GEOLOGIC RESOURCES VULNERABILITY ASSESSMENT TO ORIENT FOR VIETNAM COASTAL BAYS SUSTAINABLE USE (A CASE STUDY OF GANH RAI BAY, BA RIA – VUNG TAU PROVINCE, VIETNAM)

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ABSTRACT: Ganh Rai is one of the important bays in the East of Nam Bo in particular and Vietnam in general. This area has diversified resources, especially geological resources (geosite with high developing of seaport, geotopes with beautiful beaches, wetland with abundant mangrove etc.). They are advantageous conditions to improve the economic development such as marine transportation, aquaculture and fishing, tourism, etc. However, hazards such as erosion, channel siltation, sea level rise, oil spill, environmental pollution etc., and activities of unsuitable resources exploitation and utilization have degraded environment, decreased biodiversity and increased vulnerability. Therefore, it is necessary to assess the geological vulnerability for sustainable use.

Based on the three components (vulnerability factors, vulnerable objects and resilience capacity) the vulnerability of Ganh Rai bay has been assessed in 4 levels including: low vulnerability (off-shore areas in Tan Thanh and Ba Ria town), medium vulnerability (Thi Vai riverine area, coastal area of Ba Ria town etc.), high vulnerability (coastal area in Vung Tau city, area of 0-6m water depth etc.) and very high vulnerability (coastal and estuary areas in Vung Tau city). Based on this assessment, some solutions on management, education and awareness, hazards mitigation, geological resources use planning (eco-agriculture, silvo-fishery, eco-tourism, seaport developing and management together etc.) for sustainable use of geological resources have been proposed.

Key words: geologic resources, vulnerability, Ganh Rai bay, hazard, sustainable use

INTRODUCTION

Along approximately 3,260km of coastline, Vietnam has 48 coastal bays and shelters with total area of 3,997km.sq. Those bays and shelters take an important role in socio-economic development and national defense [19].

Located in the coastal zone of Dong Nam Bo region, between Vung Tau and Ho Chi Minh City and Ganh Rai bay is contiguous to Can Gio Biosphere Reserve (fig.1). The bay is rich of natural resources, especially geologic resources. There, geologic resources are product of geologic process that human be able to exploit and use [15]. There are 2 groups of geologic resources: non-renewable (minerals, geotopes, and position resource) and renewable (a part of wetland). Ganh Rai bay has geosite which appropriate for developing sea-port industry (Vung Tau port, Cai Mep port); has beautiful beaches what are concerned as a geotope (Bai Truoc, Bai Sau, Bai Dua); is rich of wetlands with abundant mangrove and biodiversity ecosystem in Tan Thanh, Ba Ria; and is diversified minerals. All those resources are creating potential for socio-economic (tourism, sea-port, aquaculture, fishery etc.) for this area and adjacent zone.

Although, Ganh Rai bay is impacted by vulnerability elements, especially disasters (as erosion from Cua Lap to Nghinh Phong coast; river and flow change due to siltation in Lap estuary and Dinh estuary); environmental pollution in sea-ports as Cua Lap, Sao Mai - Ben Đinh, Cat Lo, Thi Vai; and oil spill etc. Additionally, there are some threats from developing activities as unsustainable development of aquaculture and fishery in Cua Lap, Dinh estuary, Long Son etc.; sea- transportation and tourism in Vung Tau, industrial development in Phu My, My Xuan, Tan Thanh. Beside, the resilience capacity of natural - social system (geologic resources protection, management, community awareness about geologic resources functions and values etc.) is not enough. Those elements and threats give bad impact on geologic resources as quantity reduction, quality degradation, loss of biodiversity, and environment pollution lead to increasing vulnerability of geologic resources. Therefore, geologic resources vulnerability of the bay is assessed base on selected criteria. The result of research will contribute to orient for sustainable use of Vietnam coastal bays by conducting appropriate management solutions, raising community awareness, adopting of use plan, and mitigating hazard effects.

