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RISK MAPS AND COASTAL DEFENSE CRITERIA IN TAIWAN

Wei-Po Huang[1], Lien-Kwei Chien[1], and Lee-Hsueh Lee[2]

Key words: coastal protection area, risk map, coastal hazard.

ABSTRACT

To promote sustainable development, the Coastal Zone Management Act prescribes that coastal areas should be divided into two levels of protection zones. However, the complexity and variety of coastal defenses and land use cannot be described completely by using these two levels alone. Coastal risk maps, based on natural and manmade characters of a region, showing different degrees of vulnerability and hazard potentials, can aid in making decisions. In this study, the criteria for coastal protection and land use in terms of risk maps were adopted. A tentative risk map was presented for the northern Kaohsiung City coastal area, Southwest Taiwan—a first-level protection area, strongly requiring a long-term protection strategy. The safety of coastal defenses and land use at their present state were assessed for proposing the coastal protection measures for hazard prevention. The current results can be used for future coastal management.

I. INTRODUCTION

Coastal engineering in Taiwan was started in the 1960s. At that time, hard engineering measures were used for coastal safety and protection. To promote economic, the coastal exploitation continued in the 70s and 80s. Reclaimed lands were used for large-scaled industrial parks and export processing zones. Late in the last century, the repercussions of these large-scale exploitations and hazards induced by the coastal constructions began to emerge. In response, the government began to regulate the use of coastal areas and non-engineering protection measures. The concept of integrated coastal protection management was introduced. However, conflicts between parties of coastal exploitation and regulation continued as the draft of the "Coastal Zone Management Act" was pending in the Legislative Yuan of the Republic of China. This situation impeded the implementation of integrated coastal zone management (ICZM) strategies because of a lack of legal basis in land-use planning. Moreover, coastal area residents demanded the most stringent coastal defense criteria, neglecting the resulting degree of potential coastal hazards and economically viable use. These could lead to increased negative effects for the coasts. The Coastal Zone Management Act was passed in February 2015, aiming for maintaining natural systems; ensuring no loss of natural coasts; responding to climate change; preventing coastal hazards and environmental damage; protecting and restoring coastal resources, implementing integrated coastal zone management, as well as promoting a sustainable development of coastal zones. This act also regulates the coastal areas, which under the different severity levels of coastal hazards will be classified into two grades of coastal protection area and proposed their own "coastal protection plan" in the near future. Therefore, the current focus of overall coastal protection technology for future engineering plans and management is the development of coastal protection area grading. Coastal risk maps, derived from potential coastal hazards and vulnerability, provide crucial information for grading.

Coastal vulnerability can be defined as a measure of the threats of natural events, such as floods, storm surge, cyclones, and sea-level rise, can have on coastal residents (McCarthy et al., 2001; van der Veen and Logtmeije, 2005; Parkinson and McCue, 2011). Possible losses increase when risks and vulnerabilities increase (Cutter, 1996). Various methods have been used to evaluate vulnerability. The methodologies can be categorized into (1) index-based methods including several variants of the coastal vulnerability index (CVI) estimated using different indicators, (2) methods based on different numerical models that estimate potential hazards under different scenarios, and (3) Geographic Information System (GIS)-based decision support systems that overlay spatial layers of land use information to estimate coastal vulnerability (Rosedahl and Balstrøm, 2014; Tarragoni et al., 2014). Rosedahl and Balstrøm (2014) suggest that the CVI approach is thus far the most realistic option for use in data-poor regions. Considering that the basic data on coastal regions is often incomplete in Taiwan, the CVI approach seems to be the most favorable option for assessing coastal risks.

In recent years, the selection of the indicator for the CVI approach has been discussed widely. Hammar-Klose and Thieler (2001) used indicators proposed by Gornitz et al. (1994) and

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Shaw et al. (1998) to assess the vulnerability of the US coasts as results of possible sea level rise. The authors used six physical variables considering the natural surroundings to obtain a CVI and found that all six could be quantified. However, Chien et al. (2013) revealed that the results obtained using this method cannot completely reflect the vulnerability of the coasts of Taiwan, because it neglects the socio-environmental effect among the variables. The authors recommended to replace some indicators and adjust the range between the variables so that a more accurate risk map for Taiwan can be obtained. Another way to estimate the vulnerability of an area is to use its physical, environmental, social, and economic conditions as indicators (UNISDR, 2004). By adding social and economic indicators into consideration, this methodology could provide a more comprehensive assessment.

The results of the CVI approach can be used for risk maps. Chien et al. (2012) used this method to generate coastal risk maps for coastal hazard prevention and management in Taiwan. Coastal protection areas were classified into two levels to correlate with differences in land use limitations. Wang et al. (2014) employed a comprehensive assessment strategy based on the risk matrix approach (RMA). It is noted that the relationship between risk maps and coastal protection design criteria were not clearly identified in these studies. However, hazard risk maps based on defined return periods were suitable for evaluating physical damage to infrastructure or ecological surroundings (Carrasco et al., 2012) and were therefore adequate for grading coastal protection criteria.

