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# Impacts of climate change on water resources in the Huong River basin and adaptation measures

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**Abstract.** This study investigates impacts of climate change on water resource in the Huong River basin in the Central Vietnam. Hydrological responses of six climate change scenarios were calculated. Results reveal that climate change would cause significant increase in rainfall in wet season resulting in an increase in river flow. By contrast, the decreasing trend of river flow in dry season is a consequence of the decline of rainfall and increase of evapotranspiration under most scenarios. Sea level rise coupled with the lowering of river stages may exacerbate salinity intrusion. Impacts of climate change on socio-economic sectors such as agriculture, tourism, biodiversity, fishery and aquaculture are assessed, and adaptation options for Thua Thien - Hue Province are proposed.

*Keywords:* climate change, water resources, hydrological model, flood, adaptation.

## 1. Introduction

Water management planners are now facing considerable uncertainties on future demand and availability of water. Climate change and its potential hydrological effects are increasingly contributing to this uncertainty. With the total area of 2.830 km$^2$, Huong River basin falls entirely in Thua Thien - Hue Province and is of great economic and tourism importance for the province. The river basin is expected to be one of the most vulnerable basins in the Central Vietnam where climate change is likely to pose serious challenges to water resources. It is a fact that water shortage in dry season is getting worse. Moreover, annual frequent floods, such as the historical flood event in 1999, have revealed the vulnerability of water resources as well as environment to climate changes. Therefore, the need for impact assessment of climate change has undoubtedly arisen.

## 2. Methods

### *2.1. Climate change scenarios*

Six climate change projections for the period 2010-2100 based on different emission scenarios (2 High, 2 Medium and 2 Low) for Thua Thien - Hue province were developed using Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment

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published by the Intergovernmental Panel on Climate Change (IPCC). Changes in daily temperature and precipitation were computed by using Statistical Downscaling method.

The following sources of input and boundary data were used for developing the climate scenarios: (1) Results from Global Circulation Models (GCM) and Ocean-Atmospheric Global Circulation Models (OAGCM); (2) IPCC's global emission scenarios and regional climate change scenarios for South-East Asia (IPCC, 2001); (3) Past trends of observed meteorological data from stations of Hue, A Luoi and Nam Dong for the last 30 - 40 years in Thua Thien - Hue Province; and (4) Observed sea level data at stations and analysis from the Marine Hydro-Meteorological Center.

*2.2. Hydrological/Hydraulic model application*

In order to assess the potential impacts of climate change on water resources, a set of hydrological/hydrodynamic model, including NAM, MIKE11 and MIKE11GIS, was employed. Inputs for these models include daily rainfall, and temperature data from 1961-2004, and their projections for the period of 2010-2100. Potential evapotranspiration were computed for the baseline year 1990 and for the periods 2020 - 2049 and 2071 - 2100 at A Luoi, Nam Dong, and Hue stations.

## 3. Results and discussion

*3.1. Climate change scenarios*

Results from the model show that annual mean temperature is expected to increase by 2.5-2.6$^0$C by the end of the 21$^{st}$ century. The increase is more pronounced in January and February (2.6-2.7$^0$C). Among climate scenarios, the temperature would increase the most in A1FI scenario, by 3.9$^0$C in 2100, and up to 4.7$^0$C between March-May (Table 1).

Table 1. Projected increase in annual and seasonal temperature ($^0$C) in Thua Thien - Hue in 2010-2100

| Scenario | Period | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1FI | Year | 0.2 | 0.3 | 0.6 | 0.9 | 1.4 | 2.0 | 2.6 | 3.1 | 3.5 | 3.9 |
| | Dec-Feb | 0.2 | 0.3 | 0.6 | 0.9 | 1.5 | 2.1 | 2.7 | 3.2 | 3.7 | 4.0 |
| | Mar-May | 0.2 | 0.4 | 0.7 | 1.1 | 1.7 | 2.4 | 3.1 | 3.7 | 4.3 | 4.7 |
| | Jun-Aug | 0.2 | 0.3 | 0.6 | 0.9 | 1.5 | 2.1 | 2.7 | 3.2 | 3.7 | 4.1 |
| | Sep-Nov | 0.2 | 0.3 | 0.6 | 0.9 | 1.4 | 2.0 | 2.6 | 3.2 | 3.6 | 4.0 |
| A2 | Year | 0.2 | 0.3 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.6 | 2.1 | 2.6 |
| | Dec-Feb | 0.2 | 0.3 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.5 | 2.0 | 2.5 |
| | Mar-May | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.2 | 1.4 | 1.8 | 2.4 | 3.0 |
| | Jun-Aug | 0.2 | 0.3 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.6 | 2.1 | 2.6 |
| | Sep-Nov | 0.2 | 0.3 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.5 | 2.0 | 2.5 |

Results also indicate that rainfall in the rainy season would increase by 25%. In contrast, rainfalls in the early months of dry season (December to February) show a decrease by 23% for A1FI scenario. Annual rainfall has an increasing trend in most scenarios. Table 2 shows the results of projected rainfall for various periods.

