Coastal storm damage index in the Province of Naples, Italy

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ABSTRACT: Wave storms are one of the major threats to beaches and coastal infrastructure. This paper describes the evaluation of a storm damage index (SDI) on the coastline of the province of Naples, whereby the structural, erosion and flood damage can be classified on a municipal scale. Pressure, wave, and wind data was used to classify wave storm intensity, whereas information from newspapers enables the type of damage to be identified. The index is then used to assess the last severe wave storm which hit the coastline of the province of Naples in December 2020.

KEYWORDS: Coastal damage, Damage index, Wave numerical simulation, Wave storm

1 INTRODUCTION

Recently, the coastal hazards have raised their impact due to the increased occurrence of destructive coastal storms and high degree of coastal occupation (Arneth et al. 2019). As sea levels continue to rise, more combination of tides and wave events will exceed critical levels, thus increasing the duration, intensity and frequency of floods to a significant extent. (Di Paola et al. 2021).

During storms, waves overtop berms and seawalls along the shoreline when energetic winter swell and high tide coincide. This may lead to severe consequences as it often results in high ecological, infrastructural and, in some cases, even human losses. This calls for a detailed characterization of wave climate and intense storms with a view to identifying their temporal patterns and characteristics. To reconstruct such wave storms, numerical simulations, (Benassai and Ascione 2006), validated with remote sensing data (Benassai et al. 2015), were employed. These also served the purpose of assessing coastal vulnerability (Benassai et al. 2013). In recent years, several researchers have classified wave storms in terms of energy, duration and water level increase. Dolan and Davis (Dolan and Davis 1992) first used an index based on wave height and storm duration, which ranked the storms in classes. Similarly, Orford and Carter (Orford et al. 1995), Kriebel and Darlymple (Kriebel and Dalrymple 1995), Zhang et al. (Zhang et al. 2002) classified the wave storms and proposed indices based on these features. On the Spanish coast, Anfuso et al. (Anfuso et al. 2016) and on the Italian Coasts, Mattei et al. (Mattei et al. 2021) analyzed the coastal impact of the wave storms.

In order to characterize the coastal vulnerability and propose adaption strategies (Anfuso et al. 2016, Anfuso et al. 2021), a high spatio-resolution damage database needs to developed. This will enable proper spatial planning, especially in those areas with high levels of coastal vulnerability and exposure. In literature, different methodologies have already been proposed for storm damage evaluation, most of which are based on a damage index. The final aim is to set up a general method whereby damage can be classified in reference to waves and storm surges. Three important parameters define the severity of the damage likely to be caused by a wave storm. The inundation intensity dictates how high the water will rise, in terms of both storm wave energy and the total water level. Beach erosion can be defined as the removal of sand from the dry beach associated with storm induced mechanisms which remove part of the berm and sand in an offshore bar. The damage to infrastructures analyses the amount of damage to roads, railways and maritime works. Among others, Jimenez et al. (Jiménez et al. 2012) carried out a systematic information analysis from which all relevant news about coastal storm damage in Catalonia were retrieved. Gil-Guirado et al. (Gil-Guirado et al. 2019) collected information on flood cases from 1960 to 2015, by systematically consulting the digital newspaper archives, through the links between municipally names and some keywords linked to coastal damage. Sancho-Garcia et al. (Sancho-García et al. 2021) proposed a “fast approach” to evaluate storm damage on the basis of data from newspaper reports published over time which were then validated and classified on a local scale.

In this paper, the evaluation of coastal damage caused by intense wave storms was performed at a municipal scale in the Province of Naples. The information relative to coastal storm damage news and images on local newspapers were examined and classified, in order to evaluate a storm damage index, and to identify hot spots along the coast. Coastal damage classification, with a focus on the last significant storm of 28-29 December 2020, was performed in order to give a preliminary assessment of type and intensity of the damage caused.

