A GENERIC FRAMEWORK FOR ASSESSING URBAN FLOODING UNDER CLIMATE CHANGE IN VIET NAM: SYNTHESIZING KEY RESULTS FROM HA TINH, NINH THUAN AND BINH THUAN PROVINCES

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Abstract: *Viet Nam is among the nations most severely affected by climate change. In a recent effort to respond to the adverse effects of climate change on urban flooding, the Technical Support Unit (TSU), ENABLE-Belgian Development Agency, the Viet Nam Institute of Meteorology, Hydrology and Climate Change, and other institutes have studied the impacts of climate change on urban flooding in the provinces of Ha Tinh, Ninh Thuan, and Binh Thuan. Through different studies, climate change impacts on urban flooding have been determined. These three studies provide a generic framework to determine climate change impacts on urban flooding. Firstly downscaling of climate change scenarios is used to determine climate variables within each region. Hydrological and hydraulics models are then utilize to drive the simulation of the rainfall-runoff process as well as the response of water level during flood events. Based on the modelling, structural and non-structural measures are proposed to reduce the impacts of flooding. In an additional effort, flood warning systems would also be installed to provide timely warning to the authorities as well as the people. The generic framework has been agreed through consultation workshops as well as training workshops from August 2018 to March 2019.*

Keywords*: Climate change, flooding, urban planning, downscaling, modelling.*

1. Introduction

Climate change is considered as an unprecedented global environmental challenge [7]. The impacts of climate change is felt in the changes in climate variables such as temperature, precipitation, humidity, etc. Climate change also leads to changes in climate extreme events such as heavy rain and flooding [1]. This is important because flooding is a dangerous hazard.

Flooding in the context of climate change is especially dangerous and damaging in urban areas. Urban drainage system have been constructed with conveyance capacities for extreme rainfall events at a desired frequency to prevent urban flooding. However, the design of urban drainage systems is often based on historical precipitation statistics and return periods, without considering the potential changes in precipitation due to climate change [11]. Climate change leads to increased risks of urban flooding due to the increase of heavy rain and river floods as well as the limited capacity of urban drainage systems.

The study of climate change, extreme precipitation, and its relation to urban flooding have been well explored both in the past and more recently. Ashley et al. (2005) showed that flooding risks in four UK catchments could increase by up to 30 times in 2080 as compared to the year 2000, and effective adaptation measures are required to cope with the increased risk. Zhou et al. (2018) studied the impacts of climate change on

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urban flood volumes in northern China with an in-depth assessment of the effects of both climate change mitigation and adaptation on urban flooding. Miller and Hutchins (2017) studied the impacts of climate change on urban fluvial flooding for the United Kingdom and concluded that there is medium-high confidence showing increased risks of flooding. Kang et al. (2016) assessed the impacts of climate change and predicted the scale of potential future flood damage for the urban area of Gyeyang-gu, Incheon, Korea. Kaspersen and Halsnæs (2017) described an integrated framework and tool, the Danish Integrated Assessment System (DIAS) to address urban flooding during extreme precipitation as a consequence of climate change.

One important feature in assessing and determining flooding due to climate change is the ability to properly translate the changes in climate variables into urban flooding levels. This includes the downscaling of climate change scenarios, hydrological modelling to determine river flow as a result of increased rainfall, and hydraulics modelling to determine water drainage by urban drainage systems. A search in the literature provided a wide range of approaches.

This paper provides a generic framework of downscaling climate change scenarios, applying hydrological and hydraulics model to determine the level of urban flooding at the local level. The work has been applied successfully at 3 locations in Viet Nam namely urban areas in Ha Tinh, Ninh Thuan, and Binh Thuan provinces as part of the "Integrated Water Resources Management and Urban Development in Relation to Climate Change in Binh Thuan, Ninh Thuan and Ha Tinh" project funded by Enabel, the Belgian Development Agency. As part of the project, consultation workshop and training workshop on the methodology were also carried out with positive results.

