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EXTENDED ABSTRACT 216

The geospatial characteristics of island beaches: the case of Kos, Greece

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Research Highlights

Acquisition analysis of widely available geospatial information to assess the state and dynamics of island beaches.

Introduction

Assessing the state and dynamics of sandy shorelines (beaches) is vital for developing efficient management strategies (e.g. Karditsa *et al*., 2024; Chalazas *et al*., 2024), with the approaches used depending on their spatio-temporal scales and the available information and resources. In regional (island) scales, the extensive scope of studies and the high potential costs of adaptation (Narayan *et al*., 2016) may require prioritization of responses and efficient allocation of the (mostly) limited resources. This requires, among others, information of the geospatial characteristics and their interrelationships which may provide much needed information and identify potential controls of beach dynamics. Therefore, the objective of this short contribution is to present an approach that could acquire such information at a regional (island) scale on the basis of widely available geospatial data; the approach is demonstrated for the island of Kos, South Aegean Sea, Greece (Fig.1).

Study area

Kos has an area of about 295 km^2, a coastline length of 112 km and a resident population of about 37,100. Kos is a highly touristic island: in 2023, 1.3 million passengers arrived at the island of Kos. There are > 57,000 hotel beds in Kos, tourism density and intensity being very high (28,917 tourist nights/km^2). Most of this infrastructure and the tourist activities are associated with the island's beaches, as Kos is a global tourist destination for Sea-Sand-Sun - 3S tourism (SETE, 2024). Kos coast is microtidal (0.1 m astronomical tidal range). In the north NNW waves dominate with the largest waves showing heights Hs of 3.8 m and periods Tp of 7.5 s. Energetic waves occasionally impinge on western and southern coasts, with the largest waves having heights of 4–5 m and periods of 9–10 s (Monioudi *et al*., 2025). Kos is a part of the easternmost South Aegean volcanic arc. Its northeastern part is mostly formed on Plio-Quaternary sediments, whereas its southeastern highlands are made mostly of alpine and pre-alpine metamorphics and some Miocene volcanics (Pe-Piper *et al*., 2024). Following a hiatus, volcanism, resumed 3 million years ago (mostly) in the island's west; the large eruption of the Kos Plateau Tuff volcano (161 ka BP) deposited pyroclastics up to 15 m thick that covered most of the western Kos and the adjacent islands (Piper and Pe-Piper, 2020). Most large/wide beaches are found in the low-relief, sedimentary northeastern Kos (Fig. 1), indicating a potential geological control.

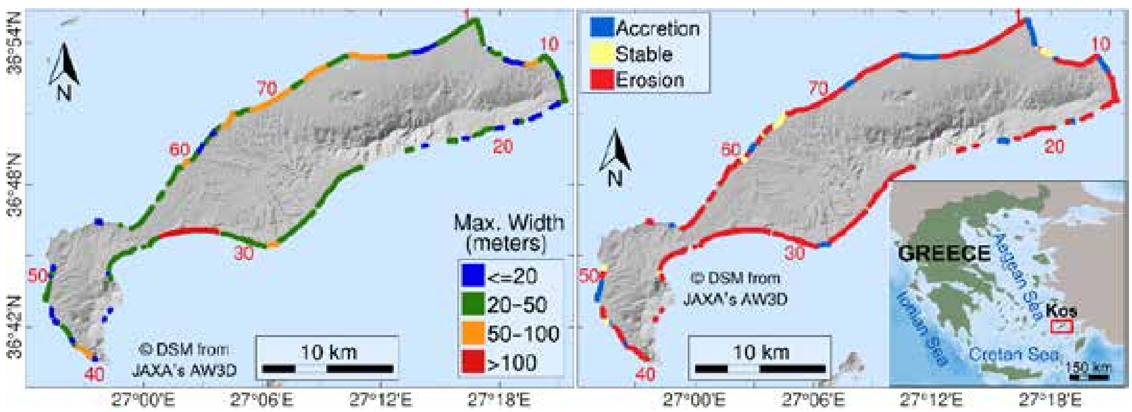

Figure 1. Kos: Beach maximum width (BMW) and long-term beach erosion trends. Numbers refer to the ID of the 78 beaches of Kos (after Monioudi *et al*., 2025).

