Risk Assessment of Coastal Erosion for Suitable Rural Planning

- Southern Red River Delta, Vietnam -

持続的土地利用計画に向けた海岸侵食域の危険度評価

—ベトナム紅河デルタ南部を事例として—

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I Introduction

In recent years, the southern region of the Red River Delta, Northern Vietnam has increased in population density. Intensive cultivation has brought about remarkable land use change. Additionally, during the last 40 years, the Red River Delta has suffered due to water-related natural disasters. Severe flooding and lengthy inundations of paddy fields have caused crop decay. Inland stagnation of water has been related to diseases and economical loss in the Hanoi metropolitan area. Increased salinity concentrations in the paddy fields along coastal regions due to storm surge, and agricultural damage due to coastal erosion have had negative impacts on land availability in the southern part of the delta. Communities has been relocated from these areas at risk and relocated to central Vietnam. Rice production from the region has also decreased due to increases in soil salinity levels. The Central Government of Vietnam is in need of solutions for these severe social problems. Coastal erosion in the study area is caused by the following reasons: (1) the Hoa Bin dam constructed in the upper part of the Red River has trapped sediment flow, (2) the destruction of the natural sea-wall system by cutting down the mangrove forests to build aquaculture farms, (3) decreasing amounts of river bed sand due to dredging for brick and building materials, (4) ground subsidence caused by the pumping of underground water, (5) increasing typhoon frequency, (6) changing mass balance in the watershed area (Haruyama, 2000; 2002). Besides, the drift sand supply has been decreasing since the construction of the tidal irrigation system in the coastal zone. Consequently, the coastline moved further inland (Vu & Nguyen, 1992; Haruyama et al., 2002).

Considering the social problem of associated with this phenomenon, prevention methods including rural planning are strongly required. The evaluation and assessment of coastal erosion to date will serve to guide conservation management plans of regional resources and will also provide suitable predictions and precautions against continued hazards. Risk assessment and risk management strategies are urgently needed in this study area. The objective of this study is to establish a method of evaluating coastal erosion and then create applications for rural planning utilizing remote sensing data.

II Study area

The Red River Delta, Vietnam (Fig. 1) is a fluvial plain located in the crustal movement region, affected by tropical monsoon with strong northeast wind in the dry-cold winter and heavy rain or typhoons in the hot-humid summer. The annual rainfall is 1,650mm in Hanoi, around 70-80% of the precipitation occurs during the summer. According to the meteorological data provided by Vietnam General Department of Meteorology and Hydrology, from 1884 to 1999, 5 typhoons or tropical depressions attacked to this alluvial plain each year in Northern Vietnam. The storm surges brought by those typhoons or tropical depressions caused severe coastal erosion and flooding damages. Based on the tidal activity data collected from Hon Dau Observation Station in North Vietnam, it is defined that the coastal erosion is also affected by recent sea-level rise in Bacbo Gulf (Haruyama, 2002). The mouth of the Red River had been expanded until the middle of the 20th century because of the embankment and reclamation projects to increase rice production.

III Methods

Fig. 1 Study area.

Fig. 2 Scheme to build coastal erosion risk map and vulnerability map.

Table 1 Eight sheets of satellite images.

Satellite Sensor	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR	JERS-1 SAR
Obs. Date	1994/9/30	1995/2/9	1995/9/17	1996/1/27	1997/1/13	1997/10/4	1998/2/13	1998/9/21
Map Projection	UTM	UTM	UTM	UTM	UTM	UTM	UTM	UTM
Earth Ellipsoid	GRS80	GRS80	GRS80	GRS80	GRS80	GRS80	GRS80	GRS80
Pixel Spacing	12.5m	12.5m	12.5m	12.5m	12.5m	12.5m	12.5m	12.5m
Center Latitude	N20.036	N20.036	N20.036	N20.036	N20.036	N20.036	N20.036	N20.036
Center Longitude	E106.336	E106.335	E106.355	E106.298	E106.312	E106.308	E106.256	E106.270
Number of Pixels	6000	6000	6000	6000	6000	6000	6000	6000
Number of Lines	6400	6400	6400	6400	6400	6400	6400	6400

The scheme for preparing risk maps against coastal erosion showed in Figure 2. The authors used the JERS-1 SAR (Synthetic Aperture Radar) images which were available in both rainy season and dry season.

