developing the European climate adaptation platform Climate ADAPT [68].

Furthermore, according to a horizontal assessment of the country-specific status with implementation of the EU Adaptation Strategy 2013, the November 2018 evaluation of Malta, based on the Adaptation Preparedness Scoreboard [68], reports that there are knowledge gaps pertaining to the assessment of vulnerability to climate change in many areas, and that it is not clear how progress will be made [68].

In the local context, a National Climate Change Adaptation Strategy (NAS) had been published and adopted by the Government of Malta in 2012. Its recent revision was however, included in the publication of the LCDS, and it consisted of measures grouped under sectors (in the former LCDS approach). None of these policy instruments have provided a specific focus on the impact of sea level rise or on actions targeted at adapting to its effects, despite Malta being a small island state that is highly dependent on its coastal resources.

In recent years, the Maltese Government sought to address coastal erosion issues nationally and in the context of climate change at a more strategic level. A coastal protection strategy is being formulated over two years (2021–2023). The project, named Coastal-COVER (Coastal-Climate Overall Vulnerability and Exposure Risk) Protection Strategy for the Maltese Islands, is funded by the European Union via the Technical Support Instrument and is being implemented by the Coastal and Marine Union (EUCC) and its experts. They will be approaching the national project through a comprehensive risk assessment of the

Maltese coast in order to identify priorities for action to adapt to the expected impacts of climate change on the coast. The Coastal COVER strategy will also refine and establish a multi-disciplinary approach to coastal erosion risk assessment based on coastal-climate overall assessment of vulnerability and exposure risks, based on IPCC definitions of risk, hazard, vulnerability and exposure. Different climate change effects (including sea level rise) will be included in the risk assessment that is a central part of the diagnosis of the national problem of coastal erosion. The use of evidence-based risk assessment methods, employed by experts through a technical approach will adopt the aforementioned concepts and definitions of hazard, vulnerability, exposure and risk, as well as the spatial mapping of results in a communicable manner. The approach will combine the results from technical analyses and assessments with structured consultations with a full range stakeholder groups, as an integral part of the project, with the aim of disseminating and communicating their significance beyond the expert base engaged for the project. The two-pronged activities, cognitive and political, both at problem diagnosis stage, and with equal importance to be given at strategy formulation stage, will render risk assessment tools a pivotal element for translating susceptibility assessments, for different risk scenarios, into policy action.

Meanwhile, a Vulnerability and Risk Assessment (VRA) for the Maltese economy is also concurrently being carried out (2021–2023). The VRA project will, on the other hand, focus on the assessment of vulnerability of Maltese sectors, the identification of climate impacts to key sectors and their assets, and it will also quantify the economic implications of climate impacts using micro- and macro-modules, and then evaluate climate impacts on the Maltese economy and describe possible adaptation priorities and goals. Coordination across the two projects reinforces the common interests in assessment of vulnerability at different levels. The VRA will focus on the impacts of climate change on the Maltese economy, assessing its vulnerability through a multi-sectoral approach; whereas the Coastal COVER protection strategy will assess risks to all coastal resources in a multi-disciplinary fashion. The issue of sea level rise impact is most directly relevant to the Coastal COVER project, but it is nonetheless an all-important one when considering climate change impact on the whole economy. The efficacy of risk assessment tools to draw upon evidence and bring concerns about likeliness and magnitude of impacts to the mind of policy makers in a tangible manner, and to enable an evaluation of repercussions to societal wellbeing based on direct inference from results, is key to the effectiveness of both projects in bringing about policy actions to address the concern for climate change which they share.

Given its specificities and insular nature, Malta is particularly vulnerable to the impacts of climate change in terms of increased frequency and intensity of coastal erosion, flooding, and landsliding. Concern for Malta's levels of socioeconomic and environmental vulnerability and exposure to climate change-induced coastal erosion risks, especially in view of Malta's dependence on the coast, warrant this subject to be considered a policy reform priority for the purpose of "climate proofing" and "climate streaming" into different sectors, in line with EU and national level adaptations strategies. For one, tourism is a major underpinning pillar of the Maltese economy as a whole, and it is predominantly coast dependent. Other sectors too would be affected by sea level rise (such as water, energy and agriculture).

While Malta has no specific policy related to sea level rise impact, or adaption, these concerns are becoming increasingly salient in policy narratives and specific initiatives across government. The importance given to vulnerability, exposure and susceptibility, is central to the direction that is likely to be followed by future policy. This focus emerges from a need to build better knowledge about the impacts that will result from climate change that is already in the pipeline, and for which Malta needs to be better prepared for, at the level of its national economy, as well as on the seafront, where sea level rise will be felt most acutely.