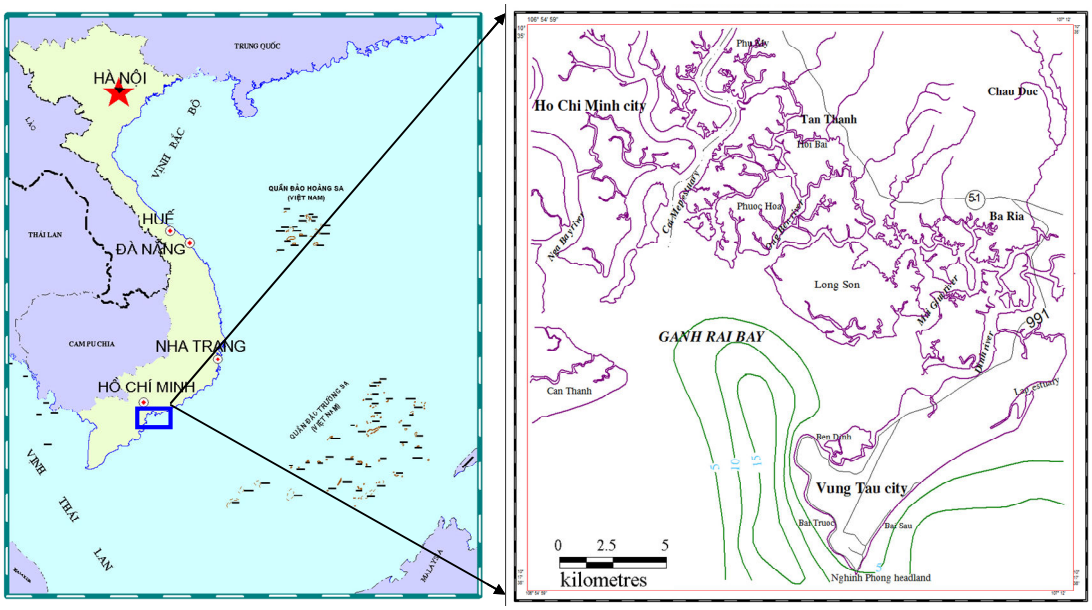

Figure 1 Location of study area

STUDY METHODS

Nowadays, methods and criteria for vulnerability assessment are set up base on 3 groups: vulnerability factors (hazards and hazard enhancement factors); vulnerable objects (urban zone, industrial zone, economic zone and multi-resources etc.); and resilience capacity of the natural-social system (infrastructure, people's intellectual level, health, gender etc.). Especially, application of past and ongoing demonstration models as Social Vulnerability Index of Cutter and NOAA [2,3,8]; A vulnerability index for the natural environment of SOPAC [18]; Coastal Vulnerability Index of United State Geologic Survey [5]; Guideline of vulnerability assessment for Vietnam coastal natural - social system of Mai Trong Nhuan and colleagues [6,9,14,17]. By consolidating and assembling the past and ongoing methods and applying them in the condition of Vietnam coastal bays, a model of geologic resources vulnerability assessment of Vietnam coastal bays is conducted (fig. 2)

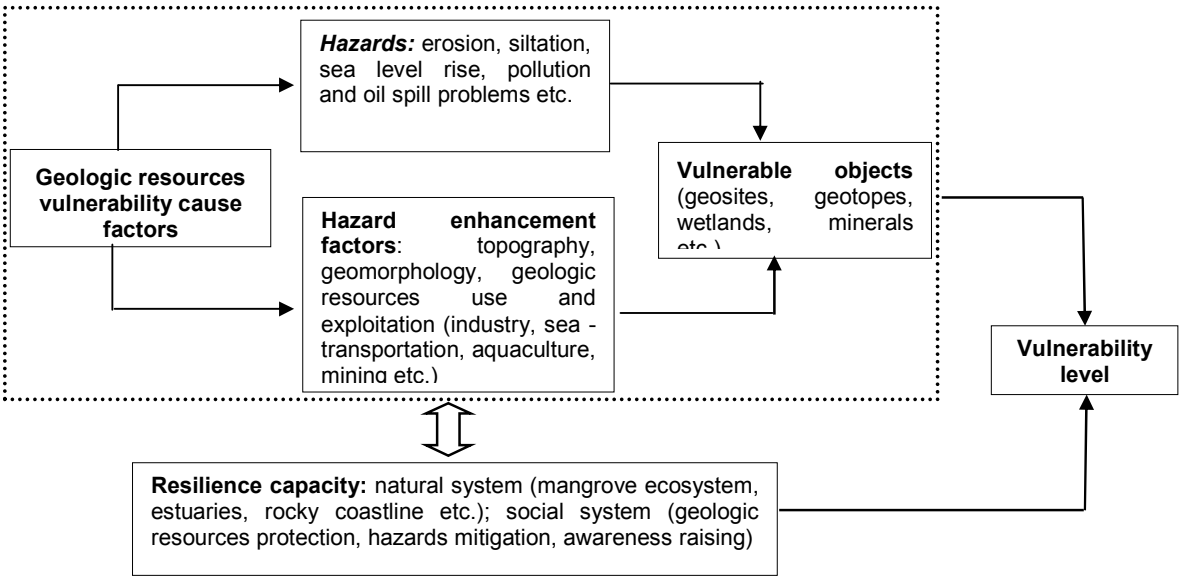

Figure 2 Model of geologic resources vulnerability assessment of Vietnam coastal bays

