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Research Article

Rising waters: Integrating national datasets for the visualisation of diminishing spatial entities

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Abstract. Preparing for the potential changes wrought by climate change can be grounded in commonly integrated real data. Efforts by various countries to prepare for such potentialities have resulted in a stepped-approach to data management and integration. Small island states experience an added burden through data limitations, disparate datasets and data hoarding. This paper reviews the processes employed in Malta that target a spatio-temporal analysis of current and future climate change scenarios aimed at integrating environmental, spatial planning and social data in line with the transposition of the Aarhus Convention, the INSPIRE Directive (Infrastructure for Spatial Information in the European Community) and the SEIS (Shared Environmental Information System) initiative. The study analyses potential physical and social aspects that will be impacted by sea-level rise in the Maltese islands. Scenarios include the analysis of areas that will be inundated, the methodology employed to carry out the analysis, and the relative impacts on land use and environmental, infrastructural and population loss. Spatial information systems and 3D outputs illustrate outcome scenarios.

Keywords: climate change, data dissemination, Aarhus, SEIS, INSPIRE, LIDAR

1 Introduction

Climate change analysis requires a high-end informational basis through which different types of datasets can be cross-analysed, a scenario that is hindered by data limitations, lack of access to information and disconnected datasets. From a situation that depended heavily on techno-centric approaches to data where a focus on technology as the fulcrum for analysis was taken as the norm, the increase in social datasets that may be cross-analysed against physical datasets has pushed research towards a more socio-technic approach. The latter has enabled the implementation of technologies as a basis of the spatial analysis of social science research. The work outlined by Fritz (2001) was tasked with the review of how different themes and phenomena interact through the study of the 'W6H' pivots; what is being analysed, why, when, where and how does something occur, who are the players involved, and what does it take to investigate the matter at hand. This methodology has pushed the boundaries of socio-scientific research dealing with spatialisation. In terms of the requirements for climate change analysis, studying the factors that impact on physical geographies and related social structures points towards the need for realistic databases. However, small island jurisdictions often suffer from data limitations, a siloing and hoarding of information within different departments, a lack of integrative approaches to data management and structuring, inter-departmental charging costs and an overall lack of data sharing protocols.

The study reported in this paper involved creating a new process through a series of steps, employing Geographic Information System (GIS) capability as its core functions. The results allowed for the depiction of a series of spatial information structures which, when using suitable visualisation tools, generate real immersive information registers. The creation of such technologies follows various actions and legislative transpositions of European Directives and/or United Nations conventions. These include SEIS (2015), Global Earth Observation (GEO2015, 2015), Public Sector Information (PSI) (OJ, 2003a), Infrastructure for Spatial Information in the European Community (INSPIRE) (OJ, 2007), Public access to environmental information (Aarhus) (OJ, 2003b) and Freedom of Information Acts (FOI) (Government of Malta, 2012).

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1.1 Early Days

The analysis of the socio-economic and structural effects of sea level rise in the Mediterranean, and specifically of the Maltese Islands, is still at an embryonic stage. The earliest studies go back only to the late 1990s: these triggered the first thematic and politico-scientific debates on climate change and its presumed impacts (Jeftic, Keckes & Pernetta, 1996; Feenstra, Burton, Smith & Tol, 1998). Malta still lacks a comprehensive risk assessment protocol that is organized along strategic research parameters (Briguglio, 2000; Farrugia, 2011; Ministry for Resources and Rural Affairs, 2004; Walker-Leigh, 2006). At European and international level, various attempts have been made to analyse the potential impacts of climate change and sea level rise (Goodchild et al., 1996; Klein et al., 2001; Tol, Klein & Nicholls, 2008). In Malta, national studies have been carried out by the University of Malta and other public entities (MEPA, 2003; Ministry for Resources and Rural Affairs, 2004; Ministry for Rural Affairs and the Environment., 2008; European Commission, 2009; Formosa, Magri, Neuschmid & Schrenk, 2011; Formosa, 2013). These studies collectively depict a scenario that requires in-depth analysis and evidence-based decision making through information systems integration. One key requirement is that of standardised protocols that engage with the spatial component to data, as governed by the INSPIRE Directive (OJ, 2007). Other studies sounded the alarm on the impact envisaged to specific sites: for example, digital elevation modelling showed significant deterioration expected at Ramla l-Hamra Beach in Gozo (Formosa & Bartolo, 2008); while Ġnejna Bay, limits of Mġarr, is similarly compromised (Zammit, 2011). Efforts to tackle the topic from an undergraduate locational perspective through the University of Malta have focused on transport vulnerability (Azzopardi, 2009).

The European Commission (European Commission, 2009, p. 2) states that "sea level rise (SLR) and coastal floods constitute less of a threat for the Maltese Islands, as just 5% of the total landmass has an altitude of less than 7.6 m above sea level and only 1% is located at an altitude of 1 m". However, the issue of storms and surges in Malta remains one of concern; and the fact that the island state is yet rather unprepared for such impacts requires further study, with the study of Busuttil (2011) on St. Julian's Bay being a pertinent example.

Research that looks at probable sea level rise is also backed up by studies that deal with the opposite end of the phenomenon, looking at the scaling back of the waters to ancient times, such as the Holocene study of Furlani et al. (2013).

In turn, the study carried out in the current paper seeks to identify the main areas that will be impacted through both sea-level rise and potential storm surges, adopting the EEA's maximal 13 m as the highest impact zone.