This requires locally specific data and assessments based on such evidence, with tools that have the potential to translate the hard data and methodological assessment of risks into policy action. This shortcoming has been identified as one of the barriers to the effective implementation of the Integrated Coastal Zone Management (ICZM) Protocol in Malta. The ICZM Protocol was ratified by Malta and brought into force on 10th May 2019 [69]. Meanwhile reports on the progress of Malta in implementing actions required under this protocol has repeatedly stated that there is still and absence of published studies which have addressed the rates and risks of coastal erosion around the Maltese Islands. In different reports it is reiterated that while it is recognized that coastal erosion is evidently occurring, the main factor that accelerates erosion is human intervention through development.

The concern for an absence of adequate data and knowledge on coastal erosion risks, highlighted in reports on the implementation of the ICZM protocol, which Malta has ratified, makes the need for a national assessment of risks a national priority to start making a move towards effective implementation of the protocol at the national level.

4. Material and Methods

4.1. General Risk Assessment Procedure

According to the most recent definition proposed by the IPCC [3] in the context of climate change impacts, risk can be considered as the result of the dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to a specific hazard. Following this definition, a methodological procedure for risk assessment requires the preliminary evaluation of the hazards potentially affecting the investigated area, the exposed elements (natural and anthropic), and the related physical and social vulnerability.

The assessment of the hazard (H)—defined as "*the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources*" [12]—is related to the concept of occurrence, which in turn is related to the temporal (e.g., return period) and spatial (e.g., potentially impacted area) pattern distribution of a potentially hazardous physical event. In the case of sea level rise as a long-term active process, it is not possible to associate a specific return period, the hazard can be expressed in terms of potential impact on the coast, which expresses "*the degree to which a system is affected, either adversely or beneficially, by climate variability or change*" and depends on the susceptibility of coastal area to inundation. Susceptibility information needs to be coupled with exposure (E) and vulnerability (V), expressing respectively "*the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected*" and their "*propensity or predisposition to be adversely affected*".

Hazard/susceptibility, exposure, and vulnerability are combined by applying the general risk formula (Equation (1)), which allows obtaining a zonation of the investigated area according to the different risk level:

$$R = H * E * V \tag{1}$$

In the following subsections, the methodological procedures followed for the evaluation of the coastal inundation risk along the north-eastern sector of Gozo Island are shown.

4.2. Susceptibility Assessment and Data Availability

The assessment of the expected coastal risk scenarios as a consequence of sea level rise requires the preliminary evaluation of the potential impact of the sea along the coast, in terms of proneness to permanent inundation.

In accordance with several previous studies carried out for the assessment of potential physical impact of future sea levels in different Mediterranean coastal areas (e.g., [25–27,37]), the susceptibility of the north-eastern sector of Gozo Island has been evaluated by considering the topographic elevation of the investigated territory. According to the specific topographic setting, the investigated territory is classified in four susceptibility classes, ranging from Class S1 (low susceptibility level), which includes all the areas with a topographic height in the range 1–5 m a.s.l., to Class S4 (very high susceptibility level), which includes all the areas expected to be below the mean sea level (topographic height ≤ 0 m) and therefore considered prone to be permanently submerged by rising sea. In addition, areas with an altitude higher than 5 m are considered as "safe" and therefore their susceptibility to sea level rise can be considered as null (Class S0).

4.2.1. Available Topographic Data

In order to analyze the topographic setting of the investigated coastal sector, a Digital Terrain Model (DTM) has been performed. The DTM [70] has a resolution of 1 m and a height accuracy < 10 cm (in terms of RMSE) cm and derives from LiDAR data collected in 2013 by the Malta Environment and Planning Authority. The freely available DTM was acquired through the Malta Inspire Geoportal. The original DTM had several "no data/empty" cells due to the processing of LiDAR data for deriving the terrain model (in which the buildings and vegetation elements are excluded). The filling of these empty cells was needed for further analysis. To this aim, the following steps have been implemented in a GIS environment: first, the available DTM provided has been converted into points cloud (vector format), then the points have been interpolated by applying the natural neighbour algorithm, implemented by using specific analysis tool in a GIS environment. In this way, an interpolated value has been assigned to all the pixels. Then, to fill the no data pixels, the original DTM has been overlapped with the interpolated DTM. For checking the accuracy of the new DTM and evaluate the presence of data spikes, the interpolated DTM has been compared with the original DTM by computing their difference.

4.2.2. Available Sea Level Projections

Different sea level projections are currently available in the literature and they are periodically synthesized in the IPCC reports. Many of these projections provide global scale scenarios [3,10,12] but in the most recent assessment report (AR6, 2021), local projections are also available for different Mediterranean coastal sites. In detail, the following sea level projections can be taken into account (Table 1):

- Global sea level projections available in the Fifth and in the Sixth Assessment Reports (AR5 and AR6—[3,10]);
- Global sea level projections available in the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC—[12]);
- Local sea level projections available in the Sixth Assessment Reports (AR6—[3]).

Table 1. Sea level values used in this study for susceptibility evaluation and risk assessment are indicated as underlined and in bold.

