**The Hazard Exposure of the Maltese Islands**

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**Abstract**

International comparisons of disaster risk frequently classify Malta as being one of the least hazard exposed countries. Such rankings may be criticised because: (1) they fail to take into account historic increases in population and its seasonal variation; (2) they are based on inadequately researched and incomplete historical catalogues of damaging events and (3), for small island states like Malta, they do not take into account the implications of restricted land area, which can be disproportionately impacted by even small hazardous events. In this paper, we draw upon a variety of data to discuss disaster risk in the Maltese Islands. In particular, the notion that Malta is one of the ‘safest places on earth’ is not only misleading, but also potentially dangerous because it engenders a false sense of security amongst the population. We argue that Malta is exposed to a variety of extreme events, that include: the distal effects of major earthquakes originating in southern Italy and Greece, plus their associated tsunamis; major ash producing eruptions of Mount Etna (Sicily), and their putative impacts on air transport; storm waves; coastal/inland landslides; karstic collapse; flooding and drought. In criticising international rankings of the islands’ exposure, we highlight the issues involved in formulating hazard assessments, in particular incomplete catalogues of extreme natural events. With Malta witnessing swelling resident, seasonal (i.e. tourist) plus foreign-born populations, and increases in the urban area, further research into hazards is required in order to develop evidence-based policies of disaster risk reduction (DRR).

**Keywords**

Maltese Islands, hazard exposure, disaster risk, vulnerability, hazard assessment

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**1. Introduction**

 In order to inform strategies of disaster risk reduction (DRR), international rankings of disaster exposure by country are published by a variety of bodies that include university-based researchers, risk advisory firms and supra-national organisations. In these evaluations, the Maltese Islands[[1]](#footnote-1) (Fig. 1) are consistently ranked amongst the countries least exposed to disaster risk, leading the *Times of Malta* to style the country the ‘safest place on earth’ (Camilleri 2011). Two examples from the many studies that have been published illustrate this point. The *Natural Disasters Risk Index* (NDRI) compiled by global risk analysts Verisk Maplecroft (2015) considers a variety of disasters relating to earthquakes, volcanic eruptions, tsunamis, landslides, flooding, storms, drought and high temperatures across 198 countries, and ranks the islands amongst the least exposed. The annual *World Risk Reports* and accompanying *World Risk Index* (WRI)[[2]](#footnote-2) meanwhile, compiled since 2011 by the University of the United Nations and Alliance Development Works (ADW), consider disaster risk for ca. 173 countries from earthquakes, floods, cyclones, drought and sea-level rise (e.g. ADW 2011, 2014, 2016), and consistently rank the islands in the penultimate position, with Qatar being the only country less exposed.

 These reports and others may be criticised on at least three counts: (1) they fail to take into account significant historic increases in population and its seasonal variation; (2) they are based on inadequately researched and incomplete historical catalogues of damaging events and (3) they do not take the land area of the states concerned into consideration. Indeed, the *WRI 2016* does not mention land area as an influence on overall disaster exposure and only includes 25 of the 46 Small Island Developing States classified by the United Nations, of which only six are in the top 20.

 In the Maltese Islands, the resident population has increased from ca. 219,000 in 1914 (Anon 1914; Anon 1915), to ca. 416,000 at the last census in 2011 and nearly 430,000 in 2014 (NSO 2016). In their post-census preliminary report, the Maltese National Statistics Office (NSO 2012) reported that with a total land area of ca. 316 km2, the islands had a total population density of 1,325 people per km2 (Fig. 2) making it one of the most crowded countries in the world, exceeded only by Monaco, Singapore and Bahrain. Associated demographic issues of concern for disaster risk assessment and management are exacerbated by the seasonal inflow of both tourists and Maltese expatriates who visit the islands every year, mainly though not exclusively during the Northern Hemisphere summer. Data from the Malta Tourism Authority and National Statistics Office (MTA 2013; NSO 2018) recorded ca. 2.3 million tourists in 2017, an increase of nearly 73% on figures for 2010 (i.e. ca. 1.3 million). In addition, the foreign-born population increased from 2% to 5% between 1985 and 2011 when compared to the national population, the majority of whom are expatriates born in the United Kingdom and the rest of Europe (Schembri and Attard 2013). A final population group that must be considered is the number of refugees arriving and staying on the islands. Between 2002 and 2016, ca. 19,000 refugees arrived in the islands, primarily from North Africa, of whom an estimated 30% remain in Malta (UNHCR 2017). As recognised across a range of countries, tourists[[3]](#footnote-3), expatriates and any stateless persons (which may include refugees) often have far less accurate perceptions of risk than indigenous people and, therefore, may severely stretch the resources of agencies concerned with civil protection (Alexander 2002, p. 249-251; Wallenstein et al. 2015, p. 220). A related factor that is not considered in these reports concerns the rapid and often speculative building of infrastructure across Malta and Gozo, with the urban ‘footprint’ increasing from 4.5% of the total land area in 1960, to 23% in 2001 and reaching 33% by 2013 (Galea 2007; Anon 2013a). This has served to increase the percentage of the population exposed to hazards generally and, since much of this new development has been at or near to the coast[[4]](#footnote-4), to the effects of coastal cliff collapse and storm surges in particular. More infrequently, there is also the risk of inundation by tsunamis.

 It is not only the character of hazard exposure that has changed, but it is also clear that it is only because of the probabilistic nature of extreme events impacting vulnerable people that the islands have not been more severely affected in recent years. One issue that has frustrated detailed hazard assessment is a lack of long historical records of extreme events and their impacts. For example, the seismic catalogue even for large magnitude earthquakes is only complete from 1542 (Galea 2007) whilst the records of storms, floods, landslides/coastal collapse and sinkhole development are even more fragmentary (see section 2).

 In this paper, we draw upon a variety of data sources to describe and discuss disaster risk on the islands in light of their international rankings. In addition to data collected in the field, we make use of published research findings, archives and our own interpretations of possible disasters in the past that are recorded in literature and legend. At present, historical catalogues are inchoate, are often far from being fully robust but allow, not only a critique of the conventional wisdom that the islands’ people lack any significant hazard exposure, but also enables conclusions to be drawn that may assist in the development of DRR policies and practices.