2. Climate Change Scenario Development

In the Fifth Assessment Report (AR5), IPCC adopted the Benchmark Emissions Scenarios approach and Representative Concentration Pathways (RCPs) of greenhouse gas (GHG) in the atmosphere. The RCPs emphasise the concentration of gasses instead of emission processes. In other words, the RCP assume the target level of GHG concentrations, providing a range of options for socio-economic development that would lead to that concentration. To simulate the effects of these emissions levels or scenarios, Global Circulation Models (GCMs) are used. These models simulates physical, chemical, biological processes that occur in the atmosphere through approximations. GCMs have relatively coarse spatial resolution (200-300km^2 per grid). Therefore, in order to utilize the results from GCMs, downscaling is required. The process of downscaling should adhere to that procedure used by the Viet Nam Institute of Meteorology, Hydrology, and Climate Change in producing the official Climate Change and Sea Level Rise Scenario for Viet Nam (Figure 1).

The changes in climate variables is compared with the baseline period of 1986-2005. The change in temperature is thus expressed as:

$$\Delta T_{future} = T^*_{future} - \overline{T^*_{1986-2005}} \quad (1)$$

While the change in precipitation is expressed as:

$$\Delta R_{future} = \frac{\left(R^*_{future} - \overline{R^*_{1986-2005}}\right)}{\overline{R^*_{1986-2005}}} * 100 \quad (2)$$

Of which: ΔT_{future} = Changes of future temperature compared to the baseline period (°C), T^*_{future} = Temperture in the future (°C), $\overline{T^*_{1986-2005}}$ = Average temperature of the baseline period (1986-2005) (°C), ΔR_{future} = Changes of future rainfall as compared to the baseline period (%), R^*_{future} = Future rainfall (mm), ($\overline{R^*_{1986-2005}}$ = Average rainfall of the baseline period (1986-2005) (mm).

The advantage of a dynamic model is the ability to simulate physical and chemical processes in the atmosphere, thus, the results are highly logical. However, the disadvantage of the model includes the limitation of simulating local climate since there is limited information from the input. In addition, each model has systematic errors. Therefore, the result of the model needs to be calibrated based on observed data to reflect local conditions and reduce errors.

Quantile mapping is used to adjust daily rainfall values based on historical data. For each percentile of the result time series, a separate transfer function is developed to eliminate the errors in the model so that calculated results closely match observed data in this percentile.

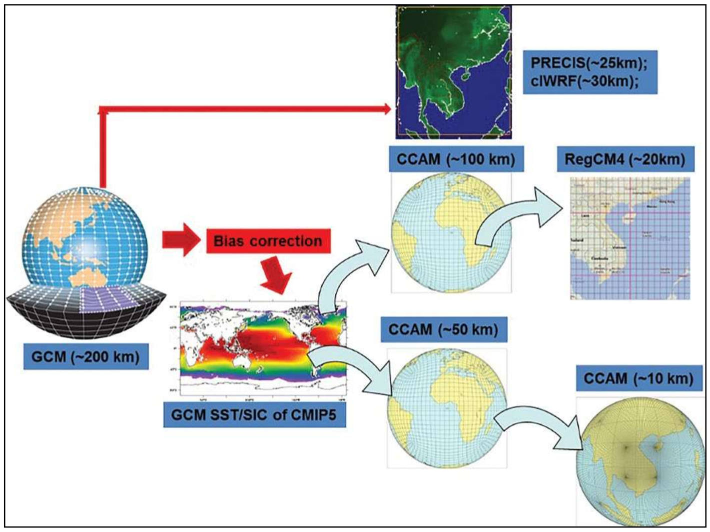

Figure 1. Dynamical downscaling procedure
(source: Viet Nam Institute of Meteorology, Hydrology and Climate Change)

