International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4s, 2025
https://www.theaspd.com/ijes.php

Erosion And Beach Loss As A Consequence Of The Construction Of The Sand Retention Breakwater In Salaverry - Peru

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Abstract: *The construction of the sand-retaining mole in the port of Salaverry, Peru, has altered sediment transport patterns, triggering erosion and the loss of emblematic beaches such as Las Delicias, Buenos Aires, and Huanchaco on the northern coast of Peru. The objective is to understand the environmental impact of coastal erosion and its effects on local communities. The methodology adopted is qualitative and descriptive, including direct observations, documentary analysis, and interviews with fishermen and local authorities. The data were collected in a non-experimental manner at a specific moment, focusing on gathering contextual information about erosion. The results indicate that human intervention has intensified erosion, seriously affecting the stability of the beaches and, consequently, the quality of life of coastal communities. The need to implement sustainable coastal management and continuous monitoring to address these issues is highlighted. In conclusion, the study reinforces the importance of integrating sustainable coastal management, promoting community participation in the conservation of ecosystems affected by erosion. It is suggested that strategies should be established that consider both natural and human factors to mitigate the negative effects of erosion and ensure the sustainability of the beaches in Trujillo.).*

Keywords: *coastal erosion; socio-environmental conflicts; loss of spas; modification of ecosystems; sand retention zone.*

INTRODUCTION

In recent decades, coastal erosion has become one of the most serious environmental problems, rooted in poor human decisions and actions that have disrupted the balance of coastal systems, generating severe ecological, economic, and social consequences. Numerous studies in various regions have addressed human impacts on the coastal marine environment, such as dam construction in the Mediterranean and other port structures that have caused erosion and beach loss in Central and South America (Guerrero et al., 2013).

Since the 1960s, the increase in artificial constructions and the high demand for aggregates such as sand have led to the retreat of the coastline, causing instability in beach dynamics (Burke et al., 2001; Cambers, 1998). In addition, phenomena such as cold fronts, tropical storms, hurricanes, sea level rise, and the disappearance of dunes have prevented the beaches of the Insular Caribbean from regaining their stability (Cambers, 1996). In the Colombian Caribbean, coastal erosion is driven by a combination of fluvial sediments and the effects of trade winds (Posada and Henao, 2008). Furthermore, the construction of ports, generally driven by government investment and contractors, faces issues such as the lack of strict compliance with plans by contractors and subsequent marine erosion (Lu et al., 2019).

Additionally, the growing maritime demand presents challenges such as port congestion and expansion planning, making it crucial to identify the factors that cause these problems and their impact on port development (Khalafallah et al., 2020). The coastal ecosystem is vulnerable to human activity, and unplanned land use increases coastal erosion, affecting the environment, ecology, and economy (Boretto et al., 2018).

In Peru, the problem is linked to coastal belt occupation and the imbalance caused by dredging for navigation (Castro, 2015; Sánchez et al., 2010). About 60% of the population lives along the more than 3,000 km of coastline, mainly concentrated in cities like Lima, Callao, Trujillo, and Chiclayo, as well as fishing villages and resorts. This zone is critical due to its diverse uses, although it faces risks from sea level rise. Despite its relevance, few studies assess its vulnerability to this phenomenon (Rondón and Tavares, 2018). In Salaverry, despite multiple pieces of evidence about the vulnerability of island areas—especially Marine Protected Areas (MPAs)—to sea level change, climate change, and human intervention, there are few studies quantifying morphological changes over the same time scale as natural variations and increasing human interference (Diaz, 2019).

Escudero et al. (2018) identified the relationship between human intervention and the loss of ecosystem services in Cancún since the 1970s. Carranza et al. (2015) emphasized that human activities and extreme natural phenomena such as hurricanes, tropical storms, and strong winds have a significant impact on beaches. In Argentina, Merlotto and Bértola (2008) reported coastal retreats and linked urbanization and dune fixation with erosion in Mar Chiquita. Loayza (2022) investigated the recovery of El Ferrol Bay through documentary review and field visits, concluding that contamination and sludge issues persist, and recommended an educational program and expert support. Castillo et al. (2023) analyzed shoreline variation in southern Caribbean Costa Rica using DSAS and ArcGIS, revealing erosion in 70.14% of transects and highlighting the need for adaptive strategies. Chinchilla et al. (2023) proposed mitigation strategies for erosion in Los Santos, Costa Rica, using infiltration ditches, live barriers, and terraces, reducing soil loss.

