Coastal Erosion Risks Assessment on Yunlin Coast

Subjects: Engineering, Ocean

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A coastal erosion risk assessment was framed as the basis for the intervention of coastal adaptation strategies under time-variant scenarios. The framework was devised to assess the influence of coastal erosion on coastal defense, the coastal inundation induced by the erosion-induced malfunction of defense, and risks using a downscaling analysis and the mechanism of the compound hazard interaction, which are innovative and practical for the application of coastal management in Taiwan.

Keywords: coastal erosion ; hazard and vulnerability risk assessment ; adaptive strategy

1. Introduction

Coastal zones are some of the most dynamic environments due to the interactions between different geospheres over a range of timescales that cause dynamic coastal rebuilding, which is referred to as coastal morph dynamics (Łabuz, 2015) [1]. The influential factors of interaction can generally be divided into two groups: Natural and anthropogenic. Anthropogenic factors have exerted significant effects on the coastal zone in Taiwan, which has a dense population but scarce land, since the 1970s when industry and commerce vigorously developed and abundant business activities ensued. During this period, many coastal defense facilities were constructed to protect the livelihood and properties of the populations against natural hazards. However, anthropogenic developments protruding from the coastline have been gradually disturbing and impeding the sediment supply, which has led to more serious coastal erosion and the decreasing capability of the buffer zone to dissipate waves. Relevant authorities have not yet taken responsibility and considered specific principles to compensate for several decades worth of erosion, which has led to the increased seriousness and complexity of the hazard.

2. The Background of the Coastal Management in Taiwan

Following the enactment of Agenda 21, which was proposed by the 1992 United Nations Conference on Environment and Development, and the adoption of the concept of integrated coastal zone management (ICZM) (United Nations, 1992), the Ministry of Interior has finally begun to enact policies and stipulations to meet the demand for coastal management in Taiwan [2]. The Coastal Management Act and the Integrated Coastal Zone Management Plan were enforced in 2015 and 2017, respectively (MOI, 2015 and 2017) [3][4]. These frameworks are intended to advocate for the prevention of coastal hazards and promote the application of coastal management. The Coastal Management Act designates coastal erosion, storm surge, flooding inundation, and land subsidence as the four statutory coastal hazards for which the Integrated Coastal Zone Management Plan (ICZMP) specifies the grading principles in terms of the physical impact of coastal hazards; it also designates first- and second-grade coastal protection zones based on the severity of hazards in coastal cells, though it does not consider the interaction between compound hazards. First-grade coastal protection zones are exposed to hazards, especially storm surges, coastal erosion, and land subsidence. The length of the coastal protections is zoned from approximately 11 to 75 km within this hazard grading, and the authority of each segment proposes corresponding reduction strategies (MOI, 2021) [5].

Although the coastal classification management system has been established, the coastal protection zones are of a large scale and the spatial distribution of hazard impacts cannot be precisely illustrated in diverse environments. Additionally, the deterioration of coastal defense due to erosion should also be considered in terms of buffer zones. In this sense, when the width of a buffer zone is decreased, increasing wave loads will affect the coastal defense, the foundations of which are consequently exposed and thus rendered unstable (Temmerman et al., 2013) [6]. That is to say when overtopping flow increases, the probability of a defense malfunction is significantly increased (Mehrabani and Chen, 2017) [7]. For example, many shorelines have suffered from coastal erosion, which led to defense malfunctions after the invasion of typhoon Fanapi in 2010. When the defense malfunctions, a storm surge can easily damage the property behind it. In other words, the impact of storm surge hazards generally does not directly damage property under the protection of a functional defense, but erosion-induced damage does lead to direct impacts and is difficult to prevent.

3. Risk Assessment of Coastal Area

Risk is the potential for consequences when something of value is at stake and the outcome is uncertain. Risk is often represented as the probability of the occurrence of hazardous events or trends multiplied by the impacts following the occurrence of these events or trends (IPCC, 2014b) [8]. Therefore, risk assessment is one of the primary quantification methods used to classify future severity under resource constraints. Coastal risk management is also used to aid protection countermeasures against hazards from the uncertainty of climate change (CPSL Third Report, 2010) [9]. Since the US Geological Survey (USGS) formulated a coastal vulnerability index (CVI) (Thieler and Hammar-Klose, 1990; Pendleton et al., 2004; Irham et al., 2021) [10][11][12], relevant calculations have been applied to evaluate worldwide vulnerability with equal weights. Boruff et al. (2005) [13] examined the vulnerability of US coastal counties in terms of maximum wave height, shoreline erosion rates, and landform susceptibility to inundation, as well as ten coastal social vulnerability indexes, to quantify vulnerability distribution. The hazard wheel employed by Appelquist and Balstrøm (2014) [14] considered geological layout, wave exposure, tidal range, flora/fauna, sediment balance, and storm climate, and it was used to assess multiple coastal hazards in the state of Djibouti. Wang (2014) [15] presented a comprehensive assessment strategy based on the risk matrix approach (RMA), including two aspects that were further composed of five second-class indicators: The first aspect, the probability phase, consisted of indicators of economic conditions, social development, and living standards; the second aspect, the severity phase, comprised geographic exposure and natural disasters. Moreover, this research weighted all of the indicators by applying the analytic hierarchy process (AHP) and Delphi Method to analyze the risk indices of 50 coastal cities in China. In addition, the shoreline change was an important element in the coastal risk assessment, facilitating the result of the risk prediction to be more meaningful for the ICZM (Park and Lee, 2020) [16]. In brief, although the risk assessment frameworks and factors are globally distinct, risk assessments are universally used to consider hazard potential and consequent vulnerability from local perspectives. Therefore, after risk assessment, corresponding countermeasures can be enacted.

The Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations, 2015) [17] proposed strategies under a people-centered approach and outlined four priorities for action: (1) Understand disaster risk, (2) strengthen disaster risk governance to manage disaster risk, (3) invest in disaster risk reduction for resilience, and (4) enhance disaster preparedness for effective response and “Build Back Better” for recovery, rehabilitation, and reconstruction. Since the SFDRR was initiated, the implementation of risk assessment has increased with an annual growth percentage of 15.9%, which implies an increase in research on SFDRR during 2015–2019 (Busayo et al., 2020) [18]. However, the level of coastal risk was predicted to increase if the trend of world climate change was not mitigated, and the distribution of hazardous hot spots and the damage probability of property would be increased in the region (Bruno et al., 2020) [19]. Therefore, risk assessment considering the relevant hazards and the vulnerability of human beings is a current cornerstone for quantifying threats and reducing disaster risk. Consequently, this type of assessment may be seen as a holistic control loop that consists of a number of interacting elements or tasks involving a comprehensive set of measures designed to either reduce or avoid vulnerability to coastal hazards (CPSL Third Report, 2010) [9]. In general, risks are expected to change over time due to deterioration processes (Mehrabani and Chen, 2017; Park and Lee, 2020; Bruno et al., 2020) [7][16][19]. Thus, this research aimed to comprehensively quantify the reduction principle of coastal erosion risk and discuss time-variant impacts.

4. Adaptive Strategy

The United Nations Framework Convention on Climate Change (United Nations, 1992) [20] proposed three categorized adaptive strategies for coastal areas: Protection, accommodation, and retreat. These strategies have been used in coastal mitigation measures and applied worldwide. In Taiwan, according to the ICZMP (MOI, 2021) [5], the protection strategies comprise preventive and contingency measures corresponding to the hazard potential under protection design criteria, including the maintenance of defense and the monitoring of coastal bathymetry changes. The accommodation strategy comprises disaster reduction and prevention for each coastal area, e.g., by improving the completeness of early warning systems and limiting land use, and it is constantly employed to reduce the risk of social vulnerability. However, if the protection and accommodation strategies cannot mitigate a hazard or enact a protective effect, the retreat strategy can be used to avoid damage. However, the rights and interests of relevant stakeholders should be seriously considered and the government must engage in multifaceted communication and coordination before enacting retreat management. In risk management, adaptive strategies are implemented following the orientation of the government and appropriate protection resources (Xian et al., 2018) [21]. Although adaptive strategies are specific to each area, relevant authorities must ultimately consider and study more resilient mitigation strategies against the overall challenge of global climate change. Ultimately, an adaptation strategy involves education, policy, and technology, among other aspects, and the promotion of these strategies must be appropriate for the considered risk, incorporated into project design, implemented, maintained and/or monitored, and arranged to work in the long term (Pathak et al., 2021; IPCC AR6, 2021) [22][23]. That is to say, adaptive management would require a long-lasting process based on social capacities, including resilient institutions, the multilevel governance system, and ecosystem services; in particular, it must be sure to take the local stakeholders' perceptions into account in the implementation of coastal management (Jacob et al., 2021; Takyi et al., 2022; Frohlich et al., 2022; Lin et al.) [24][25][26][27].

In Taiwan, although the grading principles have been applied to erosion hazards, the mechanism of erosion-induced risk and the relevant adaptive strategies still need to be refined due to the extensive scope of the protection zone. The units of the coastal protection zone and hazard-prone zones are too large in scale to enable the precise allocation of conservation resources. Therefore, this research devised an assessment with a downscaling principle that considers the influence of coastal erosion on coastal defense, coastal inundation induced by erosion-induced defense malfunctions, and coastal erosion risk. For example, the erosional coast sector was often designated by the coastal cells, from river to river or river to headland. The erosion hazard prone was regarded with the same grading with a scale of kilometers without the management priority within the diverse environment. Therefore, this research assessed the erosion hazard, risk, and corresponding adaptive strategy within the sectors of coastal defenses to clarify the hazard hotspots and the hierarchical management. The erosional coast sector scale was defined as ranging from the coastal cell to the entire length of the coastal defense and the length scale was defined as kilometers to meters in order to quantify hazards and risks in more detail. Furthermore, this research not only assessed the impact of hazards on the vulnerable socio-economy of coastal villages in terms of humans but also assumed a time-variant risk scenario. Accordingly, such a time-variant scenario assessment can be used to aid resource allocation for coastal adaption in the long term to protect property and environmental resources and achieve the goal of sustainable development. In this research, a case study on the coastal areas of Yunlin County, Taiwan, was conducted, and time-variant risk under the adaptive strategy was estimated. Its comprehensive quantification enables the risk assessment to be of practical use in the long term for developing adaptive strategies for sustainable coastal management.

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