Climate change induced sea level rise seems to be unstoppable, and hard engineering methods of coastal protection have their negative effects (Cooper and Pilkey, 2012). Thus, the losses of human lives and properties appear to an imminent threat. The Taiwan government now has a legal basis to enact regulations to limit or even ban further exploitation of hazard-prone areas as a method of climate change adaptation. Formulating adaptation strategies based on risks has been widely discussed in the last decade (Dinh et al., 2012; ESCAP/UNISDR, 2012; Luo et al., 2015; Salik et al., 2015). Adaptation strategies usually tend to be classified into protection, retreating, and accommodation (European Commission, 2004a, 2004b). In general, protection strategies involve establishing shore protection, principally through engineering structures and retreating and/or accommodation strategies involve implementation of non-engineering measures, such as delimiting setbacks and natural reserves. In other words, combined measures, including both engineering and non-engineering strategies, are indispensable for withstanding extreme events with minimal loss of human life and property.

Coastal risk maps are crucial for costal defense in Taiwan at this stage, particularly because the Coastal Zone Management Act has been passed. Notably, two levels of protection areas can be designated because this act provides accurate and straightforward regulations that central and local governments should be responsible for at each level. In other words, this act is delimited for administrative management. However, classifying the criteria for coastal defense and land use into only two categories is inadequate, owing to the various types of requirements and characteristics of the coastal areas. Coastal risk maps showing different vulnerability and potential hazard classes can be useful in the assessment of the criteria. In this study, a coastal risk map was drawn and applied for assessing the design criteria for coastal defense and land use of the coastal areas. The engineering and non-engineering measures were then proposed for preventing and reducing the effects of coastal hazards on coastal areas.

II. BACKGROUND

1. Zoning of Coastal Protection Areas in Taiwan

In preparation for the 11th and 12th paragraphs of the bill of Coastal Zone Management Act, the Water Resources Planning Institute (WRPI) has conducted a series of studies in the years of 2010-2012 under the name 'The Preliminary Planning of the Coastal Protection Project' (WRPI, 2010, 2011, and 2012). Four types of coastal hazards were identified in these studies and later listed in the Act. The four hazards are, storm surge, coastal erosion, flood, and ground subsidence. The severity levels of these four hazards for zoning coastal protection areas were assessed. Storm surges and coastal erosion were coastal hazards caused by marine force, and severe ground subsidence was the aggravating factor of the other three hazards. Table 1 classifies the severity levels of the four coastal hazards.

Table 2 presents the zoning principles of the coastal protection areas. Compound hazards and hazard severity levels were adopted as the principles for classifying and zoning protection areas. Coastal areas with severe ground subsidence were deemed to have relatively greater long-term hazard potential and were therefore categorized as first-level coastal protection areas. The others were graded according to the following principles:

(1) The extent of "coastal areas" were demarcated and declared by the Construction and Planning Agency at the Ministry of the Interior. The land areas were defined as ranging from the average high tide line to the nearest provincial highway, major coastal road, or ridgeline. Relevant assessments are restricted to the areas defined in this manner, i.e., protection areas were not to be extended beyond them.
(2) First-level protection area: areas with severe ground subsidence or with several kinds of hazards of severity level I.
(3) Second-level protection area: areas with severe ground subsidence and with one or several kinds of hazard of severity level II.
(4) Coastal areas with the similar natural hazards and having the same protection requirements were classified to have the same level of protection and thus were zoned according to the appropriate administrative boundaries or landmarks.

Fig. 1 presents the demarcation results. The total coastline length of the first-level and second-level protection areas was 478.3 and 181 km, respectively. Most first-level protection areas

Table 1. Severity level of coastal hazards.

Severity level Coastal hazards	Hazard severity level I	Hazard severity level II
Storm surge	Coastal areas with a land elevation lower than the 50-year storm surge height and a flooding depth of 1 m or deeper.	Coastal areas with a land elevation lower than the 50-year storm surge height and a flooding depth of less than 1 m.
Coastal erosion	Coastal areas subjected to coastal erosion and its potential effects within 10 years.	Coastal areas subjected to coastal erosion and its potential effects within 10-30 years.
Flood	Coastal areas with a land elevation lower than the possible range of a 50-year flood and a flooding depth of 1 m or deeper.	Coastal areas with a land elevation within the possible range of a 50-year flood and a flooding depth of 0.5-1 m.
Ground subsidence	Areas identified and announced by the Water Resources Agency as having severe ground subsidence.	

Table 2. Grading of coastal protection areas.

Hazard type	First-level coastal protection area	Second-level coastal protection area
Single hazard	Coastal sectors categorized as hazard severity level I	Coastal sectors categorized as hazard severity level II
Compound hazard	(1) Areas with severe ground subsidence and comprising coastal sectors with level I or II hazards. (2) Coastal sectors with level I compound hazards but without ground subsidence.	Coastal sectors with two or more level II compound hazards.