**2. Environmental Extremes and Historical Catalogues**

 The natural hazards faced by the Maltese people are a function of three factors that make the islands susceptible to extreme natural events: (1) regional tectonics, (2) geology and geomorphology, and (3) weather and climate.

**2.1. Regional Tectonics**

 Although the Mediterranean region is tectonically complex, the principal process involves collision between the Eurasian and African tectonic plates (Carminati and Doglioni 2004; Goes et al. 2004; Papazachos et al. 2006; Baldassini and Di Stefano 2016; Galea 2017). As Fig. 3 shows, the principal Euro-African plate collision margin passes about 200 km to the north in Sicily and along the Hellenic Arc to the east, while the seismically active Hyblean-Malta Escarpment is situated about 100 km to the east (Galea 2007, p. 725). The Maltese Islands are aligned NW-SE along the Sicily Channel, are located approximately 200 km south of the convergence boundary of the relatively stable Pelagian Platform (Galea 2007) and are surrounded by the Calabrian Arc subduction margin, the Hyblean-Malta escarpment and the Pantelleria Rift (Tinti et al. 2005 – see Fig. 3). It is because of this regional tectonic setting that the islands are exposed to the effects of earthquakes originating in eastern Sicily, the Sicily Channel and the Aegean.

 A summary of historical earthquakes with an intensity (*I*) of ≥V, and which have caused significant damage is presented as Table 1, but a number of points – in addition to those relating to the inadequacy of the catalogue (see section 2.1.1) – require elaboration. First, although some major earthquakes may be assigned with confidence to eastern Sicily and the Aegean, others can only be tentatively located within the Sicily Channel to the north of the islands (Fig. 3). It is large distant earthquakes – especially from the first two areas – that have caused the most significant damage and not those which have been generated either in the Sicily Channel or from south of the islands. The ‘far field’ effects of large earthquakes are known to differ from those felt close to epicentres and, whereas many types of buildings are affected in the latter locations, in the former damage is more selective. During historic earthquakes, ‘low frequency structures’ (e.g. high-rise complex buildings, like cathedrals, large churches and palaces), suffered far greater damage from large distant earthquakes than ‘high frequency structures’ (e.g. ‘stiff’ buildings, such as small chapels and low-rise houses with simple square or rectangular shapes). This is because high frequency waves are more rapidly attenuated with increasing distance from a given epicentre than low frequency waves (Chester and Chester 2010).

 A second feature not captured in Table 1, concerns building type and location. Vulnerability does not depend solely on a building’s frequency response, but also on other factors such as design, the quality of maintenance and the geological substrate[[5]](#footnote-5). All of these factors are considered in more detail when the impacts of historically damaging earthquakes are discussed in section 2.1.1.

 Finally, earthquakes are not just associated with ground shaking, but are also capable of generating tsunamis and triggering slope failure. Some tsunamis have been directly observed on the islands, such as those of 1693 and 1908 (Camilleri 2006), whilst others have only been inferred based on the presence of large imbricated boulders on beaches and shorelines. The emplacement process of these boulders, however, remains contentious with tsunamis and storm waves both being posited for examples along Malta’s northern coasts (e.g. Mottershead et al. 2014, 2017; Biolchi et al. 2016; Causon-Deguara and Gauci 2016). It has also been argued that earthquakes have triggered slope failure on numerous occasions (see Table 2), this being particularly associated with outcrops of Blue Clay (BC) (Fig. 4), both at the coast and inland (Soldati et al. 2011; Panzera et al. 2012; Devoto et al. 2013).

 Associated with the regional tectonics of the central Mediterranean, there are a number of volcanoes which are active, or have been active in the last 500 ka. These are the volcanoes in the Pantelleria rift system, Mount Etna on Sicily and the Aeolian Islands to the north of Sicily. Tephra fall from explosive eruptions of Mount Etna pose a particular threat to the islands. Until recently, infrequent distal ash falls from Etna would have been a nuisance but of no economic significance. Today, tourism is an important part of the economy that requires the uninterrupted use of Malta International Airport, and any episode of prolonged ash fall would cause major disruption and could be economically disastrous (Azzopardi et al. 2013 – see sections 2.1.2 and 3).

**2.1.1. The historical catalogue of earthquakes and earthquake-related phenomena**

 The damage caused by earthquakes to the Maltese people and their activities is summarised in Table 2, and from this, a number of points emerge. First, the events listed are ones that have exceeded a maximum intensity in the islands of *I=*VI and are relatively rare, however smaller earthquakes are far more frequent but remain matters of curiosity and cause little if any damage[[6]](#footnote-6) (Galea 2007; Anon 2014a). Local intensities of *I ≥*VIIare required before serious damage is caused to traditional buildings constructed of un-reinforced brick and stone blocks (Table 2).

 Secondly, several writers (e.g. Abela 1969; Galea 2007, 2017) stress that historical knowledge of damaging earthquakes is sorely deficient. Not only is the information after 1542 incomplete, but damaging earthquakes before this date – though absent from the record – may be inferred to have affected the islands. For example, the 1169 Sicilian earthquake had the same source, intensity at the source (i.e. *I=*XI) and probably a similar epicentral location as that of the 1693 earthquake, yet there are no records of its impact on the Maltese Islands (Azzaro and Barbano 2000; Branca et al. 2015). This is an instance whereby absence of evidence is not necessarily the same as the evidence of absence. ‘Gaps’ such as these have major implications for the modelling of the islands’ earthquake risk. For example, the calculated return interval of an intensity V event is just 18 years, for a VI event it is 40 years, for a VII event 92 years, and for a *≥*VIIIevent it is ca. 1000 years. However, if data from 1169 are included, then the return interval for an *I≥*VIIIevent falls to ca. 475 years (Galea 2007, p. 737-8).

 Thirdly, two of the major historical earthquakes, those of 1693 and 1856, affected traditionally constructed buildings and small populations of ca. 51,000 in the case of the former (Buttigieg 2011) and 123,000 (NSO 2012) in the case of the latter. As many buildings, including churches, public buildings and other elements of the historic patrimony are of similar, indeed in many cases the same, construction as the buildings affected in 1693 and 1856, and that today the population is approximately eight times greater than it was in the mid-nineteenth century, it is clear that the Maltese Islands are vulnerable with respect to their architectural heritage[[7]](#footnote-7).