1 Coastal Dynamics Index (CDI)

To investigate the coastline change for 5 years when coastal erosion accelerated remarkably, 8 sheets of satellite images (Table 1) taken from 1994 to 1998 were collected. And total 149 measuring points were tracked across the coastline in the interval of 500m (Fig. 3). The measurement lines which were perpendicular to the coastline were laid down on the each measuring points. The authors measured the distance in km from the coastline of 1994, coastal dynamics index (CDI) (Haruyama et al., 2004), on the measurement lines. The sea level couldn't be taken into consideration due to lack of tidal data in this study area.

JERS-1 SAR provided by NASDA had been running from 1992 to 1998. However, the satellite images in the first 2 years could not be used because of the strong noises, only the information after 1994 could be used to calculate CDI in this analysis. PCI Image Works Software in PC was applied to conduct the image analysis. The nearest neighbor interpolation was used in all of the JERS-1 SAR Images, and 15 GCP points were secured in each satellite image based on the topographic map with a 1:50,000 scale. The RMS error between the topographic map and the satellite image was 1.2, and the RMS error between each satellite image was under 0.5. Frost Filtering was used to diminish the speckle noises in each satellite image (Frost et al., 1982).

2 Riskmap for coastal erosion

CDIs are deeply related to the coastal erosion in southern Red River Delta. Next, a risk map for coastal erosion based on CDI was prepared. Considering the CDI measurement scale was 500m, the map was

Fig. 3 Measuring points (open circle) in the study area in every 20th.

Fig. 4 Mesh map.

divided into 500m meshes, covered all CDIs on the coastline. The average CDI was calculated to represent the CDI value in each mesh, for example, if there was only 1 CDI in 1 mesh, this CDI value represented this mesh; if there were 2 CDIs in 1 mesh, then the average CDIs was calculated to represent the CDI value in this mesh. Besides the CDI value, given the fact that the infrastructure was one of the important frameworks to the regional planning in the study area, some geomorphologic features should be also considered to build the risk map. The authors made the 500m mesh map of embankment locality by the documents preserved in provincial government offices. In the field study, the authors measured the height of the sea wall, relative height with sand dunes or sand ridges, and the swampy lowlands between the ridges using HANDLEVEL K50-1560 (Nobel) among Hai Hau, Ngha Hung, Thanh Hoa areas, and etc. The authors used the longest embankment to represent each mesh. Likewise it is taken into account that the areas are under-sea-level or not, regarding geomorphologic features, for example in coastal erosion area, the tidal plain, former river course, sand ridges and sand dunes, offshore beach. However, only CDIs, the heights of the dykes and sea level could be taken into consideration since all the other information were quite fragmentary and incomplete.

Fig. 5 Land use mesh map.

Fig. 6 CDI change from February, 1995 to September, 1998. 0 km is the standard coastal line (September, 1994).

The risk map now could be build by integrating those 3 major factors: CDIs, dykes, and height of land. CDIs were subtracted by former CDIs among 8 sheets of JERS-1 image, that is, these CDIs directly measured the coastline changes of the terms. To measure the risk of the dykes, a risk ranking 0 to 2 was assigned to each dyke by accessing the height of dyke. The standard height of dyke in this study area was 4m.

Risk level 0 was assigned to those existing dykes with the height more than 4m, risk level 1 was assigned to those dykes less than 4m, and risk level 2 was assigned to those areas without any dyke. The risk measurement to the sea level also could be classified into 2 categories: risk ranking 0 represents if the land level was higher than the sea level, risk ranking 1 represented if the land level was lower than the sea level. Based on the above 9 items (7 CDI data, dyke data and height of land data), 74 meshes in 500m squares were defined using the cluster analysis of UPGMA (Unweighted pair-group method using arithmetic averages, Sokal, 1963). Pearson's product moment correlation coefficient was used as similarity coefficient.

