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Flood Vulnerability Analysis in Coastal Zones: A Comparative Analysis across Five Asia-Pacific Countries

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ABSTRACT: There is increasing concern that the current management practices for many coastal regions are unsustainable. Very few countries have planned to deal with the exacerbation of problems of environmental decline in the face of climate change leading to more serious flood events caused by sea level rise, severe storms, tidal waves, etc. It is therefore necessary to assess socio-economic and environmental impacts of floods to better understand the vulnerability of the coastal zone, as part of devising adaptive and integrated management principles. The paper presents a systematic approach in which relevant stakeholders in five Asia-Pacific countries were actively engaged in identifying and prioritizing flood impact issues. Key issues of concern for flood impacts for coastal areas in Australia, Japan, Sri Lanka, Thailand and Viet Nam are compared.

KEYWORDS: *coastal zone, vulnerability assessment, flood hazard, flood impact, climate impact*

Introduction

Coastal areas are one of the most important regions from social, economic and environmental viewpoints. They are home to a large and growing proportion of the world's population. They include important ecosystems such as coastal floodplains, mangrove forests, marshes and tideflats, as well as beaches, dunes, and coral reefs (Costanza *et al.*, 1997). The coastal zone is also important for marine fisheries because the bulk of the world's marine fish harvest is caught or reared in coastal waters (Wilkinson, 2000). Coastal areas help prevent erosion; filter pollutants; and provide food, shelter, breeding areas and nursery grounds for a wide variety of organisms. Coastal regions also provide critical inputs for industry, including water and space for shipping and ports; opportunities for recreational activities such as fishing and diving; and other raw materials, including salt and sand.

Coastal regions are undergoing environmental decline due to the large growth of human populations, rapid urban and industrial development, overexploitation of natural resources and poor management. By 2025, it is expected that around 75% of the world's human population will live within 200 km of a coastline (Creel, 2003). There is an increasing concern that current management practices are unsustainable. Of particular concern are low-lying areas, which are also affected by sea water intrusion. The Intergovernmental Panel on Climate Change (IPCC) predicts that global mean sea level may rise as much as 88 cm by the end of the 21st century (IPCC, 2001). Several coastal zones are facing severe socio-economic and environmental problems due to their lower elevation. Very few countries have planned to deal with the exacerbation of these problems in the face of sea level rise.

This project involved a vulnerability analysis for selected key coastal zones in five countries: Australia, Japan, Sri Lanka, Thailand and Viet Nam. The vulnerability analysis required the identification of relevant flood hazard parameters and key issues for the study region; and the synthesis of impact responses using expert and stakeholder opinions. The outcomes of the vulnerability analysis are potentially useful as a basis for the development of adaptation measures for the region. The project required the engagement of experts and key stakeholders of the five selected regions in order to identify and prioritize the key issues. A significant outcome of the project is an insight into how stakeholders' knowledge and expertise (at regional and local levels) might be utilized for establishing such response functions for quantification of the likely impacts of climate change in coastal regions. This paper presents a comparative analysis of the results of vulnerability studies in the five selected countries to identify similarities and differences in the outcomes.

Study Areas

The following five coastal areas were selected from five participating countries in the Asia-Pacific region. The geographic locations of these study sites are shown in Figure 1.

1) Gippsland Coastal Region, Australia: The Gippsland coast is home to thousands of people who live in or near one of the many coastal towns and settlements located between San Remo on the eastern extent of Western Port Bay and Mallacoota near the New South Wales border. Away from these built up areas, the Gippsland coast remains in a largely natural state, being characterized by diverse natural and cultural values, and including an important habitat for a range of fauna species protected by National Parks, reserves and public foreshore land (GCB, 2008). The coast includes the Gippsland Lakes System, which is a series of coastal lagoons — large areas of shallow water that have been almost wholly sealed off from the sea by a coastal dune system.

