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GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam

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Abstract Vietnam's coastal zone provides a diverse range of natural resources and favourable conditions for social and economic development. However, its coastal ecosystems are highly vulnerable, due to several natural coastal hazards, over-exploitation and other human activities. In spite of diverse interventions, Vietnam's coastal zone continues to experience significant damage from floods, erosion and typhoons. These hazards are being intensified by climate change and associated rising sea levels. This paper assesses the potential vulnerability of Vietnam's coast to climate change and discusses possible adaptation policies and plan to reduce the impacts. GIS analysis was used for the assessment of coastal vulnerability. Related literature was reviewed to develop detailed understanding of coastal adaptation to climate change. Adaptation policies and plans were appraised to identify potential coastal adaptation policies and plans that could be adapted by Vietnam. It was identified that vulnerability of the coastal zone of Vietnam could not be attributed only to climatic factors, but also to the physical condition of the coastline. Much of Vietnam's coastline, particularly, areas around the Red River delta and the Mekong River have elevations below 1 m. These coastlines are largely developed and serve as economic centres of the country, which makes the coast more vulnerable to climate change and the rising sea level. The paper concluded that a non-structural approach (coastal buffer zones, building houses on stilts, storm warning systems, growing of flood-resistant crops and elevated storm shelters with medicine and food storage) could be used by Vietnam to adapt her low-lying coastline around the two deltas to climate change as this strategy enables vulnerable areas to be occupied for longer before eventual retreat. However, for these policies to be successful, it should be planned, implemented well in advance, monitored and evaluated over time.

Keywords Coastal vulnerability · Adaptation planning · Climate change and coastal zone of Vietnam

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Introduction

Vietnam's coastal zone provides a diverse range of natural resources (wetlands, minerals, and fertile agricultural land, and favourable conditions for social and economic development (fisheries, aquaculture, agriculture, tourism, transportation, urbanization). However, the coastal ecosystems are highly vulnerable, due to several natural coastal hazards such as typhoons, storm surge, erosion, earthquakes; climate change and associated sea level rise (Nhuan et al. 2009.) Irregular exploitation and human activities such as environmental pollution, mangrove logging for shrimp farming and fuel-wood intensify these natural impacts.

In spite of the diverse measures including construction of coastal dykes, improved river channels, forecasting and early warning systems to control some of these coastal hazards, Vietnam still continues to experience significant damage from floods, erosion and typhoons. Hanh and Furukawa (2007) and Imamura and To (1997)

identified rapid population growth, low coastal elevation, increasing pre-occupation around hazardous areas and insufficient financial support to construct and maintain dykes and river channels as some of the causes of the coastal problem in Vietnam. However, the vulnerability of the coastal zone of Vietnam could be attributed not only to these factors but also climate change and associated sea level rise and increased intensity of hazardous climatic elements such are storm, monsoon and typhoon. Much of Vietnam's coastline, especially, areas around the Red River delta in the North and the Mekong River delta in the South as well as the numerous inlets along the central coast has an elevation below 1 m. Unfortunately these low-lying coastal areas are largely developed and serve as economic centres of the country. These physical characteristics and the land-use of the coastline make large areas of the coastline more vulnerable to climate change and associated sea level rise.

Tuong (2001) identified sea level rise between 1.75 and 2.56 mm/year at four Vietnamese stations (Hon Dau, Da Nang, Qui Nhon and Vung Tau). The highest value was observed in the northern and the southern parts of the country. Another study conducted by Hanh and Furukawa (2007) identified a similar trend and came to a conclusion that there is enough evidence to support the fact that sea level rise occurring in Vietnam is significant. They observed that the rate of sea level rise in Vietnam is comparable with the sea level rise in the region and in the world. Two questions that need to be answered are: what impacts will the rising sea level have on the coastal communities of Vietnam? What adaptation strategies should be developed to manage the potential deleterious effects of climate change and associated sea level rise? This paper attempts to provide answers to the questions above through the application of Geographic Information Systems (GIS) for the assessment of coastal vulnerability to sea level rise. The outcome from the GIS assessment was used for the appraisal of coastal adaptation planning policies that could be applied by Vietnam in advance in order to offset some of the possible impacts of climate change and associated hazards and also enable vulnerable areas to be occupied safely before eventual climatic events or sea level that requires retreat from such vulnerable coastal zone.

Fig. 1 Location of Vietnam

The study area

Vietnam is located between longitude 102° 09′ and 109° 30′ East, and latitude 8° 10′ and 23° 24′ North. The country is bordered to the North by China, to the West by Laos and to the South west by Cambodia. The Eastern side of Vietnam is bordered by 3,260 km meandering coastline which stretches from Mong Cai in the North to Ha Tien in the South. The coastline is dissected by two major river deltas (Red River in the North and Mekong River in the South) and many small rivers at the central area (Fig. 1).

The country is divided into eight administrative regions and 64 provinces (Fig. 2). The coast of Vietnam can be divided into three cardinal areas: North coast, Central coast and the South coast. The coastal zone comprises 28 provinces out of the 64 provinces in the entire country and it is a home to nearly 50% of the estimated national population of 90.5million (CIA 2011) (Hanh and Furukawa 2007). The country is influenced by two tropical monsoon climatic regimes (South-westerly and North-easterly) and mostly affected by natural disasters associated with these two climatic regimes which include storm surges, monsoon rains, flooding, typhoons and El-Nino conditions. Vietnam has suffered numerous cyclones/typhoons, storm surges and floods, with significant human, economic, and social damage to the country (Imamura and To 1997).