The paper is organized as follows. Section 2 introduces the study area, Sections 3 and 4 describe the methods and the relative results obtained. Discussion and Conclusions are reported respectively in sections 5 and 6.

2 STUDY AREA

The study area comprised the Province of Naples, which includes the municipalities of the Gulfs of Naples and Pozzuoli and that of the Isles of Capri, Ischia and Procida (Fig. 1). The coastline covers a total of 195 km (including the 17 km of the Isle of Capri, the 43 km of the Isle of Ischia and the 16 km of the Isle of Procida) and 24 municipalities , many of which are characterised by a high population density (up to 8000 inh/km^2) and seven of which overcome 50000 inhabitants (Pozzuoli, Napoli, Portici, Ercolano, Torre del Greco, Torre Annunziata and Castellammare). The geomorphological configuration, natural beauties, excellent climate, culture and hospitality facilities make the Gulf area a very important tourist destination. As for the local wave climate, the gulf of Naples is characterised by frequent stormy events with wave height values up to 8 m associated with atmospheric low pressure systems during winter and autumn while low wave height value are recorded in spring and summer (Mattei et al. 2020). To study wave direction, the University of Naples ’Parthenope’ supervises a network of measuring instruments installed in the Gulf of Naples. Results show that the prevailing wave approaching sector is site dependent and that there are small seasonal variations due to the complex geomorphological configuration of the Gulf of Naples.

3 METHODS

3.1 *Offshore wave climate for each coastal stretch*

The entire coastline stretch was divided into eight sectors, each of which was assigned a virtual buoy (Table 1). The directional distribution of fetch length was calculated for each section, thereby we were able to obtain the effective fetch length starting from the geographical fetch length in the following way:

$$F_{eff} = \frac{\sum F_i cos^n \alpha_i}{\sum cos^n \alpha_i} \quad (1)$$

where i is the angle from wind direction, varying over $90°$, F_i is the geographical fetch, that is a straight line fetch measured along direction i, and n is the exponent accounting for the wind-wave energy directional speeding (it is typically equal to 2).

In each sector, the well-known “geographic transposition of wave gauge data” method (Contini and De Girolamo 1998) enabled the identification of the local wave climate.

For each direction, the ratio between the significant wave height H_{sv} in each sector and the significant wave height recorded by the wave gauge H_{sr} is given by the square root of the ratio of the relative fetches (Seymour 1977).

	Virtual buoy coordinates	
Sector	LATITUDE	LONGITUDE
1	*40,8377*	*14,0229*
2	*40,6811*	*13,9173*
3	*40,7713*	*14,1095*
4	*40,8128*	*14,0958*
5	*40,7743*	*14,1859*
6	*40,8170*	*14,2815*
7	*40,6736*	*14,3942*
8	*40,5450*	*14,1735*

Table 1: Coordinates of the virtual buoys positioned at each of the eight crossing sectors considered.

Newspaper	**Link**
Il Mattino	*https://www.ilmattino.it/*
Fanpage	*https://www.fanpage.it/napoli/*
Napoli Today	*https://www.napolitoday.it/*
Metropolis	*https://www.metropolisweb.it/*
Rai News	*https://www.rainews.it/*

Table 2: Online databases used to collect images of coastal damage in the days following the storm dated the 28th December 2020.

In order to highlight a possible link between the offshore buoy wave climate and the one affecting the different coastal stretches, we first analyzed the wave data provided by the Italian Sea Wave Measurement Network (Bencivenga et al. 2012) through the records of the Ponza buoy (40°52’00.10” N, 12°56’60.00” E) over the period between July 1989 and December 2014. July 1989–December 2014.