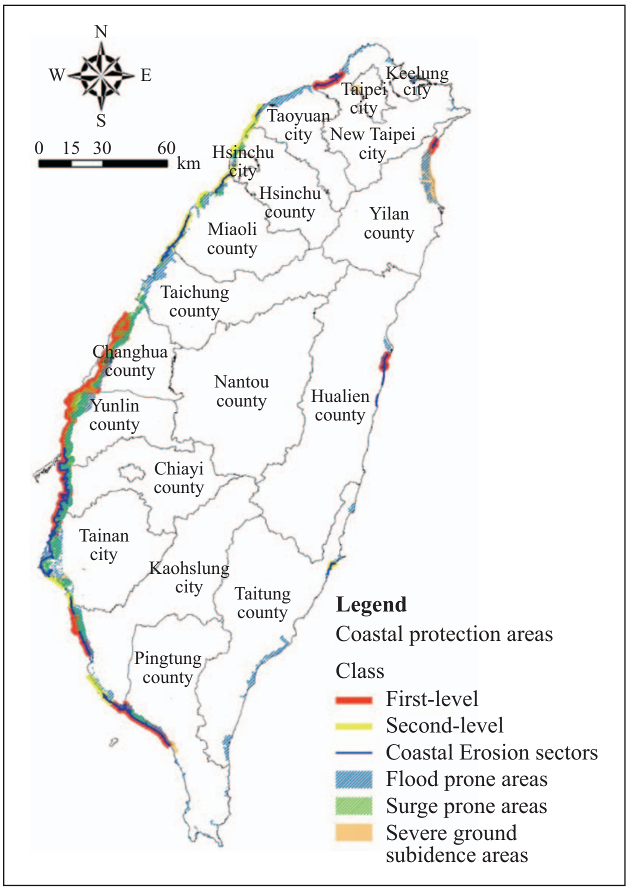


Fig. 1. Distribution of hazard prone, first-level and second-level coastal protection areas.

are distributed in the southwestern part of Taiwan in the counties of Changhua, Yunlin, Kaohsiung, and Pingtung—all having different types of coastal hazards. We selected one of these the northern Kaohsiung City for further discussion.

2. Coastal Protection Codes

Coastal protection measures were previously formulated and implemented on the basis of the seawall management regulations, which stipulate implementation within the range of seawall areas. The zoning of seawall areas was considerably restricted because of the surrounding social and economic developments, resulting in inflexibility of the coastal protection measures. The need to protect coastal areas against tides and waves, in the absence of other protection measures, led to the use of hard engineering structures, such as seawalls, with relatively strict design criteria. Consequently, relatively massive structures were constructed. However, because extreme climate events have become more frequent and more severe in recent decades, the conventional use of a single protection measure for coastal areas might become insufficient in the near future. With the conventional methods, current protection structures may need reinforcement to tackle the unpredictable trend of environmental changes. Nevertheless, regarding economic developments, environmental impact, and effectiveness, the use of one protection measure alone has its limitations. A trend of demarcating setback lines for coastal areas with high hazard risks has been noted worldwide. In other words, when encountering unpredictable natural hazards, the concept of total protection has become invalidated; hazards are allowed to occur at an acceptable level, and reduction of hazard-induced damage through risk management is attempted.

III. METHODOLOGY

Coastal areas have different characteristics and undergo various degrees of exploitation; therefore, a single set of protection design criteria is insufficient for sustainable coastal development. Consequently, differentiating the design criteria of coastal defense aims to examine the environmental characteristics of various coastal sectors. The current study established methods for assessing design criteria to be used in various coastal areas. The proposed method for assessing design criteria of coastal defense and land use management were mainly established upon a set of systematic assessment principles, from which relevant indicators were selected for further management.

1. Constructing a Risk Matrix

On the basis of the risk management policy proposed by the Executive Yuan, Taiwan, this study adopted the concept of hazard risk analysis proposed by the United Nations Disaster Relief Organization (UNDRO, 1980) involving a comprehensive examination of the relationship between hazard and vulnerability (risk = hazard × vulnerability). Coastal hazards were classified into the aforementioned four types. Vulnerability refers to the possibility of life-threatening events or property loss induced by potential hazard factors in a given hazardous area.

In the first step, spatial units for estimating vulnerability should be decided. Although adopting large scales as spatial units of analysis may enable easy and rapid operation and high data accessibility, the resulting failure reflecting the local or regional characteristics may lead to underrepresentation in analysis results. Therefore, to accurately ascertain coastal characteristics, this study adopted townships and villages as the spatial unit in the analysis. According to the spatial overlay results, the coastal areas in Taiwan comprised a total of 110 townships, consisting of 898 villages.

In the second step, the grading indicators must be selected before conducting risk analyses and assessments. From a statistical perspective, adopting more indicators generates results that better represent the characteristics of analyzed targets. However, in real-world cases, information required for indicators frequently fails to satisfy the analysis' requirements regarding spatial units and accuracy and relevant survey data may even be lacking completely. This study proposed the following principles for selecting indicators:

(1) Adopt indicators that can be easily obtained through accessible databases or simple statistical analyses and are within the required spatial unit and accuracy.
(2) To ensure data impartiality, data or research projects announced or published by public institutions or government authorities should be prioritized.

2. Criteria for Assessing Risk Classes

Regarding indicator weights, the use of expert consensus (e.g., analytic hierarchy process and Delphic hierarchy process) has generally been preferred, albeit still modified by the personal approaches of involved experts and number of survey samples (Ward, 2014). Hence, this study focused on establishing a methodology and assessing its feasibility. Hazard and vulnerability factors were therefore equally weighted for calculation.

