A spatiotemporal study on the impact of storms on shingle beach deposits at Mgarr il-Xini Bay, Gozo, Malta

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Abstract

Coastal zones are dynamic due to these different processes which act both independently but also condition each other in a complex network of cause and effect dynamics. Shingle beaches constitute sediments that range between 2 to 256mm, and studies on this type of beach environment are still relatively low, when compared to other beach systems such as sandy beaches. The aim of this research is to analyse the sediment distribution of the shingle sediments before and after storms, in order to investigate storm impact on a spatial and temporal dimension. It is a granulometric and morphometric study of the pocket beach located in a bay at Mġarr ix-Xini, Gozo, Malta. This research shows that despite the relatively small dimension of this pocket beach, the shape, size and sorting of the shingle sediments varied before and after storm events.

1. Introduction

Coasts are a dynamic type of landscape and it is the zone where the lithosphere, hydrosphere and atmosphere meet and interact together (Bird, 2008).

The sediment found at shingle beaches vary between 2 to 256 mm and vary from very fine gravel to small boulders. Shingle beaches get their sediment from the erosion of rock outcrops and headland that gets transported to the beaches. Thus, the geology of the area and high wave energy are important for shingle beach formation (Sammut et al., 2017). When waves break parallel to the beach it moves the sediments along the coast. On the other hand, when they break at an angle to the beach, waves move the sediments along the beach. This results in cross-shore zonation according to the different size and shape of sediments, in which it is evident in many shingle beaches around the world (Buscombe et al., 2006).

The temporal behaviour of beaches is affected according to the timescale. Long term (more than 100 years) beach processes are affected by sea level and sediment supply while medium (months and years) and short term (hours and months) beach behaviour is affected by storm events (Burvingt et al., 2018). The coastal response to storm events is dependent on the site conditions, such as the geology, sediment size, beach orientation and beach type, and the wave conditions, as shown in Figure 1 (Burvingt et al., 2017; Pardo-Pascual et al., 2014). Furthermore, the beach orientation determines how the storm wave arrive at the beach and the efficiency of transport deposition, which influence the recovery period after the storm event (Pardo-Pascual et al., 2014). When the storm direction is perpendicular to the orientation of the beach, the erosion rate will be higher, while sediments will be more likely to be transported cross-shore. On the other hand, when the storm is not perpendicular to the beach orientation, longshore sediment transportation prevails (Aagaard et al., 2012; Burvingt et al., 2017; Burvingt et al., 2018).

