UNIVERSIDADE
AbERTA
www.uab.pt

FUTUROS DA ÁGUA
RESILIÊNCIA, GOVERNAÇÃO E ADAPTAÇÃO

02

fevereiro
2026

AD ASTRA
REVISTA ONLINE
DA UNIVERSIDADE AbERTA

FICHA TÉCNICA

AD ASTRA
REVISTA ONLINE DA UNIVERSIDADE ABERTA

PRODUÇÃO
Divisão de Comunicação e Marketing da Universidade Aberta

ISSN
3051-6773

DOI
https://doi.org/10.34627/adastra.v2i1

ÍNDICE

ABDELLAH KHOUZ, JORGE TRINDADE, PEDRO PINTO SANTOS, FATIMA EL BCHARI, SÉRGIO C. OLIVEIRA, RICARDO A. C. GARCIA, ASMA BOUGAYOU, MUSTAPHA IKIRRI, MOURAD JADOUD, SAID RACHIDI, AND BLAID BOUGADIR
Contributo de modelos estatísticos na avaliação da suscetibilidade a cheias na província de Essaouira, Marrocos
Contribution of statistical models in flood susceptibility assessment in Essaouira Province-Morocco

ASMA BOUGAYOU ; ABDELLAH KHOUZ ; FATIMA EL BACHARI; JORGE TRINDADE; MUSTAPHA IKIRRI; SIHAM AFRAOU; FARID FAIK; BLAID BOUGADIR
Avaliação do potencial de águas subterrâneas na área de Ait Abdellah com recurso à deteção remota e SIG
Assessment of groundwater potential in the Ait Abdellah area by using remote sensing and GIS

JOÃO CARRILHO, ABDELLAH KHOUZ, JORGE TRINDADE
Águas subterrâneas na governação do nexo Água-Energia-Alimentação em áreas periurbanas exteriores
Groundwater in the Water-Energy-Food nexus governance in outer peri-urban settlements

GUSTAVO DGEDGE, CELSO CHIVALE, JAIME MAGAIA, JORGE TRINDADE
Avaliação das áreas suscetíveis a cheias na sub-bacia do rio Revúboè, Moçambique
Assessing Flood Susceptibility Areas in the Revúboè river sub-basin, Mozambique

ANDREIA ALVES DA SILVA; LUÍS PEDRO ALMEIDA; ANTÓNIO H.F. KLEIN
Abordagem multiescalar baseada em dados de satélite para a análise de tendências da linha de costa em Portugal Continental
Satellite-driven multi-scale approach for shoreline trend analysis in Mainland Portugal.

ANDREIA ALVES DA SILVA, JORGE TRINDADE; JORGE ROCHA
Avaliação do perigo e da exposição à subida do nível do mar em Portugal Continental
Hazard and Exposure Assessment to Sea Level Rise in Mainland Portugal.

MOHAMED LOUAZANI, ABDERRAFIE EL MAKNISSI
Sistemas de gestão da água nos oásis saariano e o desafio da sustentabilidade face às alterações climáticas: estudo de caso dos oásis de Oued-Noun, sul de Marrocos
The Water Management Systems in Saharan Oases and the Sustainability Challenge in the Face of Climate Change: A Case Study of the Oued-Noun Oases, Southern Morocco.

RICARDO ACÁCIO XAVIER; PEDRO PINTO SANTOS; JOSÉ MANUEL MENDES
Risco de cheias em Moçambique: estratégias comunitárias para a redução da vulnerabilidade a partir de dois estudos de caso
Flood risk in Mozambique: communitarian strategies for vulnerability reduction from two case studies.

SUSANA PEREIRA; JORGE TRINDADE; ANDREIA ALVES DA SILVA; PEDRO PINTO SANTOS; EUSÉBIO REIS; JOSÉ LUÍS ZÊZERE
Perfis de risco de perigos costeiros em Portugal Continental à escala da freguesia
Risk profiles of coastal hazards in mainland Portugal at the civil parish level.