Table 3. Hazard factor grading.

Score	Hazard type	Hazard potential (ratio of the hazard-prone area to total area)
5	4 kinds of hazards	66%-100%
4	3 kinds of hazards	
3	2 kinds of hazards	33%-66%
2	Single external hazard	
1	Ground subsidence	0% < 33%
0	No hazard	0

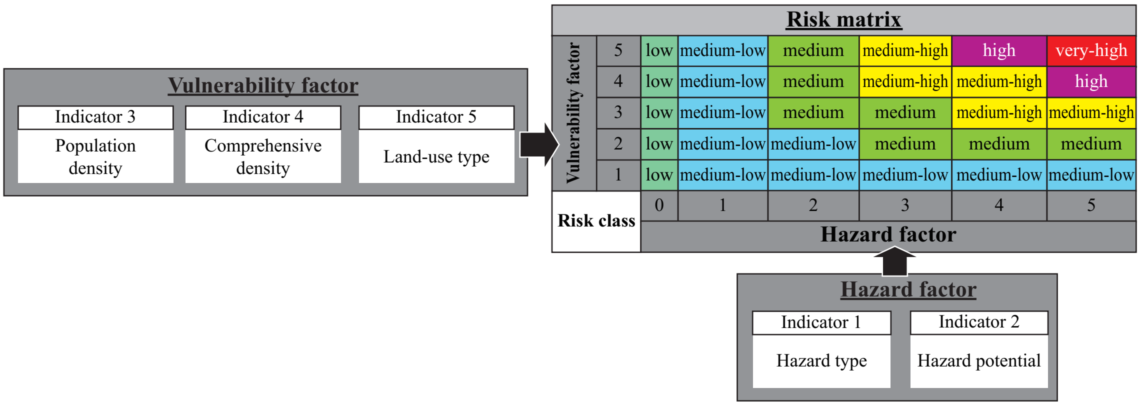
Table 4. Classification of land-use for the estimation of vulnerability.

Score	Land-use
5	Residential, commercial, educational and medical area
4	Industry, port activity and public infrastructure area
3	Productive area (agriculture, aquaculture, livestock breeding)
2	Non-productive area (mining, salt, sandstone, funerary, artificial lake and channel)
1	Nature areas

The hazard factors were categorized according to hazard type and potential. The criteria for grading hazard types and potential are presented in Table 3. Hazard type grading considered single or compound coast hazards, whereas hazard potential was defined as the ratio of the hazard-prone area to total coastal area. The score of the hazard factor was defined as the higher of these two indicators.

The indicators used for assessing vulnerability were population density, comprehensive income, and land use. The vulnerability classes were scored using a scale of 1-5, with 5 and 1 indicating greatest and least vulnerability, respectively. The population density and comprehensive income of the 898 villages within coastal areas in Taiwan was divided into the five classes by ranking them in ascending order and assigning sequential units of 20% of villages to each class. These five classes were also used for assessing land use, with vulnerability referring to the impact on human life and property. The classification of land use is presented in Table 4. The levels of vulnerability estimated in the risk matrix were the average scores of the three indicators.

The hazard and vulnerability factors were multiplied in a 6 × 5 risk matrix, generating six risk classes ranging from A to F denoting high, high-intermediate, moderate, low-intermediate, low, and zero protection levels. These risk classes were subsequently used for determining appropriate design criteria. The assessment procedure and framework for this method are presented in Fig. 2.



Risk matrix

Vulnerability factor	0	1	2	3	4	5
5	low	medium-low	medium	medium-high	high	very-high
4	low	medium-low	medium	medium-high	medium-high	high
3	low	medium-low	medium	medium	medium-high	medium-high
2	low	medium-low	medium-low	medium	medium	medium
1	low	medium-low	medium-low	medium-low	medium-low	medium-low
Risk class	Hazard factor					

Fig. 2. Coastal risk assessment procedure and framework.

3. Formulation of Design Criteria

Notably, most protective facilities in Taiwan were completed within the previous three decades. The design criteria were based on the marine climate, including the impact of waves and surges, for which a return period of 50-100 years was used. However, land use in the protection area was not considered. The use of the same design criteria is economically nonviable for protecting coastal areas with different types of land use; for instance, residential use should assume a larger protective return period than agricultural use. For sustainable use in a coastal zone, the design criteria should be formulated on the basis of the requirements of coastal protection and hazard management. In this study, coastal areas with different natural and cultural environmental characteristics were objectively investigated and provided with distinct protection strategies and suitable design criteria, on which subsequent comprehensive protection strategies were planned and designed.

The design criteria were divided into two categories: One focused on regulating coastal protection facilities, and a set of coastal protection structural design criteria were formulated on the basis of the marine climate; these design criteria specified that the protection capabilities of coastal protection facilities must fulfill the safety standards formulated on the basis of the wave and water level conditions of a certain return period. The other category of design criteria emphasized the safety of coastal social and economic environments, and a set of design criteria for land use were formulated for hazard prevention and land use modification.