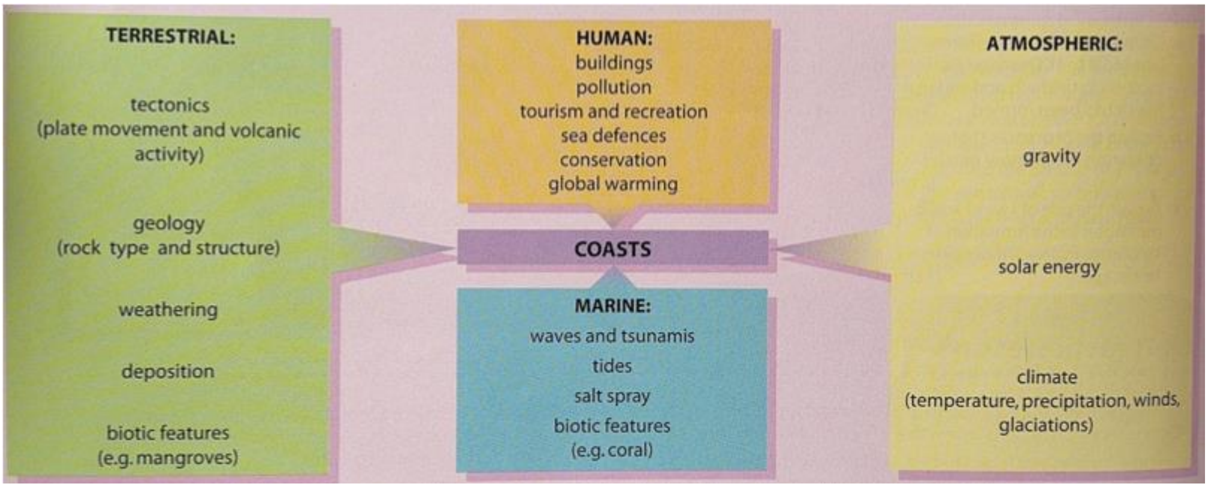

Figure 1. Factors affecting the coast. This study focuses on deposition, waves and climate. Source: Adapted from Waugh (2000) and modified by the author

The chosen beach for this research is Mġarr ix-Xini, and various reasons helped in the site selection such as the sediment type, beach situation, accessibility and the lack of studies done in the area. The main sediment type at Mġarr ix-Xini is shingle, with a bit of sand deposit in parts of the beach. The beach situation is a sheltered bay and it is not exposed to the Northwesterly wind, which is the common wind direction, but winds from the Southeast and East might affect Mġarr ix Xini. Mġarr ix-Xini beach has never been studied academically; therefore it is an opportunity for this study to give a better understanding of granulometric studies prior to and following a storm.

The main research aims are related to how the shingle sediment characteristics vary before and after storms in Mġarr ix-Xini. Thus, it deals with how sediment size, shape and sorting may be differentiated at a spatial and temporal scale. Another aim is to evaluate how the sediment transport position is affected before and after a storm.

Research about the processes of shingle beaches is scant, especially in the Maltese and Mediterranean context, so these research aims will provide a better understanding on the processes of shingle sediments. Apart from that, no research has never been conducted in the Maltese Islands of how shingle sediments react prior and after a storm. Moreover, in the Mediterranean context, this area is still limited to a few investigations. Therefore, this research will provide a wider knowledge of how sediment transportation and characteristics are affected before there will be a storm and after it has happened.

2. Method

2.1. Study area

The Maltese Islands are located on the Malta-Hyblean platform, which results in tectonic movements. Thus, the coastline of the Maltese Islands is influenced by the tectonic activities and rock formations (Said et al., 2010). The coastline of the Maltese Islands is 272 km long, and beaches only take up 2.4% of it, in which only 0.6 km of the coastline is made up of shingle beaches (Gauci et al., 2005).

The beach that is investigated in this study is Mġarr ix-Xini, which is located at the southeast of Gozo as shown in Figure 2. Mġarr ix-Xini bay is a pocket beach with cliffs on both sides and it is characterised by the Xlendi member of the Lower Coralline Limestone, with outcrops of all the layers of Globigerina Limestone, as shown in Figure 5. This geological formation has influenced the sediment budget of the beach in Mġarr ix-Xini, since the sediment of the beach is made up of Coralline Limestone shingles. The anthropogenic effects on Mġarr ix-Xini, such as the construction of the road and slipway, have resulted in a lowered beach shape, as shown in Figure 3 and 4. This would lead to more waves attacking the coast with an increased rate of erosion (Bird, 2008).

Figure 2. An inset map of the location of Mġarr ix-Xini
Source: Modified from Google Earth