GEOLOGIC RESOURCES VULNERABILITY ASSESSMENT

Assessment Criteria

Geologic resources vulnerability assessment criteria are divided into 3 groups: vulnerability factors (hazards and hazard enhancement factors); vulnerable objects (geologic resources); and resilience capacity of the natural-social system. In selected criteria, some criteria are both vulnerability factors (and vulnerable objects) and resilience capacity (Table 1).

Criteria of vulnerability factors

Hazards: including erosion, river flow change by siltation, storm and flood, sea level rise, oil spill, environmental pollution and earthquake. Selected information includes intensity, frequency and sphere of influence of each hazard. In there, erosion, river flow change by siltation, storm and flood, sea level rise, oil spill, environmental pollution occur at strong intensity, great frequency on a large area. Then, storm and flood, sea level rise and earthquake.

Erosion occurs strongly along the coastline from Cua Lap to Nghinh Phong headland (creating a cliff with 1-1.5m in height). In comparison with the UTM map in 1965, the coastline encroached upon continent hundreds meter, especially in recent years, the encroachment is 12-15m/year [7]. The consequences of erosion are destroying sea walls, decreasing the landscape values of sea beaches, threatening local people and their house and causing loss and degradation of mangrove and protective forest.

Flow change due to siltation occurs at almost estuaries and sea-ports in the study area. As in Lap estuary, siltation created a system of sandbar with length of 0.5-1km and other submerged sandbars in the estuary [12, 13]. The sandbar creation process speeds up erosion and flow change in the area, causes difficulty for river and maritime transportation. In order to maintain and develop the maritime transportation and protect geosite (sea-port) here, local government has to spend a great expense to dredge the river bed and seabed. According to Ministry of Natural Resources and Environment, toward 2020, estimated mass of sediment has to be dredged in 18 flows, seaport, river and industrial zone is 27.6mil.m^3 and the estimated cost reaches to 128 billion VND.

Sea level was forecasted rising from 23 to 117 cm in the year of 2050 and 56 to 345 cm in the year of 2100 [20]. According to Nguyen Ngoc Thuy, the average rate of sea level rise in the coastal zone of Vietnam is 2mm/year. And, UNDP has noted that Vietnam is a country affected most seriously by sea level rise. In the case of sea level rise of 1m, approximately 1/5 population will lose their houses, 12.3% cultivated area and 40,000 sq.km of coastal land (mostly coastal wetlands) are under damage. Total damage cost is estimated about 17 billion UDS/year [2]. So, in Ganh Rai bay, sea level rise will effect seriously on most area of Vung Tau city to Ganh Rai headland (especially wards of 11; 12 and Long Son commune, Vung Tau city) and coastal communes from Tan Thanh district to Ba Ria town; threaten directly to coastal wetland types, damage to tourism, transportation and aquaculture etc.

Oil spill problem occurs sometimes and causes serious consequence to resources and environment of coastal zone in general and coastal bays in particular. According to Vietnam Environmental Protection Agency, up to June 2007, total damage due to oil spill problem in Viet Nam is estimated approximately 76.8 billion VND, including 1.2 billion VND for oil collecting; 44.9 billion VND for tourism; 28.4 billion VND for aquaculture and fishery; and 1.6 billion VND for agriculture. In Ganh Rai bay, oil spill problem occurs with a great frequency, mainly due to sea- transport accidents and leaking oil from vessels. During period of 1993-1998, there was 30 shipwrecks discharged 3,200 tons of oil into the bay [12]. E.g. the accident of Formosa One vessel and Petrolimex vessel on September 7th 2001 spilled 750 tons oil to the sea, affected seriously to economy and environment of coastal zone from Nghinh Phong headland to Sao Mai – Ben Dinh resort (photo 2). Recently, there is an oil leakage during February to March 2007 which caused a serious degradation to coastal ecosystems. Collecting oil volume in sea beaches in Vung Tau reaches to 12 tons.

