

## CoastSnap as a citizen science tool for coastal monitoring: experience from Pacheco beach (Caucaia, Ceará, Brazil)

*CoastSnap como uma ferramenta de ciência cidadã para o monitoramento costeiro: Experiência da praia de Pacheco (Caucaia, Ceará, Brasil)*

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### ABSTRACT

**Research Purpose:** This study evaluates the performance of the CoastSnap project and its contribution to monitoring the beach-cliff system on a stretch of Pacheco beach (Caucaia, Ceará, Brazil), offering an integrated view of its applications.

**Methodology:** CoastSnap is a low-cost international initiative for monitoring the coastal landscape with various applications, incorporating morphodynamic monitoring of beaches, identification of risks and hazards, and occupation dynamics. It is based on citizen science as the main vector for the production of scientific knowledge, involving researchers and non-expert citizens. It uses a metal support installed on the beach to position smartphones, allowing users to capture photos and send them via QR code to the project database. After screening, approved images are aligned and processed in MATLAB with the CoastSnap Toolbox, allowing the extraction of the coastline and observation of coastal dynamics.

**Findings:** In the end, the data shows that the beach width ranged from 95 to 134 m. Between 2021 and 2024, 319 photos were taken, with the most activity in 2023 and 2024, with 105 and 124 photos, respectively, with July, August, and weekends being the busiest times. The highest frequency of records occurred at 8 a.m., 9 a.m., and 5 p.m., highlighting the preferred times of beachgoers. In addition, activities such as swimming, walking, leisure, mass movements, and the morphodynamic stability of the beach were revealed.

**Originality/Value:** Among the potential benefits of CoastSnap are its ease of replication, low cost, continuous data, and promotion of environmental awareness. However, the project faced challenges such as reduced image uploads during periods of extreme heat, discarding non-standard records, and periods of downtime due to damage to the station.

**Keywords:** CoastSnap; Shoreline; Cliff; Erosion; Community Engagement.

## RESUMO

**Objetivo da Investigação:** Este estudo avalia o desempenho do projeto CoastSnap e a sua contribuição para o monitoramento do sistema praia-falésia em um trecho da praia do Pacheco (Caucaia, Ceará, Brasil), oferecendo uma visão integrada das suas aplicações.

**Metodologia:** O CoastSnap é uma iniciativa internacional de baixo custo para o monitoramento da paisagem costeira com várias aplicações, incorporando o monitoramento morfodinâmico das praias, a identificação de riscos e perigos e a dinâmica de ocupação. Baseia-se na ciência cidadã como principal vetor para a produção de conhecimento científico, envolve pesquisadores e cidadãos não especialistas. Utiliza um suporte metálico instalado na praia para posicionar seus smartphones, os usuários capturam fotos e as enviam via QR para o banco de dados do projeto. Após a triagem as imagens aprovadas são alinhadas e processadas no MATLAB com o CoastSnap Toolbox, permitindo a extração da linha de costa e observação da dinâmica costeira.

**Resultados:** Como resultado, os dados mostram que a largura da praia variou entre 95 e 134 m. Entre 2021 e 2024, foram obtidas 319 fotos, mostrando maior envolvimento em 2023 e 2024, com 105 e 124 fotos, respectivamente, sendo julho, agosto e fins de semana os períodos de maior participação. A maior frequência de registros ocorreu às 8h, 9h e 17h, destacando os horários preferidos dos frequentadores da praia. Além disso, foram reveladas atividades como natação, caminhada e lazer, para além dos movimentos em massa e da estabilidade morfodinâmica da praia.

**Originalidade/Valor:** Entre os potenciais benefícios do CoastSnap estão a sua facilidade de replicação, baixo custo, dados contínuos e promoção da consciência ambiental. No entanto, o projeto enfrentou desafios, como a redução de envio das imagens durante períodos de calor extremo, o descarte de registros não padronizados e períodos de inatividade devido a danos na estação.

**Palavras-chave:** CoastSnap; Linha de Costa; Falésia; Erosão; Engajamento Comunitário

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## 1. Introduction

Citizen Science is an important initiative that promotes the active participation of non-specialized citizens in the collaborative production of scientific knowledge (Mamede et al., 2017). This voluntary collaboration between citizens and scientists may take different forms: contributory, when citizens collect data under scientific guidance; collaborative, when they also participate in data analysis; and co-creative, when they are involved in all stages of the research process (Bonney et al., 2009; Haklay, 2013; Gunnell et al., 2021).

This initiative occurs spontaneously, using participatory methodologies, constituting a way to include and engage the population in academia and emphasizing the importance of the link between the population, researchers, and science (Garcia-Soto et al., 2017; Wehn et al., 2021; Harley & Kinsela, 2022; Elrick-Barr et al., 2023). The active, voluntary, and collective participation of non-scientists in the production, collection, analysis, or interpretation of scientific data is the main characteristic of citizen science.

The participation of citizen scientists is particularly evident in biodiversity-related projects, a field that has expanded globally and contributed to increasing public awareness of environmental conservation (Comandulli et al., 2016). Volunteers have actively contributed to initiatives such as tracking the Asian tiger mosquito (Palmer et al., 2017), searching for meteors (EXOSS Citizen Science Project, 2023), monitoring water quality (Palma, 2016), and observing coastal environments, as exemplified by the CoastSnap project (Harley & Kinsela, 2022; Soriano-González et al., 2024).