To build the risk map for evaluating coastal erosion, an extra factor "distance from the sea" has to be included to assess the coastal erosion risks. The authors defined total 686 meshes in Figure 4 and used the same clustering calculation as coastal 74 meshes. The coastal meshes were assigned to clusters which were calculated in pre-paragraph. The inland meshes were identified as the same group of the nearest coastline meshes. The meshes which were on the opposite side of the Day river were identified whose CDIs were small. If a mesh was on the coastline the distance was 0km from the sea, otherwise, the distance was calculated as km by multiplying the number of meshes to the coastline by the length of diagonal line or side line.

3 Land use vulnerability

Current land use in the study area was examined to assess the human factor as well as the natural factor. Five types of land use are classified as follows: village, rice paddy, rush field, saltpan and mangrove forest. According to their importance to human activity, total 4 importance rankings are assigned to those

Table 2 Items used to classify the meshes

Item	Range
CDI (Sep 1994-Feb 1995)	-0.17 ← → 0.20
CDI (Feb 1995-Sep 1995)	-0.29 ← → 0.58
CDI (Sep 1995-Jan 1996)	-0.09 ← → 0.72
CDI (Jan 1996-Jan 1997)	-0.20 ← → 0.09
CDI (Jan 1997-Oct 1997)	-0.30 ← → 0.41
CDI (Oct 1997-Feb 1998)	-0.38 ← → 0.18
CDI (Feb 1998-Sep 1998)	-0.35 ← → 0.97
Dyke	4m ≤ Dyke: 0; Dyke < 4m: 1; No Dykes: 2
Height of Land	Sea < Land: 0; Land ≤ Sea: 1

Fig. 7 Coastline meshes classified by UPGMA cluster analysis.

Fig. 8 Coastal erosion risk mesh map. Total 686 meshes are classified by UPGMA cluster analysis.

groups: saltpan and mangrove forest are ranked as 1, rush field is ranked as 2, paddy is ranked as 3, and village is ranked as 4. The dominant type of land use is selected to represent the feature of each mesh on the mesh map (Fig. 5). Land use vulnerability is calculated by multiplying the importance of the land use by the risk rankings from the risk map.

IV CDI change

CDIs showed in Figure 6 can be roughly divided into 2 parts - positive section and negative section. Measuring points from the 20th to the 80th, located from the northern Hai Hau to the mouth of Ninh Co River, show the negative sign indicating the erosion zone. Measuring points from the 85th to the 130th, located from the mouth of Ninh Co River to the Day River, show the positive sign representing the deposition zone. Generally speaking, deposition is common towards the mouth of a river. The maximum expansion captured through CDIs is more than 1 km per year in the western part of Ninh Co River mouth, while the minimum is - 0.5 km in northern Hai Hau to the mouth of Ninh Co River.

The average CDI in the erosion section from is - 0.15 km from 1994 to 1997, while CDIs in year 1998 indicates more serious erosion occurred in this area. Almost all CDIs in this erosion area have the same tendency every 2 year and an adverse tendency every year.

More than 100 people died in 2 typhoons between July and August 1997. Not over 70 people died while other typhoons from 1994 to 1998. The big erosions occurred the measuring point numbers of 10, 16, 93-105, 112-113 from January to October in 1997.

V Risk map for coastal erosion

By using all the items listed in Table 2, the authors classified the 74 meshes. The coastline was divided into 4 large clusters (Fig. 7). The CPCC (cophenetic correlation coefficient) (Sokal, 1963) was 0.941. The features of those 4 groups are as follows: Group I - regardless of CDIs, most part of the dykes in each mesh are not over 4m; Group II - coastal erosion occurs, land level is below the sea level; Group III - coastal erosion or small deposition occurs, the land level is above the sea level; Group IV - large deposition occurs.

With another factor "distance from the sea" added with the previous 4 groups, total 686 meshes and 9 new clusters were classified (Fig. 8). The CPCC was 0.897. Since inland area had lower erosion risk compared to the coastal area, the risk ranking assigned to the new clusters were as follows (from the highest risk ranking to the lowest): Risk 9 - the coastal area in Group I; Risk 8 - the coastal area in Group II; Risk 7 - the coastal area in Group III; Risk 6 - the coastal area in Group IV; Risk 5 - the inland area in Group I; Risk 4 - the inland area of Group II; Risk 3 - the inland area of Group III; Risk 2 - the inland area of Group IV; Risk 1 - interior of the Risk 2 - 5 area.

