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Determining Causes of Erosion and Sedimentation at Cua Dai Beach, Quang Nam Province, Vietnam: Applying an Integrated Geographical Approach

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ABSTRACT: Cua Dai is one of the 21 estuaries in the Central region and is the first river mouth to the north of the South Central Coastal region. It is renowned for its beautiful beaches, which attract many tourists. Additionally, the Cua Dai River mouth area is a fishing ground for local fishermen due to its rich marine biodiversity. However, a serious issue has emerged in this area. Cua Dai Beach has been facing severe erosion for several years, threatening its natural beauty. This article employs an integrated geographical approach, utilizing two main methods: document collection (research on geology and hydrodynamics) to determine historical changes and on-site surveys (in point format) to assess the extent and current status of erosion. Information exchange with residents is also conducted to understand the situation and gather data identifying the causes of erosion and sedimentation in the Cua Dai area, part of the lower Thu Bon River system in south-central Vietnam. The results indicate that erosion and sedimentation in the research area are influenced by both natural and anthropogenic factors, with no single factor prevailing.

KEYWORDS: erosion, sedimentation, Cua Dai, Vietnam.

I. INTRODUCTION

The coastal river mouth area is a region undergoing frequent changes in space and time. Coastal erosion is attributed to various factors, given that this area is continually and directly influenced by natural elements (geology, topography, extreme weather events, river-sea dynamic processes) and anthropogenic activities (human land use such as tourism, hydropower, urbanization, etc.), as well as indirectly affected by activities from upstream river sources. The diversity and complexity of coastal erosion causes make researching the factors contributing to coastal erosion intricate, requiring significant efforts, observational time, and the use of various tools. However, the current coastal erosion is increasingly severe and has a significant impact on the ecological functions of the estuarine and coastal areas (expansion of coastal urbanization, beach tourism, submergence of land areas, construction projects, fields, beaches, destruction of mangrove ecosystems... [1], [2]). Particularly under the influence of climate change, the vulnerability of estuarine areas becomes more pronounced than ever. Coastal erosion and river mouth dynamics have become major threats in many places worldwide. To minimize the negative effects of erosion and coastal sedimentation [3], scientists worldwide have identified and evaluated influencing factors and observed patterns of erosion and sedimentation in various directions. Initially, geologists (Kidson, 1976; Cocco, 1973) utilized aerial photography to study erosion under the influence of water flow [4], [5], and conducted monitoring and observations at eroding river mouths periodically throughout the seasons (Dalrymple, 1985; Kraus, 2001) to determine sediment transport mechanisms and scale constraints in time and space [15], [16]. In recent years, remote sensing technology has been widely applied to assess changes in coastlines with high resolution. Alongside the development of modeling and statistical methods in studying dynamic coastal hydrological processes, there has been the advancement of surveying equipment based on the latest achievements in optics and acoustics, such as Acoustic Doppler Devices (ADCP) and Acoustic Wave and Current Profilers (AWAC), particularly for measuring suspended sediment concentration, especially bed load transport. Additionally, the achievements in computer science and information

technology have made modeling an increasingly reliable and widely used research tool. Bakker (1968, 1970), Grant (1976), Perlin (1979), Jia et al. (2005), and others have utilized 2D and 3D models to simulate the dynamic regime of estuarine coastal areas. These studies have focused on understanding the impact of external factors such as waves, wind, river flow, offshore currents, and tidal water levels on sediment transport and sedimentation, coastal erosion, and river mouths. Cua Dai is one of the 21 estuaries in the Central region and is the first river mouth to the north of the South Central Coastal region. The Thu Bon River flows through Hoi An City, Quang Nam province, before reaching the sea, passing through a river section called Cua Dai. This area is renowned for its stunning beaches, which attract many tourists. Additionally, the Cua Dai River mouth is a fishing ground for local fishermen due to its rich marine biodiversity. However, a serious issue has arisen at this beach. Cua Dai Beach has been facing severe erosion for several years, threatening its natural beauty. Nevertheless, while erosion has been ongoing for the past 10 years, a sandbar about 20 meters long appeared around the beginning of 2019, approximately 230 meters from the shore. This has led to various interpretations and explanations regarding the causes of its formation.