On these grounds, the spectral significant wave height H_{sv} and peak period T_{pv} of the virtual buoy can be predicted as follows:

$$\frac{H_{sv}}{H_{sr}} = \left(\frac{F_v}{F_r}\right)^{\frac{1}{2}} \quad (2)$$

Figure 1: Identification of eight virtual buoy for estimate fetches for each sector.

$$\frac{T_{pv}}{T_{pr}} = \left(\frac{F_v}{F_r}\right)^{\frac{1}{3}} \tag{3}$$

v and r respectively denote the "real" and "virtual" locations. As a result, the offshore wave climate could be determined, as reported in the next paragraphs.

3.2 *Wave damage classification*

The information selected from the newspaper database included: the date, location (municipality), type, and extent of the damage. Based on the news and the photos published in local and national newspapers (Table 2), the coastal damage was classified as damage to infrastructures, erosion, and flooding. The damage to infrastructures is intended for roads, railways, beach promenades, and buildings. Beach erosion is the retreat of the beach due to a storm, and coastal inundation is linked to the run-up on the promenade.

Starting from Sancho-Garcìa et al. (Sancho-García et al. 2021), a storm damage index was evaluated using the storm intensity classification adopted in Mattei et al. (Mattei et al. 2021). The data considered are maximum wind speed, maximum significant wave height, and minimum pressure. Each of these parameters associated with the storm was ranked with a coefficient A in the range from 1 to 5. On the other hand, the type of damage is assessed in the field based on the news and photographic reports published in the newspaper database in the days following the event. The sub-indices I_d (damage to infrastructures), I_e (beach erosion), and I_{in} (coastal inundation) were assigned as reported in Table 4.

The Storm Damage Index (SDI) was calculated according to Eq. 4.

$$SDI = [I_d + I_e + I_{in}]\, A \tag{4}$$

The Storm Intensity Index (A) is useful for estimating the potential impact of a storm by considering input data from weather forecasts. It is used to determine the intensity level of a storm based on three parameters: atmospheric pressure [hPa], wave height [m], and wind speed [m/s]. This index ranges from 1 (low-intensity event) to 5 (high-intensity event).

Index		Verified	Not verified
I_d	Destruction of infrastructures	1	0
I_e	Retreat of the coastline	1	0
I_{in}	Coastal Flooding	1	0

Table 3: Description and associated value for the different damage indices.

4 RESULTS

In this Section, we computed the Storm Damage Index on the coastline of the province of Naples, which was based on wave storm effects dating back to December 2020. A preliminary evaluation of the local wave climate for each sector was based on in-situ measurements (Ponza buoy), and on the geographical transposition of each virtual buoy. The value of the sub-indices I_d, I_e and I_{in} in each sector were obtained from information published by the press in the days that ensued the storm event, while coefficient A was obtained from the results of Mattei et al. (Mattei et al. 2021).

In Figure 1, the province of Naples was reported to have been divided into eight homogeneous sectors, where the eight virtual buoys have been located.

Sectors	I_d	I_e	I_{in}	A
Sector 1	0	1	1	10
Sector 2	0	0	1	13
Sector 3	1	0	0	10
Sector 4	0	0	1	9
Sector 5	1	0	1	14
Sector 6	1	1	1	15
Sector 7	0	0	1	11
Sector 8	1	0	1	15

Table 4: Evaluation of the sub-indices I_d, I_e, I_{in}, and of the Storm Intensity Index (A) for each coastal sector.

Moreover, the fetch directional distribution, along with the different exposure, is also indicated in the figure. For example sector 4 (Gulf of Pozzuoli) shows a narrow fetch distribution, while sectors 2, 3, and 8 show a wider exposure. The most severe winds and waves approaching the coast of Province of Naples come from the second and third quadrants, in agreement with Bencivenga et al. (Bencivenga et al. 2012). In Figure 2 we reported the directional distribution for the entire period in which data was collected (1989–2014), for values of H_s greater than 2 m. The wave directional distribution shows different features in each coastal stretch, which in turn depend on fetch distribution. For example, sector 4 of Figure 2d (Gulf of Pozzuoli) shows the narrowest range of wave directions and lowest wave heights, while sectors 2, 3, and 8 of Figure 2b, c, and h, respectively, show the widest range of wave directions and highest waves. This circumstance suggests a different proneness of each coastal stretch to storm damage.

