# IMPACT OF CLIMATE CHANGE ON SALINITY INTRUSION IN THE MEKONG DELTA

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## ABSTRACT

Due to climate change and global warming, sea level rise causes changes in hydromorphological regime and salinity intrusion in low-lying coastal areas. The Mekong delta is one of the places receiving these negative consequences. A two dimensional numerical model system is developed and applied to evaluate these effects on hydraulic regime and salinity intrusion on the Hau River, one of the branches of the Mekong river system. In the model system, precipitation from a general climate model (GCM) are downscaled and bias corrected, and further used as boundary conditions for the hydrodynamic and saltwater intrusion model MIKE-21. The observed data sets are used for model setup, calibration and validation. Here, we present the first results of model calibration for flow and salinity intrusion and of data assimilation for several future scenarios with climate change.

**Keywords:** MIKE 21, Mekong delta, salinity intrusion, sea level rise, climate change

## 1. Introduction

Salinity intrusion is a natural phenomenon occurring in the lands, estuaries, and aquifers being adjacent to the sea. There is a large variability in estuaries depending on the differences in the tides, river discharges and topography. The salinity distribution within the estuary is commonly used for classification purposes. For example, there are three kinds of estuaries: a) a semi-enclosed and coastal body of water b) with free communication to the ocean and c) within which ocean water is diluted by freshwater derived from land (Pritchard, 1955). There are many factors affecting the salinity intrusion: discharge and river flow periods, topography, morphology, river bed slope, tides on the sea, wind velocity and direction, water temperature, the friction on the flow, etc. One of the main causes of salinity intrusion is a difference of flow energy (both potential and kinetic energy) as well as of current density between freshwater and saltwater.

The Mekong Delta (MD) is flat, low-lying, and fertile and contributes significantly to the development of the social economy. According to the Intergovernmental Panel on Climate Change, the coastal countries of Southeast Asia are highly vulnerable to climate change. Recently, Lauri *et al*., (2012) indicated that the discharge of Mekong River should be influenced by climate change and reservoirs operation in China and Laos. Based on the simulation, by comparing the water discharges at Kratie station in the periods (1982–1992) and (2032–2042), a variation range of (−11%, +15%) for the wet season and of (−10%, +13%) for the dry season could be reached. Recently, number of researches have been conducted the impacts of climate change and sea level rise to the MD and indicate that the MD will be one of the most vulnerable areas. Salinity intrusion will be more serious by the consequences of the global climate change, the change of upstream flow and sea level rise. Wassmann *et al*., (2004) investigated the effects of sea level rise on water levels in the Vietnamese MD but only focusing on the flooding period under various sea level rise scenarios and did not consider dry season. Khang *et al*., (2008) conducted a research of salinity intrusion due to sea level rise and river flow change in the Vietnamese MD for dry season using the 1D numerical model system. However salinity intrusion and hydraulic regime at the estuaries received little attention. In this study, we apply a 2D model to simulate hydraulic regime and salinity intrusion in the Hau River Estuaries, taking the effects of climate change and sea level rise for account. The study area covers two estuaries called Tran De and Dinh An and extends to Chau Doc station (Fig. 1).

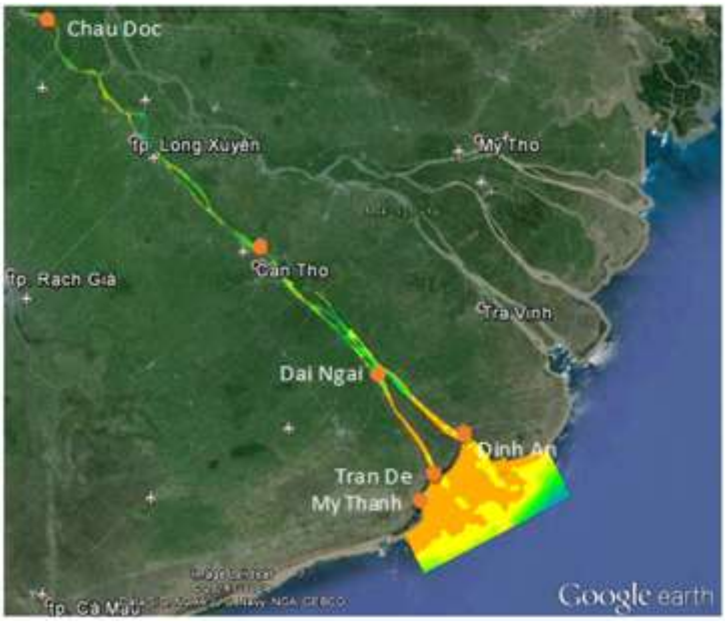


**Figure 1:** Study area and measuring stations.

## 2. Methodology

River salinity in the MD depends on the freshwater flow upstream, surface water runoff from rainfall events, and the tidal dynamics of the coastal river system. The process of mixing freshwater from the upstream river system and saline water in the coastal water occurs as turbulence is generated by wind and tidal currents. We used MIKE 21 for hydrodynamic and transport processes to capture the effects of almost the factors that affect salinity in the study area.