CoastSnap is a citizen science program specifically designed for coastal monitoring, in which fixed and georeferenced stations are installed along the shoreline to serve as standardized photographic reference points. From these stations, citizens are encouraged to take and submit photographs using their own mobile devices, following simple guidelines. The accumulation of these images over time allows the analysis of spatial and temporal variations in shoreline position and beach morphology, providing a low-cost and participatory approach to coastal monitoring (Harley & Kinsela, 2022).

CoastSnap was created in 2017 at the Water Research Laboratory of the University of New South Wales in Sydney, Australia, with the aim of monitoring changes in the coastline. Because of its low cost, the initiative quickly spread around the world, including Brazil. Currently, there are more than 300 monitoring stations distributed across 31 countries. In Brazil, several collaborative initiatives are active, such as the networks involving CoastSnap BR, CoastSnap NE, and others (Harley et al., 2019; Harley & Kinsela, 2022; CoastSnap, 2025).

Several recent studies have explored the advances and challenges of the CoastSnap project. For example, Pahlen (2021) analyzed the effectiveness and challenges of the project in Christchurch, New Zealand. Urbaneja et al. (2023) discussed the Citizen Science experience at the CoastSnap station in the Valparaíso region of Chile. Soriano-González et al. (2024) reported on achievements and lessons learned from the CoastSnap station in Spain, while Elrick-Barr et al. (2023) investigated the coastal social values associated with Citizen Science through the project in Western Australia.

In Brazil, as far as the authors know there are about 50 active monitoring stations linked to the CoastSnap BR and CoastSnap NE projects which are spread across different regions of the country, including South, Southeast, North, and Northeast regions. The locations of all stations worldwide, including those in Brazil, are available on the CoastSnap program's digital platform – Citizen Science App (<https://www.coastsnap.com/>). This demonstrates that it is a replicable methodology with regional adaptability, allowing for local adjustments according to the type of impacts and environmental characteristics.

Among the CoastSnap initiatives in Brazil, the CoastSnap NE project stands out, operating across the coastal states of Ceará, Rio Grande do Norte, and Piauí. Currently, the project comprises eight active stations, five located in Ceará, two in Piauí, and one in Rio Grande do Norte. In this context, this article aims to critically analyze the potential and limitations of the CoastSnap tool for coastal monitoring, based on the accumulated experience of the oldest station of the CoastSnap NE Project, installed in 2021 at Pacheco beach, on the coast of Caucaia, Ceará (NE Brazil). By using a longer time series derived from citizen participation and standardized photographic records, the study highlights the contributions of CoastSnap to understanding the coastal dynamics of an urban beach bordered by a coastal cliff.

## 2. Study area

Pacheco is an urban beach located in the municipality of Caucaia, in the state of Ceará, northeastern Brazil, approximately 15 km west from Fortaleza, the state capital. The area is accessed via the CE-090 highway, crossing the Ceará River, and is inserted within Sector II of the Coastal Management framework of Ceará, which corresponds to the coastline of the Fortaleza Metropolitan Region. Due to its urban setting and strategic location within the metropolitan coastal zone, Pacheco beach represents a relevant site for evaluating coastal monitoring tools in highly dynamic and anthropogenically influenced environments (Paula et al., 2021) (Figure 1).

The CoastSnap station at Pacheco beach was strategically installed adjacent to a hotel, selected based on criteria of structural stability, safety, and the maintenance of a fixed and unobstructed field of view. The station provides a lateral perspective of the beach–cliff system, enabling the acquisition of photographs with a consistent and favorable viewing angle for monitoring shoreline position, beach morphology, cliff dynamics and users' beach dynamics. This configuration contributes to the standardization of image records over time, reduces geometric distortion, and enhances the reliability of the temporal analyses derived from citizen-generated data.

The coastal area of Caucaia is characterized by sandy beaches with dunes, lagoons, fluvial-marine plains, and cliffs, whose upper parts are occupied by residences. In these areas, mass movements can occur, posing risks to beachgoers (de Farias & Maia, 2010; Leitão, 2017; Leisner et al., 2023). The sediments of the Pacheco beach cliff belong to the Ceará sedimentary basin, and its geological formation is composed of Pleistocene terrigenous sediments that extend along the northeastern coast (Neto et al., 2024). The height of this cliff varies from 15 to 20 m, maintaining an average slope of 80° (Leisner et al., 2025).

**Figure 1**  
 Location map of Pacheco beach, Caucaia, Ceará.



The climate of the coastal region of Ceará is classified as Tropical with a dry summer, with rainfall concentrated between February and May, according to Köppen's classification (1948). In the Northeast region of Brazil, there is a convergence of trade winds from the northeast and southeast Atlantic, which are controlled by the Intertropical Convergence Zone (ITCZ) (Barros et al., 2024). The prevailing wind directions along the study area are southeast (SE), east-southeast (ESE), east (E), and northeast (NE) (Meireles, 2011).

The tides in the state of Ceará have a semi-diurnal regime, with mesotidal waves, oscillations varying between 2 and 4 meters (Paula & Farrapeira Neto, 2017). The wave regime is characterized by a significant average height ( $H_s$ ) mean of 1.35 m, with an average period ( $T_p$ ) of 6 s and a predominant direction generally from the east (E), which may be modified in the east (E), east-northeast (E-NE), and east-southeast (E-SE) quadrants (SEMACE, 2016; Paula et al., 2022).

### 3. Material and Methods

The methodological framework of this research was organized into five fundamental stages, designed to reflect the operational structure of the CoastSnap tool. The analysis encompasses a 34-month (April 2021-February 2022; February 2023-December 2024) monitoring period at the Pacheco beach station, incorporating data organization, citizen-generated image acquisition, image processing, and the analysis and interpretation of results (Table 1).