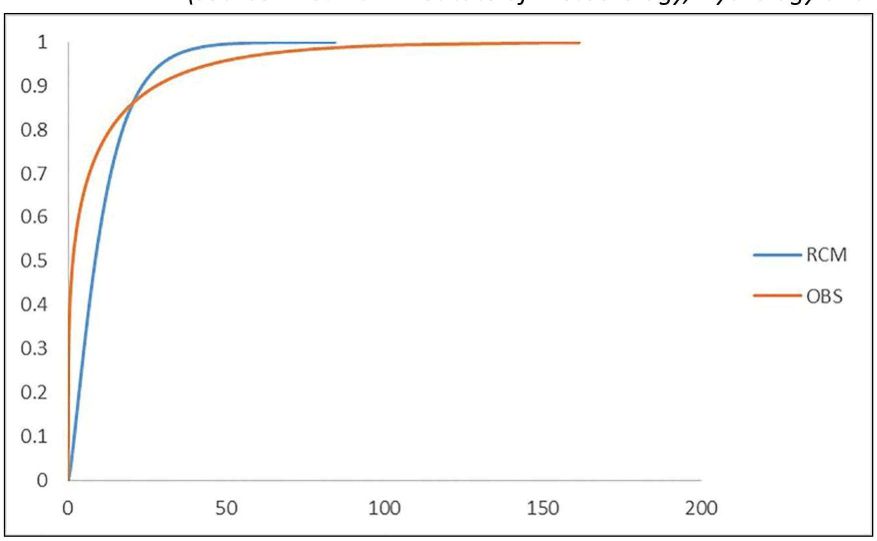

Figure 2. Rainfall cumulative distribution (red: observed, blue: simulated)

Figure 2 (x axis is the rainfall [mm]) illustrates the Cumulative Distribution Function (CDF) of the simulated and observed datasets. It is indicated that the number of wet days with daily rainfall is much higher than in reality, however, the amount of rainfall in these days is not significant. This method is applied to match CDF of a simulated dataset to CDF of the observed data in order to solve the mentioned error following 2 main steps below:

- Wet day frequency correction;
- Matching CDF of simulated dataset to CDF of the observed one.

This method can be described in more detail, as follows:

- It is assumed that theoretical gamma distribution can be fitted into observed and simulated daily rainfall datasets. Thus, the correction can be implemented based on gamma theory. The Probability Density Function (PDF) of gamma can be expressed by the following equation:

$$PDF: f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (3)$$

The CDF can be found using the following equation:

$$CDF: F(x) = \int_0^x f(t)\,dt \quad (4)$$

Where α and β are shape and scale parameters, respectively. These parameters can be computed using Equation (5) with the mean and standard deviation determined from the data series:

$$\alpha = \left(\frac{\bar{x}}{\sigma}\right)^2 ; \beta = \frac{\sigma^2}{\bar{x}} \quad (5)$$

- Both two datasets are divided into 2 parts: i) the first part consists of values, which are less than the 99th percentile of the corresponding dataset; and ii) the second part is the rest of this dataset, which are equal or greater than 99th percentile.

- To do frequency correction (the number of rainy day) for the simulated dataset, a threshold must be defined to truncate several values. Firstly, non-exceedance probability of 0.1 mm rainfall is calculated in the simulated dataset. Secondly, the threshold is obtained by taking the inverse of this probability using the shape and scale parameter of the observed dataset. Every model value, which is less than this threshold, should be truncated.

Threshold $= F^{-1}_{\alpha,\beta\text{-gcm}} (F_{(\alpha,\beta\text{-Obs}} (0.1\ mm))$ *(6)*

- Shape and scale parameters of truncated simulated dataset are computed again.

- The non-exceedance probability of all values in simulated dataset is calculated using new shape and scale parameters from previous step. And then, adjusted model values are derived from getting the inverse of corresponding probability using shape and scale parameters of observed dataset. This step is conducted discretely for two parts of dataset.

$$x^*_{base} = F^{-1}_{obs}\left[F_{base}\left(x_{RCM_{base}}\right)\right] \quad (7)$$

For other periods in the future, the same procedure is applied but the rain correction values are obtained by multiple rain correction values with scale factor. The scaling factor is expressed in:

$$x^*_{fut} = x_{fut} * \frac{F^{-1}_{obs}\left[F_{fut(x_{fut})}\right]}{F^{-1}_{base}\left[F_{fut(x_{fut})}\right]} \quad (8)$$

Calibration of temperature result is based on percentile (daily average, maximum, minimum temperatures)

+ Develop a cumulative distribution function for the observed temperature series as well as simulated temperature for the baseline and future periods