VARIA

Suscetibilidade e exposição à erosão costeira no município de Peniche – evolução recente e futura

Coastal Erosion Susceptibility and Exposure in the Municipality of Peniche – Recent and Future Evolution

Bernardo Sales
Sérgio C. Oliveira
Jorge Trindade

Resumo

Este estudo avalia a evolução recente (2008–2023) e projetada da linha de costa de Peniche, combinando modelação de suscetibilidade a movimentos de vertente com a análise da evolução costeira através do DSAS. Os resultados evidenciam recuo significativo nos setores Gambôa – Baleal e Azenhas e pequena acreção em Molhe Leste – Consolação. O setor Baleal – Pico da Mota apresenta maior suscetibilidade à erosão. Apesar da reduzida exposição atual, recomenda-se monitorização contínua e modelos preditivos mais robustos para apoiar a gestão e o ordenamento costeiro.

Palavras-chave: Erosão costeira; Peniche; Suscetibilidade de arribas; Evolução da linha de costa; Gestão costeira.

Abstract

This study assesses the recent (2008–2023) and projected evolution of the Peniche coastline, combining logistic regression modeling of cliff landslide susceptibility with shoreline change analysis using DSAS. Results show significant retreat in the Gambôa – Baleal and Azenhas sectors and minor accretion in Molhe Leste – Consolação. The Baleal – Pico da Mota sector exhibits the highest cliff erosion susceptibility. Although current exposure of residential areas is low, monitoring and improved projection models are essential for future coastal risk management and land-use planning.

Keywords: Coastal erosion; Peniche; Cliff susceptibility; Shoreline change; Coastal management.

Bernardo Sales
Instituto de Geografia e Ordenamento do Território, University of Lisbon, Portugal
Sérgio C. Oliveira
Centre of Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon, Portugal
Associate Laboratory Terra, University of Lisbon, Portugal
Jorge Trindade
Centre of Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon, Portugal
Centre for Global Studies, Universidade Aberta, Lisbon, Portugal

0000-0001-7428-0402
0000-0003-0883-8564
0000-0001-5610-5942

Introduction

The recent evolution of the coastline, marked by sediment deficits, intense coastal erosion, and intensive or uncontrolled development of these areas, is one of the main issues that, must be understood for better, improved, and more effective coastal management and risk reduction. This is due to the dynamics of sandy systems or susceptibility to slope movements on cliffed coastlines.

On the cliff rocky coastlines, erosion mainly begins with the wear of the base, resulting in erosion due to undercutting, eventually leading to retreat. Cliff evolution also includes subaerial processes, which often cause erosion due to the instability of coastal cliffs, and processes related to hydraulic erosion, especially surface runoff, both concentrated (e.g., gullying and rill erosion) and un-concentrated. On the sandy coastline, erosion depends on the balance between sediments deposited and those transported by the sea, which, in turn, are influenced by natural and anthropogenic factors operating at various spatial and temporal scales, involving several processes, some of which are related to wave propagation to the shoreline (e.g., transformation processes: refraction, diffraction, dissipation, collapse, among others) (Trindade, 2010).

The study area (Figure 1), is located in the municipality of Peniche, and consists of both sandy and rocky coastlines. The sandy coastline contains beach-dune and beach-cliff systems. The rocky coastline is predominantly composed of limestones and marls, with systems such as abrasion platforms cliffs, block cliffs, and a mixed system that corresponds to the abrasion platform with blocks and a submerged cliff system that is in direct contact with the sea. Both types of coastline, sandy and rocky, contain geomorphologically interesting features such as the tombolos of Baleal and Peniche.