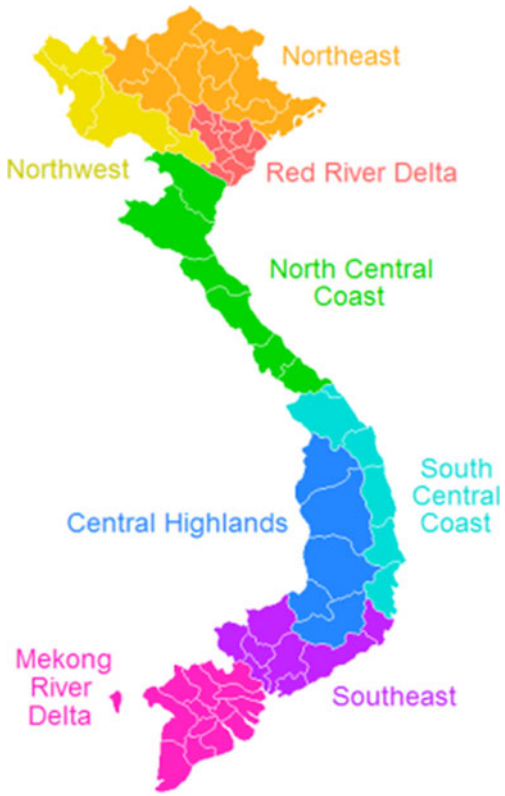

Fig. 2 Administrative regions of Vietnam

Methods

In order to do effective and reliable assessments of climate change impacts on the coastal zone of Vietnam and to recommend practical adaptation policies, relevant literature on climate change impact assessment and adaptation was reviewed. It was identified from the literature review that many scientific methodologies that have been developed by researchers for the assessment and management of the impacts of climate change are covered in Intergovernmental Panel on Climate Change (IPCC) periodic global assessment report on the impacts of climate change on the sustainability of the world environment and global economy (IPCC 2001, 2007). Apart from those methodologies covered in IPCC reports, there are numerous climate change assessment approaches and management policies that have been developed by national environmental agencies and local researchers. Examples of these include UK's, Department for Environment Food and Rural Affairs (DEFRA) (2009) *climate change adaptation report*; International Centre for Environmental Management (ICEM) (2003) *assessment report on Vietnam's protected areas and development;* Australian Department of the Environment and Heritage (2006) *assessment of vulnerability of the Australia's coastal zone* and Stern (2006) *review on the economics of climate change.* Table 1 below provides a summary of key climate change adaptation policies identified in the literature review.

Following the literature review, GIS was applied for the assessment of vulnerability of the coastal zone of Vietnam. The GIS approach has been used by many authors in similar studies (Vafeidis et al. 2008; Sanyal and Lu 2005; Tralli et al. 2005). It offers real case scenarios as to communities, land use, development and land areas that are potentially vulnerable to flooding based on ground elevation. Geo-reference Shuttle Radar Topography Mission (SRTM) data of Vietnam, which is a satellite image with ground elevation was obtained from the University of Maryland, USA. The data was rectified and opened in ERDAS Imagine (image interpretation software) Virtual GIS and then three different unsupervised flood layers were created on the image. They are:

1. **One metre,** (predicted sea-level rise by 2100; IPCC 2007),
2. **Two metres** (the latest upper limit prediction for sea-level rise by 2100; Pfeffer, et al. 2008), and
3. **Five metres** (worst case scenario involving catastrophic melting of West Antarctic ice sheet; Vaughan 2008).

Table 1 Summary of the review of sea-level rise adaptation policies

Core sea-level rise adaptation strategies	Terms of references	Sources
Sea-level rise adaptation objectives	• Prevent the loss • Tolerate the loss • Spread or share the loss • Change the affected activity • Change the location of the activity	McCulloch et al. (2002)
Sea-level rise adaptation planning process	• Information collection and awareness creation • Planning and design • Implementation • Monitoring and • Evaluation.	Klein et al. (2000)
Sea-level rise adaptation policy options	• Protection • Accommodation • Retreat	Bijlsma et al. (1996) adopted by IPCC (2001, 2007)
	(or) • Hold the line • Advance the line • Managed Realignment • No active intervention	DEFRA (2006)
Basis for selection of sea-level rise (SLR) adaptation policy options for implementation	• Risk/hazard assessment • Cost benefit analysis • Local sea-level rise projections • Appraisal of the SLR adaptation policy options based on adaptation objectives, natural vulnerability of the coast and human development.	Walsh et al. (2004)

Results

The results of this assessment are presented as the flood risk maps of Vietnam in Figs. 3, 4, 5 and 6.

The flood risk assessment result (Fig. 3) revealed that a significant proportion of the coastal zone of Vietnam is under severe threat of flooding. The assessment shows that the Red River delta in the north (Fig. 4) and the Mekong River delta in the south (Fig. 5) are the highest risk areas. Unfortunately, these two areas are the most fertile, productive and highly developed regions of the country where the capital City, Hanoi and the second City Ho Chi Minh City are located (Figs. 7 and 8). It was identified that though the central coastline (Fig. 6) has low flood risk, settlements and agricultural activities at the numerous inlets and estuaries are also largely vulnerable.

It is important to state that the sea level rise assessment in this paper did not consider possible subsidence or uplift (tectonic forces) of the coastline. Holding land movement constant, the flood risk assessment considered the potential impacts of climate induced sea level rise. The result of the assessment revealed that much of Vietnam's coastline, especially areas around the Red River delta in the North and the Mekong River delta in the South as well as the numerous inlets along the central coast has an elevation below 1 m. Unfortunately these low-lying coastal areas are largely developed and serve as economic centres of the country. These physical characteristics and the land-use of the coastline make large areas of the coastline more vulnerable to climate change and associated sea level rise.

IPCC 2007 identified that the severe impact that may be associated with climate induced sea level rise could be influenced not only by the rising waters but also the increased intensity of climatic forces such as increased waves and tidal activities, storm surges, typhoons, increased rainfalls, increase monsoon winds and flash floods. Increased intensity of these climatic forces coupled with the rising sea level could have deleterious impacts along the coast of Vietnam, particularly, the two deltas (Figs. 4, 5, 7 and 8).