H_s

The test case for SDI evaluation was the storm event that hit the Province of Naples between 27 and 30 December 2020. The study area was characterized by a low-pressure front with a minimum of 995 hPa on 28 December 2020. On the same day, this intense atmospheric low-pressure system was accompanied by widespread rainfall and strong winds coming from the southwest $(WS_s > 20m/s)$ with gusts $> 25m/s$. This wave storm was characterized by high waves (about 4 m as recorded by the wave gauge of the University of Naples ”Parthenope” (Mattei et al. 2021)). The combination of these and other (e.g., tide level) coastal dynamic agents caused a violent storm surge that strongly flooded the city and its surroundings.

The wave-damaged inventory reported in newspapers during the 28th December 2020 storm showed that the most exposed coastal stretches were the inhabited centers of Naples and Torre del Greco. Figure 4 reports the damage to the infrastructures and promenade of Naples during the selected storm event due to run-up which hit and partly destroyed some touristic infrastructures.

Figure 5 reports the damages to the tourist infrastructures that occurred on the promenade of Torre

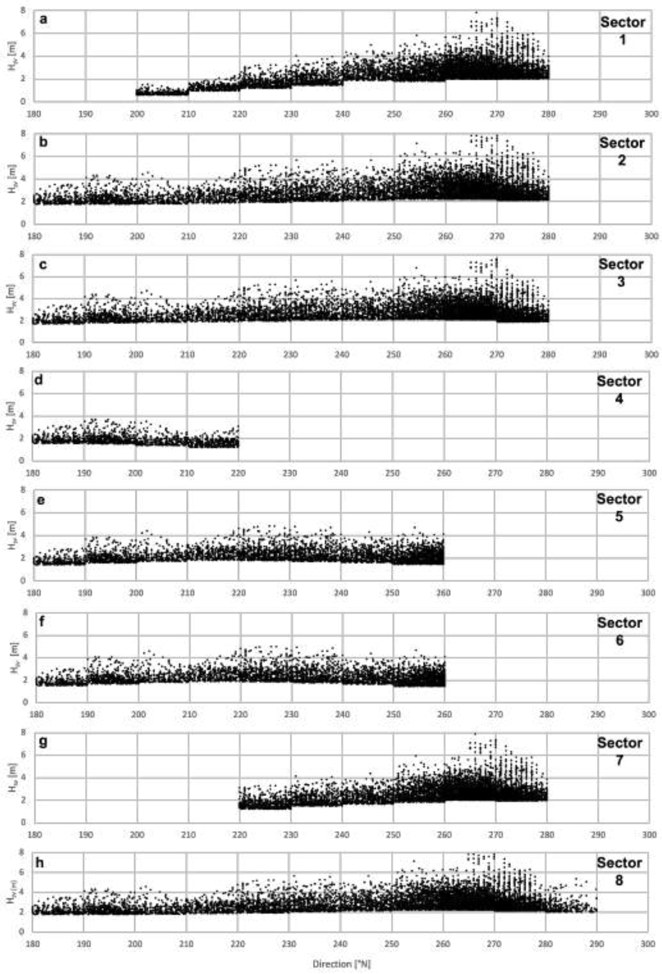

Figure 2: Wave transpositions in the different Sectors obtained from Ponza buoy records 1989-2014.

del Greco during the same event. It can be noted that the cobbles of the recently built breakwater were spread on the promenade and some tourist infrastructures were also destroyed. The reported high intensity of damages is consistent with the direction of storm waves (coming from the southwest) and the coastal stretch exposure, which is more critical for sectors 5 (Posillipo), 6 (Naples and Torre del Greco), and 8 (Capri), according to Figure 2. Damages were also reported for the coastlines of Posillipo (sector 5) and Capri (sector 8), but they were not catastrophic because of the different coastal geomorphology (high cliffs, in the case of Capri), or lower exposed value (fewer touristic infrastructures on the coastline in case of Posillipo).