IV. RESULTS

1. Design Criteria for Coastal Defense andLand-Use

Waves and storm surges are the main destructive forces along a coast. Consequently, the design criteria of relevant protection facilities must be capable of controlling and preventing tides and waves caused by extreme conditions from severely affecting protected coastal areas as well as reducing coastal hazards. This principle was a crucial factor in the safety validation preformed for designing protection facilities. The design criteria proposed in this study mainly concerned the safety of protection facilities as well as the design conditions for waves and storm surges.

The design criteria for different types of land use were also designated according to the risk levels. Land use was categorized on the basis of five types of usages for this assessment. The elevations of the different types land use are the major concern for safety assessment. It is suggested that building foundations be elevated higher than the proposed design criteria to prevent inundation caused by flood or surge. Furthermore, the use of agricultural and aquafarm lands without buildings should be modified if their elevation lower is than the design criteria.

Integrated coastal protection is realized by the combined employment of engineering and non-engineering measures. The design criteria for these two categories were flexibly formulated on the basis of the actual combinations of protection measures. The following are the proposed principles for formulating coastal protection structural design criteria and land use for various risks:

(1) High risk level: marine conditions (including wave and surge) in a 100-year return period are adopted as the design criteria.
(2) High-intermediate risk level: a 50-100-year return period is adopted as a design criterion. However, to prevent any negative environmental impact caused by upgrades in design criteria, the original design criterion is still considered applicable for a coastal defense meeting the criteria of a 50-year return period, provided that modifying the protection facilities (structural measures) or extending the buffer zone (non-engineering measures) enables the coastal defense to reduce external impact sufficiently such that the original design criterion can withstand it.
(3) Moderate risk level: a 50-year return period is adopted as design criterion.
(4) Low-intermediate risk level: a 25-50-year return period is adopted as design criterion. As mentioned, if other supportive measures can reduce external impact to the extent that the original design criterion can withstand it, the original design criterion is still considered applicable to prevent any negative environmental impact caused by upgrading design criteria.

Table 5. Coastal protection design criteriawith different risk levels.

Risk levels Protection standard		Design criteria (return period)						Considering factor
		High	High intermediate	Moderate	Low intermediate	Low	Zero	
Standard	Target object	A	B	C	D	E	F	
Coastal protection structural design criteria	Coastal structural protection facilities	100	50-100	50	25-50	25	-	Wave and storm surge level (sea)
Protection design criteria for landuse management	Building lot elevation control (residential areas or crucial social and economic areas)	100	50-100	50	25-50	25	-	Storm surge level (sea) and regional flood potential (inland waters)
	Industrial land	100	50-100	50	25-50	25	-	
	Agriculture, fishery, and animal husbandry	≤ 25	≤ 25	≤ 25	≤ 25	≤ 25	-	Storm surge level (sea) and regional flood potential (inland waters)
	Nonproductive land	-	-	-	-	-	-	
	Public evacuation facilities	100	50-100	50	25-50	25	-	Storm surge level (sea) and regional flood potential (inland waters)

(5) Low risk level: a 25-year return period is adopted as a design criterion.
(6) Zero risk level: no protection facility is required.

The proposed design criteria for coastal protection facilities and land use refer to various risk levels presented in Table 5. Both protection facilities and land-use plans can be reevaluated.

2. Case Study of Northern Kaohsiung Coastal Risk and Design Criteria

This study used northern Kaohsiung City as the case study topic to verify the proposed assessment principles on design criteria and risk analyses. The results are potentially applicable for future coastal management. The following data used in this study were obtained from the databases:

(1) Storm surges: The 50-year return period of storm surge height along the northern Kaohsiung City coast is + 1.35 m, based on The Assessment on Coastal Protection of Sea Dikes plan (WRPI, 2014). The design codes proposed in this plan were applied by the River Management Offices to assess the safety and capability of the existing seawalls. The areas of inundated depth greater than 1 m caused by storm surges were estimated on the basis of the differences in storm surge water levels and land elevation. The criterion of inundated depth of 1 m refers to the principles listed in Table 1; it defines the severity of coastal hazards where this inundated depth may be dangerous to life. Because the height of the seawall is greater than the storm surge height, the extent of inundation-prone areas was estimated assuming that seawalls were absent in the area. Some villages in Cieding, Yongan, Mituo, and Nanzih districts, but not Tzukuan district, were estimated as the surge hazard-prone areas (Fig. 3(a)).
(2) Floods: A GIS layer of 50-year return period flood-prone areas with an inundated depth deeper than 1 m was acquired from the Water Hazard Mitigation Center (WHMC, 2014). Most villages in Cieding, Yongan, Mituo, and Nanzih districts were estimated as flood hazard-prone areas. The result is shown in Fig. 3(b).
(3) Coastal erosion: The erosion coastlines of northern Kaohsiung City were estimated using data from the historical bathymetry surveys. The coastline of northern Kaohsiung City, except for the coastal sector of Yongan district, was subject to coastal erosion (Fig. 3(c)).
(4) Ground subsidence: Ground subsidence: The ground subsidence area was also acquired from the Water Resource Agency (2014). The entire area of the northern Kaohsiung City coastal coast demonstrated no threat of ground subsidence.