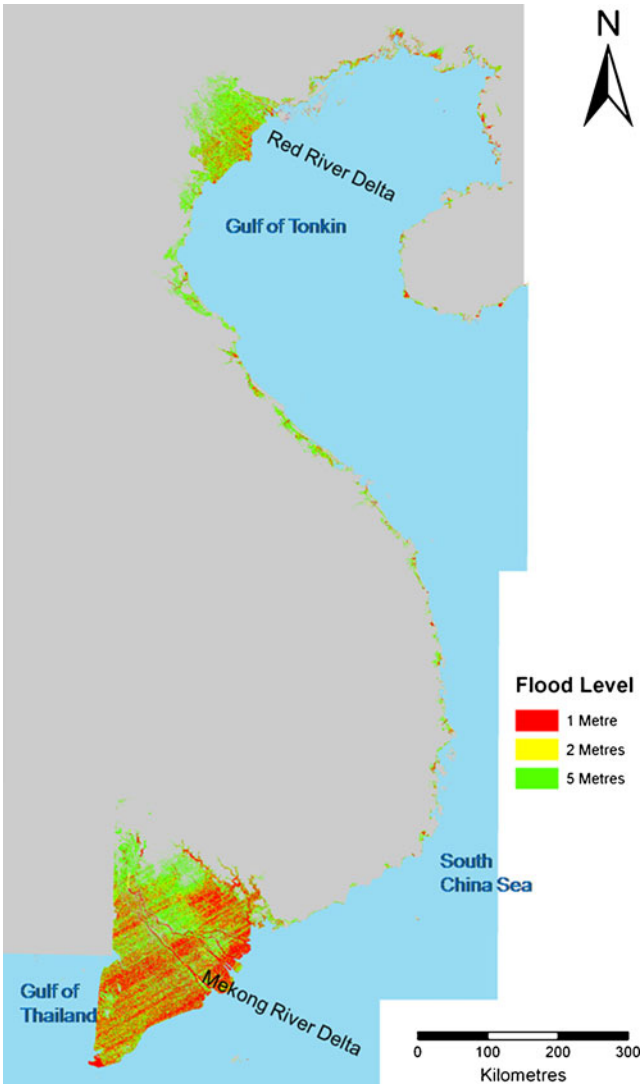

Fig. 3 The flood risk map of Vietnam

Possible impacts of climate change and associated rise in sea level identified in Vietnam based on the flood risk assessment could be outlined as following:

- Inundation Red River and Mekong River deltas, low-lying coastal areas (Inlets and estuaries) and the intervening fertile agricultural lands.
- Destruction of coastal settlements in the flood risk areas (Fig. 3) will cause displacement of many coastal dwellers and possibly result in coastal-hinterland migration. If this is not managed properly it could lead to land litigations and ethnic conflict.
- Increased coastal erosion, mass movement and land-slides, especially, around the two deltas and the cliffs along the central coast.
- Increased flooding and natural disasters (typhoons, storm surge, and monsoon) may lead to increased loss of life and livelihood associated with natural disasters.
- It may lead to significant loss of farmland, wetlands, mangrove, and cause coastal squeeze.
- It will cause intrusion of salt water into freshwater, aquifers and also increase water borne diseases.
- It will significantly reduce rice production in the country and impact on the food security of the country and other countries that import rice from Vietnam.

These impacts, if not properly managed through holistic and reliable climate change adaption policies planned in advance, could have serious ramifications on the economic development of the country. Vietnam's economy, like many developing countries, is highly supported by agricultural production and heavily dependent on natural resources. Therefore, any natural or artificial phenomena that affect the prevailing natural environmental conditions are likely to have serious effects on sustainable economic development and the livelihood of many Vietnamese. However, these effects could be reduced significantly if possible impacts are well managed through planning and implementation of pro-active coastal adaptation policies (IPCC 2007).

Discussion

The huge physical and socio-economic impacts of sea level rise on the coastal zone of Vietnam required serious research effort and policy development towards integrated and sustainable coastal adaptation strategies for the coast-line. Tol et al. 2008 revealed that to identify the most appropriate coastal adaptation strategy, one must consider the full context in which the impacts of climate change arise and realise that the aforementioned strategies (Table 1) happen within a broader policy process, which includes consideration of numerous climate and non-climate issues. Klein et al. (2000) observed that adaptation to climate change in coastal zones should be viewed as a process that comprises more than merely the implementation of tech-nologies to protect against, retreat from, or accommodate sea level rise. Studies in the Netherlands, the United Kingdom, and Japan have revealed that coastal adaptation to climate change can be considered as a multistage and iterative process (DEFRA 2009; Tol et al. 2008). In each of these countries, management approaches have been adjusted over the past decades to reflect new insights and priorities, including concerns about climate variability and, more recently, climate change. This reflects sea level rise adaptation planning process outlined by Klein et al. (2000) (see Table 1).