The cumulative effect of the wave storm of December 2020 for each coastal stretch was calculated as reported in Figure 3, and in Tab. 4. The objectivity of the damage caused by the storm is evaluated in the days following the event through newspaper reports. This damage is considered using three sub-indices: I_d represents the impact on coastal infrastructure, I_e represents the beach erosion, and I_{in} coastal inundation, respectively. They are not assigned a specific value but are considered equal to 0 in the absence of damage and equal to 1 in the presence of damage. The Storm Damage Index (SDI) is greater not only as a function of the storm's intensity (assessed through A) in the sectors considered in the study area but also as a material function of whether or not damage has occurred.

Therefore, the SDI is a simple parameter that indicates the degree of coastal damage that has occurred due to the storm.

In detail, the coefficient A is maximum for the most exposed sectors, in which the wind-wave effects were maximum, while is minimum in the most sheltered sectors. On the other hand, the reported damages for both the inundation, erosion, and destruction are found significantly in the most exposed sector 6 (municipalities of Naples and Torre del Greco, Figure 4 and 5).

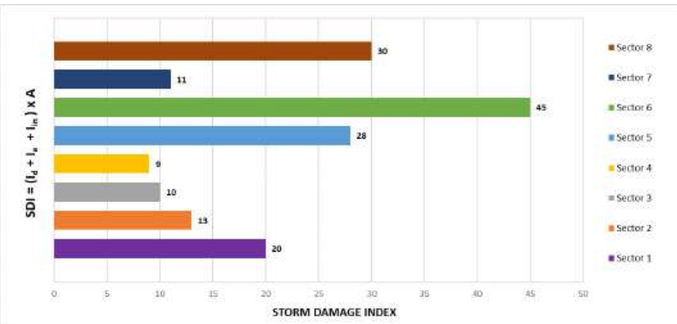

Figure 3: Obtained value of SDI for each of sector of the Naples province.

5 DISCUSSION

The SDI developed in this paper presents the advantage of giving an objective storm damage classification. The storm intensity is associated with coefficient A, which classifies the storm based on the values of pressure wind and wave height, while the different types of damages are not subjectively based on their intensity.

The comparison between the wave exposure on the different coastal stretches and the inventory of coastal damages reported in newspapers shows a correlation between the offshore wave climate and the most affected areas during the selected wave storm. In other words, the uneven distribution of the damage along the coast suggests that the amount of damage affecting a specific location depends on the differential wind, wave, and pressure conditions in the Gulf of Naples during the storms. In particular, Naples and Torre del Greco can be classified as hotspots because they are located along an urban coastline with high occupation density and a consequently high exposure value.

6 CONCLUSIONS

In this paper, a coastal storm damage index was constructed based on newspaper information to classify the infrastructural, erosion, and flood damage on a municipal scale. The damage reported by newspapers in the hotspots is consistent with the direction of storm waves and the coastal stretch exposure. The objective classification of damage prevents some bias in the newspaper reports, which are somehow influenced by the dissemination policy of the press. Indeed, more often than not, the press tends to merely give a general description of the most relevant impact of the storm supported by impressive images, rather than providing a detailed report of the damage. Nevertheless, this news becomes a good proxy data source for obtaining information about the damage in the absence of a systematic database. The application of the coastal storm damage index will be extended to a longer database of wave storms, with a view to achieving a more extensive set of damage information.

