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Erosion in the coastal areas of the Vietnamese Mekong Delta: Current challenges and solutions

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ABSTRACT

Coastal erosion is one of the types of geological disasters that is occurring quite commonly and seriously in the Mekong Delta. The problem of landslides and erosions is one of the major concerns for coastal stability. Currently, along 9 coastal provinces, there are over 115 serious erosion and landslide points; each year, a total of 300 –500 hectares of coastal land can be lost. Erosion and landslides narrow the area of mangrove forests, residential land, and aquaculture land of local people.

The Mekong Delta has to spend billions of VND yearly to build breakwaters and sea dikes and restore mangrove forests. Many structural and non-structural measures have been implemented to reduce the risk of erosion over the past two decades. However, there is not much assessment of the sustainability of landslide prevention projects. The research question is what are the challenges and difficulties in the ongoing fight against erosion in the coastal plain. Through a practical approach from surveying works in coastal areas, the results show that choosing an effective solution depends mainly on the cost factor and the terrain of the ground. Water resource management policy on the Mekong River system is difficult to find a satisfactory answer.

1. INTRODUCTION

The Mekong Delta is considered as the largest wetland in Vietnam and the third largest delta in the world (Tuan & Guido, 2007; Edward et al., 2015), with a very young geological age, formed 6,000 - 8,000 years ago due to the alluvial deposition of the Mekong River when it reached the sea (Ta et al., 2005). The deposition of sediments from upstream to delta estuaries was probably concentrated around 5,300 to 3,500 years ago (Edward et al., 2015). According to research published by Milliman and Syvitski (1992), the sediment load of the Mekong River before 1990 was up to 160 million tons/year. Jean-Paul et al. (2013) said that more than 50 years ago, the Mekong River annually transported about 150 - 170 million tons of sand and mud going down to deposit the downstream delta and out to the sea to deposit along the shoreline, creating the shape of the delta. Thanks to alluvium from the Mekong River and ocean currents in the East Sea, over 7,000 years since its formation in the past, the delta has expanded into the sea by an average of about 30 m/year (Liu et al., 2017), while in the last 3,000 years, it has expanded in river mouths at a rate of about 16 m/year and in the Ca Mau Peninsula region at a rate of 26 m/year. At that time, at Ca Mau Cape, each year the mangrove forest spread its roots out to the sea about 40 - 70 m/year. More than 40 years ago, the delta was still expanding, moving into the sea from 60 - 70 meters to nearly 100 meters per year, especially in the Ca Mau Peninsula region. Therefore, the Mekong River is ranked 10th in the world in terms of sediment load (Meade, 1996). More than two decades ago, many studies estimated the amount of alluvium from the Mekong River pouring into the coastal plain at about 145 - 160 million tons/year (Liu et al., 2013; Dang et al., 2018; Kondolf et al., 2022), depending on years of high or low river water flows.

The Delta's natural plants and very special mangrove trees such as Avicennia, Rhizophoracae, Sonneratia and Nypa fruticans, alluvium accumulates and gradually creates the foundation for the delta. The process of sedimentation according to ocean currents and the land-holding mangrove forest system has formed a tectonic process and expanded the delta over the past 3,000 years towards Ca Mau Cape in the southwest direction of the East Sea at an average speed of about 25 - 30 m per year.

However, over the past two decades, most of the sediment and sand have been trapped in reservoirs due to the construction of a series of reservoirs and hydroelectric dams in the upper and middle parts of the Mekong River basin. This trapping has caused the sediments to degrade seriously when they reach downstream and flow out to the sea. This study has the objectives of reviewing the current status of coastal erosion, evaluating prevention structural and non-structural solutions and analyzing government policies to address this problem.

