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Resilient Shores: Vietnam's Coastal Development between Opportunity and Disaster Risk

Background Paper

Coastal Development between Opportunity and Disaster Risk

An Assessment of the Coastal Protection System in Vietnam

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Abstract

This paper provides a high-level assessment of Vietnam's sea dike system and its prescribed dike safety standards. The assessment estimates that 65 percent of the sea dike system does not meet the safety standards and that about $2 billion in capital investment is necessary to meet the standards, mainly in the Red River Delta. It also shows that current safety standards need finetuning, especially in areas with high risk and growth. This paper acts as a technical background paper to the report *Resilient Shores: Vietnam's Coastal Development between Opportunity and Disaster Risk* (Rentschler et al. 2020).

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Coastal development between opportunity and disaster risk: An assessment of the coastal protection system in Vietnam

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1. Introduction

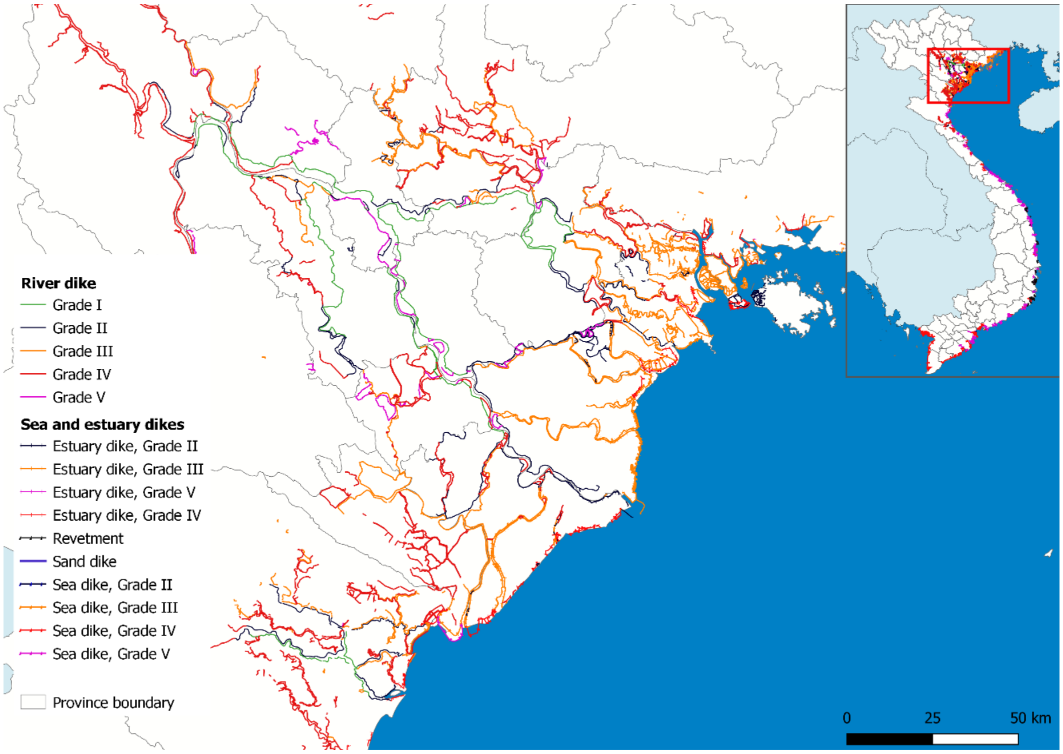
Vietnam's low-lying river flood plains, deltas and coastal margins, frequently exposed to natural hazards, are home to 70 percent of the country's population and many important economic activities. Due in part to the high concentration of population and level of development, riverine and coastal flooding is a serious problem in the deltas and lowlands of coastal Vietnam. This is particularly so in the Red River and Mekong River Deltas, with their vast low-lying areas around or just above mean sea level. Without artificial protection from embankments and dikes, these areas would flood regularly. With flooding the most serious hazard facing Vietnam, in recent decades, the government has recognized the importance of flood mitigation for the country's continued development and prosperity, investing significantly in structural and non-structural solutions for each region.

The government of Vietnam has established a clear strategy for disaster risk management and climate change adaptation, with substantially different approaches in the north, central and southern parts of the country. In the Red River Delta and North Central Regions, it aims to radically prevent floods, and take initiatives in prevent and respond to storm, drought and storm surge. In other words, it aims to completely protect these regions from flooding. In contrast, in the Mekong River Delta Region, its natural disaster prevention, response and mitigation approach is one of "living with the flood", ensuring safety for sustainable development while also taking initiatives to "prevent storm, thunderstorm, whirlwind, salinity intrusion, drought. Its approach in the Central Region combines proactive disaster prevention and adaptation for development. This mixes the two approaches, protecting the population and important economic areas from the flood, while allowing other less important areas to be flooded to a certain level.