One of the most important issues for many coastal nations now is to develop a proactive and sustainable adaptation plans and policies to deal with the present and future impacts of climate change and associated sea level rise. There is the need for all nations to prepare adaptive

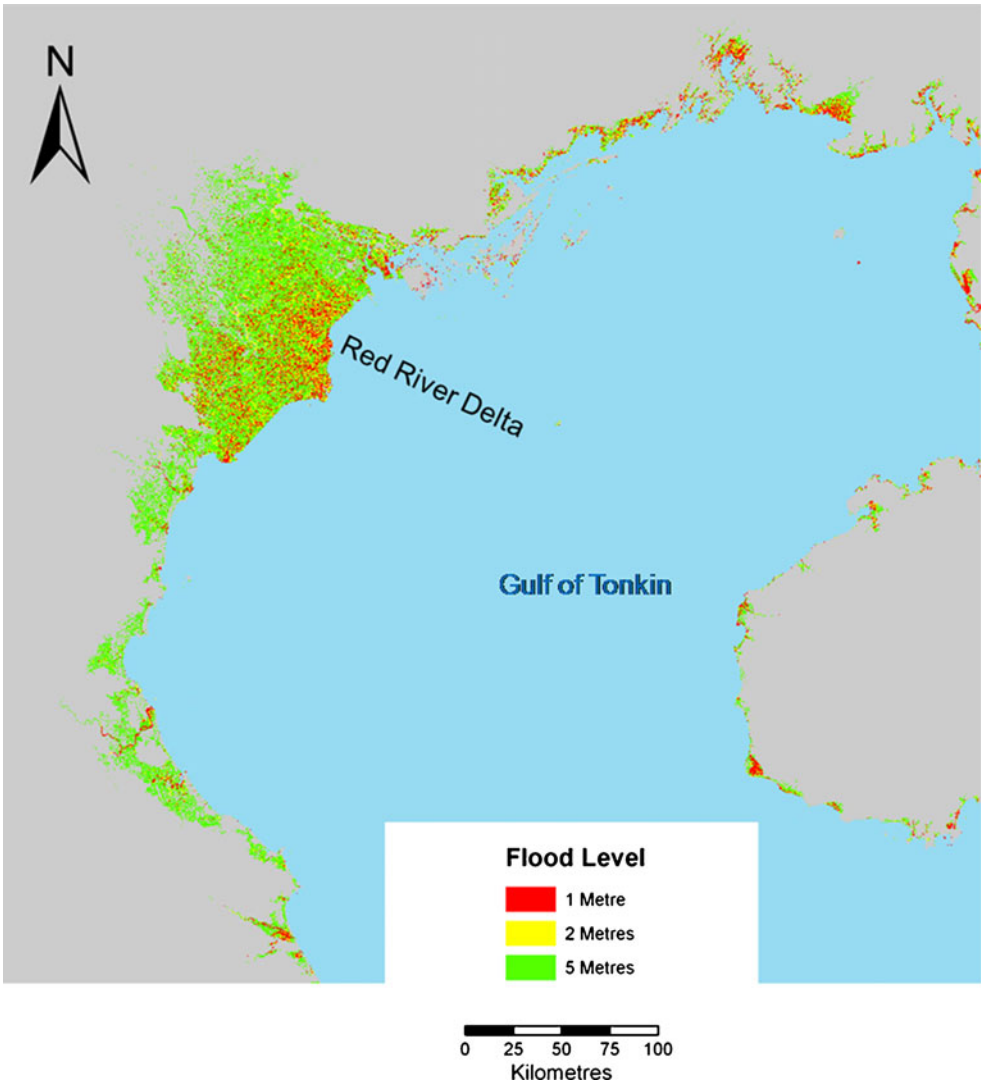

Fig. 4 Flood risk map of the North coast of Vietnam

responses to reduce impacts of climate change irrespective of the possibility of mitigating some of the more extreme effects through emissions controls. The IPCC, (2007) identified that one way of increasing adaptive capacity is by introducing sustainable development planning through adaptation measures in landuse planning and infrastructure design including measures to reduce vulnerability in existing disaster zones.

The process of coastal adaptation to climate change and sea level rise in both human and natural systems are very complex and dynamic. It often involves numerous assessments depending on existing conditions and possible future scenarios (Boateng 2008). The success of any adaptation policy depends on the ability to strengthen with the natural resilient to the change, financial considerations, the local capacity to deal with the effects of the change, effective planning policies, which depends on data and informed decisions.

Boateng (2010) outlined coastal adaptation framework (Fig. 9) which provides holistic and step by step (multi-stage) processes to develop sustainable coastal adaptation policy. The framework is based on participation and reliable data on the climate change variables and was developed after thorough review of coastal adaptation policies and methodologies for adapting to the impacts of climate change. It offers seven integrated steps of coastal adaptation planning process for practitioners. The framework (Fig. 9) provides detailed explanation as to what step, what process and why the process has to be followed to achieve sustainable adaption.

The appraisal of alternative adaptation policy options (step 4) should select for implementation the best policy option for the local area. The adaptation policy options outlined in Table 1: *Accommodation, Protection* and *Retreat* (IPCC 2007) or *Hold the line, Advance the line, Managed Realignment* and *No active Intervention* (DEFRA 2006). In case, the selected policy is identified to be ineffective after a period of implementation, then there will be the need to go back to the appraisal and selection of