Table 2. Projected change in annual and seasonal rainfall (%) in Thua Thien - Hue in 2010-2100.

| Scenario | Period | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year | 0.5 | 0.9 | 1.5 | 2.5 | 4.0 | 5.7 | 7.3 | 8.7 | 10.0 | 11.0 |
| | Dec-Feb | -1.0 | -2.0 | -3.3 | -5.4 | -8.5 | -12.0 | -15.4 | -18.5 | -21.2 | -23.4 |
| A1FI | Mar-May | 0.4 | 0.8 | 1.3 | 3.1 | 3.4 | 4.8 | 6.1 | 7.4 | 8.4 | 9.3 |
| | Jun-Aug | 0.7 | 1.1 | 2.2 | 3.6 | 5.6 | 8.0 | 10.3 | 12.3 | 14.2 | 15.6 |
| | Sep-Nov | 1.1 | 2.1 | 3.5 | 5.7 | 8.9 | 12.7 | 16.3 | 19.6 | 22.4 | 24.7 |
| | Year | 0.4 | 0.9 | 1.2 | 1.7 | 2.2 | 2.7 | 3.3 | 4.2 | 5.6 | 7.0 |
| | Dec-Feb | -0.9 | -1.8 | -2.4 | -3.6 | -4.6 | -5.7 | -6.9 | -8.9 | -11.8 | -14.8 |
| A2 | Mar-May | 0.4 | 0.7 | 1.0 | 1.4 | 1.8 | 2.3 | 2.8 | 3.6 | 4.7 | 5.9 |
| | Jun-Aug | 0.6 | 1.2 | 1.6 | 2.4 | 3.1 | 3.8 | 4.6 | 6.0 | 7.9 | 9.8 |
| | Sep-Nov | 1.0 | 1.9 | 2.6 | 3.8 | 4.9 | 6.1 | 7.3 | 9.4 | 12.5 | 15.6 |

### *3.2. Change in river flow*

Figure 1 shows period-averaged change of annual flows relative to the baseline period (1990) at four gauging stations for the periods 1977-2006, 2020-2049 and 2071-2100 under the B2 scenario. From the figure, an apparent increase in the river flow is observed; however, the magnitude is different amongst periods and streamflow gauging locations. Of all stations, flow at Ta Trach increases most significantly whereas flow at Phu Cam (downstream) has smallest increase, 9% and almost 5%, respectively. Results of streamflow simulation also reveal a reduction of flow in dry season due to the decline of rainfall.

