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A Tool for Coastal Setbacks Demarcation over Rough, Impermeable Shores: The Test Case of Kavala Coastline (Northern Greece)

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Although setback zones and lines are considered as a powerful coastal zone management tool ensuring public access, protecting the coastal ecosystem and minimizing natural hazards over developments, the lack of a solid and objective Mediterranean methodological framework for coastal setbacks demarcation appears profound. Especially for countries like Greece, this deficiency leads to long legal disputes encouraging illegal construction on the coastline. In this article a methodology on coastal setbacks demarcation over rocky, impermeable shores is proposed, followed, and implemented along a Greek shoreline, serving as a pilot case study. The methodology is consistent with the requirements of the integrated coastal zone management (ICZM) Protocol and the Greek legislation (L. 2971/2001), aiming to determine the “highest winter waterline,” accounting for the tidal and storm surge effects, the sea-level rise due to climate change impact, the extreme offshore wind and wave analysis, and the maximum potential wave run-up. Such a tool may bridge the gap between legislative provisions and actual ICZM Protocol implementation improving regional coastal management and planning.

Keywords coastal setbacks, ICZM Protocol, maximum potential wave run-up, Mediterranean Sea, methodological framework

Introduction

A coastal setback is defined as a buffer zone, demarcated by a specific distance from shoreline’s highest winter water mark, within which permanent constructions are not allowed. Setback zones consist of a powerful coastal zone management tool for a number of different reasons, such as to ensure public access, to protect the ecological and landscape integrity of the coast, but also to minimize the natural hazards risk by protecting population and developments (Rochette and Billé 2010). According to FAO (2006),
setback zones demarcation and the imposed setback rules vary substantially worldwide, in terms of the setback baseline definition, the width of the exclusion zone, the types of the activities and uses excluded or restricted, and the contents and context of the exclusion regime. Different countries have adopted various setback zone demarcation methods and variable widths, ranging from 100 m to 1,000 m. In the United States coastal setbacks serve as “no build areas,” with significant variability from state to state in their definition (e.g., fixed, erosion-based, or mixed), laws and regulations (Rabenold 2013).

Setback lines and zones provide opportunities for planners and stakeholders to consider the natural landscape elements along the shore (Cambers 1997). They were first introduced in international treaties by Article 8-2a of the Mediterranean integrated coastal zone management (ICZM) Protocol aiming to ensure biodiversity protection, to maintain the ecosystem services of coastlines, to preserve cultural and natural assets and traditional landscapes and to protect population and infrastructure from climate change risks (Sanò, Marchand, and Medina 2010). Such provision was dictated by the gradual increase of human pressures exerted on the Mediterranean coastal zone, since coastal population raises with an annual growth rate of 1.4%, projected at 174 million inhabitants by 2025 (Plan Bleu 2005); seasonal tourism flows escalate to a projected 350 million tourists (UNEP 2012); artificial land cover expands at an alarming pace, leading to the concretion of almost 40% of the Mediterranean coasts by urban sprawl, roads, tourist facilities, and ports (Plan Bleu 2005); coastal landscapes and sites of environmental and cultural importance are under constant degradation (Alpan 2011).

Indeed, the ICZM Protocol identifies in Article 8 that Parties “shall establish in coastal zones, as from the highest winter waterline, a zone where construction is not allowed. Taking into account, inter alia, the areas directly and negatively affected by climate change and natural risks, this zone may not be less than 100 meters in width…” However, a preliminary analysis of the Protocol brings out that no specific unified and integrated guidelines exist for the determination of coastal setback lines and zones, as a mean for their implementation. Furthermore, the fact that most coastlines face or are threatened by coastal erosion and the effects of climate change increase, the need for a unified European Methodological Framework on Coastal Setbacks Demarcation becomes apparent.

The development and adoption of a common method for setback lines definition appears as a prerequisite of the ICZM Protocol, but it also serves the European cohesion policy, especially for the EU Member States that are contracting parties to the Mediterranean ICZM Protocol (Spain, France, Italy, Slovenia, Greece, Malta, Cyprus). Bridge and Salman (2010) explained that a common problem occurs in delimiting and mapping the setback lines, especially when there is no precise definition of the coastal zone. The baseline, from which to measure the landward or seaward boundary appears variable and often depends on the legal definitions of waterlines, coastline/shoreline, and the level of low and high water tides.