 A fourth point to consider is that reports of responses to earthquakes frequently claim that people panicked. This is clearly incorrect because if accounts from the islands and elsewhere are examined in detail, it is apparent that the reports frequently represent journalistic ‘licence’ and imprecision/sensationalism because true panic involves “irrational, groundless, or hysterical flight that is carried out with complete disregard for others” (der Heide 2004, p. 342). Reports make clear that, although people were frightened, they still acted in a rational manner by seeking shelter on ships, in underground caves/excavations and in caring for loved ones. The authorities also acted rationally in assessing damage in a systematic way. The sources used to compile Table 2 further refer to people framing disasters in religious terms, a tendency that has also been noted in other Maltese disasters (see section 2.3.1). For example, one document claimed that the lack of deaths in 1693 was due to the direct intervention of St. Paul, the patron saint of Malta, who directed Divine wrath to religious buildings and away from the people following acts of penance, confession and frequent expositions of the Holy Sacrament[[8]](#footnote-8) (Azzopardi 1999, p. 2; Ellul 1999, p. 30). Indeed, the role of the Church and the Knights of Malta (see Table 2) in both providing immediate disaster relief and in planning and paying for recovery is well documented, especially in the context of recovery from the islands’ most serious earthquake in 1693. In fact, some of the new buildings constructed after this event rank amongst the islands’ most lavish and richly decorated (Azzopardi 1999; Ellul 1999).

 The 1856, and to a lesser extent the 1886, earthquakes (Table 2) were the most recent events to inflict major damage to the building stock of the islands, but since then the islands have been transformed, being required to accommodate a greatly increased population and a widened economic base both in traditional buildings and in new forms of construction. It is important to consider whether this represents ‘newly generated vulnerability’ (Alexander 1997, p. 292), a boost in resilience, or a subtly nuanced picture containing elements of both. The studies that have been published to date (Camilleri 1999, 2003; Galea 2007; Borg et al. 2008; Vella et al. 2013) give few grounds for optimism but allow the following summary statements to be made:-

1. The most frequently used building stone is Globigerina Limestone (known locally as *Franka*), with polished Upper Coralline Limestone (UCL) (Gozo Marble) being employed for some facings and crushed Lower Coralline Limestone (LCL) for concrete aggregate (for a discussion of Maltese rock types see section 2.2). In the nineteenth-century, floors were supported at ground level by masonry arches and timber beams at upper levels, but by the early-mid twentieth century, steel joists and reinforced concrete largely replaced this form of construction; some exceptions being noted in the islands’ local planning legislation in relation to the development of village cores (Buhagiar 2005). Today and at lower levels, framing by concrete beams is often used to create a ‘soft storey’ (Cicero et al. 2016), comprising an open layout for car parking and/or commercial use with a lack of internal vertical and horizontal support, thereby adversely affecting the strength of the whole structure (Galea 2007).

2. If buildings are classified according to the European Macroseismic Scale 1998 (EMS-98) (Grünthal 1998) [[9]](#footnote-9), then for those located on ‘hard’ LCL or UCL, the Mean Damage Ratios (MDR)[[10]](#footnote-10) for a local *I=*VII earthquake, equivalent to the highest estimate for a ‘1693 event’, would be: Type A - 60%; Type B - 45%; Type C - 10%; Type D1 - 12%; Type D2 - 6%; Type D3 - 3% and Type D4 - 1%. It is because of the interaction between the geology and buildings (Pace et al. 2011; Farrugia et al. 2016), that buildings located on Blue Clay (BC) and Greensandwill be much more severely impacted. For instance, a Type C building subject to an *I=*VI event will have a MDR of 10% rather than 1% and, if located on backfill, 25% (Camilleri 1999). Galea et al. (2016) have calculated the resonance frequency of small to medium height buildings to be 2-10 Hz, similar in fact to that of the BC,thereby causing such buildings to be severely affected when built on this substrate*.* Some strategic public buildings have been seismically engineered (see section 3), but hardly any residential buildings are earthquake resistant (Galea 2007).

 The principal earthquake-related hazards on Malta are tsunamis and seismically-induced mass movement. The most well studied tsunami is that produced by the 1908 Messina earthquake in north-east Sicily which caused damage along the south-east and north-east coasts of Malta. Damage to boats, buildings and houses was noted in Sliema, Msida, Pieta and Marsaxlokk (Borg et al. 2016 – Fig. 1) [[11]](#footnote-11). Tsunamis were also recorded following the 1693 earthquake. In view of the fact that the Messina Straits and Eastern Sicily both experience tsunamis with a probability of 1-in-100 years (Camilleri 2006), and that if the effects of the 1693 tsunami in Xlendi (Gozo) were repeated today, then waves with run-up heights of 5-7 m would encounter multi-storey buildings located near to the shoreline before penetrating ca. 300 m inland.

**2.1.2. The historical catalogue of volcanic phenomena**

 The eruption of Eyjafjallajökull in Iceland in April and May 2010 brought renewed European attention to the dangers of volcanic ash to air transport (Alexander 2013). With the Maltese economy being so dependent on tourism in general and air transport more particularly, the fact that Malta International Airport is only ca. 210 km SSW of Mount Etna is a cause for considerable concern. Mount Etna is one of the few continually active terrestrial volcanoes and persistent summit activity is punctuated by periodic flank eruptions which are either predominantly lava effusions with durations of days to years (Class A), or less frequent more violent strombolian events (Class B) that produce significant eruption columns and which cause tephra to be dispersed over distances of tens to hundreds of kilometres downwind (Branca and Del Carlo 2005). It is the latter which have closed Catania airport on several occasions since 1990 (Guffanti et al. 2009) and which pose a particular threat to the Maltese Islands.