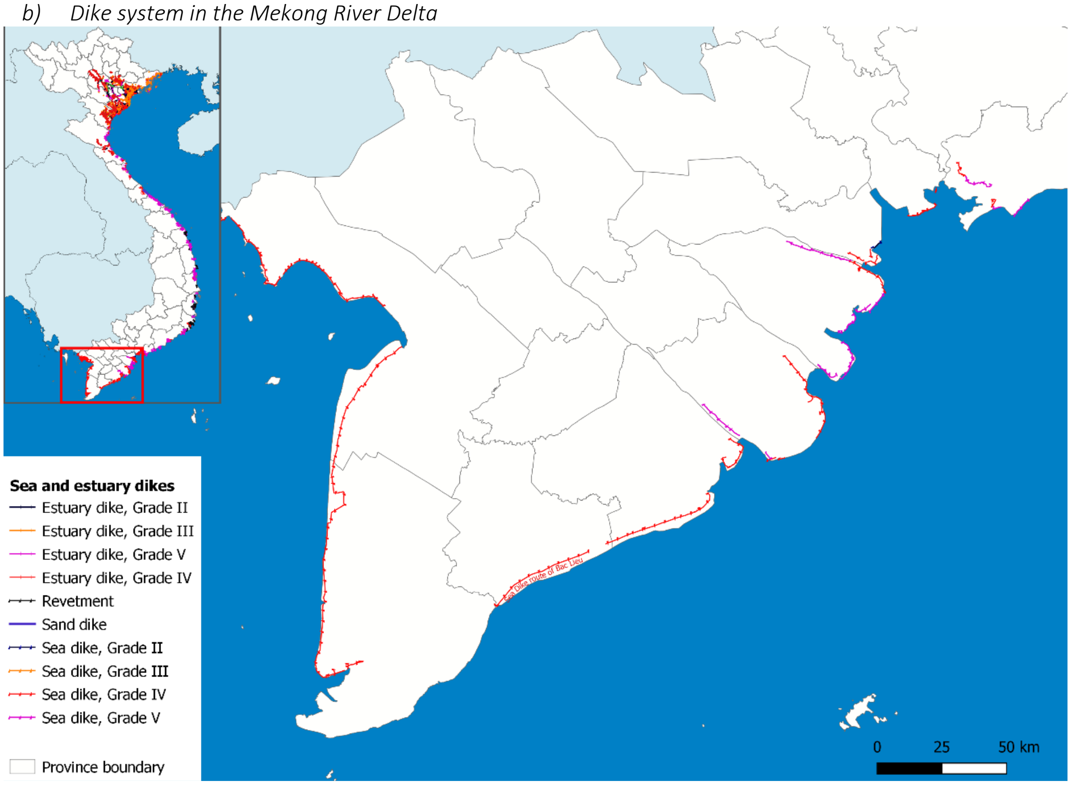
Dikes in Vietnam's coastal zone have been recognized as a central element of coastal defense for several decades.[1] Extensive low-lying regions in the Red River and Mekong River Deltas have a large system of sea and estuary dikes. In these deltas, several provinces — such as Quang Ninh, Hai Phong, Ca Mau and Kien Giang — have over 150 kilometers of sea dikes each to protect the hinterland from coastal flooding. In the Central Region, smaller dike systems provide flood safety for pockets of low-lying areas near the coast. Vietnam's sea dike system is essential for preventing extensive flooding of livelihoods and assets during high tides and typhoon surge. The total length of the sea dike system in the coastal zone is 2,659 kilometers (figure 1.1).

Figure 1.1. Extent of the river and sea dike system in Vietnam's Delta Regions

a) Dike system in the Red River Delta



b) Dike system in the Mekong River Delta



Source: Based on data from the VNDMA.

The Vietnamese government has invested significantly in its sea dike system over the past decade. In May 2009, it issued a decree on strengthening, upgrading and rehabilitating sea dikes in two phases from Quang Ninh to Quang Nam (phase 1) and from Quang Ngai to Kien Giang (phase 2).[2] This national program was divided into three periods with clear objectives for each:

- 2009–2012: Planting mangrove forests parallel to the sea dike system
- 2013–2016: Upgrading and developing the sea dike system alongside the road network
- 2017–2020: Constructing a sluice system to adapt the sea dike system to sea level rise and operate it for transportation.

