CEG Centro de Estudos Geográficos

Finisterra, *LXI*(131), 2026, e42824
ISSN: 0430-5027
doi: 10.18055/Finis42824
Artigo de Investigação

LOW-COST COASTAL MONITORING USING CITIZEN SCIENTIST DATA: AN OVERVIEW OF THE COASTSNAP PROGRAM IN BRAZIL

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ABSTRACT – Understanding the dynamics of coastal environments is challenging, as it requires reliable, high-frequency data that reflect environmental reality. In situ data collection demands high financial resources and specialized teams, while remote sensing may be limited by spatial and temporal resolution. Low-cost monitoring with citizen participation has therefore become essential for qualitative management strategies in coastal municipalities. This study provides an overview of the CoastSnap project worldwide, highlighting its implementation and dissemination in Brazil, and presenting two applications distinct from traditional shoreline analysis. The methodology employed images from the CoastSnap NE and RS networks to monitor cliff mass movements at Pacheco Beach and user density at Cal Beach. Cliff monitoring identified and mapped 91 mass movement events between April 2021 and June 2024, mostly during the rainy season, emphasizing the hazards and geomorphological evolution of cliffs, and reinforcing the importance of continuous monitoring that integrates citizen participation. User density analysis showed an area of approximately 10 hectares, peak occupancy reached 77.9% and 40.9% at 12 AM. and 3 PM., while the lowest occurred at 9 AM. and 6 PM., with 4.3% and 31.7%. These case studies demonstrate CoastSnap's potential to support coastal management at low cost, effectively involving citizens in environmental monitoring.

Keywords: Coastal management; citizen science; mass moviment; beach user density.

RESUMO – MONITORIZAÇÃO DE BAIXO CUSTO COM RECURSO A DADOS DE CIENTISTAS CIDADÃOS: UMA VISÃO DO PROGRAMA *COASTSNAP* NO BRASIL. Compreender a dinâmica dos ambientes costeiros constitui uma tarefa complexa, uma vez que exige dados fiáveis e de elevada frequência que representem, com precisão, a realidade ambiental. A recolha de dados in situ implica elevados custos financeiros e equipas especializadas, enquanto o recurso ao sensoriamento remoto pode apresentar limitações quanto à sua resolução espacial e temporal. Neste contexto, a monitorização de baixo custo, associada à participação cidadã, tem-se tornado essencial para a formulação de estratégias de gestão qualitativa nos municípios costeiros. O presente estudo apresenta uma visão geral do projeto CoastSnap em escala global, destacando a sua implementação e disseminação no Brasil, e descreve duas aplicações distintas relativamente ao uso tradicional de imagens para a análise da linha de costa. A metodologia baseou-se em fotografias das redes CoastSnap NE e RS para monitorizar movimentos de massa em arribas da Praia do Pacheco e a densidade de utilizadores na Praia da Cal. A monitorização das arribas permitiu identificar e cartografar 91 eventos de movimentos de massa entre abril de 2021 e junho de 2024, maioritariamente durante a estação chuvosa, evidenciando os riscos associados e a evolução geomorfológica destas formas. A análise da densidade revelou que, numa área de aproximadamente 10 hectares, a ocupação máxima atingiu 77,9% e 40,9% às 12h e 15h, respetivamente, enquanto os valores mínimos ocorreram às 9h e às 18h, com 4,3% e 31,7%. Os dois estudos de caso demonstram o potencial do CoastSnap para apoiar a gestão costeira a baixo custo, com efetiva participação cidadã.

Palavras-chave: Gestão costeira; ciência cidadã; movimentos de massa; densidade de utilizadores de praias.

HIGHLIGHTS

- Low-cost monitoring integrates citizen science in coastal environments
- CoastSnap applied in Brazil for cliffs and beach user density monitoring
- At Cal Beach, density data supported management of tourist carrying capacity
- At Pacheco Beach, CoastSnap images identified risk areas and natural hazards
- Results highlight CoastSnap's potential for innovative coastal management

Recebido: 22/08/2025. Aceite: 10/01/2026. Publicado: 01/02/2026.

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1. INTRODUCTION

Sandy beaches are dynamic and complex environments continuously modified by both natural and anthropogenic processes. These areas cover over one-third of the world's shoreline, providing various ecosystem services to society (Luijendijk *et al*., 2018; Vousdoukas *et al*., 2020). Over the past few decades, the intensification of urban development, population growth, and climate change scenarios has placed significant environmental pressure on coastal regions (Turner *et al*., 2001; Zacarias, 2013; Lithgow *et al*., 2014; Botero *et al*., 2015; IPCC, 2021).

To understand the complex morphodynamic variations of sandy beaches in response to different climatic conditions, it is necessary to conduct frequent and continuous monitoring of various aspects, including different scales and parameters (e.g., waves, sediments, coastal topography, bathymetry, sand transportation, and forms of use and occupation).

The high cost associated with medium and long-term monitoring is the major limitation to the high-frequency acquisition of spatial data. This, in turn, generates uncertainty in coastal planning and management and may lead to erroneous decision-making by coastal managers due to insufficient or incomplete coastal data.

Numerous measurement and observation methods have been employed to monitor coastal environments. Among the main techniques the following stand out: aerial photogrammetric surveys (Paola *et al*., 2022), remote sensing techniques using images obtained from orbital sensors (Touré *et al*., 2019; McAllister *et al*., 2022), LiDAR surveys (Bossard & Lerma, 2020), in situ surveys with GPS-RTK receivers (Splinter *et al*., 2018) and UAVs (Unmanned Aerial Vehicles), and video monitoring systems (Holman & Stanley, 2007).

Traditional remote sensing methods can be costly when high spatial resolution is required, and they may also exhibit temporal gaps caused by cloud cover or by the revisit time of orbital sensors. Field surveys, in turn, also tend to be expensive, as they require specialized equipment and trained personnel, which ultimately results in limited temporal coverage due to the associated logistical constraints.

Although each method has its advantages and uncertainties, they all share spatial, temporal, logistical, and/or financial limitations. In light of this, recent technological advancements have enabled the collection and storage of large volumes of data through smartphones and easy access to the internet, facilitating the generation and sharing of information between citizens and scientists (Hart & Martinez, 2006; Zerger *et al*., 2010; Poelen *et al*., 2014; González-Villanueva *et al*., 2023).

Faced with the challenges posed by the high costs of acquiring in situ data and the low participation of civil society, alternative data acquisition methodologies based on low-cost technologies and citizen engagement have emerged, enabling continuous data collection across broad spatial scales while fostering community involvement and the reciprocal exchange of knowledge.

To enable greater citizen participation, CoastSnap was created in 2017. Developed by researchers from the Water Research Laboratory at the University of New South Wales, Sydney, Australia, CoastSnap is a global citizen science project based on low-cost participatory monitoring (Harley & Kinsela, 2022). Citizen science involves community contributions to the development of scientific research (Bonney *et al*., 2009).