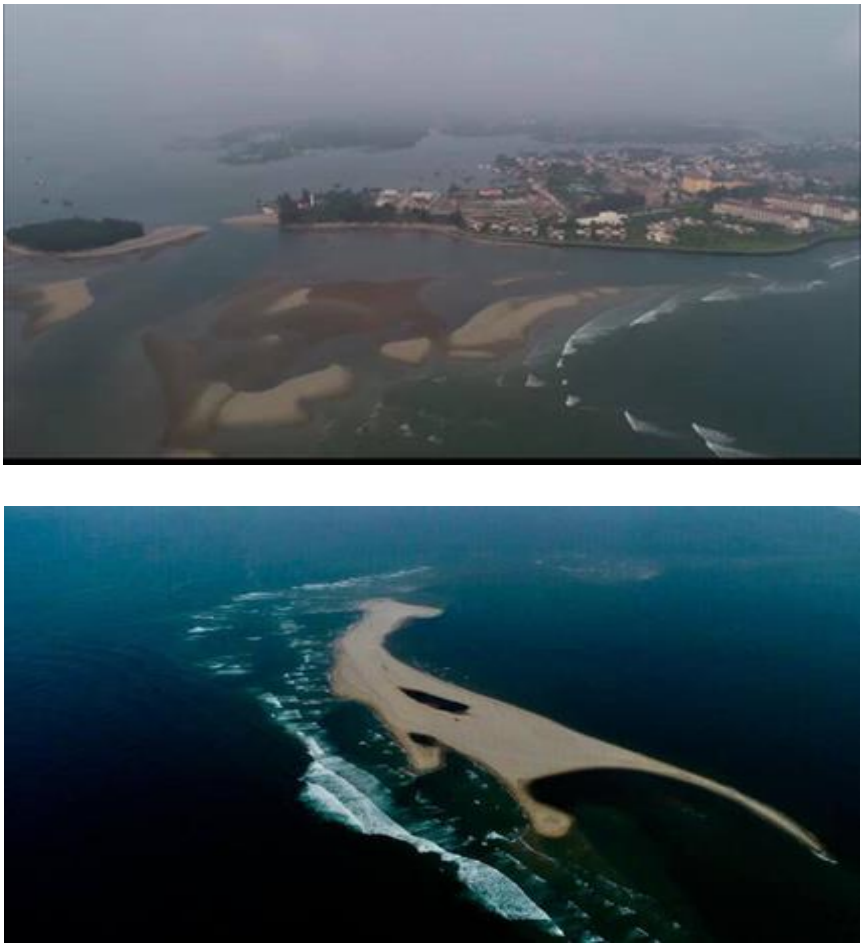

FIGURE 1: CURRENT SITUATION OF EROSION AND SEDIMENTATION AT CUA DAI

Viet Nam has a coastline of 3,260 km with 114 river mouths discharging into the sea [6], and among them, Cua Dai (Hoi An) is a river mouth area where economic activities have been bustling since ancient times (as an ancient trading port in the Central region) to the present day (developing tourism economy connected with the World Cultural Heritage town of Hoi An and the biosphere reserve of Cu Lao Cham). It illustrates a dynamic model of harmonious coexistence between culture and nature, "from ancient to modern." However, the frequent occurrence of erosion and sedimentation in recent years, with increasing intensity and speed, has caused significant damage to the local area. This has attracted the attention of many Vietnamese scientists aiming to identify the causes and mechanisms behind these phenomena. Vo Cong Hoang et al. (2016) have pointed out potential mechanisms causing this severe erosion related to the decrease in sand supply from the river due to the construction of reservoirs upstream and sand mining along the river, as well as at the river mouth [6]. Serious coastal erosion has occurred on the left side, where the supply of sand from the river has been interrupted after the river delta gradually shifted southward. In the study by Tran Van Binh and Le Dinh Mau (2016), they argue that the coastal landscape in Quang Nam province has undergone significant changes due to the influence of natural factors (waves, wind, coastal currents, storm surges, sediment

transport, etc.) and human activities [7]. The main and direct cause of the morphological changes in the beach area under study, especially the coastal erosion phenomenon at Cua Dai, is the impact of high-energy sea waves during the Northeast monsoon season. Hoang Ngo Tu Do (2016) identified that modern constructive activities significantly altered the landscape morphology and changed the flow of the Vu Gia-Thu Bon River system in the flat Quang Nam region. This alteration is considered the primary cause of erosion and sedimentation at Cua Dai [8]. Dao Dinh Cham et al. (2019), using both modern and traditional methods in their in-depth study of the dynamics of estuarine areas, argued that the primary cause of coastal erosion at Cua Dai, especially on the northern shore, and the sedimentation at the Cua Dai river mouth is the combination of large waves during the Northeast monsoon season coinciding with the rainy period and floods that bring sand and mud from the river into the intersection between the river flow and the offshore marine environment, causing sedimentation and the filling of the Cua Dai river mouth [9]. In general, the results have indicated that internal dynamics are the primary and direct cause, associated with dynamic sedimentary processes causing depletion or concentration of sediments in the Cua Dai area. However, these are mainly observations from individual disciplines, lacking interdisciplinary perspectives and a comprehensive understanding of the factors influencing erosion, sedimentation, and the formation of islands in the Cua Dai region.