2 Methodology

Malta initiated a process to ensure that data is made available publicly, which comprised the setting-up of a series of data-management procedures that ensured that data can be verified and used across the thematic domains. This process was initiated through a series of steps aimed at reversing a scenario where an ad hoc and sporadic framework is deemed untenable, even more so when Malta is required to establish its requirements based on the INSPIRE Directive and Malta's transposition in 2009. GIS technology is highly adept, allowing many different departments and the public access to the same basemaps and databases such as the mapserver of the Malta Environment & Planning Authority (MEPA, 2015) and the Shared Environmental Information Systems (SEIS) portal (SEIS, 2015). This means that each department does not have to keep separate versions of other departments' maps and data in order to use them for their own needs. Features or attributes need to be modified and updated on only one basemap and database and then are shared by everyone. By creating a shared database, departments benefit from synergies as data is collected once but used many times. This process was initiated through a European Regional Development Fund (ERDF) project entitled 'Developing National Environmental Monitoring Infrastructure and Capacity' via which Malta was mapped in 3D and useful information on environmental themes helpful in the analysis of climate change and its effects on the islands was gathered (MEPA, 2009).

The basis for climate change analysis through the use of environmental, land use and social data was enhanced following seven main initiatives: the European environment information and observation network (EIONET, 2015b), the Åarhus Convention (EC, 2015), the INSPIRE Directive (INSPIRE, 2015), SEIS (2015), the EU European Climate Change Programme (ECCP, 2015), the UN Framework Convention on Climate Change (UNFCC, 2015b) and the UNFCCC (2015).

The EIONET's impetus in this international process was the setting up of an expert network that enabled data to flow to a common repository for users as well as ensuring a timely delivery of the relevant datasets (EIONET, 2015a). This dataflow was eased through the implementation of the Åarhus Convention with its requirements for access to information, access to justice and public participation. For example, the convention's article 4 obliges public authorities to make information available to the public in the form requested by the public, unless such requests are unreasonable or if the information already exists in another form.

The environmental data aspect being covered by the convention enabled the EU to target spatial data conformities and standardisation: these allow for better data harmonisation and cross-thematic integration, as required for the analysis of the effects of climate change. The main tenets of the INSPIRE Directive include the obligation by the public authorities of the EU member states to provide datasets and services that can be used for policy making, reporting and eventual monitoring. In terms of access, datasets need to be made accessible through readily-accessible interfaces that would be capable of being discovered, viewed, and downloaded. The final implementation instrument was called SEIS which, while not legally binding, enables the EU member states to bring together the various environmental datacycle initiatives and tools in order to propose the best way forward for the reduction of redundancy and multiple-reporting, employing the 'gather once/use often' principle. SEIS and its current input phase – entitled the Shared European and National State of Environment (SENSE) – is an integrated framework that has been expanded to the wider geographical, environmental, physical, social and economic data, enabling a reliable base for data analysis across the different thematic disciplines (EIONET, 2015c).

In specific thematic terms, the UNFCCC and the Kyoto Protocol processes have enabled researchers to analyse change and model approaches to the investigation of potential transformations, ranging from an estimated minimalist sea level rise of 88 cm by 2100 (UNFCC, 2015a) to the maximal 13 m estimated output reported by the State of the Environment Report published by the European Environment Agency (EEA, 2005, p. 69).

2.1 Database Preparation

Malta's attempts to integrate the requirements resulting from international initiatives and agreements has resulted in a process initiated in 2006 by the national planning and environment agency (MEPA) aimed at the creation of a physical structure for data collection, input, storage, analysis and dissemination. Such was enabled through an ERDF project entitled 'Developing National Environmental Monitoring Infrastructure and Capacity', an initiative compliant with the requirements of EEA dataflows. Its remit was to establish monitoring networks in line with EIONET requirements. The objective of the initiative was to provide free data dissemination to the public, inclusive of spatial, environmental and physical data through the Åarhus Declaration requirements, build infrastructure capability through the implementation rules of the INSPIRE Directive and create its own shared information systems.

At the time of drafting this paper, a project entitled SIntegraM (Spatial Integration for the Maltese Islands: Developing Integrated National Spatial Information Capacity) was being drafted to enable the integration of all Maltese spatial datasets into a single core (Formosa, 2015). This would allow for better real-time data analysis, predictive modelling and compliance with international standardisation protocols. The capacity to understand and deal with complex spatial problems through the organisation of data, view their spatial associations, perform multiple analyses and synthesize results into maps and reports would be greatly enhanced. This cycle has become a prerequisite for international collaboration and data integration, such as the EU's activities to ensure data harmonisation. One such example is the creation of the Corine Land Cover across all the EU states and neighbouring countries (CORINE, 2015). Other initiatives relate to ESPON (the European Spatial Planning Observatory Network), the Common Database on Designated Areas (CDDA), bathymetric and terrestrial data gathering through Global Monitoring for Environment and Security (GMES), the Group on Earth Observations (GEO), the Global Earth Observation System on Systems (GEOSS) and Copernicus (previously known as GMES, the European programme for the setting up of a European capacity for Earth observation).

2.2 The Malta Case-Study

The methodology employed for this study entailed sourcing spatial data in vector and raster formats, reprojecting the data to a common projection, and integrating this with a model for SLR analysis. Figure 1 depicts the process that is described further below.

The process included the conversion of the .las (LiDAR) format data to a TIN (triangulated irregular network) model which rendered a raster output. This enabled the identification of those areas that pertain to specific height ranges. Through the use of various GIS tools, the relative target zones (areas under threat of potential inundation) were extracted at heights of 0.5 m, 1 m, 2 m, 5 m, 10 m and 13 m respectively. These heights were taken to be consistent with the previous Malta-related studies, as well as the maximal EEA prediction models. It was assumed that the models underlined the highest passive sea-level rise, which however does not account for possible storm surges or 'medicanes' (Mediterranean hurricanes). Thus, the 13 m maximal was employed as a proxy to account for the eventuality of such surges.

