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Coastal multi-hazard assessment along the coast of Pranburi to Sam Roi Yot district, Prachuap Khiri Khan, Gulf of Thailand

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Abstract

The Pranburi-Sam Roi Yot coast in Prachuap Khiri Khan Province contains various geomorphic features and land use types that are vulnerable to natural disasters such as storm surges and coastal erosion. This study assesses physical damage from multi-natural hazards by classifying physical indicators following the CHW method, which offers the hazard level in the studied area. As a result, the flood (storm surge) hazard is identified as very high throughout most of the area, whereas the erosion hazard is very high in the TSR-coastal type and high level in Pl-5-type. The hazards of saltwater intrusion and gradual inundation resulted in high levels for both TSR and Pl-5 coastal types. Lastly, the hazard of ecosystem disruption is moderate in TSR and Pl-5 coastal types. Most land use types in the study area were classified as very high flood hazard levels. The urban and agricultural land use categories are included at a high hazard level in the region with the greatest erosion threat. The geological setting parameter was a major factor in classifying the area as a greater danger for flooding and erosion. We suggest that additional criteria be examined in future studies to address indicators related to coastal damage, which may give more accurate results for natural hazard assessment.

Keywords: Coastal Hazard Wheel, Coastal hazard assessment, Storm surge, Gulf of Thailand

1.Introduction

The coastal area is constantly changing due to the influence of natural disasters or human activities from the utilization of various land uses. Since 1950, natural disasters have been increasingly severe worldwide, and scientists predict that sea levels will continue to rise due to climate change (IPCC, 2022). Coastal change from a natural disaster such as flooding and erosion causes damage to large areas and greatly affects to environment, society, and economy. Several strategies and approaches have been developed recently for coastal vulnerability assessment in order to evaluate and manage coastal hazards. The study by Ramieri et al. (2011) proposed "principles utilized to assess coastal vulnerability, namely (1) index and indicator-based approaches, (2) GIS-based decision support systems, and (3) dynamic computer models" for various uses and specifications of data and knowledge. A number of researchers, including Gornitz (1990), Palmer et al. (2011), Bagdanaviit et al. (2015), and Mohd et al. (2019), used the Coastal

Vulnerability Index (CVI), one of the most straightforward and widely used methodologies, to study coastal vulnerability. According to Denner et al. (2015), CVI could be modified to adjust indicators under various coastal environments.

On the other hand, according to Appelquist and Balstrøm (2014), CVI-determined indicators are used to much specific information on the coastal environment. As a result, it is not appropriate for assessment in regions with no or limited coastline data. In the same way, Appelquist and Halsnæs (2015) presented a new methodology for coastal multi-hazard evaluation and management. Coastal Hazard Wheel (CHW) has developed as a universal coastal classification system for limited data areas determining their hazard profile. CHW covers all coastal perils under damage from ecosystem disruption, gradual inundation (sea-level rise), saltwater intrusion, erosion, and flooding (storm surge). The result of this study CHW framework had appropriated as fundamental for further detailed assessment of coastal areas for regional to national assessments. Additionally, Appelquist and Balstrøm (2015) used CHW for regional hazard assessments in Karnataka to test this approach. In order to provide high-quality results, the study should be repeated in different regions. The evaluation from CHW provided another method for measuring researcher vulnerability today to construct a coastal vulnerability map to enable comprehensive local-to-regional coastal management. In addition, Appelquist et al. (2016) offered the primary manual as a starting point, which briefly introduces how to apply the CHW to facilitate coastal assessment and consideration of key indicators. As a result, the CHW method appears intriguing, as it has been studied extensively in regional coastal areas (Appelquist & Balstrm, 2014; Appelquist & Halsns, 2015; Appelquist & Balstrm, 2015). However, in small coastal areas, only a few researchers have reported the effectiveness of the CHW approach.

This study aims to assess physical damage using the classification of physical indicators following the CHW method. Additionally, the intensity of multi-natural hazards is examined in land use analysis along the coast for each land use type. The study area is located along the coast of Pranburi - Sam Roi Yot, Prachuap Khiri Khan province, and is composed of various types of coastal geomorphologic features, including rocky coasts, beaches, mangroves, and estuaries. Therefore, these regions comprise various modern land use types, including agricultural, conservation areas, residential, hotels, and resorts. However, due to climate change from global warming, natural disasters like storm surges and coastal erosion tend to affect this area, causing damage to the coastal ecosystem and people. The anticipated outcome of this research is the development of maps depicting the coastal hazard intensities for use in management planning in the study area.

2. Study Area

Pranburi and Sam Roi Yot districts are located in northern Prachuap Khiri Khan Province. These regions exhibit mountain and coastal plain characteristics (Fig. 1). The west is connected to the Tanaosri mountains, and then the topography drops down towards the Gulf of Thailand in the east. There are mountains scattered along the coast, and Sam Roi Yot Mountain, which has an average height of roughly 750 meters, is significant. Near the east coast, the average height above sea level ranges from 1 to 5 meters. The southwest and northeast monsoons influenced the climate. The average annual temperature is 28 degrees Celsius, and there are three distinct seasons: summer from February to May, rainy season from May to October, and winter from October to February (Department of Mineral Resources, 2008).