2. MATERIALS AND METHOD

Many field surveys have been organized from 2021 to 2023 along the coastal areas from Tien Giang, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, and Kien Giang. In this paper, the Ca Mau Peninsula area is more focused than other places because it has large shoreline fluctuations, weak soil, a large concentration of mangrove forests that need to be preserved and is currently the country's largest aquaculture production. In parallel with observing coastal erosion, recording erosion prevention systems and conducting interviews with technical staff in irrigation systems and staff of climate change adaptation projects, members of disaster prevention committees and provincial and administration officers of the government at province and district levels.

Table 1. The Mekong Delta's coastal erosion-related meetings and workshops

No	Names	Organizers and Year
1	Knowledge of sediment transport and discharges in relation to fluvial geomorphology for detecting the impact of large-scale hydropower projects	WWF Cambodia, 2012
2	International Workshop on Adaptation in the Mekong Delta	Thuy Loi 2 University HCM City, 2013
3	Controlling erosion in Mekong River Delta- Challenges and Solutions	GIZ, 2015
4	Mekong Delta Erosion Control - situation and solutions	MARD and GIZ, 2015
5	Organizational development and institutionalizing of coastal protection in the southern Mekong Delta, Vietnam	AusAid & ICMP, 2017
6	Seeking measures to combat river and coastal erosion in the Mekong Delta region	MARD, 2019
7	Solutions to handle river and coastal erosion in the Mekong Delta	Vietnam Disaster and Dike Management Authority (VDDMA), 2019
8	The 1st Mekong Virtual Symposium "Response to Development and Climate Change Impacts in the Mekong River Basin – a Call for Solutions and Adaptation".	Can Tho University (CTU) and Vietnam Academy for Water Resources (VAWR), the United States Geological Survey (USGS), and Seoul National University (SNU), 2021
9	Strengthening resilience of the Mekong Delta coasts with mangrove afforestation	MARD, Dutch Embassy in Vietnam & WB, 2022
10	Sustainable Sand Management in the Mekong Delta and Solutions to Sand Scarcity from an Expert and Media Perspective	WWF, 2022
11	Scientific seminar on Coastal Engineering	CTU and National Taiwan Ocean University. 2023
12	Workshop Report on the results of developing a plan to maintain stable river morphology for the Mekong Delta	Vietnam Disaster and Dike Management Authority (VDDMA) and WWF, CanTho City, 2023

Secondary data were collected from local notes, disaster damage reports and scientific articles. There were 12 group meetings, seminars and workshops at universities and localities where expert opinions on the causes of erosion phenomena in the coastal of the Delta and mitigation solutions were also compiled in this paper (Table 1).

For preliminary design of breakwaters, the equation below Hudson's formula (1961), modified by US Army Corps of Engineers (2011), can be used to determine the stability of riprap armor units on rubble structures.

$$W = \frac{w_r H^3}{K_D (S_r - 1)^3 . cotg(\theta)}$$

Where:

W - weight of an individual armor unit in the primary cover layer (kN). When the cover layer is two quarry stones in thickness, the stones comprising the primary cover layer can range from about 0.75 W to 1.25 W with about 50% of the individual stones weighting more than W. The maximum weight of individual stones depends on the size or shape of the unit. The unit should not be of such a size as to extend an appreciable distance above the average level of the slope;

H - wave height (m);

wr - unit weight of armor unit (kN/m^3);

Ww - unit weight of water, (kN/m^3), (fresh water = 9.8 kN/m^3 and sea water = 10.05 kN/m^3)

S_r - the dimensionless relative buoyant density of rock, (S_r = w_r /W_w - 1) = around 1.58 for granite in sea water.

K_d - The values for breaking and non-breaking waves refer to no-damage criteria and minor overtopping. These values were taken from table 7-8 of the Shore Protection Manual, 1984;

Slope cotg(θ) = m. θ is the angle of structure slope measured from horizontal in degrees.

According US Army Corps of Engineers (1984), the stability Hudson formula, based on the results of extensive small-scale model testing and some preliminary verification by large-scale model testing. In practial design, the breakwater should be tested in a physical model before being built. This has actually been done in the Mekong Delta in particular or in some Vietnam coastal area in genral, the design calculations in the desk study when applied must be tested on models in the hydraulic laboratory and verified for a few kilometers in real conditions to have lessons learned. before applying on a larger space.