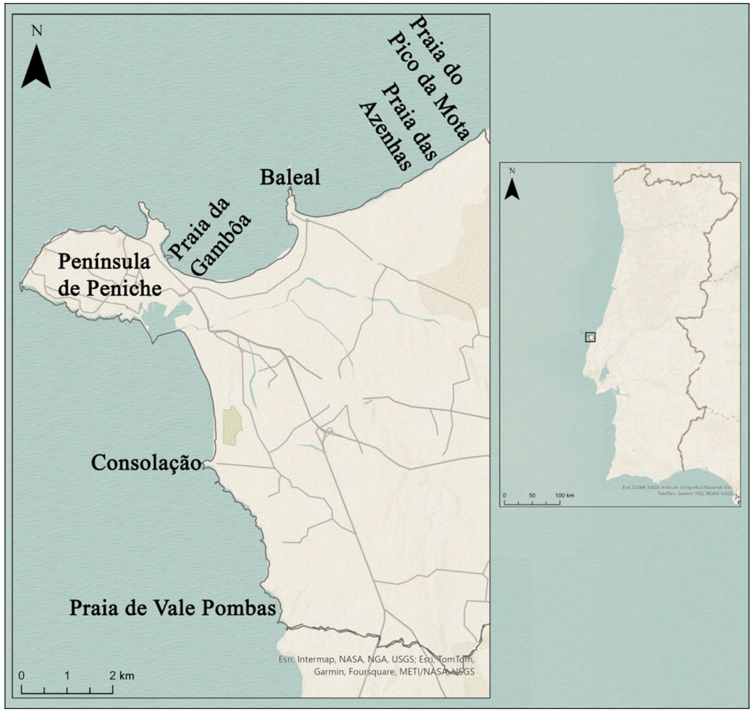

Figure 1. Geographic context of the coastline in the municipality of Peniche.

The study of coastal erosion, dynamics, and the evolution of the sandy coastline in Peniche (or covering larger areas, but including Peniche) has been developed by several authors in recent decades, which proves the relevance of the topic and study area. Examples of work on the sandy coastline include studies by Silva et al. (2013a,b,c), Ponte Lira et al. (2016), and for the rocky coastline, the works of Marques (1998), Penacho and Marques (2023). In this regard, the work to be carried out aims to continue studies on this topic, focusing on the assessment of the recent and future retreat of the coastline, considering the diversity of sandy and rocky systems present in the coastline of the municipality of Peniche, to identify and map the variation in the position of the coastline and exposure to coastal erosion.

Methods

The susceptibility to landslides on the rocky coastline was evaluated using the statistical method of logistic regression. This method allows for the estimation of the probability associated with the occurrence of landslides based on a set of independent explanatory variables, and is used in situations where the dependent variable is dichotomous in nature (0 – 1: absence – presence). This method has been applied in the assessment of landslide susceptibility in cliff coasts and non-coastal slopes, by various authors both internationally (Dai et al., 2001; Brahim & Elmoulat, 2018) and in Portugal (Marques et al., 2013; Marques, 2018; Queiroz & Marques, 2019; Penacho & Marques, 2023). Landslide susceptibility modelling was performed using IBM SPSS Statistics v29 software and an independent cross-validation process to train the final susceptibility model, this process was repeated five times, with the final model being the average of the five susceptibility models produced.

The study regarding coastline evolution began with the selection of an appropriate coastal indicator. This indicator must be suitable for the temporal scale of the study, which in this case is medium-term (2008-2023). To ensure consistent measurement, the chosen indicator should be as independent as possible from frequent changes in water levels and the seasonal morphological cycle of the beach. Thus, the vegetation line indicator was chosen for the sandy coastline, as most of the sandy coastline consists of dunes bounded by vegetation, and due to the difficulty of precisely identifying the foot of the dune from aerial photographs. For the rocky coastline, the cliff crest was considered as the indicator, as it is easily identifiable through photointerpretation. The coastline line for the sandy coastline was delineated for the years 2008, 2015, and 2023. For the rocky coastline, only the years 2008 and 2023 were considered. The rates of coastline evolution were calculated using GIS with the Digital Shoreline Analysis System v6.0.168 (DSAS) tool (Himmelstoss et al., 2024).