Sanò, Marchand, and Medina (2010) explained that coastal setbacks and baselines identification should consider the nature and morphology of the coast, and classified Mediterranean coastal stretches into four types, as open sandy coastlines, semi-enclosed coastal lagoons, rocky coastlines, and hard infrastructures. Sanò et al. (2011) described the theoretical framework for the technical definition of the highest water mark line, especially for sandy beaches, where the impact of coastal erosion and the subsequent coastline retreat and shoreline morphological changes appear significant. Climate impact trends and projections, the influence of the tide and the exposure of the coast to extreme storm surges and waves are the factors to be considered in such analysis. The deliverables of an
European Union–funded program named “Concience” (Concepts and science for Coastal Erosion Management), discussed the use of setback lines for coastal protection in Europe and the Mediterranean and attempted to prepare a set of integrated guidelines for the definition of setback lines (San/C18o, Marchand, and Lescinski 2010b).

In this article we attempt to propose a scientifically sound methodology, utilizing modern tools and techniques to determine the coastal setback zones and baselines over the rocky Mediterranean shorelines. The method will attempt to determine the highest winter water marks and demarcate the subsequent coastal setback baseline, by considering a series of physical factors, as the maximum potential wave run-up reaching the coast with a certain return period, the short-term flood tidal impact, the storm surge effect and the estimated long-term sea-level rise, together with shoreline’s morphological characteristics. The applicability of this methodology will be tested along a steep and rocky coastal stretch in Kavala Municipality (northern Greece). However, the method should be part of an integrated procedure, leading to the coastal setback demarcation, in which issues as the cultural, ecological, and human values of the shoreline, the legal and administrative provisions, and the broad public involvement should be considered.

**Coastal Setback Framework in Greece**

In this section the relevant to coastal setbacks legislation in Greece is reviewed, prior and after the ICZM Protocol adoption, exhibiting the implementation gap between legislation and practice that could be bridged through the introduction of the proposed methodology. Although the Protocol was adopted in 2008 and entered into force on 24 of March 2011, some Mediterranean countries, like Greece, had already included in their legislation the concept of coastal setback zones. Indeed, the newly established Greek state (1829) adopted by Law 21-6-1837 the public use of coastal zones as a succession from the Byzantine Code of Law and the even earlier Roman Legal Code, from where the term “highest winter waterline” originates (Roman Institute of Justinian of 533, Book II, title I). The objectives and means of the public use of coastal zones were specified later, in article 7 of Law 2344/1940, the main legal framework related to coastal protection and development for most of contemporary history of Greece. In this document a setback zone of 20 m wide was defined, using as baseline the mean sea-level datum. L. 2344/1940 was enacted for almost 61 years, putting emphasis on the citizens’ right to enjoy the coastal zone as a public property, than on the obligation of the State to protect the coastal areas as parts of the natural environment and as vulnerable ecosystems. In addition, there were no references on the types of the activities and uses excluded or restricted, on land use controls, protection from urban sprawl, and the general planning regulations for the coastal zones. Finally, it failed to specify the procedures and the technical means to define the coastal setback lines and zones with acceptable accuracy, leading to long disputes between stakeholders and significant delays in coastal developments.

Through newer legislation, construction was restricted beyond a 30 m distance from the coastline, in urban coastal areas and in old settlements preexisting 1923 (L.D 439/1970); the legal procedures for demolition of illegal constructions were defined (L.D 393/1974); special plans and programs for the protection of the coastal zone and the sustainable use of natural and cultural environment were introduced (L.360/1976); Development Control Zones with land use restrictions around urban areas and areas of high environmental and archaeological value were designated (L. 1337/1983). Finally, L. 2971/2001 abolished previous provisions and focused on the rational development of coastal areas, protecting the environmental, cultural, social, and economic aspects of the coastal zones.
This law expanded the coastal setback zone up to 50 m width, using as baseline the maximum potential wave run-up on the sloping beach, as the highest winter water mark. In this zone, public access is unlimited, environmental and social goals for public interest should be promoted and all types of construction are prohibited.

However, L. 2971/2001 fails to provide an objective method for the accurate determination of the highest winter water mark, leaving this duty to a committee of administrators derived from the regional public land management service, the regional environmental management department and the local port authority. The Law establishes a set of criteria to be considered for this process, as coastal geomorphology, vegetation seaward limit, local and broader meteorological conditions, maximum wave run-up, sea bottom morphology, wave fetch, existing and planned technical works along the coastline, sensitive ecosystems, and vulnerable areas. Although the above criteria involve the use of scientific tools and data, as topographic and bathymetric maps, remote sensing images, meteorological datasets, wave dynamics and fetch lengths, and so on there is a lack of a well-prescribed and scientifically substantiated procedure that will objectively define the maximum potential wave run-up on the coast, and thus accurately determine the highest winter water marks and the subsequent coastal setback zone. The results of this deficiency is a series of legal disputes between coastal property owners, other involved stakeholders, potential coastal developers, and the Greek state, leading to improper law enforcement and significant delays in the implementation of coastal development projects.

