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COASTAL EROSION ALONG NORTHERN MALTA: GEOMORPHOLOGICAL PROCESSES AND RISKS

ABSTRACT: FARRUGIA M.T., *Coastal Erosion along Northern Malta: geomorphological processes and risks*. (IT ISSN 0391-9838, 2008).

Coastal erosion is a global problem especially with 60 per cent of the population living within the coastal zone. Coastal erosion is considered as a hazard in addition to being a geomorphological process. In fact the range of listed hazards is a broad one with noisy and spectacular volcanic eruptions, devastating earthquakes and landslides to silent but relentless soil gullying and coastal erosion. Three simultaneous processes can be identified: the long term retreat of coasts, the medium term degradation of beaches and the short term cliff erosion. In the Maltese Islands, however, such erosion is mostly considered as a process not as a hazard. In fact several authors that contributed to the study of the Maltese coasts consider coastal erosion as a geomorphological aspect of the coast that leads or else contributes to the creation of several erosional features spread along the Islands. In contrast, this paper tackles mostly the hazard and risk aspect of the coast through two case studies: Ghajn Tuffieha Bay and Mistra Bay. The mapping of coastal shoreline movements did not only help to identify the process of coastal erosion but also to note the areas that face risks from such hazard. Also the paper addresses several sustainable shoreline management objectives which need to be undertaken to safeguard shorelines from the coastal erosion hazard. Nonetheless it is important to note that coastal erosion is an on-going process which incorporates hazards and risks only when there is human interference with the coastal zone. Thus the use of sustainable measures is important to safeguard both the natural environment and the human aspect of the shoreline.

KEY WORDS: Coastal erosion, Hazard, Risk, Erosional features, Sustainable measures, Malta.

INTRODUCTION AND STATE OF THE ART

Coastal erosion may be regarded as a relentless and silent depletion process which entangles the coastal environment, occurring when the sea engulfs the land due to wind, wave and tidal pressures (Doody & *alii*, 2004). This is mostly evident in conditions of poor sediment availability. Yet, even where sediment is available in large quantities, shoreline retreat and coastal erosion do occur. The latter process, in fact, forms part of those coastal processes influencing the erosion, transportation and deposition of sediment creating a series of landforms like headlands and bays, wave-cut platforms, including also caves, blowholes, arches and stacks when considering coastal cliffs' landforms (Horn, 2002). Coastal erosion may be seen as having in itself three simultaneous processes. These include the long term retreat of coasts, the medium term degradation of beaches and the short term cliff erosion (Hart, 1986). The long-term process has in fact been seen on the Holderness coast of Eastern England where retreat rates average about a metre a year (Waugh, 2000). In contrast, the short term process is seen evident at the demise of the village of Bormston on the Yorkshire coast where coastal erosion leads to a series of cliff falls (Hart, 1986). The third case of coastal erosion can also be seen at the Gulf of Riga where the recession of sandy beaches and dunes even reaches up to two metres annually (Hart, 1986).

Nonetheless, it is important to note that coastal erosion is an on-going process which incorporates hazards and risks only when there is human presence along the coastal zone. Truly, since early times people have sought at living at coastal areas and even in some cases at the exact strandline between water and land. By the start of the twenty-first century, this situation is not much different; as three-quarters of the world's largest urban centres together with the world's biggest cities are located in a coastal location (Haggett, 2001). In addition to this, on the coastal strandline, man-made activities like engineering works, recreational and tourism activities and also the extraction of sand and gravel for construction purposes implied further pressure on the coastal zones. This may have been worsened in some cases by human attempts to remedy the coastal erosion problem, through erecting breakwaters or

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hard engineering structures (Spencer & Viles, 1995; Bird, 1996; Doody & *alii*, 2004; Farrugia, 2006; Spencer & Viles, 1995).

With 60% of the population living within the coastal zone, coastal erosion is seen as a global problem. In fact at least 70% of the sandy beaches around the world are recessional (Bird, 1985). Also approximately 86% of U.S East Coast barrier beaches (excluding evolving spit areas) have experienced erosion during the past 100 years (Douglas & *alii*, 2004). Widespread erosion is moreover well documented in California and in the Gulf of Mexico (Douglas & *alii*, 2004). Europe furthermore faces several negative impacts due to coastal erosion including the fact that an area of approximately 15 km^2 per year is estimated to be lost or seriously influenced by erosion (Doody & *alii*, 2004; Farrugia, 2006). In addition, within 1999-2000 an average of 275 houses had to be abandoned as a result of coastal erosion with another 3000 houses having their market value decreased by 10%. Furthermore, in 2004 about twenty thousand kilometres of coast faced great retreating rates (Doody & *alii*, 2004; Farrugia, 2006).

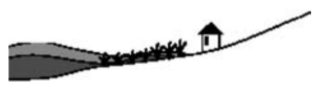
Coastal erosion may be considered as a hazard in addition to being a geomorphological process. A hazard may be defined as a product, process or condition, which potentially threatens individuals and in the case of a natural hazard, an event, which potentially causes large scale economic, social and physical damage (Gregory & *alii*, 2000). Moreover a hazard may be defined as being the probability of something to change within a specific timeframe and a specific area (Slaymaker, 1996). Such hazard may be geomorphic, that is, one which may occur from a landform change affecting the geomorphic stability of a site creating risks as it influences humans by its social and economic impacts. In fact as one may see from table 1, the range of geomorphic hazards is a broad one ranging from noisy and spectacular volcanic eruptions, devastating earthquakes to silent and relentless soil gullying and coastal erosion processes.

The problem of coastal erosion is throughout the whole of the world and several countries have tried to mitigate such hazard at both local and regional level. For example within the European Commission five policies were adopted to deal with coastal erosion. As seen in table 2, these include:

TABLE 1 - Categories of geomorphic hazards (after Slaymaker, 1996; modified)

	High magnitude	**Low magnitude**	
Geomorphic hazard	Low frequency	Continuous	High frequency
Endogenous	Volcanism Neotectonics		Neotectonics
Exogenous	Floods Karst collapse Snow avalanche Channel erosion Sedimentation Mass movement Jokulhlaups Tsunamis Coastal erosion	Solution Mass movement	Floods Solution Snow avalanche Channel erosion Sedimentation Mass movement Tsunamis Coastal erosion
Climate or land-use change	Desertification Permafrost Degradation Soil erosion Salinization Floods	Desertification	Desertification Permafrost Degradation Soil erosion Salinization

TABLE 2 - Policies adopted by the European Commission and their respective descriptions and figures (after Doody & *alii*, 2004; modified)

Policy	**Description**	**Figure**
Do nothing	No investment in coastal defence structures. No shoreline management activity	
Hold the line	Hold the existing defence line either by maintaining or else by changing the standard of protection. Works are undertaken in front of the existing defences to improve or maintain the standard of protection provided by the existing defence line. Operations to the rear of existing defences should be made as they form an integral part of maintaining the current coastal defence systems.	
Move seaward	Advance the existing defence line by constructing new defences seaward of the original defences. This policy is limited to those places where significant land reclamation is considered.	
Managed realignment	Identify a new line of defence and, where appropriate, construct new defences landward of the original defences.	
Limited intervention	Working with natural processes to reduce risks while allowing natural coastal change. Create measures that range from attempting to slow down rather than stop coastal erosion and cliff recessions to measures that address public safety issues	

- Doing Nothing
- Holding the Line
- Moving seaward
- Creating Managed Realignment
- Doing limited intervention (Doody & *alii*, 2004).