In this study, policies related to coastal protection to limit erosion are also mentioned, based on meeting discussions and observations from practice.

3. RESULTS AND DISCUSSION

3.1. Main findings

Many factors impact at the same time and also accelerate the phenomenon of both riverbank and coastal erosion. There are many main reasons, ranking according the votes of experts: (1) the decrease in silt, mud and sand from upstream causes the flow to have the phenomenon of "hungry water" which increases the velocity, making weak soil areas susceptible to erosion and erosion; (2) excessive sand exploitation in a certain area causes the channel to deepen faster than the accretion rate, causing the riverbank to become unstable and prone to collapse; (3) the increase in construction load on the river bank is too large, causing the building's foundation to collapse; (4) weather and climate abnormalities increase physical factors that can lead to coastal instability such as sudden alternating droughts and heavy floods, stronger sea winds causing large waves, sea level rise; (5) the shrinking of classes of big trees, strong roots, native plants, typical of the delta such as mangrove forests (6) the increase of high density and uncontrolled water transport; and (7) water control works are not operating properly (saline prevention dams, flood drainage canals).

The decrease in the content of sediment and suspended matter in the river, causing a "sediment-starved water" or "hungry water" situation, increases riverside and coastal lines erosion (Kondolf et al., 2015; Allison et al., 2017), the bottom of the Mekong River is also lowered by dozens of meters from inland to the sea, leading to saline water from the sea following the tides encroaching deeper into the interior of the delta (Eslami et al., 2019). In addition, the process of emitting greenhouse gases into the atmosphere creates global warming, leading to climate change and sea level rise. As the actual manifestations, natural disasters such as sea level rise are enhanced by storm winds, strong waves, high tides and increased landslides in the fragile coastal areas of the delta. Furthermore, activities carried out by humans, such as the excessive exploitation of sand, the withdrawal of underground freshwater, and coastal deforestation, result in the ground sinking at a rate several times faster than the rise in sea levels (Thorsten et al., 2013). The delta's coastal line is "sinking and disintegrating" as a result of the causes illustrated in Figure 1. The combined result is that the coastal area of the Mekong Delta is strongly eroded, with serious landslides in many places, threatening land loss, forest loss, and loss of people's residence and production. According to incomplete statistics and provincial records in 2016, there were more than 779 landslide areas with a total length of 1,134 km, including 744 km with 666 riverbank spots and 390 km with 113 coastal spots (the National Steering Committee for Natural Disaster Prevention and Control website). During the year, the transition periods from dry season to dry season is the time when landslides and erosion increase. In Figure 2, dangerous erosion hotspots and traces of shoreline changes in the Ca Mau Peninsula are recorded.

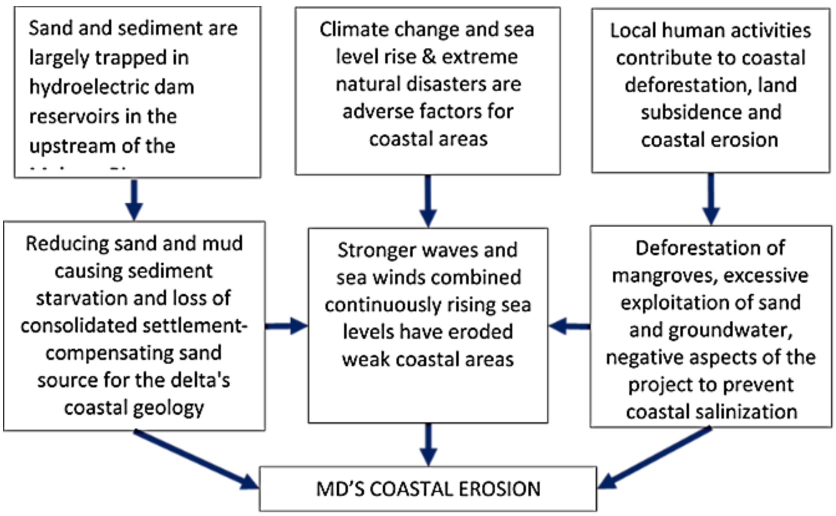

Figure 1. Overview of the causes of landslides and erosion in the coastal areas of the Mekong Delta