Materials and Methods

Site Description for Case Study Implementation

Kavala Municipality is located at the northern part of Greece, near the borders with Turkey and Bulgaria (Figure 1). The broader area borders to the north with the Paggeon Mountain, famous for its gold mines during the Alexander the Great era, to the east with the River Nestos and to the west with the Strymon River, two transboundary rivers originating from Bulgaria and the former Yugoslav Republic of Macedonia (FYROM), respectively. To the south one can view the Gulf of Kavala, the second in size semi-enclosed coastal water body of the Thracian Sea, which is part of the North Aegean Sea’s continental shelf (Sylaios, Kamidis, and Stamatis 2012). The gulf and its coastal zone are rich in natural ecosystems, developing along the 65-km-long coastline. The Gulf’s basin has an amphitheatric shape, with gentle slopes at the center, increasing rapidly toward the coast, and a symmetry axis directed NNE–SSW (Sylaios et al. 2005).

The climate of the broader area is characterized as intermediate between Mediterranean and continental type (Mariopoulos 1982), dominated by moderate precipitation, cold winters, and arid summer periods. Eastern and northwestern wind directions are dominant during the winter period having frequencies of 7% and 10%, respectively. The area is micro-tidal, with tidal range varying between 0.12 m during neap tides and 0.30 m during spring tides under the prevalence of the semi-diurnal (M2) tidal constituent. The input of Black Sea Water (BSW) through the Dardanelles governs the surface dynamics of Kavala Gulf by supplying low salinity (29–34), nutrient-rich BSW, which occupies the surface layer of the water column (20–40 m) (Sylaios 2011).

The examined coastline lies at the central-eastern zone of Kavala Municipality, between the old municipal hospital and a small marina. It is a mildly steep, rocky (granite), impermeable shore, directly exposed to the waves of the open North Aegean Sea,
where houses are built from 1920s. The shore was selected as a case study, since several legal disputes have taken place during the latest decades, among property owners and the state, on the exact definition of the baseline and the setback zone.

**Methodological Approach for the Highest Water Mark Determination**

The methodological framework for the highest winter water marks and the subsequent coastal setback zone determination is graphically summarized in Figure 2. It is presently

![Figure 2. Methodological framework for the highest winter water marks and the subsequent coastal setback zone determination.](image)
known that the highest winter water mark on a coast is determined by the following combined factors: (a) the run-up of waves breaking on the coast, with a certain return period, (b) the tidal water level during tidal flood, (c) the storm surge effect, and (d) the morphology of the shoreline, and its gradual retreat due to the high energy waves, known as beach erosion effect (Sanò, Marchand, and Medina 2010). In the case of rocky impermeable shores, this latter impact may be neglected. Thus, the water level fluctuates as:

$$X(t) = Z_0(t) + T(t) + W(t) + S(t)$$

where $Z_0(t)$ is the mean sea level, exhibiting a slow but gradual rise due to climate change, $T(t)$ is the water level due to the tidal effect, $W(t)$ is the water level due to the waves run-up, and $S(t)$ is the storm surge effect. The following sections describe the data collected and the processing methods to quantify the impact of each of the above factors, with a certain return period.

**Tidal and Storm Surge Effect**

Five years (1993–1997) of hourly water-level data collected at the central Kavala harbor, by the Hellenic Hydrographic Service, were utilized to assess the tidal and storm surge impact on the water level in the studied area. Harmonic analysis was performed on this dataset to determine the tidal amplitudes and phases of tidal harmonics. The World Tides (Boon 2006) Matlab software was used for the harmonic analyses of these water level data. After analysis, tidal data were re-synthesized for the same studied period, and the meteorological effect on the water level was produced as the difference between actual measurements and the sum of the harmonic constituents.

**Offshore Extreme Wind and Wave Analysis**

Eleven years offshore wind and wave data (2000–2010) were collected by an oceanographic platform of the POSEIDON sea observatory network, located near Athos Peninsula (39.961°N, 24.721°E, 220 m depth). The platform recorded with 3-hrs interval wave parameters (spectral significant wave height $H_{m0}$, the mean zero-up-crossing $T_{02}$, and the mean wave direction $θ_W$) and wind parameters (gust wind speed, wind speed and wind direction), recorded at 3 m height above sea level (Soukissian, Prospathopoulos, and Diamanti 2002). Sylaios et al. (2009) utilized this dataset to simulate the wind–wave relationships and produce short-term wave forecasts, through a fuzzy logic model. Overall, 14,128 wind measurements and 10,459 wave measurements were obtained and imported in the extreme wind and waves analysis system, aiming to determine the extreme meteorological and wave events with a return period of 25, 50 and 100 years.