It is widely recognized that the sea dike system is below its established grade level in many places and needs further upgrade. The government has introduced a grade level system for sea dikes that reflects the number of people and area protected. The higher the grade level, the higher the return period for which the sea dike should be able to withstand storm surge and waves. It is widely acknowledged in Vietnam that, due to funding constraints, many sea dikes do not comply with these grade levels. Moreover, the rapid growth in the coastal zone also makes it likely that these grade levels will increase in the near future to mitigate the increased risk to assets and livelihoods.

The aim of this technical note is to provide a preliminary assessment of investment needs for Vietnam's structural coastal protection system — consisting of sea/estuary dikes and revetments — based on the existing data and design standards managed by the Vietnam Disaster Management Authority (VNDMA). The work has been conducted as part of the Increasing Resilience in Vietnam's Coastal Areas Program[3] under the Vietnam Disaster Risk Management Advisory Services & Analytics. This draft note has been prepared for discussions with representatives from the Ministry of Agriculture and Rural Development (MARD) and other relevant agencies. The assessment and its results have been integrated into the report *Resilient Shores: Vietnam's Coastal Development between Opportunity and Disaster Risk* (Rentschler et al. 2020).

2. Data collection and dike safety standards

An inventory of all sea and estuary dikes and revetments has been compiled as a basis for this assessment. The dike profile information provided by the VNDMA's Dyke Management Department was used to produce a detailed list of the characteristics of each stretch of the coastal protection system. Table 2.1 shows an example for Quang Ninh Province. This information is provided for every 1–10 kilometers, and the list includes over 500 stretches of coastal protection, throughout all of Vietnam's 28 coastal provinces. Where crest height information was not available, this was estimated using the best available data from nearby locations. It is noted that the list provides information about the former flood protection level.[4] A new method of classifying this information has recently been adopted and is used throughout the assessment. It is explained in Section 3.

Table 2.1. Overview of coastal protection information used in this assessment
Example of a coastal protection stretch in Quang Ninh province

Item	Example
Numbering of the province TT (I–XXVIII), numbering for each stretch (1,2, etc)	I.1
Province and location	Quang Ninh, dike system in Quang Yen town: Ha An dyke
Location by kilometer	K0–K8+500
Length (in kilometers)	8.5
Flood protection level according to QĐ 58 (Grades 9–12, Tide 5%)	Grade 9, Tide 5%
Flood protection level based on new design (Grades I–V)	Grade IV
Type (sea dike, estuary dike, revetment)	Estuary dike
Current crest height (in meters)	+4.5 ÷ +5.0

The Technical Standards in Sea Dike Design (MARD 2012) have been used to extract relevant information, including the sea dike grade classification (table 2.2). This document provides guidance for the design and rehabilitation of various types of sea dike and other relevant structures in Vietnam and includes information on the grading classification system. The grade determines the safety standard, which depends on the area and population the section protects: the larger the protected area and number of people; the higher the safety standard. In areas of industrial or economic importance, the safety level can be upgraded on a case-by-case basis. The classification system is used to set the safety standard for each stretch of the coastal protection system. Grade I offers protection for a 150-year return period; Grade V for 10–30 years. This assessment has applied a 20-year return period for Grade V as a starting point.

Table 2.2 Sea dike grade classification

Area	Protected area (hectares, thousands)	Population (thousands)	Safety standard (years)
Developed industrial urban area	Over 100	Over 200	150
Rural areas with developed industry and agriculture	50–100	100–200	100
Developed rural and agricultural area	10–50	50–100	50
Medium developed rural and agricultural area	5–10	10–50	30
Underdeveloped rural and agricultural area	Below 5	Below 10	10<SS<30

Source: MARD 2012.
Notes: Developed industrial and agricultural areas are determined on the percentage of economic structure in the protected area. Areas with a greater industrialization are classified as a developed industrial area and so on. The protected areas are first classified according to industrial/agricultural development. The criteria about size and population size then determine the safety standard. If the protected area meets only one criterion, the level is lowered by one. Spatial planning must consider the country's socioeconomic development plan for 2016–2020 and Vision to 2030.

Sea dike grading, introduced relatively recently in Vietnam, is an important step in putting an explicit risk-based grade system in place. Most sea dike designs were originally based on a typical protection level against storm surge and waves with a 20 to 25-year return period (Mai et al. 2008). The current sea dike grade classification system differentiates between areas of high and low risk, directing more investment into protecting areas with a higher risk profile. These differentiated protection levels follow the same logic applied in other countries with extensive dike systems, like the Netherlands.