IPCC Sea Level Projections	Baseline	Scenario	Scenario
	1985–2006	**RCP2.6**	**RCP8.5**
Global (AR5, 2013)	2100	0.44 (0.28–0.61)	0.74 (0.52–0.98)
Global (SROCC, 2019)	2100	0.43 (0.29–0.59)	**<u>0.84</u>** (0.61–1.10)
	1995–2014	**SSP1-2.6 (m)**	**SSP5-8.5 (m)**
Global (AR6, 2021)	2050	0.19 (0.16–0.25)	0.23 (0.20–0.29)
Global (AR6, 2021)	2100	0.44 (0.32–0.61)	**<u>0.77</u>** (0.63–1.01)
	1995–2014	**SSP1-2.6 (m)**	**SSP5-8.5 (m)**
Local (AR6, 2021)	2050	**<u>0.19</u>** (0.11–0.28)	**<u>0.23</u>** (0.14–0.33)
Local (AR6, 2021)	2100	**<u>0.40</u>** (0.22–0.62)	**<u>0.73</u>** (0.52–1.03)

Global sea level projections included in the AR5 are available for the periods 2046–2065, 2071–2100 and 2100 (relative to the baseline period 1985–2006). They are evaluated under different climate scenarios defined for four Representative Concentration Pathways (RCP). Global and local sea level projections included in the AR6 are available from 2020 to

2150 (relative to the baseline period of 1995–2014). In this case, projections are provided accounting for five Shared Socioeconomic Pathway (SSP) scenarios. The AR6 projections can be directly downloaded from the NASA Sea Level Projection Tool [13].

In Table 1, the median values and the likely ranges (in parenthesis) of the available projections are provided. Values taken into account in this study for the susceptibility and risk assessment are indicated as underlined and in bold. In detail, the following scenarios have been calculated:

- Present day;
- Medium-term scenarios (2050) by accounting for the local sea level projections under the best (SSP1-2.6) and the worst (SSP5-8.5) climate scenarios (0.19 m, 0.23 m);
- Long-term scenarios (2100) by accounting for the local sea level projections under the best (SSP1-2.6) and the worst (SSP5-8.5) climate scenarios (0.40 m, 0.73 m);
- Long-term scenarios (2100) by accounting for global sea level projections under different worst-case scenarios (0.77 m and 0.84 m).

4.3. Exposure and Vulnerability Evaluation and Data Availability

Susceptibility data need to be combined with exposure and vulnerability data, which refer to the natural and anthropic assets located in the investigated coastal sector as well as to their physical and social capacity to cope with a hazardous event. For the assessment of exposure and vulnerability levels, the analysis was based on the results obtained in our previous study [38], in which a methodological approach for the evaluation of a coastal vulnerability index accounting for local data related to land use, anthropic and natural assets, economic activities, and social issues of the local communities is proposed. The method combines physical exposure and social vulnerability into an Overall Vulnerability Index (OVI) and allows zoning the investigated territory in five classes of overall vulnerability level with reference to the various hazards potentially impacting the area (Figure 4).