The next step in the data preparation process entailed the conversion from raster to vector formats. This was carried out to extract the zones under inundation potential. The vector model was chosen since most spatial data created in Malta is available in this format; moreover, it allows for various queries, not readily available in raster format. Each of the resultant vector files were combined to ensure that the individual 'pixel' out-

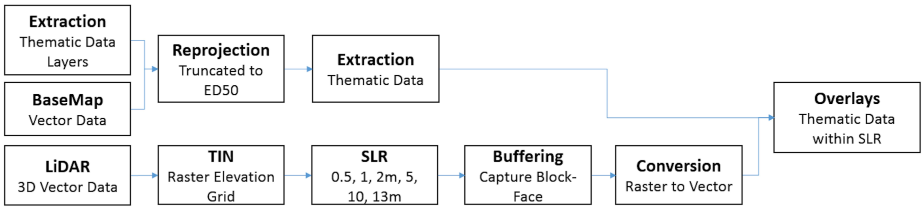


Figure 1: Methodological Process.

put from the raster was aggregated into homogenous polygons. The data was then cleaned through the removal of seacraft (higher than 0 m above the sea-level) residual from the TIN, a process that entailed the redisaggregation of the polygons and an elimination of any non-land 'pixel' polygons which proxied seacraft. This resulted in a layer that contains solely land-based polygons that was combined to render a single polygon layer for that height. All other layers were aggregated in turn.

The final step entailed the creation of a boundary area based on a 10 meter buffer which allows for potential 'flood zones' that are impacted by surges and other streets affected by the closures emanating from sea-level rise. The buffers were aggregated into one workspace and the relevant inundated layers were created.

The buffer zone areas were calculated as based on the actual inundated zone and the associated potential buffer zones. The spatial capture is based on the height under study; so the higher block-face infrastructure is not captured since the LiDAR data only posits the highest elevation available at any point. Thus, if a building has a height of 15 m and the rise under study is that of 5 m, whilst the street and open spaces would be captured in the analysis, the building's footprint would not. A buffer query was employed to enable the capture of the area falling within the building footprint, since it is assumed that any building that experiences inundation in its lower floors would be abandoned or rendered unusable.

This process shows that overlaying all the potential sea-level rise (SLR) heights under study is best served by the buffer layers as they have less 'holes' and are more structured to employ in the layering processing. Due to the projection incompatibility that Malta has yet to implement, all data was converted to a projection pertaining to the European Datum 1950 (ED50 Malta) to ensure cross-thematic analysis. Maltese data is available in a non-Earth projection and has to be converted to a real-Earth projection in order to allow overlaying of the thematic data over real-space data, as the LiDAR output requires. Various spatial data analysis tools were deployed here, inclusive of cookie-cutting, overlays, point-in-polygon and SQL querying. In addition, 3D analysis on the TIN files was carried out to render the potential changes to various areas. The findings depict the analytical outputs for the zones falling within the maximum projected SLR of 13 m.

2.3 Limitations

The study makes various assumptions that may affect the results in a real-world scenario. The main limitation lies in the fact that sea-walls or storm barriers may be built in the future, and such infrastructure could significantly halt, slow (or perhaps if badly designed, even exacerbate) the inundation of threatened, low-lying, inland areas. Such analysis may be taken up at a later stage of this study to investigate locations for the best placement of such barriers. Another limitation imposed on the study refers to the data point density on which the TIN map was created. The data employed was based on a high 4 point per metre density, as compared to the 10 metre point density normally used in such studies. However, achieving higher density counts would result in finer outcomes. In terms of thematic data, the currency of the data employed for residential and business entities has a 2013 timestamp which would change over the next few years and may result is a shift of activities to and from other zones. Predicting these changes in the short-to-medium term could be refined through the inclusion of information from strategic and local development plans as published by MEPA and other local organisations.

In terms of water flow rates, the model would be enhanced by a stream/valley data layer and a storm surge model that would show potential wave height, breaches of current barriers and of potential future sea-wall and/or barrier infrastructure. This paper assumes that the sea-surge will not be higher than the EEA prediction of 13 m SLR.

3 Findings

3.1 Findings – Spatial

The initial analysis to identify the zonal extent of the sea-level rise as based on the six heights under study (0.5 m, 1 m, 2 m, 5 m, 10 m and 13 m) took into account the buffer zones as detailed in the earlier section. The zones ranged from an actual area of $0.6\,\mathrm{km}^2$ for the 0.5 m SLR, whilst the actual affected area of the buffer zone amounts to 6.1 km^2. The latter area includes all the building footprints and the adjacent area that could potentially fall within the surge zone. Table 1 depicts the most affected zones, ranging up to a maximum of 21.4 km^2 for the TIN area and 29.6 km^2 for the 13 m buffer zone. The latter is equivalent to almost 10% of the total land area of the country. The TIN 0.5 m SLR and the 1 m SLR show relatively low areas being affected, a process that is extenuated when the buffers are brought to account. Figure 2 shows the areas from the entire Maltese archipelago that would be impacted by SLR.

Table 1: Buffer zone areas.