Various countries have adopted the policies adopted by the European Commission, as seen in Table 3. Yet, however several other countries have adopted their own mitigation measures. For example, countries such as the United Kingdom, Netherlands and German Landers use regularly ship borne surveys or locally apply video systems to discover coastal erosion rates. However other countries such as Portugal, Greece or France implement coastline monitoring techniques only at certain locations and these techniques are generally restricted to experimental research projects. (Doody & *alii*, 2004).

TABLE 3 - Policies to manage coastal erosion (after Doody & *alii*, 2004; modified)

Policy	Countries adopting such policy
Hold the line	Belgium, Bulgaria, Denmark, Estonia, France, Germany, Greece, Ireland, Italy, Latvia, Poland, Portugal, Romania, Slovenia, Spain, Sweden, The Netherlands, United Kingdom.
Move seaward	
Managed realignment	Denmark, France, Germany, Portugal, United Kingdom.
Limited intervention	Cyprus, Denmark, Estonia, France, Germany, Greece, Italy, Latvia, Lithuania, Malta, Portugal, Romania, Slovenia, Spain, The Netherlands.
Do nothing	Cyprus, Denmark, Finland, France, Italy, Malta, Poland, Romania, Spain, Sweden, The Netherlands, United Kingdom.

Also other mitigation measures tended to take a regional approach, tackling only zones not whole countries. One of these zones is North Norfolk where coastal erosion management practices were combined with sustainability issues (Hall & Walkden, 2003). Another zone is Black Rock Point in Port Philip Bay, Australia (Bird, 2000). Surveys of cliff recession were carried out in such zone where it was discovered that a cliff face was dissected and cut back by several factors including gullying (Bird, 2000).

The Maltese Islands, as seen in Table 3, are currently adopting a «Do Nothing» approach about coastal erosion. The reason for this may be attributed to the fact that to date, there are few published sources addressing the rates and risks of coastal erosion. Moreover various authors claim that Malta does not face problems from such process but instead from severe storms, hail, flooding, soil erosion, mist and fog and high winds (Barrett & *alii*, 1991). Conversely, geomorphological studies indicate that several features resulting from coastal erosion are present on the Islands and these include arches, headlands and bays (Guilcher & Paskoff, 1975; Paskoff & Sanlaville, 1978; Ellenberg, 1983; Guilcher & Paskoff, 1975; Paskoff & Sanlaville, 1978; Said & Schembri, 2004).

In fact, the fringes of Nnorthern Malta hold quite a variety of formations resulting from coastal erosion. The location of these formations is discussed hereunder and can be seen in Figure 1. Truly, on the northern coast of this part of the peninsula, bordering Mellieha Bay there are bays and steep slopes, where red-brown sand is derived from weathered Greensand on the bordering shores and the sea floor. The red sand outcrops in the corner of Marfa Point, with small coves like Ghar Baqrat and Ta' L-Imgharrqua, a natural arch at Il-Parsott, then higher cliffs to Il-Marbat and a headland at Dahlet Ix-Xilep. The coast then turns northwest to high cliffs of Upper Coralline Limestone with tumbled rocks on the shore reaching the northern coast which is embayed with small headlands including Marfa Point which shelters the Gozo ferry terminal and Paradise Bay, to the west, which is followed by a sector of scree-covered slope beneath a limestone cliff, then the headland at Ras Il-Qammieh (Paskoff & Sanlaville 1978; Said & Schembri, 2004).

The limestone cliffs continue even southwards of Ras il-Qammieh, seen in Figure 1, and eventually end into a scarp along the northern side of the Mellieha valley. The

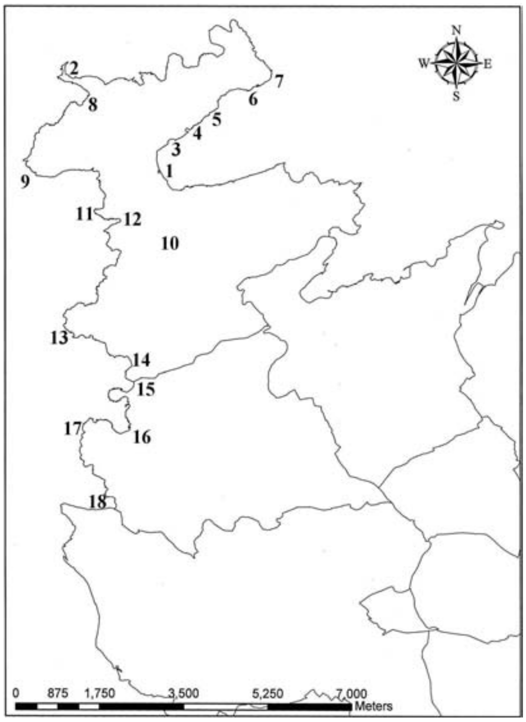


FIG. 1 - Location map of Northern Malta: Legend: 1) Mellieha Bay; 2) Marfa Point; 3) Ghar Baqrat; 4) Ta' L-Imgharrqua; 5) Il-Parsott; 6) Il-Marbat; 7) Dahlet Ix-Xilep; 8) Paradise Bay; 9) Ras il-Qammieh; 10) Mellieha Valley; 11) Ras in-Niexfa; 12) Anchor Bay; 13) Ras il-Wahx; 14) Golden Bay; 15) Ghajn Tuffieha bay; 16) Gnejna Bay; 17) Ras il Pellegrin; 18) Fomm ir-Rih Bay.

western end of this valley is truncated by vertical cliffs in Upper Coralline Limestone, which rise to the point at Ras in-Niexfa. The cliff crest is backed by very rugged karstic limestone with enclaves of terra rossa clay. On the cliff face are toppling columns of Upper Coralline Limestone, and caves, boulders and a notch at the cliff base. The plateau declines towards Anchor Bay, where there are long and deep crevices that form parallel to the cliff crest, where subsidence has occurred on the seaward side of these, with disintegrated blocks sliding down the coastal slope. On the northern side of Anchor Bay there is a small sandy bay-beach, possibly derived from a yellow horizon in the adjacent cliffs (Paskoff & Sanlaville, 1978; Said & Schembri, 2004).