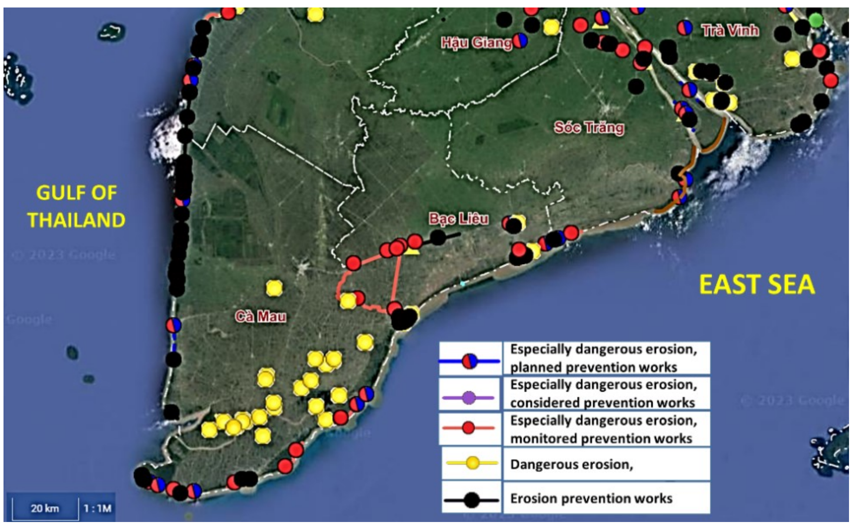

Figure 2. Erosion map in the Ca Mau Peninsula

(Source: https://satlov2.vndss.com/)

Some solutions applied in the Mekong Delta are building sea dikes to break out the sea waves and trap sediment - creating beaches with sand bars or mudflat to restore mangrove forests with appropriate native plants. The strategy to combat erosion in the coastal region of the Mekong Delta is still flexible and adaptive, as shown in Figure 3.

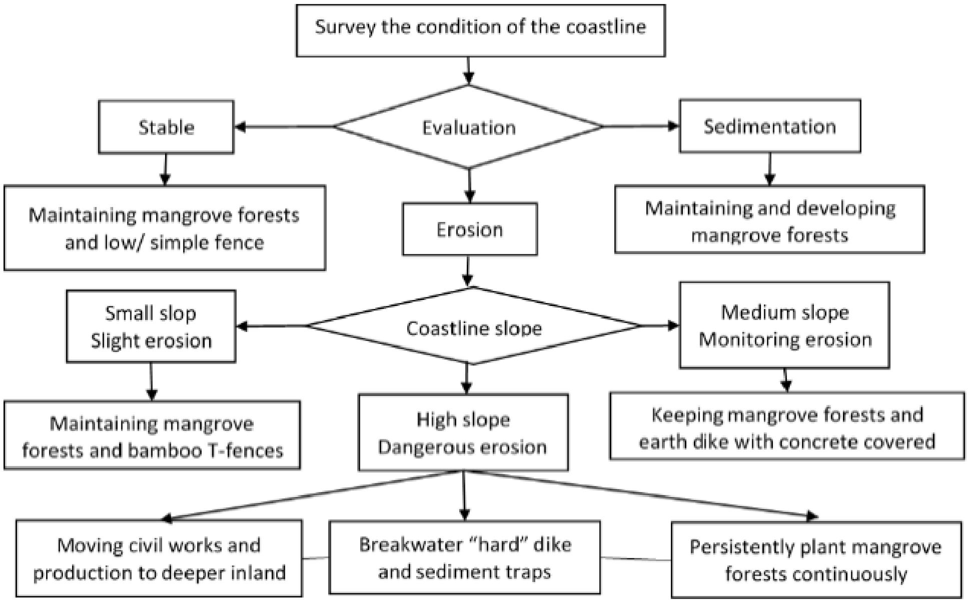

Figure 3. Solutions to prevent and mitigate coastal erosion in the Mekong Delta coastal area