 Despite a lack of detail concerning the extent of volcanic ash deposition on the Maltese Islands, historical records show that major historical eruptions of Etna that deposited ash on the Maltese Islands occurred in 1329, 1694, 1787, 1863, 1886, 1892, 2001 and 2002-03 (Branca and Del Carlo 2004). Using this historical catalogue, Azzopardi et al. (2013, p. 13) calculated that the probability of Etnean ash reaching the islands during an eruption was about 15% per annum. Assuming a north-easterly wind direction, it would take between 4 and 6 hours before ash reaches the islands, giving the authorities time to prepare an immediate response by closing the airport and diverting incoming flights, assuming appropriate warning was provided and protocols were in place to enable such swift action to be taken (see section 3). In addition, and using three scenarios based on the 1998, 2001 and 2011-12 eruptions, together with an ash dispersal model first developed for the Alaskan volcanoes, Azzopardi et al. (2013) were able to model the effects and distribution of tephra-rich plumes on the Maltese Islands. Whilst there is very limited research on the possibility of natural soil contaminants from Etnean ash, they find that as the simulated ash deposition on the islands is in the order of 0.01 g/m2, no particular damages to vegetation should be considered given a threshold value of 10 kg/m2 (Bonadonna et al. 2005; Azzopardi et al. 2013, p. 19). Furthermore and as is the case with earthquakes, Azzopardi et al. (2013) found that the Maltese were largely unaware of this category of hazard[[12]](#footnote-12).

**2.2 Geology and Geomorphology**

 The Maltese Islands predominantly comprise of a sequence of sub-horizontal Oligocene-Miocene shallow water carbonate sediments and clays that dip at low angles towards the north-east. As a result, the cliffs on the south and west coasts are high – for example Dingli cliffs on the south-west coast are the highest point on the islands at 253 m – whereas the east and north coasts are low-lying with drowned coastlines, such as those comprising the Grand and Marsamxett Harbours, being common (Fig. 1).

 Since the nineteenth century, five principal rock formations have been recognised (Fig. 4) and these have been confirmed by later research (Pedley 1975; Pedley et al. 1976, 2002; Scerri 2017). They are, from youngest to oldest: Upper Coralline Limestone (UCL), Greensand, Blue Clay (BC), GlobigerinaLimestone and Lower Coralline Limestone (LCL). The LCL belongs to the Oligocene whilst the remainder of the sequence dates from the Miocene with only limited outcrops of Quaternary deposits on the islands (Pedley 2011; Scerri 2017). The ‘hard’ LCL and UCL represent marine facies ranging from shallow water fossil reefs to deeper algal pavements; the Globigerina Limestone comprises both hard and soft layers of limestone whilst the BC lithologies range from dark grey to pale grey marls and clays. Greensand crops out as a thin porous layer ca. 1 m thick, whereas the BC is more extensive, soft, compact when dry, yet malleable when wet. From a hazard perspective, the BC is a problematic formation. This is due to the fact that, as well as being associated with seismic wave amplification (Pace et al. 2011; Panzera et al. 2012), the BC is easily weathered and forms rounded slopes, often covered with debris, that bear witness to its role as a factor in gravity-induced processes of mass movement both inland and at the coast (Farrugia 2008; Soldati et al. 2011; Mantovani et al. 2013; Galea et al. 2014; Schembri 2014).

 Geology and tectonics have strongly controlled the islands’ geomorphological development over time (Alexander 1988; Baldassini and Di Stefano 2016). Whilst southern Malta and northern Gozo are only mildly faulted, northern Malta and southern Gozo have been dissected into a horst and graben series by a system of NE-SW trending normal faults (Fig. 4). However tectonics and geology not only control the disposition of the macro-relief, susceptibility to landsliding and cliff collapse, but also the drainage pattern where a WSW to NNE alignment is dominant over streams flowing to the south and south-west, further reflecting the overall tilt of the islands to the north-east (Prampolini et al. 2017). Incision has also produced *widien*[[13]](#footnote-13) throughout Malta and Gozo, up to several kilometres long and tens of metres deep, while the eastern flank of the Rabat Plateau is incised by a series of north to south trending dry valleys (Alexander 1988, p. 48). Although dry for most of the year, episodes of intense rainfall mean that flash floods are a major recurring threat to the islands’ people and their activities (see section 2.3.1). Since the islands were first settled ca. 7-6,500 years ago this situation has been, and continues to be, exacerbated by human impact on the landscape (Cyffka and Bock 2008; Carroll et al. 2012). Karstic collapse meanwhile has been a feature of the geomorphological development of the islands and the possible hazard implications of this phenomenon are considered below.

**2.2.1. The historical catalogue of extreme geomorphological events**

Whereas catalogues of earthquakes and volcanic eruptions that have impacted the Maltese Islands are largely incomplete, those for karstic features, landslides and cliff collapse are almost non-existent.

 Large circular depressions located on massive beds of coralline limestone, first described by Spratt (1843), were identified as dolines, or karstic collapse depressions in the late-1930s by Trechmann (1938) and today 57 are recognised across the Maltese Islands. Some 90% are associated with the UCL, with the greatest concentration being on Malta and found along the Rabat-Dingli plateau (Fig. 1), whilst 23% of known dolines occur on Gozo (Calleja 2016). Processes of formation on the islands have been widely debated (e.g. Pedley 1975; Newbery 1976; Illies 1980; Galve et al. 2015) with many believed to have been formed during the Miocene. There is evidence, however, that some collapses may have occurred in historical times. For example, the formation of the large Il-Maqluba sinkhole (Fig. 1) is generally accepted in folklore, oral history and legend to have formed in the 1300s yet there is no research into whether this represents an isolated example of Holocene collapse or the degree to which the islands are at risk of further karstic collapse. Indeed a doline at Baħrija, north-west of Rabat, may be another example of late Holocene collapse as the depression contains archaeological materials of Medieval date (Buhagiar 2007, p. 369) - although lack of evidence of older material settlement cannot be taken as definite evidence of absence of earlier occupation. From other karstic areas in the world, it is acknowledged that land-use changes, such as increases in the depth of water tables, variations in static and dynamic surface loads and vegetation removal, can accelerate and/or trigger the development of such dolines (Gutiérrez et al. 2014, p. 67). Changes such as these are of relevance to the current situation in the Maltese Islands and, because of the consequences of a collapse in an urban area, further research on doline formation is timely.