2) Kushiro Coastal Region, Japan: Kushiro wetland, located on the eastern side of Hokkaido, is the largest wetland in Japan registered by the Ramsar treaty and the coastal area has been highly developed for industrial purposes. The main river flowing through Kushiro wetland is the Kushiro River whose length is 154 km. The river basin area is 2510 km^2. The incline of the Kushiro wetland area is relatively gentle. The human population in this highly developed coastal area is about 230,000. In recent years, changes in water

Figure 1. Locations of the study areas in 5 countries

circulation and mass transport have been considered problematic, causing damage to the ecological systems of the wetland. There is significant potential for damage in the Kushiro coastal region from disastrous storm surges or flood events.

3) Colombo, Sri Lanka: Climate change has clearly affected the weather patterns of Sri Lanka and this is evident in the climatological measurements of the last 3 to 4 decades. Overall, rainfall has not shown a significant change in most parts of the country, while some other indicators such as the length of rainy spells and average rainfall per spell have clearly changed. Studies have shown that rainfall intensity has increased (Herath and Ratnayake, 2004; Ratnayake and Herath, 2004). More frequent rainfall-induced disasters such as landslides and floods in the recent past can be attributed to this increase in rainfall intensity (Padma Kumara *et al.,* 2005). Colombo, the capital city and financial hub of Sri Lanka, is one of the major coastal cities adversely affected by floods and two of Colombo's highest rainfalls on record occurred in the last two decades. Such frequent extreme events have caught the attention of the public and have forced authorities to attempt mitigating work. Several drawbacks of the current management system have been identified and among the technical aspects, the inadequate capacity of drainage networks, loss of flood retention spaces and poor management is highlighted.

4) Bangkok and Gulf of Thailand: Bangkok, the capital city of Thailand, is one of the larger cities in Asia and is a regional hub. It is located on the lower flat basin of the Chao Phraya River, the largest and most important river in Thailand, which has a drainage area of 160,103 km^2 and an annual suspended sediment discharge of 11x10^6 tonne (Milliman *et al.*, 1995). The river originates in the northern most part of Thailand and discharges to the Gulf of Thailand after flowing approximately 1,200 km. The average annual discharge is about 770 m^3/s with a peak of 4,560 m^3/s recorded in 1995 (Thammasittirong, 1999). The coastal environment of the Chao Phraya delta is classified as low-energy micro-tidal. Somboon (1992) showed that the shoreline has migrated about 90 to 100 km southward from the centre of the central plain in Thailand over the last 6,000 years, which corresponds to a migration rate of about 15 m/yr. Bangkok has a hot and humid tropical climate and the rainy season spans May to October, with an average annual rainfall of 1,500 mm. Floods, mainly caused by upstream inflow and high intensity rainfall, are the most frequent natural disasters in Bangkok. They affect a large number of people and cause huge economic damage almost every year. Due to its low elevation range from 0–4 m above mean sea level, the tidal effect is prominent in the Chao Phraya River up to several kilometres inside Bangkok and that contributes significantly to floods (Engkagul, 1993).

5) Nam Dinh Coast, Viet Nam: The Nam Dinh coast is one of the most populated coasts in Viet Nam. It has the most fertile soil in Viet Nam, which is very suitable for rice cultivation. The coast is also suitable for other marine-related economic activities such as salt production, fishing, shrimp and fish farming, etc. Additionally, the area is located near Hanoi, the capital city of Viet Nam and some of its beaches have become recreation sites for Nam Dinh and Hanoi city dwellers. The Nam Dinh coast was formed by the deposition of sediment from the Red River with its four branches — the main river, the Ninh Co River, the Day River and the So River. The sediment from the Red River consists mainly of silt and fine sand. Thus, near the river mouth, deposition of silt and fine sand has enabled the development of mangrove forests. There are several distinct ecological systems in the area such as marine, mangroves and estuarine ecological systems. Thus, the coast is ecologically very diverse. Presently, the coast is facing serious environmental problems, the foremost problem being accelerating erosion.

Methodology

A systematic approach was taken to develop a standardized methodology which was applied in the five selected regions across five countries. The methodology has been elaborated elsewhere (Dutta *et al.*, 2011).