In CoastSnap, citizens participate by sharing photographs of the landscape taken with their smartphones. The images are stored in a centralized database, enabling different categories of analysis such as coastline movement and user density, among other applications.

One of the major challenges today is encouraging civil society's interest in participating in scientific research to build knowledge in different areas (Martins & Cabral, 2021). In this context, this study aims to provide a global overview of CoastSnap, describe its current status in Brazil, and present two case studies that showcase different applications of citizen-generated imagery.

The first evaluates user-density patterns at Cal Beach (RS) using CoastSnap RS data, while the second demonstrates the potential of CoastSnap NE data from Pacheco Beach (CE) for monitoring cliff mass-movement. These examples highlight the contribution of citizen scientists to coastal monitoring.

2. CoastSnap Project: a brief overview and its implementation along the Brazilian coast

Community monitoring proposals associated with advances in low-cost technologies, remote access to mobile devices, and information and communication technologies aim to enhance citizen science as a tool for including the general public in research development focused on sustainable coastal zone management. CoastSnap is a global citizen science project, regarded by Harley and Kinsela (2022) as the largest land-based coastal monitoring program (i.e., excluding the use of remote sensing data).

Using images captured through the smartphones of coastal community participants, the data generated by CoastSnap allow, for example, coastal processes to be observed at a local scale.

The success of the pilot project by Harley *et al*. (2019) in Australia ensured that the low-cost coastal monitoring methodology was rapidly adopted by various institutions worldwide.

The rapid growth facilitated an expanded range of tool applications, the development of open-source algorithms, and training courses to assist partners in managing their regional CoastSnap networks (Harley & Kinsela, 2022). Currently, CoastSnap initiatives are distributed along the coastlines of several countries, as shown in Table I.

Table I – Worldwide overview of CoastSnap projects (Period: 2018 to June 2025).

Tabela I – Panorama global dos projetos CoastSnap (Período: 2018 a junho de 2025).

Continent	Country	Projects Number
Oceania	Australia	08
	New Zealand	02
Europe	France	04
	Holland	01
	Spain	01
	Portugal	01
	Sweden	01
	Germany	01
	United Kingdom	03
North America	United States	05
	Canada	01
South America	Brazil	11
	Chile	01
	Uruguay	01
Africa	Mozambique	01

Source: https://www.coastsnap.com/

In addition to promoting greater participation from coastal communities, CoastSnap also aligns with Sustainable Development Goals (SDG 13 - Climate Action) by facilitating interaction between the academic community, public managers, and civil society.

This involvement has enabled the construction of participatory knowledge, which aids in understanding the environmental dynamics of monitored coastal segments and implementing appropriate shoreline management strategies.

In Brazil, the first participatory coastal monitoring initiative emerged in 2018 in Santa Catarina (SC) state. Implemented by the Federal University of Santa Catarina (UFSC), CoastSnap SC established its first station at Santinho Beach. Subsequently, in 2020, CoastSnap Ceará was established, due to the Covid-19 pandemic, the project only started operating in 2021 at Pacheco Beach (pilot project), involving researchers from the State University of Ceará (UECE) and the Federal University of Ceará (UFC).

The primary focus was monitoring the shoreline and the mass movements of the cliff adjacent to the beach. In 2022, with funding from the National Council for Scientific and Technological Development (CNPq), CoastSnap Ceará expanded to become CoastSnap NE (or CoastSnap Nordeste), operating in the states of Ceará, Rio Grande do Norte, and Piauí, and involving three additional higher education institutions (UESPI, UFRN, and UERN).

Also in 2020, in southeastern Brazil, the Mar à Vista Project of the Federal University of Rio de Janeiro (UFRJ) installed the first CoastSnap station in Rio de Janeiro (RJ) state. The CoastSnap RJ station is located at Prainha, in the western part of Rio de Janeiro (Lins-de-Barros *et al.*, 2022).

The successful data collection from the stations in Santa Catarina, Ceará, and Rio de Janeiro facilitated the implementation of additional stations in these states and spurred similar initiatives in other coastal states of Brazil. Table II presents the distribution and number of CoastSnap stations active in Brazil.

Table II – Overview of CoastSnap stations in Brazil (Period: 2018 to June 2025).
Tabela II – Panorama das estações do CoastSanp no Brasil (Período: 2018 a junho de 2025).

Brazilian Region	State	Responsible Institutions	Stations per Region
North	Amapá	UFAP	01
Northeast	Alagoas	UFAL	01
	Bahia	UFBA	01
	Ceará	UECE and UFC	05
	Maranhão	UFMA	02
	Pernambuco	UFPE	02
	Piauí	UESPI	02
	Rio Grande do Norte	UERN and UFRN	01
	Sergipe	UFSE	03
Southeast	Rio de Janeiro	UERJ, UFF and UFRJ	08
South	Santa Catarina	UFSC	12
	Rio Grande do Sul	IFRS	03
		UFRGS	03

Source: Authors

In Brazil, the processes of station implementation, image database creation, data processing, information dissemination on networks, and station maintenance have been the responsibility of federal and state universities.

In most cases, the management of the stations has been carried out independently, being the responsibility of the institutions that enabled the implementation of the CoastSnap stations. To a lesser extent, some institutions work together, generally as part of universal projects and with financial support from federal and/ or state research funding agencies.

To demonstrate the potential of the CoastSnap methodology for generating valuable products for coastal management, this study presents two regional case studies. In this context, the terms CoastSnap NE and CoastSnap RS refer to the regional branches of the CoastSnap initiative operating in the Northeast (‘NE’) and Southern (‘RS’) regions of Brazil, respectively.

The first focuses on the analysis of mass movements in cliffs, utilizing data from the CoastSnap NE image bank at the Pacheco beach station. The second addresses the monitoring of beach user density, based on images from the CoastSnap RS station at Cal Beach.

3. STUDY AREAS

3.1. Pacheco Beach

In the first case study, CoastSnap data were used to characterize mass-movement processes at Pacheco Beach, in the municipality of Caucaia, within the Metropolitan Region of Fortaleza, northeastern, Brazil (fig. 1). The study area corresponds to a cliffed coastal sector that hosts the first CoastSnap station installed in the region.

The municipality of Caucaia has a coastal extension of approximately 28km, distributed among six beaches, of which roughly 3km correspond to Pacheco Beach.

This shoreline is characterized by an alternation of active sea cliffs and short sandy beach segments, and in some areas coastal protection structures, primarily groins and rock revetments, have been installed to mitigate erosion (Leisner *et al*., 2023).