Figure 3. Mġarr ix-Xini beach and the surrounding area
Source: Author

Figure 4. Mġarr ix-Xini beach Source: Author

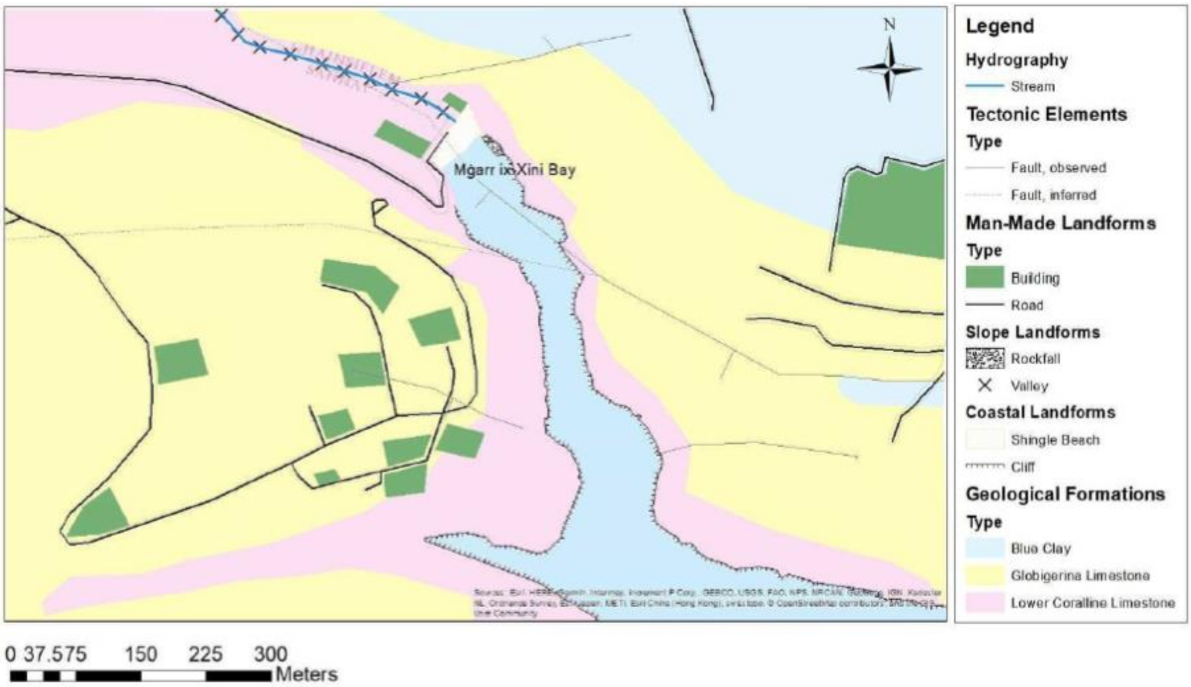

Figure 5. A geomorphological map of Mġarr ix-Xini. Source: author

2.2. Data collection

The weather is an important aspect of this study since the main aim of this research is to understand how shingle sediments in Mġarr ix-Xini varies before and after a storm. Therefore, the first step was to monitor the weather to identify when storms were approaching. Numerous site visits and observations were conducted during the study period from 19th November 2018 to 15th March 2019 to gather data. Thus, data collection was done before the storm was approaching and thereafter when the weather had stabilised, to analyse if there is a relationship between the sediment characteristics before and after a storm event. Three storm events were chosen to be analysed in this study to have a wider understanding of the processes of the shingle sediments in Mġarr ix-Xini, as shown in Table 1.

Storm Number	Dates of Storm Event	Description
Storm Event 1	17th and 18th December 2018	Low-pressure system was moving beyond southern Italy. During the same time, a high-pressure system was formed over southern France. This has resulted in strong West to West Northwest winds.

Storm Event 2	23rd and 24th February 2019	This storm was classified as an intense Mediterranean cyclone, in which the wind speed was recorded to be the strongest since 1982. The wind direction was coming from Northeast with a Force 10 speed.
Storm Event 3	11th and 12th March 2019	A cold front was moving over the Maltese Islands while a high-pressure system was developing in the western Mediterranean. This generated a West-Northwest gale.

Table 1. Storm events during the data collection
Source: Author

The jetty located at Mġarr ix-Xini has bisected the beach, and on either side shingle deposits are found. Each section was divided into line transects perpendicular to the shore, as shown in Figure 6 and 7.

