Article

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MDPI

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Abstract: This paper outlines the development of a socioeconomic vulnerability indicator framework (SVIF) which was designed to provide a tool to inform bespoke local adaptation actions along the Taiwanese coast. The framework incorporates a range of diverse indicators, from ones that are related to demographic characteristics to others that represent economic and infrastructure features. As such, the framework encapsulates multiple and complex dimensions of socio-economic vulnerability rather than deriving a less nuanced single index; this is an approach that, whilst more commonly employed elsewhere, may mask critical features of socioeconomic vulnerability at local levels. The paper describes the piloting of the SVIF as it quantifies and visually summarizes the susceptibility and resilience of four townships (Mailiao, Kauho, Linbian and Jiadong) along the exposed coast of Southwest Taiwan. The paper demonstrates the SVIF's potential in characterizing specific aspects of socio-economic vulnerability that local decision-makers could use to tailor local adaptation. The SVIF was successful in differentiating between the four local areas, highlighting clear differences between urban and rural townships. With further development by using a more participative approach and expanding its application to wider geographical contexts both in Taiwan and further afield, the authors are confident that the SVIF has the potential to provide a useful tool for local adaptation.

Keywords: Socioeconomic Vulnerability; Indicator; Coastal area; Climate change adaptation

1. Introduction

Over the last few decades, climate change and related events have greatly amplified risks to the development and security of coastal communities across the globe (for example, [1–7]). Many of the adaptation measures that societies may put in place to address such risks may also have the potential to create long-term and sometimes unforeseen legacies, influencing the socio-environmental systems of coastal areas for generations to come [8].

This paper focuses on Taiwan, where such issues are very real. Facing a combination of frequent natural hazards, notably earthquakes and typhoons, alongside high levels of coastal development, Taiwan is one of the most vulnerable countries in the world [9–11]. Statistics from the Central Weather Bureau [12] have indicated that the number and frequency of large tropical cyclones has increased significantly in the West Pacific since 2000. Others, too, have highlighted the increased impacts of such events, exacerbated by changes in rainfall patterns and sea level rises over the last few decades [13,14].

An unprecedented increase in coastal development alongside the rapid growth and transformation of industrial, residential, agricultural, and fish farming sectors has resulted in Taiwanese coastal communities becoming ever more vulnerable to climate change and extreme weather events. These

anthropogenic changes have also extensively modified natural landforms and environments, creating further pressures on the human–environmental system. Along the southwest coast of Taiwan, the increasing demand for water resources from a growing and more affluent population, has resulted in the extensive abstraction of groundwater. This has resulted in significant land subsidence: Across the southwest of Taiwan, an area of nearly 900 km^2 is afflicted by an annual average subsidence rate exceeding 3 cm [15]. These alarming rates, alongside high levels of development and population density, and increasing the frequency of intense weather-related flood events and resulting in the coast of south west being deemed one of the most vulnerable regions in Taiwan [16–19]. This region is therefore the central focus for this paper.

It is widely recognized that a full understanding of vulnerability is essential for preparing, responding to and recovering from short-term climatic hazards [20,21] as well as for developing allied long-term climate change adaptation measures [22,23]. Numerous studies have shown that vulnerability varies in magnitude and type across regions, partly in response to different social, economic and political conditions [24–29]. At local scales, there is also the growing recognition that variations in socioeconomic factors may influence the vulnerability of communities more than previously recognized [24,30,31]. As a result, various authors have attempted to identify those properties of coastal systems which make local communities particularly vulnerable [32,33]. Some authors, notably Burton et al. [34] and Webb et al. [35], have also gone on to suggest that vulnerability assessments including socio-economic evaluation should be embedded into local planning processes. In contrast, in Taiwan, whilst national and local adaptation frameworks have been developed [36], these rarely take the socio-economic vulnerability of local communities into account.

The purpose of this paper was to demonstrate the findings of a study that developed and applied a socioeconomic vulnerability indicator framework (SVIF) to various coastal communities along the southwest coast of Taiwan, highlighting the potential of this SVIF to the development of local adaptation frameworks in Taiwan, as well as applications elsewhere. Whilst many other studies have established vulnerability indices that provide a simple numerical composite of the exposure of a population to a hazard [37], this study has purposefully gone against this convention to demonstrate the added value of a more nuanced 'disaggregated' approach.

The paper commences with a brief explanation of the theoretical background to the study and to vulnerability in particular. The study method is then outlined. This includes an outline of the study region, as well as an overview of the development the SVIF. The subsequent sections outline the susceptibility and resilience capacity of the different communities before discussing the implications and applications of the SVIF.

2. Theoretical Conceptualization

Our framework builds on the existing literature that has highlighted vulnerability as a complex, multifaceted concept [38–43], and has suggested that vulnerability is underpinned and can be defined by three essential components, namely exposure, susceptibility, and resilience [44–47]. Indeed, various authors have suggested that it is vital for both researchers and policymakers to understand these three components in order to reduce vulnerability [29,48–50]. As a result, these three aspects were central to and underlaid the development of our framework.

In terms of exposure, our study builds on Adger's suggestion [22] that this concept should be considered as the nature and degree to which a system experiences environmental or socio-political stress. We therefore define 'exposure' in terms of the natural geographic characteristics of a particular locality that influence the extent to which the coastal communities are at risk from climatic hazards. With respect to susceptibility, our definition reflects the results of recent studies that have demonstrated the impact of economic activities, infrastructure, and demographic structures on the susceptibility of human systems to climate change [51–56]. Our definition of 'susceptibility,' therefore, relates to the pre-existing socioeconomic conditions of communities that increase their vulnerability to external factors, notably climate change.

Finally, our definition of resilience recognizes the common view that this concept is related to a system's capacity to absorb, respond, and recover from an external perturbation [57,58]. Given suggestions that social resilience can be measured by the response capacity of social networks, available resources, and institutions to withstand and recover from external impacts [21,58–61], we define 'resilience' as the capacity and resources of societies to respond or recover to external hazards, such as climate change. These factors, we suggest, may influence the vulnerability of communities, both positively and negatively.

Figure 1 illustrates the interrelationships between these three key components. It depicts how each component can be classified in relation to specific time periods, prior to or after a hazard event [62]. Informed by the academic literature (see, for example, [63–67]), we suggest that exposure and susceptibility are related to the characteristics of the system prior to the hazard event. In contrast, resilience, being linked to coping and response capacity, is related to the system's ability to absorb and recover from the impacts, i.e., post the hazard event.
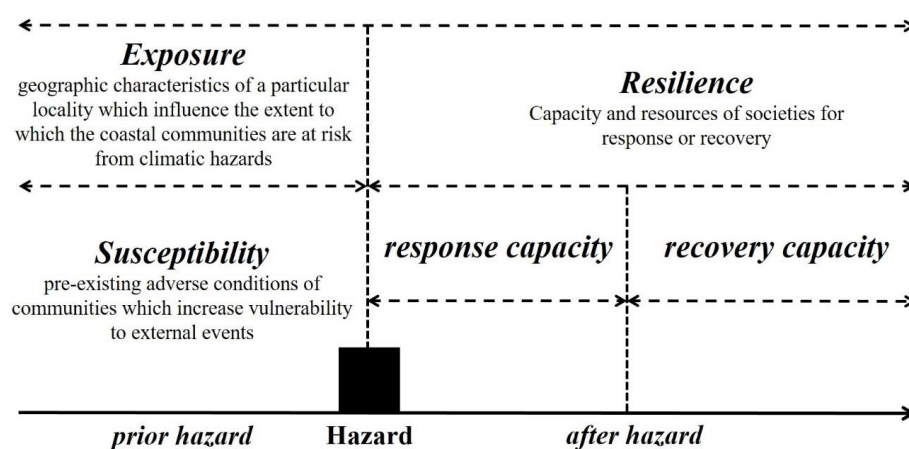

Figure 1. The components of vulnerability in relation to the timing of the hazard event.

3. Methodology

Many recent studies that have devised indicator frameworks for application at various spatial scales have pointed to the need for an explicit procedure and process to inform the development of a vulnerability assessment framework that is practically valid [21,59,68–70]. Such studies have suggested that such a process should include the following, underlying stages:

- The definition of the framework's purpose and the establishment of the spatial scale of the assessment (relating to the 'exposure' component of vulnerability: Section 3.1).
- The determination of the key dimensions of the conceptual framework underlying the study and the associated selection of appropriate indicators (pertaining to the 'susceptibility' and 'resilience' components of vulnerability: Section 3.2).
- The actual conduct of the vulnerability assessment itself (including the collection and application of relevant data to the indictor framework: Section 3.3).

This study adopted this process-based approach, as detailed below.