 As is clear from press reports, erosion of coastal cliffs is a growing area of public concern on Malta. The collapse of the world famous sea-stack and arch, known as the *Azure Window* at Dwejra on Gozo on the 8th March 2017, caused widespread regret and concern amongst both the Maltese and the international community who have visited the site over the years (Anon 2017a). No one was killed or injured, but if the collapse had occurred when the area was packed with visitors then the consequences could have been catastrophic. In recent years, much research has been carried out on landslides and the collapse of coastal cliffs in the Maltese Islands, but no catalogue of historical events has been compiled. Indeed, given that many events have occurred in remote areas such as the cliffs of the south-west, west and north-west coasts of Malta and have historically affected few people, it is unlikely that any accounts exist. In fact the only sources of information about events of this type are: (1) oral testimony of local people; (2) media reports of events (e.g. Magri 2009); and (3) what can be recovered by field investigation and/or the remote sensing of landslip ‘scars’ which mark sites where landslides have been generated in the past (Dykes 2002; Devoto et al. 2013; Mantovani et al. 2016). The fact that some slope failures occur in densely populated areas and that urban and tourist ‘footprints’ are rapidly increasing (section 1), means that risk is both increasing and spreading over a wider area.

 From this developing research field, two principal conclusions may be drawn:-

1. As mentioned in section 2.1.1, the BC is a particularly problematic formation, as seismic waves are known to have triggered historic slope failures (Table 2). Slope failures, including mudflows, landslides and rock mass movement, are also generated when the clay is wet. Whilst Dykes’ (2002) study concluded that mudflows in the area around Għajn Tuffieħa Bay, including the neighbouring Golden Bay, present a low risk to people and their activities due to their sporadic and localised nature, the instability and rock mass movement resulting from clay displacement, is believed to present the greater risk. With increased tourist development in this area, the vulnerability from these latter hazards may potentially increase.

2. BC cropping out below UCL, defines a particularly problematic situation, and as a result detailed studies have been carried out at numerous locations: Xemxija Bay (Panzera et al. 2012); the coastline between Paradise Bay and Ras il-Pellegrin (Piacentini et al. 2015; Mantovani et al. 2016; Soldati et al. 2016; Soldati et al. 2017) and at the Għajn Tuffieħa and Mistra Bays (Farrugia 2008). These investigations conclude that at least four processes are involved: (1) cliff parallel fracturing due to basal erosion; (2) formation and detachment of blocks at the cliff edge leading to collapse; (3) landsliding on sloping faces; and (4) instability of UCL outcrops that lie above the BC, which is both eroding and sliding. Indeed, some landslides are extensive, slow moving[[14]](#footnote-14) and evolve from rock spreads on plateau surfaces, into block slides often comprising of large limestone blocks (Piacentini et al. 2015).

 This is a situation where population increase and the development of tourist infrastructure is producing further examples of ‘newly generated vulnerability’ (Alexander 1997, p. 292), and there is a clear need for landslide research to continue across a wider range of locations at the coast and inland.

**2.3 Weather and Climate**

The climate of the Maltese Islands is considered typical of the central Mediterranean with hot, dry summers and warm, wet winters, with some 85% of annual rainfall (ca. 530 mm - Schembri 1997) falling between October and March, and mean monthly temperatures ranging from 12-26°C. Due to the relative isolation of the islands in the middle of the Mediterranean Sea, strong winds can occur throughout the year, especially in winter when only 8% of days are classified as ‘calm’. The predominant wind direction is north-westerly (19%) with other directions being approximately equally represented. Sunshine occurs throughout the year (mean of 8.3 hours per day) and humidity remains high all year round with a range of 65-80% (Mitchell and Dewdney 1961; Chetcuti et al. 1992; Schembri 1997; Mayes 2001).

 Such a climate description, particularly in relation to rainfall, however, masks a high annual and seasonal variation that is expressed in instances of extreme weather that have affected, and continue to affect, the islands. For example, using data collected at Malta International Airport for the period 1961-1990, Galdies (2011, p. 10) identifies November as having the highest precipitation variability from 2.6 mm to 297 mm.

**2.3.1. The historical catalogue of extreme weather events**

 Whilst groundwater flooding and that resulting from a combination of high tides, storm waves and heavy rainfall occurs to a limited extent – largely on the low-lying areas of the north and east – it is flash flooding caused by sudden rainfall events in the usually dry drainage systems of the islands that constitutes the major threat (Bowen-Jones et al. 1961). Despite this, and despite their frequency, the historical catalogue of Maltese flash flood events is sorely deficient. Indeed, when the Malta Resources Authority (MRA) assessed the islands’ flood risk, they were forced to rely upon press reports covering just 33 years beginning in 1979 (MRA 2013). According to this assessment, between October 1979 and the end of November 2011 there were 27 instances where flooding caused disruption and damage, with losses being concentrated into seven principal catchments; the details of which are summarised in Table 3 (see also Fig. 5).

 As can be seen from Table 3, the principal cause of vulnerability has been incautious urban and infrastructure development. In their 2013 assessment, the MRA estimated that population and properties at risk were, respectively: 3,300 and 1,200 in Birkirkara-Msida; 5,400 and 1,740 in Attard-Qormi; 2,200 and 620 in Żebbuġ-Marsa; 2,000 and 530 in Gżira and 3,800 and 430 in Żabbar-Marsaskala (MRA 2013). This gives a total of 16,700 people and 4,520 properties at risk in 2013, which in view of rapid increases in both population and the urban footprint in recent years (section 1), is in all probability higher today. Study of the *Times of Malta* archive shows that flooding is one category of hazard where frequent losses have raised both public perceptions and demands for state action (see section 3).

 In section 2.1.1, it was argued that large boulders found on the northern and eastern shorelines of Malta might have been emplaced by either, or both, tsunamis or storm waves. With regards to the latter, little is known about the frequency and size of high magnitude storms, such as those in excess of Category 3[[15]](#footnote-15) and medicanes[[16]](#footnote-16), and how they would impact modern buildings and infrastructure. However, between 1914 and 2013, Category 3 storms impacted the coasts on at least four known occasions: 1995, 1996, 2006 and 2011. In comparison, of the 100 recorded medicanes between 1948 and 2015, only three are known to have directly impacted the islands: 1969, 1982 and 2014 (Anon 2017b). Carabott (2014) has posited that such high magnitude storms could severely impact coastal settlements and critical infrastructure, such as the principal power station at Delimara (Fig. 1) and reverse osmosis plants. Whilst the organisations responsible for these sites claim they are located in safe areas, these assertions have never been put to the test.