All data for the four hazards were acquired from official units, following the requirement of data impartiality. After overlaying the four coastal hazard-prone area layers, Yongan, Mituo, Tzukuan, and Nanzih districts were found to be subject to a compound of three hazard types. These districts included more than 66% of the total hazard-prone area, resulting in a hazard factor score of 5. The remaining districts had scores of

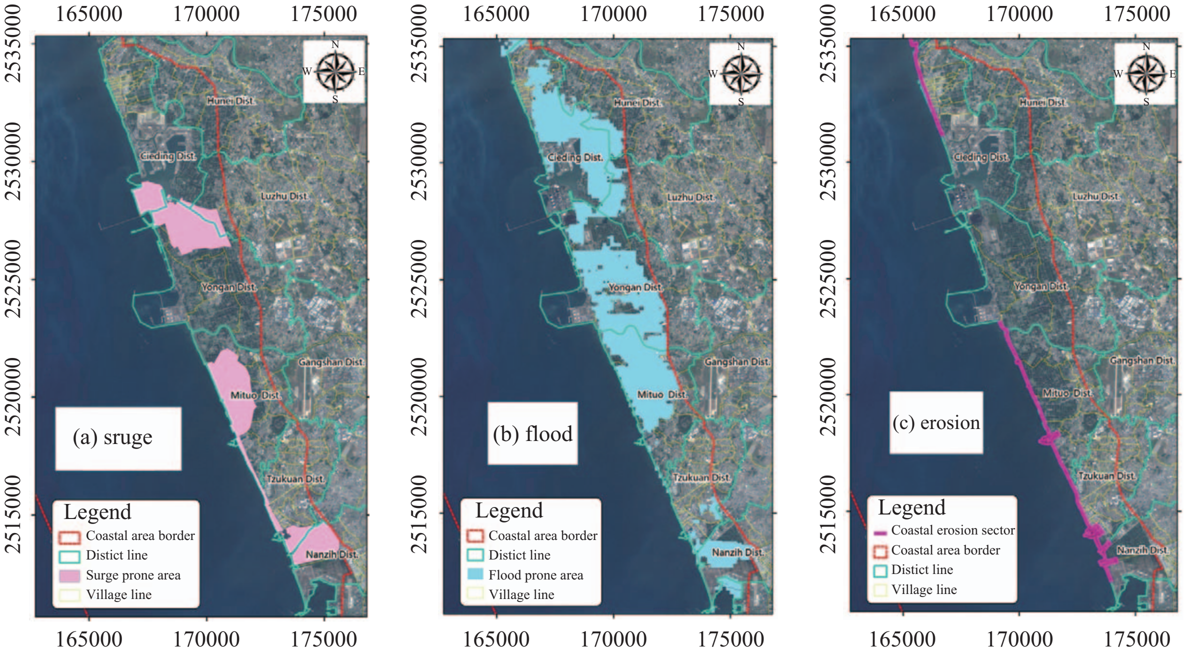


Fig. 3. GIS layers of the coastal hazard-prone areas in northern Kaohsiung City, consisting of (a) surge, (b) flood, and (c) erosion layers.

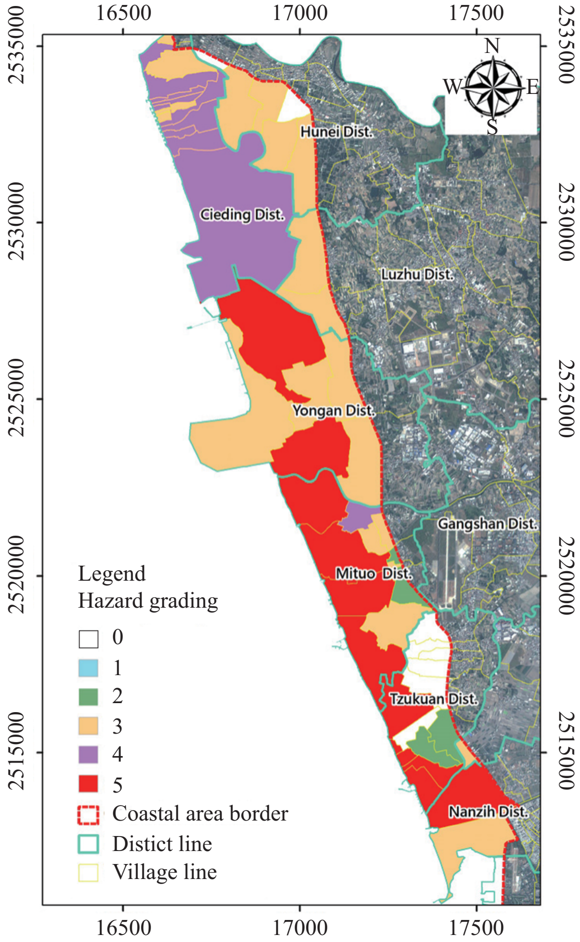


Fig. 4. Hazard grading of the coastal villages in northern Kaohsiung City.