However, it is striking that the difference in protection levels between the areas distinguished in the classification scheme is relatively small in Vietnam. For example, there is factor 5 difference in protection levels between a rural and agricultural area with medium-level development (Grade IV) and a developed industrial area (Grade I), but the difference in number of people and area size is factor 60. This results in an uneven distribution of risk, disadvantaging more urbanized areas. Various studies also show that providing a 100–1,000-year protection level along Vietnam's coast is justified from a cost-benefit perspective (see, for example, Mai et al. 2008; Hillen et al. 2008). This is much higher than the current protection levels of the sea dike classification system.

It is therefore recommended that the government undertake further analysis and potential finetuning of its grade classification system, with more detailed assessments to optimize investments in the dike system. In particular, the analysis should consider:

- **Consistency:** The safety standards of the dikes protecting low-lying areas are not always consistent, even within the same area. For example, a detailed analysis for Tien Lang in the Red River Delta shows that the dike system surrounding this polder has significant differences in safety standards for different stretches of the sea and river dikes. These inconsistencies are potential weak links in the polder's protection system.
- **Level of protection:** As outlined above, the existing safety standard framework has a limited bandwidth in terms of protection levels, despite the large differences in area characteristics; and higher safety standards are economically justifiable in Vietnam.
- **Socioeconomic and climate change:** Rapid growth along the coast and the effects of climate change will likely require higher safety standards in the future. An exploratory analysis of how safety standards may change in time and what this implies for setting existing standards is essential.

3. Methodology of the sea dike system assessment

Using the information presented in the previous section, a methodology — outlined below — was set out to preliminarily define potential investment levels for Vietnam's sea dike system. The focus of this assessment is to define the difference between the actual and required crest height of each coastal stretch, and to translate this into an investment level using a common practice unit cost for upgrading dikes (per meter of crest height and per kilometer of dike length). This approach is used only for policy analysis, to assess investment needs and define priorities, and has been used globally in other countries, such as the Netherlands. The approach has several limitations, since it does not include any geotechnical or structural assessment of the dike system, inter alia. Nevertheless, this level of analysis is considered sufficiently accurate for gaining a better understanding of the order of magnitude and geographical distribution of investment needs in Vietnam's coastal protection system.

The methodology consists of three steps. First, the hydraulic boundary conditions of the coastal stretch are defined. Second, the required crest height for each stretch is determined. Finally, based on the obtained information, the investment needs per dike stretch are determined. These steps are explained in detail below.

Step 1: Defining the hydraulic boundary conditions for each coastal stretch

The design water levels for each stretch of the coastal protection system have been directly adopted from the MARD's dike design standards. These numbers represent the best possible information available in Vietnam. Frequency curves are available for more than 120 coastal locations, providing water levels for return periods ranging from 1–100 years. In this assessment, each stretch of the coastal protection system has been assigned a design water level from the frequency curve of the nearest point. If necessary, the design water level has been interpolated or extrapolated from the frequency curve.

Apart from design water levels, wave information is also necessary to define required crest heights. The MARD's dike design guidelines also provide detailed information about waves. However, design wave heights at the dike toe are not available and have to be calculated from offshore wave heights using wave transformation modelling on the most updated bed topography. The wave information used in this assessment has therefore been estimated in a simplified way, as described in the next two paragraphs.

During storms, wave conditions near the dike toe will be severe due to strong winds, and the depth will most likely limit certain wave characteristics such as the maximum wave height that can exist during these conditions. Therefore, a constant wave height (H_s)/water depth (d) ratio has been applied, herein: $H_s/d = 0.6$. This ratio is considered to be a good first-order estimate of the maximum wave height at a certain water depth, based on coastal engineering practice. This ratio has also been verified and confirmed by analyzing the detailed wave computation results in the current dike standards.

The toe of the embankments is set at -0.25 meters with respect to the reference level in Vietnam. This number has been estimated based on wave and water depth information near the toe from the current sea dike standards. Using the toe and design water levels, a design water depth has been estimated for this assessment. For example, a design water level of 2 meters results in a total water depth of 2.25 meters. The wave height/water depth ratio is applied to determine the design wave height for the dike stretch. In this example, the design wave height is then equal to 0.6 x 2.25 meters = 1.35 meters.