 Within state archives and in other sources, there is some evidence of large-scale tornadoes impacting the islands in the past such as an event in 1551, or 1555/56 sources differ, that caused significant damage to the Grand Harbour and inland, killing an estimated 600 people and destroying several ships (Anon 2017c). However, whilst there are many small-scale tornadoes and/or waterspouts and the potential for extreme waves remains great, knowledge of past events is lacking. Vulnerability will increase as the coastal zone witnesses increasing tourist development and the siting of the potentially sensitive plants that are required for power generation and water supply[[17]](#footnote-17).

Droughts in the Maltese Islands are frequent and a mean rainfall of ca. 530 mm conceals a year-on-year variation of up to 380 mm, with droughts between the mid-1840s and 1960 occurring in: 1845, annual rainfall 202 mm; 1855, annual rainfall 228 mm; 1866, annual rainfall 207 mm and 1947, annual rainfall 225 mm (Mitchell and Dewdney 1961). Within this record, the month of July has experienced ‘absolute drought’[[18]](#footnote-18) in 97 of the 116 years (Bowen-Jones et al. 1961). However, such annual figures should be treated with caution as they often bear little resemblance to the monthly differences experienced (Bowen-Jones et al. 1961, p. 49-52). Since the 1960s much greater emphasis has been placed on: rainfall years, which in Malta begin on September 1st (Borg 2009); the standard deviation of the annual mean precipitation (Galdies 2011) and especially the period between September and February when the islands usually receive most of their annual rainfall. According to the latter measure and over the last 50 years, particularly problematic years have been: 1968-69, 251 mm; 1973-74, 266 mm; 1992-93, 261 mm; 2001-02, 219 mm; 2006-07, 278 mm and 2015-16, 297 mm. However these figures, measured at Malta International Airport, are not representative of the more rural and agricultural southern and western areas of Malta and Gozo where, for the whole of 2015 for example, 217 mm was more typical (Micallef 2016).

 Some idea of the impact of such low rainfall on the islands can be gleaned from examining the impact of the record-breaking[[19]](#footnote-19) 2015/16 drought. As in earlier droughts, agriculture suffered particular hardships as aquifers were put under increased stress, with crops that require almost constant irrigation – such as melons, watermelons and cherry plums – being particularly badly hit (Micallef 2016). Because of the poor harvest and high costs incurred by farmers, financial aid was required from the state (Borg 2016). Primary production, which includes agriculture together with fishing and mineral extraction, only accounts for 1.8% of the islands’ Gross Domestic Product (Anon 2012a) and as a result, direct impacts on local people and tourists were minimal. Responses of the public and independent non-governmental think-tanks were highly critical of: (1) the lack of any robust national ‘culture’ of water saving; (2) the security implication of frequent droughts, especially in an era of climate change and the islands’ precarious water situation (see Sapiano 2008); (3) threats to food supply and (4) the failure of successive governments to effectively develop policies of water management (Zammit 2016). Furthermore, and as in the case of earthquakes (section 2.1.1), the clergy, including a local Bishop, gave official sanction to the intercessory prayers of the people by leading penitential processions and by imploring God to send rain to the islands (Micallef 2016).

 According to the *Intergovernmental Panel on Climate Change* (IPCC 2014), future climate change will affect the frequency and intensity of extreme weather resulting in greater losses. Between 1980 and 2013, according to data obtained by the *European Environment Agency* (EEA), extreme events such as flooding and drought cost the Maltese Islands €62 million (EEA 2017). The future cost of extreme weather and the other hazards discussed in sections 2.1.1 and 2.2.1, will depend on several factors including the presence and effectiveness of policies of disaster risk reduction (DRR) designed to boost resilience (see section 3).

**3. Towards Policies of DRR and Resilience**

 It is clear from what has been written so far, that the Maltese Islands are exposed and vulnerable to a variety of natural hazards produced by tectonic, geological/geomorphological and climatic processes. The situation regarding policies of DRR and resilience however varies by hazard category.

 Although considerable academic progress has been made by the University of Malta in establishing a Seismic Monitoring and Research Group to access, process and communicate information relating to Mediterranean seismic activity to the Civil Protection Department, insurers and urban planners (Anon 2016b), so far this has not been translated into hazard reduction programmes. Although discussed for many years (Galea 2007), at present there is no comprehensive earthquake building code (Bajada 2015), with just a few strategic buildings, including the Delimara Power Station and Mater Dei Hospital at Msida (cf. Balzan 2015), being designed to withstand seismic shaking (Grech 2003, 2009). Furthermore, even if building regulations first drafted in 1995 (Grech 2009) were enacted, it is the ‘residual un-ameliorated vulnerability’ (Alexander 1997, p. 292) of the building stock (section 2.1.1) and the threat of low-lying coastal communities to the effects of tsunamis and other causes of inundation, which are additional major planning issues. Additionally, the vulnerability associated with buildings on geologically unstable deposits poses a further issue that must be considered. Indeed, through the SIMIT project[[20]](#footnote-20), scientists and engineers at the University of Malta have measured and mapped areas associated with greater vulnerability and therefore more pronounced risk associated with the Blue Clay deposits across the islands (Baldassini and Di Stefano 2016; Galea et al. no date; D’Amico et al. no date). Finally, there has been some institutional progress in seismic-related DRR in the form of an earthquake preparedness exercise that was held in September 2015 (Anon 2015).

 One area in which there has been progress involves plans to respond to volcanic ash from Mount Etna should Malta International Airport and its traffic be adversely affected. Despite a general lack of awareness concerning this category of hazard amongst the population, measures have been implemented to improve DRR and so boost resilience. First, there is detailed modelling of potential ash events (Azzopardi et al. 2013 – see section 2.1.2) and, secondly, greater awareness by the aviation and meteorological authorities of the need for accurate forecasting. The process of issuing Volcanic Ash Advisories is well developed but, despite an exercise in June 2016 involving Malta, Sicily, mainland Italy and parts of the Adriatic Sea, the response in Malta has yet to be tested by a major ash-rich eruptive plume from Etna. In addition, the vulnerability of the tourist industry and the Maltese economy more generally to even a short-lived airport closure, remains to be addressed.