### 2.1. Model setup for MIKE 21

The Hydrodynamic Module and the Transport Module of MIKE 21 are used. The flow is calculated from the shallow water equations with considering rainfall effects. The see water intrusion is simulated by the depth averaged convection diffusion equation. The mutual interaction between salinity concentration and currents can be modeled using dynamic coupling between these two modules. The governing equations are solved numerically using a finite volume method on a flexible mesh with additional initial and boundary conditions. In MIKE 21, the effects of climate change and sea level rise are taken for account by specifying the boundary conditions for tidal wave and precipitation.

The simulation domain was discretized by an unstructured mesh with about 35,000 triangular elements and 28,000 nodes. Digital bathymetric data in 2011 was used to define the bed level at every grid points. The hourly water discharges in 2011 at Chau Doc measuring station were applied as inlet boundary condition. At the outlet boundary the tide amplitudes were specified. The water level and salinity concentration observed at My Thanh, Tran De, Dai Ngai and Dinh An stations in 2011 were used for model calibration. The rainfall effects were taken into account by considering an additional water discharge at the confluence of the Vam Nao river.

### 2.2. Data assimilation for future scenarios

General Climate Models (GCMs) are the most advanced tools currently available for diverse assessments of the impact of large-scale climate variation and change on natural resources. Raw GCM output, however, is not always adequate to address the inter-disciplinary questions of interest. Two primary impediments to impacts studies are the spatial scales represented by the GCM may not be as fine as the end-use application requires, and the GCM raw output is deemed to contain biases relative to observational data, which preclude its direct use in downstream applications. In the study, we use five GCMs with the representative concentration pathways scenarios RCP 2.6, 6.0, 8.5 presented in Tab. 1 (based on van Vuuren *et al*., 2007; Riahi *et al*., 2011; Hijioka *et al*., 2008; and IPCC, 2013).

The daily precipitation outputs from GCMs are downscaled and bias corrected, which are called as regional climate modelling (RCM). Three bias correction methods are applied in this study: linear scaling (LS), local intensity scaling (LOCI) and distribution mapping (DM). The LS method works with monthly correction values based on the differences between observed and RCM simulation during the reference period. The wet-day frequency and intensity corrected by the LOCI method takes the linear scaling in the first step and adjusts the mean as well as both wet-day frequencies and intensities separately in further three steps. The DM method corrects the distribution shape of the daily precipitation based on cumulative distribution functions constructed for both the observed and the RCM simulated precipitation for all days within a certain month. More details about these methods can be found in Lenderink *et al*. (2007), Schmidi *et al*. (2006) and Teutschbein *et al*. (2012).

**Table 1:** Different GCMs with emission scenarios and spatial resolutions

| GCM | Country | Emission Scenarios | Spatial Resolution |
|---|---|---|---|
| 1. CanESM2 | Canada | RCP 2.6, 6.0, 8.5 | 64×128 cells |
| 2. CNRM-CM5 | France | RCP 2.6, 6.0, 8.5 | 96×192 cells |
| 3. GFDLS-CM3 | NOAA/USA | RCP 2.6, 6.0, 8.5 | 90×144 cells |
| 4. HadGEM2-ES | UK | RCP 2.6, 6.0, 8.5 | 145×192 cells |
| 5. MPI-ESM-LR | Germany | RCP 2.6, 6.0, 8.5 | 96×192 cells |

After downscaling, the predicted precipitations for the whole river basin are applied as source and sink terms in MIKE 21.

## 3. Results and discussions

### 3.1. Model calibration

The hydrodynamics model was calibrated by simulating the flow in 2011. The flow module has two major physical parameters that can be determined through the calibration process: the bed-surface friction coefficient and the horizontal eddy-viscosity coefficient used for horizontal turbulent-diffusions term. Based on the geometry in the study domain, coarse estimates of the bed roughness were specified. They were then adjusted until an acceptable agreement between calculated results and measured data of the water level is obtained. Fig. 2 compares exemplarily the simulated results with the water levels observed from March to June 2011. A good agreement at My Thanh station was achieved. However, there is still a large variation at the inland Dai Ngai station.  At this station, the measured data show lower tidal wave amplitudes. It might be due to the fact, that in the model the wind effects were not yet taken into account. Another factor, which could lead to this disagreement, is the constant eddy viscosity used in the whole model. Consequently, the distinction between the calculated salinity concentration and observations at this station is still considerable. By applying suitable initial condition for salinity concentration, we could reduce this difference and improve the model system.