Pacheco Beach is situated within the Baturité–Jaibaras structural domain, and its cliffs consist of sediments from the Barreiras Formation, composed of Neogene siliciclastic deposits of a pre-littoral environment that are widely distributed along the northeastern Brazilian coast (Bezerra *et al.,* 2006). The origin of these deposits is generally linked to episodes of epigenetic uplift (Bezerra *et al*., 2001; Saadi *et al*., 2005) and marine transgressive phases (Rossetti *et al.*, 2013).

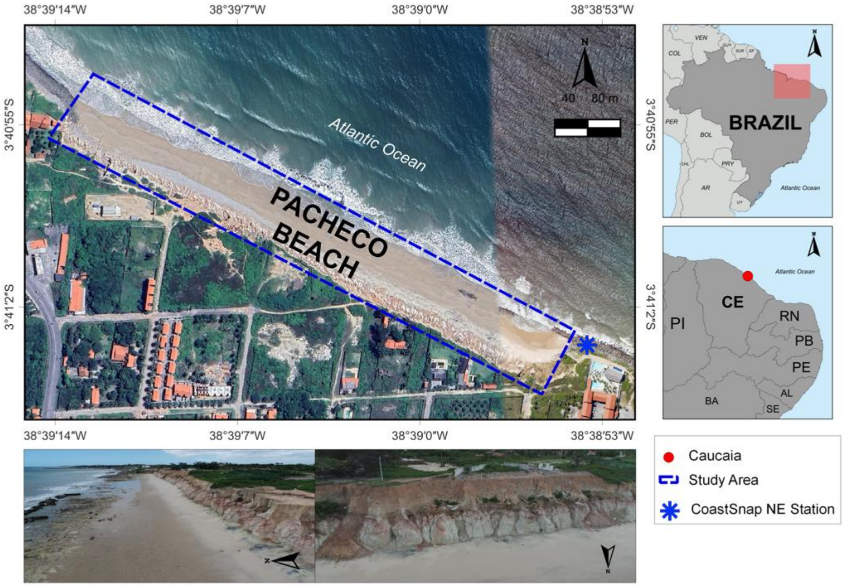

Fig. 1 – Pacheco Beach and the CoastSnap NE monitoring station, municipality of Caucaia, Ceará.

Fig. 1– Praia do Pacheco e da estação de monitoramento CoastSnap NE, município de Caucaia, Ceará.

Source: SIRGAS 2000, Zone 24S, IBGE (2022)

From a sedimentological perspective, Pacheco Beach is predominantly composed of medium sand; however, during episodes of intense erosion driven by storm waves, gravel may temporarily dominate the beach surface (Leisner *et al*., 2024). According to the study conducted by the authors, short-term analyses further show that cliff retreat and beach morphology vary on seasonal timescales, alternating between phases of erosion and deposition.

For the initial development of the CoastSnap NE pilot project, a 700m-long segment of this beach–cliff system, recognized as being under continuous erosion, was selected. This stretch was chosen due to its suitability for smartphone-based image acquisition, offering both adequate elevation and a lateral viewpoint, as well as the presence of beach users who could contribute photographs.

3.2. Cal Beach

CoastSnap data was used to characterize user density on Cal Beach in Torres, southern Brazil (Fig. 2), during the 2024 summer season. These analyses relied on images contributed by citizen scientists, that is, photos captured and submitted by tourists and visitors who used the CoastSnap RS station installed at Cal Beach. The choice of this location for implementing a CoastSnap station was due to the region having the highest degree of urbanization of the RS coast, with Torres being one of the largest coastal cities in the state with a permanent population, and 50% of the coastline urbanized (Esteves *et al*., 2003; IBGE, 2023), the exceptions are in the Conservation Unit areas (Itapeva State Park and Guarita Park) and a small part of the southern municipality (Rockett *et al*., 2018). The fact that the local economy is primarily based on tourism and leisure activities (Lopes *et al*., 2018) also contributed to the choice of the location.

Geologically, the study area is characterized by a narrower coastal plain with an internal boundary marked by the escarpments of the Serra Geral and the eastern edge of the Paraná Basin, which reach the current shoreline, forming the only rocky promontory with rock formations composed of sandstones, basalts, and volcano-clastic sequences (Pereira *et al*., 2010). In this setting, Cal Beach corresponds to an asymmetrical embayed (pocket) beach bounded by two rocky headlands – Morro do Farol to the north and Morro da Guarita to the south and exhibits typical intermediate behavior with high mobility due to significant vertical variations (Calliari & Toldo Jr., 2016). The backshore is characterized by embryonic dunes and restinga vegetation, indicative of early-stage foredune development; however, parts of these features have been altered or constrained due to the proximity of urbanized areas and coastal infrastructure (Cristiano *et al*., 2016).

The tidal regime is semidiurnal with an average height of 0.30m; however, meteorological tides can reach up to 1.20 m (Calliari *et al*., 1996; Gonzaga *et al.,* 2020), intensifying the erosive capacity of the waves and potentially causing severe damage to the coast (Calliari & Silva, 1998). These phenomena are associated with the passage of cold fronts that occur more frequently in April and May (Albuquerque *et al*., 2018).

Additionally, the most frequent winds are from the northeast (NE) followed by the south (S) (Leal-Alves *et al.*, 2020).

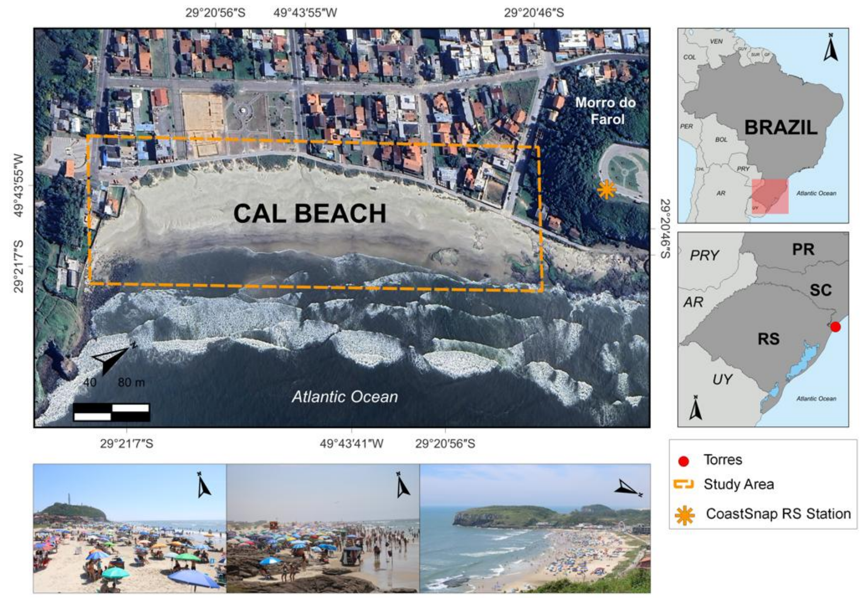

Fig. 2 – Cal Beach and the CoastSnap RS monitoring station, situated in the municipality of Torres, Rio Grande do Sul.