The major steps involved in the methodology were:

- Selection of experts and stakeholders
- Identification of hazard parameters and key issues
- Questionnaire design
- Administration of the questionnaire
- Statistical analysis of the questionnaire results
- Sensitivity analysis

Two groups — "Stakeholder Reference Group" and "International Expert Group" — were formed in order to identify relevant flood hazard parameters and key issues for the study areas and their feedback was used to identify the most important flood inundation and water quality parameters (hazard parameters) associated with coastal zone flooding, and the key social, economic and environmental issues on which these hazard parameters could impact. The key issues were used to develop a set of criteria, indicators and appropriate response functions relating to various scenarios where the intensity of the flood hazard parameters varied due to climatic and anthropogenic influences in the study areas. Tables 1 and 2 show the flood inundation parameters (4), water quality parameters (3) and key issues (22) identified for impact analysis, respectively.

The questionnaire was designed to gather information regarding stakeholders' views of the likely impacts of various levels of flood severity on key issues and assets in the study areas. For the purpose of structuring the questionnaire, magnitudes of different flood inundation and water quality parameters were classified into three categories: low, medium and high. The stakeholder and expert groups were both consulted regarding the suitability of these categories, and a range of references were consulted to finalize realistic magnitude ranges for the flood inundation and water quality parameters within these three categories for coastal zones. The questions were designed by a group of international experts in order to generate data describing stakeholders' assessments of the differing impacts of the three categories of flood inundation and water quality parameters (Table 1) on key social, economic and environmental issues (Table 2).

The questionnaire was administered independently in each case study area by the country project leader of the on-going collaborative project sponsored by APN (Dutta, 2007). A similar approach was followed in Australia, Japan, Viet Nam and Thailand in administering the questionnaire. The questionnaire was sent out to stakeholders familiar with the study areas either by email or surface mail and anonymous responses were received from the respondents. However, in Sri Lanka, stakeholders were invited to participate in a seminar and the questionnaire was distributed to all the participants who completed their questionnaire on-site.

The questionnaire was lengthy and reasonably complex and required respondents to indicate their perceptions of the likely level of negative impact for each of the flood inundation and water quality parameters (Table 1) on each of the key issues (Table 2) for each of the three conditions (high, medium, low). Respondents used an impact ranking score in the range 1–5 to indicate predictions regarding the extent of impact in each case. The instructions within the questionnaire defined each of the ranking scores (Table 3). The participants were explicitly given the option of not completing those sections of the questionnaire that were perceived as beyond their expertise. The number of responses received from stakeholders varied from

Flood inundation parameters	Water quality parameters
Depth, Duration, Velocity, Frequency	Nutrients (TN, NO2, NO3, TP, PO4), Salinity, Turbidity

Table 1. Flood inundation and water quality parameters to be modelled under climatic change conditions

Table 2. Key issues in coastal areas identified for climate change impact analysis

Key issues (with abbreviations)	
Infrastructure	*Drainage (Dr)*
	Roads (Rd)
	Railways (Rl)
	Ports & Harbours (Pt)
	Dykes (Dy)
	Coastal protection structure (Co)
	Land-use planning (LU)
Buildings	*Residential (RB)*
	Non-residential (NR)
Potable water (PW)	
Water quality (WQ)	
Erosion (Er)	
Tourism (To)	
Population	*Short-term displacement (SD)*
	Long-term resettlement (LD)
Agriculture (Ag)	
Fishery (Fi)	
Fish habitat/distribution (FH)	
Wetland health	Extent (WEx)
	Flora biodiversity — no. of veg. species (WFl)
	Fauna biodiversity — no. of bird species) (WFa)
Mangroves (Ma)	

country to country (Table 4).

A statistical approach was designed to analyze the data obtained from the returned questionnaires from all five countries. In relating the impact ranking score for a particular flood inundation or water quality parameter, x, on an individual key issue (such as drainage or agriculture), the impact ranking score (1–5 integer scale) and hazard parameter, y, was analyzed, rather than its associated predicted percentage damage (Table 3). This was done in order to homogenize the spread of response scores across the low, medium and high levels of magnitude of each parameter. For each issue, x and hazard parameter, y, the Sensitivity is a measure of the impact on y of increasing x, averaged across all stakeholders' assessments, and the Disparity is a measure of the variation among individual assessments.