Environment of Ganh Rai bay is potentially polluted by Mn, Pb and Cd in sea water and Hg, Sb, As in sea sediment [10, 12, 13]. Specifically, water environment is likely polluted by Pb in the west area of Cu Lao Ben Dinh with concentration of 12 - 14.10-4mg/l (higher than 40 times in comparison with average concentration of Pb in the world sea water, but less than standard level in Vietnam Environment Quality Standards 5943-1995).

The concentration anomaly of Mn, Cd at Mui Giui estuary, Dinh estuary (0-5m water depth) ranges from 120 to 210x10-4mg/l and 3.5 to 6,4x10-4 mg/l (higher than average concentration of Mn, Cd in the world sea water from 6 to10.5 and 3.5,5 to 6.4 times). In shallow sediment (to 0 to 6m in depth), the The concentration anomaly of Hg is determined at Ben Dinh, Long Son communes and Nga Bay, Cai Mep estuaries, with concentration of 0.3 to $0,5x10^{-4}$%. The concentration anomaly of Sb distributed in some area surrounding Cai Lo port and Cai Mep estuary with concentration of 4 to $5x10^{-4}$% (2.85-3.57 times higher than Threshold effect level of the Canadian Environmental Quality Standards).

Photo 1 Collapse sea-wall in Thuy Duong resort due to erosion

Photo 2 Oil spill in September 2001

Hazard enhancement factors: Human activities enhance hazards as erosion, siltation, salinization and pollution, include: industrial activities (an enormous waste from Vedan factory flows directly into Thi Vai river is 105,600 m3/month and the waste from My Xuan A and Nhon Trach 1 industrial zones etc.); maritime transportation (municipal waste and oil from ports as Cai Mep, Sao Mai - Ben Dinh, Dinh River); oil spill problems; excessive aquaculture; destroyed fishery (explosives, electrical impulse) and mangrove cut-down to enlarge aquaculture ponds and salt fields (in Long Son commune, ward 11, Lap estuary etc.). Add to that are some detrimental features of natural condition of coastal zone, for example topography, geomorphology, coastline sedimentary formation (mud, sandy mud, sand and rock) which can enhance or reduce the effect of hazards.

Criteria of vulnerable objects

Geosites: including headlands as Nghinh Phong, Ganh Rai; sea-ports as Vung Tau – Dinh River, Cai Mep River; estuaries as Dinh, Mui Giui, Cai Mep, Lap. Those geosites are exploited rapidly for tourism as in Nghinh Phong, Nui Lon, Nui Nho tourist areas, sea-transportation and aquaculture. Beside, headlands in the region created closed bays with weakly affected by waves and winds dynamic appropriated for stormproof of sea-transports.

Geotopes: sea beaches, which are characterized by gentle slope and white sand, create a favorable place for *sightseeing*, swimming and holiday supplements. The tourist areas, developed in this type, include Truoc beach, Sau beach, Dua beach, Thuy Van beach, Paradise resort (photo 3).

Wetlands: including 9 types of wetlands in this area, e.g: shallow sea at less than 6m water depth; estuaries; sandy intertidal flats; muddy flats; mangrove; aquaculture ponds; salt fields; rivers, streams; and rice fields [16]. Wetland type of shallow sea at less than 6m water depth covers about 5,138 ha and is a famous national fishing ground. Estuaries have total area about 1,213 ha and are favorable for developing aquaculture, transportation and sand exploitation, especially at Lap and Dinh river estuaries. Mangrove in this area covers 10,819 ha, get an important role as environmental suffer zone and storm prevention. But, most of mangrove is converted into aquaculture ponds (in Long Son commune, ward No.11 and ward No.12 of Vung Tau city) and industrial zone, urban along the 51 road (photo 4). Aquaculture ponds cover about 1,524 ha, mainly on estuarine mangrove area.