Fig. 2 – Praia da Cal e da estação de monitoramento CoastSnap RS, situada no município de Torres, Rio Grande do Sul.

Source: SIRGAS 2000, Zone 22S, IBGE (2022)

The geomorphological characteristics, with rocky outcrops forming cliffs and coves, constitute a unique landscape diversity present on the coast of the state of Rio Grande do Sul, offering high tourism potential (Cristiano *et al.*, 2016). During the summer season, Cal Beach, whose width ranges from approximately 100m to about 40m, depending on prevailing meteorological and oceanographic conditions, receives a high concentration of bathers. This intense use generates environmental impacts, including the accumulation of solid waste and the discharge of effluents, which can contaminate beach sediments and coastal waters.

4. MATERIALS AND METHODS

The CoastSnap methodology proposed by Harley *et al.* (2019) relies on community participation in coastal monitoring through smartphone-captured photos shared on social networks (Facebook, Instagram, WhatsApp, and X) by residents and tourists. For this purpose, simple and low-cost structures, known as stations or supports for smartphones, made of stainless steel, are installed on monitored beaches to control the position and angle of the photograph to be sent. The stations also feature plaques with instructions on properly positioning the smartphone for image capture (figs. 3a and 3b) and on what data should be provided when submitting the photo to the CoastSnap database.

Figure 4 presents the methodological flowchart with the main steps applied for the two case studies presented. The photographs sent by citizen scientists are stored in a database with information on the date and time of capture to enable corrections for the influence of astronomical tides on the water level, given that the images are collected at random stages of the tidal cycle. These images are processed using the Bird Eye View method, with routines applied in MATLAB software. This method involves digital image processing that results in the geometric modification of the image, transforming the view from a real perspective to an overhead/plan view (Venkatesh & Vijayakumar, 2012). This transformation is divided into three main steps: i) shifting the image into a new coordinate system; ii) rotating the image; and iii) projecting the image onto a two-dimensional plane. It is important to note that the first step is carried out using fixed ground control points (GCPs) in the study area (e.g., buildings, containment structures) previously defined by the researchers.

After the station's establishment, fixed and easily identifiable GCPs in the photos are collected using a GPS-RTK for georeferencing and image correction. The GCPs are manually identified in a single control image to aid in orthorectification, associating pairs of coordinates to each pixel, and each subsequent image is then registered to the control image using the automatic alignment function in Adobe Photoshop software.

Fig. 3 – CoastSnap RS stations located in: a) Morro do Farol with a view of Cal Beach, Torres, Rio Grande do Sul state; b) Pacheco beach, Caucaia, Ceará state.

Fig. 3 – Estações CoastSnap RS localizadas em: a) Morro do Farol com vista para a Praia da Cal, Torres, Rio Grande do Sul; b) Praia do Pacheco, Caucaia, Ceará.

Source: Authors

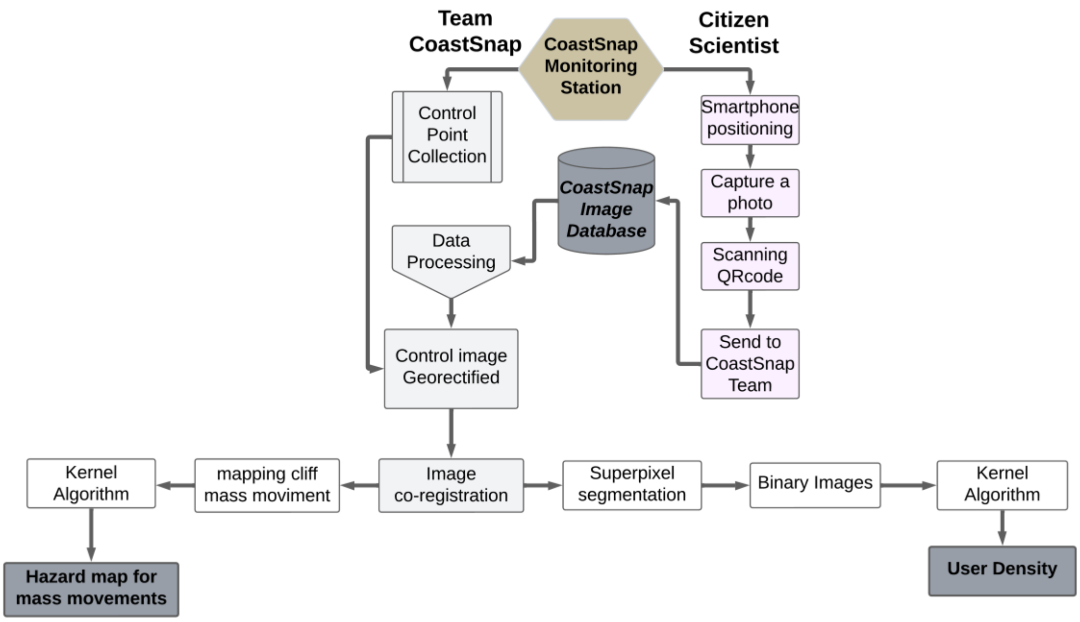

Fig. 4 – Methodological flowchart for cliff mass-movement detection and user-density analysis.

Fig. 4 – Fluxograma metodológico para detecção de movimentos de massa em falésias e análise de densidade de usuários.

Source: Authors

The images are processed using algorithms developed by Harley *et al*. (2019) in the Matlab programming language, which extract information on shoreline position as well as several other parameters relevant to coastal management. These include the characterization of beach activities and uses, the estimation of user density and distribution, the assessment of risks such as cliff mass movements, and the identification of potential pollution sources, including wastewater discharge, solid waste, and oil spills. Together, these products provide essential support for coastal monitoring, planning, and environmental quality conservation.

Through a locally adaptive thresholding algorithm, it is possible to determine the difference between the waterline and the sand, which serves as an indicator of the shoreline (Boak & Turner, 2005), allowing for automatic vectorization of this feature. The date and time information of the captured images is used to correct the shoreline position due to the influence of meteorological tides, thereby enabling the identification of beach changes and the analysis of shoreline behavior.

This standard procedure applied at any CoastSnap stations allows for the monitoring, and measurement of the constant changes occurring along the shoreline over time, with precision similar to other techniques used for beach monitoring (Harley *et al*., 2019; Harley & Kinsela, 2022).

To demonstrate the potential of CoastSnap-generated products, this study presents two new applications focusing on the analysis of cliff mass movements and the monitoring of beach user density. In the first case study, mass movements were identified in the CoastSnap Pacheco photographs and recorded in a database with information about their positioning. Two monthly images were selected, covering the period between April 2021 and July 2024, totaling 78 images analyzed.