 The most significant progress towards policies of DRR with respect to extreme weather has been the development of a *Storm Water Action Plan* (MRA 2013). Under this, key problem areas were identified and priority was given to: (1) urban rather than rural areas; (2) dense population clusters; (3) commercial and tourist-related land-uses; (4) proximity of public services and critical infrastructure (e.g. hospitals, fire and police stations) and (5) water supply issues. In particular, management was proposed for the catchments of: Birkirkara-Msida, Marsa, Gżira and Marsaskala (Fig. 5), and through a whole catchment approach, involved planning for 1-in-5 year storm events with a further stated desire to optimise water conservation by preventing some of the uncontrolled run-off into the Mediterranean Sea (MRA 2013). By the end of 2015, what became the *National Flood Relief Project* had made considerable progress, particularly for the residents of Birkirkara-Msida through the construction of ca. 11 km of underground tunnels capable of channelling ca. 40 mm of rainfall per hour to the sea at Ta’Xbiex and the construction of a storage reservoir at Gżira (Micallef 2015).

 Drought meanwhile remains a persistent threat to the islands because, not just in drought years but more generally, the annual volume of groundwater extraction exceeds the sustainable yield and the rate of replenishment (Sapiano 2008). More recent concerns centre around the question of how global climate change may affect water scarcity (De Bono et al. 2010). In addition, there are security fears over the resilience of the desalination plants and worries over long-term food security. Therefore, programmes to reduce leakage, to collect more rainwater and to divert flood waters have been innovated (Anon 2012b), but given the burgeoning population and tourist development on the islands, further policies will have to be developed to innovate some of the measures proposed by the non-governmental think-tanks. Such policy measures might involve, *inter alia*: (1) realistically pricing a scarce resource; (2) investigating the possibilities and practicalities of water re-use and (3) protecting groundwater reserves (Anon 2016c).

 In comparison with the above, progress in developing policies of DRR for other categories of hazard has been patchy. Not surprisingly given the almost non-existent historical catalogue, there has been no progress in assessing karstic collapse hazards, and this applies with almost equal measure to landslides (see section 2.2.1). However, following a cliff face collapse in November 2011 at Għar Lapsi on the southern coast, in an area important for tourism, in 2013 the first cliff protection measures were introduced by the Ministry of Infrastructure using a combination of rock nets (i.e. gabions) at the base of the cliff and rock bolts on exposed faces (Anon 2013c). Furthermore, as mentioned in section 2.3.1, knowledge of storms larger than Category 3 and tornadoes remains inchoate; only archival research will discover whether, or not, knowledge of these hazards can be improved. A start has been made, and in 2014 the Physical Oceanography Unit at the University of Malta began to work with a German research group associated with the University of Munich to form part of the European Lightning Network (LINET) to detect thunderstorms and other extreme weather conditions (Anon 2014b). The fact remains that until more detailed research is undertaken, it is not possible for the authorities to formulate a comprehensive plan to boost the resilience of the islands.

**4. Conclusion**

Although useful for informing strategies of disaster risk reduction (DRR) and for comparing countries in terms of their vulnerability, in the case of Malta international rankings of disaster exposure are open to criticism. In particular, the notion that the Maltese Islands are one of the ‘safest places on earth’ is not only misleading, but also potentially dangerous as it engenders a false sense of security. On the basis of the arguments presented in this paper, it is apparent that the islands are exposed and vulnerable to a variety of extreme natural events. Causes of vulnerability sometimes lie beyond the islands. As mentioned in sections 2.1.1 and 2.1.2 this is the case with respect to earthquakes and eruptions, but internationalisation of risk has occurred through government policy. One example is the inter-connection of the islands’ electrical supply system with the Italian grid in Sicily. In January 2017, storms in Regusa (Sicily) caused a serious power cut to occur in Malta (Anon 2017d).

In criticising international rankings of the islands’ hazard exposure, we have highlighted some of the obstacles involved in formulating detailed hazard assessments, in particular and in many instances, a lack of long historical records of extreme events and their impacts. With the Maltese Islands witnessing swelling resident, seasonal (i.e. tourist) and foreign-born populations, accompanied by increases in the urban area, further research into hazard vulnerability and resilience, based on both the existing historical catalogue and what may additionally be gleaned from archival materials that are yet to be investigated, is timely. Research along these lines should better enable both the islands’ hazard exposure to be evaluated and evidence-based policies of DRR to be proposed, these being the principal aims of an Anglo-Maltese project of which this paper is the first instalment.

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**Fig. 4** Maltese Islands: Geology