To the south of Northern Malta are cliffed headlands and steep-sided bays out to Ras il-Wahx. The cliffed coastline then recedes into Golden Bay, where the wide beach is of pale yellow-brown sand, similar in colour to the Globigerina Limestone in the cliffs, and Ghajn Tuffieha Bay, which has a red-brown sandy beach derived from the Greensand, backed by subrounded limestone pebbles and a landslide slope on Blue Clay beneath the Greensand and Upper Coralline Limestone. This ends southward in a steep narrow promontory where an arête of Blue Clay runs out to a small mesa of Upper Coralline Limestone. To the south is Gnejna Bay with slopes in Blue Clay descending to cliff-base ledges of Globigerina Limestone between more red-brown beaches. Beyond this, the cliffs run out to Ras il-Pellegrin and are fronted by a steep slope descending to Fomm ir-Rih Bay, the southern side of which is a north-facing cliff along the fault zones of the Victoria Lines escarpment (Paskoff & Sanlaville, 1978; Said & Schembri, 2004).

INVESTIGATIONS IN NORTHERN MALTA

Thus one may comment that Northern Malta holds a variety of coastal landforms resulting from the process of erosion. However this paper does not consider all the coastal landforms present on such coastal stretch, but looks at the local impacts of the coastal erosion process within selected bays and discusses the issue of whether such process creates risks or not at these areas. These bays are Ghajn Tuffieha Bay and Mistra Bay, which are situated opposite to each other, as seen in Figure 2.

Ghajn Tuffieha Bay

As seen in Figure 3, Ghajn Tuffieha Bay is located along the coast between ir-Ramla tal-Mixquqa (Golden Bay) and il-Bajja tal-Gnejna (Gnejna Bay) (Gaullaumier, 1987) with the area being morphologically composed of:

- a pronounced limestone structure named the Ghajn Tuffieha headland.
- a stretch of sand forming Ghajn Tuffieha Bay
- steep clay slopes at the back of the bay
- a highly weathered limestone ridge made up of Il-Qarraba (Malta University Services, 1997).

One can note that, at Ghajn Tuffieha Bay the most common type of sediment along the foreshore is sand. In fact, this occupies half of the bayhead in the form of a wedge-shaped belt, which is approximately 150 m long and 25 m wide, and then tapers gradually towards the south where it turns into a narrow, 100 m long sand/cob-

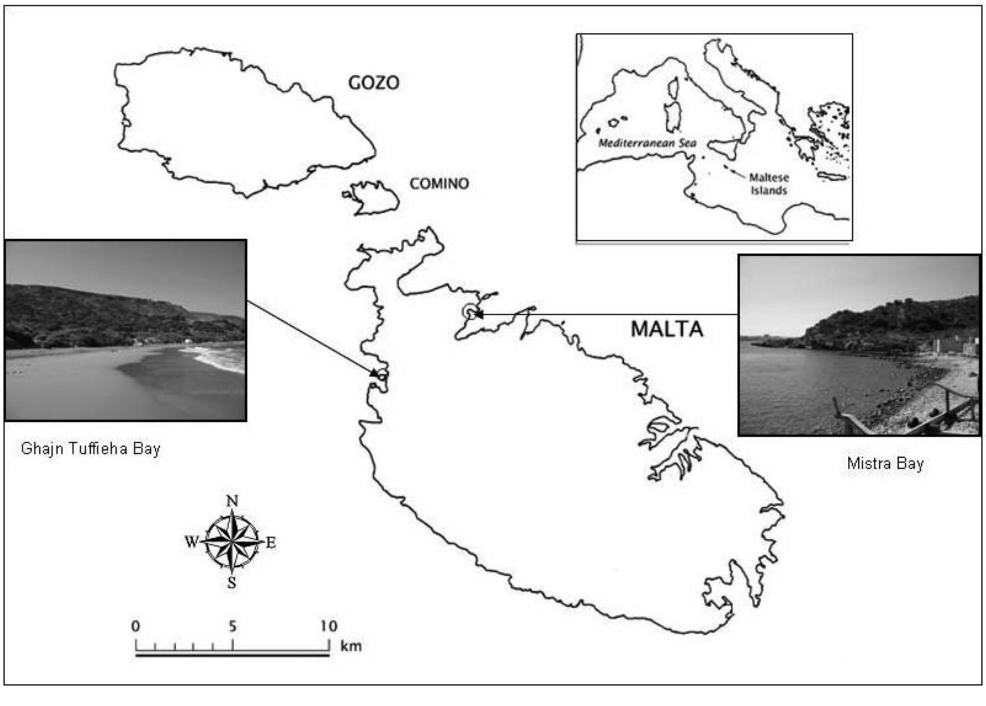


FIG. 2 - Location of case study areas (after Farrugia, 2006; modified).

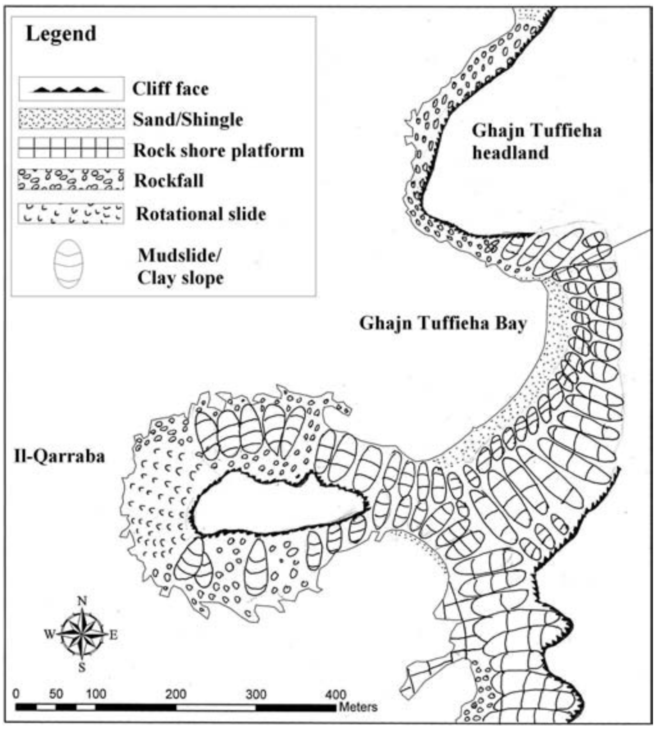


FIG. 3 - Geomorphological features at Ghajn Tuffieha Bay (after Magri, 2001; modified).

ble beach. Moreover the geology of Ghajn Tuffieha Bay is mostly Coralline Limestone. However at Ghajn Tuffieha Bay there are Blue Clay slopes too, thus most probably one can maintain that maybe the layer of greensand found under the Upper Corraline Limestone has been eroded away by the action of waves. The supply of sediment also increases as a result of a number of landslides that take place at Ghajn Tuffieha Bay during the winter season and these could eventually lead to the enlargement of the bay.