García (2022) assessed the vulnerability of coasts in the Colombian Caribbean to sea level rise, concluding that 80% are highly vulnerable and require integrated management. Barrantes et al. (2020) studied erosion in southern Caribbean Costa Rica beaches (2005–2016), identifying 11 critical points with significant retreat. Lim et al. (2024) evaluated shoreline changes due to submerged breakwaters in South Korea, noting the need to improve prediction models. Kim (2011) proposed groynes and reef mounds in Namae Beach, Korea, showing advances in shoreline stability after interventions. Iwasaki (2022) analyzed the impact of ports on coastal topography and forests in Ishikari, concluding that port construction causes erosion and alters longshore drift.

Lim et al. (2023) examined submerged breakwaters in Bongpo-Cheonjin, South Korea, concluding that while they mitigate erosion, they require better coastal management. Beach (2020) highlighted the adverse impacts of marine constructions on ecosystems and sediments, suggesting sustainable practices. Angnuureng (2023) assessed coastal protection structures in Ghana, observing sedimentation changes that affect fishing communities and recommended continuous monitoring. Rodgman (2024) reviewed coastal engineering innovations in the UK, highlighting seawalls and dune restoration as climate change responses. Katsardi et al. (2014) concluded that ports intensify erosion on sandy beaches in Greece, stressing the need for sustainable measures. Dong et al. (2024) analyzed coastal erosion in Southeast Asia linked to climate change, highlighting inclusive adaptive strategies. Lim (2020) found that 75 out of 96 areas on Korea's east coast are at risk of erosion, emphasizing the need for effective coastal management. Bocanegra and Veneros (2020) analyzed coastal erosion in Huanchaco, Peru, reporting a 96.2 m retreat that affects wetlands and ancestral fishing, worsened by the Salaverry Port structures. Rosales (2021) studied the socioeconomic impacts of coastal erosion in Trujillo, Peru, showing how beach loss affects quality of life and tourism.

The management and design of artificial beaches and coastal structures have evolved toward integrated approaches that consider both engineering and ecological impacts. Recent studies have contributed to this field by analyzing artificial structures, nature-based solutions, and morphodynamic equilibrium theories. Tomojiri et al. (2025) noted that structures like breakwaters, designed to stop erosion, can trap and bury marine debris, introducing a new environmental challenge in protected areas. In a complementary direction, Ge et al. (2021) used the parabolic equilibrium theory to model artificial beach stability, demonstrating that proper geometric configuration can maintain sediment balance even under dynamic conditions.

Eichmanns et al. (2021) reviewed the use of sand-trapping fences as a nature-based solution, emphasizing their effectiveness in promoting dune growth and reducing erosion by selectively accumulating sediment. This strategy is especially relevant in contexts where hard solutions are less sustainable or economically viable. Similarly, Wang et al. (2023) examined the structural stability of breakwaters in transitional zones under oblique wave action, revealing that concentrated forces and poor element connection can significantly compromise structural integrity, necessitating precise adjustments in structural design through correction coefficients.

Ge et al. (2023) delved into the application of headland-bay equilibrium theory in artificial beaches, validating their proposals through physical testing and in situ monitoring, with results showing high long-term sediment retention efficiency. Collectively, these studies integrate empirical, experimental, and theoretical approaches, forming a robust state of the art that guides the sustainable design of artificial coasts under increasing hydrodynamic and environmental pressures. The Peruvian coast, with its sandy beach ecosystems, faces an accelerated erosion process posing a significant threat. In Trujillo province, La Libertad department, the construction of the breakwater and sand-retaining mole in Salaverry has altered sediment transport patterns, triggering erosion and progressive beach loss. These port interventions, along with dredging work, have changed the natural dynamics of marine currents, affecting coastal stability and local ecosystems. This issue highlights the importance of conducting detailed analyses of coastal dynamics, considering factors like currents, sediment transport, and wave influence. Understanding these processes will enable the design of effective coastal management and conservation strategies, mitigating erosion's negative effects and benefiting both ecosystems and Trujillo's communities.