Methods

The compiled inventory of the Kos beaches provides information on the dimensions, sediment types and the presence of outflowing streams, coastal defenses or artificial and natural features. Using satellite images available in the Google Earth Pro application, subaerial (dry) beaches were digitized as polygons based on clearly visible boundaries: natural features like vegetated dunes or cliffs and permanent artificial structures such as embankments, seawalls, or buildings and the shoreline define the landward and seaward limits, respectively. To ensure consistency, all digitization was conducted by a single analyst adhering to strict delimitation rules. The database was constructed through the digitization of beach polygons from selected images obtained in the period 2003–2021, which allowed an estimation of the recent historical changes. The beach (CNES/Airbus and Maxar) imagery has a spatial resolution about 0.5 m, but its results are constrained by the image accuracy; comparison of satellite images with concurrent RTK-DGPS ground observations showed an RMSE of about 2 m. Moreover, although tidal effects on the shoreline position are very small care was taken to analyze satellite images from the same season and under low hydrodynamic conditions; however as the available images along the islands' coasts have been collected at different times and under different preceding hydrodynamic conditions, recorded beach dimensions may not represent synoptic conditions at the island scale. Such limitations, however, cannot be avoided in the analysis of (historical) satellite imagery at large spatial scales (Monioudi *et al*., 2023). Following these procedures, the characteristics of 78 (Kos) beaches (Fig. 1) were identified, recorded and compared.

Results

The majority of beaches (53%) were found to have maximum widths (BMWs) of 20-50 m, 35% had widths < 20 m and 10 beaches had widths > 50 m (Fig. 1); the average maximum width was found to be 31 m. Despite the higher wave energy of the north- and west-facing beaches, a clear trend was observed in the development of northwest-facing beaches (303.75°- 348.75°). Fewer beaches were found to develop with southeast (16%) and south (12%) orientations, with the remaining beaches exhibiting other orientations (Fig. 2). This supports the hypothesis that the development of the Kos beaches is not controlled by the hydrodynamics, but is mainly subject to geological controls.

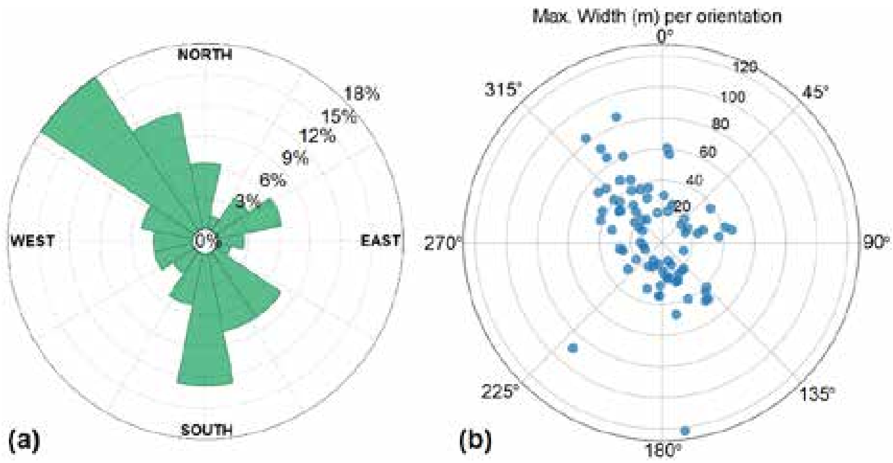

Figure 2. (a) Distribution of the Kos beach orientation. (b) Rose diagram of the beach maximum widths.

The relationship between orientation and the BMWs was further investigated using Angular-Linear correlation (Mardia, 1976; Zar, 2014) was used. This statistical test assesses the null hypothesis H_0 of no correlation between the two variables against the alternative hypothesis H_1 of a significant correlation. The results showed an $R^2 = 0.0327$ and $p = 0.279$, suggesting rejection of the H_0 hypothesis as $p > 0.05$; thus, there is no statistically significant correlation between the two variables.