The most serious threats for this bay arise from recreational, tourist and agricultural activities. Truly Ghajn Tuffieha is one of the bays in the Maltese Islands which is heavily impacted by the presence of humans during both the winter and summer months as they visit this bay for swimming purposes and even for walking and camping purposes. Moreover, although illegal in such bay, cases of offroading are still present especially during winter. The presence of humans on the bay not only leads to sediment dispersal but also to sediment compaction by offroading. Tourist facilities and buildings exactly at the shoreline of the bay and on top of the cliff, impact positively wave strength and landslips respectively. Moreover, the seasonal agricultural activities on the Blue Clay slopes behind the bay tend to reduce slope erosion rates by the absorption of runoff into the soil. However, in areas where old field systems are present slope erosion rates are increased due to an increase in runoff rates.

In addition to all this, in 1995-96 the bay was scheduled as an area of ecological importance; in 2003 it was identified as a Special Area of Conservation and in 2005 the Malta Environment and Planning Authority (MEPA) considered this bay as forming part of a Marine-Protected Area so as to safeguard the environment and control the human threats to it (Farrugia, 2006).

Yet, at Ghajn Tuffieha Bay, coastal erosion hazard management is not present. In fact, the protection given to this area aims mostly towards safeguarding the present natural habitats situated on the Blue Clay slopes Nonetheless, the buildings present at this bay are protected by membrane layers and also considerations are being taken towards relocating a dilapidated building further inland from its location. Truly this building was abandoned during the last century because it faced serious threats from landslide activity. Considerations are currently being taken regarding this latter activity, but these mainly focus at indicating people that these areas have landsliding possibilities, as seen in Figure 4.

FIG. 4 - Sign indicating possible landslide activity at Ghajn Tuffieha headland.

Mistra Bay

Unlike Ghajn Tuffieha Bay, Mistra Bay is located along the north-eastern coast of Malta between Ras il-Mignuna and Rdum Rxawn. Morphologically, as seen in Figure 5, the area is composed of:

- a steep limestone structure named Ras il-Mignuna
- a Globigerina Limestone valley named Mistra Valley
- a stretch of sand and cobbles together with rocks forming Mistra Bay
- a highly weathered limestone ridge named Rdum Rxawn (Farrugia, 2006).

The type of sediment present at Mistra Bay is mainly cobbles with pebbles scattered mostly along the foreshore and with sand being found either in the sea or along the backshore. The 690 m^2 of the sediment situated at this bay is coarser than that at Ghajn Tuffieha Bay probably due to the fact that the sediment at Mistra Bay is of a different rock type than that of Ghajn Tuffieha Bay. In fact at Mistra Bay the geology of the area is mostly Globigerina Limestone.

The current threats at this bay arise from agricultural activities, urbanisation and the presence of marine activities. In fact, terraced fields at Mistra Bay tend to decrease the amount of water that arrives at the Bay by the absorption of rain water into the soil. Moreover, the rock wall present at Ras il-Mignuna impacts negatively the erosion of the cliff as it serves as a protection shield against the attacks of the waves. In contrast with this, the slipway at the centre of the bay divides the sandy part from that with rocks and pebbles and in the long run this may lead to the eventual reduction of the sandy part of the bay. Moreover, yachting and jet skiing activities have led to dirtying of the water making it a non-swimmable place, and also to a decline in fish stocks. Together with this, the road built just behind the shoreline of Mistra Bay, although being currently undermined by wave action, also limits the amount of debris arriving to the bay. Moreover, just outside the bay there is a fish farm that may even hinder the growth of the marine biodiversity at Mistra Bay (De Giovanni, 1991; Axiak 2000; Borg, 2002; De Giovanni, 1991; Farrugia, 2006).

With regard to coastal hazard management at Mistra Bay, one can only observe two coastal structures which are a rock wall and a slipway, seen in Figure 6. However one should note that the slipway was not build for such purposes but for the use by boats. The slipway has in fact in the short run led to coastal deposition however when analysing the coastal configuration for the last century it became evident that in the long run such structure has led to the erosion of the sandy beach on the left side of the bay. Moreover the construction of the rock wall although it had declined wave impact, it has hindered sediment accumulation in such part of the bay leading to more coastal erosion.

METHODOLOGIES

At both Ghajn Tuffieha Bay and Mistra Bay, the methodologies that were used for discovering the process of coastal erosion were various, considering even its hazard aspect. Such methodologies included map and aerial photographs analyses and land use and geomorphic surveys. Data that came out from such studies were then inputted into ArcGIS as to illustrate risk areas within the case study areas.

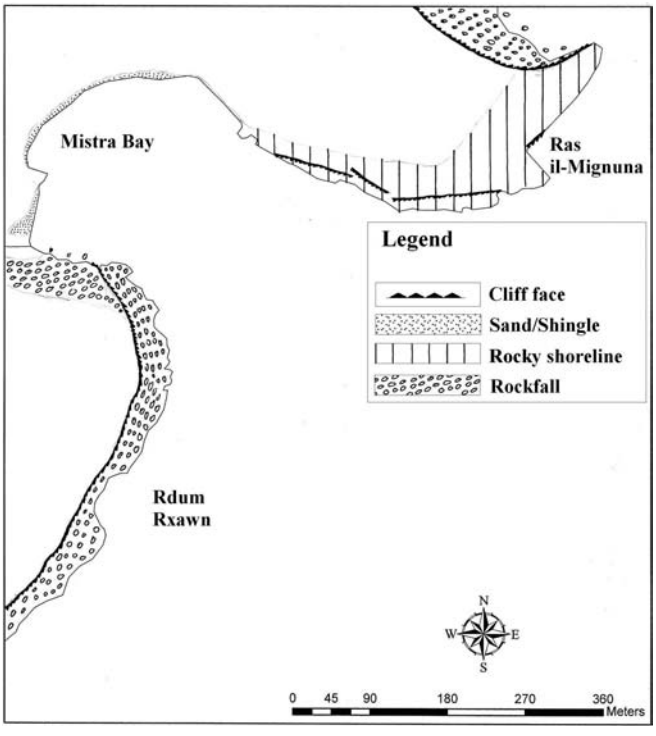


FIG. 5 - Geomorphological features at Mistra Bay (after Magri, 2001; modified).