**Table 1**  
*Steps of the Methodological Procedure*

Stage	Details
<b>CoastSnap station installation</b>	Determination of a coastal landscape with suitable conditions, followed by the positioning of the station base and the collection of control points
<b>Data acquisition and storage</b>	Receipt of images recorded by visitors and storage in organized folders, associated with the collection of priority information and the creation of spreadsheets
<b>Image processing</b>	Image selection and execution of alignment and orthorectification steps
<b>Shoreline Extraction</b>	Mapping the shoreline based on the detection of differences in pixel coloration in photographs
<b>Tool evaluation</b>	Determining the potential and limitations of the CoastSnap tool

### 3.1. CoastSnap station implementation

First, the beach environment and landscape to be monitored are selected. Next, the CoastSnap station is installed in a stable area positioned significantly above mean sea level (MSL), which is essential for orthorectifying the captured images. Subsequently, control points (fixed reference points visible in all records) are collected through a geodetic topographic survey using high-precision GNSS (Global Navigation Satellite System) positioning and navigation techniques, with the use of Real Time Kinematic Positioning, allowing the acquisition of geographic coordinates (X, Y, and Z) with centimeter precision in real time. The acquired coordinates form the basis for the rectification stage, ensuring that all records are spatially georeferenced accurately and reliably.

The CoastSnap project monitoring base at Pacheco beach is located at UTM coordinates (9592735.33 m N; 539063.93 m E) at an altitude of 13 m and an azimuth of 260° relative to north. This station consists of a wooden post approximately 1.5 m high, with a stainless-steel support fixed at the top to hold the smartphone in a horizontal position at the desired angle. This allows for standardization of the photographic records of the landscape. In addition, three PVC information boards measuring 50x45 cm and 11x32 cm were created and installed. The boards contain all the information necessary for volunteers to collaborate with the initiative, including images and instructional captions about the stages of submission and description of the project. The photos in Figure 2 illustrate all the materials that make up the CoastSnap monitoring station.

The cost of the materials needed to build the station are related to building materials (e.g., stainless steel supports, PVC information signs) and the operational costs of installation (e.g. people, food and gasoline), which may change according to the location of station. Table 2 summarizes the costs of the structural and the operational items considered for the implementation at the Pacheco beach.

**Figure 2**  
*Images of the CoastSnap NE station on Pacheco beach, Caucaia, Ceará.*



**Table 2**  
*Steps of the Methodological Procedure*

Materials	Values (US\$)
Eucalyptus wood post (1.5 m height)	24.00
Stainless steel support	18.00
PVC information signs	27.00
Screwdriver	17.00
Screws and Nuts	4.00
<b>Total</b>	<b>90.00</b>

### 3.2. Data acquisition and storage

Photographs are submitted by citizens after scanning a QR code displayed on the instruction board at the monitoring station. The QR code provides direct access to the project’s WhatsApp contact, through which volunteers upload the image and report the date and time of acquisition (day, month, year, hour, and minute). This information is essential to ensure the correct organization of the image database and to enable accurate cross-reference with tidal data.

The photographs received via the project’s WhatsApp channel are stored in the project database and systematically organized into folders by year and month. Using the date and time information provided by citizen scientists at the time of submission, spreadsheets are created to structure the image records and compile the associated metadata. Additional information collected during the submission process is also incorporated, ensuring data consistency and supporting subsequent image processing and analysis.

### 3.3. Image processing and Shoreline extraction

The images are submitted to a rigorous visual inspection based on the following criteria for excluding images: lighting (too dark or too light), blurred, cropped, or out of frame, not corresponding to the monitoring landscape,

such as personal photos or those that do not show the control points. From this selection, the images are aligned in Photoshop, following a standardization based on the choice of a master image.

The aligned images are imported into MATLAB, where they are processed using scripts from the CoastSnap toolbox for geometric calibration and orthorectification. This procedure is based on ground control points (GCPs) previously surveyed in the field with a GNSS-RTK receiver, providing accurate real-world coordinates for fixed reference features within the station’s field of view.

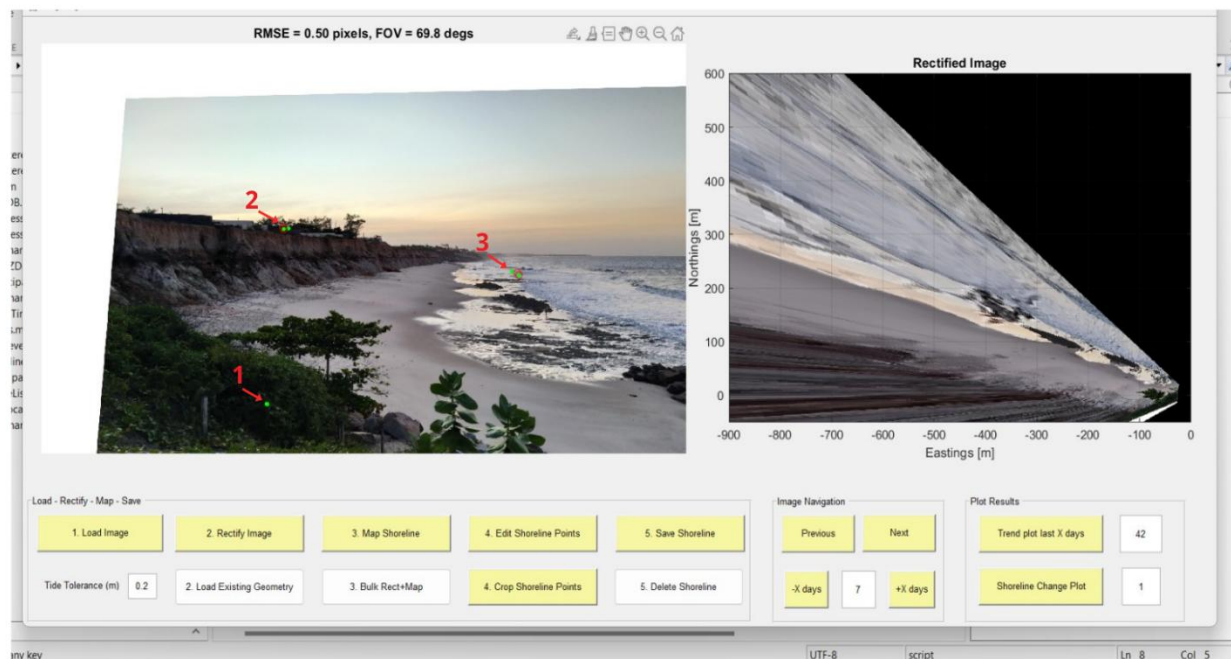
Given the oblique nature of the images acquired by citizen scientists, georeferencing is performed through the computation of a projection matrix that converts image pixel coordinates (u, v) into real-world coordinates (X, Y, Z). This transformation corrects perspective effects and minimizes geometric distortions inherent to oblique imagery, allowing the images to be used for quantitative spatial analyses.