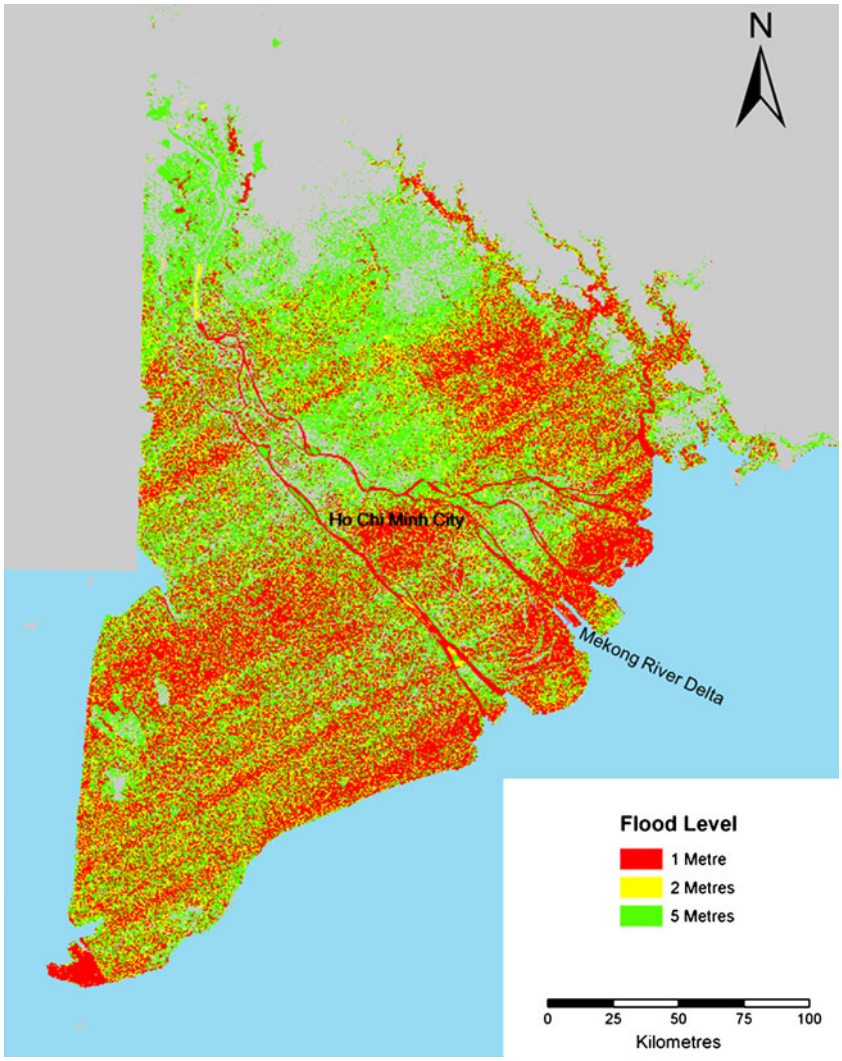

Fig. 5 Flood risk map of the South coast of Vietnam

appropriate policy option to identify alternative policy for implementation or the whole process need to start again. This has been illustrated by an external loop line at the left of Fig. 9.

The concept of multistage and iterative process for coastal adaptation to climate change (Tol et al. 2008; Boateng 2010) is mirrored in key principles in spatial planning. By this approach adaptation measures are planned and designed well in advance to reduce the vulnerability of coastal communities or ecosystems to the impacts of climate change. This is done as a process that is conditioned by policy criteria, coastal development objectives and interactions with existing management practices. It also involves monitoring and evaluation of the performance of the implemented adaptation options which may lead to the provision of new information and insights, leading to adjustments in the adaptation process, thus creating a new cycle of adaptation policy development. Coastal adaptation to climate change could be sustainable and effective if modern planning principles are applied. This is because both spatial planning and climate change adaptation are expected to deal with environmental concerns, which involve stakeholders, follow a multistage procedure to develop policies for implementation, apply monitoring and evaluation procedures and above all ensure sustainable development.

Adaptation to environmental change is a fundamental human capability and is not a new concept (Easterling et al. 2004). Throughout the ages, human societies have shown a strong capacity for adapting to different climatic conditions and environmental changes. The resilience and flexibility exhibited in the patterns of human settlements show an inherent desire and some measure of capacity to adapt. This suggests that though the coast of Vietnam is highly vulnerable to climate change, it might have significant natural adaptive capacity. However, our understanding of human adaptive capacity is less developed than our understanding of responses by natural systems,