The choice of Salaverry beach as a case study is based on its representativeness of urban coastal ecosystems in northern Peru, where complex environmental, social, and economic dynamics converge. This coast is not only a strategic point for national port and fishing development but also faces progressive ecological degradation due to tourism pressure, disorganized urban growth, and limited environmental governance. Despite its geographical and functional relevance, Salaverry beach has been little studied in relation to ecosystem services, citizen perception, and sustainable coastal management. Its analysis thus helps fill an empirical gap and provides localized evidence that can be extrapolated to similar contexts in Latin America, contributing to the design of public policies aimed at the valuation and conservation of urban coastal areas. This raises the research question: What is the environmental impact caused by coastal erosion in the coastal zone of Buenos Aires, Las Delicias, and Huanchaco?

THEORETICAL FRAMEWORK

The Theory of Sustainable Coastal Management is key to addressing environmental, social, and economic challenges in coastal zones. Huntley and Riera (2020) point out that this theory integrates strategies for the conservation of marine ecosystems, the prevention of coastal erosion, and the sustainable use of resources. Oliveira et al. (2019) highlight that its application allows for balancing economic development with environmental conservation, while López and García (2018) affirm that this comprehensive approach helps to identify sustainable solutions for coastal problems. In addition, Palomo et al. (2021) underscore the importance of including local communities in decision-making processes to ensure equity and sustainability.

The Integrated Coastal Resource Management approach complements this theory by promoting coordination among sectors and levels of government, enabling the management of issues such as coastal erosion and accelerated sedimentation (Huntley & Riera, 2020). This approach considers both natural and anthropogenic factors, evaluating past interventions to optimize resources and avoid mistakes. The active participation of local communities also fosters environmental awareness and a sense of responsibility towards coastal resources.

The Theory of Coastal Dynamics addresses the physical processes that shape coastlines, such as wave action, marine currents, sedimentation, and natural phenomena (Montgomery, 2007). These factors constantly interact and may be altered by human-made structures like breakwaters, which can trigger processes of erosion or sediment accumulation. Understanding these dynamics allows for the design of conservation strategies tailored to each area. On the other hand, the Theory of Environmental Impact assesses the effects of human activities on ecosystems, aiming to minimize damage and promote balance between development and conservation.

Likewise, morphodynamic analysis refers to the study of the processes that shape the physical characteristics of an environment, including the interaction among waves, currents, sediments, and topography (Komar, 1998). This type of analysis makes it possible to understand the dynamics of coastal systems and to predict their evolutionary trends (Masselink & Hughes, 2003), which is essential for the adequate management of coastal resources.

It is important to conceptualize key terms. An archipelago is defined as a group of nearby islands belonging to the same country or territory (Real Academia Española, 2022). Boothroyd and Nummedal (1978) indicated that archipelagos exhibit complex interactions reflected in water circulation, sediment transport, and geomorphological evolution. A resort is a place by the sea, river, or lake intended for recreational activities (Real Academia Española, 2022), as seen in the tourist beaches of Trujillo. Erosion is the wearing away of soil, accelerated by human activities such as deforestation and agriculture (Montgomery, 2007), which affects soil quality (Wang et al., 2019). Coastal erosion, caused by waves and currents, impacts ecosystems and communities (Priyadarsini et al., 2019). Additionally, El-Raey (2011) highlights consequences such as beach loss, saltwater intrusion, and ecosystem collapse. Geomorphology, the study of landforms and their evolution, is crucial for understanding geological processes and managing risks such as erosion and deforestation (Montgomery, 2007).

METHODS

The present research adopts a qualitative approach, aimed at thoroughly understanding the issue of coastal erosion and the effects derived from the construction of the Salaverry breakwater, based on the analysis of experiences, local perceptions, and contextual evidence. It is a descriptive-analytical study, as it allows the characterization of the manifestations of the physical, environmental, and socioeconomic impact of the breakwater on the coastal ecosystem and adjacent communities. The research design is non-experimental and cross-sectional, since data collection was carried out at a single point in time,

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Vol. 11 No. 4s, 2025
https://www.theaspd.com/ijes.php

without manipulation of variables, prioritizing the natural observation of phenomena. The sample was intentional and consisted of key actors directly linked to the studied coastal area, including artisanal fishermen, Salaverry port workers, local authorities, biologists, and the port administrator. Information was obtained through complementary qualitative techniques: direct observation guide, documentary analysis form, and semi-structured interview guide. This methodological triangulation allowed for the integration of different sources (both primary and secondary) to strengthen the validity of the findings. The data were analyzed using a thematic analysis approach, which enabled the identification of significant patterns, relationships, and interpretations regarding the impact of the breakwater. This methodological design provides a holistic view of the socio-environmental dynamics surrounding the Salaverry coast and contributes to the formulation of informed strategies to mitigate its adverse effects on the coastal environment and the affected populations.