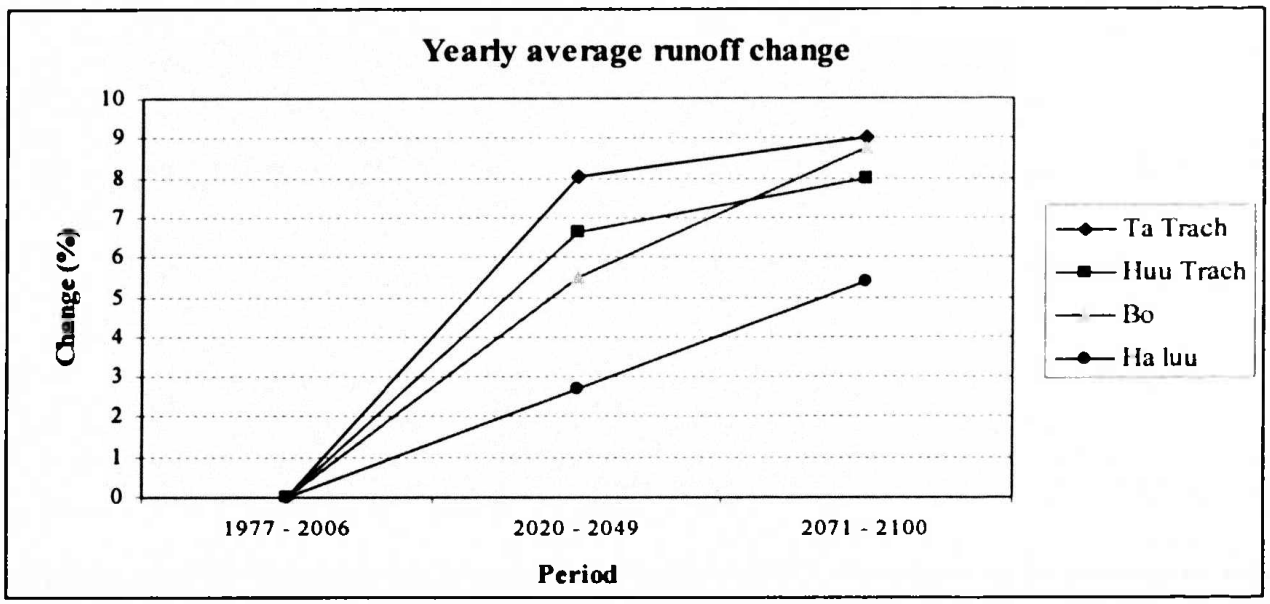


Figure 1. Average change of annual flow at some locations.

*3.3. Change in flooded area*

Based on the MIKE11 outputs, MIKE11GIS was employed to interpolate water levels at all cross-sections in order to construct a grid-based (TIN-based) water surface. The water surface was then automatically compared with a Digital Elevation Model (DEM) to develop flood depth maps [1]. Table 3 shows the predicted change of flood depth and flooded areas in Thua Thien - Hue province for the A1FI emission scenario compared to the flood event in 1999.

Table 3. Flooded area in Thua Thien - Hue under A1F1 emission scenario.

| Characteristics | 1999 | 2030 | 2050 | 2070 | 2090 | 2100 |
|---|---|---|---|---|---|---|
| Max. depth (m) | 5.81 | 5.96 | 6.08 | 6.16 | 6.27 | 6.44 |
| Area flooded ($km^2$) | 388.4 | 404.5 | 419.2 | 439.5 | 448.8 | 453.7 |
| Flooded proportion (%) | 7.69 | 8.01 | 8.29 | 8.68 | 8.88 | 8.98 |

It can be seen from the table that, the 1999 flood event caused an average flooded depth of 5.81m covering an area of 388.4$km^2$ and accounting for 7.69% area of the entire territory of Thua Thien - Hue Province. By the year 2030, flooded depth of almost 6m will result in flooding area of 400$km^2$. It is obvious that, the magnitude and flooding area will be more severe by time. Figure 2 indicates a flooded map for the Huong River basin corresponding with maximum water level under the B2 emission scenario.