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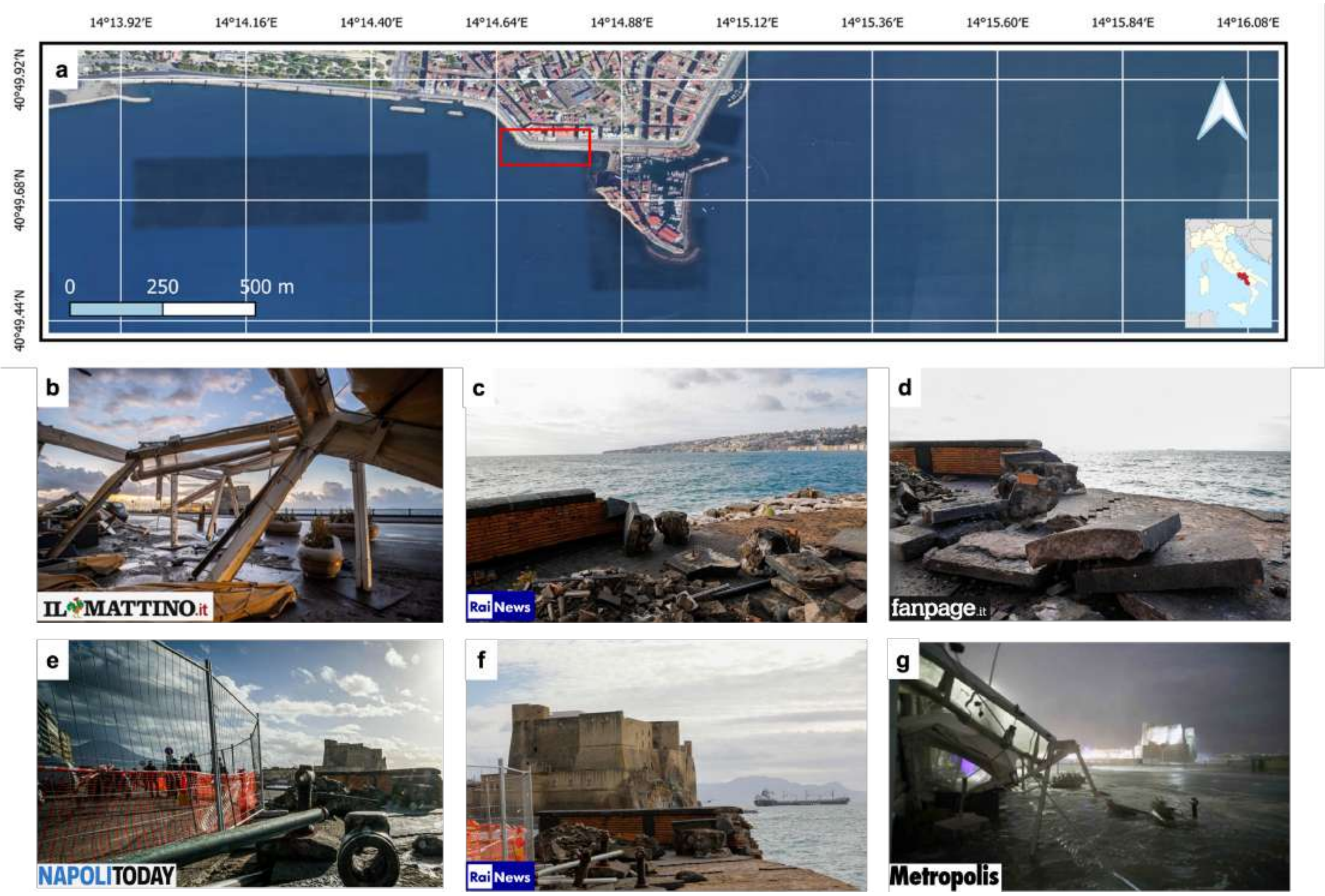

Figure 4: Promenade of via Partenope, Naples (red box in (a)), and its damages (b, c, d, e, f, g), reported by different newspaper photographs of 29th December 2020.

Figure 5: Promenade of Torre del Greco (red box in (a)), and its damages (b, c, d, e, f, g, h) as shown in the images reported by the Technical Office of the Municipality on 29th December 2020.

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