Height (m)	Area (km^2)	
SLR	Area in TIN	Buffer Zone
0.5	0.6	6.1
1.0	1.3	7.4
2.0	3.1	10.1
5.0	8.1	16.1
10.0	15.3	24.1
13.0	21.4	29.6

As expected, most of the coastal areas are affected, particularly in the northern/eastern coast of the islands which has a low degree slope as against the large degree slope verging on the vertical along the southern/western coast. The main areas affected are those that serve a variety of economic, environmental and social functions. They include Marsa (Figure 3(b)) that would experience an extensive impact with any range of SLR, Marsaxlokk and its industrial zone (Figure 3(d)), the agricultural Salina area (Figure 3(g)), the high-density Marsamxett Harbour (Figure 3(c)), the protected reserve at Ghadira Bay (Figure 3(e)) another protected reserve at St. Paul's Bay (Figure 3(f)), Marsascala, part of which would be rendered as a separate island (Figure 3(h)) and the Ghajn Tuffieha recreational/protected zone (Figure 3(i)). The smaller islands of Gozo and Comino would also be affected by SLR but to a lesser extent. The major impacts would be expected at places like the protected zones of Dwejra (Figure 3(j)) and Ramla l-Hamra (Figure 3(k)), along with the recreation and tourism-related areas of Marsalforn (Figure 3(l)), Xlendi (Figure 3(m)) and Santa Marija Bay, Comino (Figure 3(n)).

3.1.1 3D depiction

A visualisation exercise was carried out to enable the viewing of the areas under SLR from different perspectives. Such a rendition would help policy makers to prepare for such changes through immersive technology and

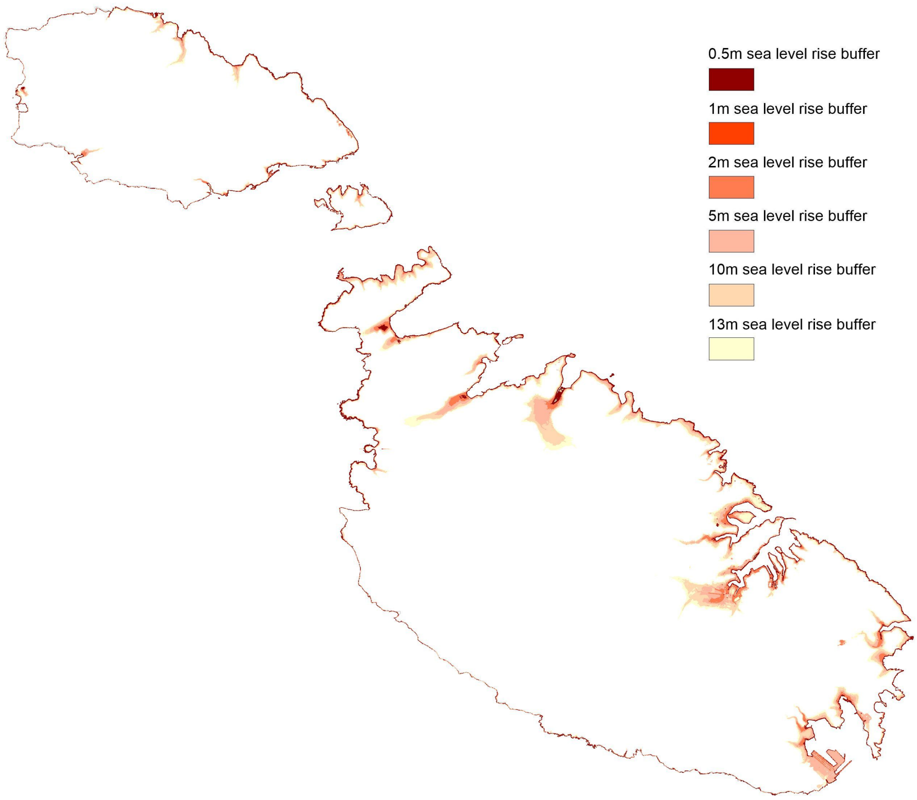
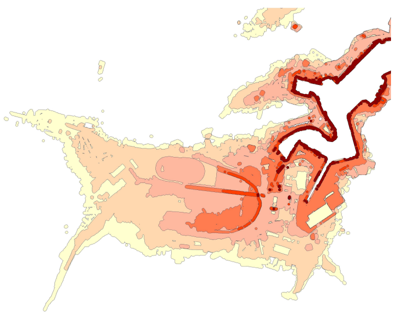
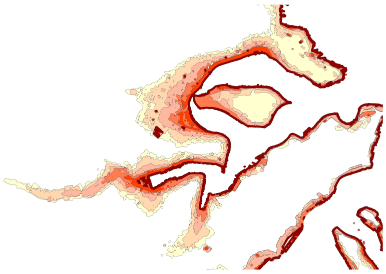


Figure 2: Sea level rise at the different potential rates.