Results and Discussion

Similarity and Differences

Figure 2 presents the scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) for different hazard parameters against the 22 issues for five countries. Overall, the patterns among different countries are broadly comparable for the various individual hazard parameters, except for Sri Lanka.

For the Sri Lankan data, disparity was low for all issues and hazard parameters. For the inundation parameter "Depth," different issues showed similar trends for Japan and Thailand. For Viet Nam, more issues showed high sensitivity compared to other countries. For Australia and Sri Lanka, more issues were less sensitive to "Depth" than for the other three countries. The trend was similar for all countries for "Duration" with higher disparity for Australia for more issues than other countries. Similarly, for "Velocity" and "Frequency," disparity was higher for Australia compared to other countries. For Australia, more issues were less sensitive to "Frequency" than the other four countries. For water quality parameters, no issue showed any sensitivity to "Nutrient" for any countries. For Salinity, trends were similar for Thailand and Viet Nam; and for Japan and Australia. For Turbidity, trends were similar for Japan and Australia. More issues show higher sensitivity against Turbidity for Viet Nam. The agreement was higher for Viet Nam and Thailand, compared with Japan and Australia for Turbidity.

These relationships show that in different countries, stakeholders had different perceptions of the impacts of flood inundation on various issues. For some issues, there were high levels of agreement compared to other issues. The low disparity for the Sri Lankan data was probably due to the way the questionnaire was administrated, which reflected more of a collective, rather than individual, opinion of the stakeholders.

Classification of relationships between impact ranking and key issues

Relationships between the impact ranking scores for the effects of high, medium and low magnitudes for all combinations of flood hazard parameters and key issues were grouped into the following four classes (Dutta *et al.*, 2011):

Class 1: High sensitivity and high agreement (or low disparity)

Class 2: High sensitivity and low agreement (or high disparity)

Class 3: Low sensitivity and high agreement (or low disparity)

Class 4: Low sensitivity and low agreement (or high disparity)

The key issues that show high sensitivity to increasing magnitude for a particular hazard parameter and for which there is high agreement among respondents were placed in Class 1. All the key issues in this class show a reasonably strong, monotonic relationship with increasing magnitude of the particular flood hazard parameters and good agreement among stakeholder respondents about these relationships. Key issues in Class 2 appear to be sensitive to the increasing magnitude of the hazard parameters, but the opinions of different stakeholders about these relationships are varied. Class 3 includes key issues that stakeholders agree are not particularly affected by an increase in magnitude of the hazard parameters. The key issues in Class 4 also appear to be less sensitive to the hazard parameters; however, there are more widely varying perceptions among stakeholders about these relationships.

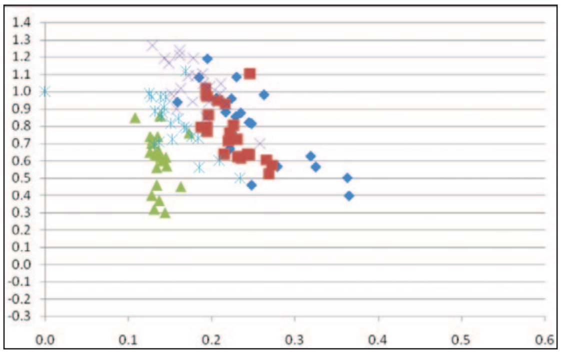
Table 5 shows Class 1 issues for different inundation and water quality parameters for the five countries. It shows that Depth is considered to be highly sensitive to most of the issues and stakeholders across all countries had high agreement. Australia and Japan had similar issues showing high

Impact ranking score	Impact definition
1	No/little impact (0–5% damage)
2	Low impact (5–25% damage)
3	Moderate impact (25–50% damage)
4	High impact (50–75% damage)
5	Extreme impact (75–100% damage)