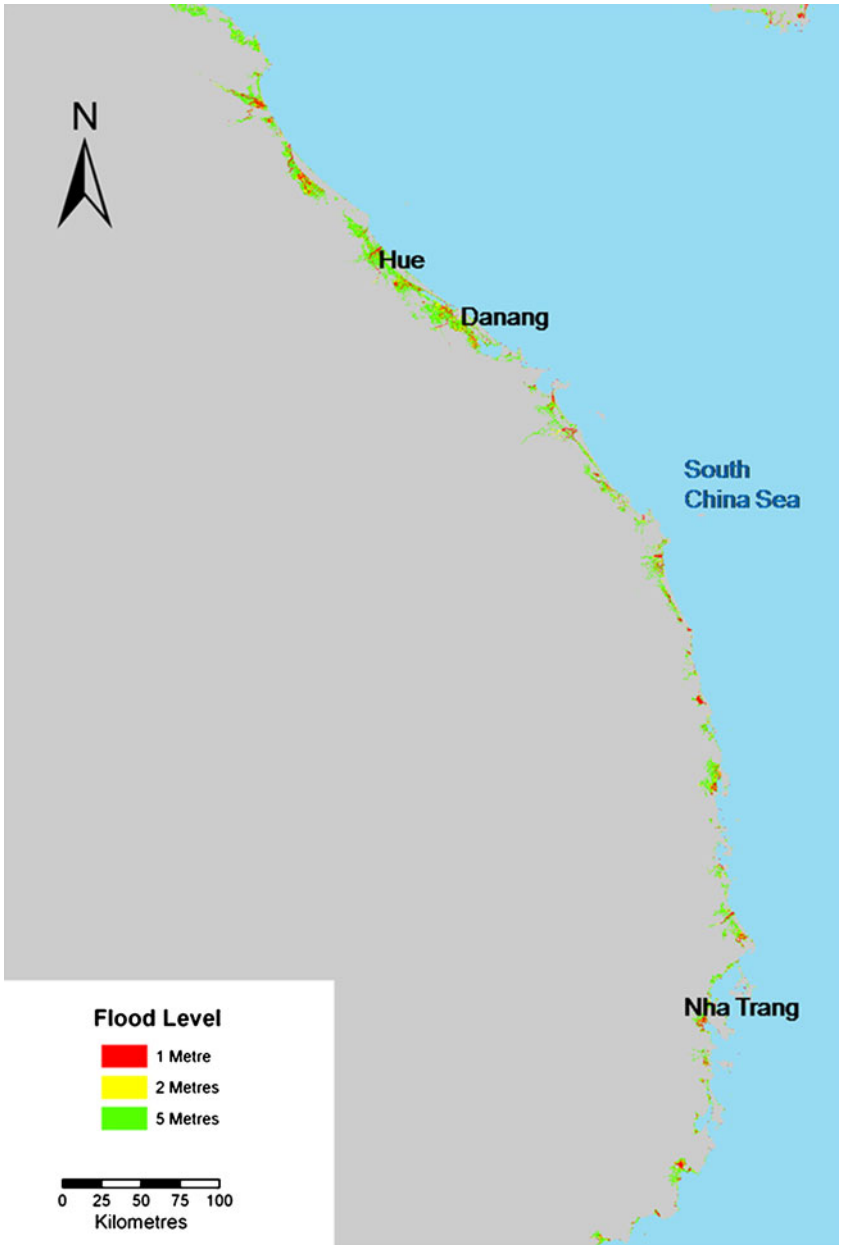

Fig. 6 Flood risk map of the central coast of Vietnam

which limits the degree to which we can quantify societal vulnerability in the world's coastal regions (Nicholls 2007).

Easterling et al. (2004) however, viewed adaptation as a risk-management strategy: that is neither free of cost nor foolproof, and the worthiness of any specific actions must therefore carefully weigh the expected value of the avoided damages against the real costs of implementing the adaptation strategy. Thus, there is a need for comparative assessment of adaptation policies and strategies so that those likely to be most effective in particular circumstances can be identified for implementation.

Vietnam could adapt to the impact of climate change through holistic assessment of the physical processes along the coastline. Such assessment could facilitate the division of the coastline into risk zones, appraisals of numerous coastal adaptation policies and strategies against various risk zones and then select the appropriate adaptation strategies for implementation. This must be done proactively and should be followed by monitoring and evaluation. For instance something could be done in advance to reduce human impacts on both the coastal zone and the river catchment areas and their effects on the environment, the ecosystems, the coastal zone and adjoining areas. Effort is also required on the reduction of the overexploitation of coastal and marine resources such as sand and gravel extraction, heavy minerals extraction, disposal of solid and liquid waste.

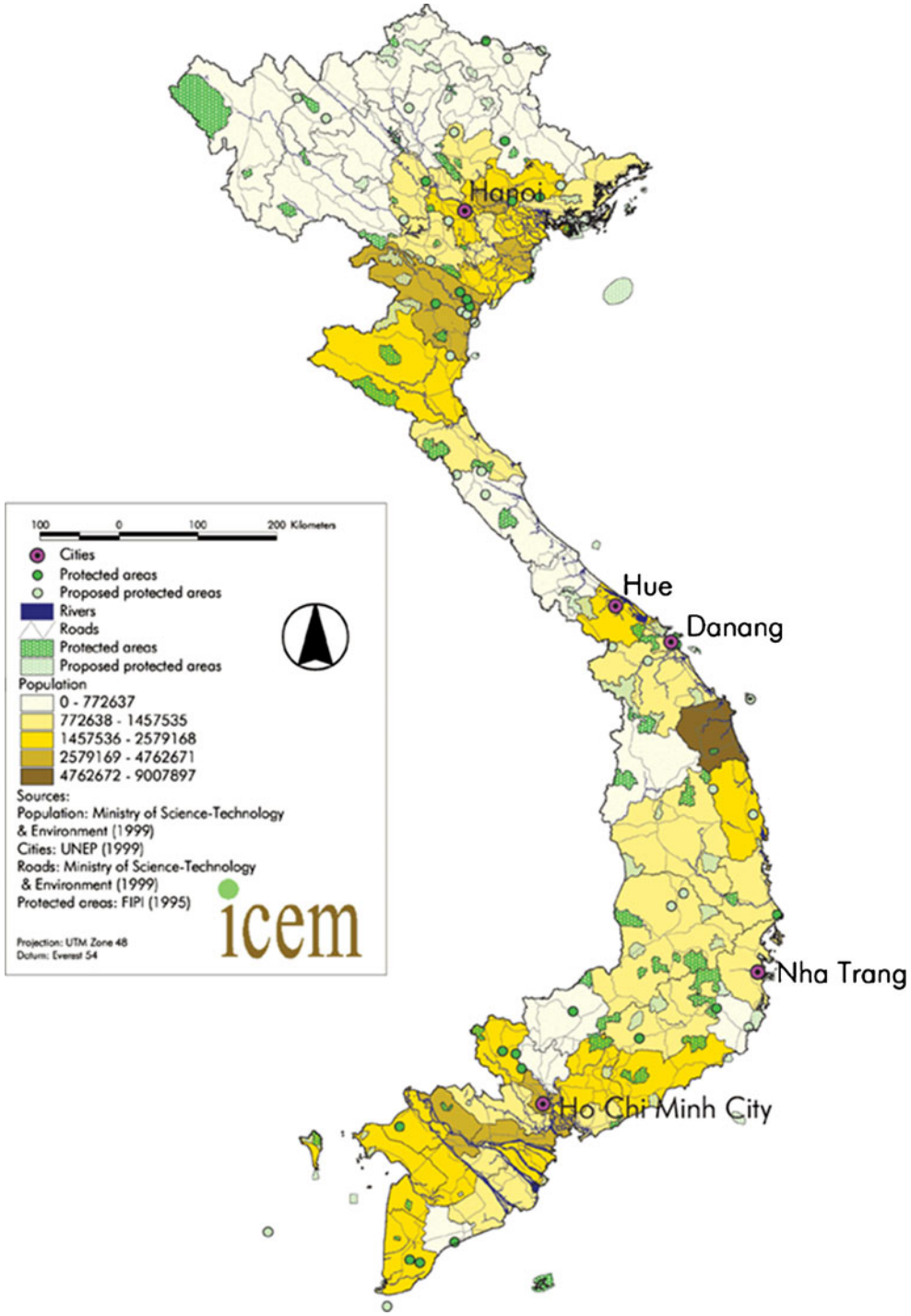

Fig. 7 Population map of Vietnam

Integrated shoreline management planning approach (DEFRA 2006 and Boateng 2009) which is based on littoral cell and sediment budget concept, provides large-scale assessment of risks associated with coastal processes and presents a policy framework to reduce these risks to people, developments, and the natural environment in a sustainable manner. Such an approach could be adopted by Vietnam to manage the shoreline. This shoreline management approach is based on four strategic policy options outlined by DEFRA (2006) in Table 1.