3.1. Purpose, Scoping, and Study Areas (Exposure)

Given the study's need to identify and characterize the specific vulnerability of different coastal communities, as well as the study's intention to demonstrate the importance of socioeconomic vulnerability in local adaptation frameworks, the SVIF was conducted at a township level. To ensure that the study addressed the "exposure" component of vulnerability, it needed to include several case studies that exhibited varying combinations of hazards and geographic characteristics. Consequently, two coastal townships in Yunlin County (the Mailiao and Kouhu townships) and two townships

in Pingtung County (Linbian and Jiadong townships) were selected (Figure 2). These encompass significant areas at risk from severe land subsidence (the annual average subsidence rate exceeds 3 cm) [15] and flooding.
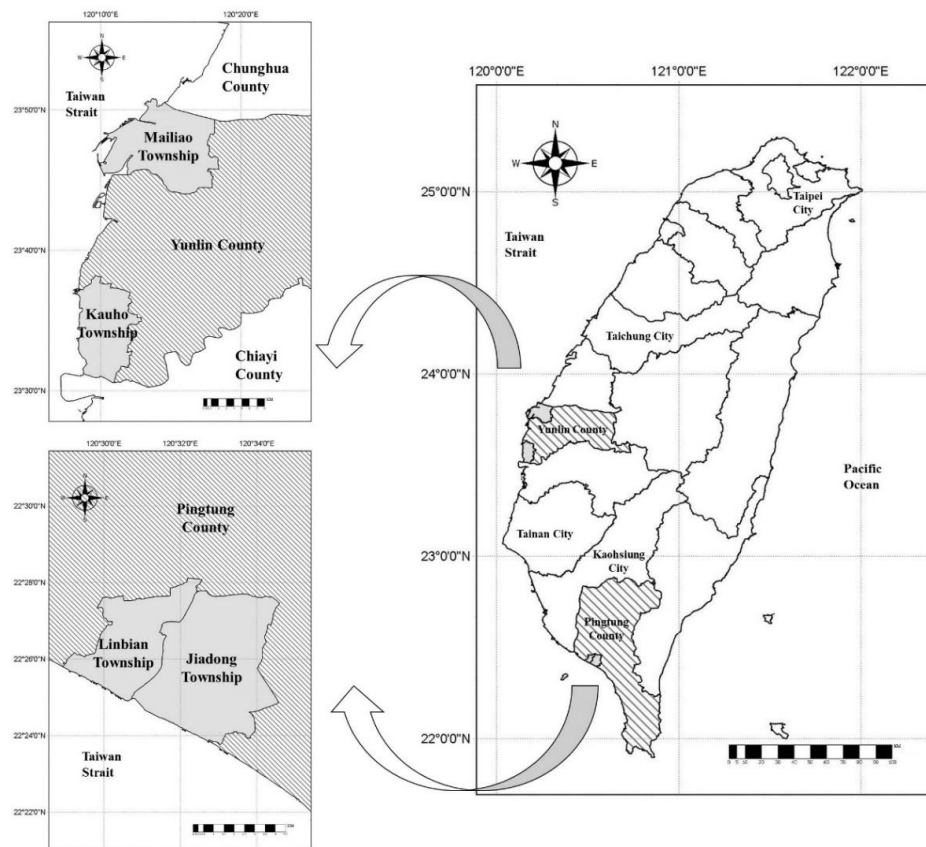

Figure 2. Case study areas along the southwest coast of Taiwan.

3.2. Conceptual Framework and Indicator Selection (Susceptibility and Resilience)

In order to ensure the transparency of the conceptual framework and the robustness of the indicators, practical definitions of "susceptibility" and "resilience" relevant to our study were developed, as noted in the section above. Based on these, various indicator groups (themes) were selected. These themes, which are listed in the left-hand column of Table 1, are related to the characteristics of the economic well-being and demographic structure of the communities, as we initially thought that these characteristics might influence the susceptibility and resilience of the communities to climate change.

Under each theme, numerous potential indicators were identified from the recent literature. These are displayed in the second column of Table 1. As these potential indicators are related to a wide range of external contexts, many of which are very different to that of the study area, it was necessary to screen each indicator in terms of its 'representativeness,' 'acceptability,' and 'accessibility' for bespoke application along the south west coast of Taiwan. The middle three columns of Table 1 denote the results of this evaluation, which followed procedures that have been outlined in the literature [24,48,71–76]. The set of bespoke, realistic, and practical indicators that emanate from this is shown in the right-hand column on Table 1.

As a result of this screening process, some indicators were deemed irrelevant to the Taiwanese social and cultural context. Several indicators, including those relating to 'housing units,' 'mobile homes,' and 'birth rates,' became obsolete as a result of their lack of 'representativeness' and 'acceptability.' In practice, the selection of indicators was driven mostly by 'accessibility' to datasets, particularly those that are related to economic well-being at the "township" level.

The SVIF that was used for our study is displayed in Figure 3. Whilst this embedded all the practical indicators from Table 1, it reclassified these in order to better distinguish between features relating to either the 'susceptibility' or 'resilience' dimensions of vulnerability. Furthermore, under each of these dimensions, a range of economic, demographic, and social—as well as resource capacity and infrastructure—aspects were included in order to capture the broad overall assessment that was required at this piloting stage of the SVIF's development. In the light of others' concerns regarding the limitations of using single indicators [71,77] and to provide a reasonably comprehensive and balanced overview for specific themes, we chose between two and four indicators to represent each theme.
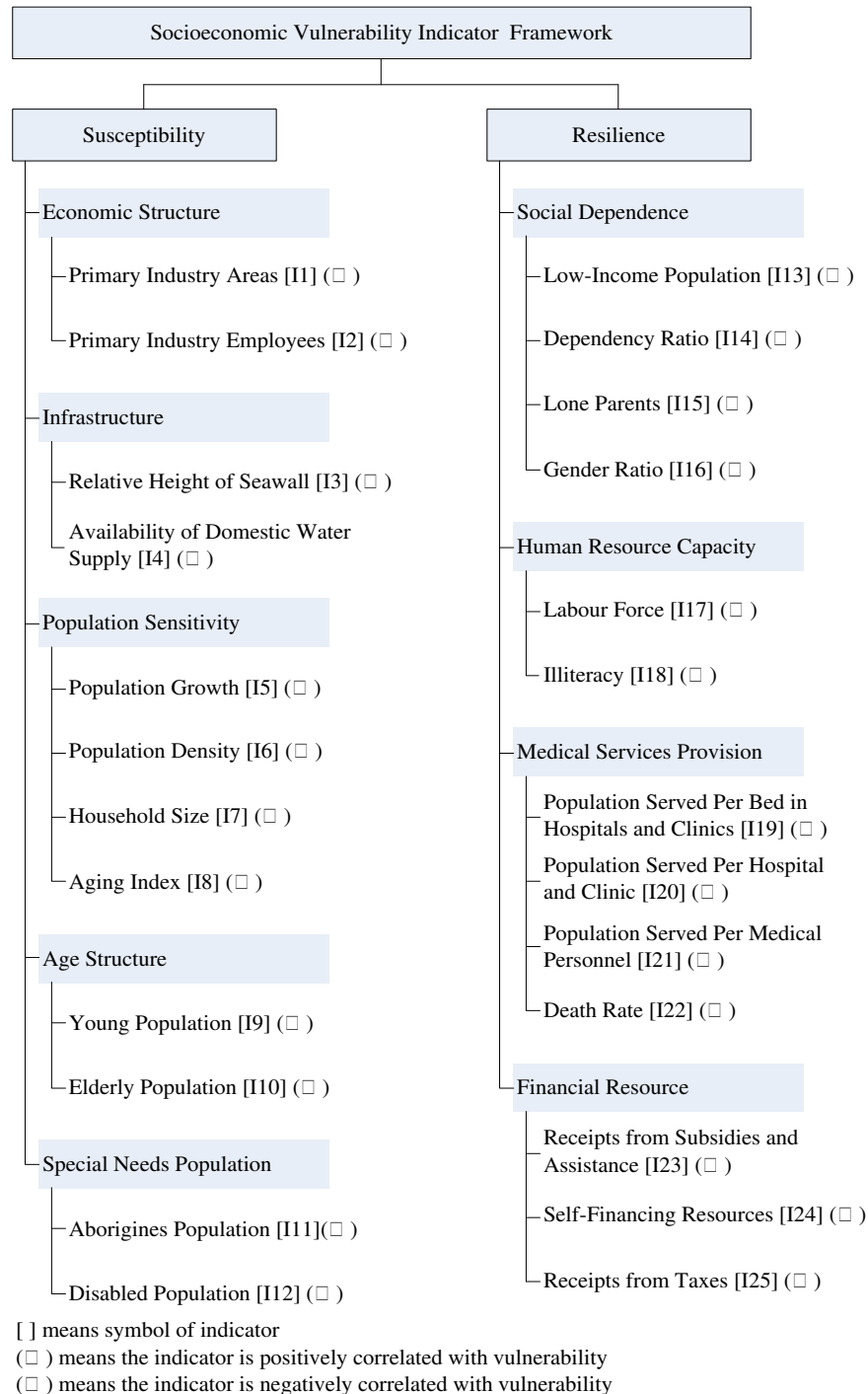
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                    Socioeconomic Vulnerability Indicator  Framework

            Susceptibility                              Resilience

        Economic Structure                          Social Dependence

          Primary Industry Areas [I1] (□ )            Low-Income Population [I13] (□ )

          Primary Industry Employees [I2] (□ )        Dependency Ratio [I14] (□ )

        Infrastructure                                Lone Parents [I15] (□ )

          Relative Height of Seawall [I3] (□ )        Gender Ratio [I16] (□ )

          Availability of Domestic Water            Human Resource Capacity
          Supply [I4] (□ )
                                                      Labour Force [I17] (□ )
        Population Sensitivity
                                                      Illiteracy [I18] (□ )
          Population Growth [I5] (□ )
                                                    Medical Services Provision
          Population Density [I6] (□ )
                                                      Population Served Per Bed in
          Household Size [I7] (□ )                    Hospitals and Clinics [I19] (□ )

          Aging Index [I8] (□ )                       Population Served Per Hospital
                                                        and Clinic [I20] (□ )
        Age Structure
                                                      Population Served Per Medical
          Young Population [I9] (□ )                   Personnel [I21] (□ )

          Elderly Population [I10] (□ )               Death Rate [I22] (□ )

        Special Needs Population                     Financial Resource

          Aborigines Population [I11](□ )             Receipts from Subsidies and
                                                        Assistance [I23] (□ )
          Disabled Population [I12] (□ )
                                                      Self-Financing Resources [I24] (□ )

                                                      Receipts from Taxes [I25] (□ )
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[ ] means symbol of indicator
(□) means the indicator is positively correlated with vulnerability
(□) means the indicator is negatively correlated with vulnerability

Figure 3. Socioeconomic vulnerability indicator framework.