II. DATA AND METHODOLOGY

The Integrated Geographic Approach has strengths in studying spatial relationships and addressing connections through the analysis of information structures (vertical structure, horizontal structure, and information linkages). This approach allows for the examination of contradictions in the development of opposing aspects, identifying development thresholds to optimize impacts on resources and the environment, and specifically addressing the influences on erosion and sedimentation in the Cua Dai region. Additionally, the holistic geographical approach provides a more accurate insight into the causes of erosion and sedimentation in the Cua Dai area. To achieve this, the article utilized data in the form of articles and research findings from projects related to the Cua Dai region in the past and present. In addition, socio-economic data recorded during field surveys in April 2022, December 2022, and August 2023 were used for comparison to identify the causes of erosion and sedimentation in the Cua Dai area.

Integrated geography is where the branches of human geography and physical geography overlap to describe and explain the spatial aspects of interactions between human individuals or societies and their natural environment, these interactions being called coupled human–environment systems. It requires an understanding of the dynamics of physical geography, as well as the ways in which human societies conceptualize the environment (human geography). Thus, to a certain degree, it may be seen as a successor of Physische Anthropogeographie a term coined by University of Vienna geographer Albrecht Penck in 1924—and geographical cultural or human ecology (Harlan H. Barrows 1923). Integrated geography in the United States is principally influenced by the schools of Carl O. Sauer (Berkeley), whose perspective was rather historical, and Gilbert F. White (Chicago), who developed a more applied view. Integrated geography (also, integrative geography, environmental geography or human–environment geography) is the branch of geography that describes and explains the spatial aspects of interactions between human individuals or societies and their natural environment, called coupled human–environment systems. The links between human and physical geography were once more apparent than they are today. As human experience of the world is increasingly mediated by technology, the relationships between humans and the environment have often become obscured. Thereby, integrated geography represents a critically important set of analytical tools for assessing the impact of human presence on the environment. This is done by measuring the result of human activity on natural landforms and cycles. Methods for which this information is gained include remote sensing and geographic information systems. Integrated geography helps us to ponder the environment in terms of its relationship to people. With integrated geography, we can analyze different social science and humanities perspectives and their use in understanding people's environment processes. Hence, it is considered the third branch of geography, the other branches being physical and human geography.

III. FINDINGS AND DISCUSSION

Erosion and sedimentation in the Cua Dai area are long-term trends related to the development of territorial structures and sea level fluctuations in the past and present. The research area is constrained by two perpendicular fault-slide lines with the strongest tectonic subsidence (100–135 m), the large slope of the submarine slope, an unstable state, combined with six phases of sea level oscillation in the transgressive-regressive period during the Quaternary about 1.806 million years ago, and the current strong sea level rise trend (Table 1) has generated powerful wave energy, causing erosion, changing the coastline, and depositing materials at the base of the submarine slope [10]–[12]. Thus, erosion is a long-term trend in the process of landscape development, and the morphological changes in the riverbed are a natural development process for the reason that, in the process of developing the quaternary sediments, there is no significant difference in lithology, creating the ability to preserve

against the effects of morphological changes in the river flow. However, with the current sea level rise trend, there is a possibility of enhancing the erosion of the surface part of the coast and the sedimentation of materials at the base of the submarine slope.

Table 1: Sea Level Oscillation Phases

Sea Level Oscillation Phases in the Quaternary Period		**Speed (mm/year)**
Phase 1	From 21,000 years to 11,700 years	4,39 - 6,76
Phase 2	From 11,700 years to 4,700 years	High: 16 - 22 Low: 2,5
Phase 3	From 4,700 years to 2,700 years	-1
Phase 4	From 2,700 years to 2,200 years	4
Phase 5	From 2,200 years to 700 years	-1
Phase 6	700 years ago	2,14
Sea level rise in the modern era		
	1978 - 2018	2,6