RESULTS AND DISCUSSION

The district of Salaverry has an area of 279.69 km² and is located southwest of Trujillo, 14 km from the city itself, at 8°13'12" South Latitude and 78°58'27" West Longitude. It has an arid to semi-arid climate, with average temperatures ranging from 7°C to 30°C, and is known for housing the most important seaport in the region.

The area of interest is located in the northwest of Peru, specifically in the department of La Libertad, province of Trujillo, covering a coastal strip of approximately 35 kilometers, from Uripe beach to Huanchaco beach, including the districts of Salaverry, Moche, Víctor Larco Herrera, and Huanchaco in northern Peru. According to the report by the Provincial Municipality of Trujillo (2020), the main resorts of the province—Buenos Aires, Las Delicias, and Huanchaco—have been severely affected by coastal erosion processes, due to sediment retention in the south, which resulted in the destruction of Buenos Aires resort and the beginning of the destruction of Huanchaco resort. Additionally, the Regional Government of La Libertad (2021), in the Trujillo Provincial Development Plan (2021), states that these resorts represent a fundamental natural and tourist heritage for the region, whose preservation is necessary to mitigate the environmental impact generated by the interventions in the Salaverry port. According to the Environmental Study by the National Port Authority (2022), the construction of the breakwater, jetty, and dredging works have altered the natural dynamics of marine currents, causing the gradual erosion of the beaches in these resorts.

It is important to explain how this situation developed, as shared by interviewees: on October 11, 1955, the Salaverry port was built with a contract signed with the company Wimpey, which executed the port works in phases. The first phase was completed in 1959. Between 1981 and 1982, the 550-meter sand-containment breakwater was built, of which 50 meters were destroyed by strong swells. In 1987, it was extended by 350 meters, reaching 850 meters, and in 2004 it was further extended by 200 meters to reach a total of 1,050 meters.

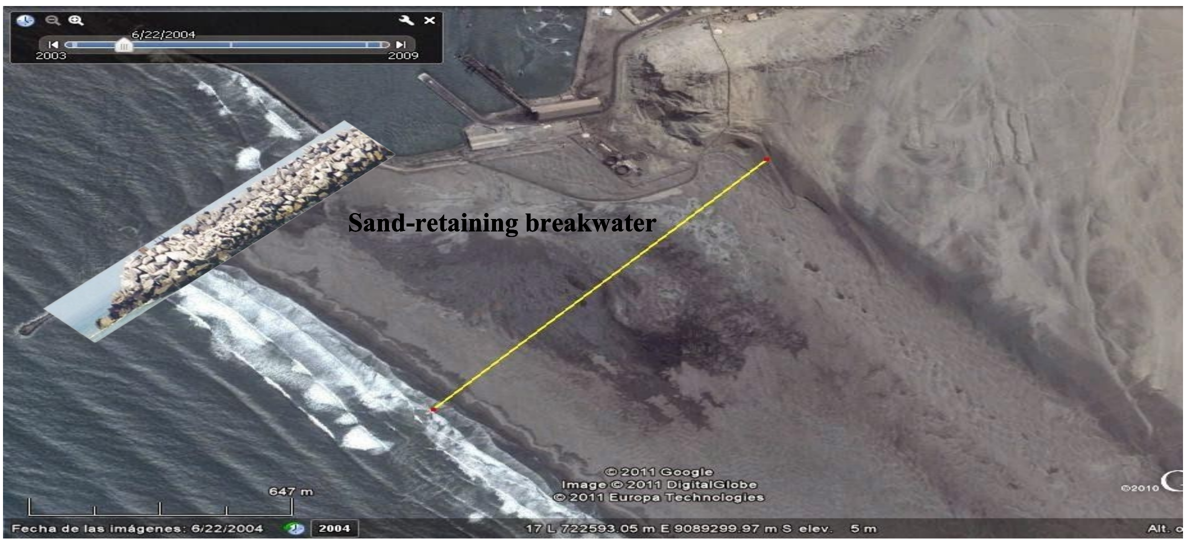

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Figure 1. Satellite image of the breakwater and Port of Salaverry. Extracted from SINIA – Environmental impacts of the sand-retaining breakwater at the Port of Salaverry. https://sinia.minam.gob.pe/sites/default/files/sialsialtrujillo/archivos/public/docs/impactos_cip.pdf

Additionally, according to the information gathered from the interviewees, they shared that the criteria considered for building a port in Salaverry were based on its proximity to the city of Trujillo and the accessibility of the quarry (Cerro Carretas) for the construction of the breakwater, without incurring high costs. During the port construction process, accelerated sedimentation processes occurred to the south of the breakwater and erosion to the north. Three groynes were built on the north side of the port, which did not solve the problem. Once the port was completed, the sedimentation process to the south continued to the point that the sand surpassed the end of the breakwater and began to form a shallow area, putting the port facilities at risk. The sedimentation grew gradually at an increasing speed, which urgently forced the National Ports Company (ENAPU) to contract dredging services.