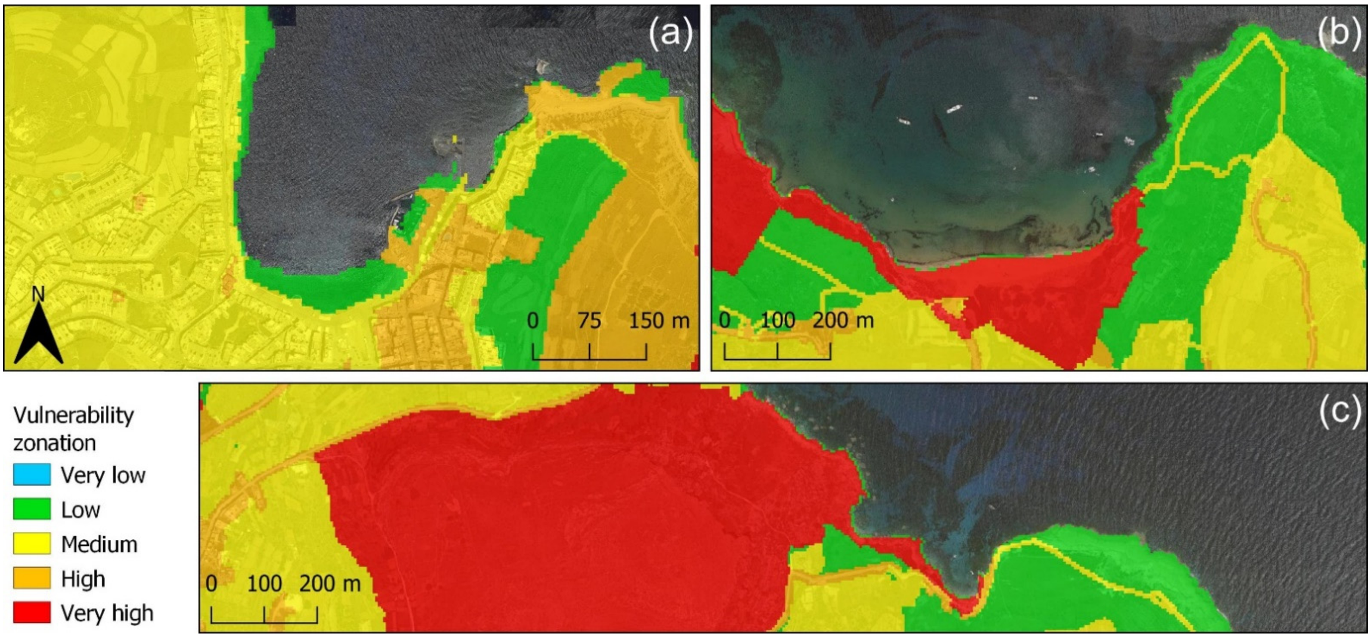

Figure 4. Extracts from the overall vulnerability map modified from Rizzo et al. [38] resulting from the spatial aggregation of the physical and the social vulnerability with reference to the hazards that can impact the investigated area. The areas represented in the boxes are: (**a**) Marsalforn Bay; (**b**) Ramla Bay; (**c**) Dahlet Qorrot Bay and surrounding areas.

4.4. Risk Assessment

As the last step, susceptibility, exposure, and vulnerability data are overlaid to calculate the risk level and to zone the investigated territory in different levels of risk.

To combine the different informative layers into a comprehensive Coastal Risk Index, the following formula (Equation (2)) has been applied (modified from Armaroli and Duo [71] and referenced in relation to the Risc-kit Project):

$$\text{Coastal Risk Index} = \sqrt{C_{Susc} \cdot C_{OVI}} \quad (2)$$

where C_{susc} represents the susceptibility value and C_{OVI} represents the value of the overall vulnerability. The coastal risk values are calculated in GIS environment, by overlapping each pixel value of the raster files related to the susceptibility with the value related to the OVI level (raster format). The obtained risk values are then classified in four classes (Table 2) ranging from Class R1 (low risk) to Class R4 (very high risk). As for the susceptibility, Class R0 includes all the areas where the risk can be considered null. These areas correspond to those included in the susceptibility Class S0, for which the equation 2 has a null result. The results of the coastal risk analysis are presented as risk maps showing in red the areas expected to be below the future sea level. The coastal inundation risk maps for different future sea levels and under different climate scenarios represent the main output of this study.

Table 2. Risk classification.

Risk Class	CRI Range	Risk Value
R0	0	No risk
R1	CI ≤ 1.5	Low risk
R2	1.5 < CI ≤ 2.5	Medium risk
R3	2.5 < CI ≤ 3.5	High risk
R4	3.5 < CIR ≤ 4.5	Very high risk

5. Results

The susceptibility analysis provided a classification of the investigated area into four susceptibility classes, as shown in Tables 3 and 4, considering the Class S0 as safe area. To each of the four classes, the potential coastal impacts under future sea level rise were qualitatively estimated based on the evidence provided by Aucelli et al. [25,37] and Di Paola et al. [26,27]. In particular, Classes S1 and S2 include areas with low-medium susceptibility to SLR but particularly prone to other processes (e.g., storm surges) that can be worsened by SLR; Class S3 (high susceptibility) identifies areas that are prone to be impacted by frequent events of temporary flooding as a consequence of sea storms and permanent morphological changes, such as beach and dune erosion; Class S4 (very high susceptibility) identifies areas prone to be permanently inundated because they are expected to be below the current mean sea level.

The susceptibility analysis for local scenarios (Table 3) from present to 2100 showed that 95% of the study area stands over the 5 m a.s.l. and can be considered as safe with respect to future permanent sea inundation. The area in the susceptibility Class S1 (low susceptibility, from 1 m to 5 m a.s.l.) is not expected to vary so much from present day to 2100 and it is settled at around the 3% of the total area considered. The area in susceptibility Class S2 (medium susceptibility, from 0.5 to 1 m) is going to experience a decrease from 0.47% to 0.35% by 2100. The same trend can be observed for Class S3 (high susceptibility, from 0 to 0.5 m a.s.l.) which undergoes a decrease by 2100, from 0.83% to 0.45% of the total area. Consequently, areas classified in Class S4 (very high susceptibility, ≤0 m a.s.l.) are going to increase consistently from 0.05% to 1.10% of the total considered area.

Table 3. Results of the susceptibility analysis for different local sea level projections under two climate scenarios.