The mapping of mass movements was conducted by integrating two methods: the orthorectified CoastSnap image was processed using Matlab 2018A, and the location of the occurrences was recorded using the GIS software *QGIS 3.28*. In this way, it was possible to identify the most active sections of the cliff over time, allowing the creation of a hazard map for mass movements.

This is only possible due to the georeferencing of the photographs during image processing, which simplifies the identification of mass movements through geoprocessing. From the interpolation of the points where mass movement occurred, heat maps (Kernel algorithm) were generated to determine the areas with the highest concentration of cliff collapse occurrences.

Mass-movement events were identified through systematic visual analysis of the multitemporal images, based on diagnostic indicators of cliff instability such as newly formed scarps, freshly exposed surfaces, detachment zones, fallen or accumulated blocks at the cliff base, and abrupt changes in the geometry of the cliff top or face. Only features that appeared or expanded between consecutive survey intervals were classified as distinct events.

To determine user density in the second case study, we applied superpixel segmentation to the CoastSnap images. Superpixels are clusters of neighboring pixels with similar spectral or textural properties, allowing the image to be partitioned into meaningful homogeneous regions. This procedure enabled the generation of binary masks that separated free and occupied beach areas. The centroids of the pixels classified as “occupied beach” were subsequently extracted and converted into georeferenced point vector files for further spatial analysis.

For user counting, this technique involves partitioning the image into several clusters of pixels. The images were segmented into two classes: free and occupied beach areas. For the second case study, images from January 15, 2024, captured at 9:00 AM, 12:00 PM, 3:00 PM, and 6:00 PM were used. Superpixel segmentation generated binary images (masks) for both classes. Next, user density was calculated using *QGIS 3.28*, employing a spatial density (kernel) algorithm, which assigned an occupancy distribution to the sand strip at each time.

5. RESULTS

5.1. Pacheco Beach

Quantitative analysis indicated a high incidence of mass movements along the cliff section of Pacheco, totaling 91 events over a stretch of 700 meters between April 2021 and June 2024.

The distribution of these mass movements was predominantly concentrated in the central-eastern portion of the study area, with higher occurrence during the first semester of each monitored year (fig. 5). These periods are associated with episodes of increased precipitation in the state of Ceará.

The months of January 2022, with 16 events, April 2024, with 10 events, and March 2024, with 8 events, recorded the highest frequencies of slope movements. In contrast, the months corresponding to the dry season showed a significant reduction in activity, with a maximum of one event, as observed in July, August, and November 2023.

These data indicate the seasonal influence of climatic processes, demonstrating that the rainy season, which occurs predominantly between January and June in the region, exerts a significant control over slope instability processes affecting the cliffs.

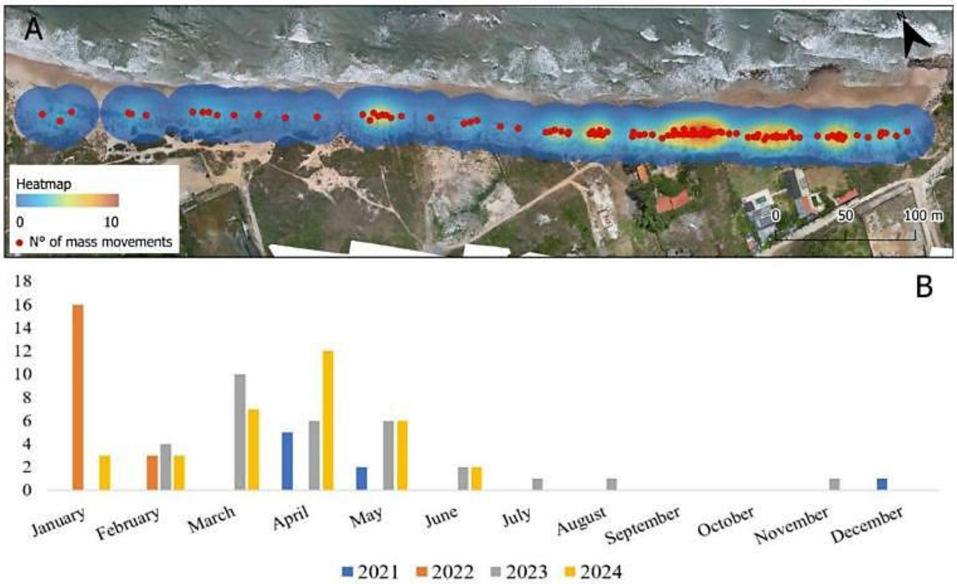

Fig. 5 – Spatial distribution of mass movements in Pacheco beach. a) Mass movement concentrations map, using kernel interpolation; b) Monthly distribution of mass movements between January April 2021 and June 2024.

Fig. 5 – Distribuição espacial dos movimentos de massa ocorridos na praia de Pacheco. a) Mapa de concentrações de movimentos de massa, utilizando interpolação kernel; b) Distribuição mensal dos movimentos de massa entre janeiro a abril de 2021 e junho de 2024.

Source: Authors

With respect to community participation, the Pacheco Beach station received a total of 401 photographs between April 2021 and June 2025 (fig. 6). Figure 6 shows the dynamics of monthly submissions since the station's implementation, highlighting peaks of participation in July 2021 (25 photos), January 2024 (21 photos), March 2023 (19 photos), January 2025 (17 photos), and February 2025 (15 photos).

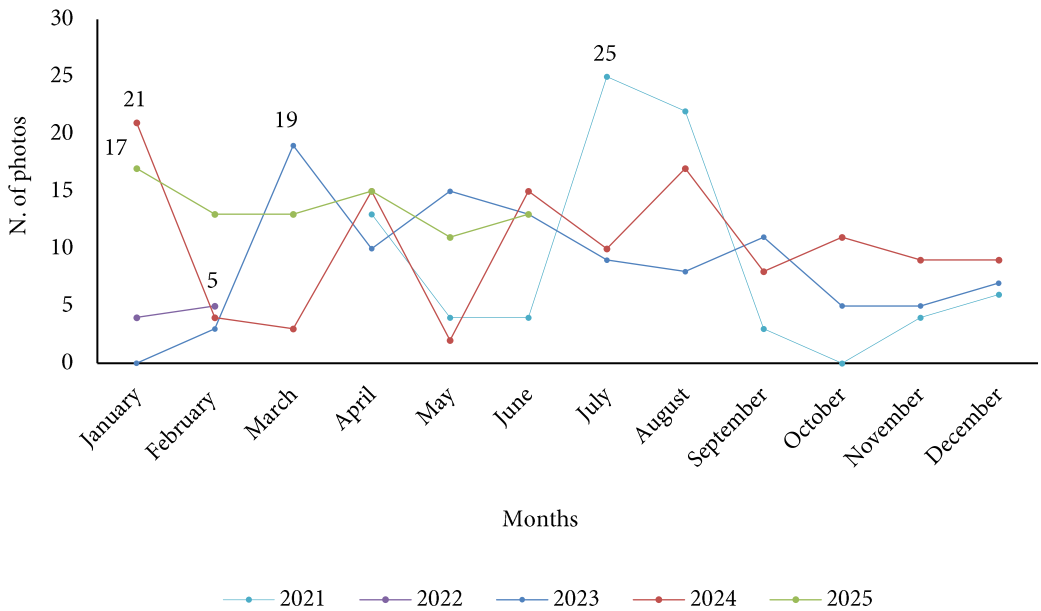

Fig. 6 – Number of photos received from April 2021 to June 2025 for Pacheco Beach.