In our analysis, only the independent non-overlapping storms with at least 6 h duration, exceeding a certain threshold (u) and separated by a minimum distance of 48 h between consecutive data points, were selected. Threshold selection involved the careful inspection of the Q–Q graphs, Hill-plots and the sample-mean-excess against threshold plots, and a value of 12 m/s for the wind series and of 3.2 m for significant wave height was adopted (Anastasiou and Sylaios 2013). Following the Generalized Extreme Value distribution (GEV), assuming that the wind and wave values were independent and
identically distributed (iid):

$$F(x; \mu, \sigma, \xi) = \begin{cases} \exp \left[ - \left( 1 + \frac{x - \mu}{\sigma} \right)^{-1/\xi} \right], & \xi \neq 0, \\ \exp \left[ - \exp \left( - \frac{x - \mu}{\sigma} \right) \right], & \xi = 0 \end{cases}$$  \hspace{1cm} (2)

where $1 + \xi (x - \mu)/\sigma > 0$, $\mu$ is a location parameter, $\sigma$ is a scale parameter and $\xi$ is the shape parameter of the distribution, being independent of the selected threshold levels. The p-year return level $z_p$ is obtained as:

$$z_p = u + \frac{\sigma^*}{\xi^*} \left[ (\lambda p)^{\xi^*} - 1 \right]$$  \hspace{1cm} (3)

where $u$ is the defined threshold, $\xi^* = \xi$, $\sigma^* = \sigma + \xi (u - \mu)$ and $\lambda$ is the exceedance rates of threshold $u$, i.e., $\lambda = P(X > u)$, defined as:

$$\lambda = 1 - \exp \left\{ - \frac{1}{N} \left[ 1 + \xi \left( \frac{u - \mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$  \hspace{1cm} (4)

where $N$ is the number of data exceeding threshold $u$. For both datasets, the estimation of GEV model parameters was performed following the Maximum Likelihood Estimator. Analysis was performed using the package extremes in the R open source statistical software and by EVIM (Gençay, Selçuk, and Ulugülyağcı 2001) in Matlab.

**SWAN Model Description and Configuration**

To reproduce the wave field in the nearshore zone, under extreme offshore wind and wave conditions, the third-generation phase-averaged spectral model SWAN was applied (Booij, Ris, and Holthuijsen 1999). The model solves the wave action balancing equations to generate waves and simulates the wave evolution by considering a set of physical processes, as the frequency downshift, wave shoaling and wave refraction from deep toward the nearshore waters.

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} (U + c_x)N + \frac{\partial}{\partial y} (V + c_y)N + \frac{\partial}{\partial \sigma} c_{\sigma}N + \frac{\partial}{\partial \theta} c_{\theta}N = \frac{S_{\text{tot}}}{\sigma}$$  \hspace{1cm} (5)

with

$$S_{\text{tot}} = S_{\text{in}} + S_{\text{wc}} + S_{\text{nl4}} + S_{\text{bot}} + S_{\text{brk}} + S_{\text{nl3}}$$  \hspace{1cm} (6)

where $N$ is the wave action spectral density function; $\sigma$ and $\theta$ are the angular frequency and the direction of a component wave; $c_x$ and $c_y$ are the group velocities in the $x$ and $y$ directions, respectively; $c_{\sigma}$ and $c_{\theta}$ are the characteristic velocities in the $\sigma$ and $\theta$ directions, respectively; $S_{\text{tot}}$ is the source term, and $U$ and $V$ are the current velocities in the $x$ and $y$ directions, respectively; $S_{\text{in}}$ is the transfer of energy from the wind to the waves; $S_{\text{wc}}$ is the dissipation of wave energy due to whitecapping; $S_{\text{nl4}}$ is the nonlinear transfer of wave energy due to quadruplet (four-wave) interaction; $S_{\text{bot}}$ is the shallow water energy
dissipation due to bottom friction; $S_{brk}$ is the energy dissipation due to wave breaking, and $S_{nl3}$ is the nonlinear triad (three-wave) interaction.

The SWAN wave model was implemented with the nominal formulations of the physical processes, to describe the wave characteristics at the nearshore zone of Kavala coastline. In order to achieve the required spatial downscaling for the produced wave field, three rectangular bilinear grids of increasingly higher resolution were used. The coarse grid covers the entire study area (North Aegean Sea), the second medium nested grid covers the Western Thracian Sea, including Thassos Island, and the third fine resolution grid focuses on the studied coastline of Kavala Municipality (Figure 3). The geometric and geographical characteristics for each grid of the above described triple nesting are shown in Table 1.