FIG. 6 - Coastal structures at Mistra Bay.

Maps and aerial photographs analyses were used to trace long term coastal erosion. Maps, in fact, were ideal to trace back the coastal movements, the changes that occurred during the past decades and even human impacts in the areas in question (Bird, 1996). Furthermore, one could say that these enable a person to make accurate measurements of size and shape of landforms, which may not be possible in the field. Besides they serve as historical data sources that enable the observation of a landform over a certain time (Cleves & Lenon, 2001). For this reason, survey sheets of Ghajn Tuffieha Bay and Mistra Bay were used to find out the rate of erosion that both bays had undergone throughout the years. The survey sheets were obtained from the Mapping Unit of the Malta Environment and Planning Authority and the years taken in consideration were 1939, 1957, 1971 and 1993. Maps of Ghajn Tuffieha Bay and Mistra Bay were copied respectively onto other sheets as only selected shorelines were needed. Difficulties arose when shorelines were divided into separate survey sheets thus attention was taken to make the features on the sheets join accurately. Eventually these sheets were superimposed over each other for Ghajn Tuffieha Bay and Mistra Bay respectively and the shorelines of the years 1939, 1957 and 1971 were drawn on the 1993 maps indicating shoreline trends throughout the years. Moreover, aerial photographs provided from the same unit were utilised, however, only for noting which structures at the bays were mostly under threat from the coastal erosion hazard. Although such methodology proved to be a very useful tool one can maintain that it also held a degree of error of about 10%. Such degree of error may have been decreased by digitizing all the maps and photographs. Yet, digitizing facilities in Malta have not yet been exploited to the full.

Nonetheless since the study of coasts is not only of great interest from a historical point of view, as shown by the analyses of survey sheets and aerial photographs but also from scientific and economic points of view (Steers, 1971), land use surveys were taken at both case study areas illustrating the major activities taking place within Ghajn Tuffieha Bay and Mistra Bay. Also geomorphological surveys were done to map data concerning the geomorphology and geology of the areas, where each landform was given a unique symbol (Hart, 1986).

After all these methods, ArcGIS was then used to combine most of the data together to illustrate the zones at each case study areas that are at risk from coastal erosion. In fact, the land use and geomorphic maps created by ArcGIS showed features that resulted from the land use and geomorphic surveys. Then the shoreline movement maps created from the analysis of survey sheets were spread over the maps created by ArcGIS and the areas mostly at risk were noted. Also other risks present at both case study areas, like risks arising from landslides and flooding were noted.

DISCUSSION OF ACHIEVED RESULTS

The results emerging from the methodology presented in this paper were various and quite inspiring with regards to the study of the coastal erosion process. Truly, from the various evidence gathered from this study it seemed evident that the three processes of coastal erosion presented by Hart (1986) are not that much relevant for the Maltese Islands. In fact, coastal erosion in the Maltese Islands seems to follow a complex pattern where coastal retreat is accelerated through developments occurring on the coast such as alterations associated with infrastructure, development and urbanization that in some cases led to loss of species. Moreover, development on limestone coastal cliffs may have accelerated the rates of erosion through destabilization from engineering works during construction, as well as increased load over the underlying rock (Borg, 2004).

Moreover, one can maintain here that maybe the statements made by Hart (1986) are not so much relevant for today's global world. Truly the impacts of coastal erosion may be divided into four sectors:

- acute coastal erosion resulting into flooding,
- coastal erosion,
- long term coastal retreat resulting in land loss
- the impacts of climate change resulting in sea level rise (Doody & *alii*, 2004).

In this classification the two case studies fit perfectly within the long term coastal retreat section where both cliff and shoreline retreat occur concurrently.

Truly, in the case of Mistra Bay, since 1939 coastal erosion was mainly present at the beach itself. In fact, as seen in Figure 7, most of the erosion took place at the mouth of the bay itself with this amounting to about 50 m in total. Moreover with the introduction of the slipway on the bay about another 12.50 m of sediment has been lost. At the toe of the cliffs coastal erosion was also present with this being mostly evident under Rdum Rxawn where a building has been destroyed and where 275 m^2 of land has been lost. However, loss of land at the top of the cliffs has been much greater than that at the toe of the cliffs as protection against toe erosion has been developed by the accumula-

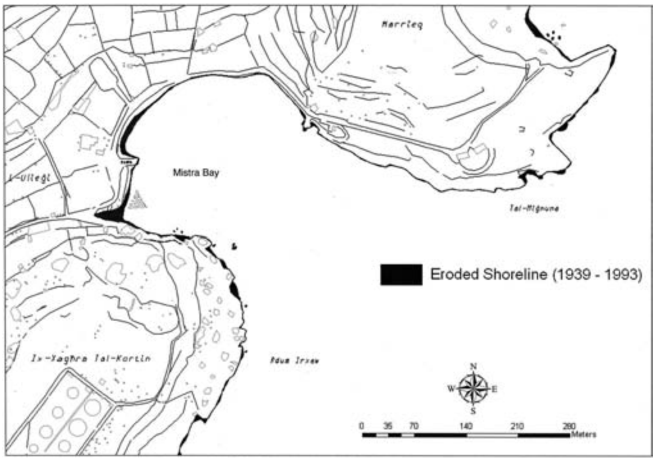


FIG. 7 - Coastal erosion at Mistra Bay (1939-1993).

tion of large boulder fields at the foot of the slope as a result of their down-slope movement. From 1939 till 1993 this lost land amounted to 290 m^2 in all of total cliff length. Although properties are evidently threatened here especially with the loss of a house from 1957 till today and the presence of the house exactly at the shoreline, coastal erosion is not exactly seen as a risk to people, as at this bay it is mainly considered as a long term retreat.

If one takes a historical look at coastal erosion at Mistra Bay in 1939, one sees that such bay was rather unreachable by mankind except for a small pathway. Truly the presence of a large number of reeds and the presence of a creek in the bay may suggest that the road to Mistra Bay suffered from inundation or flooding. This could be possible since Mistra Bay is in fact the mouth of a river valley, into which flows Wied il-Mistra coming from Wied il-Mizieb (Deidun, 2004). It is possible that these valleys formed part of the former river valley system which may have had water that goes through them in winter (Azzopardi, 1995). Also this point can be further declared, since at Mistra Bay there is a man-made well denoting the importance given to water. Such importance can also be seen since the area holds a great percentage of agricultural land. As regard to other features one may note the presence of a sand bar in 1939, probably forming from debris deposited at this valley mouth, which in turn helped at enlarging the beach from the expense of erosion to the headlands and cliffs surrounding such beach.