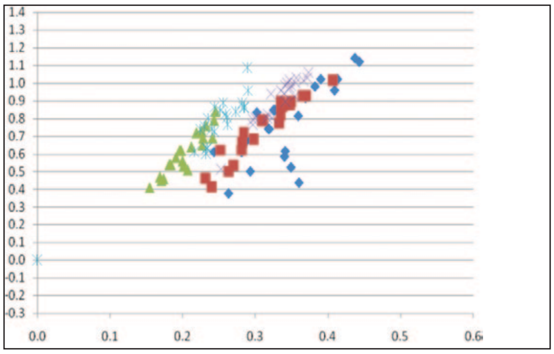
Table 3. Impact ranking scores and their definitions as used in the questionnaire

Country	Australia	Japan	Sri Lanka	Thailand	Viet Nam
Number of responses	33	35	50	34	50

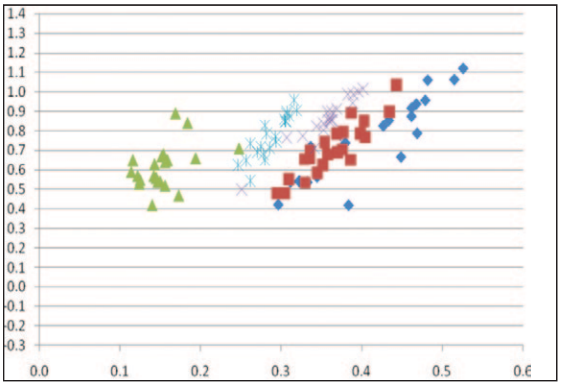
Table 4. Number of responses to questionnaire survey in different countries



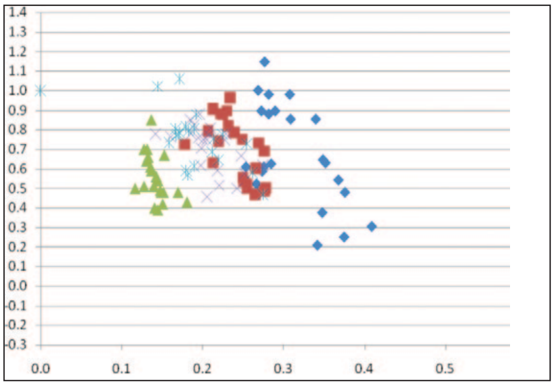
For Depth



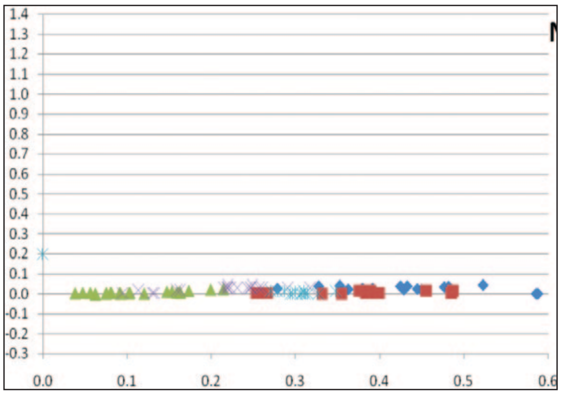
For Duration



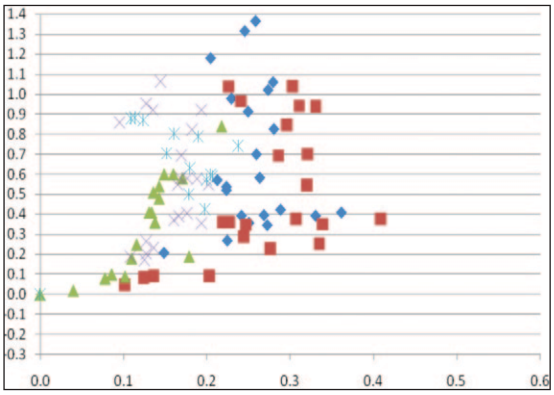
For Velocity



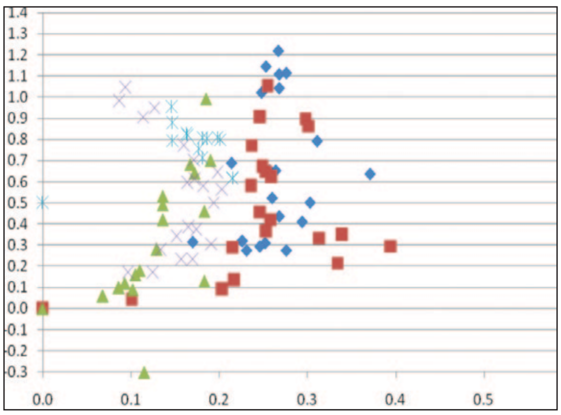
For Frequency



For Nutrient



For Salinity



For Turbidity

Legends:

◆ Australia

■ Japan

▲ SriLanka

× Thailand

✳ Vietnam

Figure 2. Scatter plots of Disparity (x-axis) vs. Sensitivity (y-axis) of all 22 issues for 4 inundation and 3 water quality parameters for five countries

sensitivity and agreement. Thailand and Viet Nam shared more similarity in terms of issues identified. Compared with other countries, Viet Nam showed the highest number of issues with high sensitivity and high agreement.

The results show that stakeholders do not prioritize issues and/or hazards for adaptation and mitigation measures similarly across all countries. It is therefore important to take into account the different priorities of stakeholders in different countries.

Pairwise correlations between sensitivities

In order to compare the impact assessments across the five countries, the product-moment correlations between the sensitivity scores across the 22 key issues for each pair of countries and for each of the 7 hazard parameters were calculated (Table 6). A high positive correlation indicates a broadly similar perception across two country panels of the relative rankings of key issues in terms of how dramatically they are impacted by changes in the level of the relevant hazard parameter. Thus, in terms of the impact of increased flood depth on the range of key issues, the relative rankings are fairly consistent across Australia, Japan and Thailand, but more disparate across Sri Lanka and Viet Nam and each of those sites with the first three. It is acknowledged that these patterns may be influenced by the selection of the panels or by the protocols used to obtain their survey responses. Overall, however, it would appear that there are some considerable differences between perceptions at the various country sites of which key issues are most sensitive to changes in levels of the various hazard parameters.

Conclusions

The present paper provides the outcome of a comparative analysis of five case studies conducted in five countries to identify and prioritize flood impact issues through the engagement of stakeholders towards adaptation and mitigation measures in coastal zone areas in the Asia-Pacific region.

It is clear that stakeholders in different countries prioritize flood impact issues differently, although there are similarities between priorities in Australia and Japan, and to a lesser extent Thailand. While differences in methodology may explain a very different response in Sri Lanka, Vietnamese and Sri Lankan stakeholders responded differently in their priorities.

Further research is needed if it is deemed desirable to develop a common methodology to flood vulnerability assessment across multiple coastal sites in different countries. Further research to look into the reasons behind similarities and differences in stakeholder responses in the selected countries would provide insight for the development of common methodologies.

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Table 5. Issues that showed high sensitivity with high agreements for flood inundation and water quality parameters for five countries
Parameters: Dep – Depth; Dur – Duration; Frq – Frequency; Nut – Nutrient; Sal – Salinity; Tur – Turbidity; Vel – Velocity