Step 2: Defining the required crest height for each dike segment

The required embankment crest height is defined by meeting an allowable/design wave overtopping, using the dike geometry and hydraulic boundary conditions. The allowable overtopping rate is not a constant and can vary depending on the quality of the dike's landward slope. The landward side of dikes in Vietnam is often unprotected but has grass cover. Hence, a maximum allowable overtopping rate of 10 liters per second per meter has been used as an initial estimate for this assessment. This maximum allowable overtopping rate originates from the current sea dike standards. Actual overtopping depends on many factors, including the magnitude of hydraulic boundary conditions, the obliqueness of the waves, dike geometry, and the use of friction elements such as blocks on the seaward-facing slope. The presence of a wave berm — an additional step on the seaward-facing side of dike that dissipates some of the wave energy — can be included in the design geometry to reduce the required crest height.

A simplified approach has been chosen to define the required crest height, by estimating the required freeboard — that is, the difference between water level and crest height — to meet the overtopping criterion mentioned above. This freeboard is generally expressed relative to the wave height at the dike toe. The assumption is made that a wave berm is generally applied for most of Vietnam's sea dikes and some friction elements are in place at the seaward-facing slope to reduce wave overtopping. The seaward-facing slope is generally built at a 1:3–1:4 gradient with a wave berm present. The typical freeboard required is then about equal to the wave height to limit the overtopping below 10 liters per second per meter. This approximation of the required freeboard is applied throughout the assessment.

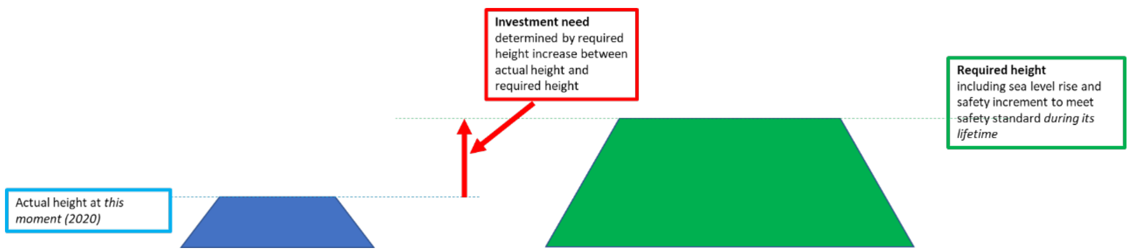
The required crest level also includes a safety height increment and provision for sea level rise and settlement. The safety height increment, established based on guidance from the MARD's sea dike design standards, varies from 0.3–0.5 meters, depending on the grade level. A provision for sea level has been included in the crest height in accordance with the design guidance, calculated by using the lifetime of the construction (which depends on grade level) and the projected average sea level rise during that lifetime, which is around 5–6 millimeters per year using a medium climate change and sea level rise scenario (MONRE 2016).[5] The provision for sea level rise in the required crest height is 0.2–0.7 meters. No allowance for settlement has been included in this assessment.

Step 3: Defining the dike system's investment needs

Potential investment needs are determined using a dike raise unit price. For this purpose, the difference between the required and actual crest height for each dike stretch (determined using Steps 1 and 2) gives a potential deficiency in crest height. This is then translated into an investment cost using a unit price for dike reinforcements from literature reviews of $0.7–1.2 million per kilometer dike stretch and per meter dike raise (Hillen 2008; see also Mai et al). Based on reviews of dike reinforcement programs in Hai Phong and Nam Dinh, this unit price is set at $1 million per kilometer dike stretch and per meter dike raise for the time being. It is noted that these are capital investment costs, and do not include maintenance costs, which are typically 2–3 percent annually of the capital investment costs.

The three-step methodology has been applied to the entire data set of dike stretches to define investment needs. First, the required dike crest height is calculated for each stretch, defined as the height needed to meet the targeted safety standard according to the MARD's design guidelines (including sea level rise and safety height increment). This height would be enough to provide the safety standard during the dike's lifetime. Comparing this future crest height with actual crest height provides the input to define the required investment costs to bring a dike stretch up to the targeted safety standard (figure 3.1).