In 1987, the first extension of the sand-retaining breakwater was carried out, reaching 850 meters in length. The extension of the sand-retaining structure increased the negative impacts on the neighboring coast of Las Delicias, such as the destruction of houses due to the sea advancing over the beach, a situation that prompted the construction of defenses (groynes or small rock breakwaters), which did not solve the problem and instead transferred it to the neighboring beaches of Buenos Aires (Víctor Larco). The sedimentation problem was not resolved with the 1987 extension; consequently, ENAPU S.A. once again contracted the second extension of the breakwater to reach 1050 meters in length. Since 2010, the total loss of beaches in the main resorts has practically occurred.

(a) (b)

Figure 2. Satellite photograph of Las Delicias (a) 1942 and (b) 2009. Taken from SINIA – Environmental impacts of the sand-retaining breakwater at the Port of Salaverry.
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(a) (b)

D= 47.69 meters

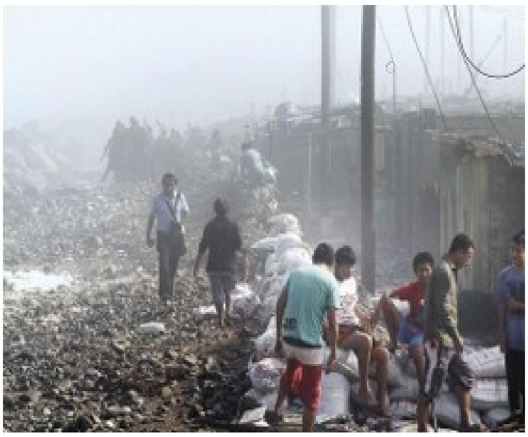

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Figure 3. Photograph of the coastal strip of Buenos Aires (a) before the construction of the sand-retaining breakwater and (b) after the construction of the breakwater. Taken from SINIA – Environmental impacts of the sand-retaining breakwater at the Port of Salaverry.
https://sinia.minam.gob.pe/sites/default/files/sialsialtrujillo/archivos/public/docs/impactos_cip.pdf