**Sea-Level Rise Effect**

The sea-level rise in the Mediterranean Sea exhibited a strong spatial variability over the last century, with a lower rise of mean sea level at the Western Mediterranean and a two-fold increase at the Eastern part. According to the EEA (2012), based on data since 1992, a mean sea-level rise rate of 1.2 mm/year for the Mediterranean Sea appears significantly...
<table>
<thead>
<tr>
<th>Grid description</th>
<th>Dimensions (Easting × Northing)</th>
<th>Cell grid size(dx = dy)</th>
<th>Geographic co-ordinates</th>
<th>Boundary conditions imposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Resolution Grid</td>
<td>164 km × 112 km</td>
<td>1,000 m</td>
<td>40° 95′N, 24° 10′E – SW point; 39° 95′N, 26° 10′E – NE point</td>
<td>Extreme values for significant wave height, period and direction; extreme wind values at all grid points.</td>
</tr>
<tr>
<td>Medium Resolution Grid</td>
<td>27 km × 16 km</td>
<td>100 m</td>
<td>40° 57′ 55″N, 24° 17′ 47″E – SW point; 40° 85′ 57″N, 24° 35′ 38″E – NE point</td>
<td>Model output from the coarse resolution grid along all open boundaries; extreme wind data at all grid points.</td>
</tr>
<tr>
<td>Fine Resolution Grid</td>
<td>0.45 km × 1.17 km</td>
<td>10 m</td>
<td>40° 56′ 24″N, 24° 25′ 05″E – SW point; 40° 55′ 2″N, 24° 25′ 12″E – NE point</td>
<td>Model output from the medium resolution grid along all open boundaries; extreme wind data at all grid points.</td>
</tr>
</tbody>
</table>
lower than the global average (1.7 mm/year). However, for North Aegean Sea, this rate seems exacerbated up to 6.0 mm/year, leading to a projected mean sea-level rise of 15 cm in 25 years, 30 cm in 50 years and 60 cm in 100 years, corresponding to the return periods of extreme waves. Due to the nature of the shoreline (steep, rough, and rocky), Bruun’s rule (Bruun 1962) to determine the response of the coast to sea-level rise is not applicable. Thus, the above projected values were simply added to the mean sea-level $Z_o$, to account for the climate change effect in the studied area.

**Determination of Maximum Potential Wave Run-Up on a Rough, Impermeable Shore**

The maximum potential wave run-up on a rough, impermeable shore of medium to high slope, as the herein examined, was based on the methodology described in the CEM (Coastal Engineering Manual, U.S. Army Corps of Engineers 2005). A new wave run-up equation was introduced by Hughes (2004) and was adopted by the CEM, as:

$$\frac{R_{u2\%}}{h} = 4.4(\tan \alpha)^{0.7} \left( \frac{M_F}{\rho gh^2} \right)^{1/2} 0.505 \quad \text{when} \quad 2.0 \leq \cot \alpha \leq 4.0$$  \hspace{1cm} (7)

where $R_{u2\%}$ is the maximum vertical run-up distance, measured from the mean sea level, exceeded by the 2% of wave run-ups; $\tan \alpha$ is the shore’s slope; $\rho$ is the water density; $g$ is the gravitational acceleration; $h$ is the water depth and $M_F$ is the depth-averaged wave momentum flux (Figure 4). Through this definition, the number of waves exceeding this level is related to the number of incoming waves and not to the number of waves that run-up. The distance BD represents the wave run-up computed as the product of $R_{u2\%}$ and the sinus of shore slope $\alpha$. Equation (7) is valid for shore slopes steeper than 1:4 ($\cot \alpha = 4$). For a wider range of slopes (up to 1:30) this equation was modified by Hughes (2004), as:

$$\frac{R_{u2\%}}{h} = 4.4(\tan \alpha)^{0.7} \left( \frac{M_F}{\rho gh^2} \right)^{1/2} \quad \text{when} \quad 1.5 \leq \cot \alpha \leq 30$$  \hspace{1cm} (8)

with relatively limited accuracy than Equation (7).

The parameter $\left( \frac{M_F}{\rho gh^2} \right)$ in Equations (7) and (8) represents the non-dimensional wave momentum flux for finite amplitude, non-linear waves. This parameter may be substituted

![Figure 4](image_url)
as:

\[
\left( \frac{M_F}{\rho g h^2} \right) = A_0 \left( \frac{h}{g T_p^2} \right)^{-A_1}
\]  
(9)

where the coefficients \(A_0\) and \(A_1\) are coefficients, as:

\[
A_0 = 0.639 \left( \frac{H_{m0}}{h} \right)^{2.026}
\]  
(10)

and

\[
A_1 = 0.180 \left( \frac{H_{m0}}{h} \right)^{-0.391}
\]  
(11)

where \(h\) is the water depth, from mean sea level, at the toe of the slope, \(H_{m0}\) is the incident significant wave height, \(g\) is the gravitational acceleration and \(T_p\) is peak wave period.