Three GCPs were defined (Table 3), strategically selected on stable, immobile, and permanently visible elements, ensuring their consistent identification across the entire monitoring period. These control points support the application of geometric calibration matrices during image processing, improving spatial accuracy and ensuring the temporal consistency of the image dataset used for shoreline and beach morphology analysis (Figure 3).

**Table 3**  
*Coordinates of the CoastSnap station control points*

CoastSnap Station Control Points (GCP's)		
P1) X: 538478,730 m E	Y: 9593006,519 m N	Z: 1,511 m
P2) X: 538821,828 m E	Y: 9592792,759 m N	Z: 19,680 m
P3) X: 538957,113 m E	Y: 9592725,317 m N	Z: 21,721 m

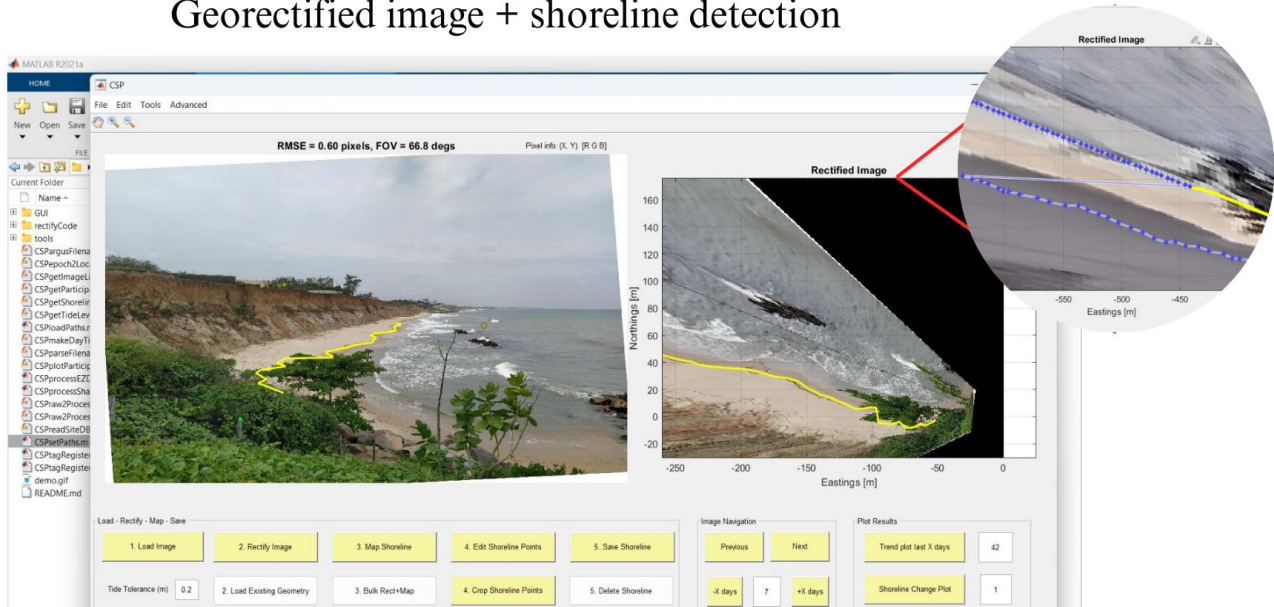
**Figure 3**  
*Image rectification stage*



The extraction of water lines is performed automatically by using the CoastSnap toolbox developed in Harley et al. (2019) and Harley & Kinsela (2022). The method is based on the edge detection technique, which delimits the difference between groups of red pixels (sand) and blue pixels (water). When necessary, these are subject to manual adjustments, designed to correct possible failures in automatic detection, as shown in Figure 4.

**Figure 4**  
*Image rectification stage*

### Georectified image + shoreline detection



In total, 49 coastlines were mapped using images received over a period of 34 months, which involved a detailed process of temporal and spatial analysis of changes in the shoreline, where each mapping corresponds to the position of the shoreline at the time the records were sent.