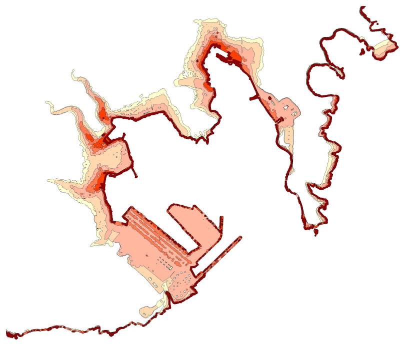
3(a) Legend



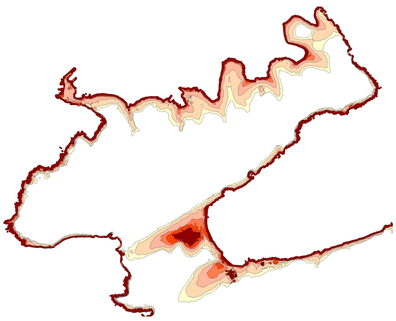
3(b) Marsa



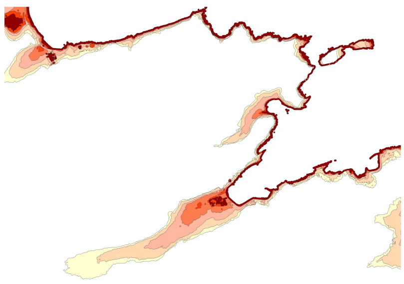
3(c) Marsamxett Harbour



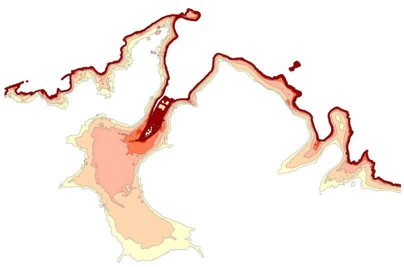
3(d) Marsaxlokk Bay



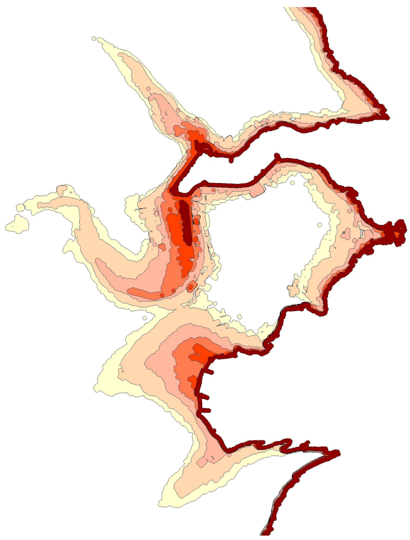
3(e) Ghadira



3(f) St. Paul's Bay

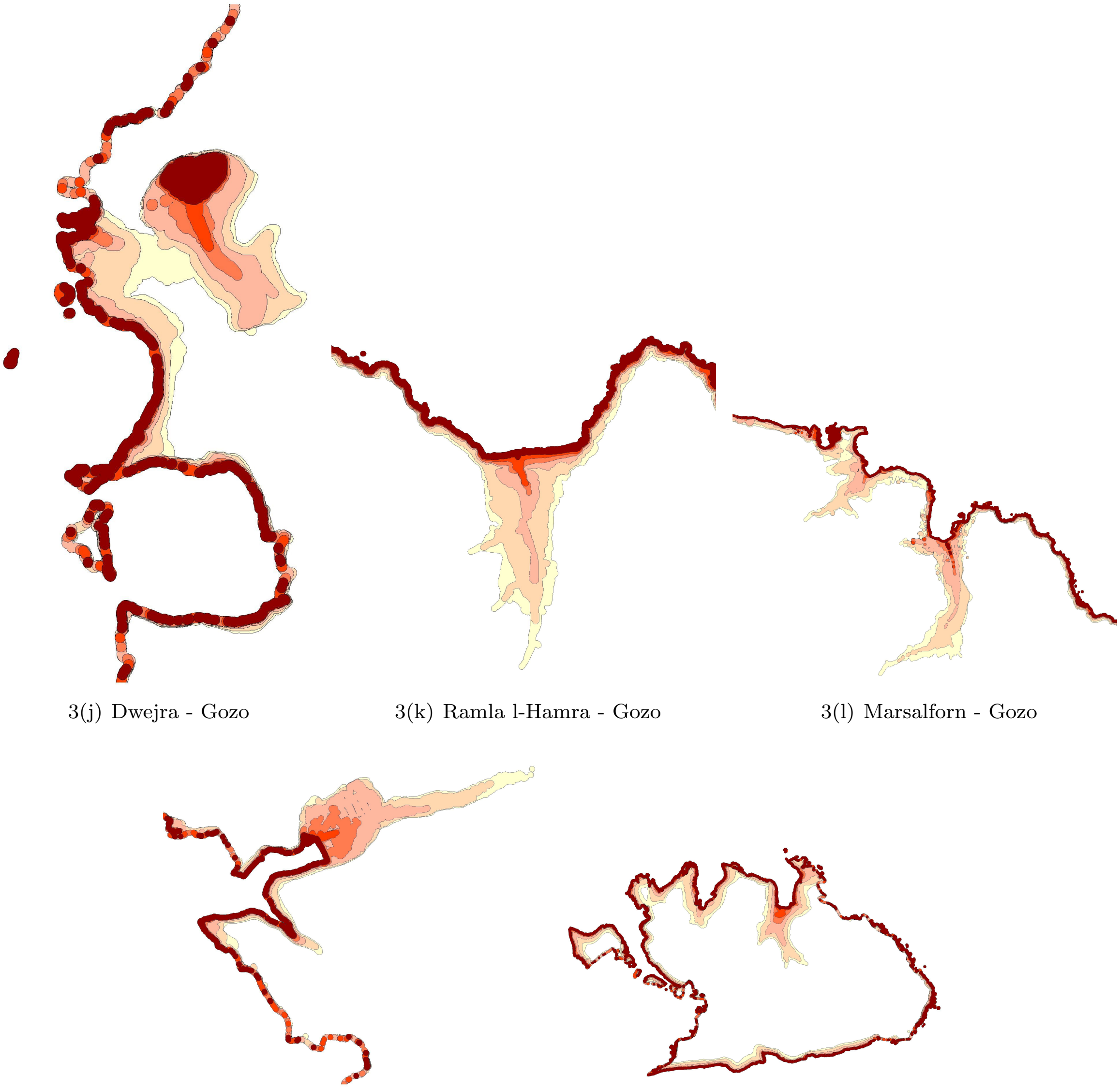


3(g) Salini



3(h) Marsascala

3(i) Ghajn Tuffieha



3(j) Dwejra - Gozo 3(k) Ramla l-Hamra - Gozo 3(l) Marsalforn - Gozo

3(m) Xlendi - Gozo 3(n) Comino - Gozo

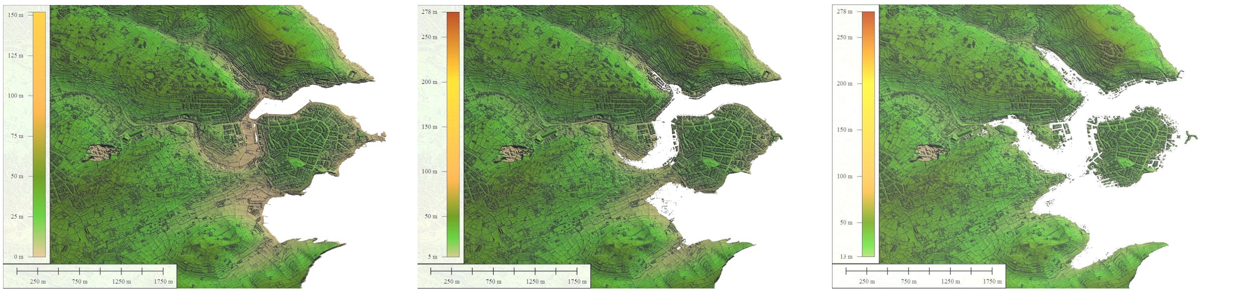
Figure 3

visual approaches. A rendition was carried out through a nadir (top-down aerial view) perspective of Marsascala's 0.5 m, 5 m and 13 m SLRs (Figures 4(a),4(b),4(c)), with the relative 3D perspective depicted beneath the relevant figures. The perspectives indicate the considerable area affected by SLR. Further analysis of the Marsa and Marsaxlokk zones, which can be expected to bear the greatest impact of SLR in the Maltese Islands, follows in Figures 5(a),5(b),5(c) and 6(a),6(b),6(c) respectively.

3.2 Findings – Thematic

3.2.1 Zoning Categories

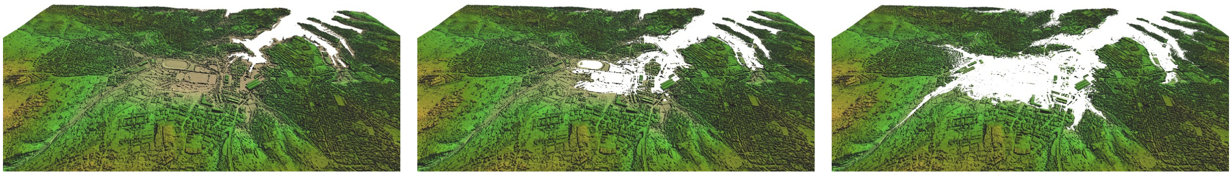
In terms of thematic analysis, the results show that the highly mixed use zoning (a mix of residential, commercial, industrial and recreational activities in one zone) evidenced in the Maltese Islands renders the outcomes distributed across various zoning categories where the main affected zones relate to protected areas, recreational areas and sports facilities that pertain to more than 13 km^2. Other highlighted zones include areas designated as constraints at 3 km^2 and transport at 2 km^2 area (Table 2). The residential zones pertain to 10% of the entire zone, which is related to the high dwelling