**Results**

**Tidal and Storm Surge Effect**

Harmonic analysis was performed on the hourly tidal data recorded in Kavala harbor, and the wind and storm surge effects on the water level variability were produced. Figure 5 illustrates a sample of the recorded and reconstructed—through harmonic analysis—time-series, together with the non-tidal effect, presented by the low-pass-filtered residual time-series. Frequency analysis on the non-tidal time-series depicted that a maximum

![Figure 5. Temporal variability of (a) recorded and reconstructed through harmonic analysis time-series of water level and (b) low-pass-filtered non-tidal influence, at Kavala Harbor.](image-url)
increase in sea level of 0.75 m (related to mean sea level), due to storm surge events, may occur in the studied area. In case such event occurs during the high water period of spring tides, an additional increase in sea level of 0.20 m is expected.

**Extreme Offshore Wind and Wave Analysis**

Statistical analysis on the wind and wave records of POSEIDON buoy produced the results summarized in Table 2. Extreme Value Analysis on the wind and wave data using the thresholds of 12 m/s for the wind series and 3.2 m for the significant wave height produced the GEV parameters summarized in Table 3. The fact that $\xi < 0$ suggests that the wind speed tail is approximated by the Weibull distribution. On the other hand, a heavy-tailed distribution in the extreme wave values is obtained, as the shape parameter $\xi > 0$. Using these GEV parameters and Equation (3), the extreme offshore wind and wave events for a certain return period were approximated. As seen in Figure 6, where the diagnostic plots obtained from the application of the GEV model on the offshore wind dataset are presented, three values were produced for each return period (minimum, maximum, and mean). Results for return periods of 25, 50, and 100 years are shown in Table 4. For the determination of the highest winter water marks on an impermeable shoreline, the mean value of the extreme wind and wave events with return period of 50 years was selected. These values were imported as boundary conditions on the outer, low resolution computational grid of the SWAN numerical model.

**Nearshore Extreme Wave Characteristics at the Study Area**

The spatial distribution of significant wave heights and wave propagation direction over the Thracian Sea (coarse grid), for extreme waves (mean value with 50 years return period) propagating from the southern direction, is shown in Figure 7. Thassos and Samothraki Islands induce significant sheltering effects in the broader area reducing the wave heights by almost 40%. The eastern part of Kavala Gulf appears affected by this sheltering effect. The distribution of the wave field in Kavala Gulf is revealed from the medium-scale computational grid (Figure 7b). The western part of the gulf exhibits higher wave heights ($H_s \sim 6.2$ m), with slightly deviated propagation to the north-west, due to wave refraction. At the central part of the gulf southern waves with $H_s \sim 5.5$ m are incident to the shoreline of interest, while further eastward wave heights diminish up to 3.2 m with propagation directions deflected to the north-east. Figure 7c presents the nearshore wave

**Table 2**

Statistical parameters of wind and wave datasets recorded from POSEIDON buoy (North Aegean Sea) during 2000–2010

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wind speed (m/s)</th>
<th>Significant wave height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum value</td>
<td>0.000011</td>
<td>0.03616</td>
</tr>
<tr>
<td>1st Quantile</td>
<td>1.696000</td>
<td>0.28920</td>
</tr>
<tr>
<td>Median</td>
<td>3.829000</td>
<td>0.57130</td>
</tr>
<tr>
<td>Mean</td>
<td>4.530000</td>
<td>0.82920</td>
</tr>
<tr>
<td>3rd Quantile</td>
<td>6.573000</td>
<td>1.10900</td>
</tr>
<tr>
<td>Maximum</td>
<td>21.960000</td>
<td>5.50500</td>
</tr>
</tbody>
</table>
field as revealed by the low resolution computational grid. Incident waves reach the shoreline of the study area propagating to the north-west with $H_S \sim 7.0–7.2$ m. The incident wave height at each 10 m nearshore cell, combined to the tidal and storm surge effects, was used as boundary condition for the wave run-up model.

