

GLOBAL SANDY BEACH AREAS

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INTRODUCTION

Approximately 30% of the global ice-free coastline is stated to be sandy (Luijendijk et al., 2018). Sandy beaches hold an important socio-economic value related to tourism and recreation and simultaneously fulfill various ecosystem services like providing food, water and maintaining biodiversity. Sandy systems are among the most dynamic environments in the world and are under enormous pressure from climate change (e.g., sea level rise) and anthropogenic influences (e.g., coastal squeeze from artificial structures), while they are only marginally monitored by costly labor-intensive monitoring campaigns (Turner et al., 2016 & Castelle et al., 2020).

Earth Observation is transforming coastal science from a data scarce into a data rich field of expertise (Vitousek et al., 2022). The increasing availability, (spatiotemporal) resolution and spatial coverage of optical imagery and the introduction of parallel cloud computational facilities (Gorelick et al., 2017) has significantly improved over the past years. This has enabled objective, global scale assessments of coastal change. For example, Vousdoukas et al. (2020) extrapolated satellite derived ambient changes in shoreline position and combined this with estimates of sea level rise driven coastal recession to obtain a first pass global assessment of future shoreline change along sandy coasts of the world. Yet, at present, there is no global dataset on sandy beach area available that allows to accurately estimate the potential loss of these aesthetic environments. In this study we will address this gap and present insights in sandy beach areas across the globe, derived from over a million of optical satellite images from the Sentinel-2 constellation.

BACKGROUND

Research on coastal change from Earth Observation has primarily been focused on the sea-ward side of the beach, the land-sea interface (or water line). The accuracy and precision of established algorithms exploiting this parameter range between 10 m at microtidal sites up to 20 m and beyond for high-energy macro-tidal environments with complex foreshore morphology (Vos et al., 2023). On the land-ward side, delineation of the beach and its hinterland is studied only marginally. Literature is limitedly available and involves in most cases the detection of vegetation edges (Rogers et al., 2021). However, this land-ward boundary encompasses a huge variability on the global scale, such as natural boundaries like cliffs, dunes, forests, mangroves, and lagoons / lakes but also anthropogenic artificial structures like buildings, roads, railways, dikes, sea walls and revetments. In the presence of an artificial structure, a beach would be unable to adapt naturally to sea level rise due to a lack of accommodation space.

METHODS

Automated methods, incorporating cloud computing and Machine Learning (ML), have been developed to (1) classify the probability of sandy beach pixels and (2) derive the beach area from its water and land boundaries along 500-m spaced transects. The first step involved improving the sandy beach classification introduced by Luijendijk et al. (2018) by replacing its ML algorithm with one capable of computing probabilities instead of binary values. Besides, the algorithm was also trained on more manually labelled locations. The second step incorporates local variations of global parameters and other data sources like the MERIT Digital Elevation Model (DEM, Yamazaki et al., 2017) to increase the global applicability of the beach area computations (see Figure 1). An automatically derived quality flag aids in assessing the usefulness of the outcomes and labels them 'unknown' if the criteria are not met. The method has been extensively validated to compute the beach area at a number of random sites around the world with different environmental characteristics with an accuracy and precision of around 80%.

The methods were applied to around 630.000 sandy transects initially identified by Luijendijk et al. (2018). The goal of this is to produce a static (composite) transect-based beach area map for the year 2020.

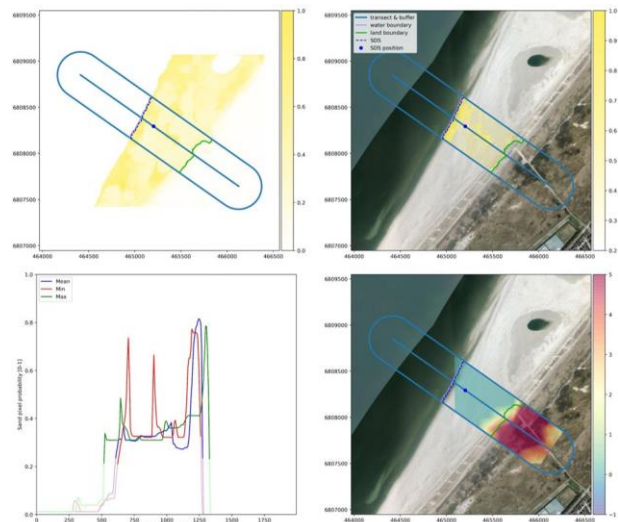


Figure 1 - Top left and right panel, sandy beach probability [0-1] and identified water line (blue) and land line (green) around a transect (buffer) at the Sand Engine, The Netherlands. The bottom right panel includes the MERIT DEM data and the bottom left panel the sandy pixel probability along three cross shore profiles within the buffer.