4(a) Marsascala - 0.5 m Nadir perspective 4(b) Marsascala - 5 m Nadir perspective 4(c) Marsascala - 13 m Nadir perspective

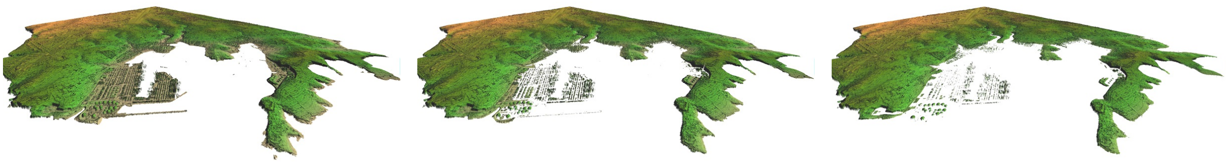
4(d) 3D perspective 4(e) 3D perspective 4(f) 3D perspective

Figure 4



5(a) Marsa – 0.5 m 5(b) Marsa – 5 m 5(c) Marsa – 13 m

Figure 5



6(a) Marsaxlokk - 0.5 m 6(b) Marsaxlokk - 5 m 6(c) Marsaxlokk - 13 m

Figure 6

density evidenced in Malta, with legislation that constrains construction outside specifically designated 'development zones'. The result is that most dwellings are clustered in very close proximity to each other near the coast resulting in high population densities there, as in the case of the Gżira-Sliema area (Figure 7).

3.2.2 Communications and Heritage

A communications-services analysis shows that of the transport corridors that pertain to both the arterial and distributary roads also forming part of the TEN-T network, 252 km in length, 49.7 km (19.7%) fall within the SLR buffer zone, effectively cutting off the main corridors linking the industrial zones such as in Birżebbuġia and Marsa-Kordin as well as the high-density transport section linking Valletta to the central zone. The SLR buffers also impact on 411.7 km (15%) of main and minor roads that service the communities falling within the zones under study. An impact of 11% on communications devices and all wired infrastructure is also identified (see Attard, this volume).