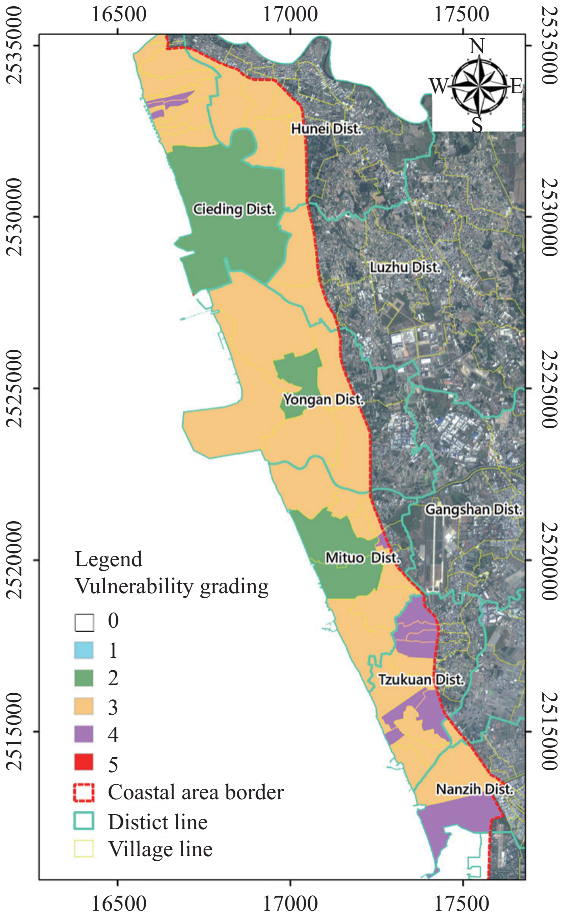


Fig. 5. Vulnerability grading of the coastal villages in northern Kaohsiung City.

Table 6. Risk levels and suggested design criteria in northern Kaohsiung.

Coastal administrative division	Risk assessment	Suggested design criteria (return period)	Protection facility
Cieding District	D	25-50	Cieding seawall Cilou seawall
Yongan District	D	25-50	Singang seawall
Mituo District	C	50	Mituo seawall Nanliao seawall
Tzukuan District	C	50	Chikan seawall Kezailiao seawall Dianbao seawall
Nanzih Nanzih	C	50	none

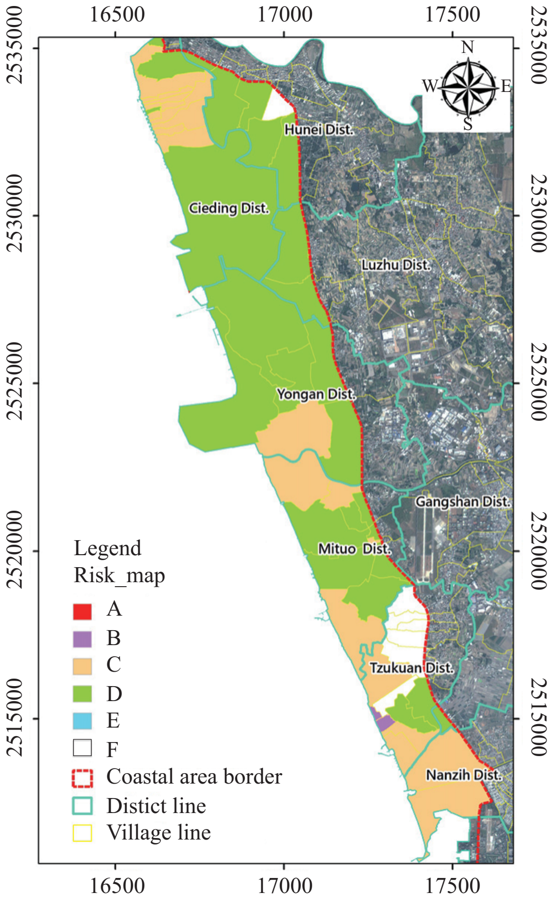


Fig. 6. Risk classes of the coastal areas in northern Kaohsiung City.

3 or higher. The hazard factor scores of each district are presented in Fig. 4.

Population density, comprehensive income, and land use were considered during the estimation of vulnerability. These data were all acquired from city government statistics. The scores of population densities and comprehensive incomes of the villages within the coastal area of northern Kaohsiung City were in the range of 1-4. Regarding land use, most of the districts constituted productive areas, whereas few were nonproductive and industry areas; land use scores were 2 or 4. The vulnerability grading was derived from the average score of the three indicators for each village (Fig. 5).

By multiplying the grading scores of hazard (Fig. 4) and vulnerability (Fig. 5) for each village, risk maps were constructed (Fig. 6). The results showed that most villages in the five districts were classified as level D (low-intermediate risk class). The village with the highest risk level, Chihsi village in Tzukuan district, was at level B (high-intermediate risk level).

According to the characteristics of each coastal area, coastal areas adjacent to others with similar characteristics can be incorporated into a single protection area unit. Therefore, an appropriate protection level should be assigned to coastal areas with similar characteristics according to each area's natural and cultural environmental characteristics. The average value of risk grading of each village was adopted as the district spatial unit. Table 6 presents the assessment of the defense of coastal areas of northern Kaohsiung City. The coastal protection level should be C and D. Thus, this study adopted return periods of 25 and 50 years as the coastal protection structural design criterion.