RESULTS

From the 630.000 transects used in the analysis, we identified about 400.000 sandy beaches. The remaining transects were identified as either non-sandy (around 105.000) or as unknown (automated quality flag, approximately 125.000). For the transects that were originally identified as sandy, the highest percentage was found in Oceania, followed by Asia and Africa (not shown). The non-sandy locations are primarily situated in South America, Europe, and North America respectively. More specifically, Norway, Chile and Canada are ranked as the top countries with non-sandy coastal areas (see Figure 2). This indicates that the algorithm improved significantly compared to the classification from Luijendijk et al. (2018) as it is well-known that these countries exhibit many kilometers of rocky shoreline. Africa, South America, and Asia rank high in the list with continents that have many locations labelled as unknown by means of the automated quality flag. Somaliland, Jordan, Oman, and Yemen, all in Africa, are all top countries with a high number of raised quality flags. This touches upon the difficulty to delineate a beach from hinterland sediment or sparsely vegetated areas (see Figure 3).

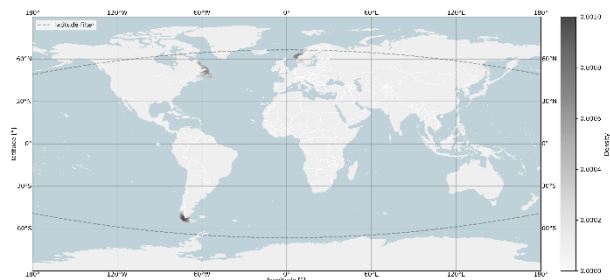


Figure 2 - Global map of locations with a high number of non-sandy coastal areas. Chile, Canada, and Norway are highlighted specifically, significantly improving the original classification.

OUTLOOK, DISCUSSION AND CONCLUSIONS

The spatially consistent global derivation of beach areas can be extended to incorporate multiple years of satellite data, resulting in the ability to assess its dynamics for the years 2015 till present. Still, the classification algorithm (see Figure 3) and transect system can be further improved to reduce the number of unknowns in the analysis and hence to increase its applicability.

In recent efforts, we have seen erosional, accretive, stable as well as regime shifts (i.e., reversal of trends) of sandy beach areas at various locations around the globe. This provides valuable information for engineers, managers and decision makers in both data-poor and -rich environments as it could be used to (timely) identify hotspots, generate a comprehensive system understanding and (re-)design (nature-based) solutions to restore or maintain the important socio-economic and ecosystem services of our beaches.

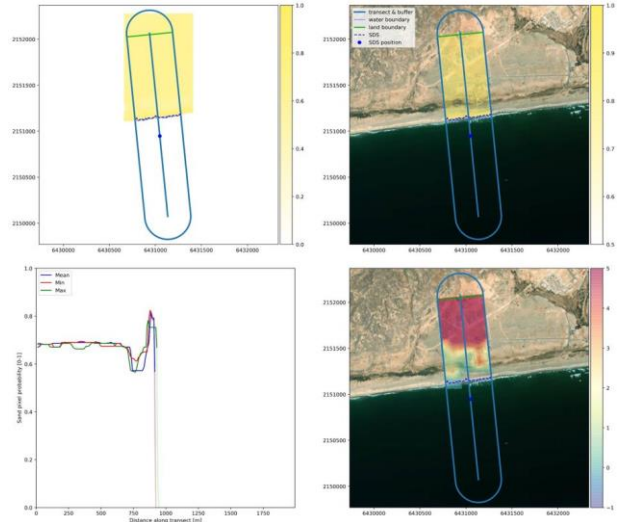


Figure 3 - Automatically raised quality flag marking the beach area "unknown" for a random location in Oman. Panels include similar information as presented in Figure 1.

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