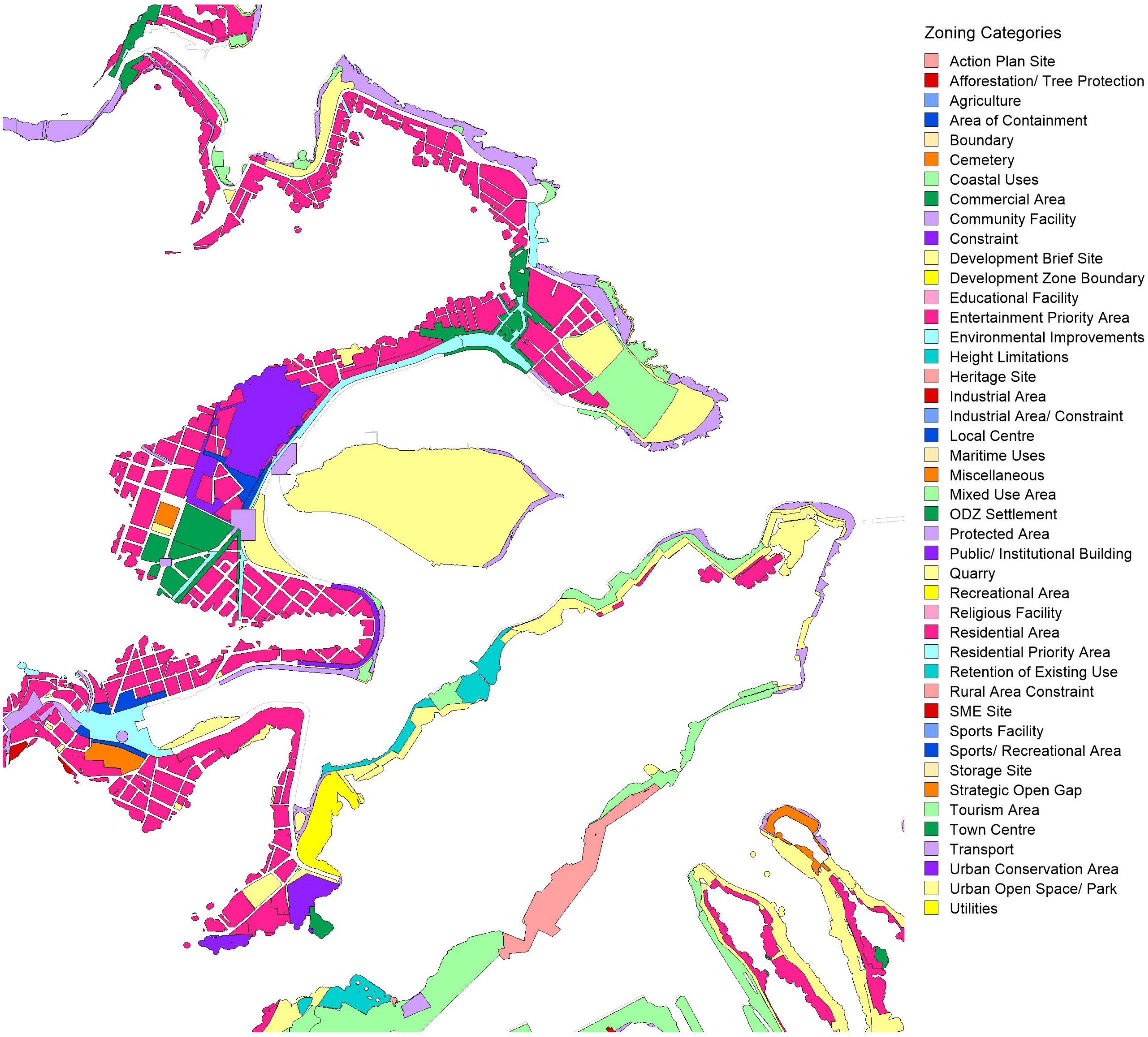


Figure 7: Distribution of Zoning Categories in Marsamxett Harbour.

Table 2: Area affected by SLR (in km^2) per Zoning Category.

Zoning Category	km^2
Protected Area	5.28
Recreational Area	4.64
Sports Facility	3.17
Constraint	3.14
Residential Area	2.29
Transport	2.16
Height Limitations	1.80
Development Zone Boundary	1.68
Storage Site	1.54
Coastal Uses	1.24
Boundary	1.13
Utilities	1.12

In terms of heritage assets, SLR in the zone under study will affect the most sensitive assets inclusive of four areas of archaeological importance, 25 archaeology schedules sites, two main areas of archaeological high landscape values inclusive of fortifications, 268 heritage protection sites covering over 12 km^2 and 700 scheduled buildings that have been tagged as of national significance. Most of these structures or sites are found in the Harbour zone, but others, inclusive of megalithic structures, are also found in the other areas that will also be heavily impacted by SLR.

3.2.3 Designated Zones and Landcover

Other affected zones pertain to the CDDA (Common Database on Designated Areas) that covers protected natural sites. Areas of ecological importance and special protection areas comprise 3 km^2 each, with that pertaining to sites of scientific importance covering another 2 km^2. Another 1.4 km^2 pertain to bird sanctuaries, protected beaches, tree protected areas and nature reserves. In conjunction with a review of the CLC (Corine Land Cover) 2012 exercise, the protected sites also border on zones that have diverse economic activity or even overlap. However, the main CLC designations within the SLR zones pertain to a discontinuous urban fabric at 5.8 km^2, agriculture, with significant areas of natural vegetation (4.6 km^2), sclerophyllous vegetation (4.2 km^2), port areas (2 km^2), complex cultivation (1.7 km^2), industrial or commercial units (1.6 km^2) and continuous urban fabric (1.3 km^2). Another 2.61 km^2 is taken up by sparsely vegetated areas, mixed forest, mineral extraction sites, non-irrigated arable land and salines in the rural areas, whilst the urban zones include sport and leisure facilities and green urban areas.