Based on the evolution rates obtained from the previous method, a linear projection of the coastline was made. The projection was carried out for a future scenario of 15 years, as the evolution rate data acquired in this study also correspond to a period of 15 years (2008–2023). In applying this projection, all values related to accretion (+0) were considered to be in dynamic equilibrium. Thus, the retreat value obtained for each terrain unit (TU) corresponds to the evolution rate (ER) of each TU, multiplied by the time period (TP) for which the projection is to be made, which in this case is 15 years (TP15). The equation is given by: $TP15 = ER * 15$.

This projection was made in an exploratory manner due to a lack of data and time to create a robust model of coastline position evolution for future scenarios. It is a simple linear projection based on the evolution rates recorded in the present, assuming that the trends observed in the last 15 years will remain similar to those expected for an equal period in the future. This assumption is valid as long as no significant changes in the conditions that govern coastal erosion in the study area occur in the short term. This projected short-term trend may be biased by the dynamics present in the sandy coastline, and thus the use of these trends is accepted, assuming their exploratory nature.

Based on the observed average retreat value for each terrain unit and coastline retreat projections, a landwards future position of the coastline was created for each TU, thus allowing for the evaluation of whether the expected coastline retreat could have any impact on existing residential infrastructure.

Results

In this study, 149 landslides were identified, resulting in a loss of cliff surface area of approximately 9,028 m². Spatially, these landslides are predominantly clustered in the Baleal – Praia Pico da Mota section, where 142 landslides are present. The remaining 7 are located in the Consolação – Praia de Vale Pombas section.

One of the reasons for this low number of occurrences is a series of anthropogenic interventions aimed at mitigating the occurrence of geomorphological instability manifestations in this sector, including the presence of hexagonal grids and protection through the application of sprayed concrete. No landslides were observed in the Peniche Peninsula sector during the study period.

The final susceptibility map for landslides in coastal cliffs, as mentioned earlier, resulted from the integration of the five landslide susceptibility models produced. The area under the curve (AUC) values for each model are represented in Table 1. The final susceptibility score is defined by the average value of the scores obtained for each TU across the five previously defined susceptibility models. This approach allows for independent cross-validation of each susceptibility model and, by using all TUs with occurrences, enhances the predictive capacity of the final susceptibility model.

Model	AUC
Model 1	0.632
Model 2	0.833
Model 3	0.830
Model 4	0.878
Model 5	0.731

Table 1. AUC values of each slope movement susceptibility assessment regression model on coastal cliffs.

In the final susceptibility model (average of the five models), it was observed that the most susceptible sector is the Baleal – Praia do Pico da Mota stretch, where the very high and high susceptibility classes predominate, it is also in this sector where the highest number of landslides occurred. In the Peniche Peninsula sector, as mentioned earlier, no landslides were observed (none were identified) during the study period (2008-2023). This record confirms the predominance of the class corresponding to low and very low susceptibility. The last sector corresponds to the Consolação – Praia de Vale Pombas stretch, where only 5 terrain units were affected by landslides. As also mentioned earlier, this sector is heavily protected from erosion by a series of (preventive) interventions aimed at limiting landslide occurrences. Therefore, some of the TUs with no landslide occurrences but classified with high susceptibility may require additional monitoring.

The study of the coastline evolution over the last 15 years (2008-2023) revealed a strong erosive trend on the sandy coastline in the Praia das Azenhas and Praia da Gambôa – Praia do Baleal Sul sectors, with the latter stretch being particularly severe. In contrast, in the Praia do Molhe Leste – Praia da Consolação sector, accretion values were observed, although they were very insignificant, as shown in Table 2.

Sector		2008 - 2015	2015 - 2023	2008 - 2023
Praia das Azenhas	**Coast Change Rate (m/year)**	-0,03 ± 0,14	-0,30 ± 0,17	-0,18 ± 0,10
	Total Coast Change Rate (m)	-0,21	-2,4	-2,7
Praia da Gambôa – Praia do Baleal Sul	**Coast Change Rate (m/year)**	-1,37 ± 0,14	-1,25 ± 0,17	-1,32 ± 0,10
	Total Coast Change Rate (m)	-9,59	-10	-19,80
Praia do Molhe Leste – Praia da Consolação	**Coast Change Rate (m/year)**	-0,21 ± 0,14	0,26 ± 0,17	0,05 ± 0,10
	Total Coast Change Rate (m)	-1,47	2,08	0,75

Table 2. Average yearly and total evolutionary trend for the sandy coastline.