### 3.4. The tool and visual methods for image qualitative analysis

As a final step, an assessment was made of the potential and limitations of the CoastSnap toolbox, based on systematic analysis of the images, which provide detailed information on coastal dynamics and beach use. In the case of Pacheco beach station, the tool's potential was considered in terms of its ability to monitor changes in the coastline, seasonal occupation patterns, recreational activities, erosion processes at the top of the cliff, mass movement events, and infrastructure exposure, among other relevant aspects, based on continuous monitoring through participation of citizens. This promotes a holistic understanding of land use and coastal dynamics.

In assessing the limitations, technical and social aspects were considered, such as a lack of understanding of the correct procedure for obtaining images, which resulted in inadequate records, taking selfies, and photographs that were out of frame. Problems related to poor image quality were also observed, with blown pixels, as well as discontinuity in contributions caused by damage or failures at monitoring stations.

Participant engagement in the project is assessed based on the number of photographs submitted and the recurrence of contributions over time. A higher frequency of submissions by the same contributor is interpreted as a greater level of engagement with the initiative, whereas sporadic or isolated contributions indicate lower adherence. Given the citizen science framework of the project, this variable is essential for evaluating the degree of interaction between the local population and coastal monitoring activities. Accordingly, the integrated analysis of the image database and associated metadata allows for the characterization of participation patterns, while the temporal distribution of image submissions provides insights into local trends in engagement and monitoring continuity.

The photographic database and its associated metadata support a structured interpretation of the visual content recorded in the images. An image-based qualitative analysis, grounded in visual content analysis methods, was applied to systematically examine observable coastal features and processes. This approach enabled the identification and classification of mass movement events, the quantitative estimation of beach users through visual counts, the recognition of fixed coastal elements (e.g. coastal protection structures), and the characterization of recreational and operational activities along the beach (Souza et al., 2011; Godoy & Silva, 2019; Leisner et al., 2025)

## **4. Results and discussion**

### **4.1. Engagement and temporal distribution of image reception**

The CoastSnap NE station, installed on Pacheco beach, presents a time series of 34 months of effective records. During this period, 319 images were received from participants, corresponding to an average of approximately 9.4 photos/month. This frequency is equivalent to about 2.2 photos/week, resulting in an average recurrence of one new image every three days.

The above data indicates that there is consistency in the specific contribution of citizen scientists (or participants) to the project, generating learning for citizenship and democratic engagement. This participation is indispensable as a driver in the generation of data for research development. According to Sobottka (2023), engagement also depends on the participants' own interest. Silveira et al. (2022) understand that engagement also needs to be understood as a form of empowerment for participants.

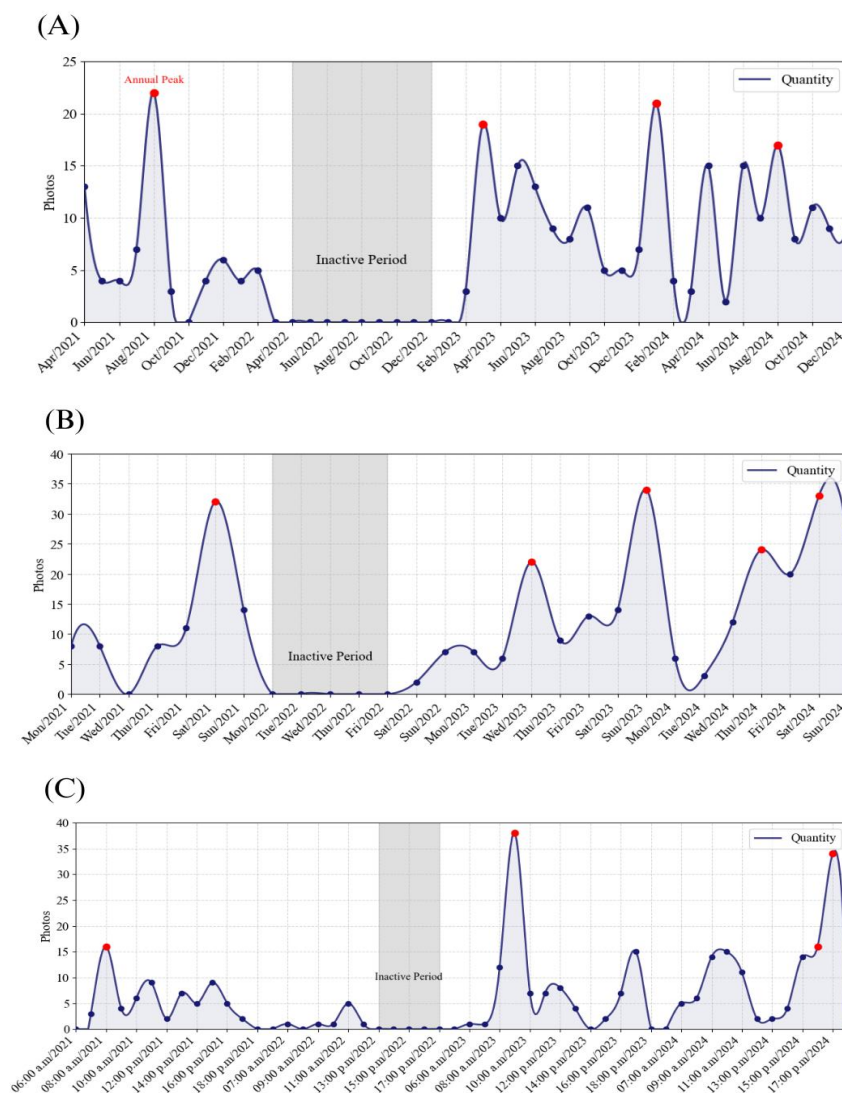
The annual distribution of images received shows that in 2021 there were 81 photos (25.4%), in 2022 there were 9 photos (2.8%), in 2023 there were 105 photos (32.9%), and in 2024 there were 124 photos (38.9%). This irregularity is justified by the station's period of inactivity between March 2022 and January 2023. This data indicates that, over the years, except for the inactive period, community engagement has increased, consolidating the Pacheco beach station as an important tool for monitoring local morphological changes.