Issues	Australia	Japan	Sri Lanka	Thailand	Viet Nam
Drainage	Dep	Dep, Frq	Dep, Vel, Frq, Dur, Sal	Dep, Frq	Dep, Dur, Frq
Roads	Dep	Frq, Dep	Dep, Dur, Frq, Vel	Dep, Frq	Dep, Dur, Frq
Railways	Dep, Frq	Frq, Dep	Dur, Dep, Vel, Frq	Dep, Frq	Dep, Vel, Frq, Tur
Ports	Dep, Dur, Frq	Dep, Dur, Frq	Dep, Frq, Dur, Vel	Dep, Frq	Dep, Dur, Frq
Dykes	Dep, Frq	Dep, Frq	Vel, Dur	Dep, Dur, Frq	Dep, Dur, Frq
Coast	Dep, Dur, Frq	Dep, Frq	Dur	Dep, Dur, Frq	Dep, Dur, Vel, Frq
Land-use	Dep	Frq, Dep	Vel, Dep, Dur, Frq	Dep, Frq, Sal, Tur	Dep, Dur, Vel, Frq
Residential buildings	Dep, Frq, Sal	Dep, Frq	Frq, Dur, Dep, Vel	Dep, Frq	Dep, Dur, Frq
Non-residential buildings	Dep Frq, Sal	Dep, Frq, Dur	Dur, Dep, Vel, Frq	Dep, Frq	Dep, Dur, Frq
Potable Water	Sal, Tur, Dep, Dur, Frq	Sal, Tur, Dur, Dep, Frq	Vel, Dur	Sal, Tur, Dep, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Water quality	Sal, Tur, Dep,	Tur, Sal, Frq, Dep	—	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Sal, Tur
Erosion	Dep	Dep, Frq	Vel, Dur	Dep, Frq	Dep, Dur, Frq, Tur, Sal
Tourism	Frq, Dep, Tur, Sal	Frq, Dep, Tur	Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur
Short term displacement	Dep, Frq, Sal	Dep, Frq	Frq, Dr, Dep, Vel	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Long term displacement	Frq, Dep, Sal, Tur	Frq, Dep	Vel, Dur, Frq, Dep	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Agriculture	Sal, Dep, Frq	Frq, Dep, Tur	Dur, Sal, Tur, Vel, Frq, Dep	Dep, Sal, Frq, Tur	Dep, Dur, Vel, Frq, Tur, Nut
Fisheries	Tur, Sal, Dur	Tur, Frq, Dep	Dep, Frq, Tur, Vel, Sal	Dep, Tur, Sal, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal
Fish habitat	Tur, Sal	Dur, Dep, Frq	Dep, Vel, Dur	Tur, Dep, Sal, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Wetland extent	Sal, Tur	Dep, Dur, Tur, Frq	Dep, Dur, Vel, Frq	Dep, Frq, Tur, Sal	Dep, Dur, Vel, Frq, Tur, Sal
Flora diversity	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Dep, Sal, Dur, Frq, Vel	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Nut
Fauna diversity	Tur, Sal	Sal, Tur, Dep, Dur	Tur, Vel, Dep, Sal, Frq, Dur	Dep, Sal, Tur, Frq	Dep, Dur, Vel, Frq, Tur, Sal
Mangroves	Tur, Dep	Dep, Frq	Tur, Dur, Sal, Dep, Vel	Dep, Dur, Vel	Dep, Dur, Vel, Frq, Tur, Sal

Table 6. Pairwise correlations between sensitivities

Hazard parameters	Countries	Australia	Japan	Sri Lanka	Thailand	Viet Nam
DEPTH	Australia		0.722	0.068	0.761	0.588
	Japan			0.288	0.74	0.545
	Sri Lanka				0.314	0.058
	Thailand					0.448
DURATION	Australia		0.732	0.609	0.67	0.434
	Japan			0.2	0.773	0.262
	Sri Lanka				0.409	0.103
	Thailand					0.224
VELOCITY	Australia		0.539	0.308	0.503	0.4
	Japan			0.6	0.353	0.133
	Sri Lanka				0.255	-0.058
	Thailand					0.238
FREQUENCY	Australia		0.793	0.296	0.558	0.053
	Japan			0.279	0.508	0.338
	Sri Lanka				0.377	0.374
	Thailand					0.223
NUTRIENTS	Australia		-0.096	-0.005	0.087	0.448
	Japan			0.027	-0.038	0.064
	Sri Lanka				0.283	-0.161
	Thailand					-0.636
SALINITY	Australia		0.916	0.428	0.936	0.702
	Japan			0.617	0.935	0.744
	Sri Lanka				0.449	0.308
	Thailand					0.781
TURBIDITY	Australia		0.939	0.464	0.915	0.635
	Japan			0.435	0.95	0.718
	Sri Lanka				0.386	-0.101
	Thailand					0.746

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PROJECT TITLE

Climate Perturbation and Coastal Zone Systems in Asia-Pacific Region: Holistic Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy

COUNTRIES INVOLVED

Australia, Bangladesh, Japan, Sri Lanka, Thailand, Viet Nam

PROJECT DURATION

2 years

APN FUNDING

US$ 80,000

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