Minerals: including ilmenite placer in Vung Tau with total reserves of 70,000 tons [12, 13] and constructive materials as: stone (165x106m^3); paving stone (7,14x106m^3); glass-sand (41,106 ton); clay (3x106m^3); additive for cement production (52.5x106 ton) [21]

Photo 3 Sau beach (Vung Tau city)

Photo 4 Mangrove forest along the 51 road

Criteria of resilience capacity

Recilience of natural systems: including mangrove ecosystems, estuaries, headlands, sandy/muddy flats, shallow sea at less than the lowest tide 6m water depth. For example, mangrove has great values and significant function on economy and environment (climate equable; sediment trap and land-based pollutants buffer zone, storm and erosion prevention). So, mangrove is concerned as highest resilience system to effects of hazards (or reducing the vulnerability). Then, coastline solid rocks at Nghinh Phong headland, which are granite of Deo Ca formation and igneous rock of Nha Trang formation, have a good resilience and loading capacity, oily unabsorbability, and mitigate the impact of erosion, oil spill, sea level rise, storm, flood and pollution. Whilst, unsolid coastlines at estuaries and tidal flats highly absorbed oil and accumulated pollutants, destroyed easily by waves, currents, and are sensitive to impact of erosion, oil spill problems and pollution. So, those coastlines have a bad resilience.

Resilience of social systems: including criteria for assessment of education, management, organization, protection and hazard response (number of schools, number of teachers, legal matter, and garbage collection) and infrastructure (transportation, number of transmitting stations). In there, education and training in study area develops rapidly with good facility schools and numerous numbers of teachers (accounting for 9,800 teachers; about 122.5 teachers/ten thousand persons). The quality of education is very good: the annual percentage of students graduating from primary school reach 99%, secondary school 90%, and high school 95%. This is an important base to evaluate local people's awareness and local community participation in natural resources protection generally and geologic resources particularly. On the contrary, the rate of unemployed people at the working age and the rate of population growth are high (accounting for 2.43%, and 13.66%) [1] and the distribution of residents is uneven (387,267 urban people, 497,578 rural people) to cause reducing the resilience of local communities.

Table 1. Geologic resources vulnerability assessment criteria for Ganh Rai bay, Vung Tau province

Factors	Criteria	Notes
Criteria of vulnerability factors	*Hazards* - Erosion - Siltation - Sea level rise - Storms and floods - Oil spill problems - Pollution - Earthquake	Geologic fomations enhance or reduce the effects of hazards (good resilience): - Sandy and muddy fomations are weakly resistant to effects of harzard (sensitive to impact of erosion, oil spill problems, sea level rise and pollution). - Rocky coastlines reduce above effects
	Hazard enhancement factors - Natural condition: topography, geomorphology, coastline sedimentary formation (mud, sandy mud, sand and rock Human activities: mangrove cutdown, industry, agriculture, tourism, martime transportation, aquacultre, fishery, mining, salt production	
Criteria of vulnerable objects	*Geosites* - Headlands - Sea-ports	Some vulnerable objects are resilient from effects of harzards, including headlands, rocky coastline, muddy/sandy flats, mangroves, and estuary (*see above)*.
	Geotopes - Beaches Coastal landscape	
	Wetlands - Shallow sea at less than lowest tide 6 m water depth - Estuaries - Mangroves - Sandy/muddy flats - Aquaculture ponds - Salt fields - Rivers and streams Rice fields	
	Minerals - Ilmenit placer Constructive meterials	

Factors	Criteria	Notes
Criteria of resilience capacity	*Resilience of natural systems* - Mangrove ecosystems - Esturies and shallow sea at less than lowest tide 6 m water depth - Rocky headlands - Muddy/sandy flats	
	Resilience of social systems - Education - Natural resources management, environmental protection and hazards mitigation Infrastructure (transportation, number of transmitting stations)	

Ganh Rai bay geologic resources vulnerability zoning

Geologic resources vulnerability assessment is based on 3 groups of factors and criteria (tab. 1). Result of the assessment is the overlap of vulnerability index by the danger level from vulnerability factors, vulnerable objects density and resilience capacity of the natural - social system per unit area of the topographic map at scale of 1/100,000. By algebraic map method, vulnerability index is determined on each map square unit. Basing on the index, Ganh Rai bay is divided into 4 zones following the vulnerable levels (fig. 3).

Zone I: - low vulnerability zone covers 18.72% total study area, distributes on mountain land in the west of Ba Ria town (Hoa Long and Long Phuoc communes) and north of Tan Thanh district (Chau Pha, Toc Tien, Hac Dic communes). This is inland zone with low vulnerable level (only influenceable by earthquakes, weak storms and less impacted by human activities). The density of geologic resources (vulnerable objects) in this zone is low (only constructive materials and small area of rice fields). The resilience capacity of this zone is at medium level.