Figure 3.1. Schematic representation of actual and required dike height
Deficiency and investment needs are indicated

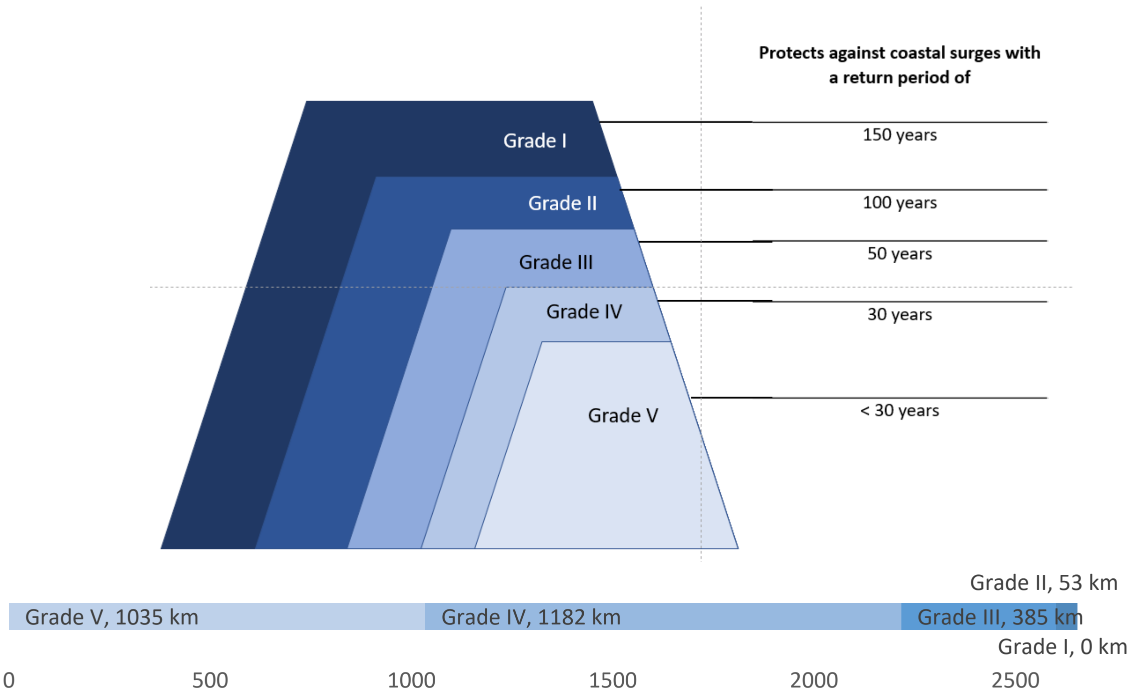


It is noted that this analysis does not consider economic and population growth and the effects of these on the required safety standards. Nor does it analyze whether another safety standard could be economically justifiable in the current situation. Hence, the results in the next sections should be considered as the minimum scenario using existing policy as a starting point. Further analysis is recommended for other scenarios.

4. Sea dike assessment results

The sea dike database built for this assessment shows that Vietnam has an extensive dike system along its coast, consisting of over 2,659 kilometers of sea and estuary dikes of varying protection levels. The sea and estuary dikes are mainly concentrated in the Red River and Mekong River Deltas, where several provinces — including Quang Ninh, Hai Phong, Ca Mau and Kien Giang — have over 150 kilometers of dikes each. While the target safety standard varies, about 84 percent of Vietnam's entire dike system is Grade IV and V, with the relatively low safety standard of 30 years and 10–30 years respectively (figure 4.1). To put this into perspective, the total length of Vietnam's sea/estuary dike system is the same size as the Netherlands' sea, river and lake dike systems. However, the Dutch safety standard is often 1/250–1/10,000 years — a much higher design protection level than the adopted safety standard in Vietnam.