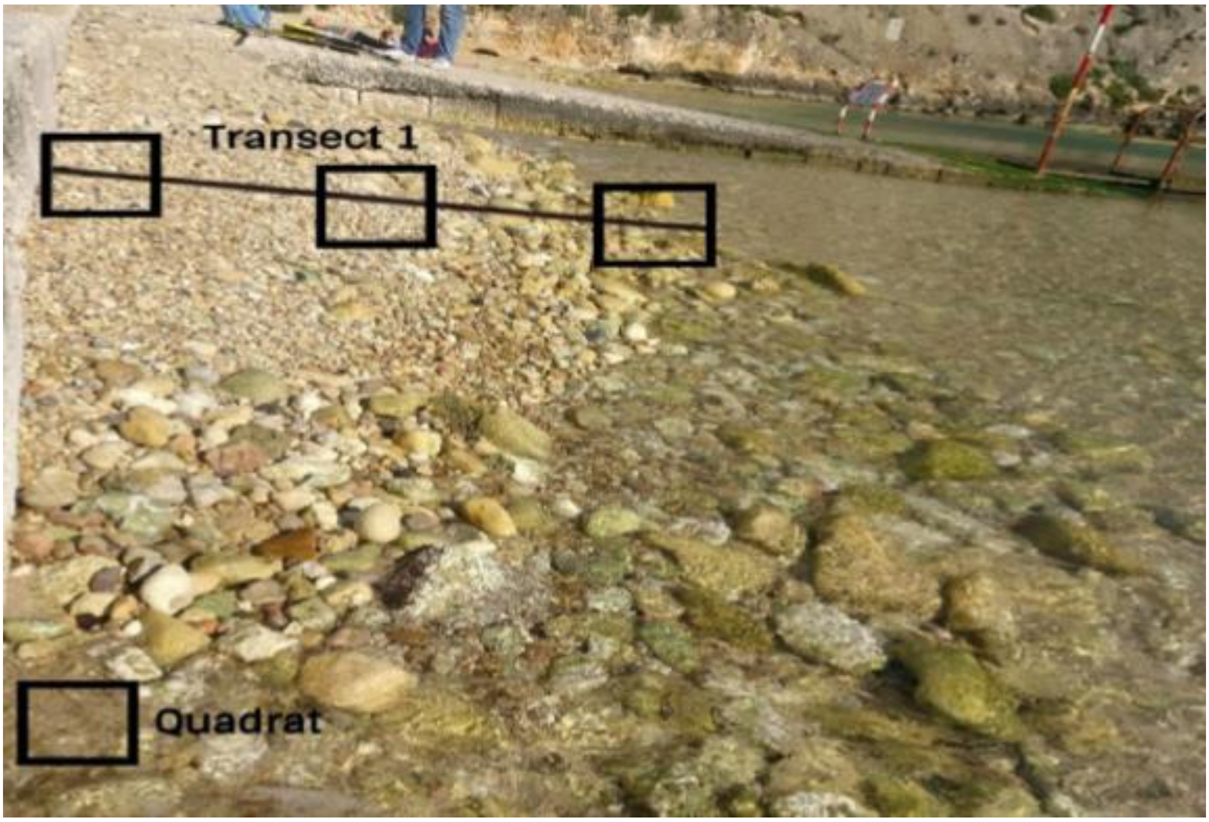

Figure 6. Representation of the positioning of the transect and quadrats in section A Source: Author