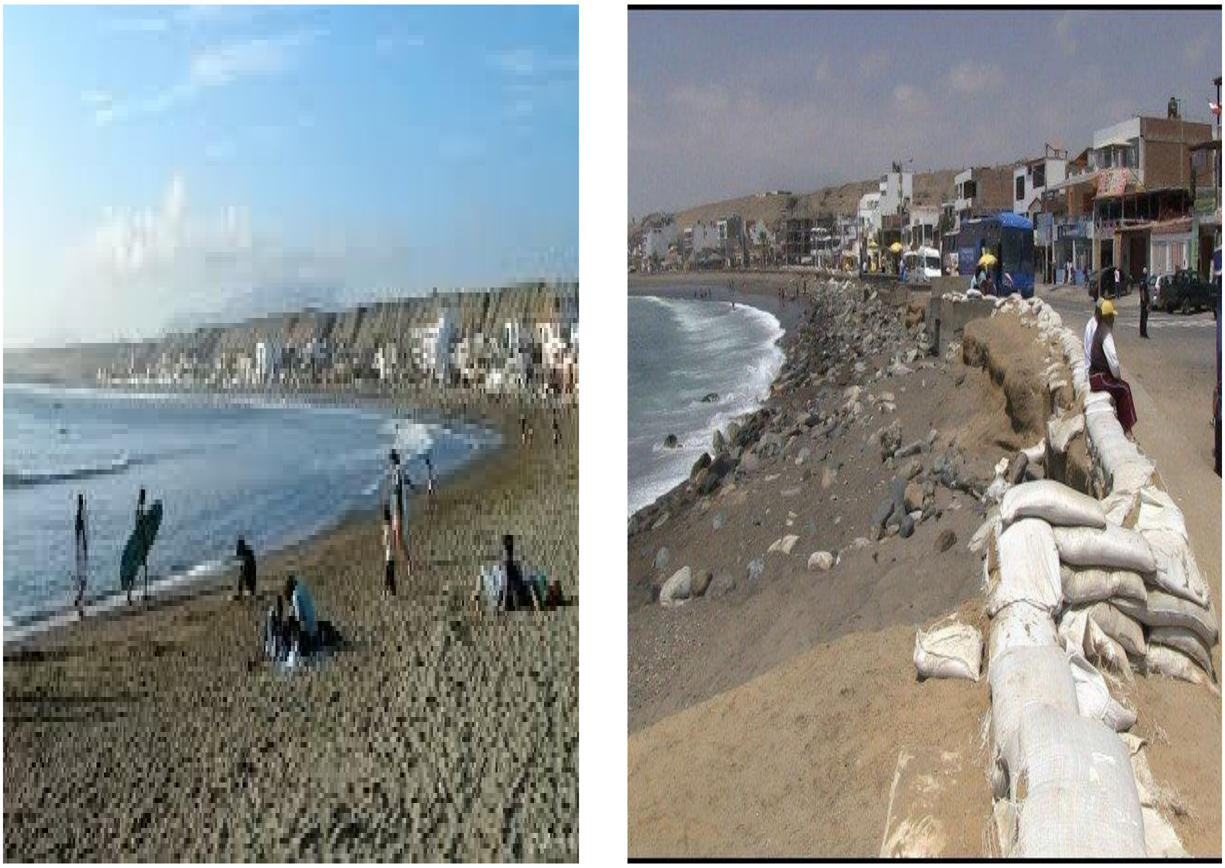

Figure 4. Photograph of the coastal strip of Huanchaco (a) before the construction of the sand-retaining breakwater and (b) after the construction of the breakwater. Taken from SINIA – Environmental impacts of the sand-retaining breakwater at the Port of Salaverry.
https://sinia.minam.gob.pe/sites/default/files/sialsialtrujillo/archivos/public/docs/impactos_cip.pdf

Interviewees shared that during the 1950s and 1960s, the construction of the Port of Salaverry was granted in concession to the British company Wimpey. During the port's operation, issues were observed related to strong wave action and sedimentation. Attempts to resolve these problems led to additional complications. Among the proposed solutions, it was suggested that, in addition to constructing breakwaters, a sand trap should have been built to address the port’s sedimentation issue. Specifically, a breakwater was recommended to the northwest to reduce large waves entering the port, and a sand trap to the southwest to prevent sand accumulation.

The sand constantly moves northward with the ocean current; however, in the study area, approximately 1,000,000 m³ of sand are transported annually. With the installation of the sand trap, only about 600,000 m³ would continue to move, leaving around 400,000 m³ accumulating on the southern side of the trap each year. Consequently, since 1980, approximately 12,000,000 m³ of sand would have accumulated on the southern side over a period of 30 years.

Bocanegra and Veneros (2020) highlight that these structures have led to the loss of iconic beaches such as Las Delicias, Buenos Aires, and Huanchaco. This aligns with the findings of Escudero et al. (2018), who linked human interventions to the degradation of ecosystem services in Cancún. Both cases emphasize how infrastructure decisions can negatively impact coastal ecosystems. The situation in

Salaverry reflects similar patterns observed by Omar et al. (2021) on the Caribbean coast of Costa Rica, where port construction and climate change have compromised beach stability. Likewise, García (2022) reported high vulnerability along the Colombian Caribbean coast due to sea-level rise—a problem also evident in the Trujillo region, where dredging and sediment retention have increased the exposure of beaches to heavy wave action.

Figure 5. Coastal sediment retained by the breakwater jetty at the Port of Salaverry.

The loss of the coastal shoreline in the province of Trujillo is the result of a complex interaction of oceanographic, sedimentological, and anthropogenic factors. Bocanegra and Veneros (2020) argue that the Humboldt Current is one of the main agents influencing the coastal dynamics of the Peruvian coastline, as it transports solid sediments from south to north, eroding the coast and depositing sediments from various river basins. This process has led to the loss of iconic beaches such as Las Delicias and Buenos Aires and currently threatens the stability of Huanchaco. However, when comparing this situation with recent international studies, it becomes apparent that solutions implemented in other contexts could offer replicable strategies.