In addition, Vietnam could consider some of the non-structural approaches which have been used with some success in India, Bangladesh, New Zealand and USA to adapt to the flood risk of their low-lying coastal cities (Mascarenhas 2004; Nicholls 2007; Healy and Soomere 2008 and Boatman et al. 2008). Examples of some of the

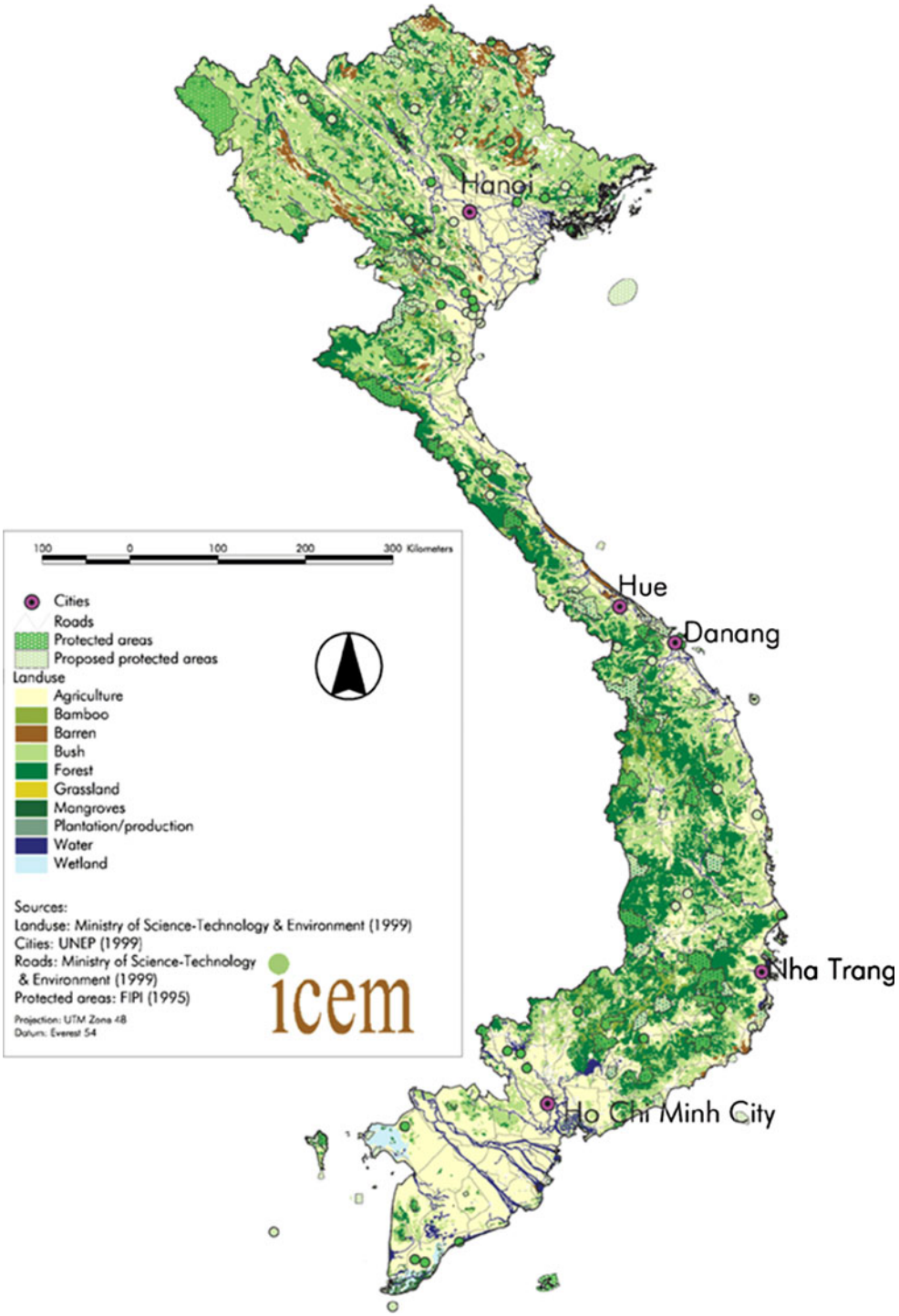

Fig. 8 Land use map of Vietnam

non-structural approaches include, coastal buffer zones, building houses on stilts, storm warning systems, growing of flood-resistant crops and elevated storm shelters with medicine and food storage. These strategies enable areas to be occupied for longer before eventual retreat. However, for it to be effective, strict land use planning and education should be used to discourage growing trends of human development along existing disaster coastal zones which could exacerbate the vulnerability due to increased risk to life and property. IPCC (2007) identified that one way of increasing adaptive capacity is by introducing the consideration of climate change development planning, inclusion of adaptation measures in land-use planning, infrastructure design and measures to reduce vulnerability in existing disaster zones.