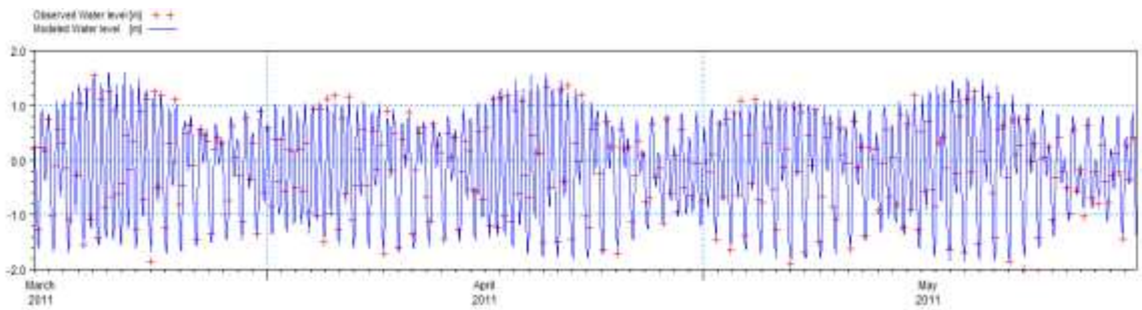


**Figure 2:** Observed and simulated water level at My Thanh station.

### 3.2. Downscaling GCM

The three downscaling methods were applied exemplarily for outputs of CanESM2. The daily observed precipitations at Can Tho station for the period 1980-2011 were used for bias correction. Fig. 3 compares the mean values of the observed annual rainfall data with the RCM predictions. It is obvious that two bias correction methods LS and DM provided better results than the LOCI method. Since during the correction process all LOCI calculated values were assumed not to be smaller than this threshold value, the quality of LOCI method depends strongly on the selection of threshold value. Table 2 illustrates the correlation for these bias correction methods with the statistical performance indices between predicted and observed data. It can be seen that the linear scaling method (LS) provided the highest correlation coefficient (R) and the lowest values for root mean square Error (RMSE) and mean absolute error (MAE). Applying the LS method in the calibrated RCM model for future scenarios we have the precipitation information for the period 2035-2065, which is used as inputs for hydrodynamic calculations concerning the climate change effects.

**Table 2:**Statistical performance of three bias correction methods

| Methods | RMSE | MAE | R |
|---|---|---|---|
| LS | 32.37 | 28.53 | 0.98 |
| DM | 45.91 | 38.56 | 0.95 |
| **LOCI** | **246.62** | **186.14** | **0.46** |

## 4. Remarks

The effects of climate change on river salinity in the MD are expected to manifest in several ways. In particular, salinity ingress is likely to be more severe in the future for two reasons: (1) freshwater flows from rivers in the upstream part are predicted to decrease during the dry season and (2) the sea level will gradually rise. This paper presents only the first results of hydraulic and salinity simulation. Model calibration is going on by taking also the effects of precipitation, evaporation, rainfall-runoff and wind in the study area. We have collected the necessary measured data and are now processing these data. Furthermore, the hydraulic model is also calibrated with hourly measured data on water discharge time series at Can Tho station. Another data set at the mentioned stations in 2010 is used for model validation. The next works concern to modelling for climate change scenarios with different precipitation, sea level rise and variation of inlet discharges. For this purpose, we use MIKE 11 model to simulate the runoff in an effective river network by changing of precipitation and temperature at basin level, which together with different scenarios for sea level rise and change in river discharge are estimated based on GCM outputs and statistical downscaling methods.

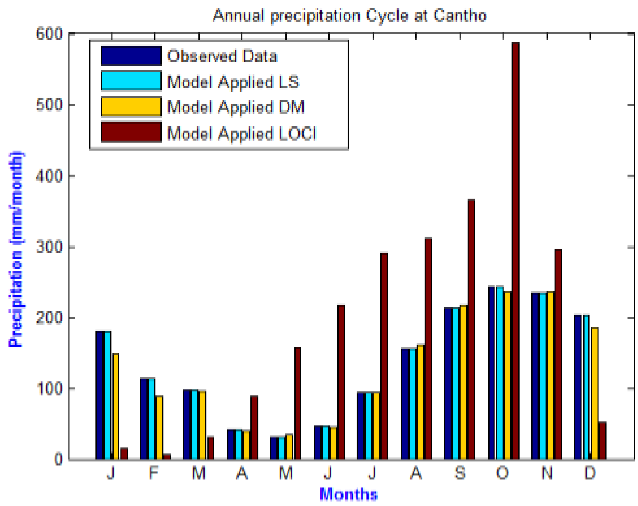


**Figure 3:** Observed and modelled precipitation at Can Tho station

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