+ At each percentile, adjust the calculated temperature from the model based on observed temperature. The transfer function is defined as:

$$P_i = O_i + g\overline{\Delta} + f\overline{\Delta_i^{`}} \quad (9)$$

Of which: *i = ith* percentile from the observed and simulated temperature, O = observed temperature, P = temperature in the model after calibration, g is set to 1, $\overline{\Delta} = \overline{S_f} - \overline{S_c}$ with $\overline{S}_f$ and $\overline{S}_c$ correspond to uncalibrated average temperature for future and baseline period, $\Delta_i^{`} = S_{fi} - S_{ci} - \overline{\Delta}$ with S_{fi} and S_{ci} being uncalibrated temperature for future and baseline period in the ith percentile respectively.

$$f = \frac{\sigma_0}{\sigma_{S_c}} \quad (10)$$

Of which: σ_{Sc} and σ_o are the standard deviation of the observed and simulated temperature in the baseline period respectively.

3. Sea Level Rise Scenario Development

In terms of the sea level rise scenarios, the calculation procedure and component should adhere to that of the Viet Nam Climate Change and Sea Level Rise Scenario (Table 1). Total sea level rise, thus, is the sum of all contributing factors, including: (i) thermal expansion, (ii) Glaciers SMB, (iii) Greenland SMB, (iv) Greenland dynamic, (v) Antarctica SMB, (vi) Antarctica dynamics, (vii) Land water, and (viii) Isometeric.

Table 1. Sea level rise scenario components

No.	Contributor	Method	Data
1	Thermal expansion and dynamics	Determined from sea level rise component due to global average temperature expansion (zostoga) and sea level rise due to dynamics (zos) from AOGCM. These components are calibrated prior linear interpolation for Viet Nam's sea region using IPCC's method.	AOGCM models
2	Glacier SMB	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data	From *"glaciers"* component in IPCC's database
3	Greenland SMB	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data	From *"greensmb"* component in IPCC's database.
4	Antarctica SMB	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data	From *"antsmb"* component from IPCC's databse.
5	Greenland dynamics	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data	From *"greendyn"* component in IPCC's database.
6	Antarctica dynamics	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data.	From *"antdyn"* component in IPCC's database.
7	Land water	Interpolated for Viet Nam's sea region using the method prescribed in Slangen (2014) from average global data	From *"landwater"* in IPCC's database.
8	Isometeric	Output from ICE5G model, inlcuding surface change rate geoid, vertical movement rate.	From ICE5G [8].

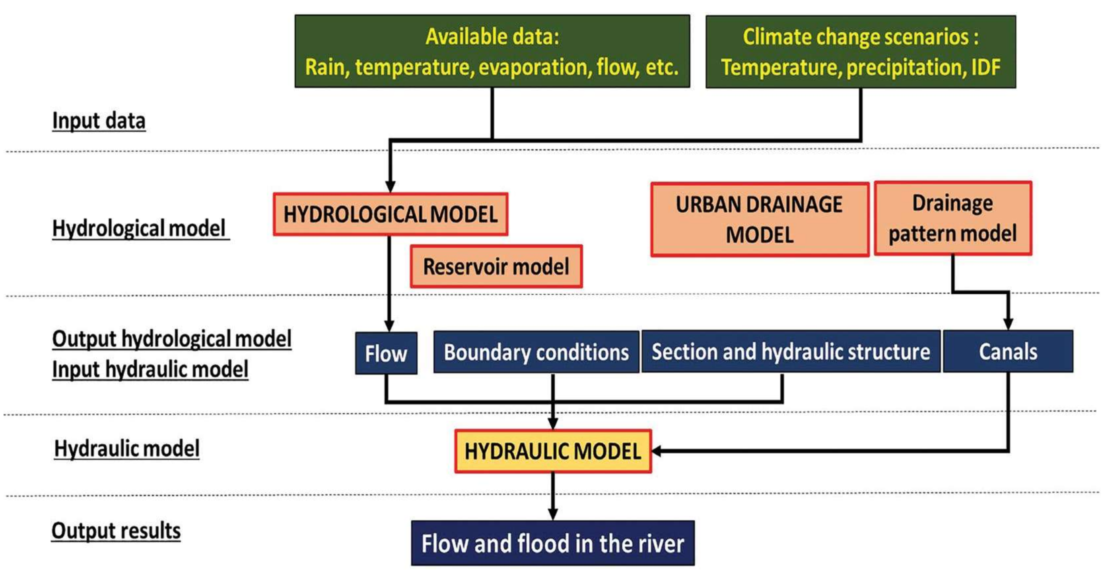

Figure 3. Overall methodology to determine the impacts of climate change on urban flooding