				Scenarios in 2050				Scenarios in 2100			
		Present Day (DTM 2012)		SSP1-2.6 (AR6) 0.19 m		SSP5-8.5 (AR6) 0.23 m		SSP5-2.6 (AR6) 0.40 m		SSP5-8.5 (AR6) 0.73 m	
Susceptibility Class	**Elevation Range (h)**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
S0	$h > 5$ m	9.01	95.53	9.00	95.40	9.00	95.38	8.99	95.26	8.97	95.04
S1	$1 < h \leq 5$ m	0.29	3.12	0.29	3.08	0.29	3.07	0.29	3.06	0.29	3.06
S2	$0.5 < h \leq 1$ m	0.04	0.47	0.04	0.45	0.04	0.45	0.04	0.42	0.03	0.35
S3	$0 < h \leq 0.5$ m	0.08	0.83	0.06	0.61	0.05	0.57	0.05	0.49	0.04	0.45
S4	$h \leq 0$ m	0.00	0.05	0.04	0.46	0.05	0.53	0.07	0.77	0.10	1.10

Table 4. Results of the susceptibility analysis for different global sea level projections under the worst-case climate scenario.

		Scenarios in 2100			
		SSP5-8.5 (AR6) 0.77 m		RCP-8.5 (SROCC) 0.84 m	
Susceptibility Class	**Elevation Range (h)**	**km^2**	**%**	**km^2**	**%**
S0	$h > 5$ m	8.97	95.01	8.96	94.96
S1	$1 < h \leq 5$ m	0.29	3.05	0.29	3.06
S2	$0.5 < h \leq 1$ m	0.03	0.35	0.03	0.35
S3	$0 < h \leq 0.5$ m	0.04	0.45	0.04	0.44
S4	$h \leq 0$ m	0.11	1.14	0.11	1.20

The susceptibility analysis considering the long-term (2100) global scenarios (Table 4) has highlighted similar results with respect to the susceptibility analysis carried out taking into account local sea level scenarios. In fact, in both analyses, the areas considered safe (Class S0, very low susceptibility) correspond to some 95% of the total area. Similarly, referring to the long-term scenario, the areas characterized by very high susceptibility varies from 1.10 (SSP5-8.5, AR6—[3]) to 1.20% (RCP-8.5, SROCC—[12]) of the total investigated area (cf. Tables 3 and 4). An example of susceptibility map is provided in Figure 5, in which the areas potentially below the sea level in 2100 are shown in blue.

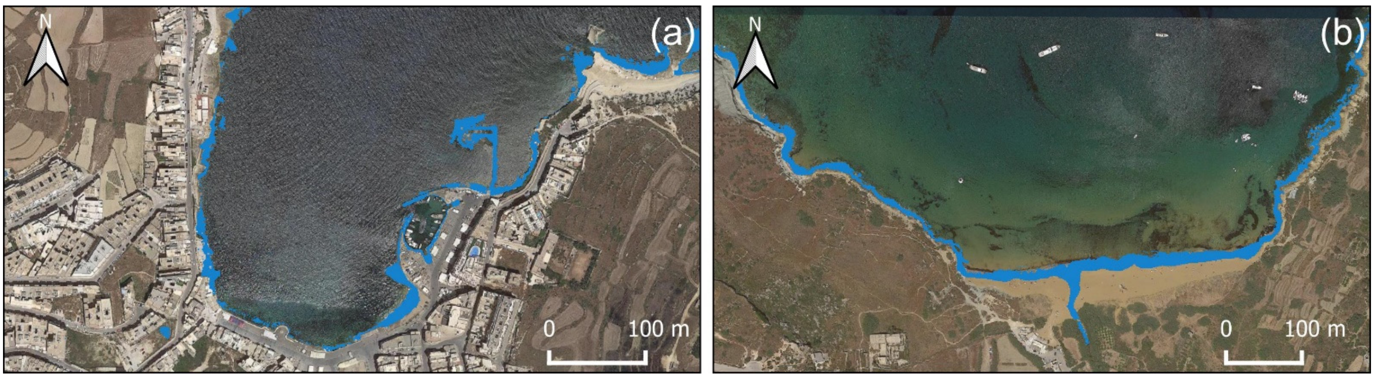

Figure 5. Areas of Marsalforn (**a**) and Ramla (**b**) bays falling in inundation susceptibility Class S4 are depicted in blue. Mapping is based on the local sea level projections in 2100 under the worst-case climate scenario.

In order to provide risk maps as useful tool for supporting stakeholders and decision makers in the land planning process, inundation risk scenarios have been evaluated for both local and global sea level projections. Safe areas (susceptibility Class S0) were excluded from the risk assessment. This means that the risk analysis procedure has been applied to approximately 4% of territory in the investigated sector. Although the investigated territory is not very large, it hosts the main tourist and economic structures of the areas and, for this reason, approximately 8% of its surface is characterized by very high-risk level. The results of risk analysis are shown in Tables 5 and 6 and mapped in Figure 6. In detail, in Table 5 the results are reported for the mid- and long-term scenarios under the best and worst local sea level projections provided in the AR6. According to these results, the area in Class R4 will increase from 2050 to 2100 from 5.2% to 6.4% under the scenario SSP1-2.6 and from 6.4% to 8.1% under the scenario SSP5-8.5. Similar results are obtained for global sea level projections (Table 6).