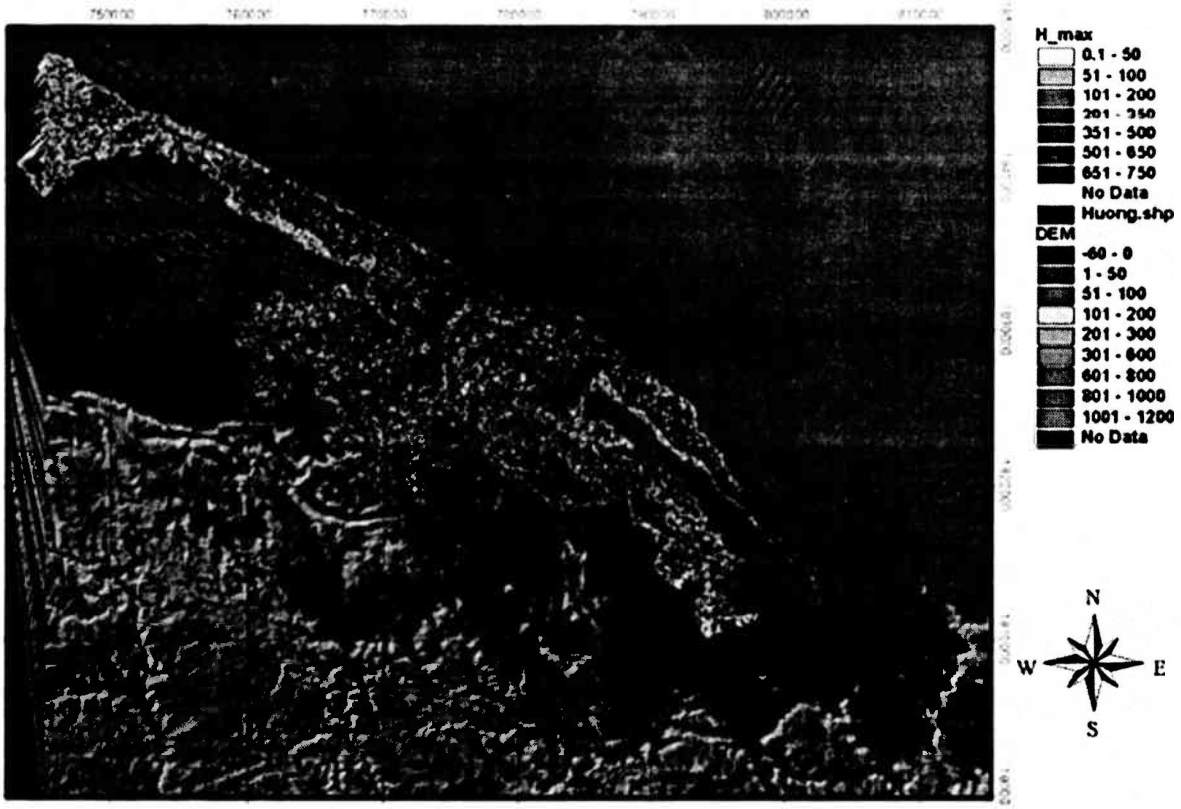


Figure 2. Inundation map for the year 2100 under B2 scenario.

### 3.4. Change in salinity intrusion

Salinity profile was simulated by the couple of HD and AD modules of MIKE 11 model taking into consideration of climate change and sea level rise. The year 2002 is selected as the reference baseline because of the availability of measured salinity data. Results of salinity intrusion computation for A1FI scenario for some cross-sections in the mainstream are presented in Table 4. As shown in the table, salinity concentration increases over time and goes accordance with magnitude of sea level rise. Result also indicates that the salinity intrusion during dry season in the Huong River basin due to a series of effect of sea level rise, water reduction and increasing demand of water users is expected to be more serious in the future.

Table 4. Salinity concentration change at Pho Nam and Phu Cam (A1FI scenario).

| Cross-section | Parameter | 2002 | 2030 | 2050 | 2070 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|
| Phu Cam | Average salinity concentration (‰) | 2 | 2.1 | 2.17 | 2.33 | 2.41 | 2.47 |
| | Percentage (%) | 0 | 5 | 8.5 | 16.5 | 20.5 | 23.5 |
| Pho Nam | Average salinity concentration (‰) | 2.45 | 2.65 | 2.84 | 3.05 | 3.24 | 3.39 |
| | Percentage (%) | 0.00 | 8.16 | 15.92 | 24.49 | 32.24 | 38.37 |

### 3.5. Impact of climate change on other sectors

Apart from assessing the impacts of climate change on water resources, the study also looked at impacts of climate change on other sectors in Thua Thien - Hue Province. In addition, more detailed assessments have been carried out in order to better understand the potential impacts of climate change on two specific areas in the province: Phu Vang District and Chan May - Lang Co Special Economic Industrial Zones.

The impact assessments were largely based on interviews and workshops/meetings with stakeholders at provincial, district and commune levels, using UNEP and IPCC methodology as well as participatory approaches. The assessment was carried out for all relevant sectors, natural and water resources, biodiversity, agriculture, aquaculture, forestry, industry and energy, transport and construction, culture and sport, tourism, trade and services, with an emphasis on the highly important coastal zone of Thua Thien - Hue Province. A brief summary including some representative examples of the climate change impacts are presented here.

*Impacts on agriculture*

Most of the current rice paddies would have a high risk of flooding during wet season. Additionally, salinity intrusion is another threat during the dry season, especially in low-lying areas. This may lead to a drop in food yields which in turn threats food security.

Rice, short-term and long-term planted trees and long-term, newly developed industrial trees such as rubber may suffer more as the occurrence of natural disasters is pronounced to be more frequent. The crop patterns and productivity are also expected to be severely affected by climate change.

The spread and introduction of new species and pathogens may cause an increase in animal, livestock and crop diseases and infections.

Increasing amount of pesticides and chemicals might be used to combat this, hence, resulting in an increasing risk of pollution and danger.

*Impacts on natural fisheries and aquaculture*

Changes in the flow regime will affect the itinerary of fishing boats and other ships and fish migration/spawning routes. Changes in the natural environment lead to changes of biodiversity, the behavior of fauna and flora and change of their genetic diversity.

When temperatures exceed 40$^0$C, the growth of animals in aquaculture ponds is slowed, and they may even die, affecting farm productivity. In addition, bacteria and fungi multiply more profusely, resulting in epidemics and eutrophication of farming ponds in the lagoon.