Table 1. Proposed indicators, selection principles, and representative proxies in the socioeconomic vulnerability indicator framework (SVIF).

Theme	Potential Indicator (reference)	Representativeness	Acceptability	Accessibility	Practical Indictor
Population structure	Population growth (C; D; H; N; P; S)	+	+	+	Population growth
	Population density (A; B; C; E; P)	+	+	+	Population density
	Dependency ratio (B; C; D; E; G; P)	+	+	+	Dependency ratio
	Young (A; C; D; F; G; I; J; K; O;)	+	+	+	Young population
	Elder (A; C; D; F; G; I; J; K; L; O; P; R; S)	+	+	+	Elderly population
	Lone Parents (A; C; D; F; I; K; L)	+	+	+	Lone parents
	Family Composition (A; C; D; F; K; O)	+	+	+	Household size
	Race / Ethnicity (C; D; K; O)	+	+	+	Aborigines population
	Aging (R; S)	+	+	+	Aging index
Access to resources	Literacy (B; E; H; M)	+	+	+	illiteracy
	Educational Level (A; C; K; O; S)	+	+	ND	-
	Population in the workforce (B)	+	+	+	Labor force
Physical limitation	Gender (A; C; D; F; I; O; R)	+	+	+	Gender ratio
	Disability (A; E; F; H; I; M; R)	+	+	+	Disabled population
	Mortality rate (N)	+	+	+	Death rate
	Infant mortality (N)	+	+	ND	-
	Maternal mortality (E; H)	+	+	ND	-
	Birth rate (B; C; E; O; P; Q)	NAP	+	+	-
	Life expectancy (B; E; H; J; Q)	+	+	ND	-
	Special needs populations (C; D; F)	+	+	ND	-
Economic Status	Income (A; B; C; D; I; J; K; M; N; P; R)	+	+	ND	-
	Poor household (D; F; J; K; P; R; S)	+	+	+	Low-income population
	Insurance (R)	+	+	ND	-
	Unemployment (A; C; D; J; K; L; M)	+	+	ND	-
Housing/ Transportation	Housing unit (G; K; M)	NAP	+	ND	-
	Housing tenure (A; C; D; F; L; M)	+	+	ND	-
	Available vehicle (I; K; L; Q)	+	+	ND	-
	Mobile home (A; K; M)	NAP	NA	ND	-
	Crowding (A; K; L; M)	+	+	ND	-
	Residential property (C; M; R)	+	+	ND	-
Industrial Development	Employment in primary industry (A; C; D; E; G; P; Q)	+	+	+	Primary industry employees
	Value of primary industry (C; E; H; N; P)	+	+	ND	-
	Area of primary industry (G; N; P; Q)	+	+	+	Primary industry areas
Physical Infrastructure	Public facility (C)	+	+	+	Relative height of seawall
	Medical service (C; D; E; H)	+	+	+	Population served per bed in hospitals and clinics
					Population served per hospital and clinic
					Population served per medical personnel
	Access to water supply (B; C; E; H; M; N; Q)	+	+	+	Availability of domestic water supply
Financial State	Financial resource				Receipts from subsides and assistance
					Self-financing resources
					Receipts from taxes

NAP: no appropriate
NA: not available
ND: no data

Source: [59] A, [71] B, [60] C, [61] D, [21] E, [78] F, [79] G, [80] H, [81] I, [82] J, [83] K, [28] L, [84] M, [85] N, [86] O, [17] P, [87] Q, [88] R, and [89] S.

In summary, there were five themes (economic structure, infrastructure, population sensitivity, age structure, special needs population) that were related to 'susceptibility' that in turn are represented by twelve detailed indicators (Figure 3). As such, our assessment of 'susceptibility' included an assessment of the natural resource dependency of livelihoods as well as the evaluation of aspects relating to public security, population distribution, and structure. The 'resilience' dimension contained four themes (social dependence, human resource capacity, medical services provision, and financial resources) with thirteen indicators that were employed to express these themes in detail. This assessment of 'resilience' emphasized the resilience capacity of economically and socially marginalized communities, and it also provided an evaluation of the key resources that enable communities to better recover from hazards. Financial resources were singled out by Adger et al. [21] as being a particularly limiting factor in determining the recovery and response capacity of local governments.

3.3. Uniform Transformation of Indicator Variables

Demographic data were collected from the local government census, and other socio-economic data were compiled from the national census and websites of the Budget, Accounting and Statistics Departments of Yunlin and Pingtung County governments in 2017 [90,91]. Many options, such as min–max linear scaling, z-score standardization, and maximum value linear scaling, were available to compute vulnerability. To enable compatibility and to ensure meaningful and straightforward comparisons between the indicators [62,92], all indicators were standardized by using a conventional technique, as suggested by many previous studies [28,75,87,89,93,94]. This approach was chosen because of the relative ease of the calculation and comparison of the results with individual indicators. This standardization process converted the original values to z scores by using the following formula:

$$z = \frac{x - \mu}{\sigma} \tag{1}$$

where x is the original value from each indicator, μ is the mean of the original data, and σ is the standard deviation of the original data.

This normalization process was then used to generate p scores, based on fitting the z scores to relative positions between 0 and 100. If the indicator was negatively correlated with vulnerability, the final score was $(1-p) \times 100$, while if the indicator was positively correlated with vulnerability, the final score was $p \times 100$. Therefore, a higher score indicated a higher vulnerability. Considering that the purpose of this paper was to highlight significant factors that contribute to the socioeconomic vulnerability of various coastal communities, a disaggregated approach [93] and average values [60,75,81,87] were used to identify the level of vulnerability in this study. Once the result of the socioeconomic vulnerability model had been produced, key patterns and trends were displayed by using radar diagram and compound bar charts. Together, these were used to identify common themes and to show outliners between cases.

4. Results and Analysis

This section highlights the findings from the application of the SVIF, demonstrating the relative levels of socioeconomic vulnerability of the four townships. Following an overview of the findings (Table 2), the section provides detailed explanation of the specific susceptibilities and resilience of the case studies in order to demonstrate the significance of the findings and, therefore, the potential of the framework. Table 2 and the detailed displays of the results for each township (Figures 4–7) reveal distinct differences in the vulnerability characteristics of the townships despite similar levels of physical exposure. When taking into account the full framework of all indicators (Figure 8), Kauho is clearly the most vulnerable (62.1) to climate change because of its high susceptibility and low resilience. Owing to its slight susceptibility and strong resilience to climate change, Mailiao (39.7) is the least vulnerable (Table 2). Faced with an increasing frequency of extreme weather events, the four coastal communities face different levels of vulnerability depending on their inadequate infrastructures (I3,

Linbian: 64.97; Jiadong: 89.22), aging societies (I8, Kauho: 61.74; Linbian: 63.61; Jiadong: 79.17; I10, Kauho: 65.21; Linbian: 62.55; Jiadong: 77.66), high social vulnerable groups (I15, Kauho: 65.93; Linbian: 58.1; Jiadong: 79.75; I16, Mailiao: 81.02; Linbian: 68.44; Jiadong: 52.15), and insufficient medical resources (I19, Kauho: 90.28; Linbian: 58.64; I21, Kauho: 87.04; Jiadong: 59.25; I22, Kauho: 76.04; Linbian: 56.64; Jiadong: 72.06).
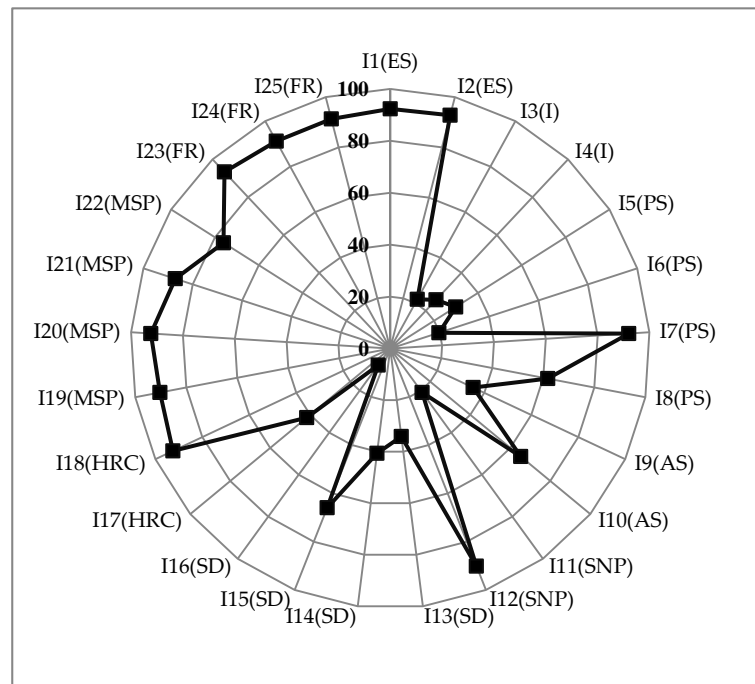