Table 5. Inundation risk for different local sea level projections under two climate scenarios.

	Scenarios in 2050				Scenarios in 2100			
	SSP1-2.6 (AR6)		SSP5-8.5 (AR6)		SSP5-2.6 (AR6)		SSP5-8.5 (AR6)	
Risk Class	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
R1	0.08	20.7	0.08	20.5	0.08	19.6	0.08	18.1
R2	0.25	65.6	0.25	64.8	0.25	62.0	0.24	57.9
R3	0.03	8.5	0.04	9.2	0.05	11.9	0.07	15.9
R4	0.02	5.2	0.02	5.5	0.03	6.4	0.03	8.1

Table 6. Inundation risk for different global sea level projections under the worst-case climate scenario.

	Scenarios in 2100			
	SSP5-8.5 (AR6)		RCP-8.5 (SROCC)	
Risk Class	**km^2**	**%**	**km^2**	**%**
R1	0.08	17.9	0.08	18.1
R2	0.24	57.6	0.24	57.9
R3	0.07	16.3	0.07	16.3
R4	0.03	8.2	0.03	7.7

As highlighted in Figure 6, the risk assessment results led to the identification of two hotspot areas, the bays of Marsalforn and Ramla, which therefore represent the locations that can be particularly prone to sea level rise and related effects.