Throughout the time series, the number of images submitted by participants varied across months, years and times of the day (Figure 5). Periods corresponding to school holidays in Brazil accounted for a substantial proportion of contributions: December and January, associated with the end-of-year school recess, represented 14.7% (47

images) of the total submissions, while July and August, which correspond to the mid-year school holiday period, accounted for 28.5% (91 images). This temporal pattern suggests that school holiday periods may influence participation levels reflecting increased beach use and availability of contributors during these months.

These results indicate increased participant engagement during periods of higher visitor traffic on beaches in northeastern Brazil, such as school holiday periods (July and December), the austral summer (December to February), and potentially the European mid-year holiday season. In contrast, during the regional rainy season, the average monthly contribution decreased to 7.3% (approximately 23 images per month), reflecting reduced beach use under less favorable weather conditions, including lower temperatures, increased rainfall, and the higher occurrence of thunderstorms, which may discourage coastal visitation and recreational activities (Figure 5a).

**Figure 5**  
*Total number of photographs submitted. a) month/year; b) weekday/year; and c) hour/year. The red dots indicate the maximum values.*



#### 4.2. Visual detections of natural and anthropogenic elements in the coastal landscape imaged from the CoastSnap station

The images sent by participants record different morphodynamic states of the beach, as they cover different days, times, and meteorological and oceanographic conditions (Figure 6). In the foreground, the photographs record the variation in the spatial position of the waterline, controlled by hydrodynamic conditions. This spatial movement causes changes in beach morphology, with moments of coastline retreat (erosive stages) and others of beach sand recovery (progradational stages).

The photographs also capture other important changes in the coastal landscape, highlighting different stages of the beach and levels of exposure to natural and anthropogenic elements. Among the observations, the following stand out: a) the appearance of pebbles along the coastal stretch, which can indicate erosion; b) the appearance of the outcrop of the abrasion platform, indicating a low level of sand volume; c) the complete exposure of the rockfill used as a coastal protection structure, revealing the lowering of the beach profile; d) the emergence of remnants of vegetation suppressed during events of instability on the cliffs. These records demonstrate the ability of citizen science to document rapid and significant changes in coastal morphodynamics with high temporal resolution.

**Figure 6**

*Images capturing some changes in the coastal landscape of the study area.*



Upon analyzing the entire photo collection, beach users were observed in approximately 30% of the images, totaling 147 people throughout the entire time series analyzed (Figure 6). The distribution of these users is directly associated with the time of day and tidal fluctuations throughout the day, coinciding with the peaks previously identified.

The low number of visitors is associated with difficulties in accessing the beach, which is reached via steep trails along the sides of the cliff, with loose soil that is prone to landslides. In addition, during high tide, the beach is short or non-existent, limiting the beach usable time, therefore reducing interest in social and recreational use (sunbathing, walking, beach soccer, beach tennis, and others).

In natural daylight, the images allow us to observe the behavior of beach users, enabling us to identify different activities carried out throughout the day. Among the various observations, we highlight the recurring practice of standing or sitting in the shade of the cliff, especially near recent deposits of mass movements (Figure 6). This behavior poses risk to users' physical integrity, given the risk of cliff collapse events involving falling blocks, debris flow, and the accumulation of construction materials, whether from the cliff or from urban structures built on it, is recurrent. Leisner et al. (2025) mapped the most active areas of this cliff, identifying 106 gravitational movements between 2021 and 2022, indicating the active nature of this relief and the associated natural hazard.

**Figure 7**  
*Some records of user behavior at Pacheco beach*



### 4.3. Mass movements identified in images

The dynamic behavior of the Pacheco beach cliff can be continuously recorded in photographs sent by participants in the CoastSnap project, allowing the morphological evolution of the cliff and its socio-environmental hazards and risks to be documented with high temporal resolution (Figure 8).

Based on systematic visual analysis, photograph by photograph, it was possible to identify episodes of mass movements associated with the cliff and perform a preliminary count of these occurrences. Considering that the materials that make up the cliff have low resistance and that the resulting deposits tend to be quickly removed by the action of the tides, the identification of events was carried out using data obtained in different weeks, reducing the possibility of overlap in the count.

In general, 204 episodes of mass movements were recorded during the analyzed period, corresponding to an average of 5.1 occurrences per month. The relative frequency of these observations indicates that, approximately every two photographs sent by participants, one records some type of instability or detachment of material from the cliff. This pattern shows high morphodynamic activity, with direct implications for the safety of beach users.

**Figure 8**

*Images of the mass movements identified on Pacheco beach, Caucaia, Ceará*



It should be noted that this figure should not be interpreted as an absolute value, since the photo database is not continuous and depends on voluntary user participation. Nevertheless, the set of records is a relevant indicator of the instability dynamics of the local cliff. Far from devaluing the information, this limitation reinforces CoastSnap's potential as an alert and awareness tool, providing input for critical discussion on risk signaling and for the development of educational campaigns focused on visitor safety and the management of coastal environments with unstable cliffs. Figure 8 shows the mass movements in different photographs.