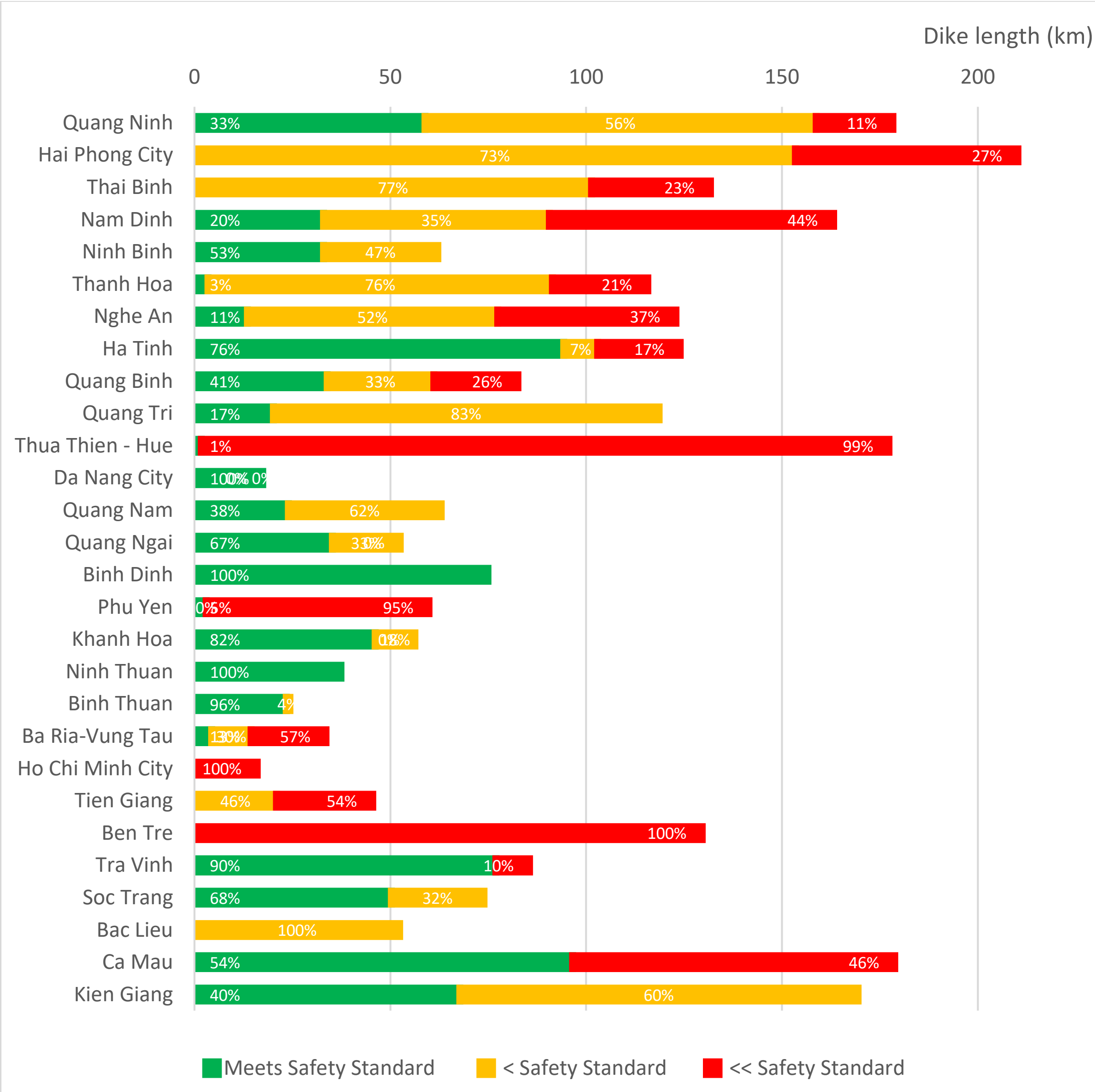
Figure 4.1. Dike length distribution for different safety standards in Vietnam
Total dike length is 2,659 kilometers



The characteristics of sea dikes in Vietnam's two main deltas differ considerably. In the Red River Delta, they have a high crest height of about 5 meters above the reference level and seaward slope protection on top of the earthen dikes due to the higher probability of severe waves from frequent typhoons, which cause severe hydrodynamic conditions, including storm surge and high waves. The safety standards for most dike stretches in this region vary between Grade III (50 years), Grade IV (30 years) and Grade V (10–30years). At 2–3 meters, the dikes in the Mekong Delta's coastal provinces are generally much lower, and are often of earthen construction. However, their protection level is about the same (Grade IV and V).

Results of this assessment suggest that a substantial part of the Vietnam dike system does not meet the targeted safety standards. This follows from a comparison of actual and required existing crest heights for each dike stretch (figure 4.2). Required crest height is the dike height needed to meet the current (2020) safety standard (figure 3.1); it does not include a safety increment or sea level rise. Figure 4.2 distinguishes between dike segments that are high enough (green), just below the required height (yellow), and considerably below the required height (red). It shows that in various provinces, a substantial portion of dike length falls below the safety standard. Nationwide, about 35 percent of the dike length meets the standard; so 65 percent is below the safety standard. In absolute terms, the provinces in and around the Red River contain most of the dike length that requires upgrading to the established safety standard.