**Fig. 5** The Principal Catchments Experiencing Flash Flooding (Adapted from MRA 2013, p. 24)

1. The Maltese Islands comprise an island archipelago in the central Mediterranean with the islands of Malta, Gozo and Comino being the only inhabited islands. [↑](#footnote-ref-1)
2. The *World Risk Index* calculates the risk of becoming the victim of a disaster using an algorithm linking vulnerability to exposure. The index includes both sudden and slow on-set events, that occurred most frequently between 1970 and 2005 and which caused the most casualties. In calculating the index, information is extracted from an emergencies database compiled by the *Centre for Research on the Epidemiology of Disasters* (CRED-EMDAT 2011; cf. Méheux et al. 2007, p. 442). [↑](#footnote-ref-2)
3. Data presented to the Parliament of Malta in February 2017 showed that twelve people had drowned off the coast in 2016 of whom all but three were foreign visitors, suggesting that more needs to be done by the authorities to warn tourists about the perils of storms when bathing in the sea (Parliament of Malta 2017). [↑](#footnote-ref-3)
4. A report by the *European Observation Network for Territorial Development and Cohesion* (ESPON 2010) identified that in 2010, 41.8% of the Maltese coastline was urbanised. [↑](#footnote-ref-4)
5. The geological substrate has a recognised role in building vulnerability through the process of *three-way harmonic interaction*. This involves the resonance coupling of earthquake waves, surficial deposits and medium- to high-rise buildings. Research in Mexico and southern Europe has found that the vulnerability of structures increases when the natural and resonance frequencies of buildings coincide with those of the soils or sub-surface geology upon which they are built (Degg 1992, 1995; Chester 2008; Chester and Chester 2010; Galea et al. 2016). [↑](#footnote-ref-5)
6. The Seismic Monitoring and Research Group at the University of Malta have recorded ca. 40 small (*I≤*IV***)*** earthquake tremors between 2000 and 2014 with epicentres around the Mediterranean region, not all of which were felt by the population (Anon 2014a). Indeed “a culture of seismic risk awareness has never really been developed in the country, and the public perception is that the islands are relatively safe, and that earthquake phenomena are mild or infrequent” (Galea 2007, p. 725). [↑](#footnote-ref-6)
7. Present-day vulnerability resulting from the heritage of a place is often referred to as ‘residual un-ameliorated vulnerability’ (Alexander 1997, p. 292). [↑](#footnote-ref-7)
8. In Roman Catholicism, the predominant Christian denomination on the islands, the exposition of the Holy (or Blessed) Sacrament occurs when a communion wafer (i.e. host) is displayed in a monstrance (i.e. a container placed on an altar). The belief is that Christ is sacramentally present within the host and brings comfort to the faithful. [↑](#footnote-ref-8)
9. In the Maltese Islands, buildings are classified as: Type A: Confined mostly to rural buildings and constructed from rubble, adobe or clay. They are often in a poor state of repair. Type B: Un-reinforced brick, stone and concrete block construction, which includes both traditional buildings and more recent construction styles. Many buildings of this type are more than 150 years old and in Valletta some are poorly maintained and suffer from water ingress. Type C: Buildings are of high quality masonry and low-quality concrete with rudimentary reinforcement. Type D: Buildings with a frame of reinforced concrete. Categories D1 to D5 represent buildings of progressively greater resistance to earthquake shaking. The majority of Maltese buildings fall into the categories B to D1 and are therefore very vulnerable (Camilleri 1999). [↑](#footnote-ref-9)
10. The Mean Damage Ratio is the average damage to buildings, expressed as a percentage of their as new value (Camilleri 1999, p. 27). [↑](#footnote-ref-10)
11. Some authors (i.e. Camilleri 2006) claim that the 1973 earthquake generated a tsunami, but the record is capable of an alternative explanation. This event may have been a *seiche*, or standing wave in a partially enclosed body of water such as a bay or inlet. Indeed, there are records of *seiches* on July 31 1910, February 25 1912 and March 26 1983, which are not related to any recorded seismic event (Abela 1969; Savona-Ventura 2005). Such waves are known to fishermen as *milgħuba*,and Drago (2009) argues that they are a particular feature of the northern, north-eastern and south-eastern coasts of Malta. They are produced by meteorological phenomena, involving waves being generated in the open sea by atmospheric pressure differences and forming ‘tsunami-like’ waves when propagating into confined bays and inlets (Drago 2008). [↑](#footnote-ref-11)
12. Whilst a questionnaire survey showed that 69% of student respondents from the University of Malta believed that Etna affects the islands, even amongst this group there remained uncertainty as to the impact of volcanic ash on the islands (Azzopardi et al. 2013, p. 15). [↑](#footnote-ref-12)
13. *Widien*, the plural of *wied*, are river valleys, ravines or channels that are either permanently or seasonally dry. [↑](#footnote-ref-13)
14. As part of a long-term programme at two coastal sites on the north-western coasts, monitoring has shown that the landslides are moving “extremely slowly” with mean displacement rates of 7 mm/year (Soldati et al. 2017). [↑](#footnote-ref-14)
15. Storms may be classified by size using the Saffir-Simpson Hurricane Wind Scale that runs from 1 to 5. A Category 3 storm has a wind speed of between 178 and 208 km per hour (Formosa 2013). [↑](#footnote-ref-15)
16. A medicane, or Mediterranean hurricane, is a low-pressure cyclonic system that is morphologically and physically similar to hurricanes and tropical cyclones. Although rare, these events can cause significant damage to coastal areas (Romero and Emanuel 2013; Tous and Romero 2013; Cavicchia et al. 2014). [↑](#footnote-ref-16)
17. With overexploitation of the perched and sea level aquifers in the Maltese Islands and resulting salinisation, ca. 55% of the total potable water production in the islands comes from the three reverse osmosis plants located at Ċirkewwa, Pembroke and Għar Lapsi (FAO 2006). Furthermore, the increasing salinity of the young, thin soils – though not well documented – is a potential significant constraint on agricultural production (Vella 2001, 2003, Vella and Camilleri 2003). Indeed, it has been demonstrated that whilst ca. 12% of arable land (ca. 1143 ha) is irrigated, largely through treated sewage effluent from the Sant’ Antnin Sewage Treatment Plant – itself believed to be responsible for a high level of copper in the south-east region (Vella 2003, p. 173) – much has already become saline (Vella 2001; Vella and Camilleri 2003). For example, salt crystals have been identified on the soil surface within the Pwales Valley in the north-west of Malta (Vella 2001). [↑](#footnote-ref-17)
18. ‘Absolute drought’ is defined as a period of at least 15 consecutive days during which the rainfall does not exceed 0.254 mm. [↑](#footnote-ref-18)
19. The period September 2015 to April 2016 broke numerous records. Records broken during the period include: the lowest rainfall since 1966 between December and February; the driest February for at least 50 years and the warmest for at least 93 years and a drier and warmer than average April (Micallef 2016; Leone-Ganado 2016; Anon 2016a). [↑](#footnote-ref-19)
20. The €2.5 million SIMIT project involves the Civil Protection Departments of Sicily and Malta together with the Universities of Catania, Palermo and Malta. The project is funded by the Italia-Malta 2007-2013 Operational Programme and deals with the establishment of an integrated civil protection system across the border area focusing on the handling of seismic risk. Benefitting from €370,000, partners from the University of Malta include the Seismic Monitoring and Research Group, the Construction and Management Unit, the Department of Civil and Structural Engineering, and the Institute for Sustainable Development (Anon 2013b). [↑](#footnote-ref-20)