4. Modelling Approach

The overall modelling approach to determining climate change impacts on urban flooding is shown in Figure 3. The assessment should start with meteorological and hydrological input data, and climate change data (changes in temperature, precipitation). The input is fed into hydrological model including reservoirs as well as an urban drainage model. The output from the hydrological simulation is then the input into a hydraulic model. The output from the hydraulic model is the flow and flood in the river.

Input data for hydrological and hydraulics model include: elevation data; hydrological and meteorological data; water level; flow; and climate change scenarios. Climate change data will be used to calculate future climate change scenarios. The factors used to model input data for climate change scenarios are: rainfall and sea level rise. Rainfall of stations considering climate change according to periods is calculated according to the increase corresponding to the current status. Specific calculations are as follows:

$$R(CL) = R(BL) \times (P/100+1) \quad (11)$$

Of which:

R (CL): Rainfall with consideration of climate change relevant to frequency at time of the case

R (BL): Current rainfall correlates with the frequency at the time at present

P: Increase percentage (or decrease) of maximum daily rainfall at the time of the case

Sea level rise considering the climate change is calculated as follows:

$$H(CL) = H(BL) + A/100 \quad (6)$$

Of which:

H (CL): Water level considers climate change relevant to the frequency at time of the case

H (BL): Current water level corresponds to the frequency at the time at present

A: Value of water level at time of the case (cm)

5. Applying the generic approach for Ha Tinh, Ninh Thuan, and Binh Thuan Provinces

Future climate change and sea level rise scenarios for Ha Tinh, Ninh Thuan, and Binh Thuan Provinces were developed using the Viet Nam Climate Change and Sea Level Rise Scenarios. This models for the RCP4.5 and RCP8.5 scenarios. 4 Regional Climate models (RCMs) were used: i) Conformal Cubic Atmospheric Model (CCAM); ii) Providing Regional Climates for Impacts Studies (PRECIS); iii) Regional Climate Model (RegCM); and iv) climate Weather Research and Forecast model (clWRF).

Sea level rise (SLR) scenarios for the coastal area were constructed on the basis of: i) guidance from AR5; ii) the findings on SLR scenario development [2,10]; and iii) SLR scenarios developed for countries such as Australia, the Netherlands and Singapore. SLR scenarios for the coastal area of Binh Thuan are calculated from the components contributing to sea level in the region. They consist of 8 principal components, i.e. thermal expansion, glaciers, Greenland ice sheet, Greenland ice sheet dynamics, Antarctic ice sheet, Antarctic ice sheet dynamics, land water storage and glacial isostatic adjustment. Among those components, the thermal expansion is calculated directly from 21 AOGCMSs following AR5. The components of sea level change due to melting ice and water storage in continentare computed by a transfer function related to global projection which is based on contribution of each element to different regions [10]. Sea level change due to vertical fluctuations in the Earth's crust reacting to changes in ice volume was estimated from the ICE5G model [11].

The uncertainty of the thermal expansion component is estimated from models. The uncertainty of SLR due to the balanced with the amount of ice is assumed to be governed by the intensity of climate change, while the uncertainty in the estimation of SLR due to melting ice in glaciers, mountain peaks or at the poles is mainly due to the calculation method. Each component contributing to SLR (except glacial isostatic adjustment) has a central estimated value (based on the percentiles) with the same upper and lower bounds, determined through 5^{th} and 95^{th}

percentiles (IPCC 2013). The central estimated value of the various components would be added together to give the value of SLR for the coastal area. The uncertainty of the trend of total SLR will be estimated according to the methodology of the IPCC [2] with the assumption that the components with a close relationship with the air temperature are also highly correlated with each other in terms of uncertainty. Squared total uncertainty of these components is estimated by getting the sum of all squared uncertainty of every component:

$$\sigma^2_{tot} = (\sigma_{steric/dynamic} + \sigma^2_{smb\_a} + \sigma^2_{smb\_g})^2 + \sigma^2_{glac} + \sigma^2_{LW} + \sigma^2_{dyn\_a} + \sigma^2_{dyn\_g} \quad (6)$$