Figure 4. Vulnerability of socioeconomic characteristics in the Kauho township.
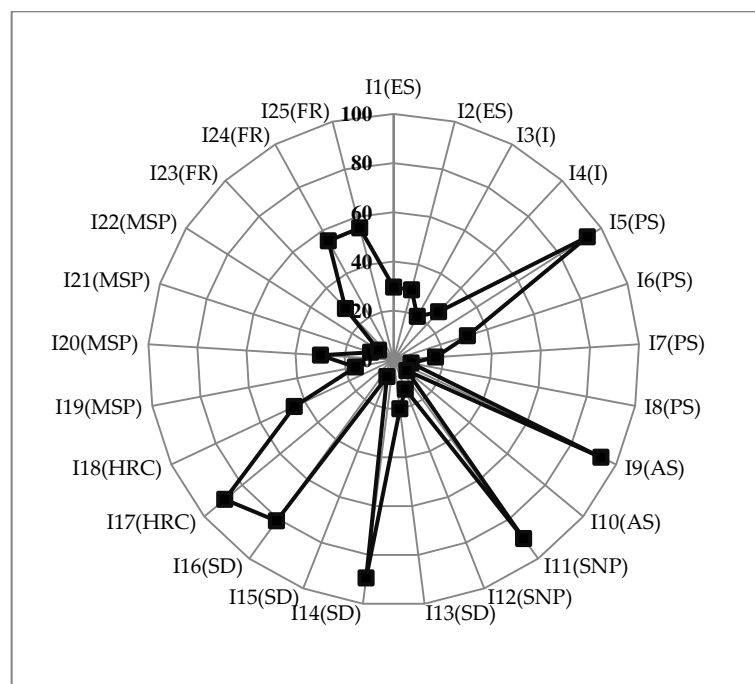
Figure 5. Vulnerability of socioeconomic characteristics in the Mailiao township.
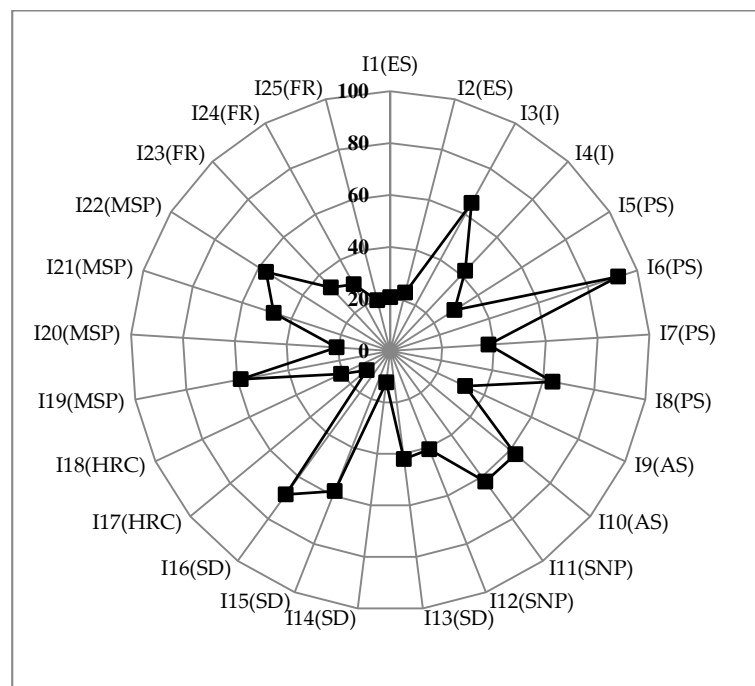
Figure 6. Vulnerability of socioeconomic characteristics in the Linbian township.
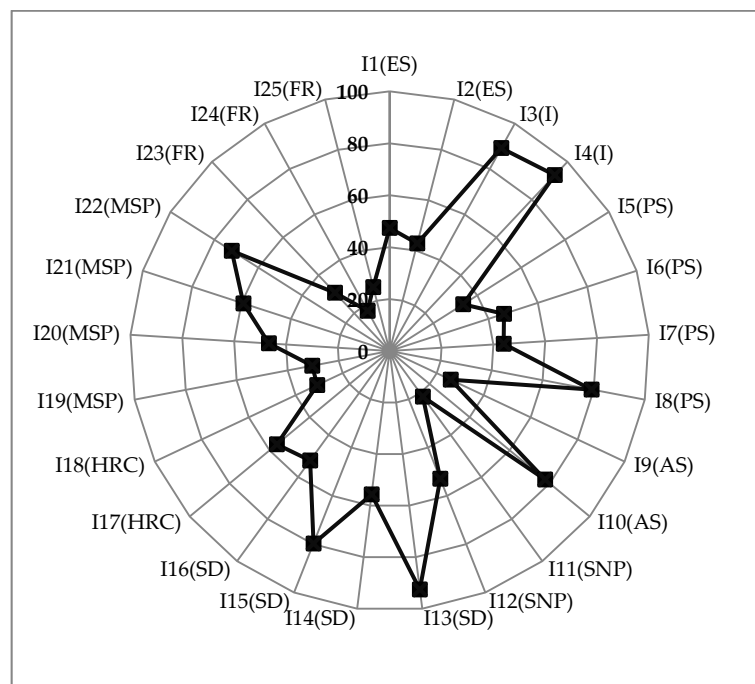
Figure 7. Vulnerability of socioeconomic characteristics in the Jiadong township.
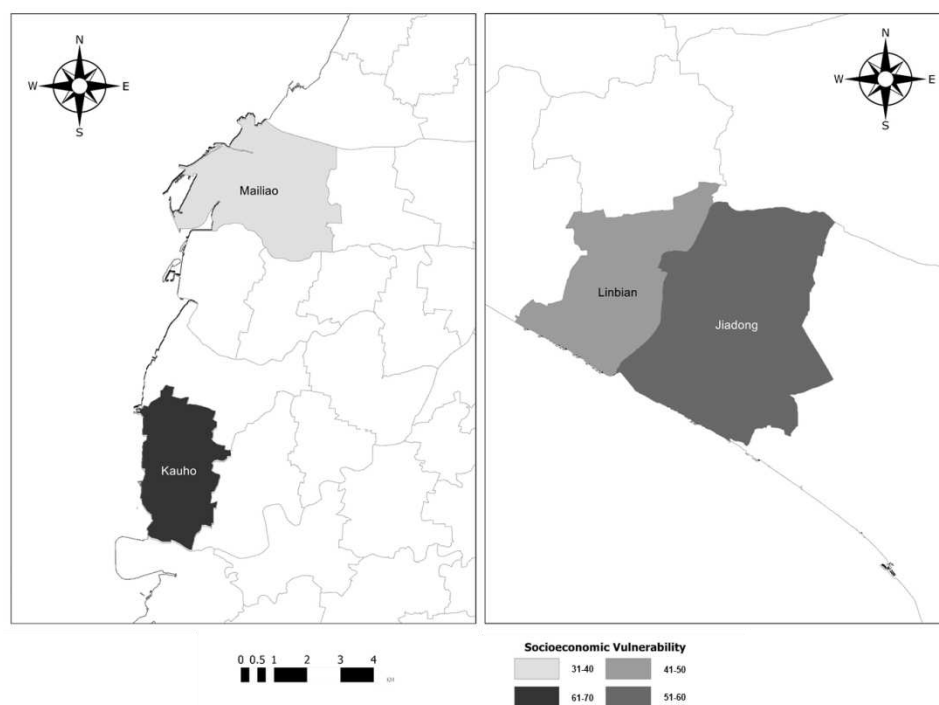
Figure 8. The level of overall socioeconomic vulnerability of the four cases.

Kauho's vulnerability is clearly linked to its higher scores across most of the indicators compared to the other townships. The figures illustrate the salient driving factors of socioeconomic vulnerability for the different coastal communities, with the radar diagrams enabling the reader to quickly identify the indicators that contribute to high vulnerability scoring indicators. For example, the figure for Kauho (Figure 4) shows a more uniform pattern of vulnerability compared with the spikey chart for Mailiao (Figure 5). In addition, it is relatively easy to pick out the indictors that contribute to each township's vulnerability from these charts: In the case of Kauho, for example, Figure 4 highlights the township's high level of vulnerability that is associated with indicators that are related to medical service provision (I19-I22), financial support (I23-I25), and economic structure (I1-I2). In contrast, the relatively less vulnerable township of Mailiao still displays some vulnerabilities, as highlighted by the occasional 'spike' in the radar chart (Figure 5). These are particularly related to the demographics of the township's population, notably its age structure (I9), excessive population growth (I5), and high dependency ratio (I14) caused by its youthful population.

Table 2. Vulnerability data for the four townships.