Zone II: - medium vulnerability zone covers 15.30% of total area, distributes mainly in Tan Thanh district (Phuoc Hoa and Hoi Bai communes), Ba Ria town (Long Huong, Phuoc Trung, Long Toan, Phuoc Hung communes) and a small offshore area of Long Son commune, wards 4, 7 and 9 (Vung Tau city). This zone has medium to high level of vulnerability (effect by sea level rise, storm, floods, pollution and impact of hazard enhancement factors as transportation, industrial zone in Than Thanh and Thi Vai River basin, mangrove cut-down to develop aquaculture and salt production in Long Son, Long Huong). The density of vulnerable objects in this zone is quite high, e.g. the most abundant mangrove in the area, many ports in Thi Vai river, many aquaculture ponds, salt fields and a dense river/flow system. But, the resilience capacity of this zone is quite high, because of large area of mangrove in Vung Tau city that has a good resilience.

Zone III: – high vulnerability zone covers a large area (43.53% of total area), includes: wards 2, 5, 6, 11 and hamlet number 9 of Long Son commune of Vung Tau city; Ding estuary, Phu My town (Tan Thanh district) and shallow sea at less than the lowest tide 6 meters water depth. The zone has high level of vulnerability due to: strong effect of oil spill problems, pollution, sea level rise and siltation; dense of vulnerable objects as geosites (headlands, sea ports), geotopes (beaches), wetlands (mangrove, salt fields, aquaculture ponds, sandy/muddy flats and shallow sea at less than the lowest tide 6 meters water depth; high resilience capacity (good resilience of mangrove and other vulnerable objects by sea dike and wall system, high people's intellectual level, good coastline protection management).

Zone IV: - very high vulnerability zone covers 24.45% of total area, includes coastal zones of Long Son commune, wards 1 and 10 of Vung Tau city, estuaries as Cai Mep, Ong Ben, Mui Gui, Lap. This zone has a high vulnerable level due to strong effect of oil spill problems, siltation and high consequence of human activities which enhanced hazards effect as dense of population, fishery and aquaculture, sea transportation… In this zone, the density of vulnerable objects is very high, e.g. mangrove ecosystem (in Phuoc Hoa commune, flats between Ong Ben and Mui Gui estuaries, coastline from Long Son to Mui Giui); geosites (sea-ports in Vung Tau and Lap estuaries); geotopes: (sea beaches in wards 1 and 10 of Vung Tau city); wetlands (aquaculture ponds, estuaries, salt fields). And, the resilience capacity of this zone is quite high basing mainly on resilience of coastline and mangrove here.

The result of research show that very high vulnerability zone usually has the overlap among the zone is affected strongly by hazards (erosion, siltation, sea level rise) and environment problems (oil spill, pollution) with the zone has high dense of vulnerable (geosites, geotope, wetlands, mangrove) and the zone has medium to high resilience capacity (basing on resilience of mangrove, infrastructure and good organization for resources management and hazard mitigation). Low vulnerability zone usually is weakly affected by vulnerability factors and low dense of vulnerable objects (few sensitive ecosystems) and medium resilience capacity. In the coming years, geologic resources vulnerability is predicted increasing due to climate global change (especially directly influenced by sea level rise) and threats from unsustainable exploitation and use of geologic resources (e.g. mass of waste discharge from Thi Vai River into Ganh Rai bay.