The coastline of Pranburi district is classified into lengths of sandy beaches of 12.02 km, rocky beaches of 3.49 km, river mouths of 0.20 km, and a total length of 15.71 km. The coastline of Sam Roi Yot district is classified into lengths of sandy beaches of 15.21 km, rocky beaches of 4.66 km, river mouths of 0.25 km, and a total length of 20.12 km. For coastal erosion, Pranburi district has a moderate rate of erosion (1-5 m/year) of 0.22 km, a low rate of 0.44 km, a coastal structure of 9.15 km, a balanced area of 5.78 km, and a large cumulative area of 0.12 km. In comparison, the coastline of Sam Roi Yot district has a low rate of erosion (0.05 km/year), a coastline structure of 4.58 km, a balanced area of 15.38 km, and a large cumulative area of 0.11 km (Department of Marine and Coastal Resources, 2018).

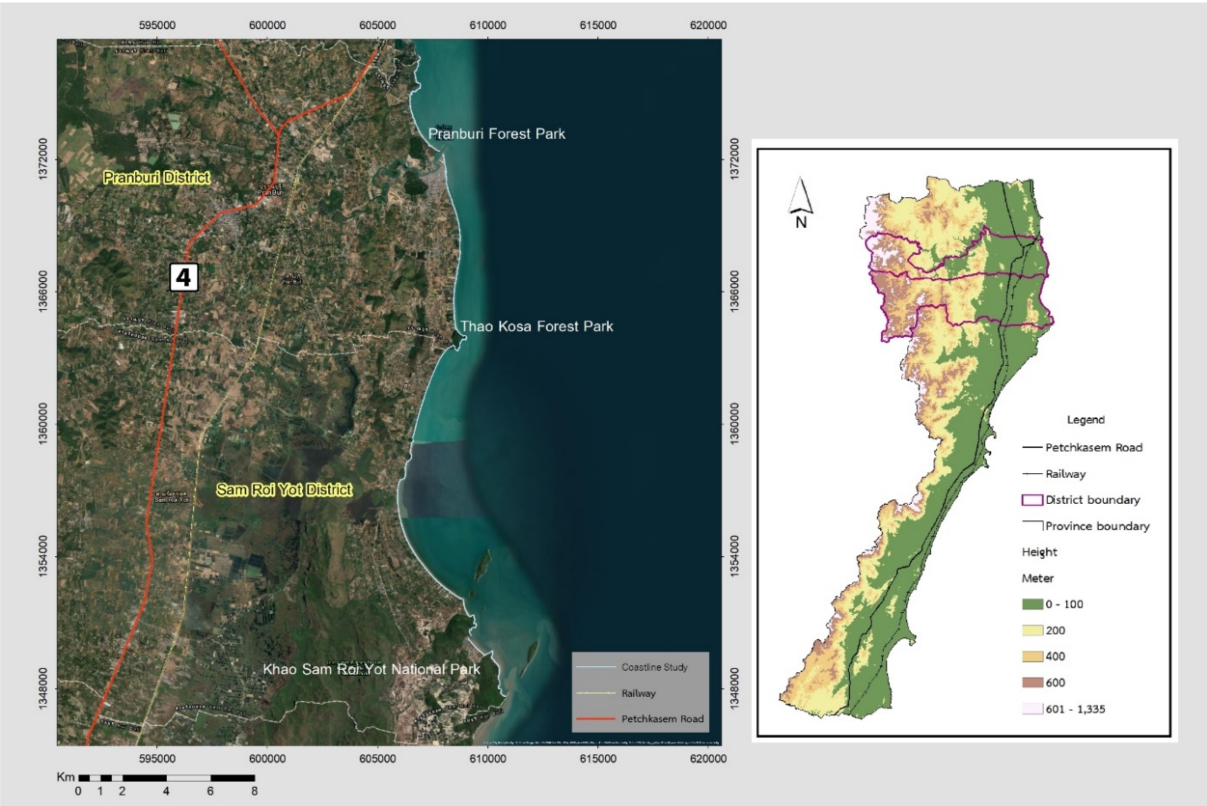

Figure 1 The location of the study area is located along the coast of Pranburi to Sam Roi Yot district.

3. Methodology

3.1 Data for coastal hazard assessment

To accomplish the hazard assessment in the Pranburi and Sam Roi Yot coastal area, we apply the methodology recommended by Appelquist et al. (2016). The data source used for classification is available in the main manual CHW framework paper, including a description of each variable and inherent hazard level (Appelquist et al., 2016). This method intergrades the different types of physical conditions of the area as indicated below:

1. The geological layout based on the classification of geomorphologies in the main manual CHW framework paper includes sediment plain, barrier, delta/low estuary island, slope soft rock coast, flat hard rock coast, sloping hard rock coast, coral island, and tidal inlet/sand split/river mouth, as determined by the geomorphological classification. The geological layout of

the studied area is then defined by satellite image interpretation from the Google Earth program, which identified four coast types, including sediment plain (PL-5), sloping hard rock coast (R-1, R-2), and tidal inlet/sand split/river mouth (TSR).