In the rocky coastline (Table 3), the sector with the greatest retreat was the Praia das Azenhas – Praia do Pico da Mota sector, where a total retreat value of 3 m was recorded, followed by the Consolação sector with a total retreat of 1.35 m. Lastly, the Baleal – Praia das Azenhas sector showed a total retreat of 0.3 m.

Sector		2008 - 2023
Praia do Baleal Norte – Praia das Azenhas	Coast Change Rate (m/year)	0,02 ± 0,08
	Total Coast Change Rate (m)	0,3
Praia do Baleal Norte – Praia das Azenhas	Coast Change Rate (m/year)	0,02 ± 0,08
	Total Coast Change Rate (m)	0,3
Praia das Azenhas – Praia do Pico da Mota	Coast Change Rate (m/year)	0,20 ± 0,08
	Total Coast Change Rate (m)	3
Consolação	Coast Change Rate (m/year)	0,09 ± 0,08
	Total Coast Change Rate (m)	1,35

Table 3. Average yearly and total evolutionary trend for the rocky coastline

Based on the evolution values present in Table 2 and assuming that the conditions governing erosion in these sectors will not change significantly compared to those observed in the last 15 years, an average retreat of 17.20 m is expected in the Gambôa – Baleal sector, 2.02 m in the Molhe Leste – Consolação sector, and 7.08 m at Praia das Azenhas.

The same process was applied to the rocky coastline, resulting in an expected average retreat of 1.55 m in the Baleal Norte – Pico da Mota sector, and an average retreat of 0.16 m in the Consolação – Vale Pombas sector. Although these values do not represent a highly pronounced erosive trend, they should not be underestimated, as they may occasionally correspond to more significant retreats associated with the occurrence of larger magnitude slope movements.

Regarding exposure in the study area, mainly due to the extent of the dune system, no TU in the sandy coastline was found to have residential buildings within the expected retreat zone.

In the rocky coastline, two situations were identified that may jeopardize the stability of certain buildings, as the expected retreat includes some urban fabric, particularly part of a parking lot and the wall/fence of a property/residence. Although no housing is directly affected, the proximity to slope movements observed in recent years, combined with the expected retreats, could undermine the stability of the cliff in the short/medium term, potentially affecting the housing itself. Therefore, there is a need to monitor this sector.

Conclusion

In conclusion, the results obtained point to retreat values related to recent coastal erosion in the rocky coastline sector, Baleal – Praia do Pico da Mota, and in the sandy coastline sectors, Gambôa – Baleal and Praia das Azenhas. The sandy sector Molhe Leste – Consolação stands out as the only sector with accretion values, although these are not significant. The Peniche Peninsula (rocky coastline) emerges as the least susceptible sector to coastal erosion during this study period (2008-2023).

The assessment of susceptibility to erosion is essential in studies addressing the coastline, as it helps identify the most critical sectors to be considered in future land-use planning.

For future studies, there is a particular emphasis on the need to apply a more robust coastline projection method that takes into account dynamics primarily related to erosion and coastal flooding, especially in sandy systems. This includes the use of different sea-level rise scenarios for the end of the century, storm surge, wave run-up, and other factors.