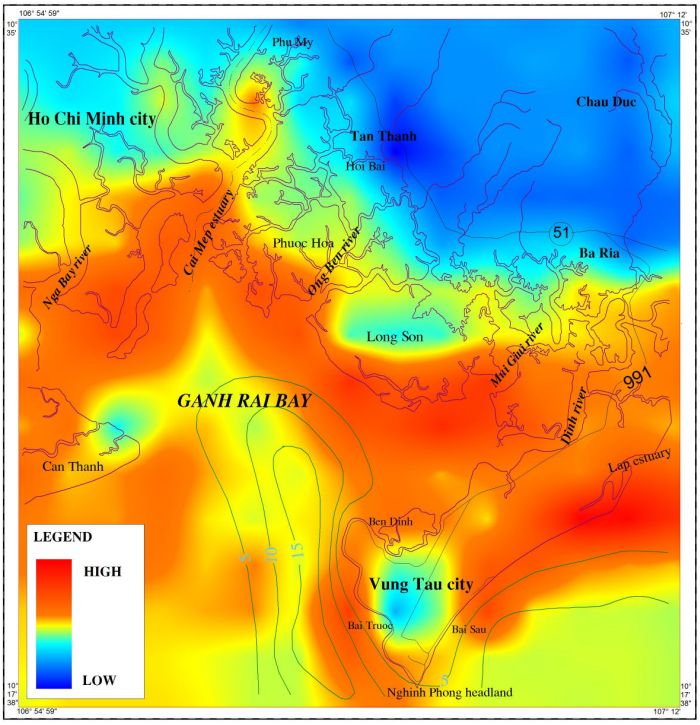

Figure 3 Diagram described the vulnerability of Ganh Rai bay

PROPOSED SOLUTIONS FOR SUSTAINABLE USE OF GEOLOGIC RESOURCES IN GANH RAI BAY

The aim of geologic resources sustainable use in Ganh Rai bay is to meet the needs of resources exploitation and use in order to develop the regional economy and improve the quality of life toward a justice and equality society and environment protection, hazards mitigation, geologic resources conservation.

In order to meet this aim, simultaneously enhance the resilience capacity of geologic resources and decrease the bad impact of hazards, the vulnerability geologic resources in Ganh Rai bay needs to reduce. That is also toward to suitable development - a development of sustainable economy, society and environment [4]. Therefore, a series of solutions is proposed, including management, education and propaganda, geologic resources use planning and hazards mitigation. The rationale of solution is based on the result of the vulnerability assessment.

Management

Law and policy enforcement: geologic resources exploitation and use have to abide not only by the national systems of laws and policies, especially Environment Protection Law, Fishery Resources Protection Law, Minerals Law… but also by international laws and conventions which Vietnam joined as Ramsar Convention, Biodiversity Agenda… Otherwise, it is necessary to enforce new policies to conduct and promote ecological-economic models (eco-tourism, silvo-fishery, sustainable mineral exploitation etc.); and establish a hazards insurance fund to mitigate and share damages of hazards. Especially, new sanctions and form of fines should be set up and enforced to agents, factories which exploited unsustainably causing loss of geologic resources, degradation of landscape and environment. Beside that, the environment restore law needs to apply and enforce to the pollution sources (industrial zone, factories, transportation means etc.). Additionally, it is necessary to strengthen and consolidate the traditional customs, rules and local regulations appropriating to environment protection, hazards mitigation and sustainable use of geologic resources.

Integrated Management was based on the result of geologic resources vulnerability assessment and conducted following characteristics of 3 groups of factors: vulnerability factors (focusing on hazards management); features of geologic resources (specialty management: fishery, tourism, transportation etc.); and resilience capacity (community based management). For the high vulnerability zone, the management should focus on hazards prevention and mitigation and resources protection, and encourage conversion of resources exploitation and use into ecological models. Beside, it is necessary to focus on the propaganda and education to raise community awareness about disaster prevention and

natural resources, environment protection; improve management capacity and awareness about geologic resources values and functions. Along with that is to promote cooperation among managers, local communities and other stakeholders in implementation of ecological economic models and strengthening institutions, policies for integrated management.

Education and propaganda

Education and propaganda aim to raise awareness about geologic resources values and functions, sustainable exploitation technology (fishery and mining) and threats of geologic resources (especially erosion, oil spill problems, storms and pollution). Education and propaganda is a necessary solution to increase social resilience capacity to the vulnerability cause factors. In order to make effectively for the solution, it needs to focus on education and propaganda objects as managers, local people and students. In this, some principles to note are: respect for the right and benefits that the community could be brought from geologic resources; appreciate the resilience, attract the active participation of communities, stakeholders; education, propaganda should be carried out continuously. Beside, it is necessary to have guidelines and regulations for visitors to travel with the sense of environmental and geologic resources protection via newspapers, radio, television, the internet, leaflets...

Hazards mitigation

In the study area, there are only erosion prevented sea walls in ward 1, ward 5 of Vung Tau city and at some resorts of Thuy Van and Sau beaches. And, Ganh Rai bay is affected seriously by oil spill problems and waste water from urban and industrial zones. In order to mitigate the damage from hazards, it is necessary to apply not only solutions of management and education, but also technical solutions as followings:

- Strengthening and building anti-erosion sea wall along the coastline of wards 1, 5, 8 and 11 (Vung Tau city);
- Setting up monitoring stations system, warning and forecasting for oil spill problems and environmental pollution;
- Restoring mangrove ecosystems in Long Son commune, ward 11 (Vung Tau City), Huong Long Ward (Ba Ria town) to create a suffer zone for preventing waves, protecting environment, maintaining biodiversity.