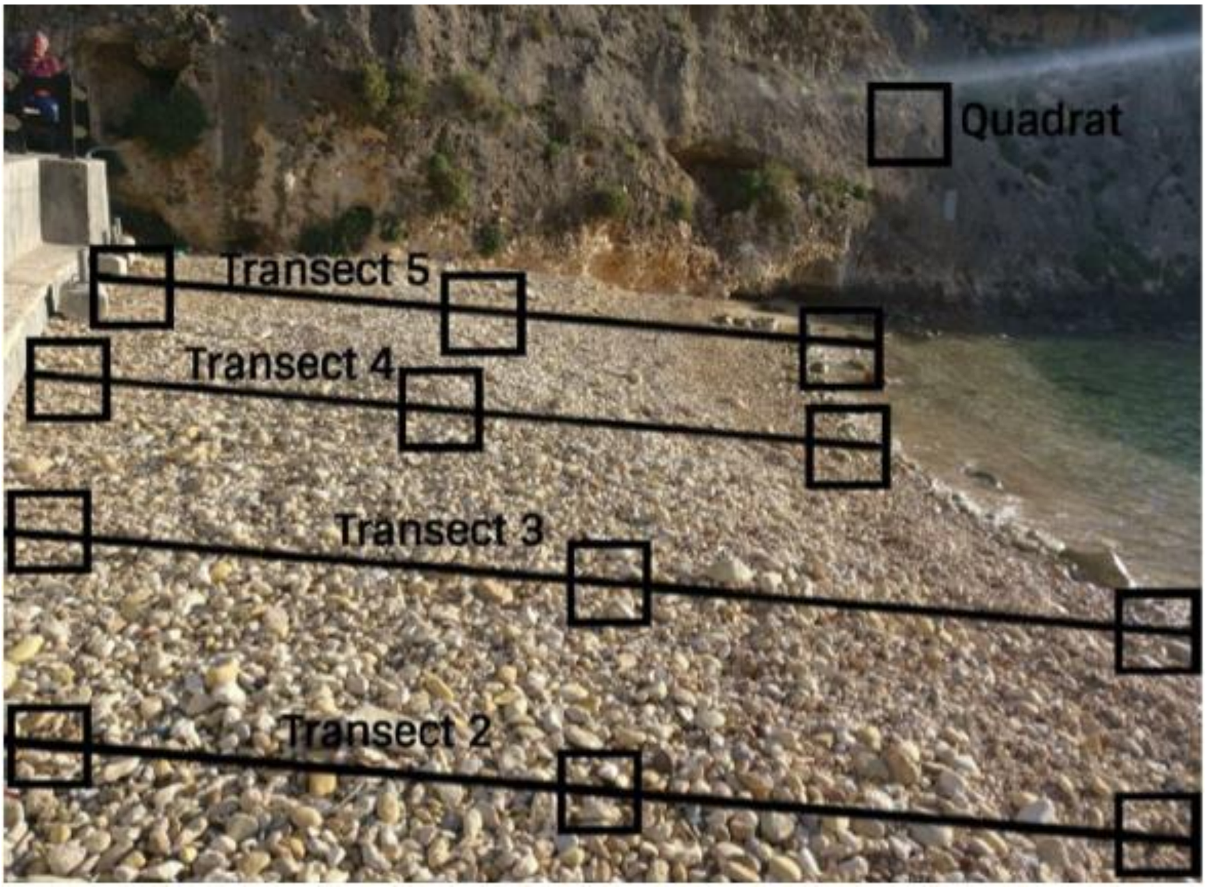

Figure 7. Representation of the positioning of the transects and quadrats in section B Source: Author

The beach profile was measured by using a pantometer along the line transects. The procedure of measuring the slope profile was in an uphill movement every 1 metre, with the values being recorded for later representation for every transect. With the use of a pantometer, it gave an idea of how the beach profile is behaving prior to and after a storm.

Every line transects had three quadrats that were systematically positioned: at the beginning, middle and end of a transect. The quadrat used in this study had the dimension of 0.5m by 0.5m. Quadrats were used to measure the dimensions of the shingle sediments to determine their size, shape and sorting. Therefore, quadrats are useful to observe the changes over a period of time and will make the data more manageable.

The shingle sediments were calculated by collecting twelve sediments in every quadrat. The measurement of the shingle sediment was done using a digital calliper, the length (A), width (B) and height (C) axes were measured.

2.3. Data analysis

To analyse the size distribution of shingle particles, the conversion of diameter from Udden-Wentworth's millimetre (d) scale to Krumbein's phi units (ϕ) using the equation ϕ=$-log2d$, with two decimal places, was done for the A and B axis of the shingle sediment. The Krumbein's phi unit is a convenient way to statistically analyse sediment grain size distributions over a wide range of particle sizes.