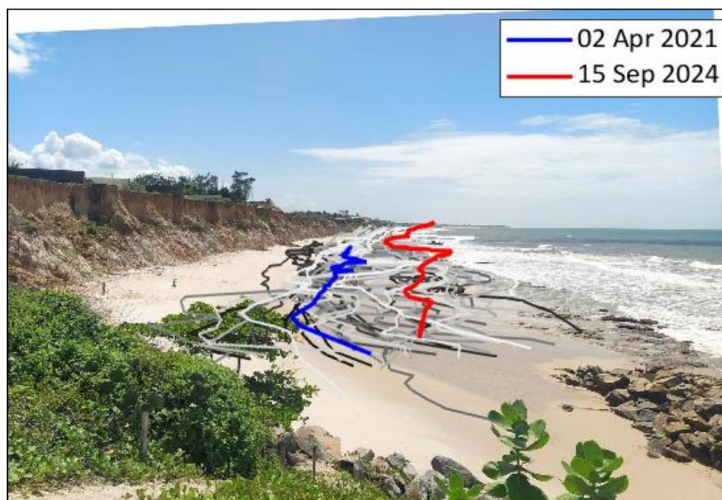
#### 4.4. Use of images to track changes in the spatial position of the shoreline

Figure 9 illustrates the results for beach width based on variations in the position of the shoreline, showing a variation between approximately 95 and 134 meters, with periods of sharp decline in 2021, followed by gradual recovery at the end of the year. These patterns suggest responses to natural processes, such as wave action, seasonal variations, and extreme events, which can cause erosion or accretion of the beach strip. During 2022, recovery continued at a slower pace, with values close to 116-118 m.

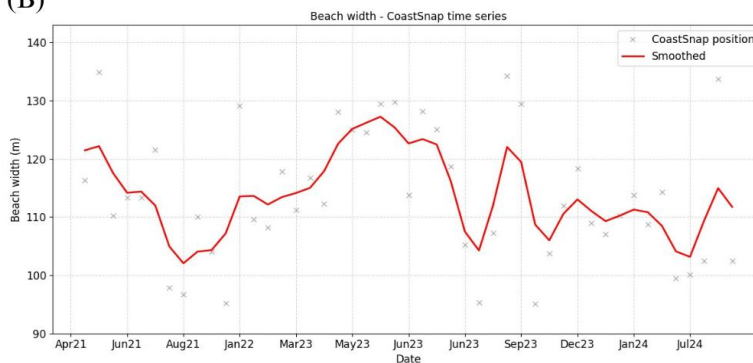
**Figure 9**

*Lines extracted using the CoastSnap ToolBox. a) Variations in the shorelines position extracted from the photographs; b) Variation in beach width based on shoreline positions*

(A)



(B)



At the beginning of 2023, there is an increase in the width of the backshore, with the highest values in the series occurring between April and June, at 125-129 m (Figure 9). After this peak, there is a decrease throughout the second half of the year, returning to values closer to the average obtained. In 2024, the width of the beach shows smaller fluctuations, varying predominantly around 110 m. This shorter variation in time indicates that the system responds quickly to local hydrodynamic and sedimentary conditions, in which the cliffs can influence this dynamic.

#### **4.5. Analysis of CoastSnap as a coastal monitoring tool**

CoastSnap stands out for its advances in participatory coastal monitoring, promoting a transformation in traditional methods of coastline analysis. In Brazil, its growing adoption in coastal states demonstrates the potential of citizen science, making data collection of coastlines more accessible, continuous, and robust. Its adoption allows for the recording and monitoring of multiple processes, such as beach width, mass movements on cliffs, rip current action, occupation dynamics, vegetation presence, bathing suitability, and storm impacts, as demonstrated by recent research on beaches in Ceará, Rio de Janeiro, Pernambuco, Alagoas, and Santa Catarina. The project also represents an advance in integrating geomorphological and social data, supporting coastal management and promoting environmental education through citizen science and educational actions with communities.

The analyses carried out over the period of operation of the CoastSnap NE station at Pacheco beach have identified its potential and limitations. The advantages of the use of this method for coastal monitoring include its simplicity and the low cost of operation and installation and decentralized participation. These factors enable a large volume of records and continuous engagement of the population in scientific activities. However, limitations have been observed on the low engagement during weekdays and a decline in the number of images sent between noon and 3 p.m., a period associated with high insolation and elevated thermal discomfort. In recurring cases, there was inappropriate use of the camera (generating distortions/discarding images) and access difficulties. The irregularity of monitoring is indicative of two things: firstly, problems in understanding the guidelines, and secondly, damage to structures. The necessity for educational actions and frequent maintenance is therefore indicated.

Looking at Figure 5 and adding up the number of photos received, the months with the most photos were July (44) and August (47), which can be related to the holidays in Brazil and Europe, where the municipality of Caucaia is significant for tourism, sports, and recreation (Façanha et al., 2017). In 2022, there was a decline in engagement, with the only months that obtained images being January and February. This reduction in engagement can be explained by the damage that occurred at the station, leaving it inactive for a few months.

Subsequently, in 2023, the monitoring station was reinstalled with some modifications to its structure. Shortly after the reinstallation and dissemination on social media, it was possible to observe an increase in engagement and image submissions, especially in 2024, due to the ease of submission via QR code.

The temporal distribution of the photographs suggests a higher level of citizen participation during the morning hours, which can be associated with recreational activities such as walking, swimming, and sunbathing. As the day progresses, a decrease in the number of submitted images is observed, particularly between 12:00 p.m. and 6:00

p.m. This pattern may be related to the limited availability of beach facilities, such as beach huts and other attractions, which reduces user permanence on the beach during these periods.