**Determination of Maximum Wave Run-Up in the Study Area**

Three baselines for setback determination were considered in this analysis: (a) the maximum wave run-up during an extreme event with a return period of 25 years (minimum value); (b) the maximum wave run-up during an extreme event with a return period of 50 years (mean value); and (c) the maximum wave run-up during an extreme event with a return period of 100 years (maximum value). These lines were drawn by applying the wave run-up model considering the combined tidal, storm surge, and wave effect in the study area. Figure 8 represents the configuration of these lines along the whole shoreline.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Wind speed (m/s)</th>
<th>Significant wave height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$, location parameter</td>
<td>$13.48 \pm 0.63$</td>
<td>$1.86 \pm 0.08$</td>
</tr>
<tr>
<td>$\sigma$, scale parameter</td>
<td>$3.63 \pm 0.46$</td>
<td>$0.75 \pm 0.06$</td>
</tr>
<tr>
<td>$\xi$, shape parameter</td>
<td>$-0.29 \pm 0.12$</td>
<td>$0.20 \pm 0.09$</td>
</tr>
</tbody>
</table>

**Figure 6.** Diagnostic plots for the GEV model applied on the offshore wind dataset, where (a) the probability plot, (b) the quantile plot, (c) the return level plot, and (d) the density function plot.
Table 4

Extreme values of wind speed (in m/s) and significant wave height (in m) for various return periods (offshore North Aegean Sea)

<table>
<thead>
<tr>
<th>Return period (yrs)</th>
<th>Wind speed (m/s)</th>
<th>Significant wave height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
</tr>
<tr>
<td>50</td>
<td>19.467</td>
<td>22.765</td>
</tr>
</tbody>
</table>

Figure 7. Spatial distribution of significant wave height and direction in (a) the North Aegean Sea, (b) Kavala Gulf, and (c) the studied nearshore zone, for northward propagating waves, during an extreme wind and wave event, with return period 50 years (mean value).
Figure 8. The Kavala Municipality shoreline with (a) the mean sea level (red line), and the lines of maximum wave run-up, as (a) under the 25-years return period (purple line), (b) the 50-years return period (dark blue line), and (c) the 100-years return period (light blue line).

Figure 9. Eastern part of the Kavala Municipality shoreline with (a) the mean sea level (red line), and the lines of maximum wave run-up, as (a) under the 25-years return period (dark blue line), (b) the 50-years return period (purple line), and (c) the 100-years return period (light blue line).
Indicative parts of the examined shoreline are shown in Figures 9 and 10. The mean water level (MWL) and all three derived lines of maximum wave run-up with 25, 50, and 100 years return period were imported and geo-referenced on the initial topographic geographic information systems (GIS) mapping, together with the existing coastal setback line, as determined by the committee of local administrators. It is seen that in this pilot case, the existing management tool demarcates the setback line in far stricter manner than the potential maximum wave run-up with 100 years return period.

**Discussion and Conclusions**

The identification of coastal setback lines through a consistent, transparent, and commonly applied approach at the European and Mediterranean level is considered as a significant issue for the harmonization of ICZM practices (Sanò, Marchand, and Lescinski 2010b). Indeed, the diversity in the different national policies regarding coastal setback definition, purpose, and demarcation clearly reflects the diversity in most ICZM national approaches over Europe (EUCC 2000). Rigid definitions of coastal setbacks, defined by a fixed distance from the coastline, fail to face the current challenges of coastal erosion and sea-level rise (in sandy beaches) or the extreme wave run-up events (over rocky shores). On the other hand, the issue of existing infrastructure leads to unavoidable easements or exemptions, altering the initial purpose of setback zone definition.

It is presently evident that setback lines demarcation should be based on a strong, technical, objective methodology, complemented by a systematic participatory approach, expressing the local socioeconomic parameters of the coastal system. Technical methodology should rely on scientific knowledge of natural processes, information on ecological and landscape values and an analysis of the costs of implementation under local circumstances. This information should be combined with the perceptions and views of stakeholders, at the local level, in a process of open communication and discussion. Projects of
public interest and areas with particular geographical or other local constraints, especially related to population density or societal needs, should be considered at this phase (Prem 2010). The outcome of this participatory process should be used to make a final decision on a setback line being scientifically valid, socioeconomically defendable, and broadly acceptable to the public (Portman and Fishhendler 2011). Appropriate pilot sites along the European and Mediterranean coasts could be used to test the methodology, summarized graphically in Figure 11.