In which:

σ_{tot}: is the uncertainty of total water level components;

$\sigma_{steric/dynamic}$, σ_{smb_a}, σ_{smb_g}, σ_{glac}, σ_{LW}, σ_{dyn_a}, and σ_{dyn_g} are the uncertainties of components: thermal expansion, mass balance of the Antarctic ice sheet, mass balance of Greenland ice sheet, ice in glaciers, water storage on the continent, Antarctic ice sheet dynamics and Greenland ice sheet dynamics, respectively.

5.1. Ha Tinh

For Ha Tinh city the flood peak discharge of the Rao Cai River is critical and within the system the Ke Go reservoir plays a key role in flood mitigation. The current flood risk is very high, as a 2% design flood would lead to 80% flooding of the city. This would still be 42% of the total city area the flood management plan of the province of 2015 is implemented. Therefore, additional measures are recommended that would reduce flooding to 14.2%. These measures would also deal with the flood risks in the middle of the century, but in the longer term more flood prevention measures are needed.

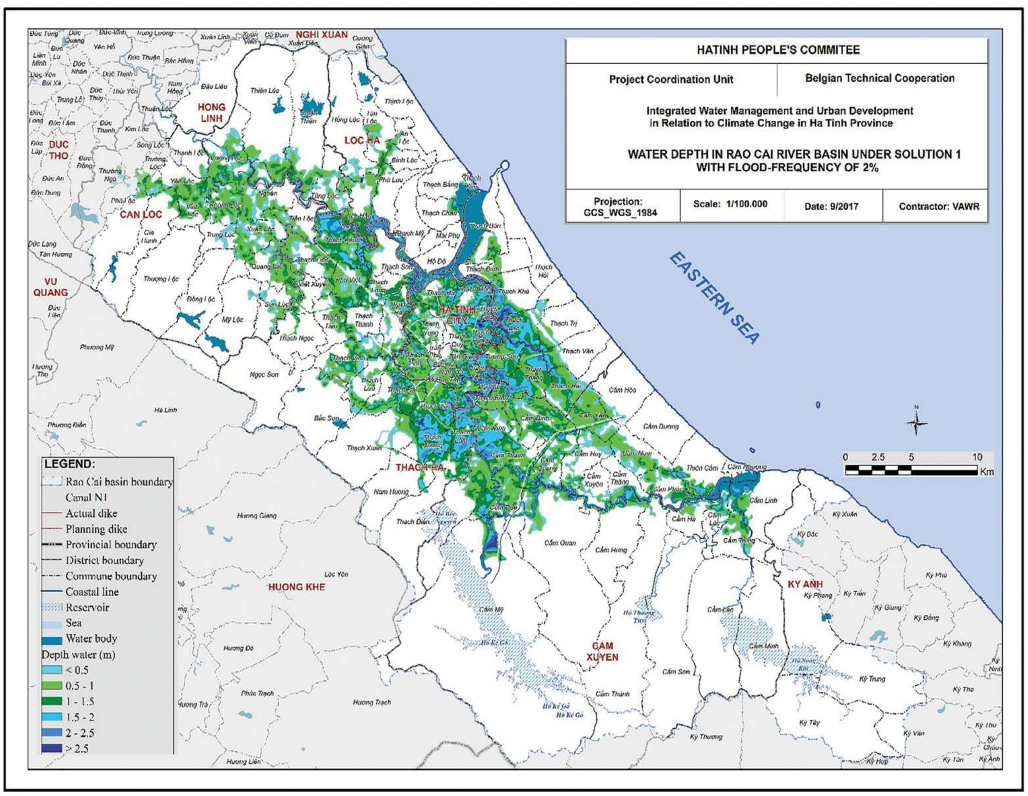

Figure 4. Flood map in Rao Cai river basin corresponding to design flood, in current situation