The designed and surveyed heights of the protection facilities are shown in Table 7. The wave run-up heights and overtopping discharges of 25- and 50-year return periods are also listed in the last 4 columns for comparison. The data were estimated using DHI MIKE 21 numerical models including the effects of waves and tides. Waves overtopped seawalls in Cieding and Tzukuan districts under the wave and water level conditions of 25- and 50-year return periods. Two types of tolerable overtopping discharges were assessed including structural safety of seawalls and danger to residence. The structurally tolerable limit of overtopping discharge proposed by Goda (1985) was quoted. The tolerable discharge of wave overtopping depends on the type of seawall structure. Two types of seawall surface armoring in northern Kaohsiung City coasts involve tolerable discharges of 0.02 and 0.05 $m^3/m/s$. All existing seawalls in northern Kaohsiung City apparently fulfilled the structural safety standards. The later one considered the direct hazard of injury or death to people and damage to property, operation, and infrastructure in the defended area. Guidance on overtopping discharges summarized in EurOtop (2007) defined the discharge limits set back 5-10 m. However, the main coastal roads and residences in northern Kaohsiung City coastal area are at least

Table 7. Assessment of coastal defense.

Protection facility	Design height (m)	Survey height (m) (2012)	Run-up height (m)		Overtopping discharge (CMS/m)	
			25-year return period	50-year return period	25-year return period	50-year return period
Cieding seawall	5.0	4.99	4.55	4.73	0	0.001
Cilou seawall	6.0	5.79	5.32	5.48	0	0.001
Singang seawall	5.0	4.78	3.48	3.59	0	0
Mituo seawall	6.0	5.62	3.09	3.22	0	0
Nanliao seawall	5.0	4.85	3.74	3.85	0	0
Chikan seawall	6.0	5.85	6.98	7.13	0.011	0.013
Kezailiao seawall	6.5	6.50	6.91	7.04	0.005	0.006
Dianbao seawall	4.0	4.00	4.34	4.49	0.002	0.003

200 m farther from the seawalls. In other words, no immediate threat to residents if the seawall areas were well cordoned off during typhoon periods. Thus, the safety of the seawalls met the criteria derived from the risk map. Nevertheless, chronic erosion remains present within the coastal areas of northern Kaohsiung City. The increasing erosion, wave run-up height, and overtopping flow are increasing the risk of flooding and the damage to the coastal defense through overtopping. The seawall slopes on the seaward side along the coast range from 1:1 to 1:2. The steep sloping structure enhances the mobilization of sediment because of the generation of standing waves and wave breaking in front of the structure leading to scouring and loss of beach (Sumer et al., 2001). Thus, we suggest that periodical monitoring projects should be conducted for further assessment. After the protection level of the existing seawalls reduces below the criteria set in Table 7 because of the local bed scouring, the engineering measures should be upgraded or modified immediately. Creating low-sloping of coastal defenses is encouraged in the future

3. Non-Engineering Measures

Considering that the hazard grade of northern Kaohsiung City is relatively high, both engineering and non-engineering measures should be conducted simultaneously to promote ICZM. We suggest the following non-engineering measures:

1) Delimiting the Setback Line

The dominant coastal hazards of storm surges and coastal erosions were considered to delimit the setback line in northern Kaohsiung City. We suggest that Tzukuan and Nanzih Districts delimit the setback line as their first priority according to the estimated risk map. Further exploitation within the zone should be limited.

A setback line of 50 m on the landward side of the 50-year return period storm surge water level is suggested.

Land use modification and construction siting is the most effective method of reducing coastal hazard caused by storms, particularly in the coastal erosion region. Local government agencies should be given a part of grant funds for reducing stockholder development within the zone.

2) Construction of the Hazard Maps

A hazard database should be established and maintained, and a risk management and economic analysis should be carried out to develop a coastal protection policy and regime.

3) Sand Budget Control

Because of high-density urbanization in northern Kaohsiung City, rivers are dammed, sand mining within the coastal area for the usage of reclaimed lands lead to loss of sand supply and balance to the beach and of course to increased shoreline erosion. Further sand mining should be restricted. The dredged material from the periodical dredge project of the channel in the downstream preventing flood in June, before typhoon season, should be taken to the beach fill project.

4) Building Renovations

Because of the threat of flooding, buildings should be modified to be prepared for flood hazards. It is suggested that the facilities or modifications include waterproof gates, foundations on stilts, temporary polder dykes, and low floors. Cieding, Yongan, and Mituo districts are particularly encouraged to deploy these measures as their first priority. The foundation elevation of any new buildings should be higher than the 50-year design criterion.

5) Community-Based Hazard Reduction

Conducting community-based exercises and education on precautions and preparedness against hazards would reduce potential losses.

V. CONCLUSIONS

This study developed a risk map using five indicators: hazard type, hazard potential, population density, comprehensive income, and land-use type. Design criteria for the assessment of coastal defenses and land use were formulated on the basis of hazard prevention and management perspectives and graded into return periods ranging from 0 to 100 years according to the risk level.

Kaohsiung City was adopted for case study to verify the proposed assessment principles for design criteria. These principles were used to evaluate the existing coastal defenses and the present status of land use. To promote sustainable management of coastal zones and to reduce coastal hazards, both engineering and non-engineering measures were suggested.

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