3.2. Practical erosion prevention

There are many options for implementation (below costs are estimates only, may vary widely, depending on time and location):

– Make 2 layers of fence made of bamboo or *Melaleuca* poles running along the beach, between the two rows of poles, dropping tree branches to dissipate wave energy but still allow sea water to carry silt. Every 200 - 300 meters, there is a T-shaped fence protruding into the sea. Surveys show that this method has the ability to reduce waves and the amount of sediment deposited by about 20 cm/year, equivalent to 700 tons/ha.year. Inside the mudflats, native plants such as *Avicennia* and *Rhizophoracae* mangroves were planted in the middle of the land. However, bamboo fences were easily damaged after 2 years due to breakage and parasites. If we do not continue to build new bamboo/*Melaleuca* fences regularly, the forest plants inside could not have enough time to grow and will die. Although this solution is cheap, quick to construct, and can use local labor, it is not durable and must be continuously monitored for reinforcement. This type costs about 500 million VND/km, mainly for piles, construction labor, and material transportation costs.

– Use Geosynthetic Tube, which are tube-shaped geotextile bags, wrapped inside with sand, placed in a row on the bottom of the beach, as a wave-blocking underground dike, running along the section that needs protection for the purpose of reducing waves, as was done on the coast of Go Cong district, Tien Giang province. However, after a few years, these bags broke and the sand inside was swept away by the waves. Installation cost was about 1 billion VND/km.

– Built "gabions" embankment by making galvanized mesh or galvanized mesh coated with PVC and zinc with a diameter of 2 - 4 mm. Gabion size can vary depending on the terrain, most commonly it is a long rectangular shape 2 m x 1 m wide x 1.5 m high. Under the gabion foundation, it is necessary to spread a layer of ART 25-type geotextile, Rocks with an average diameter of 10 - 40 cm were poured into the gabions. It can make at least 2 layers of gabions. Building such a gabion embankment costs about 25 billion VND/km due to the high cost of crushed stone in the Mekong Delta, but it can only withstand waves for about 4-5 years.

– Build earth dikes and cover the surface with concrete or completely with concrete retaining walls, the dike surface is 4 - 5 meters wide, the top of the dike surface is higher than sea level at high tide 1.5 – 2.0 meters. The outside surface of the seaward dike is roof panels made of reinforced concrete or covered with crushed stone. However, most of these types of dikes endure sea erosion for only about 5-7 years and often collapse. These types of dykes have construction costs ranging from 10 to 20 billion VND/km, depending on the type of construction material (soil, rubble, concrete), dike cross-section dimension size and material transportation distance, etc.

– Another way is to build a sea dyke of the "pre-stressed centrifugal concrete revetment" type, with a system of concrete centrifugal piles with a diameter of 35 cm, driven into the bottom up to 5-6 meters deep, spaced about 15 meters apart. - 20 cm, into 2 layers of fence about 2.5 m wide running parallel to the coastline, the pile ends are connected by concrete, every 2 m there is a horizontal connecting beam, the fence is from the shore from 160 to 230 m depending on the terrain, between the two rows of piles are crushed stone blocks. This solution has been implemented in Bac Lieu and Ca Mau with the purpose of reducing wave energy, creating mudflats, and restoring mangrove forests. This type of sea dyke can reduce high waves by about 85% and low waves by about 30%. This type has an average cost of about 32 - 35 billion VND/km. Ca Mau has built 56.7km of coastal embankments with a total cost of more than 1,840 billion VND. Of which, the embankment along the Gulf of Thailand is more than 43 km long, with a cost of more than 1,100 billion VND; while in the East Sea coastline, 12.9 km, total implementation cost was 745 billion VND.