The final risk map shows the coastal areas such as Giao Thuy, Hai Hau, and Hoang Hoa are the most dangerous places - they have the highest probability to encounter the land loss problem in the near future. The risks of deposition area are also higher than inland area because they are easily affected by the coastal erosion as well as coastal erosion area.

VI Land use vulnerability map

The land use vulnerability map in Figure 9 was used to access the coastal erosion risk from the aspect view of the land use. The vulnerability was calculated in 3-3 (Method - Land use vulnerability map) and ranked by 6 levels as follows; 1) 0-4, 2) 5-9, 3) 10-14, 4) 15-19, 5) 20-24, and 6) 25-27. The total numbers of meshes were 686. The numbers and percentage of meshes to each vulnerability were as follows: vulnerability 1 had 332 meshes (48.4%),

Fig. 9 Land use vulnerability mesh map.

2 had 124 meshes (18.1%), 3 had 88 meshes (12.8%), 4 had 59 meshes (8.6%), 5 had 70 meshes (10.2%), 6 had 13 meshes (1.9%). The average vulnerability was 2.2 and standard error was 0.46.

The land use vulnerability map indicated that the coastal erosion risk from the aspect of land use was highest at Vanly area and the village in Hoang Hoa. The coastal erosion risk of rice paddy was highest in the coastal area of Giao Thuy and inland area of Vanly.

There were rush fields in the inland area of Ngha Hung and Kim Son (Fig. 5) which were the deposition area. These rush fields could be considered to be low vulnerability from the aspect of coastal erosion (Fig. 9).

VII Discussion –Facing the mitigation

This study used the CDIs calculated from JERS-1 SAR images to build the coastal erosion risk map, consequently, combine the risk map with the current land use to evaluate the coastal erosion vulnerability of the southern Red River Delta to provide a better land use suggestion for rural planning.

The Local Provincial Government Office of Vietnam has not supported to make the proper land use policy, including the adaptability facing environment diversity. However, the local areas have the eager needs to overcome the natural hazard and living close together with natural environmental condition toward mitigation by the making method of land use policy.

Based on the natural environmental characteristics of coastal erosion and the affected areas, erosion probability can be assessed by using remote sensing data analysis. This methodology can also apply to the other regions in Vietnam or those developing counties with the restriction to extract the suitable special information such as topographic maps, historical record of disaster, and relief structure because of secret for military affairs.

The land use vulnerability map can also be used to set the priority to 1) build the artificial dykes or sea wall, 2) the “washing method” for irrigation system to maintain the water quality without saline and 3) suitable cropping pattern in the erosion area. It is also applied to protect mangrove forests which grow on muddy tidal flats, such as the mouth of the Red River.

In statistical terms, total changes of land use in this area can be estimated by using average value of vulnerability. Thus, after the actual changing or planning, ex post analysis is possible.

In high risk areas, suitable means must be taken for disaster prevention which corresponds to the local area.

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Summary

ベトナム北部紅河デルタは、人口が集中し、土地利用の高度化が顕著である。この地域では集約農業が行われているが、洪水や高潮災害などの水関連災害に脆弱である。特に南部デルタ沿岸域では近年、海岸侵食による被害が大きくなっており農地被害のみならず、沿岸部の地域社会に軋轢と組織変化をもたらしている。それにもかかわらず、海岸線変化とそれによって引き起こされる被害の予測に関する議論はほとんどなされていないばかりか、地域防災計画も皆無に等しい。本研究では、土地利用計画が未策定である紅河デルタを実例として、JERS-1 合成開口レーダ (SAR) による 1994 年から 1998 年までの衛星画像 8 枚を重ね合わせ、海岸線を得ることにより海岸線動態値 (CDI) を求め、対象地域の侵食、堆積特性を明らかにした。さらに、海岸線動態値および海抜と堤防データを利用してリスクマップを作成し、海岸侵食の観点から現状の土地利用の脆弱性評価を試みた。