Fig. 6 – Número de fotos recebidas de abril de 2021 a junho de 2025 para a Praia do Pacheco.

Source: Authors

It is observed that in almost all years, the highest number of contributions coincide with the summer period (January, February, and March), which may be associated with the tourist high season and school holidays, underscoring the influence of seasonality on user engagement.

However, when comparing across different years, distinct patterns emerge: in 2022, participation was concentrated exclusively in January (4 photos) and February (5 photos), reflecting a punctual and low contribution; in 2023, there was a marked regularity in submissions throughout nearly all months, except for January, suggesting greater continuous community engagement; whereas in 2025, from January to June, a stable pattern with low variability was recorded, with monthly submissions ranging between 11 and 17 photos, indicating a more consistent, albeit still moderate, level of contribution.

Instagram is the project's main vehicle for communication with the community, being used to publicize activities, results, educational materials, ongoing studies, and participation in events, connecting both the academic community and the general public.

In terms of performance and engagement on social media, the CoastSnap NE Instagram profile, which currently has 703 followers, reached 3860 accounts, of which 90.7% do not follow the profile and 9.3% are followers, totaling 13573 impressions. As for the audience profile, 51% of followers are women and 48.9% are men. The predominant age group is between 25 and 44 years old, representing 67.1% of total followers.

5.2. Cal Beach

Originally, CoastSnap was developed to monitor shoreline variations, identifying erosion or progradation processes along coastal segments. However, for the second case study, high-frequency database images of CoastSnap RS provided by citizen scientists were utilized for the user density analysis during a summer day (January 15, 2024) at Cal beach.

This analysis revealed that the total area of the sand beach available to bathers at Cal Beach was approximately 10.0 hectares, with an average distance of 43 meters between the base of dunes and the shoreline. At 9:00 AM and 6:00 PM, the lowest percentage of occupied area was recorded, with 4.3% and 31.7%, respectively (table III). The highest concentration of users was observed at 12:00 PM, when solar incidence is most intense, with 77.97% of the area occupied. By 3:00 PM, the percentage of beach users decreased to 40.9%.

Table III - Characterization of the free and occupied total areas, and occupation percentages of Cal beach during the survey.

Tabela III - Caracterização das áreas totais livres e ocupadas e percentuais de ocupação da praia da Cal durante o levantamento.

Hour	Free Area (m²)	Occupied Area (m²)	% Occupied	Total Area (m²)	Distance between shoreline and dune (m)
9h	94969	4281	4.3	99250	43
12h	21863	77387	77.97		
15h	58620	40630	40.9		
18h	67786	31464	31.7		

Source: Authors

Spatially, users, regardless of the monitored time of day, were predominantly concentrated in a specific area located in the southwestern sector of the beach (figure 7). The highest occupation densities are represented by warm colors, while the lowest appear in cooler tones.

This distribution pattern can be attributed to the presence of infrastructures and supporting services, such as parking, a lifeguard station, kiosks/bars, toilet, and spaces dedicated to sports activities, including volleyball and beach tennis courts. This set of attributes, typically valued by tourists seeking comfort and convenience, contributes to the greater attractiveness of this region of the beach and, consequently, leads to higher levels of occupation.

Regarding community contributions through photo submissions to the CoastSnap RS initiative, over one year and eight months of monitoring (September 2023 to June 2025), the Cal Beach station received a total of 1986 images.

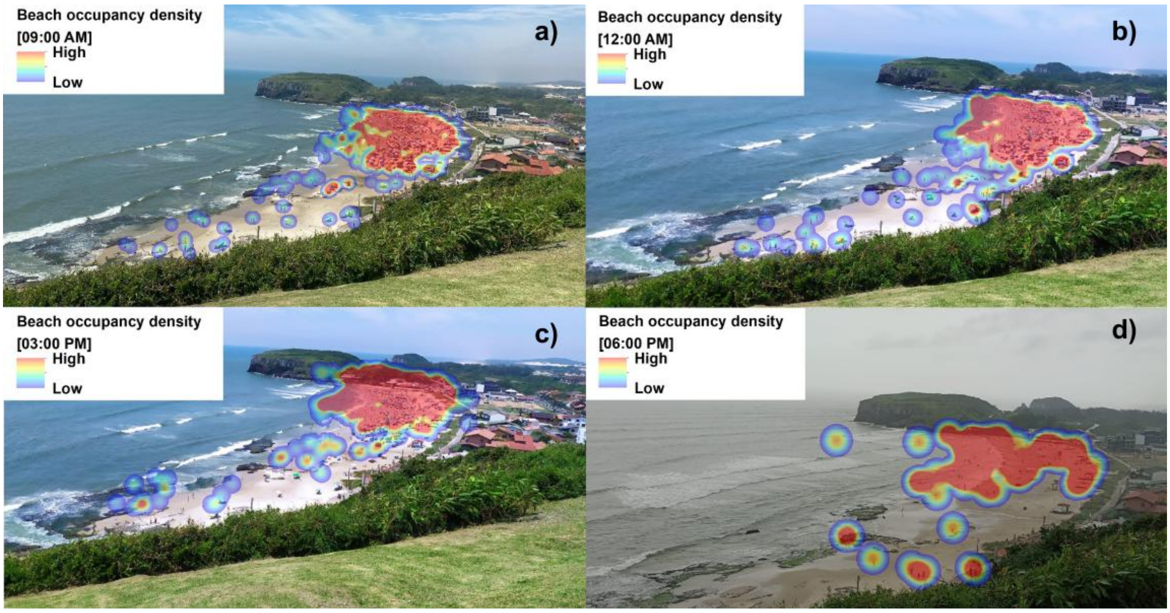

Fig. 7 – Spatial distribution of users at Cal Beach on January 15, 2024, at 9:00 AM (a), 12:00 PM (b), 3:00 PM (c), and 6:00 PM (d).

Fig. 7 – Distribuição espacial dos usuários na Praia da Cal em 15 de janeiro de 2024, às 9h (a), 12h (b), 15h (c) e 18h (d).