Socioeconomic Vulnerability Indicator Framework			*p* Scores *			
Dimension	**Criterion (abbreviated name)**	**Indicator (code)**	**Mailiao**	**Kauho**	**Linbian**	**Jiadong**
Susceptibility	Economic structure (ES)	Primary industry areas (I1)	29.5	92.3	20.59	47.38
		Primary industry employees (I2)	29.33	92.79	23.14	42.77
	Infrastructure (I)	Relative height of seawall (I3)	20.08	21.65	64.97	89.22
		Availability of domestic water supply (I4)	26.73	25.8	42.19	92.89
	Population sensitivity (PS)	Population growth (I5)	93.29	29.89	29.29	33.53
		Population density (I6)	31.54	19.71	92.31	46.27
		Household size (I7)	17.13	92.04	37.91	43.99
		Aging index (I8)	7.22	61.74	63.61	79.17
	Age structure (AS)	Young population (I9)	93.2	35.3	31.91	25.99
		Elderly population (I10)	7.05	65.21	62.55	77.66
	Special needs population (SNP)	Aborigines population (I11)	89.95	20.9	62.3	21.71
		Disabled population (I12)	12.9	90.13	40.85	52.92
Resilience	Social dependence (SD)	Low-income population (I13)	20.13	34.15	42.03	92.6
		Dependency ratio (I14)	89.52	40.69	12.27	55.67
		Lone parents (I15)	7.38	65.93	58.1	79.75
		Gender ratio (I16)	81.02	7.89	68.44	52.15
	Human resource capacity (HRC)	Labor force (I17)	89.14	41.73	11.78	56.39
		Illiteracy (I18)	44.69	92.53	20.94	30.86
	Medical services provision (MSP)	Population served per bed in hospitals and clinics (I19)	15.82	90.28	58.64	30.36
		Population served per hospitals and clinics (I20)	29.81	92.37	20.71	46.65
		Population served per medical personnel (I21)	9.83	87.04	47.15	59.25
		Death rate (I22)	7.22	76.04	56.64	72.06
	Financial resources (FR)	Receipts from subsidies and assistance (I23)	28.57	93.29	33.38	30.78
		Self-financing resources (I24)	55.13	91.13	29.18	17.63
		Receipts from taxes (I25)	55.35	91.31	20.06	25.39
Mean scores		All indicators	39.7	62.1	43.6	52.1
		Susceptibility indicators	38.2	54	47.6	54.5
		Resilience indicators	41	69.5	39.8	49.9

* The vulnerability level is between 0 and 100; a high value means a high socioeconomic vulnerability to climate change

4.1. Susceptibility

4.1.1. Economic Structure and Infrastructure

Figure 9 shows clear differences between the townships in terms of their susceptibility to climate change as a consequence of their economic structure. Whilst the Maliao, Linbian and Jiadong townships display very similar, low levels for both indicators, the situation for Kauho is very different. Figure 8 highlights this township's heavy reliance on primary economic industrial activity. Given that this is largely related to the agriculture and aquaculture sectors, which are heavily dependent on the state of natural resources, it can be suggested that the local economy of the Kauho township may be the most susceptible to climate change.
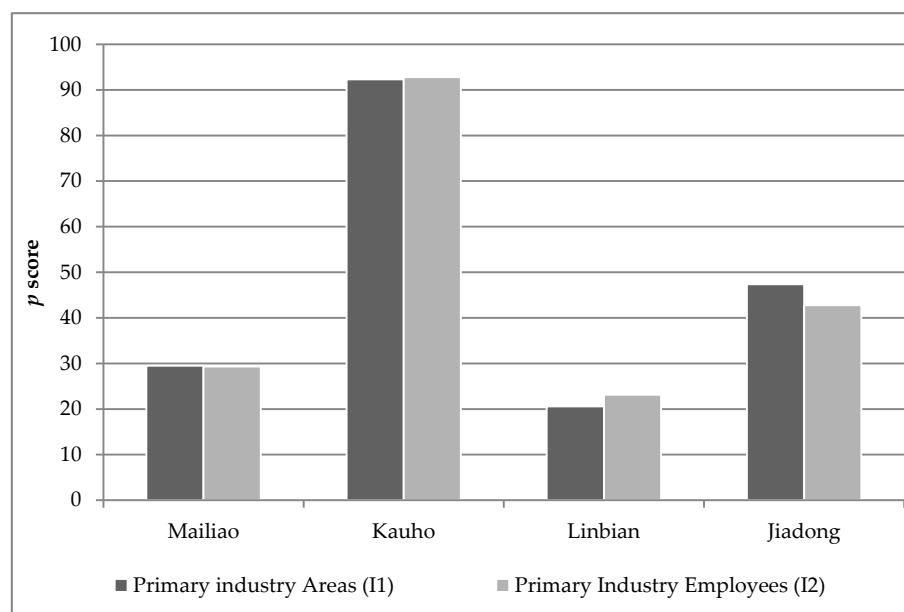
Figure 9. Vulnerability of the townships with respect to the susceptibility theme of economic structure.

In contrast, Figure 10 highlights the higher levels of susceptibility for Linbian and Jiadong in relation to the two infrastructure indicators, the 'relative height of the seawall' and the 'availability of domestic water supply.' Both are critical factors that hinder the protection of local economic activities and public security. Compared with the first theme, there is slightly greater variation between the findings for each indicator, particularly for Linbian.

In practice, there may be a close symbiotic relationship between the presence of primary economic activity and infrastructure provision. Infrastructure, particularly seawalls, may protect local economic activity, public infrastructure, private property, and community security in coastal areas. Conversely, a robust and diverse industrial structure may provide financial support to strengthen local infrastructure and to improve access to markets and resources [60,71,95].
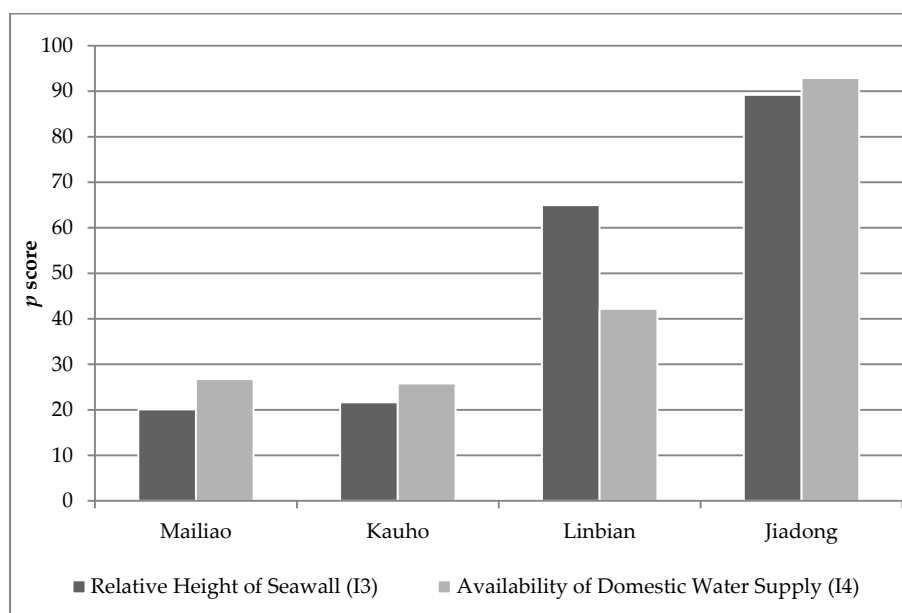
Figure 10. Vulnerability of the townships with respect to the susceptibility theme of infrastructure.

4.1.2. Population Sensitivity and Age Structure

Figure 11 reveals that the high population density and over-crowding of coastal areas are the critical susceptibility factors for climate change. There are different factors that contribute to vulnerability in each township, notably the population growth (I5) rate in Mailiao, population density (I6) in Linbian, household size (I7) in Kauho, and the aging index (I8) in Kauho, Linbian, and Jiadong. The population growth rate and the aging index also display a marked difference between the four townships. Whilst population growth is a key factor in Mailiao, the other townships are witnessing negative growth and a correspondingly aging society.
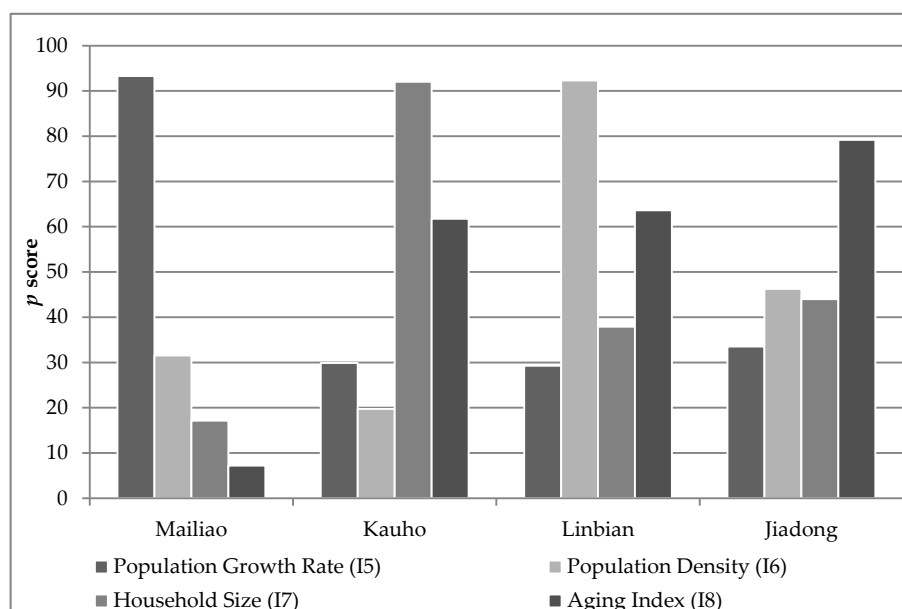
Figure 11. Vulnerability of the townships with respect to the susceptibility theme of population sensitivity.