2. Wave exposure was determined by the map of global wave environments in the main manual CHW framework paper, which utilized data on the wave climate, waterbody size (fetch length), and wind conditions. The study area is located in a non-swell wave climate due to tropical cyclone influences and fetch lengths >100km accompanied by weak onshore winds; thus, wave exposure classifications categorize it as a moderately exposed type.
3. The tidal range was classified using a map of global tidal environments in the main manual CHW framework paper, which can be divided into different tidal environments depending on tidal range, and a commonly used classification system operates with three primary categories: micro-tidal, meso-tidal, and macro-tidal. The average tidal range in the study area is 1-1.1 m. (Hydrographic Department, Royal Thai Navy, 2022). As a result, it was classified as meso-tidal.
4. Flora/fauna categories were determined by interpreting satellite images from the Google Earth program to assess the coastal area's vegetation characteristics, including marsh, mangrove, vegetated, non-vegetated, and corals. Then, a field check was performed to correct the misinterpretation result.
5. Sediment balance was detected by a series of satellite images using a timeline slider panel provided by the Google Earth program. This balance consists of four categories: "balance/deficit" and "surplus" for sedimentary/soft rock. The hard rock coastlines fall under the two categories of "beach" and "no beach." After that, a field check was performed to confirm the interpretation result.
6. Storm climate was characterized by the position of coastal areas with and without tropical cyclone activity based on a global wave environment map in the main manual CHW framework paper, and the study area was classified as a tropical cyclone activity area.

3.2 The Procedure of coastal hazard assessment

The hazard levels of the CHW are based on a scientific review of the characteristics of the world's coastal environments and how sensitive they are to climate-related parameters. Therefore, the hazard ranking is based on a qualitative analysis of how the different hazards apply to the coastal categories defined in the CHW classification system (Appelquist et al., 2016). The hazard level was divided into four categories: low, moderate, high, and very high (Fig. 2). The method for investigation is described as follows.

1. Creating the coastline from satellite imagery interpretation in Google Earth, delineating the coastline along the vegetation line and beaches identified visually, and saving the data.
2. Next, import the coastline data into the ArcMap program and add a new field to the attribute table, as it allows you to fill in the hazard code details using the CHW classification method.
3. Determine the coastal hazard level by starting at the center of the CHW diagram and moving through the

wheel's edge in the following order: geological layout, wave exposure, tidal range, flora/fauna, sediment balance, and storm climate (Fig. 2).

4. Proceed to edit the coastline using the split tool for classification and adding detail to the attribute table. Finally, the code of coast types classified hazard vulnerability as low, moderate, high, and very high.

3.3 Land use analysis

The land use (LU) data in this study were provided by the Department of Land Development (2019). We use the two natural hazard layers—flooding (storm surge) and erosion—to establish a buffer zone (only left side direction) in ArcMap that is 1 km and 300 m wide, respectively. These two natural hazards were chosen because they are annual short-term hazards that can impact land use. These buffer layers were then converted to raster with a 1x1km grid cell for usage as a determined hazard level area for each land use category.

4. Results

4.1 Coastal classifications

The classification of coastal types by CHW revealed in Table 1 that the total length of the coastline was 37.31 km. Pl-5 type occupied 56 percent of the overall at 8.08 km (21%). The last two types are TSR type, which is 6.61 km (18%), and R-2 type, which is 1.8 km (5%).

4.2 Coastal hazard levels

The coastal hazard levels map showed the coastal types and multi-natural hazard levels in the study area (Fig. 3). The flood (storm surge) hazard is very high throughout most of the area, except for the coastal types of sloping hard rock coast (R-1, R-2) that present a low hazard level. For erosion hazard, a tidal/sand split/river mount (TSR) has a very high level, while a sediment plain (Pl-5) has a high level. In addition, the hazards of saltwater intrusion and gradual inundation (sea-level rise) resulted in a high level for both TSR and Pl-5 coastal types. Lastly, the hazard of ecosystem disruption was shown as moderate in TSR and Pl-5 coastal types.

The assessment of the coastal multi-hazard level of the study area revealed that a very high level of flooding hazard extended almost the entire 27 km length of the study area. Subsequently, an erosion hazard with a high intensity yields the greatest distance, 21 km. For Saltwater intrusion and gradual inundation hazard, a high level is present in most of the area, which is 27 km long. Finally, the hazard level of ecosystem disruption in the study area was determined to be moderate intensity (27 km), as shown in Table 2. Figure 4 depicts a distribution of multi-natural hazard levels in the study area, revealing that flooding hazard is primarily distributed at a very high level by 73% of the area, followed by erosion hazard, which is primarily distributed at a high level by 55%. Furthermore, saltwater intrusion and gradual inundation hazards were represented at a high level in 73% of the area. In comparison, ecosystem disruption was distributed at a moderate level in 73% of the area.