*Impacts on biodiversity*

Climate change and sea level rise may increase the salinity concentration of the brackish lagoon water, adversely affecting the ecosystems of the Tam Giang - Cau Hai wetland. Many endangered species would be exposed to a high risk of extinction. The projected extension of the lagoon and frequently flooded area would alter the shoreline and estuary and destroy the large mangrove forest and habitat of many species, including those that are endangered.

The solutions proposed and implemented (weir, dam, etc.) to address the problem of salinization due to sea level rise could affect migratory animals and micro organisms, including the migration for reproduction of "native" species such as flower eel, ebony eel and spotted sardine. This could also restrict the transition and interaction between the freshwater, brackish-water and marine ecosystems, potentially limiting the adaptation capacity of wildlife, domestic animals and crops.

A rise in sea temperature could also affect coastal and marine ecosystems such as coral reefs.

*Impacts on the coastal zone*

The coastal zone accounts for 30% of the area and more than 30% of the human population of Thua Thien - Hue Province.

Climate change impacts on the coastal zone in the province include: (1) The shrinking of land and coastal plain due to enlarged wetland and flooded areas in Tam Giang - Cau Hai lagoon would exacerbate the effects of floods to downstream of Huong River; (2) The flooding of terrestrial ecosystems may result in the loss of mangrove forest; (3) Eroded seashore, decreased land under cultivation and dwindling residential areas will adversely affect local incomes and livelihoods, including that of fishermen, farmers, industrial workers and enterprises around the lagoon and downstream of the Huong River; (4) Threats to infrastructure and transportation networks (sea dyke and coastal highways), irrigation and water works which were designed and constructed without consideration of sea level rise; indirectly increase public and private sector expenditure for construction and protection of infrastructure in low-lying areas; and (5) Increased pollution of the aquatic environment in the coastal zone and salinity intrusion of the Huong River lead to water scarcity. This in turn results in conflicts in the use of natural and water resources.

*Impacts on tourism*

Thua Thien - Hue Province has advantages of tourism thanks to its natural and cultural features. However, climate change may harm the economic benefits deriving from the culture, sport, tourism, trade and service sectors. Sea level rise may inundate coastal beaches of the

province, some of which could disappear, while others will move further inland reducing enjoyment of the seaside. Sea level rise may also damage the cultural and historical heritage, protected areas and infrastructure of the ancient capital of Hue.

### *3.6. Towards an adaptation policy for Thua Thien - Hue province*

The Integrated Coastal Zone Management (ICZM) strategy for Thua Thien - Hue Province reflects the willingness and commitment of the provincial authorities and people to carefully balance interests with respect to the protection and the use of coastal resources and environment for the sustainable development of the coastal zone [2].

The ICZM strategy document was promulgated at the national level in 2003. The strategy of ICZM agrees with the strategy of adaptation to climate change in the approach, methods of implementation and objectives of environment protection for sustainable development. As such, the document could serve as an appropriate basis for implementing climate change policies and measures at the provincial level.

At this moment, however, the process of the preparing the ICZM strategy has not yet considered the changes in climate as well as their impacts on natural conditions of the study area. Hence the study, in close consultation with relevant provincial stakeholders, took the initiative to integrate some climate change adaptation proposals into important sections of the ICZM strategy.

The following proposal has been made for inclusion into the ICZM Strategy: (1) Raising management capacity for ICZM in the areas most likely affected by climate change: Raising awareness and knowledge among community members, local government authorities and policy makers on future climate-related disasters and adaptive measures for ICZM to respond to climate change; (2) Re-development the coastal zone management framework protocol and action plan in the administrative system of Thua Thien - Hue towards sustainable development, shared benefits and adaptation to climate change; (3) Re-recognition of the areas, fields and communities most vulnerable to climate change impacts and identification of effective measures to maintain sustainable development in these specific zones; and (4) Re-assessment of the carrying capacity of the coastal zone and lagoons and potential adaptive capacity of relevant sectors (agriculture, aquaculture, tourism and industrial development) in the coastal zone [3].

## 4. Conclusions

The study has provided a quantitative understanding of the impacts of climate change on water resources in the Huong River basin.

Climate change will result in an increase in precipitation in rainy seasons but a decline in dry season. As a consequence, river flow also changes accordingly. This may cause an unbalance in water use of various sectors.

The large uncertainty in the rate and magnitude of the changes needs appropriate adaptation measures. Both structural and non-structural measures should be considered so as to minimize the severe impacts.

Integrated approaches should drive the future research on impact assessment in order to fulfill the sustainable development of the river basin.

## Acknowledgments

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