The mean of the shingle sediments was calculated as a measure of central tendency for all the quadrats. The dispersion of the sediment size distribution was measured by means of sorting, which is the degree of classification of the sediments. This was done by calculating the standard deviation and classifying them according to Folk (1974) sorting classes.

In order to determine the shape of the sediments, the Zingg classification system was utilised. The ratio between the length, width and height were done to identify in which class the sediments fit. (Selley, 2000).

Skewness was used to measures the degree of asymmetry of a distribution function, and it indicates the level of coarse (positive asymmetry) or fine (negative asymmetry) material in the quadrat. (Shennan et al., 2015). Furthermore, kurtosis was used to measure the peakedness of the statistical distribution. Therefore, it shows the flatness or peakedness of the distribution compared to the normal distribution.

The statistical test of the Independent t-Test was used to measure if there is a statistically significant variance between two means of unrelated groups, which in this case were the phi results for the A and B axes between a pre-storm and post-storm event (Sedgwick, 2010).

3. Results

3.1. Sediment properties

Two sediment size classes were identified in Mġarr ixXini Bay, pebbles and cobbles, in which their diameter varies between -2.0ϕ to -6.0ϕ and -6.0ϕ to -8.0 ϕ respectively. While analysing the sediment size, pebbles were the most commonly found in the quadrats. The number of cobbles varied accordingly to the period of data collection. Thus, before a storm normally cobbles would mostly be found at the foreshore while after the storm has approached the waves would have deposited the cobbles at the middle shore and backshore.

The sediment shape was similar throughout the different field visits. Disc shaped sediments were found in every quadrat and transect. While spheroids and rollers would mostly be located at the foreshore and middle shore. Spheroids and rollers were only located at the backshore in small numbers. This is due to the shape of the sediments, where the disc-shape and blade sediments are more found at the backshore and the spherical and roller sediments are commonly found at the foreshore.

3.2. Beach profile

Before a storm the beach profile was gently sloped and the length of the transects were shorter than those of after storms. It was noted that where the concentration of deposited sediments was found, the gradient of the beach was steeper. After the storms, the beach profile would be steeper than that of before the storm. Since after the storms, more cobbles were found at the middle shore. A berm was mostly found after the storms at the backshore, where the sediments behind it were protected from the waves, with some cases sand sediments was also found.

3.3. Statistical parameters

The statistical parameters that were analysed are the standard deviation, skewness and kurtosis. Regarding the standard deviation, it calculated the degree of sorting of the quadrats. It was noted that there was a spatial differentiation in the sorting pattern since the quadrats located at the foreshore were generally less well sorted than those found at the middle shore and backshore. This could be since it is the most area that is influenced by wave action. Apart from that, a temporal differentiation was also noted in which the sorting patterns after a storm were more likely to be less sorted than those before a storm. In terms of skewness, it varied throughout the different transects and quadrats, but some pattern was still noticeably. Generally, before a storm, the skewness was more strongly coursed especially at the foreshore. After the storms, it was noted that more strongly fined skewed quadrats were found. As for kurtosis, all of the quadrats had leptokurtic distribution and it ranged from leptokurtic to extremely leptokurtic kurtosis.

4. Discussion

The main research aim was to understand how storms affect shingle sediment characteristics at a spatial and temporal scale. Although the first storm was not parallel to the situation of the beach, Mġarr ix-Xini was still influenced by it. As shown in Table 2, the sediment size distribution of pre and post storm was different in the foreshore and middle shore. This imply that the storm waves didn’t reach the backshore since the sediment size remained the same before and after the storm approached.