By 1957 the situation however changes drastically. The introduction of the slipway at the beach changed its configuration with the right side of the beach holding great conglomerations of cobbles and pebbles and the left hand side facing a drastic decline in its sand content. The change in the configuration of the beach was also seen with the decline in the size of the creek. In the 1950's Mistra Bay started facing also the impact of mankind on it as it started holding several buildings and constructions like boat houses and farm houses. It is important to note that, it is possible that during this time there was the concretion of the old pathway leading to the bay, with cliff erosion being still a continuous process. By 1971, the processes started in the 1950's have continued worsening. Moreover in the 1970's there was also the introduction of another slipway.

By 1993 Mistra Bay changed quite a lot from what it was in 1939. The slipway that was done after the 1950s had also been eroded. Furthermore if one takes a look at the right hand side of the slipway where there are the cobbles and pebbles, one note that this area had been extending further outwards into the sea. However there was an indentation inwards, which by 1998 had totally disappeared. Land use had not varied greatly between 1957 and 1998 as most of it concerns agricultural land. Furthermore the action of waves may have been one of the factors that led buildings situated at the rock falls at Rdum Rxawn to decrease in size. Also the area where the indentation was situated, near the second slipway build in the 1970's, has in fact been in 1957 a high-risk area because water made its way into there eroding sediment and silt.. However, by 1998 the flooded area became covered by unconsolidated sediment making it less risky for people to stay there.

However, with the use of ArcGIS, as seen in Figure 8, and the addition of the land use and geomorphological map, other issues arose. For example, the buildings situated exactly at the shore of Mistra Bay face high risk of erosion as that faced by the slipway, as indicated by the dark-

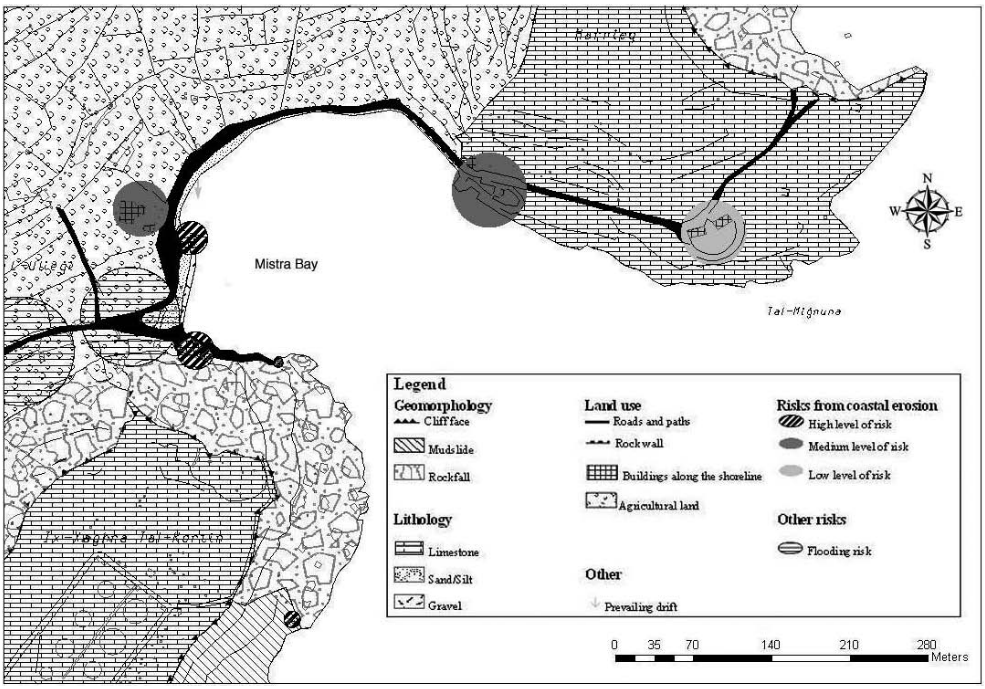


FIG. 8 - Risks present at Mistra Bay (after Farrugia, 2006; modified).

est circles within Figure 8. In contrast the building situated behind the road that is currently a restaurant faces less risk due to the road in front of it, which together with the slipway acts as a barrier against the waves. Constructions on limestone cliffs on the other hand face lesser risks due to the fact that limestone when compared to unconsolidated material or to clay is hard to be eroded. Also one may note that the street leading to Mistra Bay faces risk of flooding as the road, as already maintained, is in fact the mouth of the Mistra Valley. Thus during the rainy season it tends to get inundated by water. The presence of a great number of reeds in fact confirms this.

In contrast, coastal erosion at Ghajn Tuffieha Bay has been more predominant, as seen in Figure 9. The beach itself has lost about 872.5 m^2 since 1939. This may be attributed to the fact that sediment at Ghajn Tuffieha Bay can be carried away more easily than that at Mistra Bay. Moreover, Ghajn Tuffieha Bay is heavily influenced by the North Westerly wind. This wind blows on an average of 20% of the days in an average year (Azzopardi, 1995). This makes Ghajn Tuffieha Bay more exposed to the prevailing winds than Mistra Bay and thus greater erosive power is expected to be present along this bay. In fact, erosion at both the top and the toe of the cliffs present at Ghajn Tuffieha Bay is higher than that of Mistra Bay. Truly, since 1939 the Qarraba headland lost nearly 2677.5 m^2 of debris at the toe of the cliff only. However, in accordance to this, one has to consider that toe erosion is not to be taken as the sole cliff erosion as toe erosion is protected by the accumulation of large boulder fields at the foot of the slope as a result of their down-slope movement. In fact, coastal erosion at the top of the Qarraba cliff resulted in the loss of about 1530 m^2 of land from 1939 till 1993. The movement of limestone blocks at the Qarraba headland has been rather accelerated by the Blue Clay present under such blocks which during heavy rainfalls tends to become in a plastic state (Magri & *alii*, 2007).

This is also evidenced at the Ghajn Tuffieha headland where the cliff top presents a high risk to people. Although the rate of erosion at the cliff toe is of 405 m^2 that at the top is of the cliff is of 477.5 m^2. The buildings at risk at this headland include a medieval tower and a dilapidated building, which could have been a hotel. Truly, this hotel was abandoned during the last century because it seemed evident that it faced serious threats from landslide activities. With regard to its redevelopment, the building is proposed to be set 5 to 10 metres back form the cliff face. Furthermore due to the geology of the area, a light weight skeletal construction will be developed (ADI Associates Environmental Consultants, 2005). However the Malta Environment and Planning Authority (MEPA) remarked that an analysis is to be done prior to such redevelopment to discover the geological stability of the headland on which the hotel is situated, as the distance between the Blue Clay slopes and the hotel is very short. Also MEPA observed that effects on the geological stability of the area may arise during the redevelopment of such hotel (Malta Environment & Planning Authority, 2006).