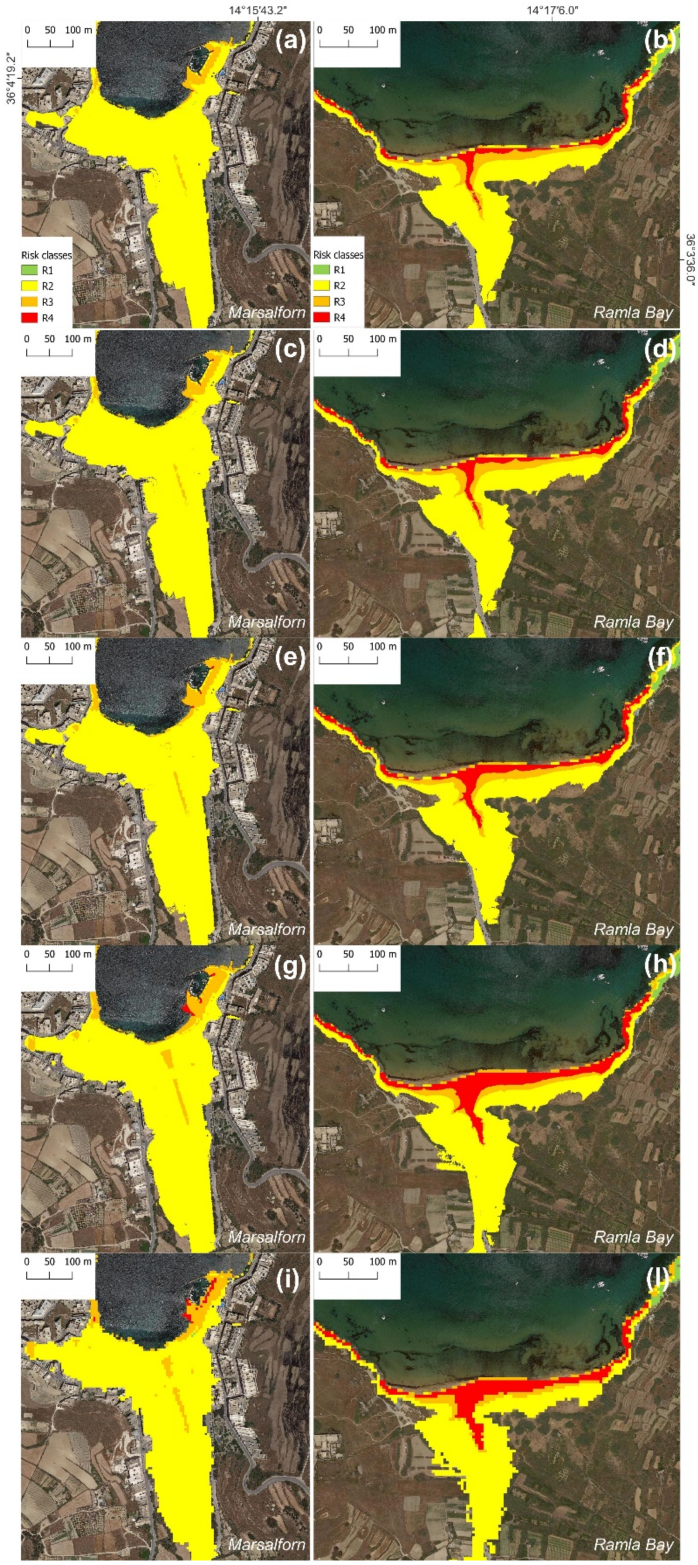

Figure 6. Maps of inundation risk classes and related potential effects, with reference to different local and global sea level local projections under two climate scenarios: (**a**,**b**) medium-term scenarios (2050) by accounting for the local sea level projections under the best (SSP1-2.6) climate scenario (0.19); (**c**,**d**) medium-term scenarios (2050) by accounting for the local sea level projections under the worst (SSP5-8.5) climate scenarios (0.23 m); (**e**,**f**) long-term scenarios (2100) by accounting for the local sea level projections under the best (SSP1-2.6) climate scenarios (0.40 m); (**g**,**h**) long-term scenarios (2100) by accounting for the local sea level projections under the worst (SSP5-8.5) climate

scenarios (0.73 m); (**i**,**l**) long-term scenarios (2100) by accounting for global sea level projections under the worst-case (RCP-8.5) climate scenarios (0.84 m).

6. Discussion

From the inundation susceptibility and risk analysis carried out in this study, it has emerged that, although most of the investigated area (95%) stands consistently above 5 m a.s.l., most of the activities and buildings are located along the coast within the remaining 5%, which can be affected by sea level rise. For this reason, it appeared very important to us to proceed by merging susceptibility with vulnerability data and provide stakeholders and planning authorities with useful and easy-to-read maps showing areas at risk of permanent sea inundation. The risk assessment analysis has allowed us to identify the bays of Ramla and Marsalforn as areas at high to very high risk, since coastline changes are expected to affect the economic and tourist activities present. Additionally, coastal retreat due to sea level rise can have an impact on the beach/dune system of Ramla Bay, which can cause a loss in terms of ecosystem services. These results are in line with the findings of Formosa [39], where the entire coastline of the Maltese Islands was investigated accounting for fixed values of future sea levels. As in this case, the recreation and tourism-related areas of Marsalforn and Ramla l-Hamra were included in the most exposed zones under all the considered sea levels. In addition, compared to the sea levels assumed for the assessments and adaptation measures in the Maltese islands by the Ministry for Rural Affairs and the Environment in 2004 and provided in the Climate Change Post [72] (corresponding to 50 cm in 2050 and 100 cm in 2100), our study has considered best and worst scenarios and therefore allowed definition of different risk levels for the investigated coastal sectors.

The study area is characterized by the absence of local factors (i.e., subsidence or uplift) contributing to future sea level variation, which instead characterize several coastal sectors of the Mediterranean Sea. By way of example, many Italian coastal plains suffer high subsidence rates which strongly increase the extent of the areas prone to sea inundation (e.g., Venezia and Grado lagoons along the northern Adriatic coast [73–75], Volturno and Sele coastal plains in southern Italy [25,76,77]). Similarly, Saylo and Marcos [78] have identified wide areas prone to inundation in the subsiding Ebro Delta. For those areas, flood risk maps under different sea level scenarios have been defined [78]. Similar analyses have been also performed along European coastal sectors subject to glacial isostatic uplift. This is the case of the Polish coast, for which the inundation scenarios have allowed the definition of social and economic impacts related to sea level rise, and suitable adaptation measures [79]. As also mentioned in the Introduction, sea level variation in the Mediterranean area has shown a spatial variability during the last decades (cf. altimeter period). Nevertheless, the Maltese Islands, not being affected by local vertical ground movements and being located in the central Mediterranean Sea, can be considered as representative of the baseline condition for the Mediterranean variation [8].

Despite the lack of contributions to local sea level increase, the intense urbanization that characterizes selected location on the coastline of the Island of Gozo favors the presence of wide high-risk areas, even if the highly susceptible territory is not extensive.