For instance, Tomojiri et al. (2025) demonstrate how artificial structures like breakwaters, while stabilizing the shoreline, also create sandy environments where marine debris accumulates and is buried—an environmental challenge that could arise in the Trujillo context. Similarly, Ge et al. (2021) apply the parabolic equilibrium theory to design stable artificial beaches, suggesting a viable alternative to counter sediment loss in areas such as Huanchaco. Additionally, Eichmanns et al. (2021) advocate for the use of sand-trapping fences as nature-based solutions that foster dune growth and sediment retention—a particularly useful option in areas where massive structural intervention is unfeasible.

Wang et al. (2023) stress the importance of structural design in the face of oblique waves, a situation comparable to the effects of Peruvian coastal currents. Likewise, Ge et al. (2023) validate the application of the headland-bay equilibrium theory for coastal protection, achieving high sediment efficiency. In this sense, integrating local knowledge with these international experiences could strengthen sustainable coastal management in Trujillo.

Another impact of coastal erosion relates to the quality of life and economy of local populations, as the districts of Las Delicias and Buenos Aires are being affected by coastal erosion, which in turn affects tourism and recreational activities on the beaches. According to Rosales (2021), the loss of beaches has directly impacted the quality of life of coastal communities—a situation also observed in Ghana, where Angnuureng (2023) indicated that changes in sedimentation patterns affect fishing communities. The report from the National Port Authority (2022) reveals that dredging activities and breakwater construction have significantly altered sediment dynamics, causing the gradual destruction of beach resorts. This finding aligns with the study by Katsardi et al. (2014), who linked port construction in

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ISSN: 2229-7359
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Greece to intensified coastal erosion. Similarly, Lim et al. (2023) emphasized that submerged breakwaters can mitigate erosion but require more effective management—similar to the needs in Salaverry.

From an environmental perspective, heavy metal contamination caused by dredging activities without proper environmental impact studies—as occurred in Salaverry in 2011—affects marine biota and local ecosystems. Silva (2015) reported a similar phenomenon in Boca Zacate, Costa Rica, where sedimentation impacted mangrove forests, highlighting the need for more rigorous environmental management.

It is therefore important to highlight the morphodynamic analysis conducted by Castillo et al. (2023) in the southern Caribbean of Costa Rica, which helped anticipate negative impacts in Trujillo. This reinforces the need for adaptive strategies that take into account both natural and human factors, promoting sustainable solutions to mitigate erosion and conserve coastal heritage. The implementation of integrated measures and active participation of local communities, as proposed by Palomo et al. (2021), are essential to ensure sustainability in Trujillo and other affected regions.

The dredging works carried out at the Port of Salaverry have altered the natural dynamics of marine currents, gradually eroding the beaches of nearby resorts. The report highlights that this interruption of sediment flow has had serious consequences for coastal stability and the preservation of coastal ecosystems.

With regard to the documentary review, the report from the Provincial Municipality of Trujillo (2020) states that sediment retention in the south, as a result of dredging activities, led to the destruction of the Buenos Aires resort and the onset of the destruction of Huanchaco beach. This highlights the negative impact these dredging works have had on the coastal dynamics of the region. In this regard, the Regional Government of La Libertad (2021), in the Provincial Development Plan for Trujillo, emphasizes that preserving the beaches and coastal ecosystems of the province is essential for tourism development and the conservation of natural heritage. Therefore, a thorough analysis of the impacts of dredging would have been important to implement integrated management measures that ensure the sustainability of these resources.

According to the Provincial Municipality of Trujillo (2020), ENAPU has been responsible for carrying out port infrastructure works at the Port of Salaverry, such as breakwater construction and dredging operations. This report mentions that ENAPU's interventions have altered the natural dynamics of marine currents, causing the gradual erosion of beaches in nearby resorts. The Environmental Study by the National Port Authority (2022) also points out that ENAPU's actions at the Port of Salaverry have had negative impacts on coastal ecosystems, such as coral reefs, which act as natural protective barriers. This study concludes that ENAPU's lack of an integrated management approach has been a key factor in the degradation of the area's natural resources.