Already by 1939, Ghajn Tuffieha Bay held several coastal features such as debris on the beach due to landslip from the Blue Clay slopes behind such bay and a shore platform away from the bay. It also held a beach on the leeward side of Il-Qarraba. Traces of terracing on the clay slopes were seen in 1939, however, one has to consider that agriculture on these slopes is only a temporary activity

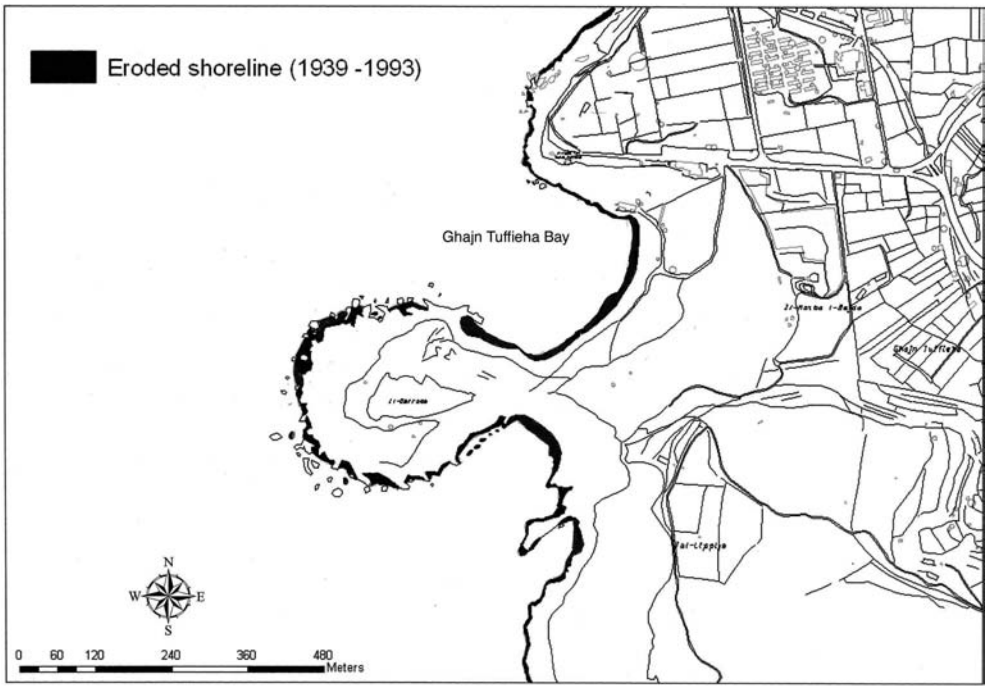


FIG. 9 - Coastal erosion at Ghajn Tuffieha Bay (1939-1993).

since in the winter season these slopes are prone to landsliding making them difficult to be cultivated. As in the case of Mistra Bay, buildings at Ghajn Tuffieha Bay do not seem to exist in 1939 except for an old tower.

By 1957, both Mistra Bay and Ghajn Tuffieha Bay were facing contact from mankind. At Ghajn Tuffieha Bay this is mainly indicated by the building of a stairway, and of structures at the upper side of the Ghajn Tuffieha Headland and beneath such headland near the shore. By 1957, erosion had been concentrated mostly on the shore platform and the beach near it and also the Qarraba headland.

By 1971 the process of erosion continued on a slow pace. However, the landslip present at the bay by this time had already disappeared as the wrath of waves has carried it away. The same happened to the beach deposits which declined terribly.

By 1993 the situation was not that different as coastal erosion was mostly present at the sides of the bay, near the Ghajn Tuffieha headland and near the Qarraba headland, making them especially risky places for swimmers to go to those areas. In fact, coastal erosion is especially dominant at this bay along the shore platform and the Qarraba headland and the areas around them, as seen in Figure 9. Truly, near Il-Qarraba Headland the rocks that topple from the headland prevent the aggressive waves from munching away the part of the beach behind it at the same rate that it erodes the part beneath the Ghajn Tuffieha Headland. This type of erosion may also have led to the creation of another bay at the left hand side of Il-Qarraba although it is probable that such bay is a manmade one due to traces of concrete present there. Blue Clay is still very dominant in the zone and this leads to a series of landslides especially during the winter months. These tend to flow into the beach leading to the development of gullies and springs along it.

Furthermore from the risk map for Ghajn Tuffieha Bay illustrated as figure 10, it can be maintained that most of the risks present at Ghajn Tuffieha Bay are not due to coastal erosion but due to landslide hazards. Truly, at the Blue Clay slopes, such hazard may be attributed to the rain infiltration rates during the rainy period that lead to their saturation and cause land sliding at the beach. Yet, such landslides are worn away by wave action as by time these decrease in size and eventually disappear.

However, at both bays, there are no real indications of the time lag between toe erosion and toppling failures for cliffs. This may be attributed to the fact that coastal erosion studies within the Maltese Islands are still at an embryonic stage, even though the risk of coastal erosion is heavily evident at the bays under investigation.

Moreover people who visit the bays do not seem to bother about the problem of coastal erosion and how such hazard could create risks around the areas concerned. Only foreigners and tourists tend to regard coastal erosion as a threat. However, since coastal erosion seems to affect the coastal localities of Northern Malta this should be given its due considerations by local authorities as it leads to land degradation and loss of property.