The proposed index-based methodological approach represents an effective way for assessing the potential impacts of rising sea level along the investigated coastal areas and for identifying those areas with higher risk level. This approach has the following advantages: (i) calculation of risk level and interpretation of results are uncomplicated, allowing a more effective benefit to stakeholders and administrators; (ii) it provides a spatial representation of the coastal environmental impacts suitable for both the regional and the local scale; (iii) it allows evaluation of differences among expected climate scenarios (and thus represent the uncertainty associated with the results); (iv) it takes into account projections for different time-periods (mid- and long-term scenarios); (v) it provides the temporal evolution of the accounted phenomenon. Nevertheless, being based on a number of parameters evaluated by means of expert-based judgments, its application in other contexts needs to be tailored accordingly to the local economic, environmental, and social aspects. In addition, in order to provide a more quantitative risk assessment level at the very local scale (in terms of single or group of buildings), high-resolution modeling approaches are required. Parameters related to the quantitative and probabilistic knowledge of the occurrence of a phenomenon (in terms of hazard) and of the expected damages (in terms of vulnerability) are not always assessable due to the lack of event-related historical data and to the difficulties in the estimation of economic, structural, and physical damages to buildings and anthropic assets in relation with different hazards characterized by variable magnitude/intensity level. In this context, qualitative approaches allow this gap to be addressed, thus providing the first level of zonation of the investigated territory, which is pre-requisite for supporting a better targeting of the economic resources and technological investments. In addition, it is important to highlight that an inundation risk assessment can be considered as one of the parameters to be evaluated in a more comprehensive multi-risk assessment framework, taking also into thorough consideration the past, present and future land and sea interface (cf. [80–82]). At the global and European level, the interest in the multi-risk assessment increased in the last decades [83,84], especially for the analysis in coastal areas, which result from potentially being exposed to different climate change impacts, such as storms, coastal erosion, saltwater intrusion, and sea level rise [9,10,85,86]. The calculation of the expected simultaneous impacts of different coastal hazards is considered of paramount importance for providing a comprehensive overview of the total risk arising from climate change for a particular investigated sector. Therefore, this study is to be considered preparatory for further research that will be aimed at providing a complete assessment of the marine- and climate-related processes (erosion, landslides, heavy rain, and fluvial flooding) impacting the coastal sectors of the Maltese Islands in order to account for each aspect contributing to the increase in the hazard, exposure, and vulnerability level in a multi-risk perspective.

7. Conclusions

The study focuses on inundation risks associated with sea level rise for different climate change scenarios, with the primary aim of mapping of the risks in a communicable manner. Using a coastal area in Gozo, it demonstrates how the adopted index-based method enables zoning of the investigated coastal stretch into different levels of susceptibility and risk related to sea level rise, providing clear guidance for future policy action.

The adopted methodological approach has been found to be cost-effective as it manages and processes the acquired data in a GIS environment, makes results communicable with relative ease, and without the need for much further interpretation or explanation. Its outputs are legible directly from maps with reference to the local context and the assets at risk. Additionally, the datasets and information used in this study are generally easily accessible, as in the case of topographic data, made available on demand for scientific purposes by many countries for easy download from national geoportals, as well as freely accessible IPCC future sea level projections. The proposed assessment procedure, the application of which can be extended to all the Maltese Islands, represents a useful tool for the identification of the areas with the highest risk levels, for which operative management actions should be implemented so as to reduce losses of natural resources and economic activities.

The representation of the outputs from the analysis through spatial mapping of the expected impact, under different scenarios, provides an effective means of communicating the significance of risk in the local context, thus enabling policy makers to take appropriate action for adaptation and for building resilience to climate change. The methodology seeks to bridge the gap between data-driven, expert-based analysis and climate change risk assessments, and the comprehension of their results by policy makers. It provides an output presented as a directly communicable inference of results from a technical analysis, into a form which can be taken up for policy action in practice.

The approach to climate risk assessment proposed also provides a stronger link between local-level susceptibility analysis and national policy making. The methodology and form of output in such specific terms is relatively new to the Maltese policy context, where, to date, no type of strategy for adaptation or defense to sea level rise has been planned [87]. A similar approach is to be adopted, in due course, in the diagnosis stage in preparation of a national coastal protection strategy for Malta. The Coastal-COVER initiative which is to take such a nationally strategic approach to coastal erosion, was instigated by landslide accidents linked to coastal erosion around the Maltese Islands, which has been associated with climate change effects. The approach offered by this paper reinforces the need to shape national policy for climate change adaptation on the basis of local susceptibility analysis. The outputs of the method proposed here, being readily communicable provide a basis for stakeholder engagement and consideration of local concerns into national policy in bottom-up fashion. Likewise, at a broader level, concerns for climate change impacts on the Maltese economy have led the Maltese Government to undertake a Vulnerability Risk Assessment (VRA). The results from vulnerability assessments from both the Coastal-COVER and VRA projects are likely to increase interest in climate risk assessment methodologies similar to the one adopted by this study. These approaches have the potential to bring about policy development in a bottom-up fashion. This is timely, with the broader influence of EU level policy and the increasing attention being given to climate adaptation and resilience strategies that highlight the needs for vulnerability assessment. The results of risk assessments, outputs of these two national projects, if communicated widely beyond the expert circles, can raise awareness and highlight the relevance of broader climate action goals to the local context, thus increasing the drive for policy convergence to EU level climate policy.

In combination, the bottom-up and top-down influence of risk assessment results on policy development, can potentially sharpen the focus on susceptibility risk assessments as basis for evidence-based policy actions for climate change, and, in response to sea level rise in particular. Whether or not the risk assessments and results from the aforementioned initiatives will lead to policy action in practice is something yet to be seen. This could possibly offer an interesting focus for future research to evaluate the effectiveness of the susceptibility and risk methodologies similar to the ones adopted in this study, in translating technical risk assessment and their results into policy action in practice. Nonetheless, the approach proposed by this paper highlights the opportunity to link local susceptibility analysis with national policy making.

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