In detail, Figure 12 reveals a distinct difference between Mailiao and the other townships in terms of their age structure. Two groups, the young and old sections of society, are particularly vulnerable

to external hazards and require specific assistance. The high young population (I9) in Mailiao and the large proportion of elderly people (I10) in the other townships (Kauho, Linbian and, Jiadong) are notable. The latter, which clearly corresponds to the previously mentioned high aging indices, is a major issue because of the demands that elderly populations place on social welfare provisions [96,97].
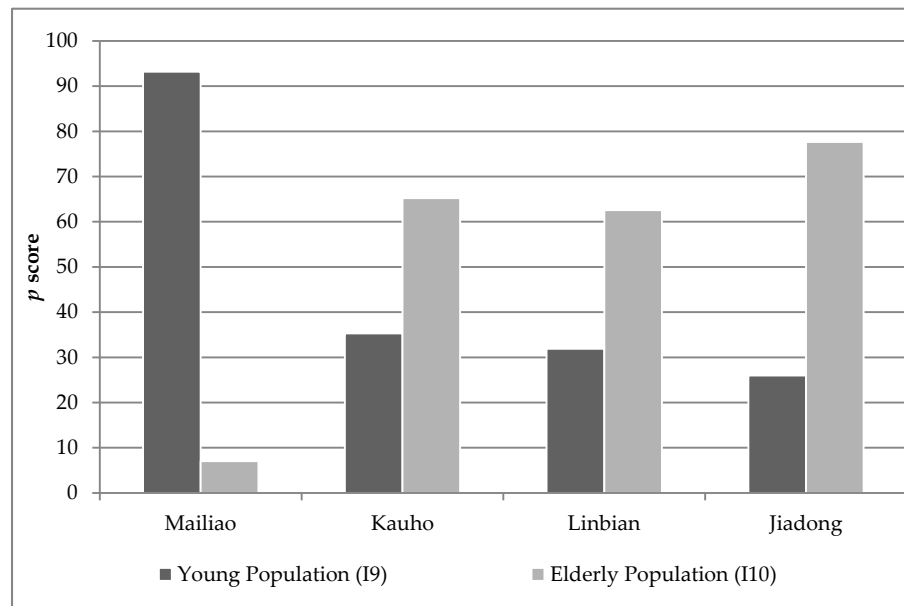
Figure 12. Vulnerability of the townships with respect to the susceptibility theme of age structure.

Figures 11 and 12 indicate a clear contrast between the population structure of the urban and rural coastal areas, particularly with respect to population growth and aging. Whilst such findings reflect the demographics of other rural and urban areas, the explanation for such a contrast in the case study region can likely be explained by the petrochemical industry in Mailiao. This is a major attraction for young workers from elsewhere [98].

4.1.3. Special Needs Population

Figure 13 reveals that all four townships are highly susceptible to climate change as a result of their high proportion of underprivileged populations, particularly their aboriginal and disabled populations. It has been suggested that a large aboriginal population, such as those in Mailiao and Linbian, may pose issues for adaptation as a consequence of their specific cultural and language needs [12,99]. Such sections of society frequently require different types of information on adaptation and may even have contrasting information accessibility needs as well.

Regarding disabled populations, there are significant differences between the townships, with the highest proportion of disabled populations living in Kauho and Jiadong. Disabled people pose particular challenges for adaptation to climate change as a result of their particular physiological and sometimes intellectual needs, making them potentially more susceptible [87,100].
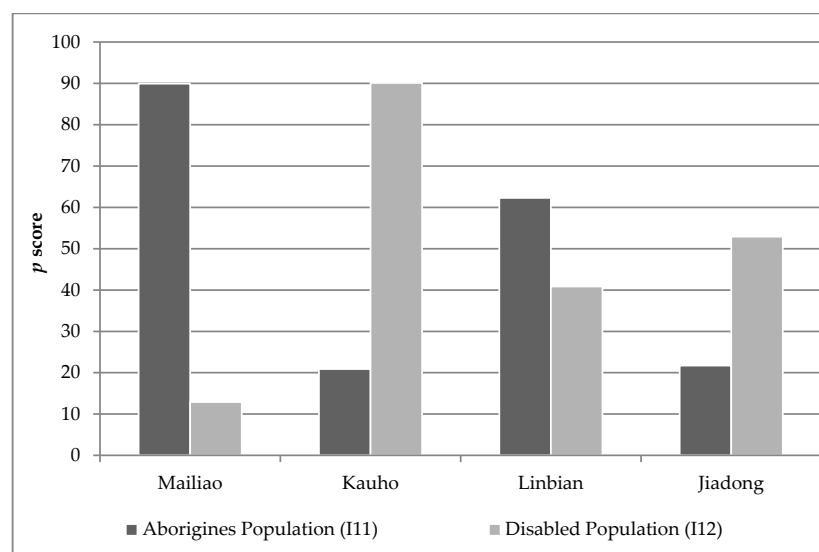
Figure 13. Vulnerability of the townships with respect to the susceptibility theme of special needs population.

4.2. Resilience

4.2.1. Social Dependence

Figure 14 shows the varying resilience capacities of the four townships in terms of their social dependency. A large low-income population (I13) has increased vulnerability in Jiadong, whereas the high dependency ratio (I14) in Mailiao and Jiadong are more critical to climate change. The high proportion of lone parents (I15) in Kauho, Linbian and Jiadong have also created specific demands on social support and associated networks, as well as a decreased community resilience to climate change [28]. The high proportion of the female population (I16) in Mailiao, Linbian and Jiadong is also significant in terms of vulnerability. Given that females tend to have lower salaries and more family care responsibilities than males in current Taiwanese society, it is suggested that natural hazards may have a stronger impact on those townships along the Taiwanese coast that have a higher proportion of females [101,102].
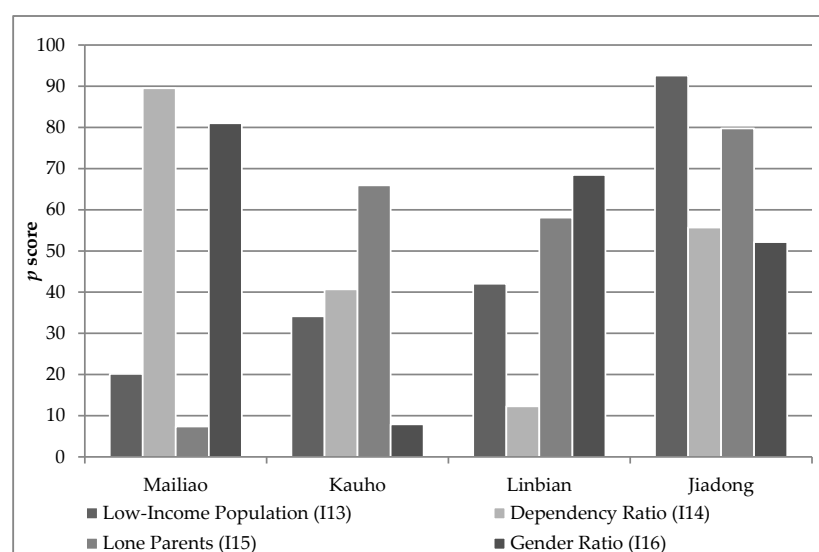
Figure 14. Vulnerability of the townships with respect to the resilience theme of social dependence.

4.2.2. Human Resource Capacity

Figure 15 highlights higher levels of susceptibility for Mailiao (I17) and Kauho (I18) in relation to the two human resource capacity indicators, the 'labor force' and 'illiteracy.' These two aspects play a significant role in supporting emergency responses and recovery from natural disasters. Compared with other townships, Mailiao has a relatively small labor force. However, because it is possible that this results from the township's current high proportion of young people under the age of 15, it may therefore be a temporary feature. It is worth noting the illiteracy rate in Kauho is much higher than in the other townships, with a difference of 4.5 times between the highest and lowest *p* scores.
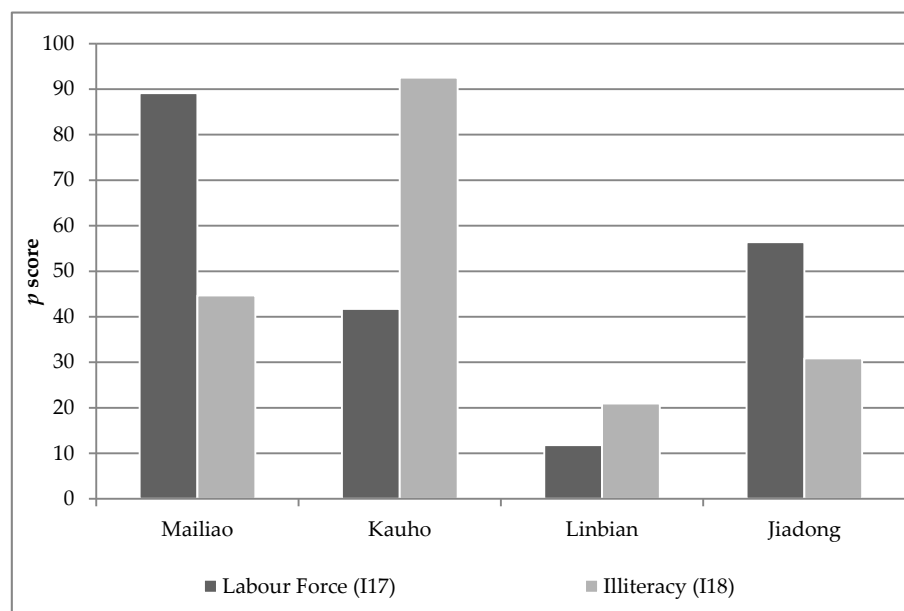
Figure 15. Vulnerability of the townships with respect to the resilience theme of human resource capacity.