– Other types of embankments, such as hollow pier dikes are filled with stones. Dykes are prefabricated, circular or trapezoidal concrete blocks with hollow holes for water and silt to pass through. These dike pillars were placed on the bottom of the beach by crane barges, then crushed stone was poured in to make the dike heavier and stabilized by its own load. This type has the ability to reduce waves and keep some of the silt inside. However, the ability to create this type of beach is less than the "prestressed centrifugal concrete embankment" because the receding tide can drag part of the silt back out to sea. The cost of construction materials and installation fees was approximately 25 - 28 billion VND/km.

– The 4-legged concrete coastal breakwater, called TetraPod, is molded into a special shape. The inside can be filled with concrete and steel or modified into a hollow shape to accommodate forest trees. These blocks are quite heavy, with many sizes, ranging in weight from 5 - 25 tons/block. The blocks are arranged to hold each other or placed randomly, all with the goal of breaking and blocking waves. Implementing these types of embankment sections has a high cost, possibly tens to hundreds of billions of VND/km, depending on the type, thickness and height of installation, and the distance to transport the tetrapod blocks of the dyke.

Estimating the construction cost of these types of sea dikes is often inconsistent and varies greatly due to differences in the time of calculating the prices of building materials, dike shape designs, construction locations, geological characteristics, working travel distances, and labor and project supervision costs. The MARD and GIZ have also provided a Decistion Support Tool for consideration of the coastal protection regions (CPRs). The design of a type of dyke should be considered based on seven criteria: (1) Tidal regime, (2) Wind regime (including typhoons), (3) Wave climate, (4) Currents, (5) Exposure (angle) to surging waves, (6) Sediment composition and -movements, and (7) Bathymetry (seafloor topography and angle of near-shore water depth profile). For cost estimation for each sort of recommended coastal protection measure, Table 2 can be used for reference.

Table 2. The cost estimation for coastal protection regions (CPRs)

Construction type	Dim.	Unit cost (Mil. VND/m)	Total cost (Bil. VND)
Nearshore: pillar massive wavebreaker in m or beach / foreshore nourishment by creating sandbars	10 m	22	246.56
Foreshore stabilization: groynes/ T-fence/ U-fence/ trapping fence in m	10 m	2.4	29.60
Foreshore and backshore stabilisation: Mangroves in ha	10 ha	172	1,832.65
Sea-dyke with toe protection or/and revetments in m	10 m	70	759.90
Earthen Sea-dyke (newly designed) in m	10 m	5	59.38
Sluice gate in m	10 m	4,400	45,099.52

(Source: Vietnam Disaster Management Authority, 2018)

In general, the construction of sea dikes combined with planting and protecting mangrove forests seems the only current solution to combat landslides and sea erosion. The cost of these measures is extremely large and requires almost continuous investment because of their vulnerability and breakdown to natural abnormalities. Most concrete construction materials are susceptible to damage and corrosion over time due to waves and salt water of the sea. These concrete breakwaters do not have good effects on the coastal landscape and can cause collisions with approaching boats, not to mention they can be displaced and damaged by the continuous impact of ocean waves, especially when there is a big storm. Forest trees resist waves better on the condition that the trees are restored in alluvial areas, the trees are large enough (trees over 4 meters high, with a tree density of 2,000 - 3,000 trees/ha or more and thicker than 1.5 km from the coast to the sea), this condition is difficult to achieve in mangrove restoration areas at sea. To deal with the immediate and long term, provinces in the Mekong Delta need to conduct detailed research and mapping to classify landslides and landslide risks in riverside, estuary, and coastal areas, non-structural and structural solutions need to be considered and weighed between costs and effectiveness for the goal of minimizing the damage caused by land loss, forest loss and loss of people's livelihood areas.