Geologic Resources use plan

Basing on the result of geologic resources vulnerability assessment, different zones have different distribution and exploitation form of geologic resources, therefore, proposed activities need to meet spatial content and requirements of the plan and implementation of priority activities in order to increase the resilience capacity in the zone. In there, prioritizing the application of geologic resources sustainable use model (eco-tourism/sustainable tourism, silvo-fishery, ecological agriculture and forestry etc.) to reduce the bad impact to resources and environment and conflict in geologic resources exploitation and use. Beside that, application hazards mitigation methods to reduce the loss of resources is needed (table 2). Thus, in order to implement effectively the plan in each region, it is necessary to have a good cooperation and active participation of relevant stakeholders in setting up and implementing plan and the plan has to set up based on national enforcement laws and regulations.

For example, in the high vulnerability zone, in order to enhance the resilience capacity, planning should reduce the negative impact from geologic resources exploitation and use (transportation, sea ports, tourism, fishery and aquaculture) and from hazards (erosion, oil spill problems, and siltation). Therefore, proposed activities in planning are: ecotourism (ward 1, 10 - Vung Tau city), silvo-fishery (Long Son - Vung Tau city), sustainable fishery and mangrove protection, conservation (at estuaries) in combination with hazard mitigation solutions.

Table 2 Solutions for sustainable use of geologic resources in Ganh Rai bay

Vulnerability characteristics	Proposed solutions for sustainable use
Very high vulnerability zone: estuaries, coastal zones of ward 1, 10 and Long Son commune (Vung Tau city)	- Prioritizing investment and consolidation of anti-erosion seawalls and siltation, protecting mangrove - Enhancing the response for oil spill problems - Applying ecotourism and silvo-fishery models, sustainable fishery and integrated managing sea-ports
High vulnerability zone: Vung Tau city (wards 2, 5, 6, 11, 12); Dinh estuary and shallow sea less than 6m water depth	- Prioritizing to invest in prevention and mitigation damages from erosion and oil spill problems. - Applying and promoting new models of ecological economy as eco-tourism and silvo-fishery, fishery and minerals sustainable exploitation
Medium vulnerability zone: Thi Vai river banks, coastal wards of Ba Ria town and wards 4, 7, 9 of Vung Tau city	- Prioritizing to apply and promote new models of silvo-fishery and eco-agriculture, develop the sea-ports and manage effectively rivers and flows. - Protecting and conserving mangrove - Implementing the solutions to reduce the damages from hazards, pollution and oil spill problems
Low vulnerability zone: highlands, offshore parts and sea-ports in Tan Thanh district and Ba Ria town	- Prioritizing to apply and promote new models of eco-agriculture and sustainable mining - Launching programs of education and propaganda to raise local community awareness about values and function of geologic resources

CONCLUSION

Geologic resources vulnerability assessment criteria was set up basing on 3 factor groups: vulnerability factors (criteria of hazards and hazard enhancement factors); vulnerable objects (multiform of geologic resources) and resilience capacity.

The result of geologic resources vulnerability assessment, Ganh Rai bay is divided into 4 zones following the vulnerability levels: low, medium, high and very high. The very high vulnerability zone usually has high to very high damage from hazards (erosion, siltation and sea level rise), oil spill problems and pollution. This zone has high density of vulnerable objects (geosistes, geotopes, and mangrove) and medium to high resilience capacity (high restoration and resilience of mangrove; good infrastructure; good hazards response and geologic resources protection). On the contrary, the low vulnerability zone usually is weakly affected by vulnerability factors and has low density of vulnerable objects (few sensitive ecosystems) and medium resilience capacity.

Based on this assessment, some solutions for sustainable use of geological resources have been proposed such as management (law and policy enforcement, community based management etc.,), hazards mitigation (strengthening and building anti-erosion sea and monitoring stations system, warning and forecasting for oil spill problems etc,.), geological resources use planning (eco-agriculture, eco-aquaculture, eco-tourism, sustainable fishing and mining, seaport developing and management together etc.) and education and awareness.

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