3.2.4 Building Infrastructure and Population

To review the impact of SLR on residential and commercial areas, a specific use analysis was carried out, based on the number of building units and resident population. This was made possible through the creation of data layers that were composed of attributes populated by demographic data (sourced from the 2011 Census), dwelling units (number of occupied and vacant residential buildings pertaining to the same Census obtained from the NSO), utilities data (sourced from MEPA), and data regarding commercial units (businesses, retail and recreational units (also sourced from NSO and MEPA). The buildings located in the SLR impacted areas total 34,094 units, with 5,015 commercial properties and 29,079 registered as residential units (Table 2). Whilst five thousand commercial companies are affected, the presumed impact on the resident population is comparatively low. This is because the SLR zones register only 0.99 person per household (33,849 persons as per Table 4 residing in the 34,049 units listed in Table 3), which is far below the national rate of 2.94 persons per household as per Census 2011 figures. This indicates that most of the residential housing stock under threat comprises summer residences, vacant dwellings or tourism-related units that are rented out for part of the year. In effect, the population data does not include those persons who are renting property in the area. This is supported by the fact that the main areas partaking to this category include St. Paul's Bay, Sliema and Birżebbuġia (in Malta), along with Żebbuġ (which comprises Marsalforn) and Munxar (which comprises Xlendi) in Gozo.

In terms of population counts affected by SLR, Sliema, Birżebbuġia and Gzira, St Paul's Bay, Marsascala and Msida are the towns most affected. Projected impacts here will be severe: they will affect some 60% of their resident population.

Table 3: Affected Building Infrastructure.

Locality	Commercial	Residential	Total
St. Paul's Bay	561	4234	4795
Sliema	808	3926	4734
Birżebbuġia	286	3057	3343
Gżira	546	2570	3116
Marsascala	204	2168	2372
Żebbuġ (Gozo)	108	1717	1825
Msida	334	1487	1821
St. Julians	278	1219	1497
Mellieha	164	1229	1393
Qormi	242	985	1227
Pieta	155	822	977
Marsa	438	494	932
Marsaxlokk	120	773	893
Cospicua	153	707	860
Ta' Xbiex	168	581	749
Senglea	62	564	626
Vittoriosa	71	489	560
Naxxar	38	516	554
Munxar	58	411	469
Xghajra	9	410	419
Valletta	94	324	418
Kalkara	53	221	274
Paola	65	175	240
Grand Total	**5015**	**29,079**	**34,094**

Table 4: Affected Resident Population.

Locality	Population
Sliema	4309
Birżebbuġia	4257
Gżira	3965
St. Paul's Bay	2822
Marsascala	2586
Msida	2211
Qormi	2154
Marsaxlokk	1559
Pieta	1304
Cospicua	1287
St. Julians	1114
Senglea	954
Marsa	848
Ta' Xbiex	837
Vittoriosa	694
Naxxar	589
Valletta	568
Żebbuġ (Gozo)	487
Paola	345
Kalkara	341
Xghajra	298
Mellieha	196
Munxar	124
Grand Total	**33,849**

The population data is further analysed as per Census 2011 enumeration areas; the analysis shows that the counts, as compared to the rest of the island, are high for the areas under SLR and which aids the identification of the real population density as against the residential versus the building counts. Some zones have a very high population count as compared to others; some census enumeration areas (each comprising 130 households) have a household size that is higher than the national mean, in some cases registering 4–5 persons per household. This finding shows that, whilst a large number of units are either registered as unoccupied, in affect those areas that are occupied have spots with high household rates, requiring population movement strategies in preparation for episodes of surge occurrence, which may lead to homes being abandoned. Whilst policy makers are in the process of creating information on critical infrastructure and drafting policies on the urban changes expected in the future (MEPA, 2014), the same documents do not cater for change in terms of sea level rise, further complicated by the placement of both economic generators such as tourism-related infrastructure, main roads and utilities infrastructure on the shore, inclusive of energy and water extraction facilities. Such have yet to be integrated into the national strategic preparedness scenario. In addition, a population strategy is still to be drafted, involving the integration of spatial datasets into a national spatial data infrastructure (Formosa, 2015).

4 Conclusion

The study of potential sea-level rise and surge scenario in Malta as investigated through spatial analysis depicts a need to integrate national datasets that would enable a modelling approach to SLR preparedness. This study has shown that a wide range of thematic aspects can impact on a small island, including such impacts as population growth and movement, building development, agriculture (see Meli, this volume), transportation infrastructure (see Attard, this volume), tourism activity (see Jones and Galdies, this volume), archaeological sites, heritage and protected sites. The high mixed use and land cover that islands exhibit posits a need to recognize that SLR changes can dramatically affect both natural and urban ecologies, with the result that communication modes are severed, population migration needs to be planned for, whilst heritage and protected sites risk being degraded and lost. Based on the outcomes of a 3D LiDAR scan of the Maltese Islands and taking stock of a number of related environmental themes, this paper has identified those areas most prone to SLR changes, with the analysis carried out at the maximal expectation of a 13 m SLR, The analysis was undertaken in conjunction with spatial data emerging from an integrated national spatial data framework, as required by international legislation (such as the INSPIRE Directive) and other tools emanating from climate change protocols.

One gingerly looks forward to a better integration of hard science with hard-nosed policy making in the face of the very real challenges of global environmental change, and of sea level rise in particular, on small island states like Malta.

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