5.2. Binh Thuan

The current flood risks in the Luy river basin and drainage systems for Luong Son and Cho Lau towns in Binh Thuan province were modelled. The reservoirs in the Luy river basin play an important role in the mitigation of flood risks downstream. Modelling the current situation for a design flood shows that even if existing plans for e.g. upstream reservoirs are implemented, the flooded area in the river basin would increase by 2030 as a result of climate change. In the present situation, the inundated area of Luong Son and Cho Lau towns would be 13.6% and 10.4% of the surface areas of these towns respectively with a design flood of 1%. The risks will increase in 2030 because of the urban drainage infrastructure planning to 2025 plus the effects of climate change, to 39.8% and 20.1% of the surface areas of these towns respectively. Additional measures would deal with current and 2030 flood risks.

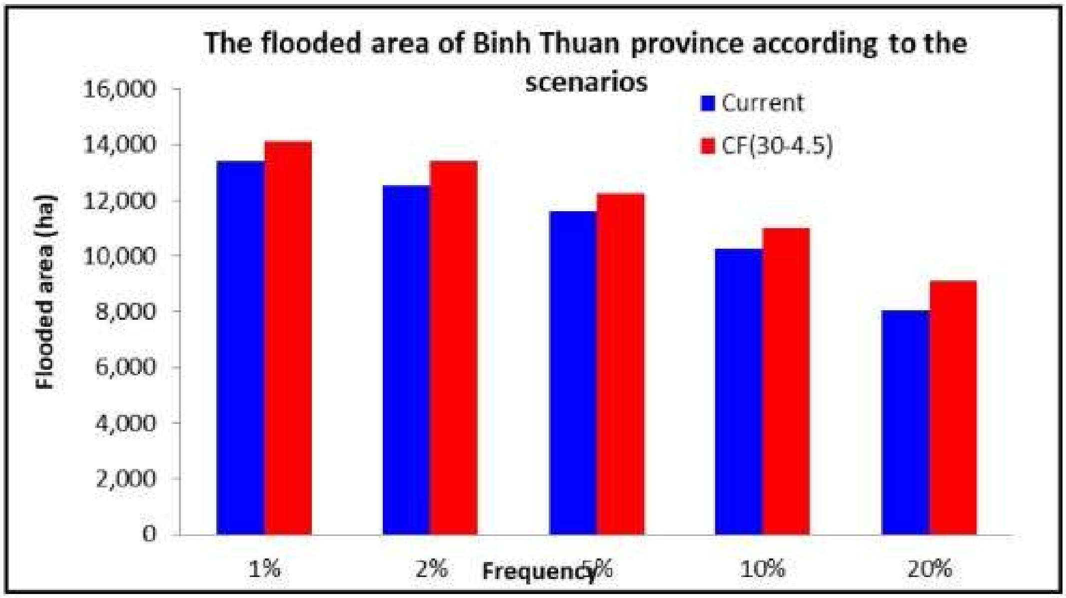

Figure 5. Comparison of flooded area in case of climate change till 2030, scenario RCP4.5 in current condition and planned topography

5.3. Ninh Thuan

The current flood risks in the Cai Phan Rang river basin in Ninh Thuan as well as the Phan Rang - Thap Cham city drainage systems province were assessed. Flooding is caused by occasional extreme rainfall. Modelling with the present topography and infrastructure shows that the Cai Phan Rang river basin inundation is 16,000 ha (1% design storm and flood), affecting especially Ninh Phuoc district. The planned measures for the period to 2025 in the river basin, Phan Rang - Thap Cham city and Ninh Phuoc district will decrease inundation in the current situation, but climate change will increase the flooded area in the river basin around 2030. Therefore, it is recommended to accelerate the construction of the Cai river reservoir, to increase flood retention capacity. The flooded areas in Phan Rang - Thap Cham city are limited in the current situation to just 1.25% of the city's land area (1% rainstorm). If the city's residential areas and drainage system expand according to the Planning to 2025, this would be 9.7% of the city's surface area, and adding climate change would further increase the inundated area to 17.5% of the city by 2030. Flooding can be minimised by improving the city's drainage system in addition to existing plans. The ongoing northern river bank dyke upgrading will protect the city, but it could mean increasing the flood risk for Ninh Phuoc district. This district needs retention reservoirs and possibly an additional dyke along the southern river bank.