References

BRAHIM, L. A., & ELMOULAT, M. (2018). Application of logistic regression method to produce landslide susceptibility map: A case study of Tetouan Mazari, Morocco. MATEC Web of Conferences, 149, 02082. https://doi.org/10.1051/matecconf/201814902082

DAI, F. C., LEE, C. F., Li, J. X. Z. W., & Xu, Z. W. (2001). Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong. Environmental Geology, 40(3), 381–391. https://doi.org/10.1007/s002540000163

HIMMELSTOSS,E.A.,HENDERSON,R.E.,FARRIS,A.S.,KRATZMANN, M.G., BARTLETT, M.K., ERGUL, A., MCANDREWS, J., CIBAJ, R., ZICHICHI, J.L., and THIELER, E.R., 2024, Digital Shoreline Analysis System version 6.0: U.S. Geological Survey software release, https://doi.org/10.5066/P13WIZ8M

MARQUES, F. (2018). Regional scale sea cliff hazard assessment at Sintra and Cascais counties, western coast of Portugal. Geosciences, 8(3), 80. https://doi.org/10.3390/geosciences8030080

MARQUES, F. M. S. F. (1998). Sea cliff retreat in Portugal: overview of existing quantitative data. Fifth Cong. Nacional Geologia, 18-20 Nov. 1998, Lisboa, 75-78.

MARQUES, F. M. S. F., MATILDES, R., & REDWEIK, P. (2013). Sea cliff instability susceptibility at regional scale: a statistically based assessment in the southern Algarve, Portugal. Natural Hazards and Earth System Sciences, 13(12), 3185–3203. https://doi.org/10.5194/nhess-13-3185-2013

PENACHO, N. D., & MARQUES, F. M. (2023). A statistical approach for sea cliff hazard and setback lines mapping in the northeast of Peniche, Portugal. Geomorphology, 430, 108669. https://doi.org/10.1016/j.geomorph.2023.108669

PONTE LIRA, C., NOBRE SILVA, A., TABORDA, R., & FREIRE DE ANDRADE, C. (2016). Coastline evolution of Portuguese low-lying sandy coast in the last 50 years: an integrated approach. Earth System Science Data, 8(1), 265-278. https://doi.org/10.5194/essd-8-265-2016

QUEIROZ, S. M., & MARQUES, F. M. (2019). Sea cliff instability susceptibility considering nearby human occupation and predictive capacity assessment. Engineering Geology, 253, 75–93. https://doi.org/10.1016/j.enggeo.2019.03.009

SILVA, A.; TABORDA, R.; LIRA, C.; ANDRADE, C.; SILVEIRA, T.; FREITAS, M.; (2013a); “Determinação e Cartografia da Perigosidade Associada à Erosão de Praias e ao Galgamento Oceânico”; Entregável 1.3.2.a, Consultoria para a Criação e Implementação de um Sistema de Monitorização do Litoral abrangido pela área de Jurisdição da Administração Regional Hidrográfica do Tejo, FCUL, Lisboa.

SILVA, A, N. PONTE LIRA, C. ANDRADE, C, F. TABORDA, R., & FREITAS, M, C. (2013b). “Análise da evolução da linha de costa em litoral baixo arenoso nos últimos 50 anos”; Entregável 1.2.2.2.a, Consultoria para a Criação e Implementação de um Sistema de Monitorização do Litoral abrangido pela área de Jurisdição da Administração Regional Hidrográfica do Tejo, FCUL, Lisboa.

SILVA, A, N. PONTE LIRA, C. MATILDES, R. ANDRADE, C, F. TABORDA, R., & FREITAS, M, C. (2013c). “Utilização de ortofotomapas e fotografias aéreas para a delimitação da linha de costa”. Entregável 1.2.2.2.c, Consultoria para a Criação e Implementação de um Sistema de Monitorização do Litoral abrangido pela área de Jurisdição da Administração Regional Hidrográfica do Tejo, FCUL, Lisboa.

TRINDADE, J. (2010). Dinâmica morfossedimentar de praias dominadas por sistemas de arriba: (Peniche-Cascais) (Dissertação de doutoramento, Universidade Aberta). http://hdl.handle.net/10400.2/1733

FUTUROS DA ÁGUA
RESILIÊNCIA,
GOVERNAÇÃO
E ADAPTAÇÃO

UNIVERSIDADE
ABERTA
www.uab.pt

AD ASTRA
REVISTA ONLINE
DA UNIVERSIDADE ABERTA