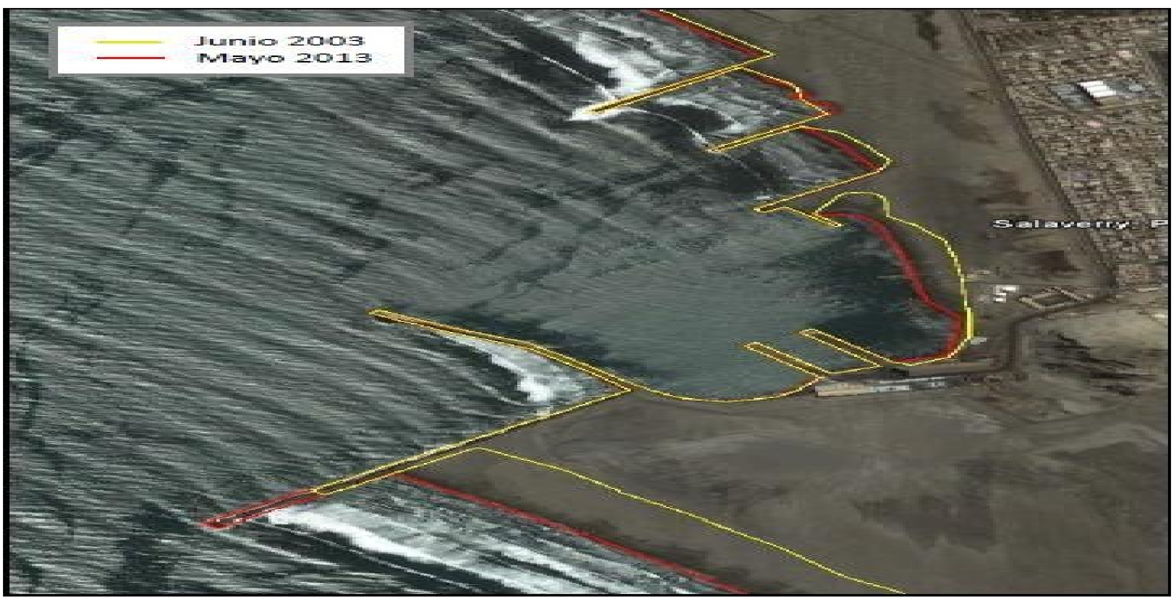

Figure 6. Shoreline variation as of 2013. SINIA – Environmental impacts of the sand-retaining jetty at the Port of Salaverry.
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According to the report by the Provincial Municipality of Trujillo (2020), the Port of Salaverry is one of the main ports in Peru and has been managed and operated by ENAPU since its inception. This report states that port activities have boosted the growth of the mining-export sector and contributed to the economic development of the province. However, the Environmental Study by the National Port Authority (2022) indicates that ENAPU's interventions at the port—such as the construction of the breakwater and dredging operations—have altered the natural dynamics of marine currents and caused the gradual erosion of beaches in nearby coastal resorts. The study concludes that ENAPU's lack of an integrated management approach has generated negative impacts on coastal ecosystems.

CONCLUSIONS

The construction of the breakwater and the sand-retaining groyne at the Port of Salaverry has caused significant alterations in the coastal dynamics of the Trujillo shoreline, affecting the natural sediment transport and exacerbating erosion processes on emblematic beaches such as Buenos Aires, Las Delicias, and Huanchaco. This disruption of the sediment balance has led to evident environmental consequences—such as the progressive loss of coastal ecosystems—as well as social and economic impacts that negatively affect local livelihoods, tourism activities, and community cohesion.

This study highlights the urgent need to design and implement comprehensive coastal management strategies that incorporate both environmentally compatible engineering solutions and participatory decision-making mechanisms. The sustainability of coastal ecosystems requires not only immediate corrective actions, but also long-term planning, systematic monitoring of sediment dynamics, and effective coordination among authorities, community stakeholders, and experts in marine sciences, urban planning, and territorial development.

In this regard, future research should deepen the hydrodynamic modeling of sediment transport after infrastructure interventions, assess the long-term effects of port operations on marine and terrestrial biodiversity, and develop studies on social perceptions regarding conflicts and aspirations of affected communities. Additionally, it is recommended to explore prospective scenarios using climate change adaptation approaches and local environmental governance frameworks in order to design resilient and equitable public policies for the conservation of northern Peru's coastal ecosystems.

DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests that could have influenced the results or interpretation of this article.

AUTHOR CONTRIBUTIONS

Aranda-Vásquez Santos: conceptualization and writing – review and editing; Vergara-De la Cruz Rider: formal analysis and project administration; Soto-Cáceres Manuel: methodology; Briceño-Caipo Luis: writing – original draft; Chiclayo-Zavaleta Alexis: data analysis and information gathering; Quispe-Burgos Lener: investigation.

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