There are outflowing streams in many Kos beaches (49%), indicating (potential) terrestrial sediment supply. Comparison of the BMWs with the occurrence of streams, shows that stream presence affects the beach size. In 2021, beaches with streams were found to have an average maximum width of 40.4 m which was almost double the width of beaches without streams (22.8 m). In order to examine the potential correlation between stream presence and BMWs it was checked whether the BMWs follow a normal distribution. Using the Shapiro-Wilk regularity test (Shapino and Wilk, 1965), it was found that the BMWs do not show 'normality' in terms of distribution (the Shapiro-Wilk regularity control gave $W = 0.772$, $p < 0.001$); thus, the non-parametric Mann-Whitney test was used. Its result showed that these two types of beaches differ (U = 307.5, $p < 0.001$), i.e., there is a correlation between beaches without streams and smaller BMWs with a median width of 22 m (Fig. 3a).

Regarding beach sediments, the majority of Kos beaches (53%) form on sandy sediments, whereas 32 % of the beaches on mixed sediments (gravels/sands) and 15% on pebbles. Comparison of the BMWs with the different sediment types showed good correlations; sandy beaches had an average BMW of 40.8 m (standard deviation 20), i.e. they are significantly wider than mixed sediment beaches and pebble beaches which showed average BMWs of 23.4 m (10.8 standard deviation) and 16 m (7.3 standard deviation), respectively. Even when the mixed sediment and pebble beaches were grouped together, their comparison with the sandy beaches showed a clear difference. Sandy beaches were found to have significantly greater BMWs (40.8 m) compared to the grouped mixed sediment/pebble beaches (21 m). It appears that the coarse sediment beaches attain BMWs 10-25 m, whereas the sand beach BMWs 30-50 m and 50-80 m (Fig. 3b).

In addition, it appears that about 60% of sandy beaches are also associated with outflowing streams, compared with those beaches forming on mixed sediments (45%) and pebbles (17%). To check this hypothesis the non-parametric Kruskal-Wallis test was used (the BMWs do not follow a normal distribution). The test checked the hypotheses: H_0, no correlation between the BMWs and the local sediment; and H_1, correlation between BMWs and the local sediments. The test showed that there is a clear difference between the maximum widths of beaches forming on sand and those forming on mixed/coarse sediments ($H_1 = 25.911$, $p < 0.001$). Beaches forming on pebbles have a median BMW of 14.9 m, whereas those formed on mixed sediments and sands 22.6 m and 40.5 m, respectively. A Kruskal-Wallis test (Kruskal and Wallis, 1952) was also applied in the case that beaches divided into two classes: those with sand sediments and those with mixed sediments and pebbles. The test showed a clear difference between these beach classes ($H_1 = 25.090$, $p < 0.001$).