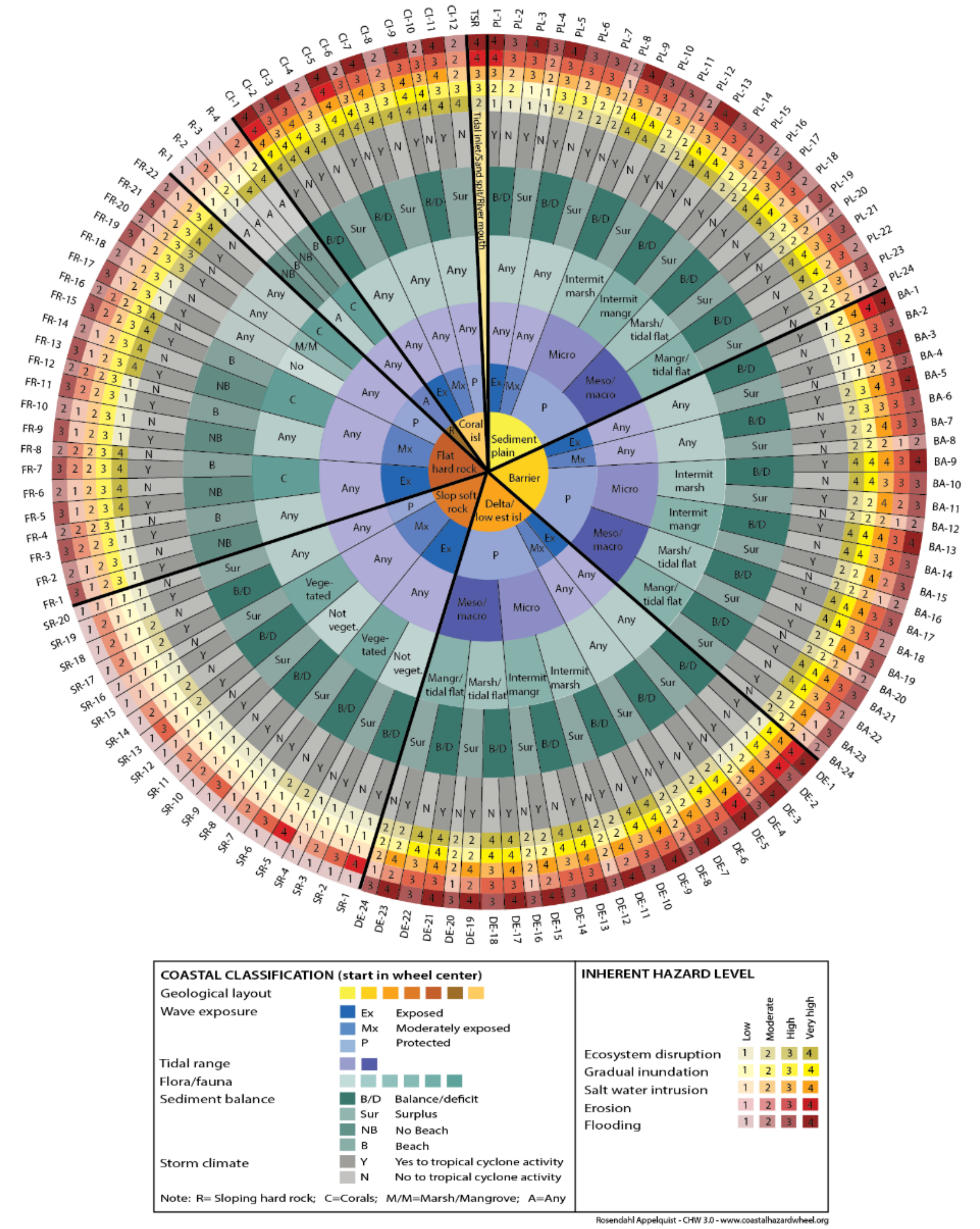

Figure 2. The illustrated show the coastal Hazard Wheel (Appelquist et al, 2016).

Table 1 The coastal types and multi-hazard levels in the study area based on CHW method.

Variable	Coastal types				Total (km)
	R-1	R-2	PL-5	TSR	
Geological layout	Sloping hard rock coast	Sloping hard rock coast	Sediment plain	Tidal/Sand split/River mount	
Wave exposure	Any	Any	Moderate exposed	-	
Tidal range	Any	Any	Any	-	
Flora/Fauna	Any	Any	Any	-	
Sediment balance	No Beach	Balance/Deficit	Balance/Deficit	-	
Storm climate	Any	Any	Yes	-	
Code CHW					
Flooding	1	1	4	4	
Erosion	1	2	3	4	
Saltwater intrusion	1	1	3	3	
Gradual inundation	1	2	3	3	
Ecosystem disruption	1	1	2	2	
Length (km)	8.08	1.80	20.82	6.61	37.31
Percent of length	21	5	56	18	100

Table 2 The coastal multi-hazard classified by intensity and distance in the study area.

Hazard levels	Length (km)				
	Flooding	Erosion	Saltwater intrusion	Gradual inundation	Ecosystem disruption
Low	10	8	10	8	10
Moderate	0	2	0	2	27
High	0	21	27	27	0
Very high	27	7	0	0	0