Pre-Storm 1 VS Post-Storm 1						
		Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
A-Axis	Q.1	0.861	0.113	0.000	0.002	0.002
	Q.2	0.040	0.005	0.121	0.100	0.639
	Q.3	0.053	0.501	0.837	0.297	0.296
B-Axis	Q.1	0.427	0.206	0.000	0.000	0.000
	Q.2	0.036	0.006	0.043	0.006	0.501
	Q.3	0.015	0.938	0.753	0.085	0.008

Table 2. The t-Test of the first data set, highlighting in yellow the statistical differences in sediment size distribution
Source: Author

Since the second storm was an intense Mediterranean cyclone it produced winds of Force 10 with waves being 10.1 metres in height. Thus, the backshore was also affected after the second storm, in which the sediments characteristics were similar to that of the pre-storm 3. On the other hand, the third storm affected the backshore and changed the sediment size of the data collection after the storm.

Pre-Storm 3 VS Post-Storm 3						
		Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
A-Axis	Q.1	0.257	0.793	0.259	0.123	0.956
	Q.2	0.163	0.996	0.482	0.513	0.850
	Q.3	0.012	0.332	0.042	0.003	0.285
B-Axis	Q.1	0.493	0.997	0.127	0.120	0.822
	Q.2	0.059	0.651	0.861	0.727	0.874
	Q.3	0.002	0.383	0.105	0.001	0.322

Table 3. The t-Test of the third data set, highlighting the differences in sediment size distribution
Source: Author

Regarding the sediment shape, spheroids and rollers would mostly be located at the foreshore and middle shore. Spheroids and rollers were only located at the backshore in small numbers where the length of the transects was short. In some way, this confirms the studies done by Sammut et al. (2017), Grottoli et al. (2015) and Buscombe et al. (2006), in which they noted that due to the shape of the sediments, the disc-shape and blade sediments are more likely to be found at the backshore and the spherical and roller sediments are commonly found at the foreshore. Since after the storms, more cobbles were found at the middle shore and backshore it confirms with the study done by Sammut (2013) that larger shingle sediments produce steeper beach profile. The cross-shore sorting patterns were similar to the research done by Bonello (2015), in which the quadrats located at the foreshore were less well sorted than those at the backshore. These studies are related to seasonal not storm driven events, thus it shows that sediment characteristics can be variable, even when assessed as event based and not seasonal. Thus, storm data needs to be more studied in order to capture such intense dynamic events.

5. Conclusion

The result of this research shows that, notwithstanding the relatively small dimension of this pocket beach, the shape, size and sorting of the shingle sediments varied before and after a storm events. The characteristic of the storms was one of the factors that helped sediment size distribution along the beach, even when the storms were not parallel to the situation of the beach. Furthermore, the beach profile was also diverse since after a storm more cobble sized sediments were transported to the middleshore and backshore, and hence resulted in a steeper beach profile after storms.

From this study, it was concluded that it does not imply that longer times-scales will result in larger differences in the sediment size. This result may suggest that various storms may collectively contribute to a form of sediment mobility that make readjust differences produced by single storm events.

This research contributes to a better understanding about shingle beaches and how their sediments are affected before and after a storm event. This could help coastal zone managers to evaluate the impact of storms on beaches, in order to implement effective management measures. Apart from that, this research gives more knowledge about the effect of storms on shingle beaches, since this area of study is still limited in the Mediterranean context, especially in Malta.

One of the main limitations of this study was the huge number of raw data that was collected. Furthermore, data reduction has to be performed in which the C-axis of the sediments were not included in the inferential data analysis. Another challenge was the limited number of available literature about the effects of storms on shingle beaches, especially in the context of the Maltese Islands. Although it was a challenge, it was a motivation to study this topic further.

A possibility for further research is to use different data collection techniques, such as sediment tracers, to determine the transport pathways after storms. Moreover, different analysis techniques could also be implemented, such as the degree of roundness of sediments. Furthermore, the relationship between wave strength and the sediment distribution could be further studied to give a better understanding of how waves affect the sediment size, shape and sorting, while also affecting the beach profile.

6. Acknowledgements

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