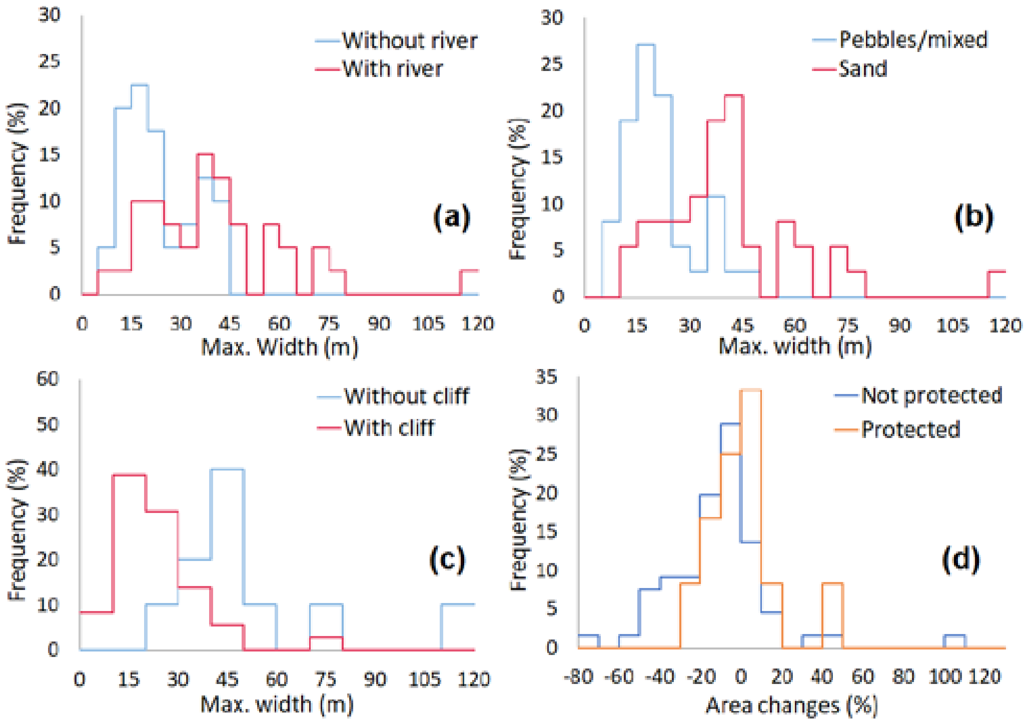

Figure 3. (a) Beach maximum widths (BMW) and the presence of beach streams (5 m steps), (b) BMWs and sediment texture (2 categories), (c) BMWs with the presence of backshore cliffs (10 m steps) excluding beaches with backshore infrastructure, and (d) Histogram of frequencies of areal changes.

A total of 50% of the island's beaches are characterized by the presence of backshore coastal cliffs. An initial investigation of the potential correlation with the BMWs did not reveal a significant relationship. However, as the presence of infrastructure/assets along the immediate backshore might affect the BMWs and other beach dimensions due to e.g., reduction/interruption of the land sediment supply and, thus, the correlation. Excluding beaches where there are backshore infrastructure/assets (about 50% of the total), a significant relationship is apparent (Fig. 3c). Many beaches with cliffs show BMWs of 10-20 m (and up to 30-50 m), whereas the beaches without cliffs attain obviously greater BMWs. The relationship was tested using the Mann-Whitney method excluding beaches with backshore infrastructure/assets. It appears that there is a statistically significant relationship (U = 34, p <0.001). Those beaches without a backshore cliff are larger (a median BMW of 46 m) than those with a backshore cliff (median of 22 m). It seems that the coastal topography controls beach formation and size.

To assess the impact and effectiveness of coastal protection schemes, the areal changes between the beach polygons obtained from older imagery (2004-2009) and 2021 were considered which was preferred over more recent ones, as images were taken in spring/summer months (Fig. 3d). The Shapiro-Wilk regularity test for the variable 'beach area change' yielded results W = 0.889 and p <0.001 showing that the data do not follow a normal distribution. Thus, the non-parametric Mann-Whitney control was also applied by controlling the following assumptions: H_0, the distribution of the continuous variable "percentage of change of beach area" is similar between beaches with coastal protection works and beaches without protection works; and H_1, the distribution of the continuous variable "percentage of change of beach area" differs between beaches with protection works and beaches without works. The test results show there is a significant areal difference (U= 260, p=0.050) between beaches with and without coastal works.

Discussion and Conclusions

The analysis of the geo-spatial data using both basic statistical metrics and more complex parametric and non-parametric tests, led to interesting findings regarding the Kos beaches. Comparison of the digitized polygons of the beaches showed erosion trends (Fig. 1) with the average BMW having decreased in 76% of the beaches compared to the period 2004-2009 (average decrease of 3 m). In addition, the area was reduced in 61 beaches out of the 78 beaches of the island, with an average decrease of 15% per beach. As the maximum dry width is considered a relatively conservative indicator of beach erosion (Monioudi and Velegrakis, 2022), the estimation of the areal reduction offers a more comprehensive picture. The analysis also showed that the detection of long-term erosive trends requires availability of time series of data with spatio-temporal resolution better than that currently available in open source imagery. In the near future, when it is expected that the availability of such data will increase significantly (Velegrakis *et al*., 2024), the approach developed/applied in the present study can be used more for the detection (and management) of coastal morphodynamics (erosion). In Kos, the orientation of the beaches does appear to affect the size of the beach, which on the contrary is related to stream presence and sediment texture size. In addition, the presence of backshore cliffs is correlated with small BMWs. Generally, it appears the Kos beach dimensions are primarily controlled by the geology rather the hydrodynamics.

Acknowledgements

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