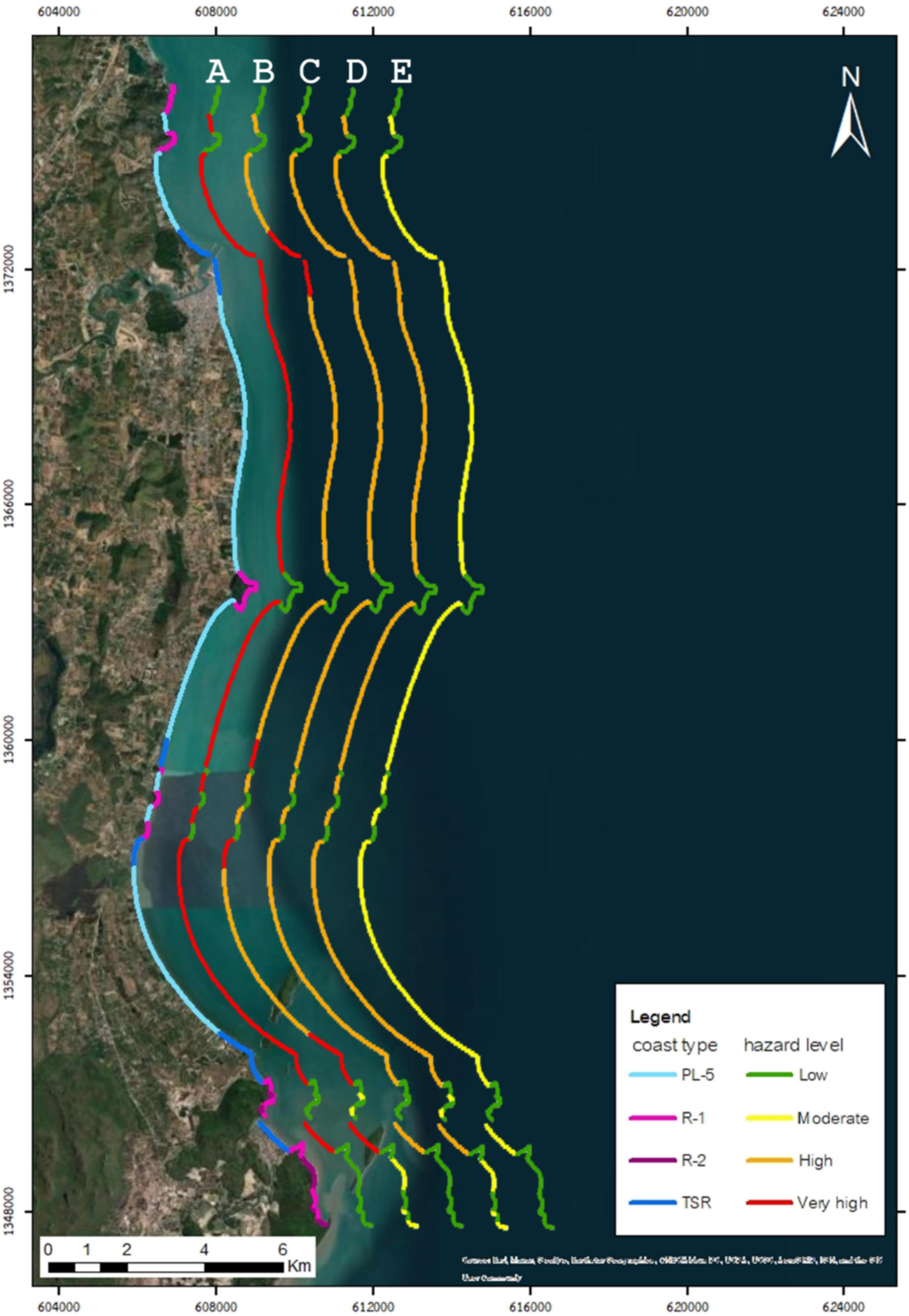

Figure 3 The coastal hazard map showed the coastal types and multi-natural hazard levels in the study area, including the hazards of flooding(A), erosion(B), saltwater intrusion(C), gradual inundation(D), and ecosystem disruption(E).

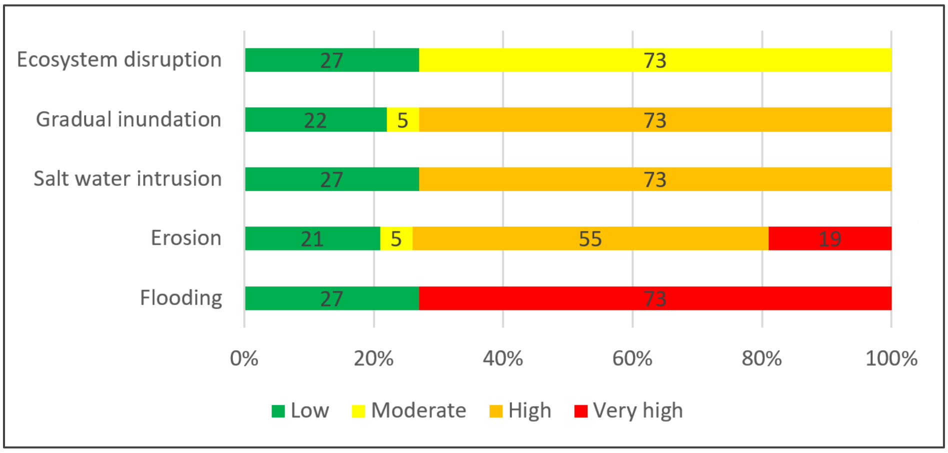

Figure 4 The distribution of hazard levels as a percentage of length across the study area.

4.3 Land use analysis

The analysis of land use by multi-natural hazards was divided into five categories (Table 3), which included agriculture (A), forest (F), rangeland/marsh and swamp/other miscellaneous areas (M), urban (U), and water body (W). For flooding hazard, evaluated at a distance of 1 km from the coast, agriculture type covers the greatest area with 9.51 km^2, or 29%, followed by forest type with 9.03 km^2 (28%), urban type with 8.02 km^2 (24%), and others with 6.2 km^2 (19%). It was determined that most land use types throughout the study area were located at a very high hazard level, including agricultural (34%), urban (27%), miscellaneous (20%), and forest (17%). However, at a low hazard level, 74% of the area was covered by forest-type land use (Fig. 5A and 6).