Source: *Authors calculate*

The rising sea level is a factor enhancing the erosion process. According to the publication of the Ministry of Natural Resources and Environment in 2021, the trend of sea level change in the Quang Nam-Da Nang region from 1978 to 2018, based on actual measurements from the Son Tra hydrological station, showed an increase of 2.6 mm/year. Satellite image analysis results have identified significant fluctuations in the shoreline from 1965 to 2022, especially in the area near the river mouth. The northern part of Cua Dai Beach tends to move towards the shore, but there are also times when it extends away from the shore, with a maximum amplitude of up to 700–800 meters (Tong Phuc Tuan, 2022) [13], [14]. The complete sedimentation and filling of the river mouth over an extended period have led to the shifting of the river mouth, a common phenomenon in the central coastal region. In the period from 1985 to 1995, Cua Dai (Hoi An) shifted southward at a rate of 50 meters per year. The prolonged filling of the river mouth is a geological development, but this process can be significantly accelerated due to increased sediment sources from upstream and the accumulation of sandbanks along the coast. Additionally, the formation and landward movement of coastal sandbars, as well as sandbars along the river mouth, often intrude inland, causing rapid siltation in the river mouths. The process of erosion and sedimentation is driven by economic and social development activities in the Cua Dai and adjacent areas. These activities include narrowing the river mouth drainage area, altering natural land reserves, reducing vegetation cover, and adjusting watershed water sources. Firstly, the research area is located in a region with a complex river system that has been exploited for trade activities since an early period. Particularly during the prosperous period of the Hoi An port (16th–18th centuries), the Co Co River was bustling with boats of merchants from various countries engaging in exchanges and trade with the Dang Trong region. However, nowadays, the traces of the river are only left in the form of ponds, lakes, shallow water areas, and short river sections interspersed with villages. Secondly, activities such as embankment construction and dam building have interfered with the natural drainage patterns, affecting the water and sediment transport to the sea. This has led to dynamic changes resulting in the phenomenon of sedimentation and erosion in the river mouth area and the formation of barriers near the sea entrance. Thirdly, changes in land use related to river flow (water and sediment flow) such as population growth, current land use, deforestation (current forest status), and water resource utilization (hydraulic structures) significantly reduce temporary water storage areas during the rainy season and diminish water regulation during the dry season, despite the dense network of artificial lakes and ponds in the basin. This increases the susceptibility to erosion and sedimentation in the Cửa Đại area. Additionally, the reduction in vegetation cover in the upstream and downstream areas (mangrove forests) affects water regulation from the upper reaches, increasing the flow of materials into the sea. Fourthly, the advantage of steep terrain, combined with numerous waterfalls, lies in an area with heavy rainfall. Therefore, the water resources in the Vu Gia-Thu Bon River basin are considered to have significant hydropower potential, ranking fourth nationwide (after Da River-Lo Gam, Dong Nai River, and Se San River). According to 2021 planning data, Quang Nam has 46 hydropower projects with a total capacity of over 1,816 MW and an average electricity output of over 6,524 million kWh per year. Among them, 10 large cascade hydropower projects on the upper reaches of the Thu Bon and Vu Gia rivers are operational, under construction, or nearing completion, with a total capacity of nearly 1,200 kW. Moreover, there are 36 small and medium-sized hydropower projects, with half of them already operational and the remaining half in the process of implementation, expected to be operational soon with a total electricity generation capacity of 560 kW. These small and medium-sized hydropower projects have undergone a review by the provincial People's Council, resulting in a reduction from the initial plan of 42

hydropower projects. The flow regulation and water control structures have disrupted the natural flow patterns, leading to unpredictable variations in water and sediment transport. This not only affects the erosion and sedimentation processes, forming deltas in the mouth of the Thu Bon River, but also complicates the comprehensive and integrated monitoring of the entire system. It poses challenges to managing the basin effectively and makes it difficult to determine the causes and quantify the processes of erosion, sedimentation, and delta formation in the Thu Bon River mouth area.

IV. CONCLUSIONS

The causes of erosion and sedimentation in the Cua Dai area are diverse and complex, involving both internal and external factors. Throughout the historical development of the Cua Dai region, the phenomena of erosion and sedimentation have been recurrent and closely tied to geological processes. However, the prolonged human activities over many years, with unpredictable developments due to various cultivation methods, livelihood strategies of the people, and the asynchronous nature of development policies, have accelerated the erosion and sedimentation processes in this area. Therefore, in the future, to mitigate this process, synchronized measures for erosion control are needed, involving multiple sectors and fields and encompassing both the natural and cultural behavior of residents according to the laws of nature.

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