Despite this decline, a relatively high number of photographs is recorded between 9:00 a.m. and 5:00 p.m., corresponding to daylight hours, which reinforces the influence of favorable lighting conditions on image acquisition and submission by volunteers. These results indicate that both beach use patterns and environmental conditions, such as sunlight availability, play an important role in shaping citizen participation within the CoastSnap framework.

The tidal fluctuations are apparent in all photographs, where at their peak, tourists are unable to walk along the beach because the tide reaches the base of the cliff, rendering the backshore non-existent. In addition, it is possible to observe the evolution of the landscape from smartphone photographs, such as the growth of vegetation. A different result from other studies that normally verify changes in vegetation through aerial photographs, such as in the work of Neves et al. (2010), who conducts a floristic survey and identifies characteristics of local recovery through remote sensing. According to Elrick-Barr et al. (2023), there are few examples of social and biophysical data in which, with the innovation of data collection in the physical environment and the contribution of citizen scientists, it is possible to acquire a holistic data set without relying solely on researchers.

Due to poor accessibility and limited infrastructure, this beach is less appealing compared to others, which directly contributes to the low demand for leisure activities. These activities are also mentioned in the work of Elrick-Barr et al. (2023), which discusses the social value of beaches, using as an example the Peron Naturaliste region, located in southwestern Western Australia.

The analyzed photographs of the Pacheco beach CoastSnap station exhibit significant technical versatility, making them suitable for various applications. Specifically, in the study of mass movements, these images facilitate the detection of unstable areas, even when the photographs are taken at irregular intervals. This capability is largely attributed to the geomorphological dynamics of the region, where changes occur at a slower pace compared to the rapid transformations that are characteristic of beach environments. By comparing images from different months, it was possible to observe the intensity and types of movements, with falling blocks being the most frequent type of movement over the months observed.

Regional monitoring of beaches with active cliffs is essential for effective coastal risk management. The recurrence of erosion processes in these areas presents significant challenges to both public safety and heritage preservation. This underscores the need for expanding scientific studies focused on predicting and mitigating mass collapses.

Several studies have highlighted these concerns. For example, Oliveira (2022) discusses landslides during the rainy season at Canoa Quebrada beach in Aracati (Brazil). Leisner et al. (2023) examine the risks posed by mass movements to beachgoers at Pacheco beach, mapping affected areas and distinguishing between zones of high and moderate danger. A tragic incident at Pipa Beach, Rio Grande do Norte (Brazil), where mass movements led to the deaths of three members of the same family in 2020 (Maia et al., 2022), further illustrates the severity of the

problem.

Given the highly unstable nature of these environments and their popularity among visitors, ongoing observation and regional monitoring are crucial. This is supported by Câmara (2023), whose study on the cliffs of Tibau do Sul (RN, Brazil) highlights that visitors become particularly vulnerable to the risks of cliff collapse due to their tendency to remain close to the cliff edges.

The result obtained after processing the CoastSnap images indicated values between 94-134 meters, showing that the fluctuation in beach width over the years has been stable, with no signs of significant erosion. However, it is important to note that the value obtained does not accurately reflect the exact width of the beach, necessary to obtain a more comparable result.

The results of the work by Harley e Kinsela (2022) also show changes at the CoastSnap station in North Narrabeen, Australia, where variations in the first half of 2020 are quite discrepant, with peaks of regression and accretion, unlike in the second half of the year, when the variation is around 30-70 m.

The CoastSnap methodology is an innovative and cost-effective approach for monitoring coastlines (Harley & Kinsela, 2022; Solanki, 2023; Lins-de-Barros et al., 2023). It can be utilized independently or integrated with other complementary technologies. Demonstrating its flexibility, Leisner et al. (2023) combined CoastSnap photographic records with aerial photogrammetric surveys using RPAS (drones) to analyze morphological changes in cliffs at multiple scales.

## 5. Conclusions

The CoastSnap project has been used in recent years as a low-cost alternative for monitoring shorelines, and as a result, it is rapidly expanding around the world. In the case of the station installed at Pacheco beach, the investment in materials was approximately 90.00 dollars. The project in the Northeast has proven effective for coastal monitoring, mainly due to the growing participation of citizen scientists in this initiative.

Long-term use of the tool ensures a vast image database for coastal monitoring and a greater understanding of changes in the coastal landscape, which can contribute positively to future decisions on coastal management in risk areas, such as the stretch monitored in this study.

Community involvement in the CoastSnap project is also a major driver for raising awareness about beach preservation. Gradually expanding this initiative can turn scientists into active citizens within environmental initiatives, thereby increasing awareness about the impact of their actions on the coastal and marine environment.

CoastSnap presents itself as an important tool for coastal analysis, and it is extremely necessary that more research be developed with this new methodology. Despite its great potential, the project faces some difficulties in terms of maintaining the population's engagement in sending photographs to the monitoring stations. Because of this, proposals for communication activities in local communities and schools are important to raise awareness and

promote participation among regular visitors.

Finally, the results of this study show that the information collected by the CoastSnap NE project is useful and can assist local authorities in coastal management by identifying the coastline, activities carried out, community engagement in projects, and areas of risk. Furthermore, CoastSnap is an accessible and efficient tool for participatory coastal monitoring, and its continuation and expansion are recommended. Amplifying community involvement through educational and awareness initiatives is essential to increase volunteer participation and improve the quality of the data collected. This data contributes significantly to sustainable and integrated coastal management, enabling future interventions in the coastal environment.

## Supplementary Information

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