In terms of erosion hazard, calculated at a distance of 300m from the coast, urban type has occupied the greatest area with 3.4 km^2, or 34% of the area, followed by forest type with 2.75 km^2 (27%), agriculture types with 2.01 km^2 (20%), and others with 1.9 km^2 (19%). A high hazard level covering the largest erosion hazard distance comprises urban land use type (42%) and agricultural land use type (27%). The very high hazard level, a second hazard length distance found near the outlet, comprises forest land use type (38%) and urban land use type (28%). Lastly, the low and moderate hazard levels show a forest-land use type covering 72% and 91% of the area, respectively (Fig. 5B and 6).

5. Discussion

5.1 Factor controlling coastal hazard intensity

This assessment found that most of the area was evaluated as a high level for the multi-natural hazard, except for an ecosystem disruption hazard (Fig. 3). In addition, the geological layout parameter contributed directly to the area being classified as high hazard level in flooding and erosion hazard. The sediment plain (PL-5), which covers most of the area, along with moderate wave exposure in a tropical cyclone climate, is responsible for the very high hazard level of flooding and high hazard level of erosion hazard in this area. The TSR type was also identified as a highly susceptible coast form due to its high morphological activity and rapid response to changes in other coastal processes (Appelquist et al., 2016). Therefore, a very high hazard level was determined. In contrast, the hazard intensity for the R-1 type was classified as low due to the

Table 3 Land use types in flooding hazard and erosion hazard zone in the study area.

LU Types	Lu2019 in flooding hazard zone 1 km (km^2)	Percent of flooding hazard in the area	Lu2019 in erosion hazard zone 300 m (km^2)	Percent of erosion hazards in the area
Agriculture	9.51	29	2.01	20
Forest	9.03	28	2.75	27
Rangeland/Marsh and Swamp/Other miscellaneous lands	5.61	17	1.74	17
Urban	8.02	24	3.40	34
water body	0.59	2	0.16	2
Total	32.76	100	10.06	100

geological layout of the area, which featured a sloping hard rock coast. Following that, the R-2 type, defined by a beach between a sloping hard rock coast, was classified as an erosion hazard of moderate intensity. Since R-1 and R-2 are rocky coasts, the hazard intensity is lower than on the PL-5 (Fig. 3).

5.2 Uncertainties and Limitations

Since the CHW method is designed to assess the coastline for main hazards influencing coastlines with general criteria at a regional scale, thus data availability and accuracy requirements are relatively low when evaluated on a local scale (Micallef et al., 2018; Paul and Das, 2021). Although TSR type determines by a distance to both sides from the tidal inlet of 1 km (Appelquist et al., 2016), some inlets in the study area are too small to induce the morphological change over those specific distances. Since this is the case, the CHW-estimated hazard should be considered too high for those areas (Fig. 7). We suggest that for further study, the distance from the tidal inlet for TSR should be adjusted based on the inlet size, especially hazard assessment on the local scale.

Furthermore, the engineering structures along the coast are a key component CHW did not include while assessing coastal hazards. Most of the area has been constructed with coastal engineering features to protect the coastline from storm surges, flooding, and erosion. As a consequence, the result of the multi-natural coastal hazard assessment may differ from the actual situation. Compared to the Department of Marine and Coastal Resources' coastal situation data 2017, the erosion-coast type is rarely presented because a seawall already covers most of the region. As a result, as indicated by Paul and Das (2021), coastal engineering structures and other influential indicators of coastal change, such as porosity, permeability, and erodibility of coastal materials, should be considered as additional parameters to cover indicators related to coastal damage. The assessment of natural hazard damage may yield more accurate results.

5.3 Land use analysis

The pie chart of flooding and erosion hazards with LU type in Figure 6 reveals that most urban land use was located at high to very high hazard levels. The urban land use in this study area was discovered dispersed around the coast, but most were concentrated near the beach in a popular tourist destination (Fig. 5 and 8). Additionally, McLaughlin et al. (2002) noted that the probability of damage from natural disasters is higher in densely populated areas because of the greater number of people living there. Furthermore, Kantamaneni (2016) stated that continuous settlements along the coast would raise pressure, resulting in coastal vulnerability. Consequently, this coastal area should be considered for new land use planning to mitigate future natural hazards.

The concern with this analysis is that it still doesn't have economic information about the value of the area. Therefore, it is suggested that future research include more economic variables because changes in socioeconomic factors, like land use or transportation, affect coastal vulnerability faster than physical processes (Duriyapong & Nakhapakorn, 2011). These will improve the analysis results used by management and budgeting to overcome challenges and provide more precise preventive measures.