3.3. Policies

The Vietnamese government is clearly aware of the serious risk of erosion and landslides occurring in the riverine and coastal areas of the Mekong Delta, viewing it as a long-term national disaster. The Prime Minister (2020) issued Decision No. 957/QĐ-TTg dated July 6, 2020 on approving the “Project to prevent riverbank and coastal erosion until 2030”. The decision to approve these national projects has 6 main solutions: (a) Review and improve policies and laws related to riverbank and coastal erosion prevention and control; (b) Organize basic surveys, build databases, and design planning; (c) Implement immediate urgent solutions, long-term fundamental solutions, structures and non-structures to prevent and combat landslides; (d) Science and technology: Promote research and application of science and technology to serve landslide prevention and control; (d) International cooperation; and (e) Resource mobilization.

These solutions cannot completely prevent the risks of landslides and erosion, the main thing is to minimize and limit damage because the biggest cause is the decline of sand sources and sediments from upstream that cannot be controlled and prevented. Concrete embankment or seas-dyke solutions are often very expensive, and in the long term, there is still a risk of frequent damage. This decision also does not mention this difficult issue; however, it has been nearly 2 years since Decision No. 957/QĐ-TTg was issued, all six of these solutions have been implemented very slowly, and some solutions were not even operational yet. Currently, large projects such as bridges and roads, large building complexes, river dikes, etc. have a huge demand for construction and leveling sand, while sand prices are still steadily increasing because of scarce supply. Many places for backfilling have to use materials with very weak physical and mechanical properties compared to sand, such as dredged soil, mud, sand, coal slag, waste, etc. These cause the construction to sink and quickly degrade.

In order to limit practical wrinkles, especially construction costs, on October 8, 2023, the Deputy Prime Minister signed Decision No. 1162/QĐ-TTg on additional capital from the central budget reserve in 2023 for provinces in the Mekong Delta to promote the implementation of projects to prevent and combat riverbank and coastal erosion. Specifically, the Prime Minister added 4,000 billion VND for localities in the Mekong Delta including Long An 250 billion VND, Tien Giang 200 billion VND, Ben Tre 300 billion VND, Tra Vinh 200 billion VND, Vinh Long 500 billion VND, Can Tho 250 billion VND, Hau Giang 200 billion VND, Soc Trang 300 billion VND, An Giang 250 billion VND, Dong Thap 250 billion VND, Kien Giang 500 billion VND, Bac Lieu 300 billion VND, Ca Mau 500 billion VND, as proposed by the Ministry of Planning and Investment. This additional amount of finance from the central budget for these localities currently partly solves the urgent need to prevent landslides and erosion, which the Ministry of Agriculture and Rural Development estimates is up to about 13,400 billion VND to handle 63 points in dangerous erosion situation with a total length of 240 km of the delta.

4. CONCLUSION AND RECOMANDATION

The results of this study also answered questions about the challenges and difficulties in the process of combating coastal erosion, as well as policies that need attention. The most difficult problem is that there is currently no effective diplomatic and economic negotiation solution to prevent the development of hydroelectric projects upstream. Coordination with the Mekong River Commission only stops at monitoring and calculating the volume of sediment and sand. This shows a scenario of shrinking the natural land area as an image of a disintegrated plain in terms of land geography. This difficult problem, up to now, still has no satisfactory answer.

The combat against erosion will continue for many years to come. The recommendations are: (i)

Localities must have landslide and erosion risk maps. (ii) The management of rivers and canals needs to be stricter, do not arrange new settlements near river banks, and gradually clear riverside structures and houses to limit landslides. Areas at risk of landslides must limit boat speeds and post warning signs. (iii) The irrigation industry needs to study river regulations to have proposals to build projects to stabilize the channel in key economic and population locations. (iv) Coastal areas must choose to prioritize the solution of planting mangrove forests and planting trees to protect the soil before looking for structural solutions to prevent landslides or prevent the spread of landslides. (v) Localities in flooded areas should reduce the area of dikes for the third crop, opening the flood waters to receive alluvium, instead of letting the flood flow become more rapid downstream, increasing the risk of landslides and erosion.

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