Source: Authors

Figure 8 illustrates the monthly frequency of photos submitted during the analyzed period. In 2023, 500 images were recorded in only four months of operation, with December standing out by concentrating 220 submissions. During the first full year of monitoring in 2024, a total of 1161 photos were received, with a notable peak in January (314 submissions).

In 2025, during the first six months, the total contributions amounted to 325 images, with January once again representing the month of highest participation (79 photos). This outcome highlights a significant reduction in engagement compared to the same period of the previous year, when 805 images had been submitted.

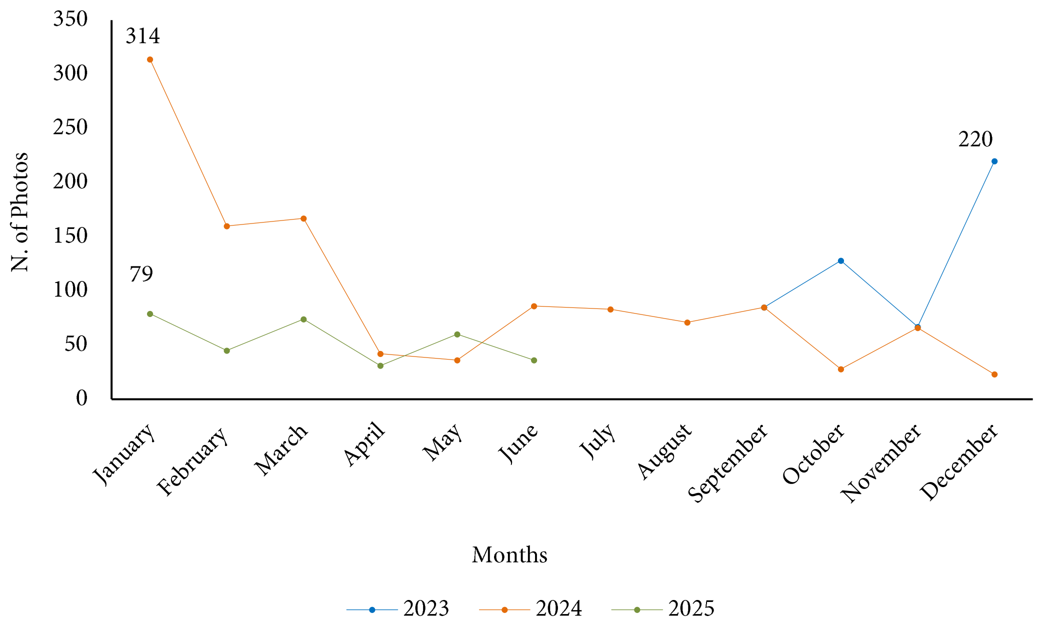

Fig. 8 – Number of photos received from September 2023 to June 2025 for Cal Beach.

Fig. 8 – Número de fotos recebidas de setembro de 2023 a junho de 2025 para praia da Cal.

Source: Authors

Figure 8a also shows that most contributions occur during the summer months (December to March), a period characterized by the high tourist season and increased beach attendance. Although the peak of submissions in both 2024 and 2025 occurred in January, the number of photos in 2025 was substantially lower compared to 2024. In April and May, participation levels were similar across both years. Additionally, a marked difference is observed between December 2023 and December 2024, with submissions being significantly higher in the first year, highlighting a notable contrast for the same period.

In terms of performance and audience engagement, the CoastSnap RS Instagram account currently has 450 followers, having reached 2971 accounts and generated a total of 6168 impressions. Among its followers, the gender distribution is nearly balanced (50.3% male and 49.6% female), and the most representative age group ranges from 25 to 44 years. Although the follower base is relatively modest, these metrics demonstrate that the project's digital presence effectively enhances public visibility and promotes meaningful community engagement, reinforcing the role of social media as an important tool for awareness-raising and participatory coastal monitoring.

6. DISCUSSION

The natural evolution of cliffs poses significant risks to residents and bathers in areas where such formations occur, although the intensity and nature of these risks depend on the lithology of the cliffs, which influences their stability and erosion processes (Rio & Gracia, 2009; Teixeira *et al.*, 2014). Understanding the dynamics of these landforms requires continuous monitoring, often involving high costs due to the use of advanced technologies (e.g., UAVs and laser scanners) and the need for specialized personnel to operate this equipment.

Leisner *et al*. (2023) identified that the sea cliffs at Pacheco Beach exhibit markedly high average retreat rates, exceeding 2 m/year. The authors note that this erosional behavior is highly variable and difficult to predict, as it is modulated by the seasonal climatic forcing of waves, tides, and precipitation, as well as by the friable sandy–clayey lithology of the Quaternary deposits of the Barreiras Formation, which enhances susceptibility to mass-movement processes. Furthermore, the authors emphasize the importance of long-term monitoring of this coastal segment in northeastern Brazil to improve the understanding of the mechanisms driving its local morphodynamic evolution.

Contrary to the traditional use of the CoastSnap project for coastal data extraction, the case study developed at Pacheco Beach demonstrated additional applications beyond those previously recognized. Over two years (2021–2024), photographs submitted by beachgoers played a key role in understanding cliff evolution, analyzing the significant influence of rainfall on slope mass movement, and identifying areas of higher instability that may present potential risks.

Furthermore, the study conducted by Freitas *et al*. (2024), which analyzed images from the CoastSnap NE station at Pacheco Beach, identified that the walls of the houses located on top of the Pacheco Beach cliffs are progressively approaching the cliff edge. This evidence, in the medium term, confirms the erosive processes previously described by Leisner *et al*. (2023) and reinforces the potential of CoastSnap as a low-cost, effective tool for the identification and continuous monitoring of risk areas.

These findings open new discussions on the applications of citizen science through image collection within the CoastSnap Project. Previous studies, such as those by Lusty (2019), Zabota and Kobal (2020), Tavani *et al*. (2020), and Burningham *et al*. (2024), explored the feasibility of low-cost methodologies and community engagement for monitoring cliff dynamics using smartphone cameras, representing a strategy similar to that employed by CoastSnap NE at Pacheco Beach.

Regarding the understanding of daily beach user dynamics, although this parameter is not yet a standard environmental indicator widely adopted by coastal managers in Brazil, it represents a valuable tool for promoting sustainable tourism development by generating relevant information for the proper planning and management of coastal areas, particularly those with high recreational and tourist potential. Medeiros *et al*. (2016) highlight that the uneven distribution of beach users reveals the need for spatial management to reduce congestion levels and enhance the quality of recreational experience.

According to Silva *et al*. (2020), the high concentration of beach users has become a significant issue. In the absence of effective coastal management strategies, combined with the intensification of mass tourism, the ecological integrity and natural resources that attract visitors can be substantially impacted, creating a "tourism paradox" (Defeo & Elliott, 2020; Fanini *et al*., 2020).