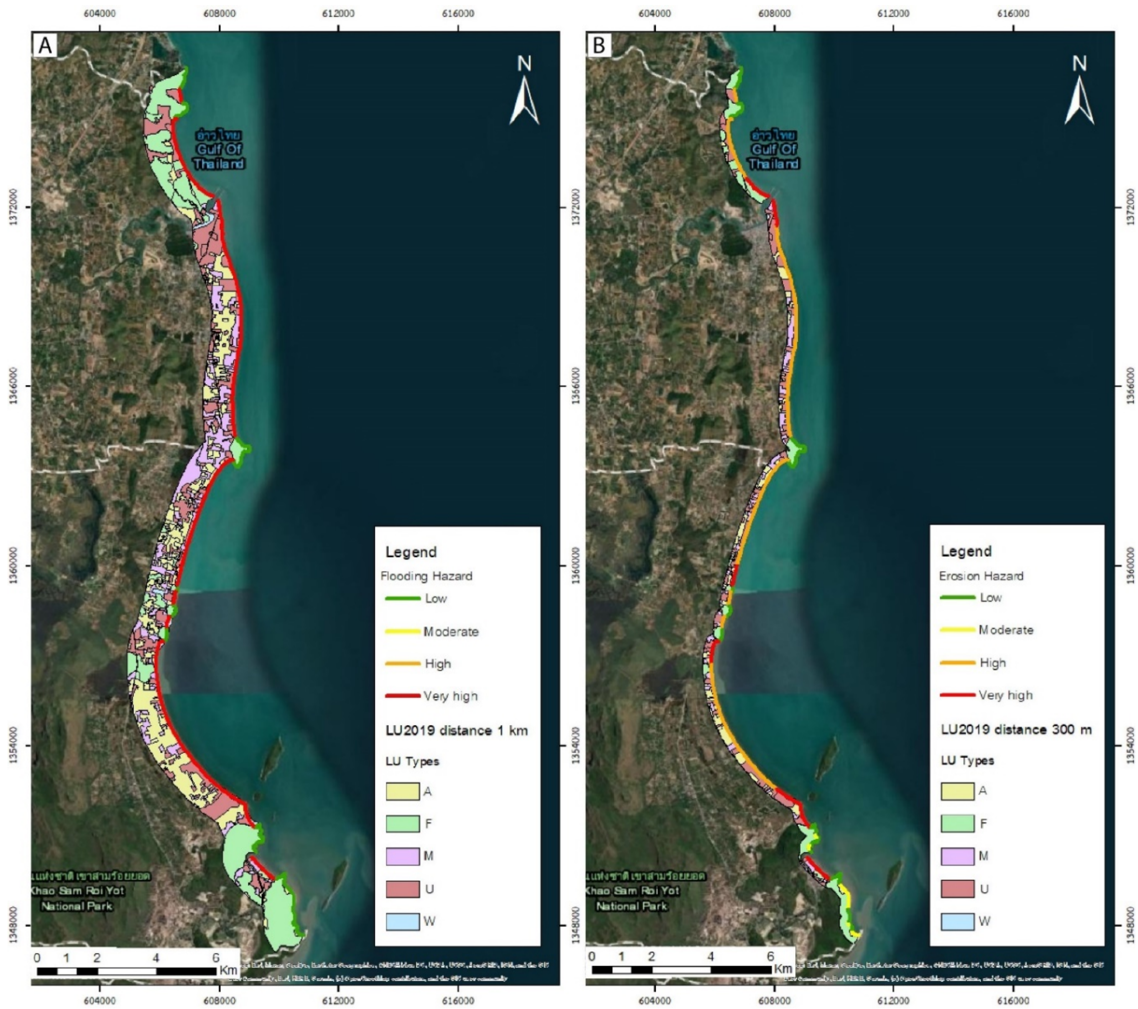

Figure 5 A land use map 1 km (A) and 300m (B) from the coast showed LU types with flooding hazard and erosion hazard level, respectively.