Correct implementation of article 8-2 of the ICZM Protocol requires that national authorities conduct an integrated method to configure the precise point reached by the highest winter wave run-up over any shore (Rochette et al. 2010). The setback baseline and zone should then be reported, mapped and regularly updated to follow shoreline changes due to coastal erosion and sea-level rise. Purpura (1972) developed a technical method for the demarcation of coastal setback lines along the sandy beaches of Florida, USA. The method considered the maximum impact of tides, waves, storm surges, and wave set-ups. Detailed shoreline topography, vegetation, and existing structures were considered and the maximum wave run-up based on the composite slope method was derived. Ferreira et al. (2006) used integrated coastal hazard mapping techniques to compose a method for coastal setback lines demarcation over sandy shores, taking into account the shoreline evolution rate, the expected sea-level rise and the impact of extreme storms. They applied this method over the sandy coasts of Algarve, with 50 years return period of extreme events and considering shoreline retreat rates based on historic and projected sea-level rise. Goble and MacKay (2013) followed a similar cost-effective methodology to define the hazard risk setback lines along a South African shoreline by considering historical shoreline change, sea-level rise, and coastal vulnerability.

Figure 11. Coastal setback demarcation process (adapted after Sanò, Marchand, and Medina 2010).
The above depict clearly that technical delineation studies applied on specific coastal areas are rare and mostly focus on the more sensitive sedimentary coastlines (Sanò et al. 2011). In this work, a solid methodology on coastal setbacks demarcation over rocky, impermeable shores is proposed, followed and implemented along a Greek shoreline, serving as a pilot case-study. The methodology is consistent to the requirements of the ICZM Protocol and the Greek legislation (L. 2971/2001), aiming to determine the “highest winter waterline” serving as the baseline for the coastal setback zone. Baseline delineation includes all physical processes taking place along a rocky shoreline, as the tidal and storm surge effect, the sea-level rise due to climate change impact, the probability of occurring an extreme offshore wind and wave event within a specified return period, and the maximum potential wave run-up event, corresponding to this return period. Blended bathymetric and topographic data derived from various sources may be utilized and imported in a GIS to comprise an analytical Digital Elevation Model (DEM) for the examined shoreline. Presently, several instruments and methods for conducting topobathymetric surveys exist; however, their accuracy should be extensively evaluated. For the emerged part of the beach, methods as the direct topographic surveying, global positioning system (GPS) surveying using geodetic receivers, aerial photogrammetric survey combined to stereoscopic image analysis, the use of laser-scan, and finally, the airborne Light Detection and Ranging (LIDAR) scanning are some of the available techniques to produce highly accurate DEMs. For the submerged part of the beach, hydrographic survey echo-sounders (single or multibeam) with an accuracy of up to 1 cm could be used.

Similar methods have also been followed by South African authorities in the West Coast District (van Weele and Breetzke 2013), where 100 years return period was employed, following the precautionary approach under conditions of high uncertainty. A similar methodology, built on the current deterministic approaches commonly used in New Zealand, was also established for the definition of coastal hazard risk and inundation zones (Ramsay et al. 2012).

For Greece and other Mediterranean countries, the use of modern technology will lead to faster inventory and demarcation of coastlines, something increasingly significant for the processes of sustainable development of Mediterranean coastal areas and the proper implementation of the ICZM Protocol. Present conditions of failures, delays and disputes in the clear definition of boundaries of coastal zones with different rights of use (public versus private, etc.) encourage phenomena such as illegal construction, uncontrolled development, and degradation of the quality of the coastal environment—which sometimes could be irreversible. Focusing in Greece, the significance of a scientific method for demarcation of coastline is even higher, due to particular characteristics of the structure and functioning of the state, the legal tradition, and the interactions of administration and the citizens. In comparison to legislative frameworks of other European countries, Greek planning legislation is complex, and often contradictory, with fragmented and inadequate legal provisions regarding the means of use and protection of seashores. Seashores definition and designation of its boundaries are usually made by “ad hoc” court decisions in an excessively slow pace. In this way, the implementation of definite policies on a national or regional level was impossible and coastal protection was ineffective and excessively slow. It is characteristic that only 20% of the seashore zone in Greece had been demarcated by officially approved boundaries until 1999, leading to the rise of uncontrolled construction very close to the sea (Greek Technical Chamber 2005).

The beginning of the 21st century found the need to protect, plan, and manage the coastal areas of Greece more urgently than ever. Urban and rural areas throughout the country have been suffering by the old and widespread phenomenon of illegal
constructions, built within the coastal setback zone. According to the L. 2971/2001, these properties should be expropriated and illegal buildings demolished, although the lack of a fast and reliable coastal demarcation mechanism leads to long delays in this process. The Hellenic Public Corporation of Real Estate is the legal authority responsible for coastal management, with administrative control on the seashore. However, modern coastal protection and management schemes, besides sound legislation, need pragmatic policies and effective tools at operational level.

The herein proposed methodological tool aims to bridge the gap between the existing theoretical provisions of legislation (supra-national and national) and the actual implementation of ICZM Protocol along the Mediterranean coastlines, posing as a vital factor in facilitating coordination between the relative legal provisions and urban, regional, and environmental coastal planning.

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References