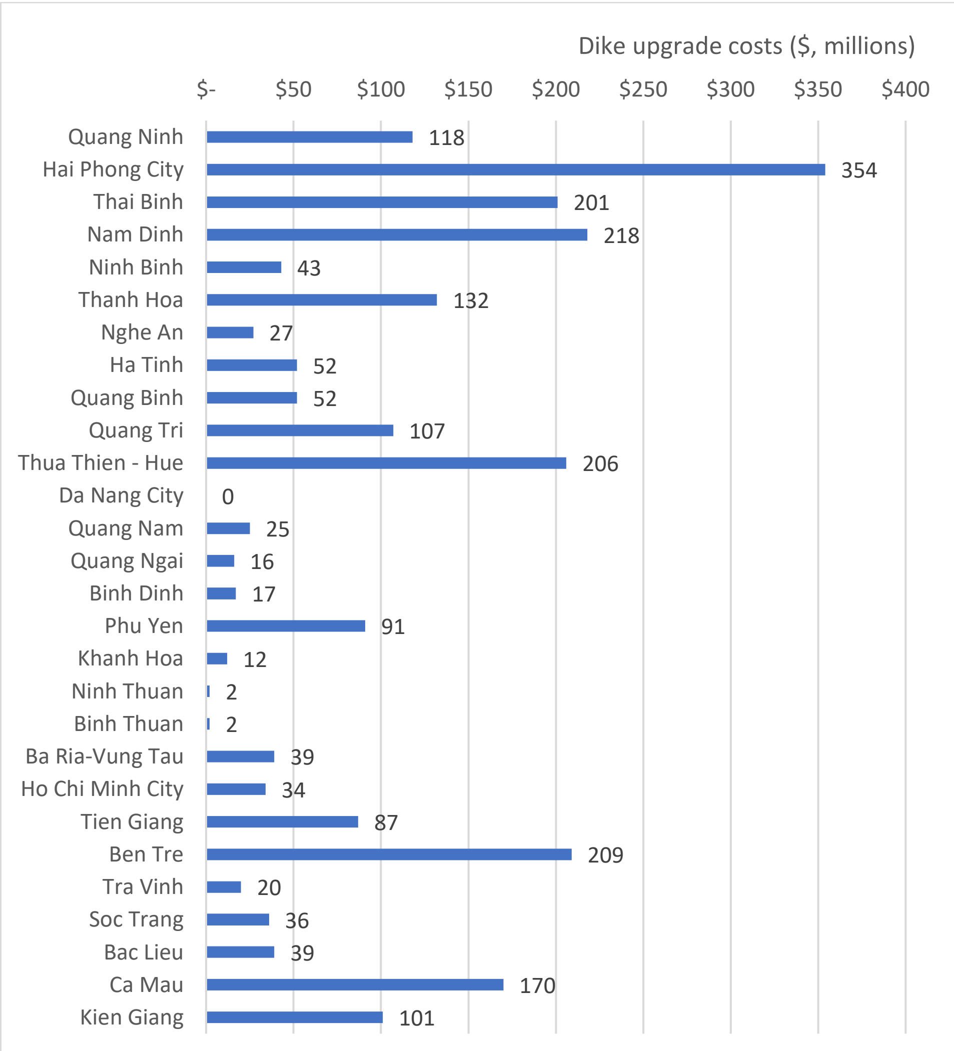
Figure 4.2. Assessment of existing sea dike system in Vietnam



The analysis suggests that several billions of dollars are required to upgrade the existing system to the established safety standard. Although this is a first-order estimate, it provides direction on likely required investments per province (figure 4.3). In total, about $2 billion is needed to bring the system up to the established safety standard (CAPEX), and some provinces require investments of several hundreds of millions of dollars. Hai Phong, Nam Dinh and Thai Binh Provinces in the north and Ben Tre Province in the south have the highest investment needs per kilometer of dike length.

These results are based on a minimum scenario analysis. If the population and economy grow at likely rates in the coming years and decades, the investment need will be much higher, since the necessary safety standards will also rise. A further assessment of investment needs for the dike system and other interventions is recommended once more details are known about the geographical distribution of current and future flood risk. This assessment focuses on the dike system only, which contain many hydraulic structures such as sluice gates and sometimes road crossings. Upgrading these structures and special objects generally requires significant additional investment, which will be further assessed in more detailed analyses.

Figure 4.3. Assessment of dike investment need in Vietnam



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[1] The focus is on sea and estuary dikes. Vietnam also has an extensive river dike system, especially along the Red and Mekong Rivers, which extend into the delta regions. These river dikes in the coastal zone are not considered in this assessment due to the lack of comprehensive data sets at national level.
[2] Decree No. 667/QĐ-TTg, 2009.
[3] TF0A4573.
[4] According to Prime Minister's Decision #58/2006/QĐ-TTg dated March 14th, 2006

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