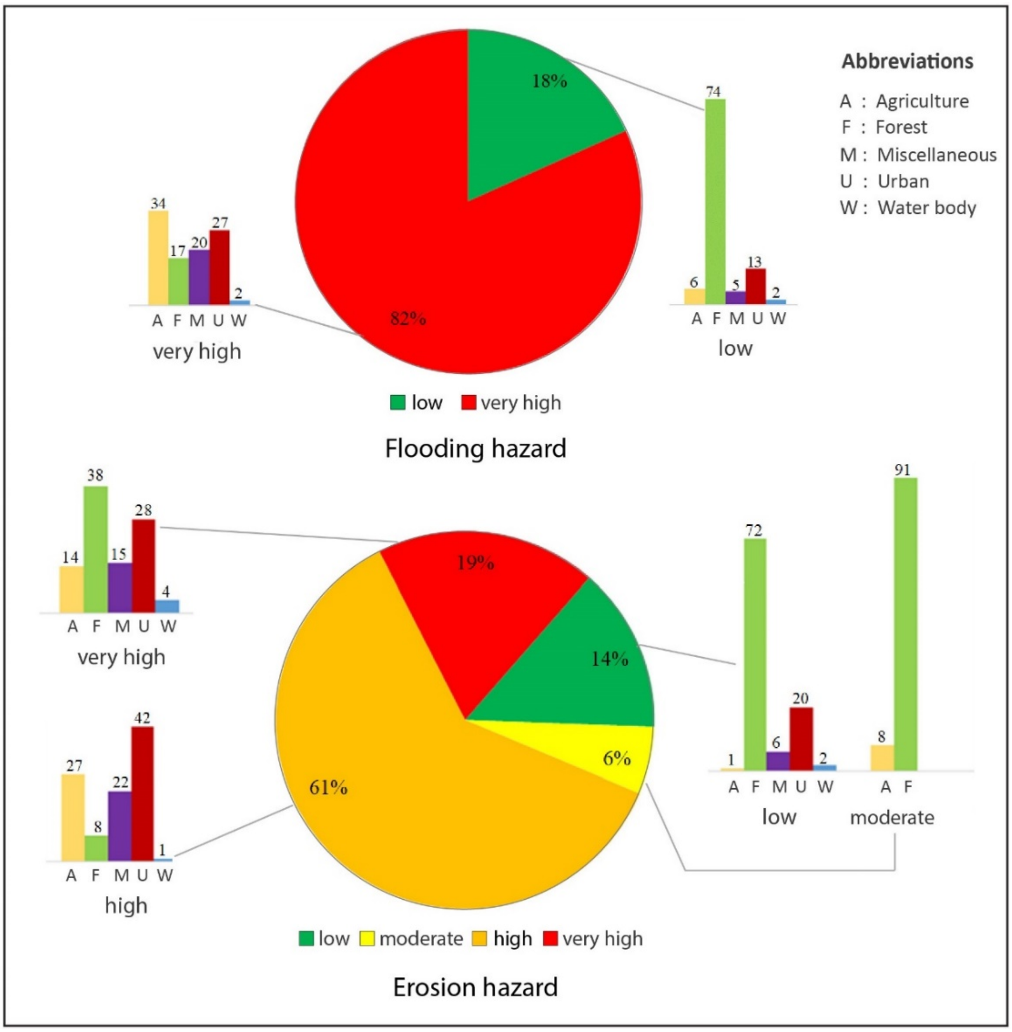

Figure 6 The pie chart of flooding and erosion hazard by intensity level with LU types.

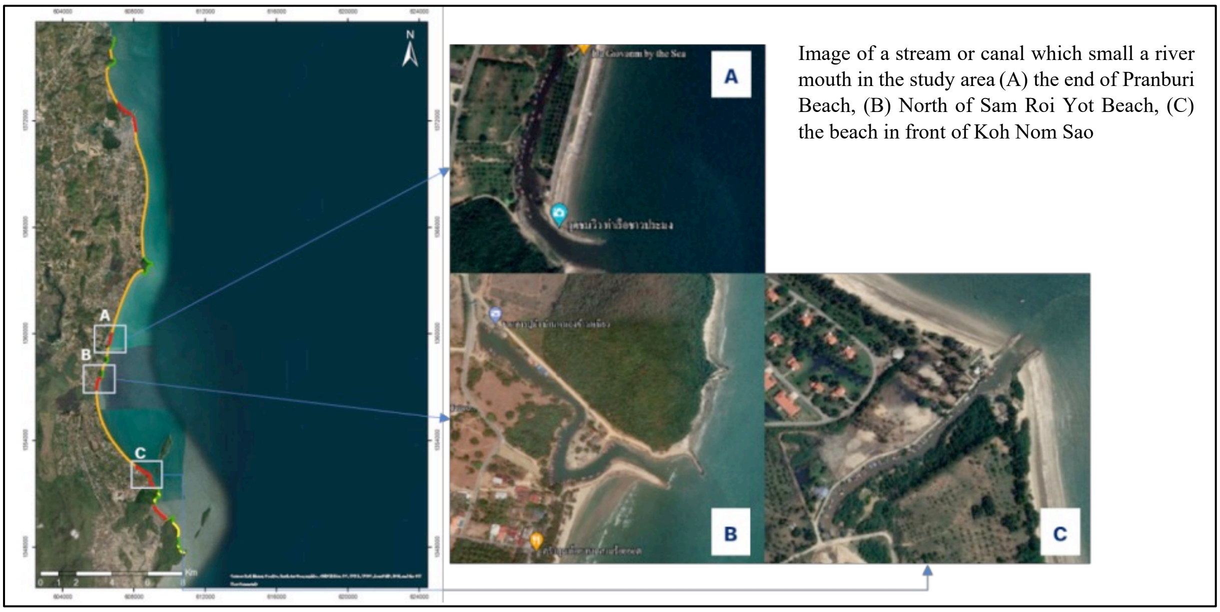

Figure 7 The map of erosion hazard levels shows a small inlet or canal in the study area.

Figure 8 The map of flooding and erosion hazards, satellite images, and Google street view shows examples of land use type in very high hazard level (A) north of Pranburi Beach, (B) Sam Roi Yot Beach, and (C) Bang Pu Beach.

6. Conclusion

This study evaluates the physical damage caused by coastal hazards using the CHW technique, which offers the inherent hazard level in the studied area. As a result, the flood (storm surge) hazard is very high throughout most of the area, except for the coastal types of sloping hard rock coast. For erosion hazard, the TSR-coastal type has a very high hazard level, and Pl-5-type has a high hazard level. In addition, saltwater intrusion and gradual inundation hazards resulted in high hazard levels for both TSR and Pl-5 coastal types. Lastly, the hazard of ecosystem disruption was moderate in TSR and Pl-5 coastal types.

Most land use types throughout the study area were located in a very high hazard level for the land use analysis of flooding hazards. Regarding erosion hazard, a high hazard level covering the greatest erosion hazard distance includes urban and agricultural land use types. Furthermore, the geological layout parameter directly contributed to the area being categorized as having a high flooding and erosion hazard.

The CHW method employed in this research provides insight into indicators influencing coastal dynamics as well as detecting natural hazard conditions in the study area. Although the results are not entirely accurate on a local scale, they are satisfactory given the objectives of this evaluation. Additional field data is also suggested to be checked to improve the assessment parameters' data. Finally, natural disasters might occur at any time and are unavoidable. Planning for environmental response, education, and coastal research will improve public safety and prevent loss of life and property.

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