6. Conclusion

Climate change poses a significant challenge for Viet Nam. This includes the increase in severity of heavy precipitation and flooding in urban areas. The ability to accurately depict the impacts of climate change on phenomena such as urban flooding is thus important. There has been a significant amount

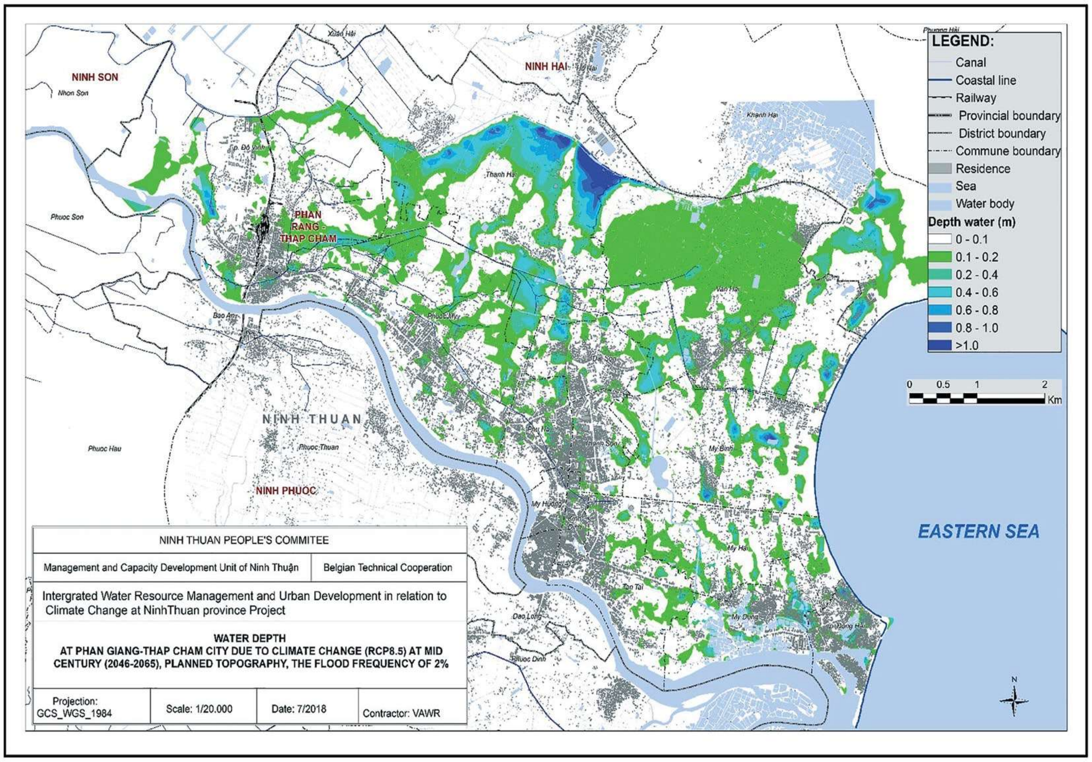

Figure 6. Flooding in Phan Rang - Thap Cham city in 2050, included Planned city expansion and drainage infrastructure, with 2% storm (once in 50 years), according to the emissions scenario RCP8.5

of effort in determining such impact, and this paper contributes to the volume of literature by providing a generic framework for urban flooding assessment within the context of climate change.

The approach described the various components and procedures that are vital in assessing the impacts of climate change on urban flooding in Viet Nam. The approach includes, firstly, to downscale climate change scenarios using GCMs to obtain changes in climate variables. Secondly, hydrological and hydraulic models are applied to simulate future conditions using downscaled climate variables. The paper provided examples of applying the approach in the three provinces of Ha Tinh, Ninh Thuan, and Binh Thuan. Given the limited availability of space, the reader is advised to refer to IMHEN (2018) for a more detailed description of work for the three provinces of Ha Tinh, Ninh Thuan, and Binh Thuan.

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