The non-structural approach could be applied to the Red River Delta in the North and the Mekong Delta in the South which has low elevation but highly developed. However,

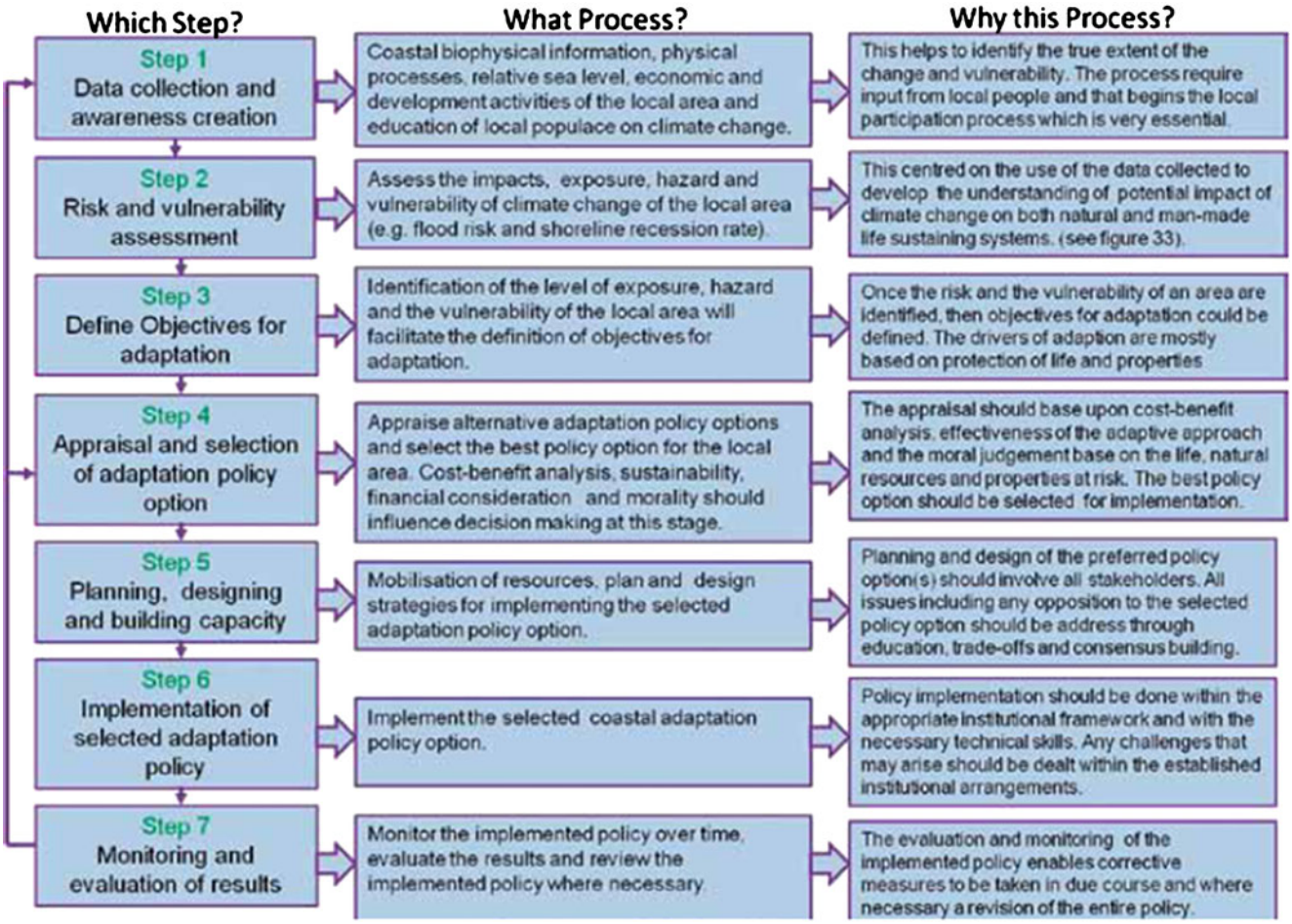

Fig. 9 A framework for coastal adaptation planning

structural approach as such as dykes, breakwaters, sea defence and groynes could be applied along the central coast due to its high elevation and hard geology. This should be adopted only after detailed assessment of the impact of such measures and development of mitigation of their impacts on the adjoining coastlines. It is also worth mentioning that sustainable coastal adaptation may require diversification of Vietnam's economy from its dependency on natural resources to manufacturing based economy.

Conclusions

The paper has revealed that the physical character of the coast of Vietnam and the effects of human development and over-exploitation of the coastal resources are among the causes of increased vulnerability of the coastal zone to climate change and sea level rise. Unfortunately the highly vulnerable areas such as the Red River delta and the Mekong River delta are the most prosperous, populous and well developed coastal areas of Vietnam. This makes issues of coastal adaptation to climate change a very serious subject that requires the attention of the government, coastal provincial authorities, coastal dwellers and other stakeholders. The study identified many possible impacts of climate change and sea level rise on the coast with significant ramifications on the socio-economic development of Vietnam. It was identified that adaptation to environmental change is a fundamental human capability and is not a new concept, hence the coastal zone of Vietnam, though highly vulnerable to climate change—it might have a significant adaptive capacity (resilience) which must be explored, developed and implemented in advance.

The study recommends that Vietnam should conduct an integrated risk assessment of her coastline to enable division of the coast into risk zones. This could be followed by an exploration of various adaptations strategies and policies. Then, based on environmental sustainability and cost benefit analysis, choices should be made from alternative adaptation policies for implementation at specific sections of the coastline. Based upon the large-scale flood risk assessment conducted (Figs. 3, 4, 5 and 6), it was identified that non-structural approach could be used to

adapt the low-lying coastline to climate change. This strategy enables vulnerable areas to be occupied for longer before eventual retreat. However, structural adaption approaches could also be used to adapt the central coast which has high elevation and hard geology. In addition, the paper suggested that coastal adaptation should be planned, implemented well in advance, monitored and evaluated before the occurrence of a natural disaster or an environmental change. Based on this, Vietnam should develop and implement coastal adaptation policies now, in order to forestall the possible impacts of future climate related disasters.

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