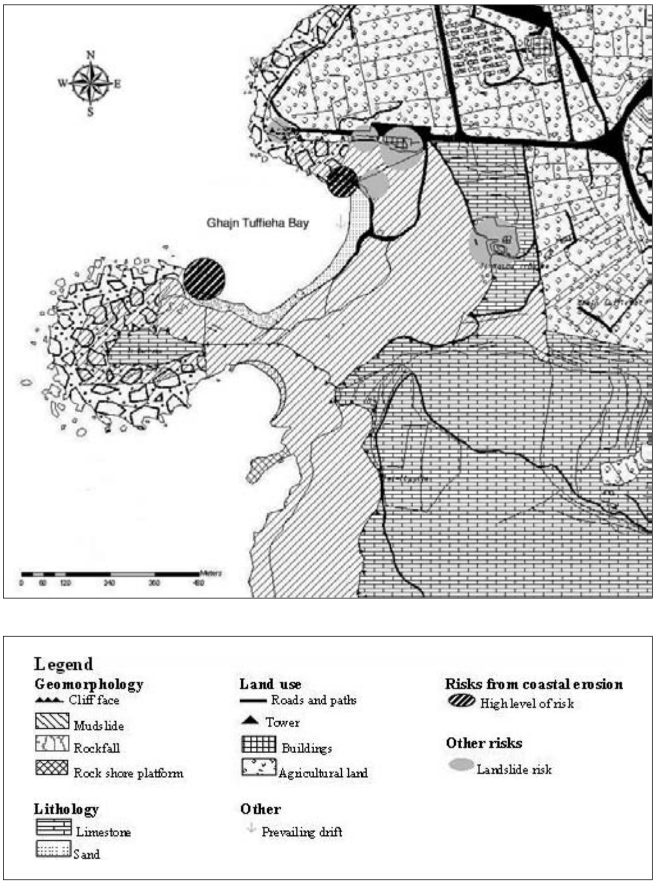


FIG. 10 - Risks present at Ghajn Tuffieha Bay (after Farrugia, 2006; modified).

Truly, one has to consider that the nearer to the coast a feature is, the higher is the potential of impact it faces from coastal erosion hazards. Features may include natural ones like rocky shorelines and debris and human ones like buildings and concrete structures. Yet, at Mistra Bay there is a restaurant which is just behind the coastal road and at Ghajn Tuffieha Bay there is a snack bar which is found on a rocky plateau facing the wrath of waves.

By using the risk maps, shown in Figure 8 and Figure 10, one may be able to determine a buffer zone for buildings. Buildings especially hotels should be prohibited on such areas where the level of risk is high, as this risk could eventually lead to a decline of the people visiting such area and eventually even to a decline in the tourism industry.

However, one can maintain that to safeguard an area from coastal erosion and reduce the risks faced by people when going to such areas there need to be not only hazard identification and mapping but also the development of actions to safeguard such zone. As seen in table 4, the proposed actions fall into two categories; those that deal with restrictions and others that deal with further studies. Overall these actions tend to maintain that

TABLE 4 - Restrictive actions to protect the coast against the coastal erosion hazard (after Farrugia, 2006; modified)

		Recommendations	
Action number	Action	Short term	Long term
1	Limiting building and development near the coast.	Deny or restrict building permits near the coastal fringe. Remove abandoned structures from the coastal zone as these may create further risks to the people if these should collapse.	Create boundaries for limiting construction near the coastal zone. Mention the action as one of the priorities in the Housing Topic Paper.
2	Restrain development in hazard prone areas especially where there have been occurrences of landslides.	If possible move structures landwards so as the probability of risk would decline.	Develop Hazard Management Schemes that look not only at hazards like coastal erosion but also at the processes that help such hazards or else that result from them.
3	Restrict hard-engineering structures along the coast.	Hard engineering structures should be minimally used. However in the short run these tend to bring more positive results than soft engineering structures.	Create an organisation that analyses the impacts of hard engineering structures on the coastal in the long and short run and establish whether they are viable to construct on not.
4	Carry out coastal erosion studies over the years to understand the process and try to create appropriate methods to mitigate its movement.	Invest in monthly studies that can be carried out on a number of bays to analyse the dominant processes on each bay.	Create a Management Plan for the Coastal Zone, which not only looks at shoreline movements throughout the years and the factors which instigate such movements but also at methods of how to mitigate coastal erosion.
5	Consider the coast not as a zone to be exploited but a zone for safeguarding.	Limit most of the development along the coastal fringe especially with regards to recreational use.	Unintentional and intentional management of coast need to look at the sustainable use of the coast and also at safeguarding such zone from further deterioration.

coastal erosion is not an issue that has to be taken for granted and that such actions or similar ones need to be implemented to ensure better management. In fact, such hazard needs to be kept within control since if taken for granted the potential of risk on the people would heavily increase. If people would see the area as one of high risks this would then lead to less people going to the area. Mismanagement of the site, together with land loss and even in some cases collapse of buildings may lead to a further decrease in the number of people visiting the site. Only then would the stakeholders interfere to preserve the coastal zone. However, when people would start visiting the site again coastal protection would decline. All this may lead to a vicious circle in which coastal protection is to be kept only when heavy losses are made.

Monitoring is also to be done to discover the rate of coastal erosion. Public consultations and environmental impact assessments, on the other hand, need to be created to ensure that the engineering approaches done on the coast are satisfactory and also to consult whether the development on the area needs to be done or not.

CONCLUSION

Overall, from this paper it seemed evident that like other countries, coastal erosion processes shape, mould and sculpt the shorelines of the Maltese Islands. Thus since Malta has around 270 km of coast and an area of 316 km^2, priority needs to be given to coastal issues like coastal erosion.

As regards Northern Malta, coastal erosion is an on-going process which develops as a risk only where there is human presence at the coastal zone. Truly, the cases where such process is considered to be as a risk is where it would eventually in the long run lead to loss of land and even loss of property. The mapping of such process would surely be an important contribution to the Islands; however this has to be developed not only on a regional scale but rather on a local scale. This would lead not only to the identification of small regional processes but rather it would give a local outlook to the whole coastal erosion aspect. Moreover, with regard to the two case study areas, in coordination with the European Commission policies mentioned earlier in this paper, it is recommended that at Ghajn Tuffieha Bay no active intervention should be taken, as most of the areas at risk from coastal erosion are not easily accessible. However, studies related to the coastal erosion hazard are highly recommended especially those that tackle the landslide activity. At Mistra Bay, on the other hand, managed realignment should be done since humans have surely modified the shoreline by the construction of the road along the bay. This coast road, in fact, has been undermined by wave action throughout the last years. However, no real considerable judgements were taken to safeguard such coast road from the threat of coastal erosion.

The development of risk assessments is seen as crucial, not only for the two case study areas but also for the whole Maltese Islands, so as to know the risks and also other impacts faced by buildings situated at the coastal fringes. Such impacts arise from sea spray and sand impacts on the limestone blocks by which Maltese buildings are constructed. Moreover, actions or proposals mentioned in the paper, or similar to them are surely ideally be carried out if one would not like to face land loss as seen in other European countries. Together with land loss and loss of property, hazards like landslides and flooding would surely have a negative contribution to the tourist sector that visits the coast. In fact coastal studies would be ideal if these are carried out.

However, overall one can maintain that future directions and recommendations need to be taken, mostly on persuading stakeholders in seeing the coast as an area to be safeguarded rather than exploited. For such reason good coastal protection measures together with monitoring and eventually public participation measures need to be given their due respects since overall the coast can be considered as one of the most important venues for tourism purposes.

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