4.2.3. Medical Services Provision

Figure 16 reveals unequal provision of medical resources across the townships. Given the likely relationship between medical resource provision and socioeconomic vulnerability to climate change, Miliao, with a higher medical resource provision and lower death rates than the other townships, is the most resilient. The Kauho township is the most vulnerable. Insufficient medical facilities (I19), hospitals and clinics (I20), and medical personnel (I21) in this township, as well as in Linbian and Jiadong, are also accompanied by high death rates (I22), suggesting high levels of potential vulnerability across all three townships [21,103]. The previously noted higher proportion of elderly people in the rural areas clearly influences death rates and creates a high demand for the provision of medical services.

4.2.4. Financial Resources

From the perspective of financial resources, Figure 17 reveals that Kauho is potentially most vulnerable to climate change. There is a high dependency on subsidies and assistance from the central government (I23), as well as insufficient self-financing resources (I24) and taxes (I25) in this township. Mailiao has a similar profile with respect to self-financing resources and tax receipts, potentially indicating that this township may also have a reduced resilience to climate change. Such results are not surprising given the suggestions by Xu [104] and Jang [105] that local government financial resources are not unrelated to population structure and economic development in Taiwan. Indeed, it is likely that the high dependency of Kauho on primary industrial activity (Figure 9) and its high proportion of elderly people (Figure 12) contribute the township's financial shortfall.
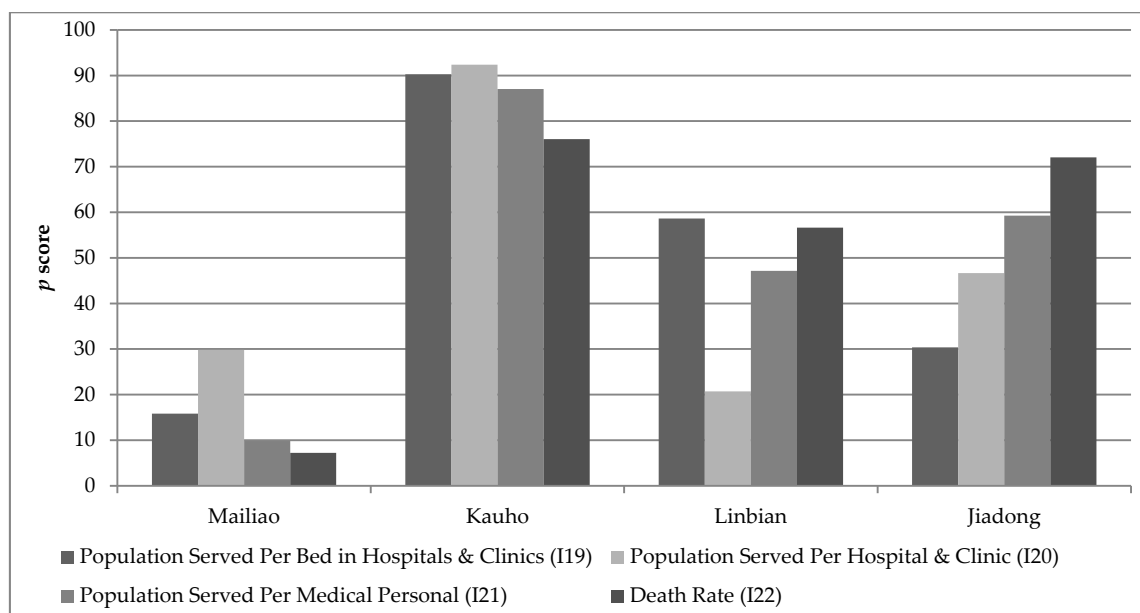
Figure 16. Vulnerability of the townships with respect to the resilience theme of medical services provision.
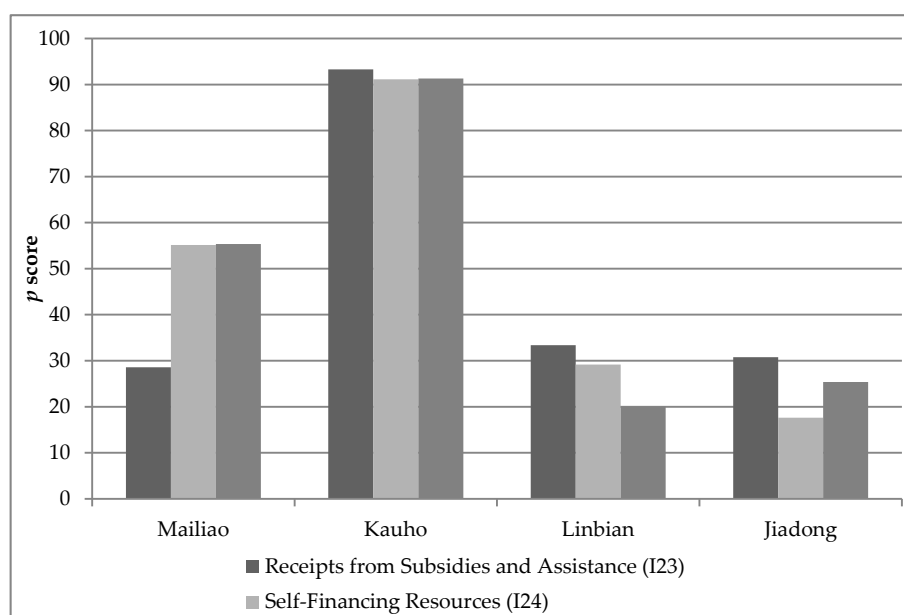

Figure 17. Vulnerability of the townships with respect to the resilience theme of financial resources.

5. Discussion

This section provides comments on the ability of the SVIF to characterize patterns of socioeconomic vulnerability to climate change. It also provides an evaluation of the extent to which the model is able to inform the orientation and scope of future local adaptation. Finally, there is a short critique of the SVIF, focusing on key aspects of the framework that require further development.

5.1. Characterizing Potential Susceptibility and Resilience Factors to Climate Change

The piloting of the SVIF along the south west coast of Taiwan has demonstrated considerable success in identifying the key socio-economic characteristics of coastal townships that may influence community vulnerability. Along this particular stretch of coast, the results explained in Section 4 suggest that increased vulnerability can be attributed to a small range of characteristics. These are

the townships' susceptible industrial activities, inadequate infrastructure, high population densities, high aging rates, high proportions of specific socially vulnerable groups, and the limited provision of financial resources.

The SVIF has also been successful in highlighting significant variations between townships, as noted in Sections 4.1 and 4.2 In particular, there is a noticeable divide between rural and urban ones. The quantification and simple scaling revealed a marked difference between the more urbanized Mailiao township and the three other more rural ones. The robust industrial structure and infrastructure of the former may make the community in this township more adaptable to potential climate change impacts, whereas in Kauho and Jaidong, a less resilient economic structure and infrastructure, respectively, are key critical vulnerability factors.

The SVIF has provided a more nuanced profile and unique assessment of the vulnerability of different places, sectors, and communities [26,106–109]. In line with suggestions made by various authors, including Adger et al. [21], Wongbusarakum and Loper [110], Vincent [82] and Moss et al. [71], it has provided a useful simplification of the complexities of the real world for decision-makers whilst retaining a sufficiently detailed quantification of the indicators. Our findings certainly demonstrate that this practical tool has the potential to enable local governments to explore 'who' within local communities are vulnerable as well as to consider possible reasons for this. Furthermore, the authors suggest that these socioeconomic vulnerability factors can be combined into an overall coastal vulnerability index [111,112] to provide detailed overall vulnerability levels of coastal areas.

5.2. Informing Bespoke Local Adaptation Options

The comprehensive understanding of socioeconomic vulnerability that is supplied by the SVIF provides a lens to help decision-makers target the most vulnerable sectors [62,69,71,82,113,114] and to formulate tailored adaptation policies for these in the context of a broader understanding of vulnerability identified by the framework [77,107,115–121]. The results of this study suggest widely different socioeconomic vulnerabilities even exist in similar geographical areas that are characterized by similar hazards and, in the case of Mailiao and Kaoho, lie within a common local adaptation framework.

The wide range of indicators provides local decision-makers with a wealth of relevant information to help target their local adaptation actions in a more focused way rather than the usual suite of conventional actions. Some indicators, notably those that are related to infrastructure, medical service provision and even literacy rates, may highlight and help prioritize specific inadequacies that require future local government investment. A wider geographical coverage of townships might also help central governments prioritize the major support and funding of significant infrastructure projects.

Whilst many of the other critical vulnerability factors (for example, the demographic ones) are not ones that local governments can usually control through direct interventionist approaches, at least in the short-term, the knowledge of levels and spatial variations in many of these indicators, such as the high percentage of aborigines in Mailiao, should help direct and target communication strategies. This should ensure that all sections of the community are communicated within an appropriate way, both in terms of the levels and types of language used as well as the modes and formats of communication. Different sections of the community, such as the elderly, may also need different types of communication as well as additional forms of assistance and support in the context of climate change adaptation. Thus, in the context of our results, the communication approach that is taken in Mailiao should be considerably different to that of the other townships due to of contrasting demographics of this area compared with those of the others.