In this context, data extracted from photographs submitted to the CoastSnap RS network are promising for supporting strategies to mitigate pressures on coastal environments and optimize the provision of services during periods of peak tourist activity. The ability to identify the daily number of beach users, as well as their spatial distribution along the shoreline, provides valuable insights for coastal management.

This information can guide the appropriate sizing of support infrastructure and services, such as public toilets, waste collection containers, parking areas, and other elements essential to ensuring a positive user experience. Additionally, such planning contributes to ecological preservation, as the lack of adequate infrastructure can generate negative impacts; for example, the absence of public toilets has been identified as a factor compromising bathing water quality (Araújo & Costa, 2016).

Traditionally, studies on beach user numbers require field monitoring teams, specialized equipment, and laboratory data processing. However, the high costs involved in conventional image collection and analysis techniques often make them economically unfeasible for many coastal municipalities (Proença, 2024).

Given this limitation, the past decade has seen a significant expansion of low-cost coastal monitoring alternatives. In the context of monitoring beach user dynamics, Albuquerque *et al*. (2024) demonstrated the potential of CoastSnap RS images to identify beachgoers at Guarita Beach, Torres (RS), comparing the accuracy of visitor-submitted photographs with high-resolution images simultaneously captured by a UAV. Complementarily, Leal-Alves *et al*. (2022) showed the feasibility of monitoring high-frequency variations throughout the day in beach environments using electronic measurements and computational algorithms applied to accessible devices.

Regarding coastal management, high-frequency information is essential for understanding relationships between socioeconomic and environmental parameters, identifying areas affected by erosive processes, delineating risk zones, and assessing the resilience of beaches to the effects of climate change, such as sea-level rise and increased storm activity. These data make it possible to determine whether a beach is recovering after extreme events, which is particularly relevant in urbanized coastal settings where infrastructure limits the natural adjustment of the shoreline, thereby supporting the implementation of appropriate coastal protection measures when necessary. In this sense, the results obtained with CoastSnap highlight the relevance of local community involvement in scientific knowledge production, directly contributing to expanding available datasets and providing valuable information to support management strategies and decision-making for the conservation of coastal environments.

Differences in engagement observed between the Pacheco Beach station (CoastSnap NE) and the Cal Beach station (CoastSnap RS) underscore the influence of station location on data collection frequency. The Cal Beach station received a considerably higher number of photo submissions, largely due to its strategic position at Morro do Farol, a viewpoint with constant visitation regardless of direct beach use. In contrast, the Pacheco Beach station, situated in an area with lower spontaneous visitor flow, recorded more limited participation.

Social media metrics from CoastSnap RS and CoastSnap NE further reveal differences and similarities in community engagement, indicating that even with relatively small follower bases, both initiatives are able to reach wider audiences, enhancing project visibility and stimulating social participation. Moreover, as highlighted by Lins-de-Barros *et al.* (2022), CoastSnap methodology strengthens Ocean Literacy by connecting the public to critical ocean-related issues and promoting greater awareness of ocean preservation and sustainable use. However, the authors also note that irregular public participation in data generation can hinder the consistency of contributions, creating challenges for subsequent data analysis.

Given these dynamics, it becomes essential that the locations selected for CoastSnap station implementation present substantial visitor flow. This condition is crucial to ensure the creation of robust, high-frequency image databases, one of the core strengths of the CoastSnap approach. Regardless of the specific application, CoastSnap stands out as a low-cost tool for beach monitoring and public engagement. In a context where coastal managers require agile and accessible solutions to address daily challenges across multiple dimensions of the coastal zone (Silva *et al*., 2020), the initiative demonstrates considerable potential to deliver high-frequency information on diverse coastal processes.

The primary limitation identified in this study relates to the low and irregular participation of the community in image submissions, which directly affects the temporal resolution and consistency of the datasets generated. This challenge reinforces the need for strategic station placement, continuous outreach, and improved mechanisms to motivate public engagement. As future perspectives, we intend to validate the data collected from the CoastSnap stations, both for user detection and for identifying mass-movement events on cliffs, using traditional methods with UAVs. This comparison will allow us to assess the accuracy, reliability, and operational potential of citizen-generated imagery as a complementary tool for coastal monitoring and risk analysis.

7. CONCLUSIONS

Coastal monitoring, in its conventional form, employs methodologies that require extensive logistics and continuous financial investment. However, this type of initiative often fails to engage with society and has largely disregarded civic knowledge. In recent years, citizen science has been on the rise in Brazil, enabling greater citizen participation in coastal data collection, which has led to a better understanding of the dynamics and complexity of these environments.

On the northeastern coast, the submission of photographs and the mapping of mass movement occurrences at Pacheco beach underscore the importance of studies that involve community participation in data collection while simultaneously raising awareness of the risks associated with cliffed beaches. The data generated from CoastSnap NE images have allowed for an accurate overview of areas at risk of mass movements, in addition to complementing more complex studies on the morphodynamic evolution of the cliffs.

In the southern littoral, CoastSnap photographs acquired and shared by citizen scientists proved effective in monitoring the user density at Cal beach. In the short term, the data obtained has shown great potential to provide almost real-time information on beach occupancy. In the long term, this information can help coastal managers plan tourism strategies, especially during summer seasons, and help to manage carrying capacity on the beaches.

CoastSnap, in its initial conception, was structured to characterize shoreline movement over time. The two case studies presented open a discussion on the potential for various applications of photographs submitted by beachgoers and coastal communities, contributing to the implementation of new applications and sustainable coastal management strategies. Given Brazil's extensive coastal zone, establishing regional projects focused on citizen science contributes to the development of new shoreline monitoring tools and supports conservation and protection efforts along the coast. Finally, the involvement of citizen scientists has improved continuous data collection, fostering social engagement in beach monitoring initiatives and contributing to the preservation of these environments, while raising awareness within the participating communities.

In national and Latin American contexts, regions often characterized by limited investment in science and environmental management, coastal monitoring based on citizen science becomes even more relevant. In Brazil, where more than half of the population lives in coastal zones and coastal tourism represents an important economic pillar, the availability of reliable, frequent, and low-cost data is essential not only to support decision-making in the face of natural hazards and disasters but also to strengthen the sustainability of tourism, ensuring the protection of the natural resources that underpin local economies. Similarly, in several Latin American countries that face comparable socioeconomic constraints, the adoption of accessible and replicable methodologies such as CoastSnap can empower coastal communities, enhance environmental governance, and expand the capacity of local managers to address the challenges associated with effective and resilient coastal management.

ACKNOWLEDGEMENTS

The authors thank the Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFRS) - Campus Rio Grande, State University of Ceará (UECE), and Federal University of Rio Grande (FURG) for their support. This study was supported by the National Council for Scientific and Technological Development – CNPq (Project N°. 406334/2023-4, 420516/2022-0, and Productivity PQ 309102/2022-7).

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