5.3. Development of the SVIF

There are various aspects to consider in the further development of the SVIF, including the refinement of indicators, the spatial resolution of data, and the visualization of the final product. These and other related aspects are considered below.

5.3.1. Spatial and Temporal Scales

In the academic literature, Zahran et al. [118], Eriksen and Kelly [69] and Kuhlicke et al. [119], amongst others, have demonstrated how vulnerability analyses can embrace many different spatial scales from the national scale down to the local and even the household scale. For the purpose of informing local adaptation strategy development, which is the function and purpose of our framework, further local and even household-scale data would be preferable. This would enable the identification of further variations in socioeconomic conditions that might demand differing specific adaptation requirements. However, the availability of easily accessible datasets is always a limiting factor (Table 1). In the context of our study, the spatial resolution of the data that are associated with the granularity of the Taiwanese census meant that it was not possible, unlike other countries such as the UK, to drill down below the township level to explore smaller scale local geographical variations in vulnerability. With any study, however, there is always a compromise between local needs for adaptation and the availability of data. Experimenting with data at various scales and investigating the 'added value' of gathering more detailed local data for key indicators could improve the identification of the most appropriate scaled data and the most proportionate approach, not entailing excessive cost or effort.

There is also a need to investigate and determine the appropriate time interval between assessments by using the framework in order to determine temporal trends in socio-economic vulnerability. This could help to assess the effectiveness of existing local adaptation actions as well as strategies to help update ineffective ones, assuming an iterative approach to adaptation, as suggested elsewhere [22,23, 34,35]. Where the data are largely derived from a national census, such as the case here, the update period is likely to be every decade. Ensuring compatibility between this time scale and the review of the relevant adaptation strategy would be beneficial to ensure that actions are revised on the basis of up-to-date new evidence. Armstrong and Lazarus [122] suggested that spatially explicit modelling to predict future coastal risk may also be needed to address feedbacks between hazard, exposure, and vulnerability and to capture emergent patterns of risk in space and time.

5.3.2. The Selection of Indicators

This study has demonstrated that the selection of a range of representative and practical socioeconomic indicators provides sufficient local specificity to tailor local adaptation. The research has also shown that such a selection should be based on both a knowledge of the relevant literature and a detailed understanding of the local context. It is suggested that such an approach is preferable to the adoption of a crude, blind aggregation of indicators, as suggested by Birkmann [121], Kuhlick et al. [119], and Krishna [123].

Clearly, as noted above, data availability was a major constraint for several indicators in our study. With further resources, bespoke surveys could be designed to address these gaps. It is suggested that the possibility of additional data streams could be explored with local government and data providers. Indeed, in order to get a 'buy in' for this framework approach from decision-makers and to facilitate further contextualization, the next stage of development of the framework could be more inclusive. Key decision-makers, including local adaptation planners and data providers, could be invited to a series of workshops to further refine the indicator selection. Given the broad range of indicators and the similarity between some of these (notably including those relating to 'aging' (I8) and the 'elderly population' (I10)), such deliberations could also investigate where there may be redundant indicators and possible gaps within the framework.

5.3.3. Disaggregation Vs Aggregation

As noted above, many traditional approaches to risk evaluation aggregate findings into a single risk index for each areal unit that is under investigation in order to prioritize management efforts, support, and funding (see, for example, [49,71,94,106]). Whilst such approaches are appealingly simple, such 'one-size-fits-all' approaches may result in an overly simplistic understanding of vulnerability.

Indeed, they may mask the identification and understanding of very significant factors that contribute to vulnerability at the local scale [93,124] that, in turn, informs a more nuanced approach to adaptation. Our study's intentionally 'disaggregated' approach provides a richer 'contextualization' for local adaptation. Its consideration of multiple dimensions of vulnerability, through the inclusion of a range of multiple indicators, enabled clear contrasts between different spatial contexts to be appreciated, as previously suggested by Malone and Engle [77]. However, as noted above, there may be some scope for investigating 'redundancy' in future iterations of the framework's development.

5.3.4. Standardization and Thresholds

The decision to employ the standardization of the indicators is justified in Section 3.3. In the absence of appropriate standards and thresholds for individual indicators, various studies (for example, [60,75,81,87]) have suggested 'average' values as an alternative means of identifying levels of vulnerability. Whilst this approach clearly enabled variations between the townships to be identified in our study, we do recognize that such an approach can lead to an over or underestimation of socioeconomic vulnerability. The exaggeration of mere, small differences between sites may occur, particularly when there are relatively few sites being compared.

Therefore, further research may be required to determine appropriate thresholds for the individual socio-economic indicators. This will be particularly important when identifying baseline levels for the provision of dedicated community safety and early-warning systems, for example. However, as highlighted by Luers [125], Mastrandrea and Schneider [126], Dessai et al. [127], Eakin and Luers [120], and Birkmann [121], identifying such thresholds is both complicated and time-consuming. Jhan [62] suggested that this result from the multiple dimensions and variability of human systems and climate change, as well as the relationship between them.

5.3.5. Visual Display of Indicators

As demonstrated in Section 4, the use of radar charts was effective in providing a visual overview of our findings for each township, whereas the complimentary bar charts in subsequent sections (Sections 4.1 and 4.2) were useful in providing more easily readable, detailed interpretations for each theme. As well as helping the reader to quickly identify the indicators which contribute to high and low vulnerability through the interpretation of the 'spikes' in the radar graphs, the use of the standardized format of these charts enabled them to simply and clearly demonstrate both the 'outliers' and the 'commonality' between the case studies. The difference between Kauho and the other townships in terms of the medical services provision (MSP) indicators, for example, is clear from a glance at the left-hand side of Figures 4–7.

Whilst Chambers [40] and others have acknowledged the usefulness of radar charts in displaying multivariate observations based on arbitrary numbers of variables, their use has not been without some criticism. However, we attempted to address the most common issues associated with their usage. As there can be some concerns regarding how easy it is to compare spoke lengths between figures, we tried to minimize this issue by using concentric circles as grid lines. This research also overcame their perceived weakness in facilitating trade-off decisions by using standardized values for each indicator. Finally, we considered the placement of 'neighboring' indicators on the charts to ensure that grouped indicators were next to each together, reducing the possibility of viewers misinterpreting relationships between neighboring variables. Further enhancements to the visual display of these figures through different colored shadings of each theme could facilitate interpretation.

In terms of future development of the SVIF, we suggest the continued use of both graph types with some interactive discussion with users and, particularly, decision-makers to try to test their practical usability and effectiveness. Given that two-dimensional radar charts are commonly used in program quality control, the study suggests that they could be used with updated data on a regular basis to help identify the effectiveness of local adaptation programs over time.

5.3.6. Uncertainty of Assessment Model

Every stage of a socioeconomic vulnerability assessment may be imbued with uncertainty as a result of the multiple decisions that are made during model development, including those associated with index construction, indicator selection, analysis scale, measurement error, data transformation, normalization, and weighting [128]. The overall weighting influences uncertainty, most especially as the researcher focuses on the ranking of overall vulnerability levels. Therefore, a disaggregated approach and the average value approach were chosen. The further development of the approach that uses uncertainty and sensitivity analyses would help differentiate between those assessment stages that most influence vulnerability. This is recommended because it would help improve the robustness of the model [129,130].

6. Conclusions

While numerous international studies have focused on vulnerability assessment and associated rankings, many consider a single ranking of vulnerability as not sufficiently nuanced to be able to adequately inform locally specific climate change adaptation. Instead, many have suggested that a range of socio-economic indicators are required to produce a more credible and understandable profile of location-specific vulnerability for policymakers [62,77,106,107,113]. As a consequence, this study set out to develop and apply a socioeconomic vulnerability indicator framework (SVIF) to various coastal communities along the southwest coast of Taiwan, an area most vulnerable to climate change.

A place-based and theory-driven SVIF was devised to identify and explore a better understanding of the specific factors of socioeconomic vulnerability along this stretch of coast. The approach, which incorporated both susceptibility and resilience aspects, included nine key themes represented by 25 indicators. As such, it encapsulated and contextualized the complexity of socioeconomic vulnerability into a relatively simple framework. This was successful in demonstrating the inherent inequalities of vulnerability along this coastline and helped operationalize the concept, providing a location-specific assessment of potential use to policy makers (I1,I3,I5,I6,I8,I12,I13,I14,I18,I22,I24). Not only could the framework help prioritize government investments, it could also assist in formulating more tailored, context-specific adaptation actions. Currently, there is no evaluation program for assessing local level Taiwanese adaptation actions. Further improvements to the framework, notably those that are related to data, indicators, and thresholds, are desirable, as noted in the discussion section. In particular, research should center around refining the indicator selection, ideally with the involvement of local decision-makers, so that both relevant spatial and temporal trends can easily be identified. As part of this process, the possibility of including other potential proxies and indicators (such as unemployment rates, income levels, and infant mortality rates) could be explored, particularly if these provide more detailed information that is relevant to local community vulnerability. A longer-term study could facilitate a better understanding of how local adaptation actions may influence the susceptibility and resilience of communities over time.

There is considerable potential for using this framework and, particularly, the process used to generate the SVIF for other localities and contexts, both in Taiwan and further afield. As part of this, future research should prioritize the identification of the range of indicators that is relevant to wider geographical contexts, as well as the determination of associated standards for vulnerability assessment. Given the potential implications of climate change on our global coasts and the need to develop appropriate and timely adaptation strategies for local areas, such research should be a priority of governments across the world.

Conflicts of Interest: The authors declare no conflicts of interest.

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